DEPARTMENT OF THE ENVIRONMENT
CONSERVATION AND PROTECTION
ENVIRONMENTAL PROTECTION SERVICE
PACIFIC AND YUKON REGION

THE PERSISTENCE OF GLYPHOSATE AND ITS METABOLITE AMINO-METHYL-PHOSPHONIC ACID IN SOME COASTAL BRITISH COLUMBIA STREAMS

REGIONAL PROGRAM REPORT 85-01

By

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ABSTRACT

From 1982 to 1984, the Environmental Protection Service, Pacific Region, conducted studies at the UBC Research Forest and Chilliwack/Sechelt forest districts to monitor the residues of glyphosate and its metabolite, amino-methyl-phosphonic acid (AMPA), in stream water and sediment. The objective of these studies was to evaluate the persistence of the two chemicals in coastal British Columbia streams protected and unprotected by a buffer zone during aerial and ground based operational sprays.

Glyphosate residues in unprotected stream water reached a level of 0.023 mg/L within 2-3 hours following aerial application at 3 kilograms of active ingredient per hectare (kg a.i./ha). These residues peaked at 0.100 mg/L following the first major rainstorm eight days later, and then dropped to levels below the detection limit of 0.005 mg/L within two weeks. In two protected streams, the highest water level detected was 0.025 mg/L, following several heavy rainstorms. In both the protected and unprotected streams, the concentration of AMPA in water was below the detection limit of 0.005 mg/l during the study period.

One week after spray application, glyphosate residue in a sediment sample from the unprotected stream was 0.100 mg/kg. Peak levels of 0.400 mg/kg glyphosate were detected at three weeks and three months post-spray, and thereafter concentrations declined to 0.040 mg/kg which persisted for 574 days post-spray. AMPA residues were also found in the sediments, peaking at 0.400 mg/kg three months after treatment. This metabolite showed a more gradual decline to 0.090 mg/kg which also persisted for the duration of the study (574 days).

Glyphosate residue in a sediment sample from a protected stream was 0.200 mg/kg one week after an aerial spray application at 3 kg a.i./ha. Herbicide residues from vegetation along the stream bank or in the treated area may have washed into the creek following major rainstorm events. AMPA residues were detected only once in this stream at 0.100 mg/kg, 15 days after treatment. Both glyphosate and AMPA residues were below the level of detection in protected stream sediments for the remainder of the study (600 days post-spray).

RÉSUMÉ

De 1982 à 1984, le Service de la protection de l'environnement (région du Pacifique) a procédé à diverses études à UBC Research Forest et dans les districts forestiers de Chilliwack/Sechelt sur les résidus de glyphosate et de son métabolite, l'acide amino méthyl phosphorique, présents dans les cours d'eau de la Colombie-Britannique et leurs sédiments. L'objet de ces études était d'évaluer la persistance de ces deux corps chimiques dans les cours d'eau de la zone côtière de la Colombie-Britannique, cours d'eau protégés ou non par une zone tampon, durant les pulvérisations faites à partir des airs ou du sol.

Les résidus de glyphosate trouvés dans les cours d'eau non protégés avaient atteint un niveau de 0,023 mg/L, 2 à 3 heures après pulvérisation aérienne faite à raison de 3 kg/ha. Ce niveau avait atteint un maximum de 0,100 mg/L après la première pluie importante, huit jours plus tard, puis était descendu, en 2 semaines, au dessous de la limite de détection située à 0,005 mg/L. Le plus haut niveau relevé dans deux cours d'eau protégés, après plusieurs pluies importantes, s'élevait à 0,025 mg/L. Durant la période de l'étude et dans les deux sortes de cours d'eau, protégés et non protégés, la concentration de résidus de glyphosate et d'acide amino méthyl phosphorique, est restée en dessous de la limite de détection de 0,005 mg/L.

Une semaine après la pulvérisation, le niveau de concentration de résidu de glyphosate trouvé dans un échantillon de sédiments prélevé dans un cours d'eau non protégé s'élevait à 0,100 mg/kg. On a relevé des maximums de 0.400 mg/kg 3 semaines et 3 mois après la pulvérisation; on a également constaté que les concentrations étaient tombées à 0,040 mg/kg mais s'étaient maintenues à ce niveau pendant 574 jours après pulvérisation. Ces mêmes résidus ont également été détectés dans les sédiments à un niveau de concentration maximum de 0,400 mg/kg, trois mois après traitement. Le niveau de concentration de ce métabolite a décliné graduellement pour atteindre 0,090 mg/kg, niveau qui a persisté lui aussi pendant toute la durée de l'étude (574 jours).

Dans un échantillon de sédiments provenant d'un cours d'eau protégé on a détecté la présence de rendu de glyphosate à raison de 0,200 mg/kg une semaine après pulvérisation aérienne à raison de 3 kg/ha. Des résidus de pesticide provenant de la végétation poussant le long de la rive des cours d'eau ou de la superficie traitée ont pu contaminar le cours d'eau à la suite de fortes pluies. On n'a détecté des résidus d'acide amino méthyl phosphorique dans le cours d'eau qu'une seule fois, 15 jours après le traitement et le niveau s'élevait alors à 0,100 mg/kg. Dans les sédiments des cours d'eau protégés, les résidus de glyphosate et d'acide amino méthyl phosphorique étaient tous deux en dessous du niveau de détection jusqu'à la fin de l'étude (600 jours après la pulvérisation).

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CONCLUSIONS

1. Glyphosate was detected in water immediately after aerial treatment in a creek that was not protected by a buffer zone, despite good stream bank vegetation cover, but not in two creeks protected by buffer zones.

2. Glyphosate and AMPA were detected in the sediment of the unprotected (treated) creek after the first rainstorm; residues persisted for the duration of the study (574 days).

3. Very low concentrations of glyphosate and AMPA were found briefly in the water and sediment of one of the protected creeks. The entry of the chemicals into the water course was attributed to the frequency and intensity of rainstorms which carried glyphosate-contaminated soil particles into the stream.

4. Laboratory and field observations indicated that glyphosate adsorbed onto sediment particles was not readily released to the water phase.

1 INTRODUCTION

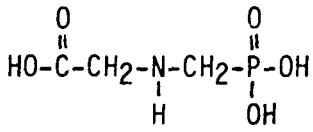
Glyphosate (Roundup™) is used as a selective or a non-selective post-emergent herbicide to remove unwanted vegetation in agriculture and forestry. In the coastal forest areas of British Columbia, it has the potential to replace the phenoxy herbicides such as 2,4-D and 2,4,5-T for brown/burn and conifer release programmes.

Prior to this study, there were no data available on the environmental behaviour of glyphosate under local conditions. Most of the information used to support its registration in Canada was produced in the Prairie Provinces, Eastern Canada, and the U.S.A. Information was required on the potential impact of glyphosate on the west coast fishery if this herbicide is used extensively in forestry. To assist the regional office of the Environmental Protection Service in the evaluation of provincial permit applications for aerial and ground based use of glyphosate, a monitoring program was initiated in 1981 to assess the persistence of glyphosate and its metabolite amino-methyl-phosphonic acid (AMPA) in coastal British Columbia streams.

The monitoring objectives were: (1) to determine the levels and persistence of glyphosate and AMPA in water and sediments of streams protected and not protected by buffer zones during aerial and ground based spray operations; (2) to establish the concentration, if any, of these chemicals in a creek when a large area of its watershed was aerially treated with Roundup™; and (3) to determine the sediment/water partitioning properties of glyphosate and AMPA.

2 LITERATURE REVIEW

Glyphosate is the common chemical name for N-(phosphonomethyl)-glycine, represented by the following structural formula:



Glyphosate is the active ingredient of a formulated herbicide sold by Monsanto Canada Ltd. under the trade name Roundup^{TM}. Due to the low solubility of glyphosate in water (1.2% at 25°C), its water soluble iso-propylamine salt is used in formulating Roundup^{TM}.

Glyphosate is a broad spectrum, non-selective, post-emergence herbicide for almost all annual and perennial plants (Franz, 1985). Glyphosate is absorbed through the foliage and translocated throughout the plant (Mullison et al., 1979). Studies show that its primary mode of action is the inhibition of a step in the bio-synthetic pathway of certain essential plant aromatic amino acids (Amrhein et al., 1980a; Amrhein et al., 1980b).

In pure water without suspended clay particles, photolytic degradation plays a major role in the breakdown of glyphosate (Lund-Hoie and Friestad, 1986).

Glyphosate degradation in soil, however, occurs primarily by microbial metabolism rather than hydrolysis or photolysis (Rueppel et al., 1977). The first degradation product from metabolism is amino-methyl phosphonic acid (AMPA) and the final breakdown components are carbon dioxide, water, nitrogen and phosphates (Young and Khan, 1978; Monsanto, 1984).

Laboratory studies demonstrated that glyphosate has a very strong affinity for mineral soil particles (Sprankle et al., 1975a; Hensley et al., 1978). It is quickly adsorbed onto soil particles which deactivate the herbicidal action of this chemical (Hance, 1976; Torstensson and Aamisepp, 1977; Tortensson, 1985). Soil particles with adsorbed glyphosate have the

potential to move from treated areas in the forest environment in stormwater runoff following major rainstorm events (Comes et al., 1976; Edwards et al., 1980).

The persistence of glyphosate in the environment depends, in part, on the rate of application and the prevailing conditions in the various ecosystem matrices such as leaves, litter, soil, and sediment. Newton et al., (1984) and Monsanto, (1984) reported that glyphosate, when used at rates of up to 3.3 kg/ha in an Oregon forest ecosystem, degraded in soil within one to six months.

3 MATERIALS AND METHODS

3.1 Unprotected Creek (No Buffer Zone)

This creek is located at the UBC Research Forest, Maple Ridge, B.C., 35 km east of Vancouver, in a 14.5 ha spray plot (Figure 1). Deciduous cover in the plot includes alder, coppice maple, salmonberry, and birch. The stream flows southward and is located at the southwest corner of the plot. It was completely covered by streambank vegetation and had an estimated discharge of approximately 60 L/min at the sampling station during the spray operation. The flow increased to approximately 300 L/min after each of the four rainstorms, which occurred 8, 14, 18, and 56 days after herbicide treatment, and subsided to 60 L/min a few days later. This forest plot was aerially treated with Roundup™ at the rate of 3 kilograms of active ingredient per hectare (kg a.i./ha) on June 18, 1982.

3.2 Buffer Zone Protected Creek I

This creek is located about 95 km east of Vancouver, B.C. on the north side of the Chilliwack River within a project area of approximately 110 ha (Figure 2). The deciduous vegetation mix includes alder, maple, birch, and salmonberry. The creek was protected on both sides by a 60 m-100 m buffer zone during an aerial treatment of 3 kg ai./ha Roundup™ on August 17, 1982. The estimated stream discharge at the sampling station prior to the herbicide application was approximately 60-70 L/min. This increased to 300-400 L/min after each of the three rainstorms which occurred 7, 15, and 21 days after aerial treatment.

3.3 Buffer Zone Protected Creek II

This creek is located at Pender Harbour, B.C. approximately 75 km northwest of Vancouver (Figure 3). The deciduous vegetation mix consists of alder, coppice maple, and salmonberry. The creek flows through a 10 ha treatment plot and was protected on either side by a 10 meter buffer zone during a ground backpack spray application of Roundup™ on August 4, 1983. The application rate varied from 0.5 to 1.5 kg ai./ha. The approximate rate of discharge at the sampling station prior to herbicide treatment was estimated at 50-60 L/min.

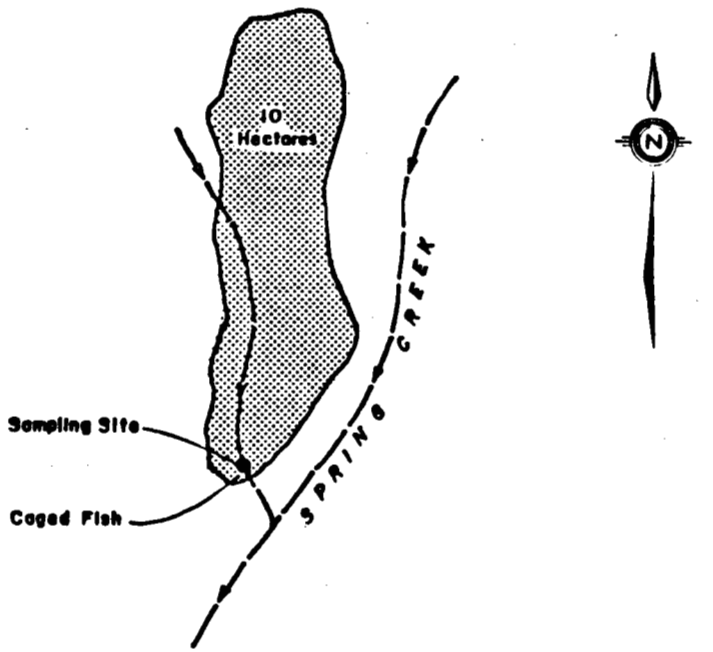


FIGURE 1 AERIAL GLYPHOSATE TREATMENT PLOT - U.B.C. RESEARCH FOREST, MAPLE RIDGE, B.C.

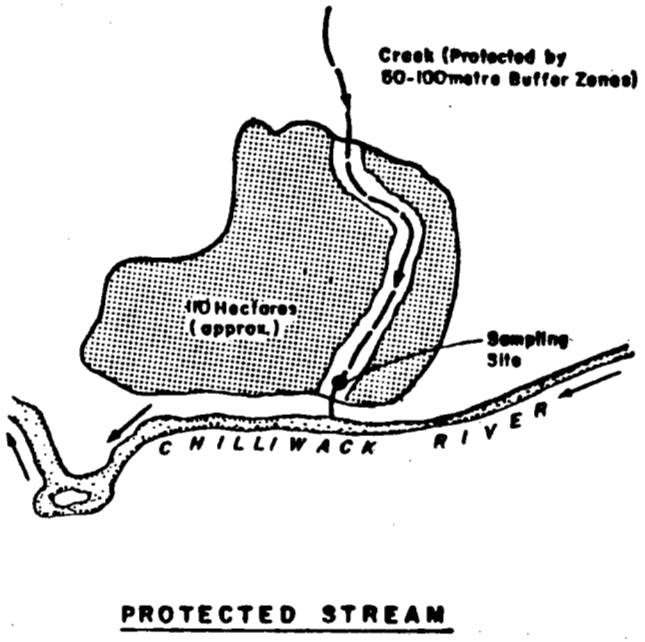


FIGURE 2 AERIAL GLYPHOSATE TREATMENT AREA - CHILLIWACK, B.C.

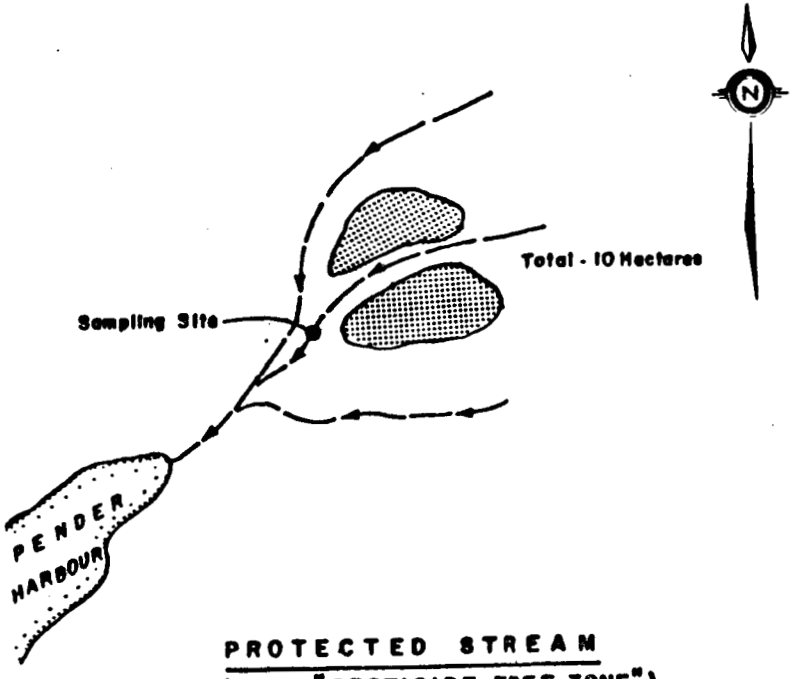


FIGURE 3 BACKPACK GLYPHOSATE TREATMENT
PENDER HARBOUR, B.C.

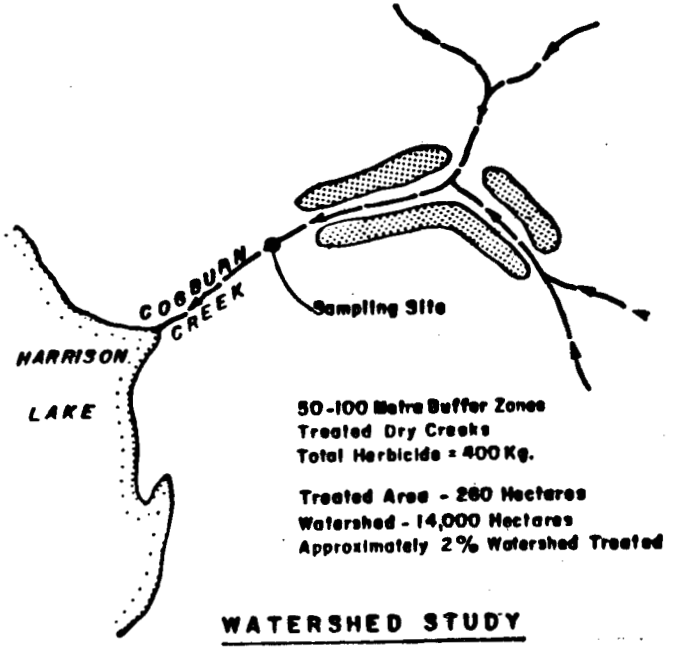


FIGURE 4 AERIAL GLYPHOSATE TREATMENT
COGBURN CREEK, B.C.

3.4 Cogburn Creek Watershed Study

The Cogburn Creek watershed is located on the east side of Harrison Lake and is approximately 150 km east of Vancouver, B.C. (Figure 4). Deciduous vegetation consisted of alder, vine maple, birch and salmonberry. Of the approximately 14,000 ha in the watershed, 260 ha were aerially treated on September 1, 1984 with a total amount of 400 kg a.i. of Roundup™. The estimated rate of creek discharge at the sampling station was 1000 L/min. This flow increased to an estimated rate of 3000-5000 L/min after a rainstorm one week after treatment.

3.5 Application Methods

3.5.1 Aerial Application. A Bell-47 helicopter was used for the aerial operations at UBC Research Forest, Chilliwack River, and Harrison Lake West (Cogburn Creek). The helicopter had a loading capacity of 225 L of spray mix per run. It was equipped with three spray jet nozzles placed equidistant along a boom length of 2.1 m. The centre nozzle was a V-jet type (H0.25-U), complemented by two off-centre T-jet nozzles (OC-150) on either side. The V-jet nozzle had a maximum discharge capacity of 19.35 L/min, while each of the T-jet nozzles was capable of discharging up to 58.5 L/min. These nozzles were adjusted and set to discharge at a combined rate of 50 L/min. The average flight speed of the helicopter was 50 km per hour. The herbicide mixture was released at an average height of 9 m above the brush/tree canopy.

3.5.2 Backpack Application. A Sanex Spray Mate backpack sprayer was used for the ground operation at Pender Harbour. This machine was pressurized via a hand pump and had a loading capacity of 15 L.

3.6 Residue Sampling

3.6.1 Water Samples. Grab water samples were collected in 450 ml amber glass bottles at each sampling time. All bottles were rinsed with redistilled acetone and petroleum ether, and heated to 300°C for 12 hours

prior to use. A piece of chemically washed and heat-treated aluminum foil was used to line the opening of each bottle before capping to prevent sample contamination.

3.6.2 Sediment Samples. Sediment samples were collected in 500 gm wide-mouth amber glass jars. The jars were chemically cleaned and heat treated before use as described in 3.6.1. Five composite sediment samples were pooled at each sampling time. The samples were collected at random along the same general section of the stream with the aid of a clean steel trowel. Chemically washed and heat treated aluminum foil was used to line the opening of each glass jar before capping.

3.6.3 Sampling Regimes. The following sampling regimes were used for the water and sediment samples taken at the various study locations:

i) Unprotected Creek (UBC Research Forest)
   a) Water Samples - Prespray; postspray 0.04, 0.12, 1, 2, 3, 8, 14, 18, 20, 28, 56, 90 days
   b) Sediment Samples - Prespray; postspray 1, 8, 10, 14, 20, 57, 90, 220, 350, 450, 531, 574 days

ii) Buffer Zone Protected Creek I (Chilliwack)
   a) Water Samples - Prespray; postspray 0.2, 1, 3, 7, 15, 21, 36, 80 days
   b) Sediment Samples - Prespray; postspray 7, 15, 28, 75, 600 days

iii) Buffer Zone Protected Creek II (Pender Harbour)
   a) Water Samples - Prespray; postspray 0.04, 1, 4, 7, 14, 24, 44, 20, 110, 154, 190 days
   b) Sediment Samples - Prespray; postspray 0.04, 1, 4, 7, 14, 24, 44, 20, 110, 154, 190 days

iv) The Watershed Study (Cogburn Creek)
   a) Water Samples - Prespray; postspray 0, 1, 7 days

3.7 Sediment/Water Partitioning Studies

3.7.1 Contaminated Stream Bottom Sediments. A 200 gm sediment sample from the UBC Research Forest stream was mixed with 400 gm of de-ionized water (20°C, pH = 5.73) in a 1000 mL volumetric flask. The flask was then agitated by hand shaking for 10 minutes and allowed to settle for 5 minutes. The water and sediments from the flask were then separated into different sample containers and submitted to the laboratory for glyphosate and AMPA residue analyses. A similar procedure was applied to the control sediment sample collected from an untreated creek.

3.7.2 Laboratory Spiked Sediments. A 200 gm sediment sample collected from an untreated creek was weighed out in a 1000 mL volumetric flask. The sample was spiked with 0.100 mg/L glyphosate and 0.100 mg/L AMPA. Four hundred gms of de-ionized water (20°C, pH = 5.85) were added to the volumetric flask water which was mechanically agitated for 30 minutes, and allowed to settle for about 1 hour. The liquid and solid phases were then separated to different sample jars and submitted to the laboratory for residue analysis. A similar procedure was applied to a control sediment sample.

3.8 Residue Analysis

All residue analyses were conducted by the British Columbia Ministry of Environment Laboratory. Unfiltered water samples were derivatized and cleaned up prior to ion suppression High Performance Liquid Chromatography (HPLC). Sediment samples were extracted and the process of anion exchange applied prior to derivatization and clean up procedure. The analysis was performed on a Hewlett Packard 1084B HPLC with an ultrasphere ODS 5 u column.

3.9 Detection Limits

The detection limit of glyphosate and AMPA in water was 0.005 mg/L. The detection limit for sediment was 0.100 mg/kg before October, 1983 and 0.040 mg/kg after October, 1983. The average recovery rate for glyphosate and AMPA from both sediment and water was greater than 95%.

4 RESULTS

4.1 The Unprotected Creek (UBC Research Forest)

Glyphosate residues were detected in water soon after the aerial spraying and reached a peak of 0.023 mg/L, 2 to 3 hours post treatment (Table 1). A detectable concentration of glyphosate was measured at 24 hours post-spray in stream water. After 24 hours glyphosate residues were below the limit of detection. Glyphosate residues reappeared in the stream water following the first major rainstorm eight days post-spray and peaked at 0.100 mg/L. Following the next two rainstorms low levels of glyphosate were also found in the stream. Water samples collected after these two rainstorms contained no glyphosate residues above the limit of detection.

After the first rainstorm glyphosate and AMPA residues appeared in the stream sediment and thereafter both were found at very low concentrations on newly deposited stream sediments for a period of up to 574 days. Good control of deciduous growth in the spray block was noted including effects on streambank vegetation.

4.2 Buffer Zone Protected Creek I (Chilliwack)

Glyphosate residues were not detected in samples taken shortly after the aerial treatment (Table 2). However, after several rainstorms had occurred post- treatment, very low concentrations of glyphosate of up to 0.025 mg/L, were found in the stream water. As well, low concentrations of both glyphosate and AMPA (0.100-0.200 mg/kg) were detected on newly deposited creek sediments on two occasions. Sediment samples collected after 15 days post-spraying did not contain glyphosate and AMPA residues above the limit of detection.

4.3 Buffer Zone Protected Creek II (Pender Harbour)

Water contamination did not occur during and after this backpack spray operation (Table 3). On one occasion, two months post-treatment, a very low concentration of glyphosate and AMPA residues (0.050 mg/L) was detected in stream sediments.

TABLE 1 GLYPHOSATE AND AMPA RESIDUES IN WATER AND SEDIMENTS OF THE UNPROTECTED CREEK FOLLOWING AERIAL APPLICATION OF ROUNDUP™ AT 3 kg a.i./ha (UBC Research Forest)

TIME (days)	WATER (mg/L)		SEDIMENT[1] (mg/kg)	
	Glyphosate	AMPA	Glyphosate	AMPA
Prespray	< 0.005	-	< 0.100	-
0.04 (post-spray)	0.020	-	-	-
0.12	0.023	-	-	-
1	0.005	-	< 0.100	-
2	< 0.005	-	-	-
3	< 0.005	-	-	-
8 (rain)	0.100	-	0.100	0.100
10	-	-	0.300	0.100
14 (rain)	0.006	-	0.100	0.100
18 (rain)	< 0.005	< 0.005	-	-
20	< 0.005	< 0.005	0.400	0.200
28	< 0.005	< 0.005	-	-
56 (rain)	-	-	-	-
57	< 0.005	< 0.005	0.200	0.200
90	-	-	0.400	0.400
220 (rain)	-	-	0.100	0.200
350	-	-	0.120	0.310
450	-	-	0.050	0.230
498	-	-	0.050	0.220
531	-	-	0.040	0.090
574	-	-	0.040	0.090

[1] Detection limits were 0.100 mg/kg before October 1983 and 0.040 mg/kg after October 1983. The lower limit applied after day 450 for sediment samples.

TABLE 2 GLYPHOSATE AND AMPA RESIDUES IN WATER AND SEDIMENTS OF PROTECTED CREEK I FOLLOWING AERIAL APPLICATION OF ROUNDUP™ AT 3 kg a.i./ha (Chilliwack)

TIME (days)	WATER (mg/L)		SEDIMENT[1] (mg/kg)	
	Glyphosate	AMPA	Glyphosate	AMPA
Prespray	< 0.005	< 0.005	< 0.100	< 0.100
0.2 (post spray)	< 0.005	< 0.005	< 0.100	< 0.100
1	< 0.005	< 0.005	< 0.100	< 0.100
3	< 0.005	< 0.005	< 0.100	< 0.100
7 (rain)	0.013	< 0.005	0.200	< 0.100
15 (rain)	-	-	0.100	0.100
21 (rain)	0.025	< 0.005	-	-
28 (rain)	-	-	< 0.100	< 0.100
36	< 0.005	< 0.005	-	-
75	-	-	< 0.100	< 0.100
80	< 0.005	< 0.005	-	-
600 (rain)	-	-	< 0.040	< 0.040

[1] Detection limits were 0.100 mg/kg before October 1983 and 0.040 mg/kg after October 1983. The lower limit applied after day 450 for sediment samples.

TABLE 3 GLYPHOSATE AND AMPA RESIDUES IN WATER AND SEDIMENTS OF PROTECTED CREEK II FOLLOWING BACKPACK SPRAY APPLICATION OF ROUNDUP™ AT 0.5 TO 1.5 kg a.i./ha (Pender Harbour)

TIME (days)	WATER (mg/L)		SEDIMENT[1] (mg/kg)	
	Glyphosate	AMPA	Glyphosate	AMPA
Prespray	< 0.005	< 0.005	< 0.100	< 0.100
0.04 (post spray)	< 0.005	< 0.005	< 0.100	< 0.100
1	< 0.005	< 0.005	< 0.100	< 0.100
4	< 0.005	< 0.005	< 0.100	< 0.100
7	< 0.005	< 0.005	< 0.100	< 0.100
14	< 0.005	< 0.005	< 0.100	< 0.100
24 (rain)	< 0.005	< 0.005	< 0.100	< 0.100
44	< 0.005	< 0.005	< 0.100	< 0.100
76 (rain)	< 0.005	< 0.005	0.050	0.050
110 (rain)	< 0.005	< 0.005	< 0.040	< 0.040
154 (rain)	< 0.005	< 0.005	< 0.040	< 0.040
190 (rain)	< 0.005	< 0.005	< 0.040	< 0.040

[1] Detection limits were 0.100 mg/kg before October 1983 and 0.040 mg/kg after October 1983. The lower limit applied after day 76 for sediment samples.

4.4 The Watershed Study (Cogburn Creek)

Residues of glyphosate and AMPA in the water samples collected from Cogburn Creek before, during, after the aerial spray application, and following the first major rainstorm seven days post-spray were below the limit of detection.

4.5 Sediment/Water Partitioning Study

Table 4 shows that glyphosate and AMPA, when adsorbed on soil particles, are not readily released to the water phase.

TABLE 4 GLYPHOSATE AND AMPA RESIDUES IN WATER AND SEDIMENTS OF PARTITIONING TESTS

SEDIMENTS	WATER (mg/L)		SEDIMENT (mg/kg)	
	Glyphosate	AMPA	Glyphosate	AMPA
Untreated Creek	< 0.005	< 0.005	< 0.040	< 0.040
Treated Creek	< 0.005	< 0.005	0.040	0.090
Spiked with 0.100 mg/L glyphosate and AMPA	< 0.005	< 0.005	0.100	0.100

5 DISCUSSION

Although the unprotected creek was well covered by stream bank vegetation such as alder, birch, salmonberry, and thimbleberry, residues of glyphosate were found in the water course from the outset of sampling following the spray operation. A dry period of seven days post-treatment afforded no protection to this creek from herbicide contamination following a rainstorm, suggesting that conditions for glyphosate breakdown were minimal during that time.

In contrast, glyphosate residues were not detected during and soon after spray operations in creeks having a similar type of stream bank vegetation and protected by a buffer zone. However, in one of the buffer zone protected creeks (Chilliwack area), very low concentrations of glyphosate residues were detected after several rainstorms post-treatment. Herbicide residues from vegetation along the stream bank or in the treated area may have washed into this creek.

Glyphosate residues in sediments in all the study creeks were found only after the occurrence of one or more rainstorms. In the buffer zone protected streams the residue appeared at low concentrations on two occasions, while in the unprotected creek both glyphosate and AMPA appeared after the first rain and persisted above the limit of detection to the end of the study 574 days post-treatment.

Newton et al. (1984) found that in a forest environment stream sediments adsorbed herbicide residues more slowly but reached higher levels than water. In this study, the occurrence of glyphosate and its metabolite, AMPA, in the unprotected creek sediment was apparently from the deposition of herbicide-contaminated soil particles carried by runoff after each rainstorm. The herbicide residues found in water soon after spray treatment probably did not contribute any appreciable concentration to the bottom sediment.

In the absence of a buffer zone, the herbicide effectively controlled or eliminated stream side vegetation, but this resulted in detectable levels of residues of glyphosate and AMPA in the stream. Reduction or elimination of stream bank vegetation, however, can have adverse impacts on the integrity of a stream by enhancing stream bank erosion.

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