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Levels of the Herbicide Glyphosate in Well Water

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As is common with utilities across Canada, Newfoundland and Labrador Hydro have a maintenance program for electrical substations. One of the aspects of this program involves the management of vegetation. In many cases drinking water is extracted from wells located on the sites. Consequently, the utility has refrained from using chemical vegetation control measures, instead opting for mechanical control techniques.

In recent years the utility has been exploring the possibility of using chemical agents to manage vegetation at substations. Formulations containing the active ingredient glyphosate had been identified as offering safe and effective vegetation control at substations with wells.

Glyphosate is a systemic, broad spectrum herbicide used in controlling deep-rooted perennial species, annual and biennial broad-leafed plants, grasses and sedge species (Payne 1987). Glyphosate, or N-(phosphonomethyl)glycine, is the active ingredient in several formulations. More specifically, the isopropylamine salt of glyphosate is the active ingredient in herbicides like Roundup® (Trotter 1990).

Substations are typically built on gravel platforms above excavated ground. The ground, over which gravel is placed, consists of parent material with the top soil horizon removed during excavation and substation construction. The relatively high precipitation rates, combined with the parent material and gravel base, provide considerable potential for off-target movement of chemical agents applied to these sites.

To determine the extent of glyphosate off-target movement and to determine if well water contamination could result from operational spray programs, three substations in Newfoundland, Canada (Fig. 1) were sprayed with a 2 % solution of Roundup®. Glyphosate levels in well water from the sites were examined for 32 weeks post-spray .

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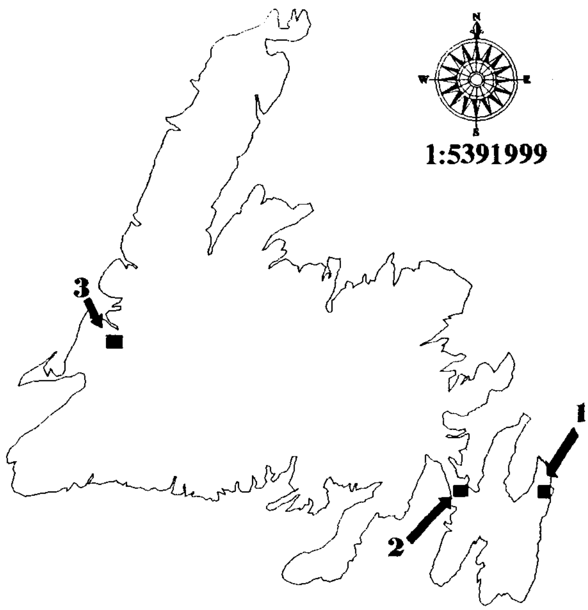

Figure 1. Location of the Oxen Pond substation (1 - 47°34"30' lat 52°45"24' long), the Western Avalon substation (2 - 47°31"00' lat 53°41"12' long) and the Massey Drive substation (3 - 48°31"00' lat, 53°41"12' long).

MATERIALS AND METHODS

Three electrical substations were sprayed with a 2% solution of Roundup® (active ingredient glyphosate, 356 grams per litre present as isopropylamine salt). The Massey Drive substation (0.82 ha) was treated at a rate of 13 l/ha on August 3, 1994 and retreated on September 3 at a rate of 12 l/ha. The Oxen Pond substation (0.91 ha) was treated at a rate of 12 l/ha on July 30, 1994 and retreated on September 1 at a rate of 13 l/ha. The Western Avalon substation (1.4 ha) was treated only once on July 27-28, 1994 at a rate of 11.4 l/ha. The herbicide was applied uniformly over the three sites using a hand held wand from the back of a truck.

Following the first spray, wells at the treated substations were sampled at 1, 2 and 4 weeks. After the second spray, the wells were sampled again at 1, 2, 4, 13 and 32 weeks. Before sampling, wells were first purged by allowing three times the well water volume to pass through the tap. Two 250 ml samples were collected in polypropylene containers and kept cool and dark during transportation to the laboratory.

For analysis, a fortified sample was prepared by decanting a portion of water to a 15 ml centrifuge tube and fortified with an aqueous glyphosate solution. A deionized spike was then prepared in the same manner. A portion of each sample was decanted into a 15 ml centrifuge tube. Borax was added to buffer the samples, blanks and spikes to pH 8-9. A solution of 9-Fluorenylmethyl chloroformate (> 97 % purity) was prepared in acetonitrile (HPLC grade) and was then added to the samples. All samples were capped and mixed by vortexing.

The solutions were left to stand at room temperature for twenty minutes to allow the reaction to occur. After reaction had occurred, dichloromethane (HPLC grade) was added to each sample. The aqueous layer was then extracted by vortexing and the phases allowed to separate. A portion of the aqueous phase was transferred to a Hewlett Packard autosampler vial, capped and sealed.

A glyphosate (99% purity) standard was prepared in water and derivatized along with the samples for analysis. The extracts were analyzed by HPLC with fluorescence detection (FLD) using a C18 column and an acidic buffer solution and acetonitrile as the mobile phase.

To determine soil characteristics at the substations, two pits were dug at each site. Each pit opened was approximately 0.5 m long and 50-65 cm deep. Soil horizons on the freshly dug pedon were identified. The profile was described according to Day (1982). Bulk density and hydraulic conductivity were determined at the surface (0-10 cm) and at 20-30 cm. Bulk density values were then compared to the classification of Day (1982) to obtain the type of soil drainage. Mean values are reported in Table 1. In addition, total sand, silt, clay and gravel were determined at 10 cm increments starting at the surface of the pit and progressing downwards. In addition, soil pH, % organic matter, Ca, Mg, K and P were determined for the first 5 cm and then at 10 cm increments afterwards. Mean values are reported in Table 2.

Table 1. Bulk Density and Hydraulic Conductivity for Electrical Substations Pedons at Various Depths.

Parameter	Depth (cm)	Western Avalon	Massey Drive	Oxen Pond
Bulk Density (g/cm^3)	0 - 10 20 - 30	1.57 1.76	1.47 1.57	1.51 1.61
Hydraulic Conductivity (cm/hr)	20 30	Low Slow	Low Moderate - Slow	Slow Very Slow

Table 2. Soil Chemical and Physical Characteristics of Electrical Substation Pedons. Values are reported as Mean (Standard Deviation).

Parameter	Western Avalon	Massey Drive	Oxen Pond
Total Sand (%)	73.0 (3.3)	78.0 (4.4)	74.3 (9.5)
Total Silt (%)	25.3 (3.4)	20.8 (4.1)	23.8 (8.0)
Total Clay (%)	1.7 (0.7)	1.1 (0.8)	1.9 (1.8)
Gravel (%)	39.5 (4.4)	37.2 (15.7)	50.5 (8.9)
pH	5.4	7.5	5.2
Organic Matter (%)	0.3 (0.2)	0.4 (0.2)	1.6 (1.2)
Ca (ppm)	170.7 (98.8)	481.4 (187.4)	245.0 (191.2)
Mg (ppm)	17.0 (7.2)	19.5 (14.0)	10.9 (6.7)
K (ppm)	17.7 (4.9)	16.0 (1.8)	20.3 (4.8)
P (ppm)	177.3 (14.7)	33.1 (35.1)	139.8 (84.5)

RESULTS AND DISCUSSION

Levels of glyphosate at the Western Avalon and Oxen Pond substations were below the limits of detection throughout the duration of the study. Glyphosate levels ranging from 0.0072 mg/l to 0.045 mg/l (Fig. 2) were detected in well water from the Massey Drive substation. Levels peaked two weeks post-spray to 0.025 mg/l and then dropped off to 0.004 mg/l by the 4th week of sampling. After the second treatment approximately 5 weeks after the first spray, levels increased to a maximum level of 0.045 mg/l at 7 weeks post-spray and again dropped off. Levels increased slightly to 0.013 mg/l 37 weeks after the second spray.

The highest detected level of 0.045 mg/l is considerably lower than the Canadian maximum acceptable concentration in raw drinking water of 0.280 mg/l (Trotter 1990). Water from the substations is sporadically consumed by Hydro workers. Given the infrequent consumption of well water from the Massey Drive well, the water does not pose a serious health risk to these workers.

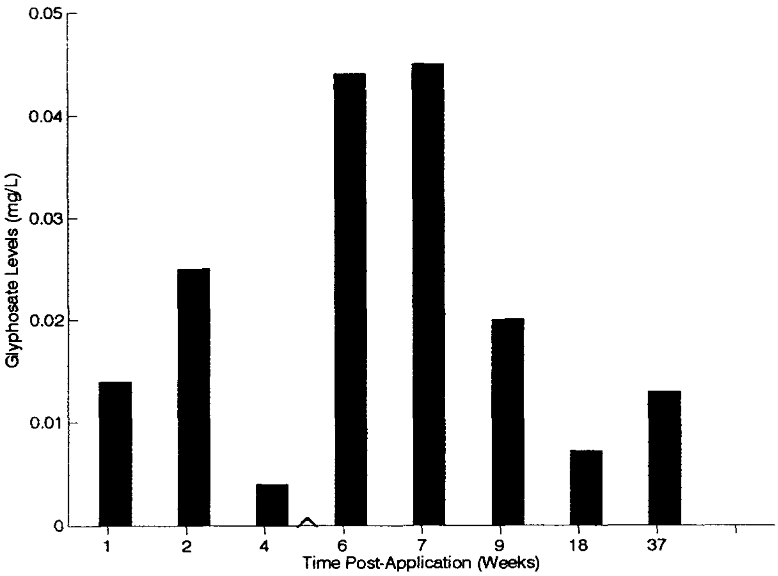

Figure 2. Glyphosate levels in Massey Drive well water following substation spray with a 2% Roundup® formulation at 13 l/ha. Substation was treated again 4 weeks after the first spray with a 12 l/ha rate, denoted by "^".

Analysis of the Massey Drive substation soil foundation showed that the substation was on a rapid to welldrained site. The soil association was North Lake. North Lake soil is developed from moderately coarse textured, dark yellowish brown to reddish brown glacial till. The soils were derived from red and light grey limestone, grey to black shale, sandstone, phyllite and minor red and white quartzite. Soil structure was a very weak subangular blocky pseudo structure, slightly sticky with a firm, very hard plastic consistency (Button 1983). The site was on a limestone bed and did not have a soil constricting layer.

In contrast, the Oxen Pond and the Western Avalon substations both had fragipan constricting layers. The soil association for both sites was Cochrane. For the Oxen Pond substation the association was derived from white orthoquartzite interbedded with green, gray and red arkose and siltstone. The Western Avalon substation soil was derived from greenish-grey and red siltstone and tuffaceous sandstone (Heringa 1981).

The presence of soil constricting layers (fragipans) at the Western Avalon and Oxen Pond substations had an influence on herbicide migration to the water table. The fragipans had a loamy subsurface horizon which had a high bulk density and a high silt content, low organic matter, low clay content, low pH, and low hydraulic conductivity. Fragic soils restrict the movement of roots and the vertical infiltration of water (Smalley 1982).

There is documented evidence of the tendency of glyphosate to sorb strongly to soils (Feng et al. 1990). This factor alone did not prevent off-target movement of the herbicide. However, when combined with the presence of fragipans at two of the substations, these considerations are important factors in explaining the absence of detectable levels of the herbicide.

Measured precipitation did not have a significant influence on herbicide levels detected in well water. The Massey Drive substation recorded the least amount of precipitation of the three sites with a total of 767 mm of rain and snow. The Oxen Pond substation recorded 1383 mm of rain and snow while the Western Avalon substation recorded 928 mm of precipitation.

Furthermore. the Massey Drive substation is located on a limestone bed (Department of Environment 1983). Permeability is commonly high in limestones. This could create a path for contaminants to reach subterranean water from the surface.

While precipitation would be responsible for providing the mechanism for vertical leaching, soil composition, the presence or absence of a soil constricting layer and drainage type had major influences on herbicide leaching dynamics. This ultimately resulted in levels of glyphosate detected in a well receiving the least amount of precipitation of the three sites examined.

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