EFFECTIVENESS OF STREAM BUFFER ZONES DURING AERIAL APPLICATIONS OF CHLOROPHENOXY AND PICLORAM HERBICIDES

by

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ABSTRACT

The effectiveness of 150 foot buffer zones to protect stream bankside integrity and water quality was determined during aerial applications of chlorophenoxy and picloram herbicides to control hardwoods in conifer plantations and in powerline rights-of-way. Direct and lateral drift, creek water and air contamination, effects on non-target vegetation, and persistence of residues in the forest soil/litter were monitored within the buffer zones of four different programs.

Fixed-wing application of 2,4-D/2,4,5-T contaminated the streams flowing through the treatment area. The high herbicide concentrations may have been a potential hazard to fish and tainted domestic water supplies. The other programs, all helicopter sprays, did not contaminate water in the buffer zones but did cause some mortality of bankside vegetation. The maintenance of buffer zone integrity and water quality appeared to depend on aircraft type, microclimatic conditions, plot demarcation, effective drift control agents, spray application equipment, and operator skill.

The implications of these findings are discussed in relation to more advanced application methods and possible effects of herbicide drift on the aquatic environment.

RÉSUMÉ

Des applications aériennes de chlorophenoxie et d'herbicides picloram (visant à éliminer les feuillus dans les plantations de conifères et les servitudes de passage des lignes électriques) ont permis d'étudier l'efficacité de zones-tampons de 150 pieds de large, destinées à empêcher la détérioration des rives des cours d'eau et de la qualité de l'eau. Dans les zones-tampons de quatre programmes différents, on a étudié la dérive directe et latérale, la contamination de l'eau des ruisseaux et de l'air, les effets sur la végétation non visée par l'opération, et la persistance des résidus dans le sol et dans les matières végétales en décomposition dans les forêts. L'application de 2,4-D/2,4,5-T par des avions entraîna une contamination importante des cours d'eau traversant la zone traitée. Les fortes concentrations d'herbicides peuvent avoir constitué un risque pour les poissons et altéré les réserves d'eau potable. Les autres programmes, utilisant tous des hélicoptères, ne contaminèrent pas l'eau dans les zones-tampons, mais détruisirent une partie de la végétation des rives. L'efficacité des zones-tampons et le maintien de la qualité de l'eau semblent dépendre de plusieurs facteurs: type d'aéronef, conditions microclimatiques, démarcation de la zone, efficacité des agents anti-dérive et du matériel de pulvérisation, et compétence du pilote.

On parle des conséquences de ces découvertes relativement à des méthodes d'application plus perfectionnées ainsi que des effets que pourrait avoir la dérive des produits herbicides sur le milieu aquatique.

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CONCLUSIONS

The results of this study indicate that 150 foot buffer zones are a minimum requirement for the protection of stream bankside integrity and water quality during aerial applications of herbicides with conventional spray equipment. Moreover, larger buffer zones may be desirable especially during applications of picloram/2,4-D where a broad spectrum of non-target plants is susceptible to this herbicide mixture. Fixed-wing aircraft should not be used for application of chlorophenoxy herbicide esters because of excessive drift problems.

Drift control with specialized equipment and/or formulations appears to be desirable and warrants further investigation for application of chlorophenoxy dormant sprays and picloram/2,4-D mixtures. Adequate flagging of plot boundaries and stream buffer zones, as well as measurement of microclimatic conditions in the spray area, appear to influence drift control success.

In the future, greater emphasis should be given to monitoring biological effects of herbicide sprays, especially to those segments of the terrestrial and aquatic habitat amenable to short-term quantitative studies such as terrestrial or aquatic arthropods. The effects of herbicides on different trophic levels in the aquatic and terrestrial ecosystem also require investigation but such studies must be conducted on a long-term basis.

1 INTRODUCTION

1.1 Aerial Brush Control Operations

Aerial applications of herbicides are used in British Columbia to control hardwood competition in conifer plantations and to control brush along powerline rights-of-way in areas of rough or mountainous terrain. Natural plant succession is generally toward hardwoods (alder, salmonberry) in conifer plantations and forest managers prefer cultural treatment to reduce hardwood competition and assure increased growth and development of conifers. Management of all hardwood, softwood, and conifer brush is required on powerline rights-of-way to prevent interference with high voltage transmission lines.

Iso-octyl esters of 2,4-D and 2,4,5-T are currently recommended for brush control in conifer plantations (Council of Forest Industries of British Columbia, 1972). The chlorophenoxy herbicides are applied either as dormant or foliar sprays at rates of two to four pounds active ingredient in volumes of four to ten gallons of spray mixture per acre. Dormant sprays are applied in a diesel or fuel oil carrier in the early spring when hardwood buds are beginning to swell but have not opened. Foliar sprays, applied in a water carrier, usually coincide with full leaf bloom during the active-growth period from early to late summer.

A mixture of triisopropanolamine salts of picloram and 2,4-D (Tordon 101 Mixture*) is commonly used for brush control on utility rights-of-way. These sprays are applied at a rate of 1.5 - 2.0 pounds active ingredient picloram and 6.0 - 8.0 pounds active ingredient 2,4-D in fifteen to twenty gallons of total spray volume per acre. The solutions are particulated with NORBAK* prior to application to reduce drift and volatilization of the herbicides. Picloram/2,4-D are usually applied following full-leaf development during periods of rapid plant growth.

* Registered Trademarks of the Dow Chemical Company

1.2 Effects of Aerial Herbicide Sprays on the Aquatic Environment

Studies on the environmental effects of herbicide use on forest lands or rights-of-way have been largely concerned with the release and distribution of spray materials and their persistence and fate in the terrestrial and aquatic environment. Aerial sprays will be distributed to the air as drift and to the vegetation, forest floor, and water in the target area (Norris, 1971).

Drift may be defined as that portion of the spray material released as fine droplets that are carried via airborne movement to non-target areas in the vicinity of the spray site. The degree of movement of spray drift depends primarily on the droplet size, the height of the aircraft, and the wind velocity. Small diameter droplets ($<100\mu$) are not only subject to greater drift than larger ones, but also are more likely to evaporate and be lost before reaching the vegetation. Thus drift occurs both in a droplet and vapour form (Grover, 1974).

Application of herbicides to forest lands or rights-of-way usually requires spraying in rough mountainous terrain flying at a height of 50 to 100 feet above the vegetation. Under such conditions, particulate drift and evaporation may result in loss of more than half of the active ingredients when applying chlorophenoxy herbicides. Approximately 60 to 75 percent of low volatile esters of 2,4,5-T in diesel oil were lost from an early spring aerial application in an Oregon forest (Norris, 1967).

Most of the herbicide which is intercepted by vegetation will eventually enter the environment of the forest floor. The residue will either be absorbed and translocated within the tissues or remain on the surface of the leaves where it is subject to removal by rain. Of the material absorbed into the leaf, only a small percentage (5% or less) is actually translocated to other plant parts (Norris, 1967). Hence, additional residues will be added to the forest floor environment at the time of leaf abscission.

Streams flowing through treated areas are usually contaminated either by direct application of herbicides or by leaching of residues and movement with surface flow from adjacent land. In general, high residue levels are detectable in running water for only a short period following direct aerial treatment. Surface flow from treated land will not cause high residue levels in streams unless there is appreciable precipitation shortly after application. However, small quantities may be continuously transported to the aquatic environment via leaching and runoff, especially during periods of high rainfall in the winter months. Norris (1971) concluded that the magnitude of contamination is more a function of how treatment areas are laid out with respect to fish-bearing streams than the kind of herbicide or the geographical location in which it is used (i.e., it is more important to exclude spray plots from areas with many streams or maintain appropriate buffer zones between running water and the spray plots).

The biological implications of herbicide residues in steams has received little formal study beyond considerations of known acute effects to fish. These assessments have been based on comparisons of measured residues and the median lethal concentration (LC_{50}) for appropriate fish species. Conclusions derived from such information usually indicate no acute toxicity of residues to fish except possibly for a short time after spraying when concentrations in water may approach the LC_{50} or a significant proportion thereof. Little information now exists on the sub-lethal effects that may occur from the overspraying of riparian (stream-side) vegetation important for providing nutrients, erosion control, shade, and cover to rearing fish and their food organisms.

This report documents residue contamination from four aerial herbicide sprays monitored by the British Columbia Inderdepartmental Pesticide Monitoring Committee and includes:

(1) two dormant 2,4-D/2,4,5-T applications (helicopter application on T.F.L. No. 10, Toba Inlet; fixed-wing application on Christmas tree plantation, Sechelt);

(2) one foliar 2,4-D/2,4,5-T application (helicopter application on T.F.L. No. 38, Squamish);

(3) one foliar picloram/2,4-D application (helicopter application on powerline right-of-way, Pemberton-Mount Currie).

Monitoring was conducted during 1974-75 to evaluate operating procedures and non-target contamination during aerial applications of chlorophenoxy and picloram herbicides. Specific emphasis was placed on the effectiveness of buffer zones along major streams to prevent water contamination and destruction of stream-side vegetation. The concerned environmental protection agencies (Environmental Protection Service, B.C. Fish and Wildlife Branch) requested the use of 150 foot leave strips and drift into these buffer zones was measured either as lateral (i.e., spray movement at right angles to the flight path of the aircraft) or as direct (i.e., spray movement directly in front or behind the aircraft and parallel to its flight path). Persistence of herbicides in the air immediately after a spray and persistence of the chlorophenoxy compounds in the forest soil/litter was also determined.

It was anticipated that results from this study and similar studies conducted by the British Columbia Fish and Wildlife Branch would provide some information toward the drafting of meaningful guidelines designed to protect aquatic flora and fauna during similar chemical weed control programs in British Columbia.

2 MATERIALS AND METHODS

2.1 Monitoring Site Descriptions and Herbicide Applications

2.1.1 Foliar 2,4-D/2,4,5-T Application, Squamish, B.C. This hardwood control program was located on Weldwood Tree Farm Licence No. 38 between Mile 33 and 34 on the main logging road from the City of Squamish. Red alder, redstem ceanothus, and salmonberry were controlled in approximately 30 acres in two separate blocks of 18 and 12 acres. Monitoring was conducted on the 18 acre plot located on a steeply sloping mountain-side, about one-half mile from the main logging road to Squamish and about one mile from the Squamish River (Figure 1). A small creek flowed parallel to the spray plot about 100 feet away, crossed the main logging road below the plot, and eventually emptied into the Squamish River. The boundaries of the treatment area were flagged with small strips of red marking ribbon tied to the vegetation.

Iso-octyl esters of 2,4-D and 2,4,5-T (1/1 mixture) were applied by helicopter at 2 lbs total a.i. in 10 gallons of aqueous emulsion per acre. A sticker-spreader was added to the spray emulsion to facilitate greater penetration of the herbicides into the plants. The helicopter was equipped with a conventional spray system consisting of twenty-foot booms which delivered the spray material at 40 psi through Tee Jet 8010 nozzles.

Spraying commenced at 0710 hours on July 5, 1974, during light wind conditions (approx. 0-3 mph) and was completed at 0730 hours. The aircraft flew at 30 mph at a height of approximately 50 to 100 feet above the ground and had a capacity of 100 gallons of spray mixture per load, sufficient for a coverage of 10 acres of young forest. All mixing and loading was conducted at a heliport near the spray area but remote from any body of water (Figure 1).

2.1.2 Dormant 2,4-D/2,4,5-T Application, Toba Inlet, B.C. This alder control program was located on Weldwood Tree Farm Licence No. 10 about ten miles west of the main Weldwood logging camp. The treatment site was

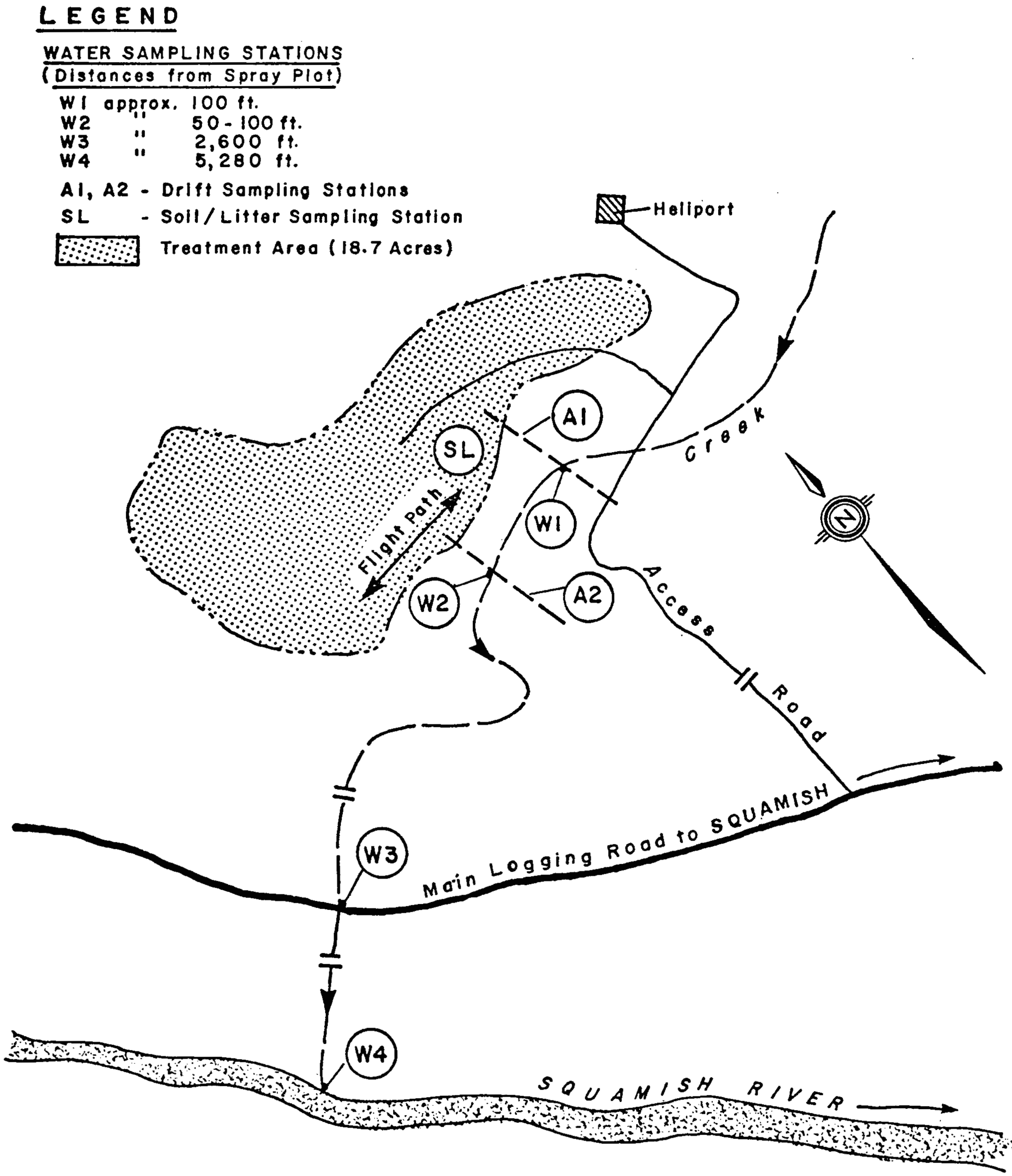
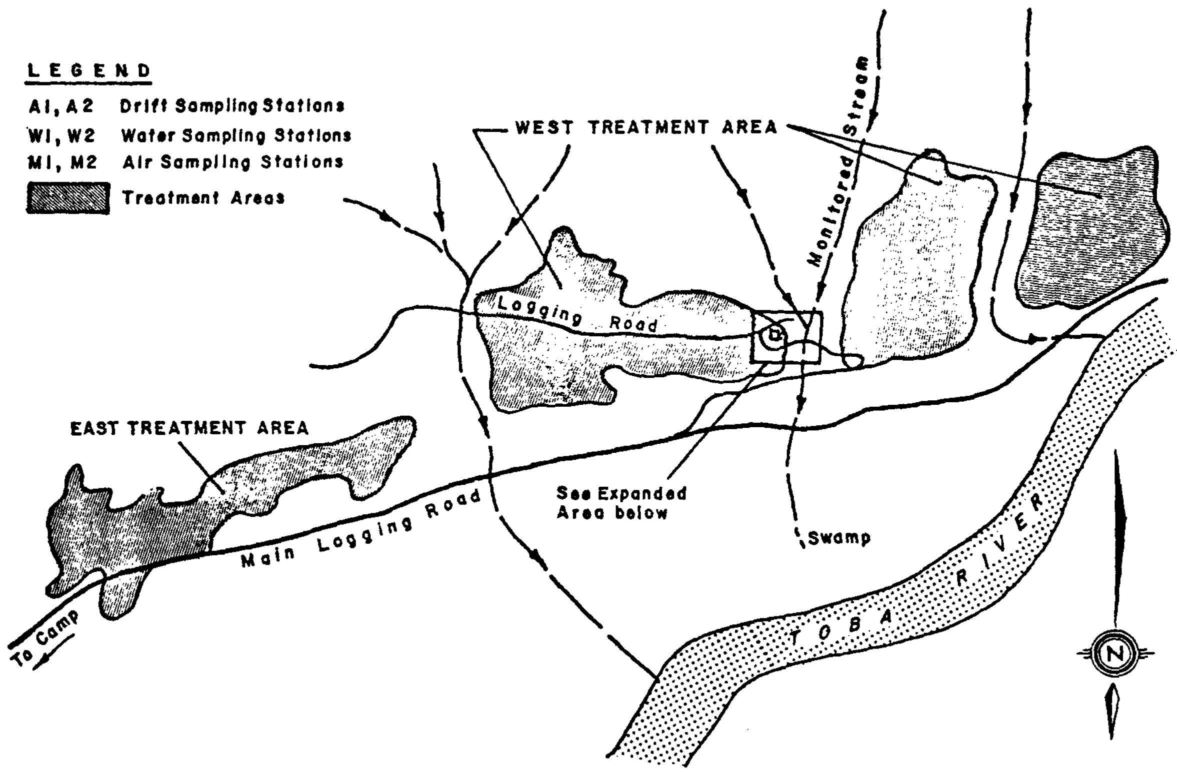


FIGURE I DIAGRAM OF SPRAY PLOT, SQUAMISH, B.C.



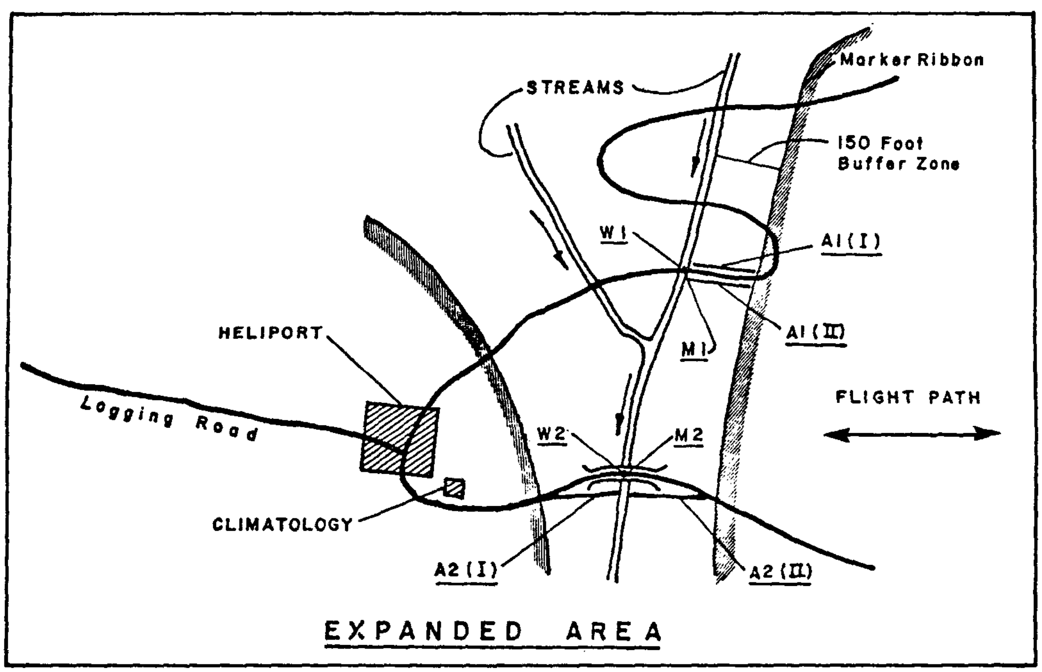


FIGURE 2 DIAGRAM OF SPRAY PLOT, TOBA INLET, B.C.

steeply sloping and encompassed an area of approximately 260 acres, divided into a west and east treatment block (Figure 2). Monitoring was conducted in the west treatment block along a stream that flowed through the spray plot, crossed the main logging road below the plot, and eventually emptied into the Toba River about one-half mile away. Large brightly coloured ribbon was used to mark the 150 foot buffer zones on both sides of the major creeks in the area. Considerable effort had been made to extend the flagging up the mountain to mark the upper reaches of all streams.

Iso-octyl esters of 2,4-D and 2,4,5-T (1/1 mixture) were applied by helicopter at 3 lbs total a.i. in 10 gallons of diesel oil mixture per acre. A conventional spray system consisting of twenty-foot booms delivered the spray material at 30 psi through 16 Tee Jet 8020 nozzles set an at angle of 90° to the air flow.

Spraying commenced at 0630 hours on April 14, 1975, during light wind conditions (approx. 0-1 mph) and was completed by 1045 hours. The aircraft flew at 30 mph at a height of approximately 60 feet above the ground and had a capacity of 50 gallons of spray mixture per load, sufficient for a coverage of 5 acres. About 40 runs were required to complete the job. All mixing and loading was conducted at a heliport near the spray area but remote from any running water (Figure 2).

2.1.3 Dormant 2,4-D/2,4,5-T Application, Sechelt, B.C. This program was designed to control competing alder in a Christmas tree plantation on 45 acres of a B.C. Hydro and Power Authority transmission right-of-way. The powerline was located on the Sechelt Peninsula near Highway 101 north of Gibsons, B.C., and ran north and south about one-half mile from the highway (Figure 3). Monitoring was conducted on Stephens and Joe Smith creeks, both flowing across the powerline and highway and eventually into the ocean. All major creeks flowing across the powerline were flagged with sheets of brown paper placed 150 feet on both sides of the streams.

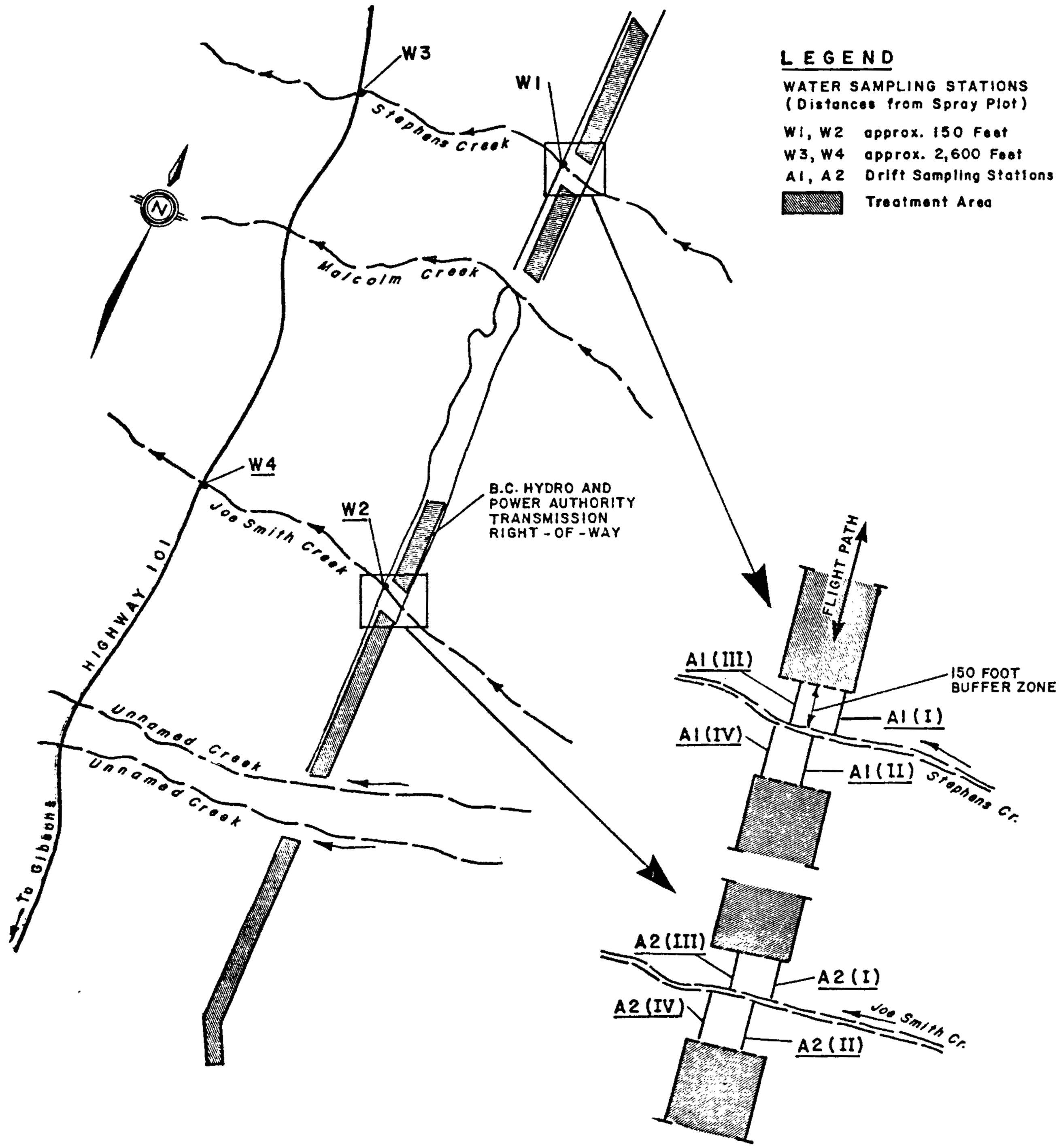


FIGURE 3 DIAGRAM OF SPRAY PLOT - SECHELT, B. C.

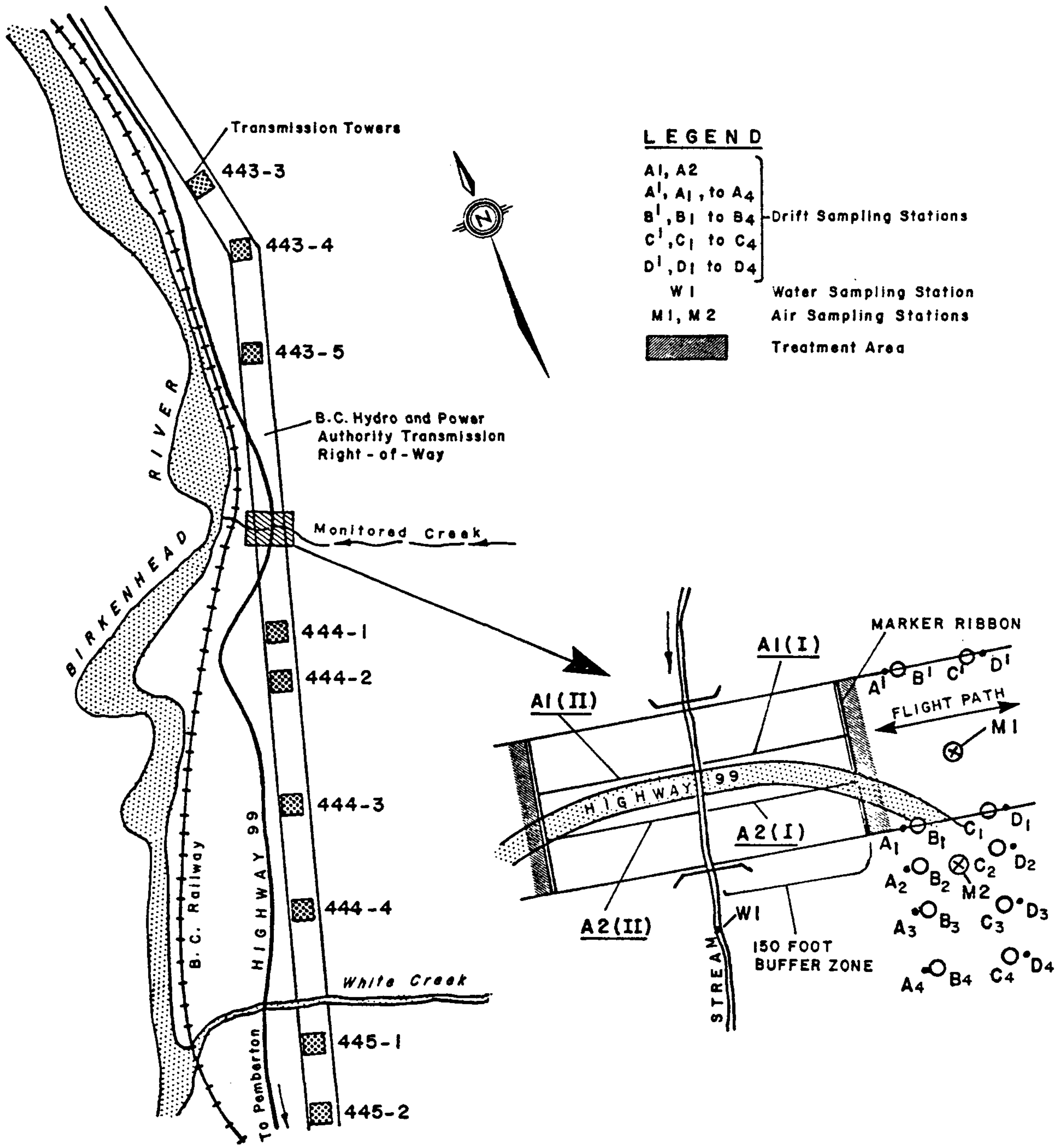


FIGURE 4 DIAGRAM OF SPRAY PLOT - PEMBERTON, MOUNT CURRIE, B.C.

Iso-octyl esters of 2,4-D and 2,4,5-T (1/1 mixture) were applied by fixed-wing aircraft (Cessna Agwagen) at 4 lbs total a.i. in 10 gallons of diesel oil mixture per acre. A conventional spray system delivered the spray material at 40 psi through 40 Tee Jet 8020 nozzles set at an angle of 90° to the air flow.

Spraying commenced at 0700 hours on April 4, 1975, during light wind conditions (approx. 0-3 mph) and was completed by 0830 hours. The aircraft flew at 100 mph at a height of approximately 60 to 70 feet above the ground (20 feet above the powerlines). In areas on the right-of-way adjacent to the transmission towers, the aircraft's elevation was considerably lower (20 to 30 feet above the ground). The spray capacity was 150 gallons, sufficient for a coverage of 15 acres. The job was completed in three runs. Mixing and loading was conducted at the Sechelt airport.

2.1.4 Foliar Picloram/2,4-D Application, Pemberton-Mount Currie, B.C.

This program covered an area of 276 acres and was designed to control brush that would eventually interfere with the transmission lines on the B.C. Hydro and Power Authority right-of-way running north and west of Mount Currie, B.C. The northern section, paralleling the Birkenhead River, was located for the most part on a mountain-side about one-half mile from the river. Monitoring was conducted on a small creek on the upper end of this section where the powerline descended from the mountain and paralleled Highway 99, the B.C. Railway, and the river south of the town of Birken (Figure 4). The monitored creek and other creeks in the area flowed across the powerline, highway, railway tracks, and into the Birkenhead River. The 150-foot buffer zones were flagged with brightly coloured ribbon on both sides of all major creeks crossing the right-of way.

Triisopropanolamine salts of picloram and 2,4-D (1/4 mixture) were applied by helicopter at 1.88 lbs a.i. picloram and 7.50 lbs a.i. 2,4-D in 20 gallons of aqueous solution per acre. The spray solution was particulated with NORBAK for drift control. A conventional spray system delivered the spray material at 40 psi through three Tee Jet nozzles of which two were set at an angle of 45° and one at an angle of 90° to the air flow.

Spraying commenced at 0625 hours on July 25, 1975, and was completed in this section by 0730 hours. The aircraft flew at 30 mph at a height of approximately 75 to 125 feet above the ground depending on the height of the power transmission towers. The spray capacity was 50 gallons, sufficient for a coverage of 5 acres. Eight runs were required to complete the job.

2.2 Sampling Procedures

2.2.1 Direct and Lateral Drift. Pyrex petri dishes (150 x 20 mm) were set at 90° to the spray plot or buffer zone borders in order to measure direct or lateral drift from the spray area (illustrated at A1 and A2 in Figures 1 to 4). The dishes were set on stands about three feet above the ground at 50-foot intervals within the buffer zones, except at the Squamish site where the stands were placed 20 feet inside the plot, at the plot border, and 10, 20, 30, 50, 100, 200, 300, and 600 feet outside the treatment area. Drift off the powerline right-of-way at Mount Currie was also measured at 50-foot intervals but 254-mm diameter plates were used in addition to petri dishes. The plates were about 15 feet from the dishes (petri dishes illustrated as A and D, and plates as B and C in Figure 4).

The petri dishes and plates were removed 10 to 15 minutes after the final spray application. The residue on the dishes and plates was then removed by either washing with a 5% KOH solution into collecting jars or storing the dishes in dry ice until analysis. All dishes and plates had been rinsed with redistilled acetone and petroleum ether and heated to 200°C for 16 to 20 hours prior to use.

2.2.2 Water. Creek water was collected in 16 fluid ounce bottles at the sites marked W1 to W4 in Figures 1 to 4. Samples were taken from these areas before treatment and during the post-treatment period at the Squamish site at 0, 15, 30, 45 minutes; 1, 2, 4, 8, 24, 48, and 96 hours. The same regime was used at Toba Inlet but sampling continued only until 8 hours after treatment. At Sechelt, samples were taken at 0, 5, 10, 20, 40 minutes; 1, 1.3, 2, and 5 hours after spray. The same regime was used at Pemberton - Mount Currie but sampling was continued here until 10 and 24 hours after treatment.

Approximately 30 to 50 millilitres of a 5% KOH solution were added to each water sample to arrest the hydrolysis of chlorophenoxy or picloram residues. All bottles had been rinsed with redistilled acetone and petroleum ether before use.

2.2.3 Air. Misco Air Samplers with midget impingers (Figure 5) were used to collect the aerosol component of the herbicide drift at the Toba Inlet and Pemberton - Mount Currie sprays. Samples were taken at either one or two-hour intervals at Stations M1 and M2, illustrated in Figures 2 and 4. The machines sampled air at the rate of 2 litres per minute for a total of either 120 or 240 litres per sample. A one-hour sampling interval was used at Toba Inlet for six hours after the beginning of the spray. At Pemberton - Mount Currie, a two-hour sampling interval was used for four hours after the beginning of the spray. The collecting solvent in the impingers was ethylene glycol at Toba Inlet and 5% KOH solution at Pemberton - Mount Currie. The samplers were placed in the middle of the powerline and 50 feet off the right-of-way at Pemberton to determine the persistence and drift of the aerosol herbicides in these areas.

2.2.4 Soil/Litter. Soil/litter samples were taken inside the Squamish spray plot (Figure 1). Within a measured square foot, all dead leaves, branches, and four cores of soil (one and one-quarter inches wide by two and one-half inches deep) were collected. Samples were collected before treatment and post-application at 1/2, 4, 8 hours; at 1, 2, 4 days; and

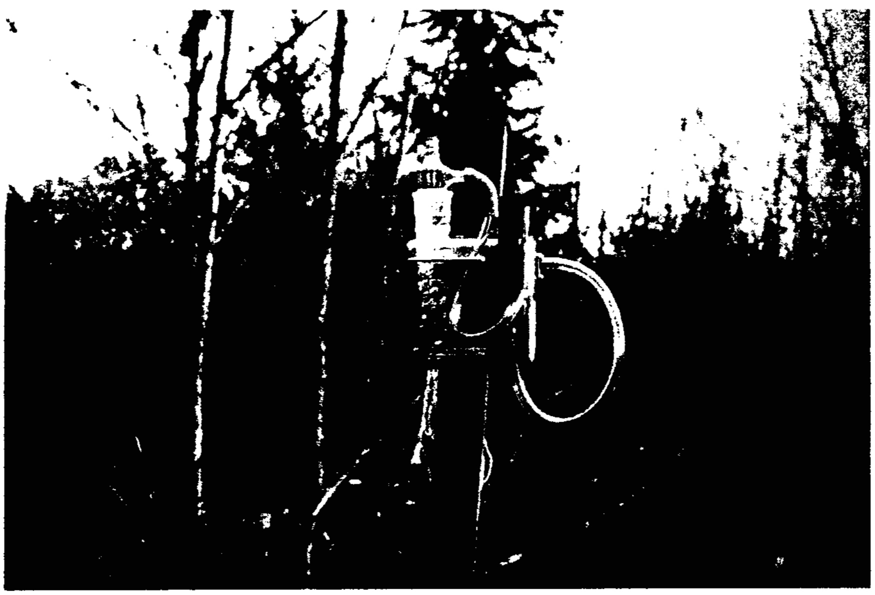


FIGURE 5 MISCO AIR SAMPLER WITH MIDGET IMPINGER

at 1, 2, 4, 6, 9, and 12 weeks. Soil/litter samples were also taken inside the plot 10 months after the application in May, 1975.

2.2.5 Physical Measurements. A Gurley mechanical current meter (PH-1) was used for the measurement of stream velocity. Flows were measured at intervals across a representative transect at two sections of the stream usually near the water sampling stations. Water depths were measured at each station where current readings were taken. The discharge of water was then calculated from Embody's formula for volume of water flow (Welch, 1948).

Microclimatology was determined in the spray areas and included measurements of relative humidity, temperature, and wind speed. At Toba Inlet, the temperature gradient was measured between 8 and 32 feet to determine whether a lapse or inversion thermal condition existed during the spray application. Results of these measurements and other conditions during the spray applications are recorded in Appendix I.

2.3 Residue Analyses

All solvent analyses were performed by the British Columbia Department of Agriculture Pesticide Analytical Laboratory, Vancouver, B.C.

2.3.1 Extraction and Cleanup. The extracts were stabilized with a 5% KOH solution and heated to 80°C for 30 minutes to convert the chlorophenoxy and picloram herbicides to their sodium salts. Acidification to pH 1 with HCl then converted the salts to their corresponding acids. The acids were partitioned into methylene chloride and this solvent evaporated to dryness. Methylation of the herbicides was then accomplished by addition of diazomethane in ethyl ether to produce the methyl esters of picloram, 2,4-D, and 2,4,5-T.

Air, water, and petri-dish extracts did not require clean-up and the ethyl ether - diazomethane mixture was diluted with hexane for gas-liquid chromatographic analyses. Soil/litter extracts were cleaned on 10 g Florisil columns deactivated with 5% water. One hundred millilitres of hexane : methylene chloride 4:1 (v/v) were used to elute the compounds from the columns. The eluates were taken to dryness in a flash evaporator and the residues taken up in hexane for gas chromatographic analysis.

2.3.2 Gas-Liquid Chromatography. GLC analysis was in a Microtek MT-220 equipped with a ^{63}Ni electron capture detector. A 183 cm x 0.30 cm I.D. glass column was used packed with a mixture of 4% OV 101 + 6% OV 210 on Chromosorb W "H.P.", 80/100 mesh. N_2 was used as carrier gas at 60 to 80 ml/min. Temperatures were: injector 220°C, oven 180 to 190°C, and detector 300 to 325°C. Known amounts of methylated herbicides were injected into the chromatograph to prepare standard peak-height curves for quantification of residues in the samples.

3 RESULTS

3.1 Drift Residues

Mean residues from the direct and lateral drift measurements are presented in Tables 1 to 3. The corresponding metric data for the individual herbicide residues and drift sampling stations are presented in Appendices II to VI.

In general, detectable contamination within the buffer zones was considerably below the rates of application. Comparing the two dormant sprays, direct herbicide drift into the 150 foot buffer zones was much higher at the Sechelt fixed-wing application than during the Toba Inlet helicopter spray (Table 1). Residues did not decline rapidly within the buffer zones but were, to some extent, evenly distributed or declined only gradually.

Direct drift into the buffer zones at Pemberton indicated a more abrupt drop, between 150 and 100 feet, than occurred at either Toba Inlet or Sechelt (Table 1). However, this drop in residues was detected only on two sets of plates (A1 [I] and A2 [I] in Appendix IV) and residues between 100 and 0 feet from the stream declined only gradually as in the other programs.

Lateral drift from the foliar applications at Pemberton and Squamish is tabulated in Tables 2 and 3, respectively. Total residues were similar for both programs up to 50 feet from the spray plot borders. However, beyond 50 feet, residues declined more rapidly at Pemberton. Larger plates did not appear to be of greater sensitivity or advantage for measuring drift residues (Table 2). 2,4-D and 2,4,5-T were detected at distances greater than 500 feet outside the Squamish spray plot and much variability in residue concentrations within the plot indicated a non-uniform application (Appendix VI). At Station A1, the average concentration of 2,4-D and 2,4,5-T was 1.72 lbs/acre within the spray area. By contrast, only 0.65 lbs/acre average concentration was detected at Station A2.

TABLE 1 DIRECT HERBICIDE DRIFT INTO STREAM BUFFER ZONES (TOBA INLET, SECHELT, PEMBERTON, B.C.)

Distance from Creek (feet)	TOTAL RESIDUES lbs/acre [Mean ± S.E. (Range)]		
	Helicopter - Dormant (Toba Inlet)	Fixed-Wing - Dormant (Sechelt)	Helicopter - Foliar (Pemberton)
0	0.007 ± 0.005 (0.001 - 0.021)[1]	0.154 ± 0.047 (0.022 - 0.334)[2]	0.020 ± 0.011 (0.012 - 0.027)[3]
50	0.004 ± 0.003 (0.001 - 0.013)	0.203 ± 0.066 (0.022 - 0.519)	0.059 ± 0.029 (0.014 - 0.111)
100	0.005 ± 0.004 (0.001 - 0.015)	0.210 ± 0.086 (0.003 - 0.705)	0.057 ± 0.028 (0.006 - 0.116)
150	0.017 ± 0.014 (0.001 - 0.052)	0.246 ± 0.081 (0.006 - 0.651)	0.500 ± 0.319 (0.050 - 1.189)

[1] n = 4, Reference: Figure 2 and Appendix II

[2] n = 8, Reference: Figure 3 and Appendix III

[3] n = 4, Reference: Figure 4 and Appendix IV

TABLE 2 LATERAL HERBICIDE DRIFT FROM SPRAY PLOT BORDER (PEMBERTON, B.C.)

Distance from Right-of-Way (feet)	TOTAL RESIDUES lbs/acre [Mean ± S.E. (Range)] Helicopter - Foliar		
	(All Plates)	(150 mm Plates)	(254 mm Plates)
0	0.657 ± 0.210 (0.007 - 1.662)[1]	0.741 ± 0.343 (0.007 - 1.662)[2]	0.572 ± 0.239 (0.225 - 1.266)[2]
50	0.257 ± 0.177 (0.025 - 0.684)	0.364 ± 0.320 (0.044 - 0.684)	0.150 ± 0.125 (0.025 - 0.275)
100	0.012 ± 0.003 (0.007 - 0.017)	0.013 ± 0.004 (0.009 - 0.017)	0.010 ± 0.003 (0.007 - 0.013)
150	0.003 ± 0.001 (0.002 - 0.005)	0.005 ± 0.001 (0.004 - 0.005)	0.002 ± 0.000 (0.002 - 0.002)

[1] n = 8, rest n = 4 Reference: Figure 4 and Appendix V

[2] n = 4, rest n = 2

TABLE 3 LATERAL HERBICIDE DRIFT FROM SPRAY PLOT BORDER (SQUAMISH, B.C.)

Distance from Plot Border (feet)	TOTAL RESIDUES lbs/acre [Mean ± S.E. (Range)] Helicopter - Foliar
0	0.449 ± 0.195 (0.311 - 0.587)[1]
10	0.282 ± 0.175 (0.158 - 0.406)
30	0.294 ± 0.092 (0.229 - 0.359)
80	0.159 ± 0.045 (0.127 - 0.190)
180	0.010 ± 0.011 (0.002 - 0.018)
280	0.003 ± 0.003 (0.001 - 0.005)

[1] n = 2, Reference: Figure 1 and Appendix VI

TABLE 4 CHLOROPHENOXY RESIDUES IN CREEK WATER AT DIFFERENT TIME INTERVALS POST APPLICATION (SQUAMISH, B.C.)*

Time (Hours)	Station W1 Conc-PPM**		Station W2 Conc-PPM**		Station W3 Conc-PPM**		Station W4 Conc-PPM***	
	2,4-D	2,4,5-T	2,4-D	2,4,5-T	2,4-D	2,4,5-T	2,4-D	2,4,5-T
Pre-Spray	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
0	0.004	0.001	0.007	0.004	N.D.	N.D.	-	-
0.25	0.033	0.008	0.003	0.002	N.D.	N.D.	-	-
0.50	N.D.	0.001	0.001	0.001	N.D.	N.D.	-	-
0.75	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	-	-
1.00	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	-	-
2.00	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	-	-
4.00	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
8.00	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
24	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	-	-
48	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	-	-
96	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	-	-
240	-	-	-	-	N.D.	N.D.	N.D.	N.D.
288	-	-	-	-	N.D.	N.D.	N.D.	N.D.

* Reference: Figure 1
** Limit of detection 0.8 PPB 2,4-D; 0.4 PPB 2,4,5-T
*** Limit of detection 0.025 PPB 2,4-D and 2,4,5-T

N.D. Not Detectable

3.2 Creek Water Contamination

Creek water contamination from the various programs is presented in Tables 4 to 6. Serious water contamination occurred during the Sechelt dormant spray (Table 5) associated primarily with the oil/herbicide mixture on the surface of the water. At Squamish and Pemberton, only small quantities of 2,4-D or 2,4,5-T were detected immediately following the spray application (Tables 4 and 6). No residues were detected in water sampled from the stream at Toba Inlet.

3.3 Air Contamination

Picloram/2,4-D residues persisted in the air at Pemberton for up to four hours after the beginning of the spray (Table 7). Lateral drift was evident during the first two hours as indicated by the similar amounts detected both on and off the powerline. No chlorophenoxy residues were detected at Stations M1 and M2 (Figure 2) during the Toba Inlet dormant spray.

3.4 Residues in Forest Soil/Litter

Measurable quantities of 2,4-D and 2,4,5-T were found in samples of surface soil and forest trash, one-half hour post-application at Squamish (Table 8). The highest quantities found were 1.84 ppm of 2,4-D and 1.20 ppm of 2,4,5-T, 24 hours after treatment. Thereafter residues declined until 9 weeks post-spray, when detectable quantities of 2,4-D and 2,4,5-T appeared to increase. Soil and litter samples collected and analyzed separately after 12 weeks indicated high concentrations of chlorophenoxy compounds in the forest litter. However, these levels declined to non-detectable in both the soil and litter, ten months after application.

3.5 Effects on Non-Target Vegetation

The effects of lateral drift were most apparent within 100 feet of the plot border at the Squamish spray site. At 80 feet, where the creek was situated, mortality of several species of broad-leaved aquatic and terrestrial plants growing in and near the water was observed. This mortality was most apparent for broad-leaved herbaceous species, although leaf mortality was also noted on some woody-stemmed plants (alder, willow). These wood species had not recovered at Station A1 (Figure 1) when the area was inspected ten months after application. Vegetation at 100 to 180 feet outside the spray area was only slightly affected as indicated by browning of young foliar parts. Plants at distances greater than 180 feet were not visibly affected.

Drift effects were also evident in the Pemberton spray program. Inspection of the monitoring area two weeks after the application indicated that while the vegetation in the monitored site had been browned, it was evident that some streamside vegetation near White Creek (Figure 4) had been killed. White Creek had been flagged with 150-foot buffer zones like all major streams in the area but greater drift problems apparently occurred at this point on the right-of-way.

TABLE 5 CHLOROPHENOXY RESIDUES IN STEPHENS AND JOE SMITH CREEK WATER AT DIFFERENT TIME INTERVALS POST APPLICATION (SECHELT, B.C.)*

Time (Minutes)	Stephens Creek (Station W1) Conc-PPM**		Joe Smith Creek (Station W2) Conc-PPM**	
	2,4-D	2,4,5-T	2,4-D	2,4,5-T
Pre-Spray	N.D.	N.D.		N.D.
0	0.160	0.270	5.760[b]	6.050[b]
5	0.060	0.060	-	-
10	0.010	0.020	0.180	0.150
20	N.D.	N.D.	0.060	0.050
40	0.920	0.820	1.850[b]	1.800[b]
60	0.250	0.210	0.040	0.040
70	0.010	0.010	-	-
80	0.030	0.050	0.060	0.090
120	0.004	0.003	0.220	0.340
300	N.D.[a]	N.D.[a]	N.D.[a]	N.D.[a]
300	0.009[a]	0.007[a]	N.D.[a]	N.D.[a]

a Samples taken downstream from treatment area near the highway (Stations W3 and W4)

b Oil/herbicide mixture on surface of water

* Reference: Figure 3

** Limit of Detection 0.8 PPB 2,4-D; 0.4 PPB 2,4,5-T

N.D. Not Detectable

TABLE 6 PICLORAM/2,4-D RESIDUES IN CREEK WATER AT DIFFERENT TIME INTERVALS POST APPLICATION (PEMBERTON, B.C.)*

Time (Minutes)	Station W1 Conc-PPM	
	Picloram	2,4-D
Pre-Spray	N.D.	N.D.
0	N.D.	0.004
5	N.D.	N.D.
10	N.D.	N.D.
20	N.D.	N.D.
40	N.D.	N.D.
80	N.D.	N.D.
160 (2.7 hrs)	N.D.	N.D.
320 (5.3 hrs)	N.D.	N.D.
640 (10.7 hrs)	N.D.	N.D.
1440 (24.0 hrs)	N.D.	N.D.

• Reference: Figure 4

N.D. Not Detectable

TABLE 7 PICLORAM/2,4-D RESIDUES IN AIR (PEMBERTON, B.C.)*

Time (Hours)	Station M1 Conc. (Total Micrograms)**			Station M2 Conc. (Total Micrograms)**		
	Picloram	2,4-D	Total	Picloram	2,4-D	Total
Pre-Spray	N.D.	N.D.		N.D.	N.D.	
0-2	0.08	0.44	0.52	0.07	0.40	0.47
2-4	0.001	0.004	0.005	N.D.	0.04	0.04

* Reference: Figure 4
** Total micrograms detected in 240 litres of air sampled
N.D. Not Detectable

TABLE 8 CHLOROPHENOXY RESIDUES IN FOREST SOIL/LITTER AT DIFFERENT TIME INTERVALS POST APPLICATION (SQUAMISH, B.C.)*

Time	Concentration - PPM	
	2,4-D	2,4,5-T
(Hours): Forest Soil and Litter		
0	N.D.	N.D.
0.5-	0.48	1.01
4.0	0.59	0.31
8.0	0.42	0.21
24.0	1.84	1.20
48.0	0.15	0.09
96.0	1.50	0.85
(Weeks): Forest Soil and Litter		
1	0.51	0.54
2	0.35	0.25
4	0.06	0.07
6	0.06	0.07
9	0.09	0.35
(Weeks): Forest Litter		
12 Sample No. 1	2.75	3.80
Sample No. 2	4.91	3.98
43	N.D.	N.D.
(Weeks): Forest Soil		
12 Sample No. 1	N.D.	0.06
Sample No. 2	N.D.	0.08
43	N.D.	N.D.

* Reference: Figure 1 (Samples taken at Station SL in sprayed area)

N.D. Not Detectable

4 DISCUSSION

4.1 Evaluation of the Aerial Spray Operations

The protection of the water resource during aerial herbicide applications must be an important consideration for all forest plantation or rights-of-way managers to prevent contamination not only of fish-bearing waters but also of domestic water supplies. The most serious water contamination of the four programs occurred during the Sechelt 2,4-D/2,4,5-T dormant spray and appeared to result primarily from the use of a fixed-wing aircraft and the diesel oil carrier. Although the spray was effectively shut off at the 150 foot mark, the high speed of the fixed-wing aircraft (100 mph) caused considerable turbulence at the low flight elevation and resulted in substantial drift into the buffer zones.

The release and distribution pattern of the spray solution in the aircraft wake has been described by Akesson and Yates (1964). A strong vortex pattern is usually evident with both fixed-wing and helicopter equipment at the wing tips or at the end of the spray booms on helicopters. Conventional booms on helicopters or fixed-wing aircraft produce a large number of fine droplets and mist that are drawn up in whorls off each end of the spray boom and carried high above the aircraft where they either drift with the wind or evaporate and drift as vapour. However, helicopter drift patterns are usually considerably better than patterns from fixed-wing aircraft because the high speed and disrupting propellor wake are not present (Akesson and Yates, 1964). The much lower contamination of stream buffer zones and creek water at the Toba Inlet versus the Sechelt spray application clearly demonstrates the superiority of the helicopter system for dormant sprays.

Direct drift into the stream buffer zones during the foliar application of picloram/2,4-D at Pemberton was low considering the high rate of application used (9.4 lbs a.i/acre versus 2 to 4 lbs a.i./acre for the chlorophenoxy herbicide programs). A combination of effective spray shut-off and the NORBAK particulating agent appeared to account for the low residues. However, NORBAK did not completely control either the vapour or the droplet component of the herbicide drift during the spray application. Residues detected in the air both on and off the powerline indicate that NORBAK does not prevent the formation of aerosol picloram/2,4-D. The vapour component persisted in the air for up to four hours after the spray and may represent only a fraction of the total since the air samplers were located near the ground and could not detect residues at higher altitudes. The lateral movement of the droplet component was comparable to the drift that occurred during the Squamish foliar spray where no drift control agent was used. However, it should be noted that a much higher rate of application was used at Pemberton than Squamish (9.4 versus 2.0 lbs a.i./acre) and residues did appear to decline more rapidly at a distance of 50 feet or more from the spray area.

Efforts to control drift in aerial applications have been largely concerned with methods to increase droplet size. Formulations, nozzle type and orientation, orifice diameters, and pump pressures can be varied on conventional booms to produce larger droplets (Gratkowski, 1974), but limitations with this system do occur because fine droplets can never be eliminated. The conditions under which these conventional systems were used in the monitored programs probably resulted in the release of a majority of medium-sized droplets with the fine component lost as vapour. Because of these limitations, drift control agents should be used with conventional equipment or, alternately, more advanced spray equipment should be considered for use in ecologically sensitive areas (Gratkowski, 1974).

Recent advances in methods to reduce drift include the use of particulating agents (e.g. NORBAK) to produce coarser spray atomizations, invert emulsions (water-in-oil) to reduce volatility, and adjuvants (thickeners) to increase viscosity. Some of these formulations may be used with conventional equipment, while others require more specialized apparatus. At present, these additives can only be used in foliar sprays. Effective drift control agents are not available for use in dormant applications. However, the recently developed Microfoil spray boom system for helicopters may have great potential to substantially reduce drift (Kirch, 1971). This spray system produces nearly uniform droplets with a minimal amount of small drops using conventional spray carriers (i.e. solutions or emulsions without thickening or particulating agents). Applications of herbicides with the Microfoil boom to powerline rights-of-way in Ontario have demonstrated the usefulness of this spray system in ecologically sensitive areas or in areas adjacent to private properties where optimum drift control is required (R. Gardner, Environmental Advisor, B.C. Hydro and Power Authority, *personal communication*, 1975).

In addition to spray equipment specifications, restrictions required at the operational level include consideration of the effects of microclimate, spray plot demarcation, and personnel supervision. Drift reduction and control in general requires application under atmospheric conditions of low wind speed (0-5 mph), air temperature below 75°F (24°C), and relative humidity above 50 percent (Gratkowski, 1974). Evaporation of volatile herbicides, especially 2,4-D or 2,4,5-T esters, is dependent to a large extent on air temperature and relative humidity. Evaporation and hence aerosol drift is reduced at low air temperatures and high relative humidities. These optimum atmospheric conditions occurred during all four herbicide programs (Appendix I).

During the Toba Inlet dormant spray, temperature gradients were measured to determine whether a <u>lapse</u> or <u>inversion</u> thermal condition existed. A lapse condition occurs during a temperature reduction with elevation while the reverse is true during an inversion. Under various lapse conditions, the main particle movement during a spray application is vertical whereas inversion conditions result in particle movement in a lateral direction, enhancing drift problems. According to Akesson and Yates (1964) the best thermal conditions for application occur during conditions of normal lapse (difference of 0.1°F (0.06°C) or less between an 8 and 32 foot elevation above the ground). A normal lapse was indicated during the Toba Inlet spray although this condition deteriorated with time (Appendix I). Differences of -0.1° to -5°F (-0.06° to -2.78°C) under lapse conditions may result in air turbulence enhancing drift problems although a difference of up to -3°F (-1.67°C) did not appear to affect the spray application.

Flagging or plot demarcation must be adequate for easy observation by the spray pilot. Flagging with brightly coloured ribbon at Toba Inlet and Pemberton provided excellent plot demarcation. Flagging at the Squamish spray was too small while at Sechelt the use of brown paper resulted in flagging not easily visible to the pilot. Flying in mountainous terrain is difficult and adequate flagging is essential for aircraft guidance, especially in buffer zone areas. Communication between the pilot and ground crew would greatly improve operations, especially if important information such as wind speed, air temperature, and relative humidity in the spray area is to be provided immediately prior to application. Gratkowski (1974) expands on these ideas and given an excellent discussion on personnel and supervision requirements during aerial spray programs.

Effective spray shut-off should be considered a prerequisite to the maintenance of buffer zones and for the comparability of monitored programs. The comparison of different programs was based on the observed fact that effective spray shut-off had occurred in all spray applications.

4.2 Biological Effects of Drift

Residues of chlorophenoxy herbicides potentially toxic to fish occurred in stream water during the Sechelt dormant application in contrast to the other programs where residues were either non-detectable or minute. Contamination at Sechelt appeared to result from a much higher aerial deposit, as compared to the other programs, in the vicinity of the monitored steams (see Table 1, 0 feet). Residues in Stephens and Joe Smith creeks were similar except in samples taken at the water surface where high concentrations were detected (Table 5). Dilution of the herbicide residues was not rapid and apparently was not related to stream discharge (Appendix I).

Although fish were not observed in any of the streams at Sechelt, concentrations of 2,4-D and 2,4,5-T were either near or above the threshold toxicity to salmonid fry. Threshold toxic levels for a number of salmon fry species ranged from less than 1 ppm to 10 ppm for 2,4-D isooctyl esters (Meehan et al, 1974), while isooctyl 2,4,5-T esters appear to be even more acutely toxic to fry (Wan, 1975). Moreover, the influence of the oil carrier in dormant sprays needs further investigation not only for the determination of possible synergistic effects from the oil and herbicide, but also for the influence of the oil/herbicide mixture on the distribution of residues in water.

In retrospect, the most serious consequence of these water residues appeared to be the contamination and tainting of domestic water supplies. Many of the creeks in the area, including Stephens and Joe Smith creeks, serve as water supplies for residents adjacent to the powerline right-of-way. The odour threshold for 2,4-D tainted water has been reported to be in the order of 3 ppm (Sigworth, 1965). However, chemical hydrolysis and/or biological degradation of 2,4-D in water to 2,4 - dichlorophenol can result in odour and taste problems at concentrations of 2 and 8 ppb, respectively (Faust and Aly, 1963). 2,4 - Dichlorophenol is also present as an impurity in commercial formulations of 2,4-D and therefore may be introduced into water at the time of application. In addition, the application of 2,4,5-T to water is contrary to the regulatory status of this compound under the *Pest Control Products Act* as defined in Memorandum No. T-87 from the Canada Department of Agriculture.

It is clear that fixed-wing application of chlorophenoxy esters can result in serious water contamination but it should also be emphasized that these compounds can be safely applied by other methods. Indeed, the three helicopter sprays in combination with effective buffer zones resulted in negligible water contamination either comparable or lower than monitoring results reported elsewhere (Norris, 1967, 1971). Residues of 2,4-D and 2,4,5-T detected in the forest litter 12 weeks after the Squamish application may have entered the aquatic environment during periods of heavy rainfall and leaching that occur in the fall or early winter. However, Norris (1971) concluded that overland or subsurface flow were not important mechanisms of stream contamination.

Apart from the water contamination concerns of aerial herbicide spraying, a more subtle and perhaps more serious concern is the possible indirect effect of herbicides on stream ecology by destruction of bankside (riparian) vegetation. Although herbicide concentrations within the buffer zones were on the whole below the rate required for the death of deciduous vegetation, some mortality did occur during the foliar sprays. Bankside vegetation is necessary to provide erosion control and to provide shade and protection for rearing fish and their food organisms. Moreover, terrestrial vegetation is a major source of aquatic nutrients both in the form of plant material and terrestrial insects.

In the majority of streams and river systems, the primary production which supports the animal communities is allochthonous (i.e., most of the food supply is derived from outside the running water ecosystem). Detritus, derived originally from terrestrial vegetation, and to a lesser extent from communities in standing fresh waters, is of major trophic importance (Hynes, 1970). Thus almost all riverine animals of the second level (primary consumers) are detritus-feeders. In temperate regions, this detritus is derived primarily from leaf fall by deciduous riparian vegetation during the autumn months. The accumulation of allochthonous material during the autumn and winter provides for expansions of populations of benthic invertebrates to serve as fish food and of populations of some fish species which feed directly on dead organic matter. In their study of two Oregon streams, Chapman and Demory (1963) have estimated that up to 66 percent of the total energy supplied in the diet of coho salmon was ultimately derived from terrestrial sources.

At the present time, it is difficult to assess in a practical way the impact of herbicide destruction of streamside vegetation beyond some general conclusions on its known importance to fish productivity. Some information may, perhaps, be inferred from current studies underway on the effects of logging on water quality although this information would not be strictly comparable and similar long-term studies would appear to be required on the herbicide issue. However, that trophic effects from pesticides can occur has been clearly demonstrated by reductions in fish biomass following destruction of their insect food from spraying New Brunswick forests with the insecticide fenitrothion (Symons and Harding, 1974). Similar drastic effects on terrestrial insects may also occur from chlorophenoxy herbicide sprays. Wan (1975) studied the impact of 2,4-D/2,4,5-T amine and ester formulations for roadside alder control and found a 50 to 58 percent reduction in terrestrial arthropods 20 to 30 hours after an early or late summer spray. Clearly, the implications and maintenance of stream productivity requires further evaluation and documentation, especially if large tracts of forest land are to be treated with herbicides as occurs now in Oregon forests in the United States.

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APPENDICES

APPENDIX I PHYSICAL MEASUREMENTS AND GENERAL WEATHER AND MICROCLIMATE PARAMETERS DURING THE SPRAY APPLICATIONS

	Squamish	Toba Inlet	Sechelt	Pemberton
Time of Spray	0710-0730 hrs.	0630-1045 hrs.	0700-0830 hrs.	0625-0730 hrs.
Weather	Sunny	Foggy then clear and sunny	Overcast, some sunny periods	Sunny, some clouds
Humidity	-	56% - 68%	56% - 95%	68% - 81%
Rainfall (inches)	Nil	Nil	Some Drizzle	Nil
Temperature (°F)				
8 feet	-	41 - 47	35 - 43	51 - 61
32 feet		41 - 44		
Wind Speed (mph)	0 - 3	0 - 1	0 - 3	0 - 3
Stream Discharge (cfs)	2.0	7.7	1.7 (Joe Smith) 5.1 (Stephens)	∿10.0

APPENDIX II DIRECT HERBICIDE DRIFT INTO STREAM BUFFER ZONES (TOBA INLET, B.C.)*

Location of Drift Plates	Distance from Creek (feet)	Station A1 Conc. (mg/M^2)			Equiv. (lbs/acre)	Station A2 Conc. (mg/M^2)			Equiv. (lbs/acre)
		2,4-D	2;4,5-T	Total		2,4-D	2,4,5-T	Total	
I	0	0.89	1.41	2.30	0.021	N.D.	0.09	0.09	0.001
	50	0.42	0.99	1.41	0.013	N.D.	0.07	0.07	0.001
	100	0.72	1.01	1.73	0.015	N.D.	0.13	0.13	0.001
	150	0.36	1.02	1.38	0.012	N.D.	0.07	0.07	0.001
II	0	N.D.	0.53	0.53	0.005	N.D.	0.08	0.08	0.001
	50	N.D.	0.27	0.27	0.002	N.D.	0.05	0.05	-
	100	N.D.	0.23	0.23	0.002	N.B.	0.10	0.10	0.001
	150	2.29	3.55	5.84	0.052	N.D.	0.09	0.09	0.001

* Reference: Figure 2

N.D. Not Detectable

APPENDIX III DIRECT HERBICIDE DRIFT INTO STREAM BUFFER ZONES (SECHELT, B.C.)*

Location of Drift Plates	Distance from Creek (feet)	Stephens Creek (Station A1) Conc. (mg/M^2)			Equiv. (lbs/acre)	Joe Smith Creek (Station A2) Conc. (mg/M^2)			Equiv. (lbs/acre)
		2,4-D	2,4,5-T	Total		2,4-D	2,4,5-T	Total	
I	0	0.52	2.34	2.86	0.026	9.69	10.37	20.06	0.179
	50	0.47	2.80	3.27	0.029	12.30	12.90	25.20	0.225
	100	0.10	0.28	0.38	0.003	5.28	6.39	12.67	0.113
	150	0.34	0.36	0.70	0.006	5.59	5.40	10.99	0.098
II	0	8.36	10.86	19.22	0.171	1.01	1.41	2.42	0.022
	50	16.69	12.73	29.42	0.262	19.35	19.52	38.87	0.347
	100	14.83	11.66	26.49	0.236	45.27	33.72	78.99	0.705
	150	19.98	23.77	43.75	0.390	45.27	27.73	73.00	0.651
III	0	2.37	2.90	5.27	0.046	22.64	14.83	37.47	0.334
	50	1.78	3.41	5.19	0.046	35.14	23.03	58.17	0.519
	100	2.37	4.14	7.51	0.067	21.22	18.17	39.39	0.351
	150	1.17	1.76	2.93	0.026	17.43	19.35	36.78	0.328
IV	0	7.62	6.51	14.13	0.126	16.52	20.20	36.52	0.326
	50	8.95	10.25	19.20	0.171	1.04	1.44	2.48	0.022
	100	6.00	7.72	13.72	0.122	3.23	5.86	9.09	0.081
	150	12.26	13.99	26.25	0.234	11.32	14.71	26.03	0.232

• Reference: Figure 3

APPENDIX IV DIRECT HERBICIDE DRIFT INTO STREAM BUFFER ZONES (PEMBERTON, B.C.)*

Location of Drift Plates	Distance from Creek (feet)	Station A1 Conc. (mg/M^2)			Equiv. (lbs/acre)	Station A2 Conc. (mg/M^2)			Equiv. (lbs/acre)
		Picloram	2,4-D	Total		Picloram	2,4-D	Total	
I	0	0.26	1.07	1.33	0.012	0.56	2.41	2.97	0.027
	50	0.32	1.29	1.61	0.014	0.38	1.55	1.93	0.017
	100	0.67	2.75	3.42	0.031	0.14	0.58	0.72	0.006
	150	15.56	63.10	78.66	0.702	27.45	105.82	133.27	1.189
II	50	2.04	8.26	10.30	0.092	3.23	9.22	12.45	0.111
	100	2.55	10.41	12.96	0.116	1.95	6.56	8.51	0.076
	150	1.11	4.53	5.64	0.050	1.13	5.32	6.45	0.058

* Reference: Figure 4

APPENDIX V LATERAL HERBICIDE DRIFT FROM SPRAY PLOT BORDER (PEMBERTON, B.C.)*

Location of Drift Plates**	Distance from Right-of-Way (feet)	Concentration (mg/M^2)			Equiv. (lbs/acre)
		Picloram	2,4-D	Total	
A^1	0	16.41	64.23	80.64	0.719
A_1	0	34.24	152.05	186.29	1.662
A_2	50	14.71	61.91	76.62	0.684
A_3	100	0.38	1.52	1.90	0.017
A_4	150	0.10	0.38	0.48	0.004
B^1	0	27.65	114.31	141.96	1.266
B_1	0	11.05	45.10	56.15	0.501
B_2	50	5.82	25.06	30.88	0.275
B_3	100	0.29	1.21	1.50	0.013
B_4	150	0.05	0.21	0.26	0.002
C^1	0	4.88	20.33	25.21	0.225
C_1	0	6.49	26.80	33.29	0.297
C_2	50	0.55	2.23	2.78	0.025
C_3	100	0.16	0.64	0.80	0.007
C_4	150	0.05	0.19	0.24	0.002
D^1	0	12.73	51.95	64.68	0.577
D_1	0	0.15	0.62	0.77	0.007
D_2	50	0.94	3.96	4.90	0.044
D_3	100	0.19	0.79	0.98	0.009
D_4	150	0.10	0.40	0.50	0.005

* Reference: Figure 4

** Plates A and D: 150 mm diameter petri dishes
Plates B and C: 254 mm diameter plates

APPENDIX VI LATERAL HERBICIDE DRIFT FROM SPRAY PLOT BORDER (SQUAMISH, B.C.)*

Distance of Plates from Plot Border (feet)**	Station A1 Conc. (mg/M^2)			Equiv. (lbs/acre)	Station A2 Conc. (mg/M^2)			Equiv. (lbs/acre)
	2,4-D	2,4,5-T	Total		2,4-D	2,4,5-T	Total	
-40	53.58	70.73	124.31	1.109	-	-	-	-
-30	-	-	-	-	47.02	48.09	95.11	0.848
-20	133.42	123.57	256.99	2.292	33.95	35.36	69.31	0.618
-10	100.09	100.99	201.08	1.794	28.29	30.61	58.90	0.525
0	37.23	28.52	65.75	0.587	17.48	17.37	34.85	0.311
+10	25.74	19.75	45.49	0.406	8.54	9.22	17.76	0.158
+30	12.74	12.96	25.70	0.229	17.09	23.20	40.29	0.359
+80	10.52	10.81	21.33	0.190	6.34	7.92	14.23	0.127
+130	0.14	0.12	0.26	0.002	1.01	1.05	2.06	0.018
+280	0.06	0.06	0.12	0.001	0.26	0.33	0.59	0.005
+580	0.06	0.08	0.14	0.001	-	-	-	-

* Reference: Figure 1

** Due to pilot error, the treatment extended approximately 20 feet beyond the plot border. The distances have been adjusted accordingly.

\- Inside Spray Plot

\+ Outside Spray Plot