# PRESERVATIVE LOSSES FROM UTILITY POLES:
# A COMPARISON OF LABORATORY AND FIELD RESULTS

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## Abstract

This paper discusses an attempt to quantify the preservative losses from poles of three preservative treatments, namely pentachlorophenol in oil (PCP), copper naphthenate in oil (Cu-Nap), and chromated copper arsenate with polyethylene glycol (CCA-PEG). Average annual loss rates of preservative components were estimated based on laboratory and field experiments on matched sets of pole sections. Results for the oil-borne preservatives showed good agreement between methods, but the laboratory method produced much greater wash-off and leaching losses from CCA-PEG poles than did the field method. The ranking of the three preservatives, from greatest to least in terms of the predicted mass losses, are Pentachlorophenol > Copper Naphthenate > Chromated Copper Arsenate-Polyethylene Glycol.

## Introduction

It has been well-established that PCP and other preservatives are detectable in soils in the vicinity of treated poles (1). The means by which they reach the soil are likely to be by rainwater washing preservatives from the surface of the pole, pole-soil contact, and, in the case of oil-borne preservatives, by the migration of treating oil down the pole and into the soil. The presence of PCP, for example, in the soil around poles is thought to contribute to the service life of the pole by inhibiting wood-destroying fungus in the soil near the pole, where fungal attack most often occurs. Concerns arise when preservatives escape from the treated wood and enter surface and groundwater, possibly killing fish or contaminating drinking water supplies.

This paper reports the results of an investigation of the loss of preservatives from treated wood poles in the first year of service. It was part of a larger study that was undertaken to determine the extent to which preservatives in treated poles enter the environment and accumulate in, or migrate from, the soil surrounding the poles (2). The preservatives of interest were PCP, the standard for the last several decades, and two proposed alternatives, CCA-PEG, and Cu-Nap.

### Environmental Levels of Wood Preservatives

Pentachlorophenol. PCP can be found as a contaminant in air, rainwater and soils in many locations. Sources are all anthropogenic, primarily from wood treatment, although the metabolism of other pesticides and chlorination of water supplies are thought by some to be minor sources (3).

Copper, Chromium and Arsenic. Copper, chromium and arsenic are released to the environment through the weathering of crustal materials, application of agricultural materials, combustion of wood and coal, and via volcanic dust emissions. Environment Ontario Guidelines for the Decommissioning and Cleanup of Sites in Ontario (4) lists upper limits of normal concentrations in Ontario surface soils for many inorganic contaminants. Copper levels are usually below 100 mg/kg (urban) and 60 mg/kg (rural). The cleanup criteria for copper ranges from 150 mg/kg to 300 mg/kg, depending on proposed land use.

Chromium levels in soils have been found to be up to 3000 mg/kg, with a typical average value of 100 mg/kg (5). Background chromium levels in Ontario are usually under 50 mg/kg, for both urban and rural environments (4). Cleanup criteria range from 750 - 1000 mg/kg for total chromium, and from 8 - 10 mg/kg for chromium (VI).

Worldwide, the typical range for As in soils is 0.2 to 40 mg/kg, with a median concentration of 6 mg/kg (6). Background levels for Ontario do not normally exceed 10 mg/kg (rural) to 20 mg/kg (urban). Cleanup criteria range from 20 - 50 mg/kg, depending on soil type and land use (4).

The significance of the incidental addition of biocidal materials to the environment is a subject of current interest to producers, users and regulators of preservative-treated wood. If the losses of chemical(s) from treated wood in service are so small as to be insignificant compared to normal background levels, there is no cause for concern. If the losses are large enough to raise local concentrations much above background, or if the losses are mobile and can be found at some distance from the source, then the risks associated with these losses should be evaluated. The current study attempted to quantify the losses of wood preservatives from utility poles. The assessment of any associated risks is left to others.

## Quantifying Preservative Losses from Poles

In order to assess, and to compare, the environmental impacts of wood preservatives, it was necessary to obtain an estimate of the amount of preservative lost by a treated pole during its first year of installation, assumed to be the time of highest loss rates. This was approached in two ways: by "leaching" pole sections using an artificial (acid) rain in a laboratory setting at the University of Guelph (7), and by monitoring the levels of preservatives found in activated carbon-containing collars and soil around newly installed pole sections placed in an outdoor test plot near Barrie, Ontario.

## Methods

### University of Guelph Leaching Study

Utility Pole Stock. Six Class 5, 40′ utility poles of each of three treatments, namely Red Pine CCA-PEG, Red Pine Pentachlorophenol, and Lodgepole Pine Copper Naphthenate, were the source of freshly treated stock for this study. The poles were of uniform size, within class specifications, and from the same treatment charge. Treatment appeared uniform among poles, except for one PCP "bleeder" pole requested. From each pole, 45 cm pole sections (mean volume 0.0123 $m^3$), were removed from approximately the same location to provide uniform specimens for study.

Leaching Apparatus. A 45 cm pole section was suspended directly over a 15 litre leachate bath (see Figure 1 of Reference 8). The basal portion of each pole segment was encircled with a 5 cm stainless steel drip skirt, and sealed with silicone to prevent wetting and leaching of the cut surface, which otherwise would be unrepresentative of an actual in-service situation.

The CCA-PEG pole sections were subjected to a NaOH buffered, pH 7.0, distilled water bath, using a recirculating water system. This was applied for four hours per day for 32 days. The procedure was then altered to avoid problems encountered with maintaining the pH in the recirculating water bath, so the Cu-Nap and PCP poles were not given this same "initial" treatment.

For the rest of the leaching study, the recirculating water system was replaced by a once-over wetting and collection system which more closely simulated actual rainfall. A positive displacement multichannel peristaltic pump delivered continuous fresh simulated acid rain solution (9), Table 1, to the upper circumference of each pole section. The leaching solution was applied to each pole section via a perforated annular ring of Teflon tubing. This ring encircled the top of each pole section allowing even distribution of the leaching solution over the circumference of the pole.

The entire apparatus was covered with a polyethylene plastic enclosure during operation, both to create a constant humidity and to prevent evaporation of the leaching solution. The enclosure was removed following each leaching event, to allow pole surfaces to dry. The temperature throughout the duration of the leaching study was maintained at approximately 20°C.

An estimate of the total volume of precipitation expected to contact the surface of a pole in an in-service situation was calculated based on a total annual average precipitation for southern Ontario of 833 mm/y. Assuming a rainfall angle of incidence of 70° to the pole surface, it was calculated that the portion of annual precipitation expected to contact the surface of a pole would be approximately 30.0 mm (tan 20° x 833 mm). The average dimensions of exposed pole sections employed in this study were, 21.2 cm in diameter, and 42.5 cm in length. The total amount of annual precipitation expected to contact one side of a pole assuming a unidirectional source, was determined to be 27 L. To account for the need to wet the entire pole circumference during the simulated rainfall exposure, rather than one side as occurs in practise, th is calculated amount of SAR applied was doubled. Thus, a total of 54 litres of simulated acid rain was applied to each pole section over ten leaching events (36 min. each), simulating the total expected precipitation for a one-year period. Preliminary tests indicated that an application rate of approximately 150 mL/min was required to adequately wet the pole surface, simulating an actual rainfall event. Details of the leachate analyses are given in Reference 7.

## Barrie Test Plot Installations

Pole Installations. Six 40′ (13 m) poles of each of the three treatments, were delivered to a local pole supplier. Each pole was sectioned into three portions. The top 1 m and the bottom 10 m were installed in a field (test plot), while the middle 2 m section was sent to the University of Guelph for the associated leaching study (described above). Of each treatment, three 10 m sections and two 1 m sections were selected for installation, as well as an additional 3 m section of a PCP pole that appeared to be a "bleeder".

An Ontario Hydro test plot near Barrie, Ontario, was weeded and graded prior to the installation of the test poles. In the test plot, the poles were installed to a depth of three feet (1 m) in augered holes. These were backfilled with a mixed soil of known composition. One hole was dug as if for a pole installation and filled with the same mixed soil as was used for backfilling the pole-containing augered hole. "Blanks" were taken from this site, to account for any changes in soil concentrations not due to the presence of a pole.

Carbon Collars. The 10 m installed pole sections had granular activated carbon-containing stainless steel mesh collars placed just above ground level. At 7, 19, 49, 135 and 360 days post-installation, the collars were removed, emptied of their contents, washed, refilled with fresh carbon and re-applied to the poles.

Soil Cores. At the same time as the carbon was replaced, samples of the soil adjacent to the poles were taken to a depth of approximately four feet, on opposite sides of the pole. Thick-walled aluminum tubing was pushed or pounded into the soil. These cores were pulled out manually, capped and labelled. After each sample was taken, the holes were filled with clean soil, and a marker nailed to the pole to indicate the positions that had been sampled. Subsequent samples were taken from different locations around the pole.

Aluminum tubes containing soil cores (120 cm deep) were cut into three sections (0-30cm, 30-75cm, 75-120cm) with a bandsaw, then frozen. The soil cores were removed from the freezer to thaw overnight before the sample preparation was done. Details of the analyses can be found in Reference 2.

## Results

### University of Guelph Leaching Results

Copper Chromium Arsenic. The recirculating distilled water bath results shown in Table 2a are the final concentrations on Day 32. The levels of all metals increased over sampling days 2, 4 and 8, then levelled off between days 8 and 16. Table 2b shows the total metals lost from the test poles after exposure to a volume of simulated acid rain equivalent to one year of rainfall.

Copper Naphthenate. Table 3 shows the copper losses from the test pole sections after exposure to one year's simulated rainfall.

Pentachlorophenol. The results of the leaching experiments using PCP treated poles are given in Table 4, for one year's equivalent exposure to simulated acid rain (SAR).

### Barrie Test Plot Results

Individual pole results are available elsewhere (2), and only a summary of the results will be presented here. The three CCA-PEG 30' poles showed similar amounts of adsorbed metals after one year, with copper (average annual loss of 357 mg) being about 10-fold greater than chromium (average annual loss of 47 mg) and arsenic (average annual loss of 19 mg). Background levels (subtracted from the above results) were obtained from carbon collars installed on PCP-treated poles, and were analysed on the same time schedule as those on CCA-PEG and Cu-Nap poles.

The three Cu-Nap 30' poles gave consistent copper losses, with an annual average of 2500 mg per pole. This is seven-fold greater than the copper loss from CCA-PEG poles.

The PCP 30' pole losses were less consistent between poles than were the other two treatments. The 10' section of a "bleeder" pole, with much less aboveground wood than the other poles, showed about the same accumulated PCP as the 30' poles. One non-bleeder pole had twice the PCP as was found in the other poles' collars. The average (for 30' poles) annual PCP loss to carbon collars was 3900 mg PCP. The "blank" values were obtained from carbon collars on CCA-PEG and Cu-Nap poles. The Neutron Activation Analysis method detects Cl, so a conversion to equivalents of PCP, using 177.5 g Cl to 266.5 g PCP has been made. This counts all chlorine as PCP, which it is not, giving artificially high "background" levels. The values listed in the table have been corrected by subtracting this "background" from the total PCP detected in the carbon.

Figure 1 shows all three treatments, average accumulated mass of preservative in the activated carbon collars as a function of time for the first year post-installation. The curves for all preservatives can be well approximated by straight lines between the origin and the final year-end value. The slopes of these lines are the amounts of preservative lost, in mg/day. For

CCA-PEG components, these rates are 1.0, 0.1 and 0.05 for Cu, Cr and As respectively. For Cu-Nap, average Cu loss was 7.0 mg/day. For PCP poles, the average loss rate was 11 mg/day.

Soil Column Preservative Accumulations. The concentrations of preservatives found at depths of 0-30 cm, 30-75 cm and 75-120 cm, in soil columns taken adjacent to the installed poles at the Barrie Test Plot are reported elsewhere (2). Column average values were calculated over the length of soil column sampled, as $(0.3 * A + 0.45 * B + 0.45 * C)/1.2$, where A, B, and C represent preservative concentrations in core slices at the three given depths. For calculations, a value of less than the detection limit was substituted with one-half the detection limit (of the ICP method).

The total mass of preservative contained in the soil surrounding the pole was calculated by assuming that the average core concentration was constant around the pole, that the soil volume containing all the lost preservative extends 10 cm radially from the pole surface, to a depth of 1.2 m, that the pole is 25 cm in diameter, and that the soil bulk density is 1600 $kg/m^3$.

## Discussion

### Quantifying Preservative Losses

No attempt was made to quantify those routes of preservatives into the environment that did not intercept the surface soil around the poles, such as volatilization. Similarly, no attempt was made to quantify the rates at which preservatives exit the environment, through bio- and photo-degradation. The extent of naturally occurring biodegradation of pentachlorophenol is unknown; the interpretation of field data was done assuming that no biodegradation had occurred in the test period, i.e. that all material leaving the pole was retained, and not degraded, in the soil. If this assumption is not true, then the actual PCP losses to soil will be greater than those calculated in the following pages.

The University of Guelph leaching studies and the Barrie Test Plot installations were undertaken to provide two estimates of the same quantities--namely, the amount of preservative that is washed off, or leached out, of a pole by one year's rainfall. The below ground losses, (and the above ground losses that escaped capture by the carbon collars) from the poles of the Barrie Test Plot were also estimated by determining the amounts of preservatives in the soil at various times throughout the year, and assuming that no losses occurred from this soil.

The losses of preservatives by the poles through the butt end buried five feet (1.5 m) below ground were not measured in this study, yet they may be much greater than the losses occurring from the pole surface above and at groundline. These unaccounted losses remain unseen, yet, being released at depth, may be a larger supply to groundwater than the aboveground losses considered in this study.

### Comparison of University of Guelph and Barrie Collar Data

CCA-PEG. Table 5 compares the scaled-up laboratory leaching results to the carbon collar results. It was intended that these two approaches would measure the same losses, i.e. the aboveground, pole surface rainwater wash-off of mobile preservative components. The scale-up of laboratory results obtained on 45 cm pole sections to 27' was done by multiplying the leaching results (expressed as mass of preservative lost per volume of pole washed) by the aboveground volume of a 30' pole as installed in the Barrie Test Plot. This volume, assuming an average pole diameter of 25 cm, is 0.404 $m^3$.

For each component, the annual loss was "added" to a hypothetical collar of soil which surrounds the pole at groundline, extending 10 cm radially from the pole surface, and extending down 30 cm from the ground surface, and having a density of 1600 kg/m$^3$. This soil mass is 22.6 kg. This was done to estimate the contribution that the pole run-off would make to soil concentrations, if the material were not intercepted by a carbon collar. The concentrations of copper, chromium and arsenic found in the (clean) Barrie Test Plot backfill soil are given in the table as background levels.

Copper showed similar projected (scaled-up) losses from the distilled water washing and from the simulated rainfall. The distilled water wash represents an initial loss following installation, during which the surface deposits and unfixed material will be removed from the pole. The subsequent "rainfall" values cannot be attributed to surface deposits. Arsenic shows roughly similar losses, though of smaller magnitude, for the washing off of surface deposits and the first year "exposure" to acid rain. Chromium loss, in contrast, was of the same magnitude as arsenic for the wash-off, but chromium lost very little to "acid rain" leaching.

The scaled-up results from the laboratory leaching experiments give losses of metals that exceed the losses determined using carbon collars by a significant amount. The sum of the pH 7 and acid rain losses are, except for the very high As loss from Pole #1, about an order of magnitude larger than the field-determined losses. The resulting soil concentrations near poles are predicted to be much larger than background levels.

If the differences between the results obtained by the two methods was due to the carbon collar method not collecting all that ran down the pole, i.e. if the carbon is either bypassed or does not adsorb the leachate materials, then the soils under the carbon collars would be expected to show elevated Cu, Cr and As levels compared to soils around the 3′ sections of the same poles installed nearby. In other words, if the carbon collars are efficiently collecting the runoff, the differences between the 30′ and 3′ pole soils should be negligible. Table 6 compares the above and below ground losses (to the carbon collars and the soil, respectively) for CCA-PEG components. Data are from one year post-installation. Also given are the average pole (wood) concentrations of metals in the outer 24 mm.

These data do not permit the explanation of carbon collar bypass to be entirely ruled out, but it appears that soil concentrations under the collars are not high enough to account for the projected losses, based on the U of G leaching results. In other words, if the U of G losses (scaled up to 30′) were accurate, and were added to the soil around the poles, soil concentrations would be expected in the range presented in Table 5 (i.e. 27 mg/kg Cr, 47 mg/kg As, 200 mg/kg Cu combined wash-off and rainfall leaching). However, it was found that the Cu and Cr values are at or below the detection limit and the As values do not exceed 2.8 mg/kg (2).

An alternate explanation is offered, as follows: The U of G results accurately represent the amount of water-borne, mobile metals on a pole surface. The total amount of this material that actually leaves the pole in the form of runoff is much less (perhaps a factor of 10). A water-treated CCA-PEG pole, as opposed to an oil-treated Cu-Nap pole, for example, will take up a considerable volume of water. If the rain falling on the pole, and mobilising the metals, is adsorbed by the pole and evaporated once the rain has stopped, the losses to the ground will be much reduced than if all the rain ran off.

This implies that the scaling up of losses determined on small pole sections in the laboratory cannot be done simply by a ratio of pole heights, surface areas, or volumes. The relationship between amount of preservative lost and pole height is likely to be logarithmic, i.e. a fast rate of loss at small heights, and a diminishing rate of loss at greater heights, with a limiting height above which no increased losses are expected. The carbon collar results, therefore, are accepted as being more representative of field losses than are the laboratory-generated values.

If the above explanation holds, then the differences between laboratory and field (carbon collar) results should be much less for the oil-borne preservatives, because they do not adsorb appreciable amounts of rainwater. The oil treatment makes them water-repellant, and most of the rainwater would be expected to be shed quickly.

Cu-Nap. Table 7 compares the results obtained in the laboratory leaching study with those from the Barrie Test Plot, for Copper Naphthenate treated poles. These pole sections had not received a distilled water bath prior to the "acid rain" exposure.

As Cu-Nap is an oil-borne treatment, the Barrie collars were expected to contain copper from both rainfall wash-off and mobile oil moving down the pole. In contrast to the CCA-PEG copper results, in which the U of G results were much higher, Cu-Nap copper measured in the Barrie carbon collars were about 1.3 times higher than the U of G results. For a slowly migrating oil-borne preservative, the time over which the experiments are conducted is likely to be significant, whereas for a fixed preservative it is not. The Barrie study was run for one year, the Guelph study for 10 days. Also, the outdoor poles were subjected to summer temperature extremes, while the Guelph poles were indoors. These factors would be expected to contribute to oil mobility and increased copper losses.

Table 8 gives a summary of above- and below-ground losses (to carbon collars and to soil respectively) for CuNap poles in the Barrie Test Plot, measured over one year. Also given are the average pole (wood) concentrations of copper in the outer 24 mm of wood. Both soil and carbon corrected for background copper levels.

All three 30′ sections have similar soil and similar carbon concentrations, yet the copper concentrations in the wood varies by a factor of two. The carbon collar capture of copper is significant ranging over the three poles, from 73% to 82% of the total copper lost from the poles.

PCP. Table 9 compares the U of G leaching results with the Barrie Test Plot carbon collar results for the PCP treated poles.

With the exception of the (suspected) low result for Pole #1 obtained in the leaching apparatus, the correspondence between the two methods is good. The same average annual aboveground loss is obtained by each method. The qualifying statements about the conditions in the laboratory and the field made for Cu-Nap also apply in the case of PCP.

Table 10 gives a summary of the above- and below-ground losses for PCP poles in the Barrie Test Plot, measured over one year. Also given are the average wood concentrations of PCP in the outer 24 mm of the pole. Carbon collar values were corrected for background Cl, soil background levels of PCP were less than 1 mg. Wood concentration of PCP were determined by NAA.

Table 11 gives the above- and below-ground loss rates from all treatments. Data are corrected for background concentrations. The aboveground results were scaled up from the Barrie 30′ poles by multiplying by (45-5)/(30-3) and the "totals" results scaled up by multiplying by 45/30.

The daily loss rates, multiplied by 365 give annual loss rates. These are given in Table 12, along with the U.S. E.P.A. Drinking Water Standards for the preservatives. Also calculated are the volumes of water required to dilute one year's estimated loss from a 45′ pole down to the given drinking water standard.

## Conclusions

Wood is a variable material. Its properties are not constant within or between poles. Soil is also highly variable. In attempting to draw conclusions from data collected from six poles of each of three treatments, this environmental non-uniformity should make one cautious.

Unknown quantities remain, including the preservative losses from the butt end of the pole, adding to the soil 1.5 m below ground surface, preservative losses via volatilization and photodegradation aboveground, and biodegradation belowground. The extent of oil, and its contained preservative, migration within a pole is not known. It is likely that once it drains to a residual volume, shortly after installation, subsequent oil movement would not be significant. Volatilization of PCP was formerly ignored, but it has recently been proposed (10) that this route may be a more significant loss mechanism than previously thought.

These information gaps are raised to communicate our awareness that the experiments reported here are not fully comprehensive, and that the number of poles used in our trials was necessarily small, and may not represent poles supplied to us by any particular supplier at any given time.

1. More PCP was lost, on a mass basis, than were the other preservatives, by the sample of 6 poles of each preservative used in this study. Copper naphthenate ranked second, and CCA-PEG lost the least. The losses of naphthenate, oil and chemical contaminants were not estimated.

2. Above-ground losses were determined by extrapolating results from the University of Guelph leaching experiments and the Barrie test plot carbon collars to full size pole equivalents. These were very similar for CuNap and PCP. In contrast, U of G results for CCA losses were about 10 times greater than those found at Barrie. A possible explanation for this is that the dry, water absorbing CCA poles do not release the Cu, Cr and As during all but the heaviest rainfall, while the oil-treated, water-repellant poles shed the leached PCP and Cu-Nap.

3. One year's estimated losses of CCA components result in soil concentrations in the soil surrounding the pole that are within the range of normal background levels. One year's estimated losses of CuNap and PCP components result in soil concentrations well above normal background. These treatments also release oil, which was not considered in this report.

4. With any preservative, quality control is important, but with CCA-PEG it is essential to ensure adequate fixation before treated poles are accepted. With PCP (and presumably CuNap), poles that are obvious bleeders are rejected. Within the small sample of poles used in this study, it was found that a pole not identified as a bleeder lost more material than one so identified.

5. Future work of this kind should look at temperature gradients, carrier oil viscosity, sampling orientation (N-S-E-W) and, if possible, storage orientation, i.e. which side was down during storage. The rainfall runoff vs adsorption down the pole hypothesis could be tested. This effect could be significant for water-borne treatments as new water-repellant additives are developed and combined with CCA treatments.

## Acknowledgements

The CEA technical advisors were Mr. Wade Munro of Manitoba Hydro, Dr. Roland Gilbert of IREQ, and Mr. Terry Toner of Nova Scotia Power. Dr. Hugh Hawthorne of Ontario Hydro was an internal advisor on the project. Mr. Randy Buchanan of the University of Guelph conducted a portion of the laboratory studies as part of his Master of Science degree program.

This study was co-funded by Ontario Hydro.

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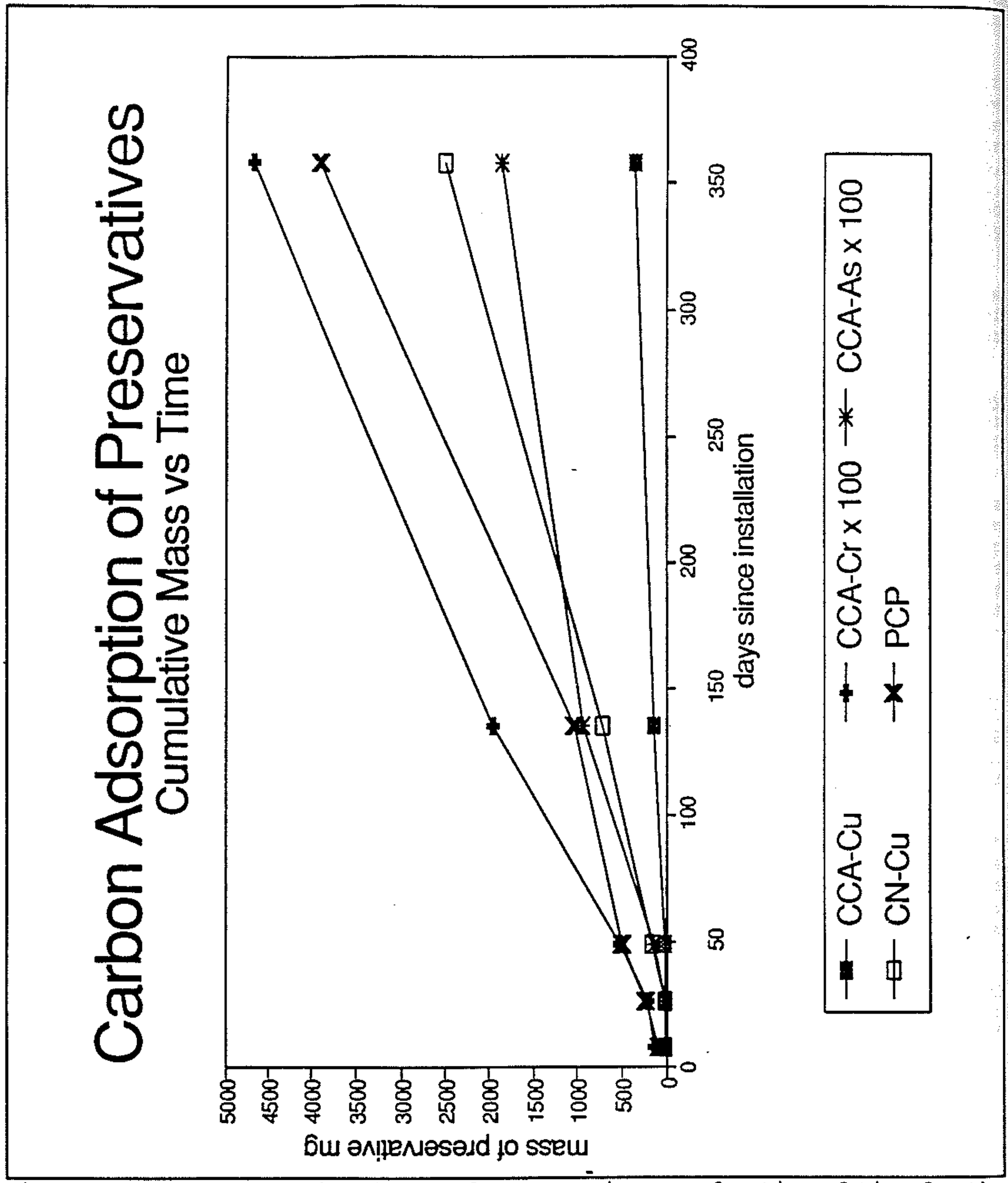

Figure 1. Average accumulated mass of preservative as a function of time for the first year post-installation.

Table 1. Simulated acid rain stock solution used in leaching studies.

| Chemical | Concentration (g/L) |
|---|---|
| Potassium Chloride (KCl) | 0.035 |
| Calcium Sulfate ($CaSO_4$) | 1.239 |
| Ammonium Sulfate $(NH_4)_2SO_4$ | 0.912 |
| Ammonium Nitrate ($NH_4NO_3$) | 1.304 |
| Magnesium Sulfate ($MgSO_4.7H_2O$) | 0.715 |
| Sodium Sulfate ($Na_2SO_4$) | 0.226 |
| Potassium Bisulfate ($KHSO_4$) | 0.053 |
| Potassium Sulfate ($K_2SO_4$) | 0.027 |
| Sulfuric Acid | 0.92 mL/L |
| Nitric Acid | 0.81 mL/L |

Table 2. Laboratory leaching of CCA-PEG pole sections, preservative losses, a) 32-day recirculating water bath, pH 7.0 b) Simulated one year exposure to acid rain, pH 4.2.

| Pole No. | a) Total Metals Leached (g/m$^3$ wood) | | |
|---|---|---|---|
| | Copper | Chromium | Arsenic |
| 1 | 5.92 | 2.49 | 4.65 |
| 2 | 1.19 | 0.49 | 0.20 |
| 3 | 1.87 | 0.54 | 0.24 |
| 4 | 2.17 | 0.57 | 3.04 |
| 5 | 3.44 | 1.34 | 0.14 |
| 6 | 2.39 | 0.85 | 0.15 |
| Mean<br>(*s*) | 2.83<br>(1.54) | 1.04<br>(0.71) | 1.40<br>(1.79) |

| Pole No. | b) Total Metals Leached (g/m$^3$ wood) | | | Pole Section Volume (m$^3$) |
|---|---|---|---|---|
| | Copper | Chromium | Arsenic | |
| 1 | 7.27 | 0.048 | 2.002 | 0.0142 |
| 2 | 5.50 | 0.044 | 0.408 | 0.0150 |
| 3 | 7.23 | 0.040 | 0.413 | 0.0124 |
| 4 | 8.01 | 0.060 | 0.915 | 0.0110 |
| 5 | 7.93 | 0.054 | 0.440 | 0.0103 |
| 6 | 9.07 | 0.098 | 0.098 | 0.0123 |
| Mean<br>(*s*) | 7.50<br>(1.08) | 0.057<br>(0.02) | 0.769<br>(0.20) | 0.0123<br>(0.0017) |

Table 3. Laboratory leaching of Cu-Nap pole sections, preservative loss after simulated one year exposure to acid rain.

| Pole No. | Copper Leached per Pole Section (mg) | Pole Section Volume ($m^3$) | Copper Leached ($g/m^3$ wood) |
|---|---|---|---|
| 1 | 67.5 | 0.0155 | 4.32 |
| 2 | 51.9 | 0.0179 | 2.89 |
| 3 | 67.7 | 0.0138 | 4.89 |
| 4 | 64.7 | 0.0162 | 3.97 |
| 5 | 99.1 | 0.0152 | 6.49 |
| 6 | 94.3 | 0.0177 | 5.30 |
| Mean<br>(*s*) | 74.2<br>(16.7) | 0.0161<br>(0.0015) | 4.64<br>(1.13) |

Table 4. Laboratory leaching of PCP pole sections, preservative loss after simulated one year exposure to acid rain.

| Pole No. | PCP Leached per Pole Section (mg) | Pole Section Volume ($m^3$) | PCP Leached ($g/m^3$ wood) |
|---|---|---|---|
| 1 | 48 | 0.0118 | 4.1 |
| 2 | 160 | 0.0168 | 9.5 |
| 3 | 330 | 0.0137 | 24.0 |
| 4 | 165 | 0.0156 | 10.6 |
| 5 | 255 | 0.0139 | 18.4 |
| 6 | 251 | 0.0164 | 15.3 |
| Mean<br>(*s*) | 202<br>(44) | 0.0147<br>(0.0017) | 13.6<br>(6.5) |

Table 5. Comparison of distilled water and simulated rainfall losses to Barrie test plot carbon collar accumulations--CCA-PEG poles. Laboratory results scaled to 27′ exposed pole.

CHROMIUM-COPPER-ARSENIC--POLYETHYLENE GLYCOL
U OF G vs BARRIE TEST PLOT COMPARISON

| Pole No. | Distilled Water Losses/ 27′Exposed Pole (mg) | "Acid Rain" Losses/ 27′ Pole (mg) | Barrie Carbon Collars/ 27′ Pole (mg) |
|---|---|---|---|
| COPPER (background 1.9 mg/kg) | | | |
| 1 | 2392 | 2937 | 280 |
| 3 | 755 | 2937 | 437 |
| 5 | 1390 | 3204 | 337 |
| AVERAGE | 1512 | 3026 | 351 |
| Expected Conc. Near Pole, 0-10cm, mg/kg | 67 | 134 | 16 |
| CHROMIUM (background < 0.5 mg/kg) | | | |
| 1 | 1006 | 19.4 | 39.4 |
| 3 | 218 | 16.2 | 52.6 |
| 5 | 541 | 21.8 | 48.0 |
| AVERAGE | 588 | 19.1 | 46.7 |
| Expected Conc. Near Pole, 0-10cm, mg/kg | 26 | 0.85 | 2.1 |
| ARSENIC (background 0.5 mg/kg) | | | |
| 1 | 1879 | 809 | 22 |
| 3 | 97 | 167 | 21 |
| 5 | 56 | 178 | 13 |
| AVERAGE | 677 | 384 | 19 |
| Expected Conc. Near Pole, 0-10cm, mg/kg | 30 | 17 | 0.8 |

Table 6. Copper, chromium and arsenic losses to carbon collars and soil from CCA-PEG poles in Barrie test plot. Pole wood concentrations in kg/m$^3$.

| Pole No. | | First Year Losses of Preservatives (mg) | | |
|---|---|---|---|---|
| | | COPPER | CHROMIUM | ARSENIC |
| #1-3′ | SOIL | 0 | 0 | 77 |
| #1-30′ | SOIL | 0 | 9 | 99 |
| Wood Conc.<br>Cu: 1.81 | COLLAR | 280 | 39 | 22 |
| Cr: 3.58<br>As: 2.80 | SUM | 280 | 48 | 121 |
| #3-3′ | SOIL | 0 | 0 | 40 |
| #3-30′ | SOIL | 16 | 0 | 43 |
| Wood Conc.<br>Cu: 1.95 | COLLAR | 437 | 53 | 21 |
| Cr: 4.17<br>As: 3.22 | SUM | 453 | 53 | 63 |
| #5-30′ | SOIL | 412 | 8 | 56 |
| Wood Conc.<br>Cu: 1.92 | COLLAR | 337 | 48 | 13 |
| Cr: 3.71<br>As: 2.89 | SUM | 749 | 56 | 69 |

Table 7. Comparison of simulated rainfall losses to Barrie test plot carbon collar accumulations--Cu-Nap poles.

COPPER NAPHTHENATE
U OF G vs BARRIE TEST PLOT COMPARISON

| Pole No. | "Acid Rain" Losses Scaled to 27′ (mg) | Barrie Collars (mg Cu) |
|---|---|---|
| 1 | 1745 | 2354 |
| 2 | 1168 | |
| 3 | 1976 | |
| 4 | 1604 | 2377 |
| 5 | 2628 | 2769 |
| 6 | 2141 | |
| AVERAGE | 1992 | 2500 |
| Expected Conc. Near Pole, 0-10cm, mg/kg | 87 | 110 |

Table 8. Copper losses to carbon collars and soil from Cu-Nap poles in Barrie test plot, measured over one year. Copper values given in milligrams. Pole wood concentrations in kg/m$^3$.

| | | Days since installation | | | | |
|---|---|---|---|---|---|---|
| Pole No. | | 7 | 26 | 49 | 135 | 360 |
| #1-3′ | SOIL | 0 | 34 | 0 | 0 | 33 |
| #1-30′ | SOIL | 51 | 272 | 283 | 34 | 860 |
| Wood Conc Cu: 1.93 | COLLAR | 2 | 3 | 126 | 681 | 2354 |
| | SUM | 53 | 275 | 409 | 715 | 3214 |
| #4-3′ | SOIL | 85 | 0 | 0 | 193 | 0 |
| #4-30′ | SOIL | 0 | 0 | 0 | 617 | 611 |
| Wood Conc. Cu: 2.75 | COLLAR | 0 | 0 | 279 | 807 | 2377 |
| | SUM | 0 | 0 | 279 | 1424 | 2988 |
| #5-30′ | SOIL | 0 | 0 | 362 | 973 | 591 |
| Wood Conc. Cu: 1.32 | COLLAR | 0 | 0 | 84 | 620 | 2760 |
| | SUM | 0 | 0 | 446 | 1593 | 3351 |

Table 9. Comparison of simulated rainfall losses to Barrie test plot carbon collar accumulations--PCP poles. University of Guelph laboratory results scaled to 27′ pole. Barrie results for Pole #1 scaled to 27′ pole.

PENTACHLOROPHENOL
U OF G vs BARRIE TEST PLOT COMPARISON

| Pole No. | U of G results scaled to 27′,mg | Barrie carbon collars, mg |
|---|---|---|
| 1 ("bleeder") | 1648 | 11444 |
| 2 | 3830 | 2341 |
| 3 | 9716 | |
| 4 | 4278 | 3092 |
| 5 | 7438 | 6339 |
| 6 | 6169 | |
| AVERAGE | 5515<br>(6286 without Pole #1) | 5804 |
| Expected Conc. Near Pole, 0-10cm, mg/kg | 244<br>(278 without Pole #1) | 257 |

Table 10. Pentachlorophenol losses to carbon collars and soil from poles in Barrie test plot, measured over one year. PCP values given in mg. Pole wood concentrations given in kg/m$^3$.

| Pole No. | | Days since installation | | | | |
|---|---|---|---|---|---|---|
| | | 7 | 19 | 49 | 135 | 360 |
| #1-3′ | SOIL | 1212 | 10 | 8 | 8 | 5893 |
| #1-10′ | SOIL | 112 | 580 | 108 | 3375 | 8489 |
| Wood Conc. PCP: 12.4 | COLLAR | 110 | 206 | 380 | 651 | 2967 |
| | SUM | 222 | 786 | 488 | 4026 | 11456 |
| #2-30′ | SOIL | 20 | 84 | 298 | 2980 | |
| Wood Conc. PCP: 6.75 | COLLAR | 102 | 226 | 415 | 944 | 2341 |
| | SUM | 122 | 310 | 714 | 3925 | |
| #4-3′ | SOIL | 10 | 77 | 75 | 987 | 1405 |
| #4-30′ | SOIL | 28 | 731 | 1957 | 2504 | 7586 |
| Wood Conc. PCP: 6.97 | COLLAR | 91 | 223 | 443 | 888 | 3092 |
| | SUM | 119 | 955 | 2400 | 3393 | 10678 |
| #5-3′ | SOIL | 1581 | 22 | 25 | 11176 | 5205 |
| #5-30′ | SOIL | 24 | 13215 | 23944 | 77996 | 67790 |
| Wood Conc. PCP: 9.57 | COLLAR | 70 | 213 | 652 | 1307 | 6339 |
| | SUM | 95 | 13428 | 24597 | 79303 | 74129 |

Table 11. Calculated daily loss rates for all preservatives, aboveground and pole total, including carbon collar material.

| | Aboveground and Total Preservative Loss Rates (mg/day) | | |
|---|---|---|---|
| Treatment Species | Source | Range Preservative Loss | Range Scale-up to 45′ |
| CCA-Cu | aboveground | 0.77 - 1.20 | 1.1 - 1.8 |
| | total | 0.77 - 2.33 | 1.2 - 3.5 |
| CCA-Cr | aboveground | 0.11 - 0.14 | 0.16 - 0.21 |
| | total | 0.11 - 0.16 | 0.16 - 0.24 |
| CCA-As | aboveground | 0.04 - 0.06 | 0.06 - 0.09 |
| | total | 0.15 - 0.33 | 0.22 - 0.50 |
| CuNap-Cu | aboveground | 6.45 - 7.59 | 9.68 - 11.2 |
| | total | 8.07 - 9.95 | 12.1 - 14.9 |
| PCP | aboveground | 6.41 - 17.4 | 9.62 - 25.8 |
| | total | 27.2 - 203 | 40.8 - 304 |

Table 12. Annual preservative loss estimates for 45′ poles and volume of water required to dilute to U.S. Drinking Water Standard.

| | Annual Total Preservative Loss Rates (mg) | | |
|---|---|---|---|
| Treat-ment--Species | Annual Loss (mg) | US EPA DWS (mg/L) | Volume of Water to Dilute to DWS (L) |
| CCA-Cu | 440 - 1300 | 1 | 440 - 1300 |
| CCA-Cr | 58 - 80 | 0.05 | 1 200 - 1 600 |
| CCA-As | 80 - 182 | 0.05 | 1 600 - 3 600 |
| CuNap-Cu | 4 400 - 5 400 | 1 | 4 400 - 5 400 |
| PCP | 15 000 - 111 000 | 0.2 | 75 000 - 560 000 |
| | | 0.001* | 15 000 000 - 111 000 000 |

* Proposed Jan. 1991