A FIELD STUDY OF THE MOBILITY OF SUPPLEMENTAL WOOD POLE PRESERVATIVES IN ADIRONDACK WETLANDS.

Edward M. Michalenko, Ph.D.[1]
Swiatoslav W. Kaczmar, Ph.D.[1]
Bryant A. Browne, Ph.D.
Kevin T. McLoughlin[2]

ABSTRACT

On behalf of the Empire State Electric Energy Research Corporation[2], O'Brien & Gere Engineers, Inc.[1] conducted a field study to evaluate potential ecological and human health impacts related to the application of five supplemental wood preservatives to electric utility transmission poles. The field study involved post application monitoring for active ingredients and subsequent degradation products, and microbiological effects associated with Osmoplastic, Dursban, Woodfume, Hollow Heart, and Cop-R-Nap at 20 utility wood poles located in New York State Adirondack Park wetlands. Wood preservative residues from treated poles were not found at concentrations above background levels in ground water, surface water, or soil. The absence of detectable residues was attributed to the small original mass of applied materials, a high affinity for sorption to wood surfaces, and the ability of preservatives to undergo volatilization and biodegradation. Soil micro-organism populations were not effected by supplemental wood pole treatment as evidenced by measurements of carbon dioxide and methane evolution, and microbial biomass. Consistent with the results of soil respiration and microbial biomass indices, no impact was observed among the soil macro-invertebrate community. Based on the field study results, supplemental utility pole treatments of Osmoplastic, Dursban, Woodfume, Hollow Heart, and Cop-R-Nap were concluded not to cause measurable post application impacts to Adirondack Park wetlands.

Keywords: Supplemental Wood Pole Preservatives or Treatments; Osmoplastic; Woodfume; Dursban; Hollow Heart; Cop-R-Nap; Ground Water; Surface Water; Soil; Monitoring

Address correspondence to: Edward M. Michalenko, Ph.D.
O'Brien & Gere Engineers, Inc., P.O. Box 4873, 5000 Brittonfield Parkway, Syracuse, NY 13221 Tel: (315) 437-6100 Ext. 2726 FAX:(315)463-7554

INTRODUCTION

Over two million wood poles are used in New York State to support electrical transmission and distribution lines for the Empire State Electric Energy Research Corporation (ESEERCO) member utilities (ESEERCO, 1987). The utility use of supplemental wood preservatives to protect poles from groundline decay is a common industry practice. Typically, wood poles undergo initial inspection and treatment approximately 20 years post installation, and thereafter on a ten year basis (Kenderes pers. comm. 1993). Wood preservatives are critical to assuring effective service life which defers early pole replacement and maintains the reliability of the electric facility (OSMOSE, 1978). Supplemental treatments are cost effective. Wood distribution and transmission pole replacement costs about 1,000 and 3,500 dollars, respectively (ESEERCO, 1987). Supplemental wood preservative treatment costs only 30 to 50 dollars per application and extends pole service life by 50 to 100%. Studies indicate that overall savings are substantial (350 dollars per distribution pole and 1200 dollars per transmission pole) (ESEERCO, 1987).

Supplemental pole treatment causes less ecological perturbation than pole replacement because adjacent soil and vegetative communities are not physically disrupted, and forest and energy resource requirements of new pole production are conserved (Morrell, 1978). Also, supplemental treatments utilize far less quantities of chemical preservative than that contained in a new pole (Morrell, 1978). Nevertheless, questions have arisen regarding possible environmental impacts related to supplemental wood pole treatments in sensitive wetland environments. The primary concern is the potential for migration of supplemental preservatives from treated poles to surrounding soil, ground and surface waters (ESEERCO, 1987). Therefore, a field study was funded by ESEERCO and conducted by O'Brien and Gere Engineers, Inc. in order to evaluate the environmental dynamics of preservatives applied as supplemental treatments to wood utility poles in wetland environments.

OBJECTIVES

The study objectives were:

1. To investigate the environmental release and fate (migration, distribution, and persistence) of five supplemental wood preservatives (Table 1) in soil, surface and ground water of Adirondack wetlands that have the potential to facilitate their environmental release.

2. To evaluate the potential health and environmental impacts, if any, associated with the typical application of each supplemental wood preservative treatment.

METHODS AND MATERIALS

APPROACH

Research was conducted in wetland environments within the New York State Adirondack Park. Emphasis was placed on unique edaphic, physiographic, and hydrologic environments, in particular sites with seasonally high water tables and sandy soil conditions. Due to low organic matter contents, saturated soil moisture regimes and coarse textures, soils of the Adirondack Park, are highly susceptible to the release and migration of wood pole preservatives. In this sense, the selected wetlands are representative of all environments which would facilitate release and detection of wood preservative constituents.

SUPPLEMENTAL WOOD PRESERVATIVES

Five supplemental wood preservatives are under consideration for, or are in use in New York State by ESEERCO member utilities. These commercial products include Osmoplastic, an externally applied paste; Woodfume, an internally applied fumigant; and Dursban, Hollow Heart, and Cop-R-Nap, internally applied liquids. Active ingredients of each formulation were monitoredin soil ground and surface water. Formulations are applied to preserve wood poles from groundline rot, where the potential for microbial and insect invasion is greatest.

Inert ingredients were not monitored. Inert ingredients are not active in that they are not responsible for the desired chemical behavior of the formulation. Inert ingredients are added to mixtures for bulk and weight purposes (Sax and Lewis, 1987). Certain inert ingredients enhance the solubility of active constituents. In order to prevent competitive companies from counterfeiting products, chemical manufacturers typically withhold the identity of inert ingredients as proprietary information. A confidential business agreement to identify inert ingredients was not obtained with the manufacturers of supplemental wood preservatives because the resultant data would not be public domain, and therefore, useless to the overall process.

SCOPE OF FIELD WORK

Field study was organized according to a ground water evaluation and chemical and biological monitoring programs. Ground water was evaluated prior to establishing the chemical and biological monitoring programs in order to ensure sampling occurred at proper times and locations. Chemical migration from treated wood poles was monitored with four samplings of ground and surface waters and three collections of soil. Biological monitoring was implemented to test ecological response to wood preservative release. Four biological sampling events measured soil for changes in respiration, microbial biomass, and macro-invertebrate community structure. Well surveys, mapping, ground water elevation monitoring, hydraulic conductivity measurements, time-of-travel calculations and tracer tests were performed in support of the chemical and biological monitoring programs.

SITE SELECTION

United States Geological Survey (USGS) topographic maps, maps of Adirondack Park Agency (APA) designated wetlands and United States Department of Agriculture (USDA) Soil Conservation Service (SCS) soil surveys for Hamilton, Warren and parts of Essex and Clinton counties were used to develop soil-wetland associations along utility line right-of-ways in the Adirondack Park. Limited soil data were available for the latter two counties because their respective soil surveys were incomplete. The Niagara Mohawk Power Corp. provided plan and profile maps of transmission lines in Hamilton and Warren counties, whereas New York State Electric Energy and Gas Corp. (NYSEG) identified transmission lines in Clinton and Essex counties. APA wetland locations were transferred to utility transmission line maps. Soil types were identified from SCS soil surveys and corresponding soil characteristics were compiled on spreadsheets and sorted by location.

Preliminary site selections were based on two primary and three secondary criteria. Both sets of criteria related to soil properties that potentially facilitate wood preservative environmental release and migration. Soil texture and depth of water table were the primary selection criteria. The soil fractionization scheme utilized particle size classes established according to the USDA texture and unified soil classification system. Coarse soil allows the rapid movement of solutes to and in ground water. Transmission lines in areas with coarse gravel to fine sand were designated as candidate experimental sites. A high or seasonally high water table maintains maximum contact between ground water and the groundline area of a wood utility pole, which is the region of supplemental treatment. Water is probably the single most important agent in releasing supplement preservative from a wood pole. Sites with water tables greater than 3 m (3.2 ft) deep were screened from among soil-wetland associations exhibiting coarse soil textures.

The secondary criteria (permeability, slope and organic matter content) were used to further qualify the list of candidate experimental sites. A high soil permeability allows rapid infiltration of precipitation. A low to moderate slope maintains a long residence time of soil water in pole contact. The mobility of inorganic and organic substances is greater in soils with low versus high organic matter contents due to the increased sorption and retention properties of organic materials. Each condition, a high soil permeability, low to moderate slope and low soil organic matter content, favored the potential release and migration of supplemental wood pole preservatives in the environment.

Data regarding the candidate experimental sites identified during the preliminary selection process were verified in the field. Topographical and vegetative features, and accessibility and visibility to the public were assessed among the candidate experimental sites. The field screening was performed with the aid of consultant soil scientist, Charles Maine, and botanist, Jerry Jenkins. Soil types were identified and described to the series taxonomic level using SCS standard protocol. Reported SCS soil classifications and soil properties were confirmed by soil sampling, excavating and describing the soil profile. Field descriptions were contrasted with SCS soil series description sheets. Vegetation, including rare, threatened and endangered plants species, were identified and enumerated. Wetland types were catalogued and wetland values were estimated based on Part 578 of APA regulations (Jenkins pers. comm. 1988). Water tables were measured via test holes. Soil water conditions were evaluated by soil characteristics such as moisture content, elasticity, the degree of mottling and the presence of wetland indicator, hydrophytic plant species.

Significant physical features were also recorded in the field. Slope and terrain were determined with a clinometer. Standing water at distances less than 10 m (30 ft) from a pole during the wet season eliminated candidate experimental sites from further consideration due to label restrictions regarding wood preservative application. Surface waters included, but were not limited to lakes, streams, swamps and bogs. Each site was evaluated for accessibility to field monitoring, preservative application crews, and ground water well drill rigs, yet sufficiently remote to limit vandalism.

POLE TREATMENT

A total of 20 utility poles were selected with the participation and approval of the APA. Each pole was western red cedar wood treated with pentachlorophenol prior to installation. Western red cedar tree has a small sapwood zone (0.13 to 1.9 cm, 0.05 to 0.75 in) relative to pine (6.4 to 7.6 cm, 2.5 to 3.0 in) or douglas fir (1.9 to 3.2 cm, 0.75 to 1.26 in). Consequently, western red cedar receives a relatively low amount of primary treatment upon dipping and is susceptible to checking in the field (Morrell, 1987). The estimated date of installation for each study pole was 1950 with the exception of six poles whose installation was recorded in 1958.

Nine study poles were located directly within wetlands; the remainder were in hydraulic connection with wetlands. Each pole received a one-time standard application of supplemental preservative on June 26, 1990 by a licensed pesticide applicator (Osmose Corp). For worker protection and that of the environment, licensing is required for pesticide application under New York State Environmental Conservation Law, Article 33 section 1301 subsections 7 to 8a. Manufacturer recommended application procedures were followed as outlined on product labels. Six poles received combined treatments of Osmoplastic, Dursban and Woodfume (ODW). No single chemical constituent was common to individual products. Each residue could be traced to a parent commercial product, and interactions such as cosolublization among differing treatments would generally facilitate chemical release to the environment. Eight poles were treated with Hollow Heart; and six received Cop-R-Nap.

Four of the five commercial products are internal treatments whose active constituents bind to cambium cellular wall matrices within the wood pole's interior cavities. Liquid products Cop-R-

Nap, Dursban, and Hollow Heart are poured into wood poles via drilled holes which are subsequently capped with treated wood plugs. Woodfume, a fumigant, is applied in a similar manner. The difference is fumigation occurs under pressure with the use of a special applicator. The only external treatment is a groundline bandage, Osmoplastic. Soil around the pole is excavated to a depth of about 50 cm (20 in) and Osmoplastic is applied as a paste to the pole exterior in the groundline area. The pasted pole surface is covered with a plastic-lined moisture barrier wrap to shield against direct contact with soil and water.

GROUND WATER EVALUATION

Ground water was evaluated in three phases. The initial phase involved hand installation of temporary ground water monitoring wells adjacent to each study pole. Temporary wells were used to qualitatively locate depth and flow direction of ground water without disturbing potential biological monitoring areas. These wells also aided in selecting permanent hydraulically down gradient ground water monitoring positions and biological study plots.

During the second phase (March 12 to April 20, 1990), a total of 138 permanent ground water monitoring wells were situated about the 20 study poles. Typically, four or five wells were dedicated to sampling within 2 m (6.5 ft) of the pole. Three or four wells were situated at hydraulically down gradient positions, while one or two wells were up gradient. An additional two to four permanent wells contained piezometers for monitoring ground water depth, flow rate and direction. Altogether, as many as eight individual wells were positioned around each pole.

The third phase validated permanent ground water monitoring well positions. Quantification and mapping of seasonal fluctuation in ground water depth, flow rate and hydraulic conductivity were used to substantiate the accuracy and precision of the chemical monitoring program. Hydraulic conductivities were measured during annual high ground water flow periods (late April to mid-May 1990) and continued throughout the 1990 dry season (August). Ground water direction and flow calculations were verified with a tracer test. Small quantities of lithium bromide (0.1 or 0.5 moles) were injected into the ground at two positions 15 to 30 cm (6 to 12 in) from the study poles over a 2 min period. Bromide was monitored before and after injection using a specific ion electrode in down gradient sampling wells at periods of 3, 15 or 33 days. The shortest interval at which bromide was detected above background concentrations was used to estimate ground water time-of-travel from study pole to sampling well.

Meteorologic data were reviewed to determine if the tracer studies were conducted under representative weather conditions, and whether high and low hydraulic conductivity measurements were indicative of extremes in the annual moisture cycle. Local weather information for 1986 through 1990 (which included air temperature, soil temperature at 10, 20 and 50 cm (4, 8 and 20 in) depths, wind speed and direction, relative humidity, precipitation and solar radiation reported as minimum, maximum, and average measurements on hourly, daily, and monthly bases) were provided by the State University of New York, College of Environmental Science and Forestry (SUNY-CESF) Pack Forest Meteorological Station (Sheppard and Mitchell, 1990). The station is located (43°33'N, 73°48'W) in Warrensburg Township approximately 5 km (31 miles) north of the City of Warrensburg in the southeastern portion of the Adirondack Park. The elevation is 240 m (787 ft) above mean sea level (MSL). Study poles were to the east and northeast of Warrensburg with ground water elevations ranging from about 24 to 69 m (226 ft) above MSL.

CHEMICAL MONITORING PROGRAM

A total of four sampling events were performed over a period of 1.5 years. Surface and ground waters were sampled during each event. Surface waters either in direct hydraulic connection or immediately down gradient according to ground water flow were monitored on the same schedule as ground waters. Potential overland runoff was evaluated based on site specific field conditions. Consequently, sampling locations varied between poles and not all poles were adjacent to surface waters. One Hollow Heart; two Cop-R-Nap and 611 and two ODW treated poles did not require surface water monitoring. With the exception of the fourth sampling event, soils were also collected. Up to six soil cores were sampled at two soil depths (surface and 50 cm) and three radial distances (10, 50 and 100 cm) per wood pole. A single pretreatment sampling event, conducted just prior to supplemental preservative application to wood poles on June 26, 1990, established background soil and water quality. In order to detect a pulse release of preservative constituents, the second sampling event commenced with the first post treatment rainfall (June 30, 1990). The third sampling event coincided with the third post treatment biological sampling event (September 12 to October 15, 1990). The fourth sampling event occurred November 4 to 7, 1991.

Analytical Methods

Sample analyses were performed by OBG Laboratories, Inc., Syracuse, NY using standard GC/MS procedures (U.S.EPA, 1983; Greenberg, et al. (eds) 1985) developed under the Resource Conservation Recovery Act (U.S.EPA, 1986) and the Clean Water Act (U.S.EPA, 1984).

The Laboratory quality assurance/quality control (QA/QC) program included the use of procedural blanks, recovery monitoring, matrix and surrogate spiking, and statistical evaluation of instrumental performance. A field QA/QC program was also implemented, which consisted of field blanks and field spikes.

Monitored Preservative Constituents

Arsenic, fluoride and chromium were the test constituents of Hollow Heart. Test compounds for Cop-R-Nap were copper and naphthenate. Monitored components of Osmoplastic were fluoride, chromium, 2,4-dinitrophenol (DNP), and creosote. Chlorpyrifos and 1,1,1-trichloroethane (TCA) resulted from Dursban treatment. Residues of Woodfume were methyl dithiocarbamate (MDC) and methyl isothiocyanate (MIT).

BIOLOGICAL MONITORING PROGRAM

The biological monitoring program consisted of three study components identified by the APA as a condition of project approval: soil respiration (carbon dioxide and methane), soil biomass (chloroform fumigation /potassium sulfate extraction method), and soil macro-invertebrate community analysis. Coincident sampling enabled the identification of inter-relationships among biological and chemical study components. Four biological monitoring events were conducted between late spring to early fall 1990. These included one pretreatment and three post treatment sampling events.

A paired sampling plot design (treatment versus reference areas) was employed for respiration, biomass and macroinvertebrate monitoring at 15 of 20 study poles. Each plot consisted of a 2.5 X 3.5 m (8.2 to 11.5 ft) grid. Sampling locations for each study componentwere randomly selected from grid positions. Treatment areas, referred to as study plots, were positioned hydraulically down gradient from wood utility poles based on ground water flow direction. Reference plots were situated hydraulically up gradient in sites with similar topographic, soil and vegetative characteristics. Pretreatment sampling was used to evaluate the appropriateness and compatibility of reference to study plots.

A radial sampling plot strategy (pole at center) was also employed only for carbon dioxide measurements at seven selected poles. Radial plot and methane measurement additions were incorporated into the scope of the biological monitoring program at the request of the APA.

Soil Respiration Method

Soil respiration was studied, *in situ*, as an indicator of ecological response.

Soil air was extracted from the upper solum by inserting a 30 cm (0.98 ft) perforated teflon tube vertically into the ground. A template was used to establish a nominal 25 sampling positions within each plot (Figure 2). Larger sample numbers were incurred when difficulties with water, plugging and instrument calibration required the additional placement of teflon probes. Microbial carbon dioxide evolutions were recorded *in situ* with a direct reading instrument, an infrared carbon dioxide indicator (model RI-411) with a measurement range of 0 to 9950 ppm. Direct infrared carbon dioxide measurement afforded high sampling density with minimal study zone disturbance.

Moist wetland soils possess microspheres of anaerobiosis in which methanogenic bacteria may express a response to supplemental pole treatment under reducing conditions. Hence, direct methane measurements were also obtained to supplement carbon dioxide evolutions. Methane levels were recorded at three sampling points in each study and reference plot using an organic vapor monitor with a flame ionization detector (FID). Positions were selected to reflect low, medium and high carbon dioxide concentrations.

Soil Biomass Measurements

Changes in soil biomass were used as an index of ecological response to chemical exposure. Soil sampling dates for biomass measurements coincided with those recorded for macro-invertebrate collections. Analyses were performed according to the chloroform fumigation/potassium sulfate extraction method of Tate et al. (1988).

Soil biomass was measured in five soil core samples selected from random positions within each study and reference plot on four sampling dates. Soil cores were collected using a split-spoon sampler. Proper care was taken to minimize soil disturbance and retard microbial activity due to increased temperature. At the laboratory, root mats were removed from soil cores to reduce variability in organic matter contents caused by vegetative mass. Soil was sieved (2 mm, 0.09 in) and homogenized by hand mixing. Water content was recorded for each sample; results were later corrected for percent soil moisture. Approximately 20 g portions from every study and reference plot sample were tested in side by side comparisons of fumigated and non-fumigated soil. Fumigation was accomplished with a vacuum sealed desiccator containing chloroform vapor. Cell disruption occurred in the dark over a 24 hr incubation period at 25°C. Non-fumigated samples were incubated without chloroform. Upon elimination of residual chloroform from fumigated soil, all samples were extracted with 50 mL of 0.5 M potassium sulfate, vibrated for 24 hr and filtered with carbon-free glass substrate (Whitman G/C). One mL of remaining supernatant liquid was added to 0.03 N sulfuric acid to obtain a dilution factor of 20:1. Dissolved organic carbon content (DOC) was measured using an Dohrman Carbon Analyzer. Levels of DOC were converted to measurements of total organic carbon (TOC). The difference in TOC between fumigated and non-fumigated soil represents the total carbon dedicated to biomass calibrated per gram of dry soil.

Soil Macro-Invertebrate Sampling Program

Four macro-invertebrate sampling events were performed on study and reference plots at 15 treated poles. Reference and study plots were situated at different elevations relative to ground and surface water. Elevational differences, when coupled with near surface ground water tables, can generate differences in soil invertebrate community composition, structure, and characteristics. Plots were located, however, in such a way as to minimize as many differences as possible relative to ground water and other site variables. Invertebrate samples were collected in pitfall traps at five randomly selected coordinate positions within each matched plot. Altogether 650 pitfall traps were set and tended. Approximately 27,000 organisms representing 140 different species were identified. Analyses were performed by Dr. William Hamilton of Penn State University and Ms. Deborah Y. Sillman. Predictive models of theoretical ecology were used to evaluate the effect of dilute, chemical stress on macro-invertebrate community structure in matched plot comparisons (Hamilton and Sillman, 1991).

STATISTICAL ANALYSES

An analysis of variation was performed on each data set. For the chemical monitoring program, pretreatment and post application sampling means were compared using ground and surface water and soil data. For the biological monitoring program, study microbial respiratory (carbon dioxide and methane evolutions) and biomass data were contrasted with corresponding reference information. Pretreatment comparisons were used to evaluate the appropriateness and compatibility of reference to study plots. Statistical analyses were performed on validated data using one-half the detection limit for non-detect samples. Average values presented in text are conservative, however. These means are calculated from detected values only. Direct carbon dioxide, methane and laboratory soil biomass results for study and reference plots were also evaluated using box plot comparisons of interquartile ranges.

RESULTS AND DISCUSSION

Time of travel estimates based on hydraulic conductivity measurements corresponded with tracer test results. Tracer data confirmed that the down gradient sampling configuration provided adequate coverage to detect wood pole preservative release during the post treatment study period. The integrity of biological study plot positions were also evaluated. Results demonstrated that biological and chemical monitoring occurred at proper times and locations. Biological and chemical responses would, therefore, have been detected providing significant quantities of preservative constituents were released from the treated wood poles.

Ground Water Monitoring

Preservative constituents or corresponding degradation products were not detected, or were not found at concentrations above background values at poles treated with Hollow Heart (eight poles) or Cop-R-Nap (six poles) on any sampling date. Products of Woodfume were detected post application in low concentrations, ranging from 0.006 to 4 ppm, at three of six ODW treated poles. Overall, the frequency of detection was low (<20%) for each preservative constituent in ground water.

Hollow Heart in Ground Water

Arsenic was not detected in any pretreatment or post treatment ground water samples.

Chromium was found only in three fourth round composite samples from three poles. Respective concentrations were 0.17, 0.12 and 0.08 ppm. Although concentrations were low, chromium was not detected in ground water from previous sampling events.

Fluoride was not detected at concentrations above background levels. Background levels of fluoride ranged from 0.1 to 0.4 ppm.

Cop-R-Nap in Ground Water

Background copper levels ranged from 0.02 to 0.04 ppm for eight of twelve samples from three poles. Only one sample from the second sampling event showed copper at a concentration of 0.01 ppm. Copper was not detected elsewhere in the second or third sampling event. Copper was ubiquitous among 21 fourth round composite samples at concentrations identical to background levels (0.02 to 0.04 ppm); a single pole had 0.07 ppm.

Naphthenate went undetected in ground water.

ODW in Ground Water

No organic residues of Osmoplastic (creosote, DNP) or Dursban (chlorpyrifos, TCA) were detected in ground water during any pre- or post- treatment sampling event. Likewise, inorganic constituents of Osmoplastic (chromium, fluoride) were not detected above background concentrations in ground water at the six ODW treated poles. Chromium was not detected. Background levels of fluoride were similar to those at Hollow Heart treated poles (0.1 to 0.4 ppm). Fluoride concentrations ranged from 0.1 to 0.3 ppm.

The primary ingredient of Woodfume, MDC, degrades to MIT upon exposure to soil moisture. Neither MDC or MIT were detected during pretreatment sampling. Post application sampling events showed MDC and MIT release at two of six ODW treated study poles, however. Maximum MDC concentrations declined between the second and third sampling events from 3.6 ppm to 0.056 ppm, with respective frequencies of detection of 12% (three of 26 samples) and 8% (two of 24 samples). MDC was not detected during the fourth sampling event. Ground water levels of MIT also declined from a maximum of 4 ppm in the second round to single detections of 0.014 and 0.019 ppm in subsequent sampling events. Frequencies of MIT detection for three consecutive post application sampling events were 15% (4 of 26 samples), 4% (1 of 23 samples), and 5% (1 of 22 samples). In general, individual and combined MDG and MIT concentrations and frequencies of detection decreased with time. This can be attributed to the small mass of Woodfume applied to the pole, the susceptibility of MDC and MIT to chemical and biological degradation, and the tendency of MIT to volatilize (O'Brien & Gere Engineers, Inc., 1992).

Surface Water Monitoring

With the exception of two metals (copper and fluoride), residues of ODW, Hollow Heart and Cop-R-Nap were not detected in surface water during the four sampling events. A single detection of

0.02 ppm copper occurred at one Cop-R-Nap treated pole. Fluoride was ubiquitous among first, second and third round samples at a single HH treated pole. No preservative constituents were found at any of the 18 remaining test poles. No detections occurred during the fourth sampling event. Surface water concentrations of fluoride (0.20 ppm) were representative of background levels. Consistent quantities of fluoride were observed at hydraulically up gradient (reference) and down gradient sample locations, both before and after preservative application.

Soil Monitoring

Except for TCA of Dursban and MIT of Woodfume, preservative constituents were not detected in soil, or were not detected at concentrations that exceeded background levels. Both TCA and MIT were ephemeral in soil.

Osmoplastic in Soil

No organic constituents of Osmoplastic (creosote and DNP) were detected during pre- or post-treatment sampling events. Inorganic Osmoplastic constituents (chromium and fluoride) were detected at concentrations largely representative of background levels in soil. Chromium was detected in 18 of 26 pretreatment soil samples at concentrations ranging from 7 to 20 ppm, with the exception of a single sample at 43 ppm. Second and third round chromium levels were slightly elevated; concentrations ranged from 5 to 23 ppm and 7 to 270 ppm for 15 of 27 and 20 of 26 samples, respectively. Consecutive post application mean concentrations (± standard error) of 12 ± 2 ppm and 37 ± 13 ppm did not significantly differ ($\propto = 0.05$) from the average pretreatment chromium concentration of 15 ± 2 ppm, however.

Fluoride was detected in 19 of 26 pretreatment soil samples. Levels of fluoride ranged from 3 to 850 ppm; most pre-treatment sample concentrations were less than 25 ppm. Post application fluoride levels ranged from 5 to 650 ppm for 19 of 27 and 22 of 26 second and third round soil samples. No statistical significance was observed between mean fluoride levels for the first (47 ± 32 ppm), second (17 ± 3 ppm) and third (75 ± 28 ppm) sampling events.

Dursban in Soil

Residues of Dursban were not detected in pretreatment soil samples. Chlorpyrifos was not detected during any sampling event. A volatile carrier matrix component of Dursban, TCA, was detected with 100% frequency of detection (six of six samples) during the first post treatment sampling event at a single pole. Yet TCA was not detected at any other pole, and the overall frequency of TCA detection for the second sampling event was 23% (six of 26 samples). TCA concentrations ranged from 0.010 to 0.070 ppm with no apparent horizontal spatial trend. However, TCA residues were consistently higher (statistically significant $\propto = 0.05$) in shallow soil (0.047 to 0.070 ppm) than in deep soil (0.01 to 0.03 ppm). Spatial TCA distribution in soil suggests upward volatilization following radial vapor phase migration. TCA did not persist through the second post treatment sampling event. The absence of TCA during the latter sampling event is likely due to volatilization and physical or biological degradation during the intervening period (O'Brien & Gere Engineers, Inc., 1992).

Woodfume in Soil

The active ingredient of Woodfume, MDC, was not detected in soil. A hydrolic residue of Woodfume, MIT, was detected at a single pole during the second sampling event. Concentrations of MIT were low (1.5 to 4 ppm), but statistically significant ($\propto = 0.05$) with no apparent spatial trend. The frequency of MIT detection for the first post treatment soil sampling event was 15%. MIT did not persist in soil to the second post treatment sampling event. Volatilization and/or physical or biological degradation can account for the lack of MIT detection.

Hollow Heart in Soil

Fluoride was ubiquitous in first round soil. Pretreatment fluoride levels ranged from 2 to 110 ppm. Concentrations were generally less than 20 ppm, and the mean level of fluoride for the first sampling event was 15 ± 4 ppm. The post application fluoride content increases with respective second and third round means of 37 ± 17 ppm and 58 ± 21 ppm. No statistical difference was observed, however, between these sample means. Fluoride concentrations at radial distances up to 10 cm (4 in) from the pole were significantly different ($\propto = 0.05$) from levels at 50 and 100 cm (20 and 40 in), which indicates that minor releases of fluoride were attributable to Hollow Heart treatment.

Chromium was not detected in four of six pretreatment samples at a single pole; it was ubiquitous elsewhere in the first round. Frequency of chromium detection remained relatively constant for the first (65%), second (73%) and third (60%) sampling events. The mean chromium content of 13 ± 1 ppm for the initial sampling event did not statistically differ from subsequent post application means of 19 ± 4 ppm and 17 ± 4 ppm. As with fluoride, however, the average chromium concentration in 10 cm (4 in) soil was statistically higher ($\propto = 0.05$) than in soil at greater radial distances from the pole.

Arsenic was found in 35 of 37 pretreatment and 100% of post application soil samples. Representative background levels ranged from 0.6 to 13 ppm with a mean of 6 ± 1 ppm. Mean arsenic contents for the second and third sampling events were statistically comparable, but slightly less at 3 ± 11 ppm and 2 ± 1 ppm, respectively. The only arsenic (69 ppm) potentially attributable to Hollow Heart occurred at a 10 cm (4 in) distance from a single pole. Arsenic levels at 50 and 100 cm (20 and 40 in) radial distances did not exceed background concentrations.

A trend was evident of decreasing soil arsenic concentrations with distance from the pole. Above background levels of chromium, fluoride and arsenic were restricted to an area of soil substantially less than 3.1 m^2 (9 ft^2) at Hollow Heart treated study poles.

Cop-R-Nap Residues in Soil

No soil residues of copper or naphthenate attributable to Cop-R-Nap treatment were detected at any study poles. Copper was present in every first round soil sample. Background levels of copper ranged from 5 to 9 ppm. Post treatment copper concentrations did not statistically differ with second and third round levels. Respective maximum concentrations were 12 and 9 ppm. First, second and third round means were 6.3 ± 0.3 ppm, 6.1 ± 0.4 ppm and 4.9 ± 0.6 ppm. Naphthenate was never detected in soil. Detection limits varied per sample, however, at about 100 ppm.

Soil Respiration Results (Study Versus Reference Plots)

Comparison of soil respiratory interquartile ranges between study and reference plots indicates that supplemental preservative application did not induce an ecological response over time. Levels of carbon dioxide generated prior to supplemental treatment ranged from 800 to 16,800 ppm and 550 to 19,825 ppm for reference and study plots, respectively. No statistical difference was observed between pretreatment study and reference mean carbon dioxide concentrations, thereby indicating that reference plots were appropriately matched with study plots. Carbon dioxide evolutions generally increased for latter sampling events. Post treatment reference plot carbon dioxide concentrations ranged from 800 to 54,543 ppm at ODW treated poles, 366 to 63,050 ppm at Hollow Heart treated poles, and 325 to 32,453 ppm at poles treated with Cop-R-Nap. At the respective study plots, carbon dioxide concentrations ranged from 640 to 51,268, 360 to 94,094, and 2575 to 51,713 ppm. As evidenced via box plots, reference and study plot measurements showed no statistical difference at Cop-R-Nap, Hollow Heart and ODW treated poles. The increase in study and reference plot microbial respirations between pre- and post- treatment sampling periods was attributed to increased seasonal metabolic activity.

Other *in-situ* measurements of soil carbon dioxide were not located in the available literature. Laboratory derived carbon dioxide evolutions are highly variable. Average reported values range from 1.58 mg/10.0 g of soil/24 hr for a sand microcosm (Stamatiadis and Dindal, 1986) to 250 mg/100 g of soil/24 hr for an old field soil (Alfisol, Aeric Ochraqualf) from an abandoned state wildlife farm in west central Ohio (Dindal, Folts and Norton, 1973). Laboratory microbial respirations are not comparable, however, with direct field measurements.

Based on time-of-travel estimates of ground water movement, ample time elapsed for vapor phase and solute migration preservative constituents. Because post treatment chemical monitoring data show that concentrations of preservative constituents generally declined over time, the 1990 data likely reflect maximum residue levels due to supplemental treatment. Hence, respiration data indicate that a significant biological response is not experienced due to wood pole application of Osmoplastic, Dursban, Woodfume, Hollow Heart and Cop-R-Nap.

Soil Respiration Results (Radial Plots)

Results of each sampling event were evaluated by comparing interquartile box plots at the seven poles. Mean soil carbon dioxide evolutions according to radial distance and angle to ground water flow direction exhibit no systematic temporal or spatial patterns indicative of ecological response. Pretreatment levels of carbon dioxide ranged from 1200 to 63,202 ppm for Hollow Heart treated poles and 950 to 17,400 ppm for Cop-R-Nap treated poles. Pretreatment measures were not obtained at poles treated with ODW due to saturated soil conditions. Post treatment microbial respirations were 600 to 1,684,496, 763 to 105,883, and 370 to 154,280 ppm for ODW, Hollow Heart, and Cop-R-Nap treated poles, respectively.

Soil Respiration Methane Results (Study Versus Reference Plots)

Results indicate that methane was a minor end product of soil respiration at the study sites. Pretreatment methane levels were identical for study and reference plots. Undetectable amounts of methane were generated at each pole to high levels of 7, 9 and 6 ppm for ODW, Hollow Heart and Cop-R-Nap treated poles, respectively. No statistical differences were observed between study and reference plots. Hence reference plots were appropriate controls to study plots. Post treatment study and reference plot methane concentrations were also nearly identical and without statistical significance. Methane was not detected at Hollow Heart treated poles. At Cop-R-Nap and ODW treated poles, methane concentrations ranged from undetectable levels to 1 and 700 ppm, respectively, for study plots, and to 1 and 1,000 ppm for reference plots. Relative concentrations of carbon dioxide and methane suggests that methanogenesis was not an important mechanism for microbially mediated organic matter decomposition at the study sites. No ecological response to preservative treatments was evident in the methane data.

Soil Biomass Results (Study Versus Reference Plots)

Pretreatment reference plot measurements of microbial biomass at ODW, Hollow Heart, and Cop-R-Nap treated poles ranged from 0.01 to 1.24, 0.08 to 1.08 and 0.14 to 0.80 mg organic carbon (OC)/g of soil, respectively. Respective biomass at study plots were undetectable to 2.77, 0.08 to 0.92 and 0.15 to 1.19 mg OC/g of soil. Levels of microbial biomass at post treatment study plots for ODW, Hollow Heart, and Cop-R-Nap treated poles were 0.05 to 1.40, 0.09 to 1.21 and undetectable levels to 1.29 mg OC/g of soil, respectively. Corresponding post treatment reference amounts were undetectable to 1.54, 0.08 to 2.45 and 0.11 to 1.62 mg OC/g of soil. Box plot comparisons of interquartile ranges also demonstrated no changes in study and reference plots.

Macro-invertebrate Community Analysis

The following discussion summarizes the findings of Hamilton and Sillman (1991). Differences in pre- and post- treatment macro-invertebrate communities at three study poles were substantial. Differences were also observed in mosquito populations between seasons. Reference and study plot communities remained similar, however. The differences do not reflect site disturbance, but rather climatic effects on macro-invertebrate communities. Wet weather conditions of 1990 caused high ground and surface water levels which strongly influenced soil invertebrates at six of 15 study poles. Study plots were markedly affected by high water levels due to down slope locations relative to reference plots. At the six poles, invertebrate communities were enriched with gastropods and aquatic or moisture-loving organisms. Invertebrates such as the collembolan, *Lepidocyrtus cyaneus,* and most spider species were scarce on wet plots reflecting an intolerance of moist conditions. Numbers of hydrophyllic invertebrates like the minute fungus beetle, *Corticaria* sp., increased with moderate elevations in soil moisture. Seasonal senescence of invertebrates was observed at four study poles. Communities in study and reference plots at these poles were equivalent, however. At a single pole, invertebrates were nearly non-existent during the third post treatment sampling event, which may reflect early seasonal senescence. Yet the population crash was attributed to mechanical disturbance. Hamilton (pers. comm. 1993) noted that new pole replacement causes greater impact to invertebrate populations than supplemental pole treatment.

No direct indication of post treatment chemical perturbation was evident among soil invertebrate communities. Hamilton and Sillman (1991) concluded that study and reference plot communities were equivalent (with consideration of fluctuating soil moisture levels) and the initial model of potential disturbance was not actualized.

SUMMARY AND CONCLUSIONS

The field study consisted of three major components, a ground water evaluation and chemical and biological monitoring programs. Ground water was evaluated in order to develop samplings that were spatially and temporally situated to quantify preservative release and/or discriminate an associated ecological response. Up to eight ground water monitoring wells were installed at each study pole. Ground water elevations were monitored prior to, and with each sampling event. Potentiometric maps of ground water flow and hydraulic conductivity measurements were used to estimate ground water velocities. Tracer tests validated the ground water velocity calculations. Local weather and soils data confirmed that ground water velocity calculations accurately reflected hydrogeological conditions at the study sites. In conclusion, the ground water evaluation established the integrity of the chemical and biological monitoring programs by demonstrating that sampling intervals and positions were capable of defining the influence of preservative treatment on localized chemical and biological quality.

The chemical monitoring program was implemented at 20 study poles with a single pretreatment and three post application samplings (first rain event, 3 and 17 mo) of ground water, surface water and soil. Most preservative constituents, naphthenic acid (Cop-R-Nap), arsenic (Hollow Heart), chromium, dinitrophenol and creosote (Osmoplastic), chlorpyrifos and TCA (Dursban) were not detected in ground water. Inorganic preservative constituents, copper (Cop-R-Nap), chromium (Hollow Heart, Osmoplastic) and fluorine (Hollow Heart, Osmoplastic) were detected at concentrations representative of background levels. The only organic preservative constituents detected in ground water were residues of Woodfume, MDC and MIT. However, concentrations and frequencies of MDC and MIT detection decreased with time. No preservative constituents were detected in surface water except for copper (Cop-R-Nap) and fluorine (Hollow Heart); concentrations did not exceed background levels. In soil, each inorganic preservative constituent, copper (Cop-R-Nap), arsenic (Hollow Heart), chromium (Hollow Heart, Osmoplastic) and fluorine (Hollow Heart, Osmoplastic), was detected at background levels. The only organic preservative constituents detected in soil were TCA (Dursban) and MIT (Woodfume). Neither TCA or MIT persisted to the third sample event, probably due to volatilization release from the pole and vapor phase migration through soil.

The biological monitoring program evaluated ecological response to supplemental pole treatment. Paired (reference vs. study) and radial plots were established at 15 and seven study poles, respectively, in order to test impacted areas (down gradient of chemical migration) against unimpacted (up gradient) sites. Pretreatment monitoring demonstrated the appropriateness and compatibility of reference to study plots. Soil microbial carbon dioxide and methane evolutions were recorded *in situ*. Biomass of soil micro-organisms were measured via the chloroform fumigation/potassium sulfate extraction procedure of Tate et al. (1988). Hamilton and Sillman (1991) conducted a community analysis of soil macro-invertebrates. According to each index: soil respiration, microbial biomass and macro-invertebrate community structure, no measurable or sustained response was attributable to supplemental pole treatment with any of the five commercial wood preservatives.

Final Conclusion

The absence of significant measured effects during the study period indicates that no significant chemical or biological response likely occurs in the immediate vicinity of wood poles due to supplemental preservative treatments with Osmoplastic, Dursban, Woodfume, Hollow Heart, and Cop-R-Nap. Likewise, no significant health risks to humans or micro- and macro-flora or fauna are expected to result from supplemental wood pole treatment. These conclusions are not surprising given the small quantity applied (especially when compared to the amount contained in a new pole) and the affinity of preservative constituents for wood surfaces.

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