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EFFECTIVENESS OF BEST MANAGEMENT PRACTICES FOR AERIAL APPLICATION OF FOREST PESTICIDES

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EFFECTIVENESS OF BEST MANAGEMENT PRACTICES FOR AERIAL APPLICATION OF FOREST PESTICIDES

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METRIC TO ENGLISH CONVERSIONS

Multiply	by	To Obtain
meters (m)	3.281	feet
millimeters (mm)	0.0394	inches
hectares (ha)	2.471	acres
liters (L)	0.2642	gallons
liters/second (L/s)	0.0353	cubic feet/second
kilometers/hour (km/hr)	0.6214	miles/hour
kilograms (kg)	2.2046	pounds
kilograms/hectare (kg/ha)	0.8922	pounds/acre
liters/hectare (L/ha)	0.1069	gallons/acre
kilopascals (kPa)	0.145	pounds/square inch

ABSTRACT

Forest practices, including the use of pesticides, are conducted in accordance with Best Management Practices (BMPs) established in the Washington Forest Practices Rules and Regulations. This project was undertaken to evaluate BMP effectiveness through intensive field monitoring of forest pesticide applications. Determination of BMP effectiveness is based on interpretation of various provisions of state water quality standards (WQS), forest practice rules, pesticide registration labels issued by the U.S. Environmental Protection Agency (EPA), and Department of Agriculture pesticide regulations.

The study employed intensive sampling of streams that flow through or adjacent to units treated by aerial (helicopter) applications of forest pesticides to monitor the entry of chemicals into surface waters. Seven of these case studies served as representative examples of BMP implementation, and were used to determine BMP effectiveness for the application scenarios represented. We sampled dormant and early foliar herbicide operations conducted during April and May, late foliar herbicide sprays conducted in September, and an insecticide/fungicide spray conducted in early June of 1991. The silvicultural operations included five conifer release herbicide sprays (one dormant spray, two early foliar sprays, and two late foliar sprays), one site preparation herbicide spray (late foliar), and one Christmas tree pest control spray. Pesticides applied included 2,4-D, triclopyr, glyphosate, imazapyr, metasystox-R, and chlorothalonil.

Pesticides were detected in streams following applications at all seven sites, with peak levels ranging from 0.02 to 7.55 μg/L. Pesticides were also detected in runoff at the four sites where runoff events were sampled. Runoff sampling occurred 2 to 25 days following the applications, and concentrations ranged from 0.17 to 2.49 μg/L. Maximum instantaneous concentrations found were 1.29, 2.49, 7.55, 1.15, 1.72, and 2.80 μg/L, respectively, for triclopyr, 2,4-D, glyphosate, imazapyr, chlorothalonil, and metasystox. Excluding runoff events, peak concentrations occurred within the first three hours following the spray in all cases. Maximum 24-hour average levels were 0.13, 0.69, 0.56, 0.36, 0.18, and 3.25 μg/L, respectively, for the same six pesticides. Based on the timing of peak concentrations, the majority of pesticide introduction to streams was attributed to off-target swath displacement and drift from spray areas near streams. The overall distribution of pesticide levels indicated that overspray of small headwater streams (which the applicator had incorrectly assessed as not having surface flow) also contributed to levels found at some sites.

The BMPs were determined to be partially effective or ineffective based on three tests of effectiveness. First, water quality standards regarding toxic levels of pesticides were not met in at least one of the case studies. Second, the BMPs were not effective at avoiding drift causing direct entry of pesticides into surface waters or Riparian Management Zones, as required by the Forest Practice Rules. And third, the BMPs were not effective at complying

with certain pesticide product label restrictions regarding entry to surface waters and avoidance of off-target drift. Recommendations for improving the BMPs include revised stream buffer requirements, specifications for spray nozzle configurations, and improved procedures for determining whether small streams must be buffered. Recommendations for stream buffers include minimum buffers of 15 to 25 meters for downwind applications and 75 to 90 meters for upwind applications along all flowing streams.

INTRODUCTION

This report describes a research project conducted to evaluate the effectiveness of forest pesticide best management practices. It describes the background and purpose for the project, documents the methods used, presents the results, and formulates conclusions and recommendations pertinent to managing aerial applications of forest pesticides. The information presented will be of interest to forest land managers, silviculturalists (including Christmas tree growers), pesticide applicators, water quality and resource protection specialists, those who regulate forest practices, educators in the field of pesticide use, and others seeking to understand pesticide interactions in managed forest land.

Background

Forest practices, including the use of pesticides, are conducted in accordance with best management practices (BMPs). The BMPs are intended to control nonpoint source water pollution and ensure that state water quality standards are met. The Washington Forest Practices Rules and Regulations establish the BMPs to be followed for forest practices conducted on state and private forest lands in Washington. These regulations are promulgated jointly by the Washington State Departments of Natural Resources and Ecology. It is the responsibility of the Department of Ecology to ensure that the BMPs it establishes are effective at achieving water quality standards. The Timber/Fish/Wildlife Agreement (TFW) has established a program of cooperative monitoring, evaluation, and research to evaluate and develop BMPs for achieving water quality and other environmental goals on state and private forest lands in Washington.

This project is part of an overall effort by the Water Quality Steering Committee (WQSC) of the TFW Cooperative Monitoring, Evaluation, and Research Committee to address questions related to impacts of forest chemicals on water quality and aquatic life. Other aspects of the WQSC effort include determination of biologically significant concentrations of selected chemicals in streams, use of aerial photography to evaluate herbicide application to non-target areas, and a review of technological considerations pertaining to aerial application practices. This project was undertaken to evaluate BMP effectiveness through intensive field monitoring of pesticide applications.

The BMPs in effect at the time field monitoring was conducted for this study are established in Chapter 222-38 WAC (Washington State Forest Practices Board, 1988). These regulations are intended to ensure that the handling, storage, and application of forest pesticides do not endanger public health or aquatic life. With respect to the aerial applications monitored in this study, several specific practices were required by the regulations. These included: 1) a 50-foot buffer along all Type 1, 2, 3 and flowing Type 4 and 5 streams; 2) no aerial application of herbicides or insecticides within Riparian Management Zones; 3) parallel flight paths and use of drift control agents adjacent to stream buffers; 4) reconnaissance over-flight by pilot and landowner prior to application to identify target areas and buffers; and 5) shut-

off of chemical spray devices during turns and over open water. (Stream type is defined in the forest practice rules, and is based on fish use, stream size, and hydrology.)

A copy of the best management practices that were in effect during the field monitoring phase of this study is presented in Appendix A. The regulations dealing with forest pesticides have since been revised, effective June 26, 1992. A copy of the current rules (*i.e.*, BMPs) governing pesticide applications is presented in Appendix B.

Regulatory Questions

To determine BMP effectiveness, we must interpret various provisions of the forest practice rules, the water quality standards (WQS), pesticide registration labels issued by the U.S. Environmental Protection Agency (EPA), and Department of Agriculture pesticide regulations.

Forest Practice Rules

Although the forest practice rules that were in effect at the time we conducted our field studies have been revised, our monitoring results are suitable for evaluating the current rules. The rules pertaining to aerial application practices are essentially the same in terms of their provisions restricting pesticide entry to surface waters, with changes made primarily to add clarification.

The forest practice rules emphasize BMPs designed to prevent the direct entry of pesticides into surface waters. The rules require that aerial applications "Avoid applications that might result in drift causing direct entry of pesticides into . . . all Typed Waters, except segments of Type 4 and 5 Waters with no surface water." This is essentially a performance standard for the applicators. The policy statement on forest chemicals states that the purpose of the regulations is to ". . . regulate the handling, storage, and application of chemicals in such a way that the public health, lands, fish, wildlife, aquatic habitat, and water quality will not be endangered by contamination." The regulations further provide that chemicals must be applied in accordance with EPA-approved registration labels and Washington State Department of Agriculture regulations regarding pesticide use.

Water Quality Standards

In keeping with state and federal water quality policy, the BMP evaluation must determine whether water quality standards are being met when pesticides are applied in accordance with the BMPs. The WQS established in Chapter 173-201A WAC include various criteria which relate to potential effects of forest pesticide use (Washington Administrative Code, 1992). The most significant provisions of the WQS are the narrative criteria for protection of beneficial uses. These criteria require that "Toxic, radioactive, or deleterious material concentrations shall be below those which have the potential either singularly or cumulatively to adversely affect characteristic water use, cause acute or chronic conditions to the most

sensitive biota dependent upon those waters, or adversely affect public health . . ." Characteristic water uses include domestic and agricultural water supply, aquatic life uses, and wildlife habitat. The WQS further provide that toxic substances shall not be introduced above natural background levels which may cause adverse impacts as determined by the Department of Ecology. The standards state that Ecology shall determine allowable concentrations in consideration of published EPA water quality criteria and other relevant information. Other relevant information would generally be information regarding pesticide toxicity (either chronic or acute) in the aquatic environment.

In the case of the forest chemicals to be evaluated as a part of this study, the WQS do not establish specific numeric criteria for surface water concentrations, nor has the EPA published criteria in most cases. The narrative criteria for protection of water uses and aquatic life thus become the yardstick with which to judge the effectiveness of forest pesticide BMPs. If entry (either direct or otherwise) of pesticides or related chemicals (e.g., surfactants, carriers, or degradation products) to streams has the potential to adversely affect aquatic life or the suitability of the water for any characteristic use, then the BMPs are not effective at achieving WQS.

Other Regulations

The Department of Agriculture has overall authority for enforcing pesticide laws and regulating pesticide use in Washington. A key provision in the Rules Relating to General Pesticide Use (Chapter 16-228 WAC) prohibits application "in such a manner as to pollute water supplies or waterways, or cause damage or injury to land, including humans, desirable plants and animals, or wildlife . . ." The Washington Pesticide Control Act (Chapter 15.58 RCW) makes it unlawful to use ". . . any pesticide contrary to label directions . . ." Thus, interpretation of the EPA-approved label directions is key to evaluating BMP effectiveness. An interpretation of the relevant Department of Agriculture regulations and EPA-approved labels has been provided by the Department of Agriculture, and is presented in Appendix C.

Technical Questions

In addition to answering the regulatory questions to make a determination of the effectiveness of current BMPs at achieving applicable environmental standards, this study was designed to answer certain technical questions. The study collected information to answer questions about which environmental and management factors influence BMP effectiveness. Since monitoring of aerial applications of herbicides and insecticides is sometimes required or desirable, it is also important to evaluate the efficacy of various monitoring techniques. The information and experience gained from this intensive sampling program was used to define the characteristics of a monitoring protocol that is practicable, reasonably affordable, and effective at identifying peak and average levels of pesticides in streams due to forest applications.

Study Objectives

The specific objectives of this study were:

1) Characterize the peak and average concentrations of pesticides and related chemicals in streams which result from aerial application of forest pesticides conducted according to the forest practice BMPs.

2) Determine whether BMPs for aerial application of forest pesticides are effective at achieving applicable surface water quality standards.

3) Determine whether the BMPs for aerial application of forest pesticides are effective at meeting the provisions of the forest practice rules, other state pesticide regulations, and EPA-approved label restrictions.

4) Evaluate the factors contributing to the effectiveness or ineffectiveness of BMPs.

5) Evaluate the efficacy of various monitoring techniques for assessing water quality impacts of aerial application of forest pesticides.

METHODS

The study employed intensive sampling of streams that flow through or adjacent to units treated by aerial (helicopter) applications of forest pesticides to monitor the entry of chemicals into surface waters. A total of seven of these case studies served as examples of typical BMP implementation, and were used to determine BMP effectiveness for the application scenarios represented. We sampled dormant and early foliar herbicide operations conducted during late April and May, late foliar sprays conducted in September, and an insecticide/fungicide spray conducted in early June of 1991. By monitoring spray operations conducted during different seasons, the project evaluated BMP effectiveness under different weather and hydrologic conditions. Study site locations are shown in Figure 1.

Study Site Selection

Selection of study sites was guided by the original project study plan approved by the Water Quality Steering Committee (Rashin, 1992). The study plan called for evaluating herbicide applications under three scenarios with varying potential to impact forest streams: scenario 1) sites that have a stream adjacent or nearby with no tributaries within the spray unit; scenario 2) sites that have a stream adjacent or nearby with multiple tributaries within the spray unit; and scenario 3) sites that have one or more flowing stream located within (rather than adjacent to) the spray unit. Large streams (e.g., Type 1) which have high background flows were not used as sampling sites to avoid large dilution effects. The plan

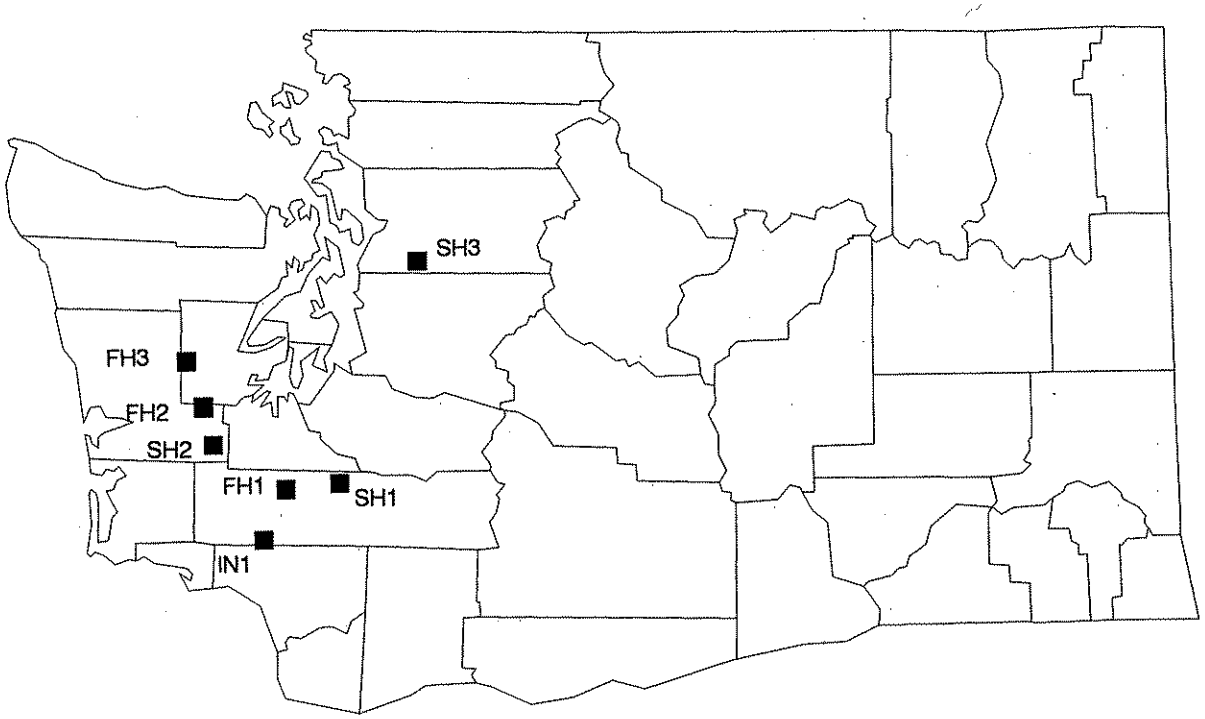


Figure 1: Locations of the Study Sites

called for one example of each scenario to be selected for each monitoring season, for a total of six study sites for herbicides. For insecticides, the intent was to sample two of the three scenarios described above, for a total of two study sites. For the spring herbicides we succeeded in sampling one example of scenario 1 and two examples of scenario 3. For the fall herbicides we sampled one example of scenario 2 and two examples of scenario 3. We sampled one insecticide application (scenario 3) on a Christmas tree plantation; a fungicide was also applied in the same operation. A second insecticide operation that we were prepared to sample was canceled.

Prospective study sites were identified by reviewing Forest Practice Applications (FPAs) submitted for the spray season of interest. Potential study sites were first screened for suitability in consideration of location and access, drainage density and other stream characteristics, spraying schedule, chemicals to be used, application rate, and management practices to be employed. Preference was given to sites where management practices adhered most closely to regulatory requirements without voluntary controls (*i.e.*, enhanced stream buffers) above and beyond such requirements.

Reconnaissance visits were made to candidate sites to evaluate access to the spray unit and sampling locations, stream locations relative to spray areas and streamflow regimes, any factors which might interfere with study results such as upstream land use, and to assess potential stream sampling sites. As appropriate sites were selected, scheduling of field operations was confirmed with cooperators, and laboratory analysis plans were finalized.

Study Site Characterization

Shortly before spray operations were conducted, we characterized the study sites in terms of drainage patterns, streamflow regimes, and time-of-travel for streams to be sampled. Stream distance from the sampling point to the nearest and farthest spray area was measured by walking the stream channels. For headwater streams, the point where surface flow began was determined by direct observation. These stream distances were used to determine the point from which time-of-travel would be estimated.

Streamflow was gaged at the sampling site, the downstream unit boundary, and at or near the upstream boundary of the spray unit to define groundwater relationships (flow loss or gain) that could influence surface water concentrations of pesticides. In addition, streamflow was gaged periodically during the day of sampling to estimate the cumulative loading of pesticides being exported from the unit via the stream system.

Selection of Sampling Sites

For each study site a primary sampling station was chosen, usually on the largest stream within or adjacent to the spray unit. The primary sites were located 20 to 220 meters downstream of the spray unit boundaries. Sampling sites were located above any tributaries that did not flow across the spray unit. Sites that had a small waterfall or other channel

feature that facilitated the filling of sampling containers were selected. Sites for automatic pump samplers were located immediately upstream of the grab sampling locations. Information from these primary stations was used to evaluate pesticide concentrations that occur immediately downstream from aerial application projects, as well as the stream transport of substances away from spray units (*i.e.*, pollutant loading).

For some sites that had multiple streams within the spray unit, secondary sampling stations were located along the lower portion of one or more tributaries. The purpose of this station was to evaluate chemical concentrations that occur in smaller streams in the immediate area of the project. At one study site, secondary sampling sites were established to characterize a spring discharge emanating from the base of a hill slope at the spray unit boundary.

Time-of-Travel Determinations

An estimate of stream time-of-travel from the spray area to the sampling site was needed to establish the sampling schedule. Time-of-travel studies were conducted using Rhodamine WT® fluorescent dye and a Turner® Model 10-005 field fluorometer equipped with a continuous flow cuvette system. At one study site, time-of-travel was estimated based on average stream velocity measurements taken at a representative cross-section. A Unidata® datalogger was used in conjunction with the fluorometer, with fluorescence readings logged at 30-second intervals. For these time-of-travel determinations, a measured amount of dye was added to the stream at a point midway between the nearest and farthest spray area adjacent to the stream to be sampled. The amount of dye used was based on a target concentration of 1 part per billion (ppb) at the sampling site. The time-of-travel for the leading edge of the dye plume to reach the sampling site was used to adjust the sampling schedule.

In most cases, time-of-travel studies were conducted within a few days of sampling. Flow measurements taken at the same cross-section during the time-of-travel studies and immediately prior to sampling were compared to determine if there was a need to adjust time-of-travel estimates based on a difference in discharge or stream velocities. If discharge or velocities were substantially different on the day of sampling, then the previous time-of-travel measurement was adjusted in proportion to the change in average velocity.

Spray Monitoring

Stream Sampling

Stream water sampling included collection of timed discrete grab samples, hand-composites of grab samples, and composite samples collected by automatic compositors (pump samplers). Timing of collection for most samples was adjusted to account for stream time-of-travel from the spray unit to the sampling site. The sample collection schedule is presented in Figure 2.

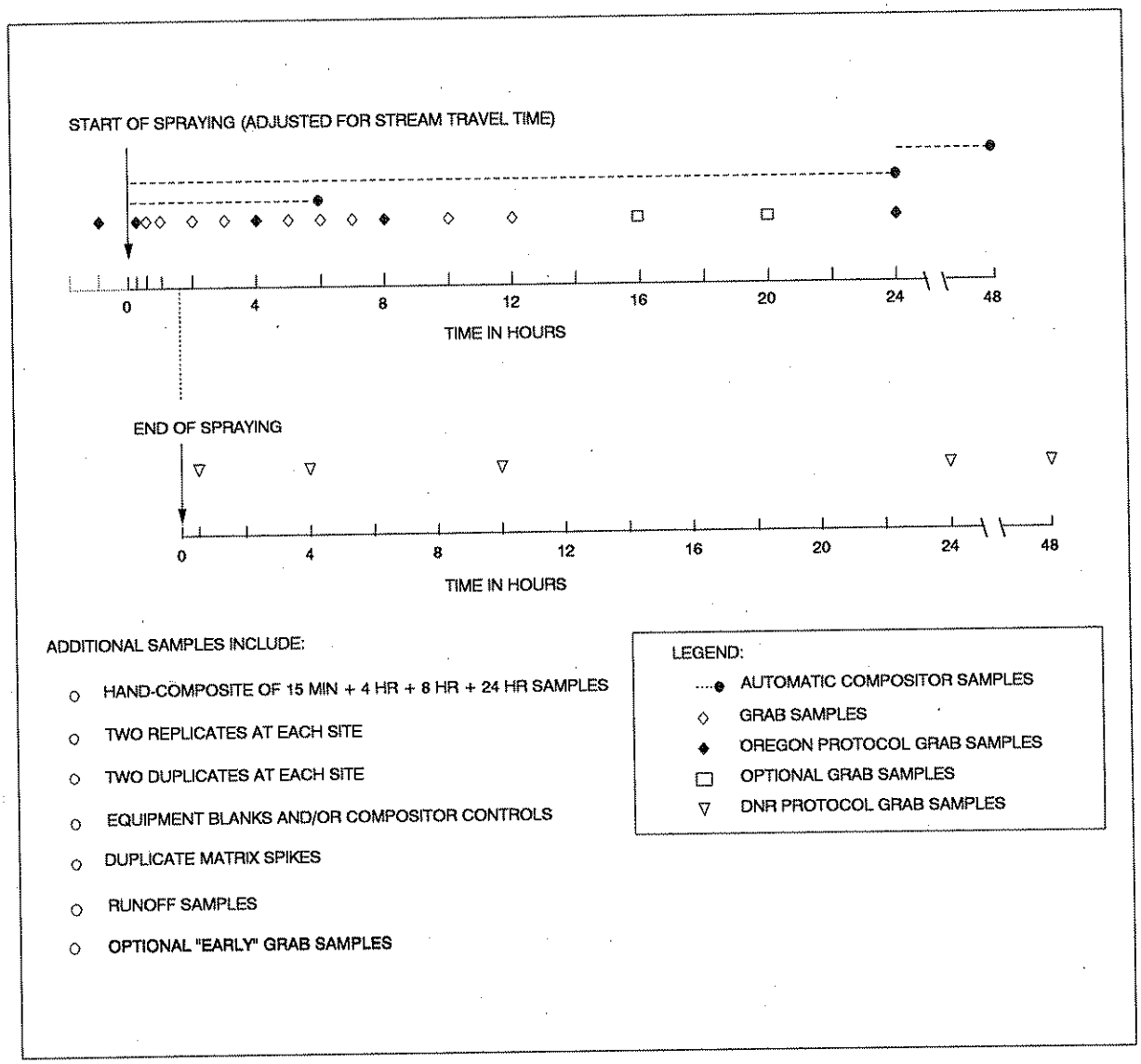


Figure 2: Sampling Schedule

A pre-spray control grab sample was collected at the sampling sites prior to spraying. Timed discrete grab samples were collected at 15 and 30-minutes, and 1, 2, 3, 4, 6, 8, 10, 12, and 24 hours from the estimated time of arrival of stream water from the spray area. These sample collections were timed from when the first swath adjacent to the stream was sprayed, adjusted for stream travel time from the mid-portion of the unit to the sampling site. A hand-composited sample was prepared from equal parts of the 15-minute, 4-hour, 8-hour, and 24-hour samples. Additional timed grab samples were collected on a schedule which is timed from the completion of all spray operations for the unit being sampled. These were timed at 30 minutes, 4 hours, 10 hours, 24 hours, and 48 hours from completion of spraying without allowance for stream time-of-travel. However, separate grab samples were not collected where the two schedules corresponded very closely to one another. Optional "early" grab samples were collected before the regular schedule commenced for sites with long travel times, and at 16 and 20 hours post-spray at selected sites where the budget could accommodate additional samples. As indicated in Figure 2, some of the grab samples correspond to two state monitoring protocols for purposes of evaluating the efficacy of these protocols.

With the exception of the fall herbicide sprays, all samples were collected in 4-liter clear glass containers with teflon lid liners. Samples for glyphosate and imazapyr analyses were collected in 0.5 liter clear polyethylene containers. For grab samples, the containers were filled directly from the stream thalweg, without rinsing, often using a small natural waterfall to aid in filling the container quickly. Collection personnel wore disposable vinyl gloves while handling sample containers and otherwise took care not to contaminate the samples or sampling areas. No one entered the stream upstream of the sampling point during the sampling period.

In addition to the discrete grab samples and hand-composites of certain grab samples, ISCO® Model 2700 and 3700 automatic compositors were used to collect 6-hour and 24-hour composite samples from aliquots taken at 15-minute intervals. The automatic compositors were used to obtain more accurate information on average chemical concentrations over the durations of interest. The 24-hour duration corresponds to an averaging period which has been used in suggested water quality criteria for evaluation of herbicide monitoring results (see for example, Newton and Norgren, 1977 and Norris and Dost, 1992). The 6-hour duration corresponds to the time period in which the majority of elevated herbicide and insecticide levels have been detected in previous forest chemicals monitoring efforts (Bernhardt *et al.*, 1978; Tracy *et al.*, 1977; and Fredriksen *et al.*, 1975).

The 6-hour and 24-hour composite samples were timed from the time of spraying along the stream buffer adjusted for the time-of-travel delay. In addition, a second 24-hour composite sample was collected over the period from 25 to 48 hours after spraying. In one case where a precipitation runoff event occurred soon after spraying, additional 24-hour composite samples were taken throughout the first 96 hours following the spray.

At two of the study sites, one or more secondary sampling sites were established. These were sampled either using automatic compositors, where a pre-spray control sample and 6- and 24-hour composite samples were collected, or by grab sampling at irregular intervals.

Field Quality Control Procedures

Planning and preparation for field sampling were designed to ensure that the techniques of sample collection, sample labeling, chain of custody, and transport did not limit the quality of results. All grab samples were collected in containers supplied by the laboratory and were iced soon after collection. In the case of automatic compositors, the sampler and receptacle were cleaned according to protocols approved by the analytical laboratory, and the sample receptacle was iced continuously during sampler operation. Samples were transferred to laboratory containers at the conclusion of the compositing period.

In addition to taking care in sample collection, labelling, and handling, field quality control procedures included the collection of pre-spray control samples, duplicate samples, replicate samples, equipment blanks, and transfer blanks. All of these quality control samples were sent to the laboratory as "blind" samples; they were mixed in with the primary stream samples in a random fashion and labelled in a similar manner as the other samples. These quality control samples provided a means of assessing the accuracy and precision of analytical methods and field sample collections.

Control grab samples were collected at the sampling sites on the same day as the spray operation, but before any spraying of the subject unit had begun. Compositor controls were another type of control sample, reflecting the pre-spray conditions of both the stream sampled and the automated sampling equipment. These were taken by pumping a volume of water from the stream to be sampled through the ISCO® sampler before spraying occurred. As an additional quality control check, compositor blanks were taken by pumping organic-free water provided by the laboratory through the ISCO® sampler when it was installed at the sampling site. Typically one compositor blank and one compositor control sample, taken from separate compositors, were obtained prior to sampling for each study site. At the secondary sampling sites where ISCO® samplers were used, the pre-spray compositor control sample was the only control sample collected (*i.e.* a separate control grab was not collected).

Two or more pairs of field duplicate samples were prepared and two field replicate sample pairs were collected at each study site to assess sampling and analytical variability. Field replicates are samples collected side-by-side at the same time, in some cases by different personnel. Both sample containers are filled directly from the stream, though at slightly different locations. These are used to assess the combined variability inherent in field sample collections, sample handling, and laboratory procedures. Field duplicates are prepared by splitting the homogenized contents of a single oversized collection vessel into two sample

containers after collecting a volume from the stream. Duplicates are used to assess the variability inherent in sample handling and laboratory analytical procedures. The schedule for collection of replicates and duplicates was determined in the field and varied from site to site.

As an additional quality control check, field transfer blanks were prepared during some of the sampling efforts. Transfer blanks were prepared by filling sample containers with organic-free laboratory water in the field to determine whether sampling personnel, clothing, or other aspects of the sampling environment were contaminating samples during container filling or handling.

Runoff Sampling

Sampling of post-spray runoff events was conducted at four of the study sites. The intent of runoff sampling was conducted to assess the effects of the first runoff-producing precipitation event following herbicide application. At one study site, 24-hour composite samples were collected using ISCO® samplers during a runoff event. A recording rain gage was used at this site to document the precipitation event. At three additional sites we conducted limited runoff sampling involving the collection of one or more grab samples at each sampling station. Rain gages were not deployed at these sites, but rainfall records for the nearest National Oceanic and Atmospheric Administration (NOAA) weather station were used to approximate the timing and amount of rainfall.

Weather Data

For most of the study sites, a weather station consisting of a Unidata® weather instrument cluster, a tipping bucket rain gage, and Unidata® datalogger were installed in an area adjacent to the unit the evening before the spray operation, and operated during and following the operation. Weather information collected included wind speed and direction, temperature, relative humidity, and precipitation. The datalogger recorded cumulative precipitation at 15-minute intervals and 15-minute average values for the other parameters. At two sites, the weather station was not installed at the site. We used a hand-held wind meter and compass to estimate wind speed and direction during the spray operations at one of these sites. At the other site, our weather station deployed at a different study site 25 kilometers to the south-southeast during the time of application was assumed to represent local weather conditions. In addition to our measurements, the foresters in charge of operations at each of the units took measurements of wind speed, wind direction, and relative humidity which they recorded on the operator questionnaire we provided.

Observations of Spray Operations

Wherever possible during the spraying, we observed the operations from a vantage point that allowed us to see the pattern and timing of each load applied. This information was recorded on a map of the spray unit. The time of spraying the first swath along the sampled stream

and the time the entire unit was completed were of particular importance for establishing the sampling schedule. In cases where we could not observe the critical parts of the operation, we maintained radio contact with the on-site forester to get the information we needed. In addition to our records, the forester and/or pesticide applicator provided us with a map of the unit showing the areas sprayed, areas buffered, and pattern of spay swaths. The information from our observations and from the forester and/or applicator was combined to produce the spray maps presented with our results.

Operational Information

Operational information collected included composition of the spray mixture, application rates, aircraft and flight characteristics, characteristics of application equipment (nozzle and boom configuration, operating pressure, etc.), locations of chemical mixing and landing areas, and other pertinent information. Much of this information was obtained from the on-site forester and/or applicator using a questionnaire that we provided. The questionnaire we used is presented in Appendix D.

Fluorescent Dye Tracing

The original study plan called for using fluorescent dye tracing to monitor the introduction of pesticide spray mixtures into streams. However, we found that this was generally not acceptable to the helicopter pilots, because of the potential for staining the external surfaces of the aircraft. Because of the very low laboratory detection levels obtained for most of the analytes, fluorescent dye tracing would not necessarily have offered any advantages in terms of detectability. However, it may have provided a cost-effective means of continuously monitoring spray introduction to streams for water-based spray mixtures.

Analytical Procedures

All samples collected were analyzed for the primary active ingredient herbicide, fungicide, or insecticide. Samples collected on a similar or reduced schedule were also analyzed for primary degradation products, carriers (where diesel was used), and/or secondary herbicides. The primary analytes included the herbicides 2,4-dichlorophenoxyacetic acid (2,4-D), glyphosate, and triclopyr, the insecticide metasystox-R, and the fungicide chlorothalonil. Secondary analytes included the herbicide imazapyr, the 2,4-D degradation product 2,4-dichlorophenol (2,4-DCP), and the glyphosate degradation product aminomethylphosphonic acid (AMPA). Since the dormant spray we sampled used diesel as a carrier, each sample collected was analyzed for diesel.

Analytical methods and detection limits are summarized in Table 1. Triclopyr, 2,4-D, 2,4-DCP, metasystox-R, and chlorothalonil were analyzed at the Department of Ecology's Manchester Environmental Laboratory using modifications of EPA-approved methods. Triclopyr, 2,4-D, 2,4-DCP, and chlorothalonil were analyzed by gas chromatography (GC) using electron capture detection. Metasystox-R was analyzed by GC with flame photometric

Table 1: Analytical Methods Summary

Analyte	Method[1]	Detection Limit ($\mu g/L$)[2]
2,4-D (ester)	SW 846 method 8140	0.03 to 0.04
glyphosate	Monsanto method (Oppenhuizen & Cowell, 1991)	0.20
triclopyr (ester)	EPA DW method 515.1	0.01 to 0.04
metasystox-R	SW 846 method 3510 & PAM2 180.330	2.50 to 4.10
chlorothalonil	SW 846 method 8080	0.01
imazapyr	American Cyanamid method (unpublished)	0.20
2,4-DCP	SW 846 method 8140	0.63 to 0.84
AMPA	Monsanto method (Oppenhuizen & Cowell, 1991)	0.20
Diesel	WTPH-D (Wa. Dept. of Ecology, 1992)	15.7 to 197

1: References for numbered methods: SW 846 refers to U.S. EPA (1986); EPA DW refers to Graves (1989); PAM2 refers to U.S. FDA (1975).
2: Range of detection limits reported by lab for sample analysis. Limits vary with sample batches; details in Appendix E.

detection. Diesel was analyzed using a hydrocarbon quantification method (WTPH-D) developed by the Department of Ecology which uses GC with a flame ionization detector and pattern matching to identify the product in the sample. A sample of the diesel used in the spray mixture was provided to the laboratory for pattern matching with water sample results.

Manchester's large-volume, in-vessel extraction procedure is an important modification from standard laboratory procedures. Resolution of the analysis is enhanced by extracting the entire three- to four-liter sample directly from the sample collection vessel, resulting in lower than usual detection limits. (The usual procedure extracts about one liter of sample after transferring it to a separate extraction vessel.)

Glyphosate, AMPA, and imazapyr were analyzed by the A&S Environmental Testing laboratory in Reading, Pennsylvania. The method used for glyphosate and AMPA was developed by Monsanto Company. This method involves evaporation of the sample followed by high performance liquid chromatography (HPLC) using post-column reaction with a fluorescence detector (Oppenhuizen and Cowell, 1991). The method used for imazapyr is an unpublished method by American Cyanamid Company, using an evaporation step and HPLC with an ultra-violet detector.

Measures to ensure data quality include various laboratory procedures for quality control and quality assurance. Laboratory quality control activities included the use of instrument calibration standards, duplicate method blanks, surrogate spike recovery tests, and duplicate spiked sample recovery (matrix spike) tests. In the case of glyphosate, AMPA, and imazapyr analyses, surrogate spikes were not used as a part of the method, nor were method

blanks run in most cases. In these cases the laboratory chose to rely on matrix spikes for assessing recovery efficiency, and blanks included with the samples served the purpose of method blanks.

Matrix spikes are one of the most important and reliable means of assessing the efficiency and bias of the laboratory method as applied to the sample matrix. They indicate whether the analytical measurements are biased in a positive or negative direction due to interfering substances or matrix effects (PTI Environmental Services, 1991). In other words, matrix spikes can help determine whether interfering substances (either in the water sample or introduced via laboratory procedures) or matrix effects (physical/chemical interactions between the pesticide and stream water or sample container) are biasing how well the analytical results represent the true amount of pesticide in the sample. For this study, one to two stream samples were spiked, in duplicate, with a known amount of the analyte of interest for each batch of samples submitted to the laboratory (at least one matrix spike duplicate pair for each 20 samples). The recovery of the analyte is reported as a percentage of the amount added. Duplicate matrix spike recovery results serve as a measure of the efficiency of the extraction process and overall bias of the method as well as analytical precision. In the case of chlorothalonil analyses, the laboratory inadvertently neglected to spike the selected samples, so matrix spike recovery data is not available. The surrogate spike recovery data was used instead for an overall assessment of extraction efficiency. Surrogate spikes are similar to matrix spikes except that samples are spiked with a chemically similar compound rather than the analyte of interest, and each individual sample is spiked once rather than running duplicate matrix spikes on selected samples.

Development of Recommended Monitoring Protocol

The sampling schedule used in this study replicates two state protocols for monitoring forest pesticide application. Additional discrete (grab) and composite samples were included to provide greater resolution of data for evaluating chemical concentrations and potential adverse impacts, and for evaluating the efficacy of these two state monitoring protocols.

The pre-spray control, 15-minute, 4-hour, 8-hour, and 24-hour grab samples (timed from the first spray swath adjacent to the stream), and the four-sample hand-composite are specified in the Oregon Department of Forestry forest chemicals monitoring protocol (Oregon State Department of Forestry, 1989). The pre-spray control, 30-minute, 4-hour, 10-hour, 24-hour, and 48-hour grab samples (timed from the completion of spraying) are specified in the Washington State Department of Natural Resources forest chemicals monitoring protocol (Washington State Department of Natural Resources, 1990). Although these two protocols are based on slightly different approaches, each with its own merits, they share a common objective of identifying chemical concentrations in a cost-effective manner. Each protocol was evaluated for its ability to provide adequate monitoring information for aerial applications of forest herbicides and insecticides.

MONITORING RESULTS

We sampled seven operations involving pesticide applications conducted in accordance with the BMPs. The silvicultural operations monitored included five conifer release herbicide sprays (one dormant spray, two early foliar sprays, and two late foliar sprays), one site preparation herbicide spray, and one Christmas tree pest-control spray. The results from all seven study sites are summarized in Table 2. Tables showing the complete laboratory results for each study site are contained in Appendix E.

Quality control results are presented in Appendix F. This appendix presents the analytical results for quality control samples as well as the relative percent difference (RPD) for all blind field replicate and duplicate pairs for which the analyte was detected. RPD describes the range as a percent of the mean. Appendix F also summarizes laboratory performance in terms of the matrix spike recovery results, showing the recoveries for each analyte and the RPDs for matrix spike duplicate pairs. Based on analysis of quality control samples, overall precision (considering both sampling and laboratory variability) for our analytes was good, with only a few problems noted.

On blind quality control samples (field duplicates and replicates), RPDs ranged from 0% to 111% for 35 sample pairs, with 26 of 35 (74%) having RPDs less than 25%, and only 4 of 35 (11%) having RPDs of greater than 50%. Average RPDs for blind duplicates and replicates with detectable amounts of pesticides were 23.5%, 15.2%, 6.2%, 17.3%, 111%, and 18.7%, respectively, for triclopyr, 2,4-D, chlorothalonil, metasystox-R, imazapyr, and glyphosate. This indicates acceptable precision with the possible exception of imazapyr. For imazapyr, we had only one replicate sample pair (collected during runoff sampling) with detectable amounts in both samples, and the RPD was 111%. However, two matrix spike duplicate pairs analyzed had RPDs of only 3% each, indicating acceptable laboratory precision and suggesting field variability during the runoff event.

Duplicate matrix spike RPDs ranged from 0% to 126% for 22 sample pairs, with 15 of 22 (68%) having RPDs below 25% and 3 of 22 (14%) having RPDs exceeding 50%. Matrix spike recovery precision was acceptable for all compounds based on average RPDs. Average percent recoveries for matrix spikes (which reflect the overall efficiency and bias of the analytical technique at quantifying the amount of pesticide in the stream water matrix) were 39.8%, 77.4%, 98.6%, and 99.3%, respectively, for metasystox-R, triclopyr, imazapyr, and glyphosate. The lab noted a problem with matrix spike recovery for 2,4-D. The stock 2,4-D standard that the laboratory used to spike samples was apparently contaminated with a compound that eluted similarly to 2,4-D and caused chromatographic interference. In the absence of meaningful recovery results for 2,4-D, duplicate matrix spikes of the chemically similar compound 2,4,5-TP (obtained from a different standard mixture) were used as a surrogate. Average recovery for 2,4,5-TP was 64.4%. For chlorothalonil, the laboratory recovery efficiency cannot be definitively quantified, because the laboratory inadvertently neglected to spike the matrix samples with the compound. Recoveries for the surrogate compound dibutylchlorendate (DBC), which was added to each sample, ranged from 66% to

Table 2: Forest Pesticides Monitoring Summary

Site ID	Type of Application	Pesticides Applied	Hectares Treated	Maximum Instantaneous Conc. (μg/L)[1]	6-Hour Average Conc (μg/L)[1]	Maximum 24-Hour Ave. Conc. (μg/L)[1]
SH1	Dormant	triclopyr (ester)	37	1.29	0.18	0.13
SH2	Early Foliar	2,4-D (ester)	105	2.49	0.48	0.69
SH3	Early Foliar	2,4-D (ester)	39	<0.04	<0.03	<0.04
		triclopyr (ester)	39	0.02	<0.02	<0.02
IN1	X-Mas Tree	chlorothalonil	15	1.72	0.58	0.18
		metasystox-R	15	2.80	2.70	3.25
FH1	Late Foliar	glyphosate	12	2.39	0.48	0.32
		imazapyr	12	<0.50	<0.50	<0.50
FH2	Site Prep	glyphosate	57	7.55	1.29	0.56
		imazapyr	57	1.15	0.81	0.36
FH3	Late Foliar	glyphosate	61	4.36	0.77	0.29

1: Maximum levels found at sampling sites located downstream of spray areas. Values shown may be an average of two results where duplicate or replicate samples were analyzed (see Appendix E); "<" indicates compound not detected at the level shown.

131%, and averaged 90%, indicating acceptable overall performance of analytical method. The recovery data show that the analyses were essentially unbiased for quantifying glyphosate and imazapyr levels in the samples. Matrix spike recovery results indicate a slight negative bias for quantifying levels of triclopyr and a compound similar to 2,4-D, and a substantial negative bias (*i.e.*, relatively inefficient extraction or incomplete oxidation reactions) for metasystox-R. Therefore, the results presented are not likely to over-represent the true amount of pesticides present in the stream, but for some compounds these results may under-represent true concentrations.

Information on the pesticide products applied at our study sites is presented in Table 3. The results from each of the applications monitored are presented in the following case summaries. These summaries include a narrative description of the case followed by graphical presentations of the sampling results, maps of the study units showing spray areas and drainage patterns, results of time-of-travel studies, and tabular summaries of weather and operational details.

Table 3: Pesticide Product Information

Common Name	Trade Name	EPA Registration Number	Active Ingredient
2,4-D (ester)	Weedone LV4®	264-20ZA	2,4-dichlorophenoxyacetic acid, butoxyethyl ester
chlorothalonil	Daconil®	50534-188	tetrachloroisophthalonitrile
glyphosate	Accord®	524-326	glyphosate N-(phosphonomethyl)-glycine in the form of isopropylamine salt
imazapyr	Arsenal Applicator's Concentrate®	241-299	isopropylamine salt of imazapyr (2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-3-pyridinecarboxylic acid)
metasystox-R or oxydemeton methyl	Metasystox-R®	3125-111	S-[2-(ethylsulfinyl)ethyl]),)-dimethyl phosphorothioate
triclopyr (ester)	Garlon 4®	464-554	3,5,6-trichloro-2-pyridinyloxyacetic acid, butoxyethyl ester

Site SH1: Bigwater Creek Unit

Site SH1 was a dormant conifer release spray applying a triclopyr ester formulation (Garlon 4®) in an invert (water-in-diesel) emulsion, at the rate of 1.1 kilogram/hectare (kg/ha) active ingredient (a.i.). Operational details are summarized in Table 5. The 37 hectare spray unit was adjacent to Bigwater Creek, with several Type 5 tributaries and one Type 4 stream traversing the unit (see Figure 3). Our primary sampling site (Station A in Figure 3) was on the Type 4 stream, with a secondary sampling station on one of the Type 5 streams (Station B). There were spray areas on both sides of the streams, and none of the streams in the spray unit had Riparian Management Zones or other riparian leave areas. The topography of this site was the steepest of the seven spray units monitored, with slope gradients ranging from 35 to 80% and an average slope of about 50%. The steep topography of the unit was not conducive to parallel flight paths along most streamside buffers, but parallel swaths were flown along the lower portion of our primary sampling stream (see Figure 3).

Rainfall began five days after the spray, and we sampled the runoff with a single grab sample on the sixth day. Area weather stations reported rainfall accumulations of 8 to 13 mm over the two-day period preceding our runoff sampling.

All samples were analyzed for triclopyr and diesel. Triclopyr was detected in 19 of 26 post-spray samples, including the runoff sample, at concentrations ranging from 0.01 to 1.37 μg/L (see Appendix E). It was not detected in either of the two pre-spray control samples. Diesel was not detected in any samples (detection limits ranged from 16 to 197 μg/L). Triclopyr levels peaked sharply within 30 minutes of the spray, then tapered off to undetectable levels over the next eight hours, as shown in Figure 4. The time-of-travel study revealed a good deal of longitudinal dispersion in the stream we sampled (note the broad, low peak and extended declining tail on the dye concentration curve in Figure 5). The step-pool morphology of these small, steep streams results in water being temporarily stored in plunge pools and eddies, where it mixes with surface flows from upstream and groundwater seepage.

The forester in charge indicated that all streams within the unit were buffered except the uppermost portions of two Type 5 streams that were tributary to our primary sampling site (see Figure 3). Following his site reconnaissance, which included checking culverts and aerial surveillance, his assessment was that these segments were not flowing at the time of spraying. However, during our field reconnaissance about one week prior to the spray, we walked the streams and determined that there was surface flow in these segments. Although streamflow had decreased by the day of application, we believe that there may have still been minor amounts of surface flow in these upper reaches. Following our study protocol, we did not share our streamflow information with the forester so as not to bias normal BMP implementation. Two days following the spray we checked the mouths of the upper tributaries and verified that at least one still had surface flow at that time. Minor amounts of surface flow would not have been visible from aerial reconnaissance (much of the stream

channel is obscured by logging slash), or by checking the culverts at the upper road crossings. On the day of spraying, streamflow was about 18 liters per second (L/s) at Station A, and about 3 L/s at Station B, and this remained fairly constant throughout the sampling period. Based on streamflow measurements taken at different points along the stream, groundwater seepage within the unit is a significant source of streamflow (at least 25 percent). Based on 24-hour average concentrations for the first 24 hours following the spray, we estimate that the cumulative downstream loading of triclopyr was about 78 mg/day and 35 mg/day, respectively, from the streams at stations A and B. This corresponds to about 0.0003 percent of the amount of triclopyr applied at this unit (1.1 kg/ha x 37 ha = 40.7 kg a.i. applied at the site) lost to surface water within the first 24 hours of spraying. However, we do not know what additional amounts were exported via other tributaries or the mainstem of Bigwater Creek.

Some portions of the Type 5 segments that were oversprayed likely had some minor amount of surface flow intermingled with shallow subsurface flow. This probably contributed somewhat to the pesticide levels we observed at our primary sampling station. However, we believe the majority of pesticide introduction was due to off-target swath displacement and drift because the timing of the peak concentration corresponds to the initial settling of near-stream spray swaths. Weather conditions were intermediate relative to the other study sites, with average wind speeds of less than 4 kilometers/hour (km/hr), as shown in Table 4 and Figure 3. Relative humidity was less than ideal, as it rapidly decreased during the spray operation, dropping from about 60 to 45 percent. We observed downwind displacement of some of the spray swaths.

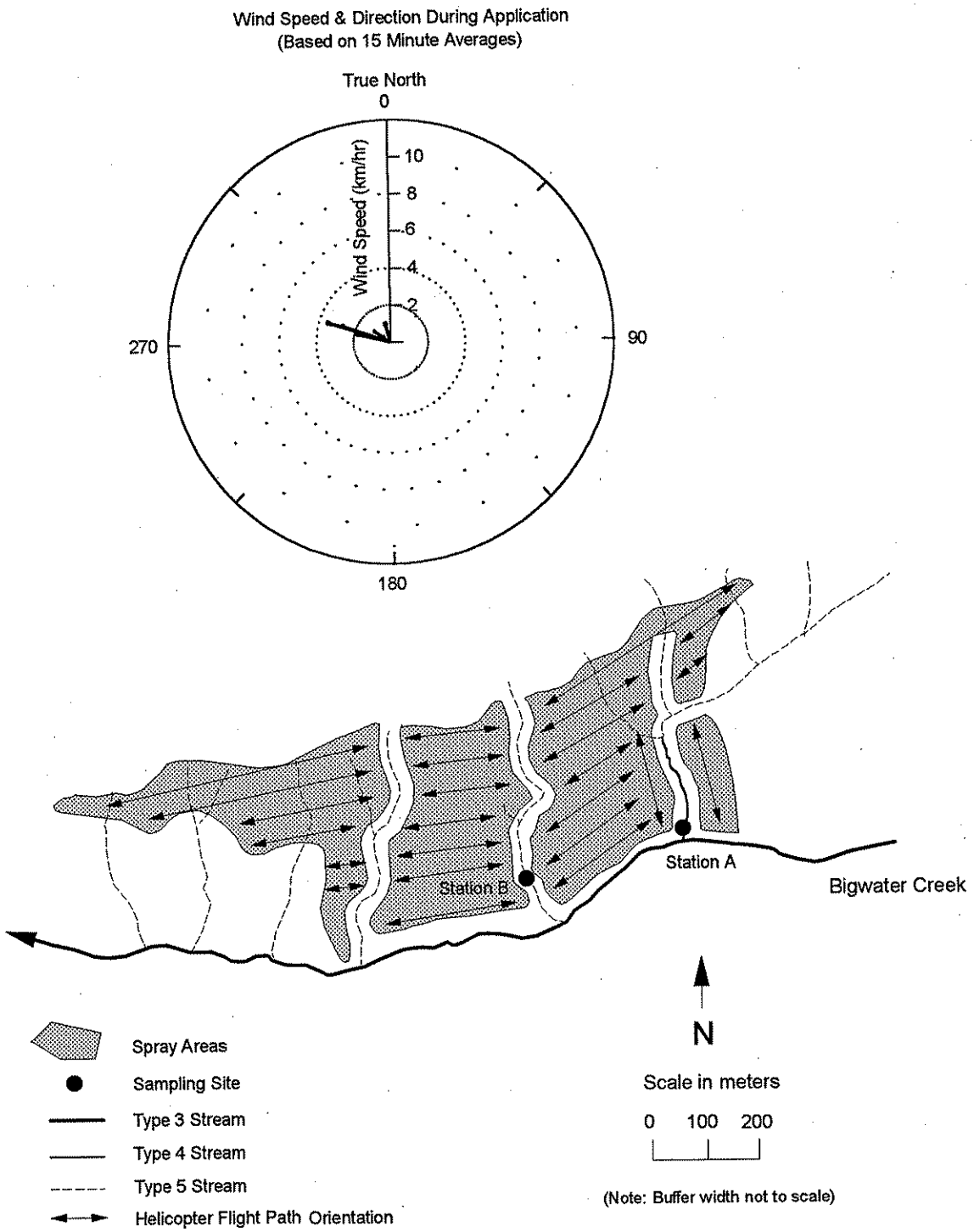
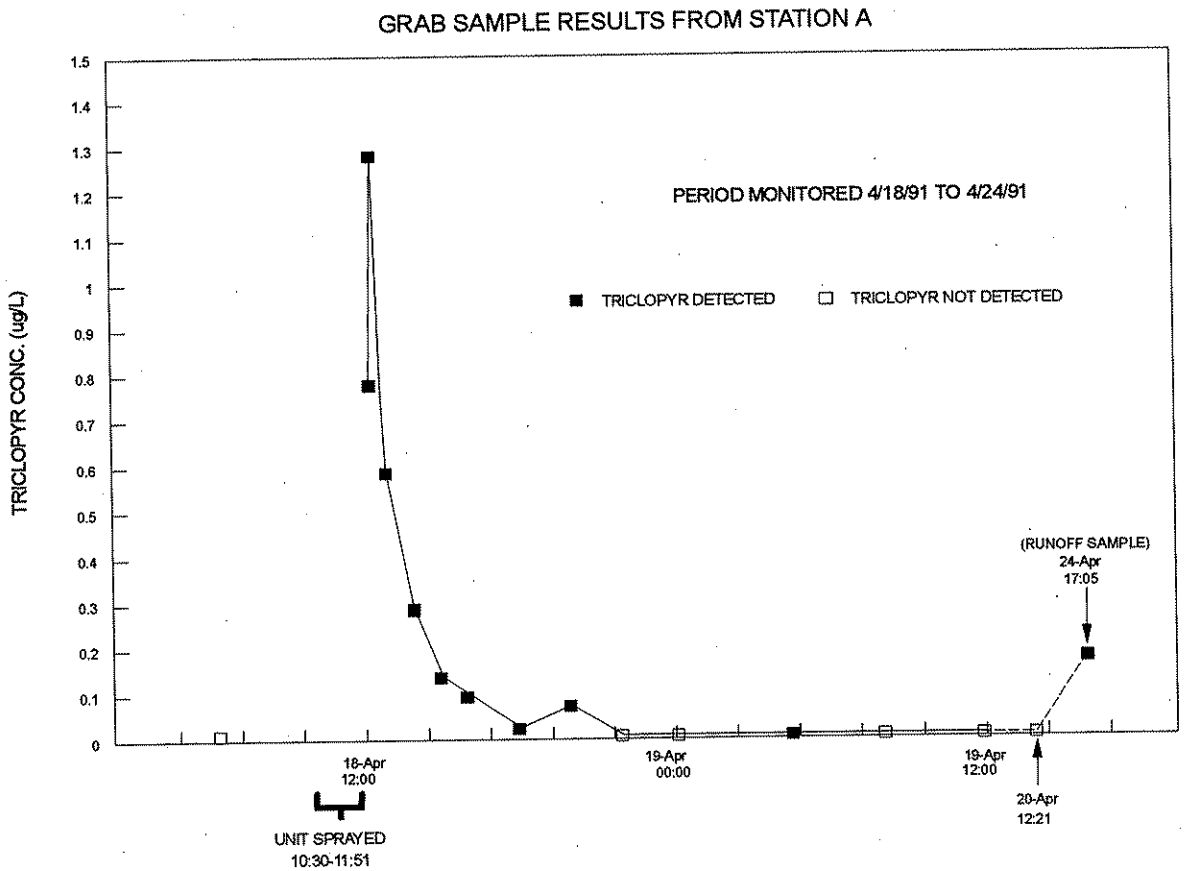


Figure 3: Map of Study Site SH1 - Bigwater Creek Unit



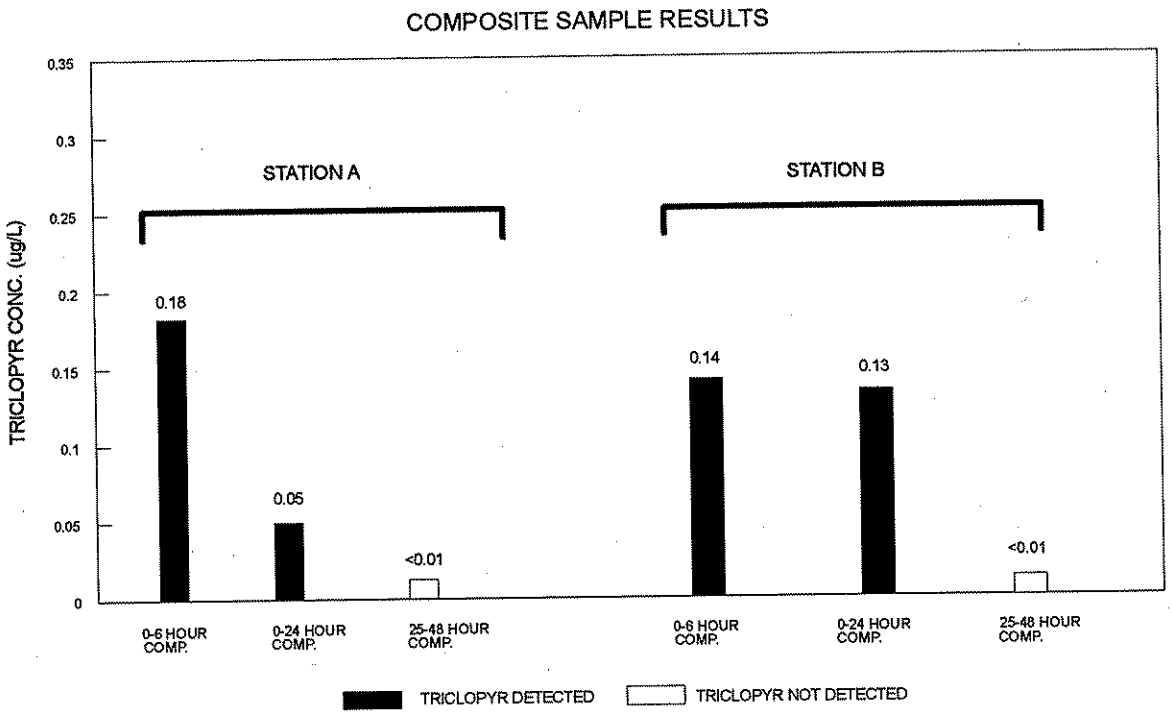


Figure 4: Triclopyr Levels at Site SH1 - Bigwater Creek Unit

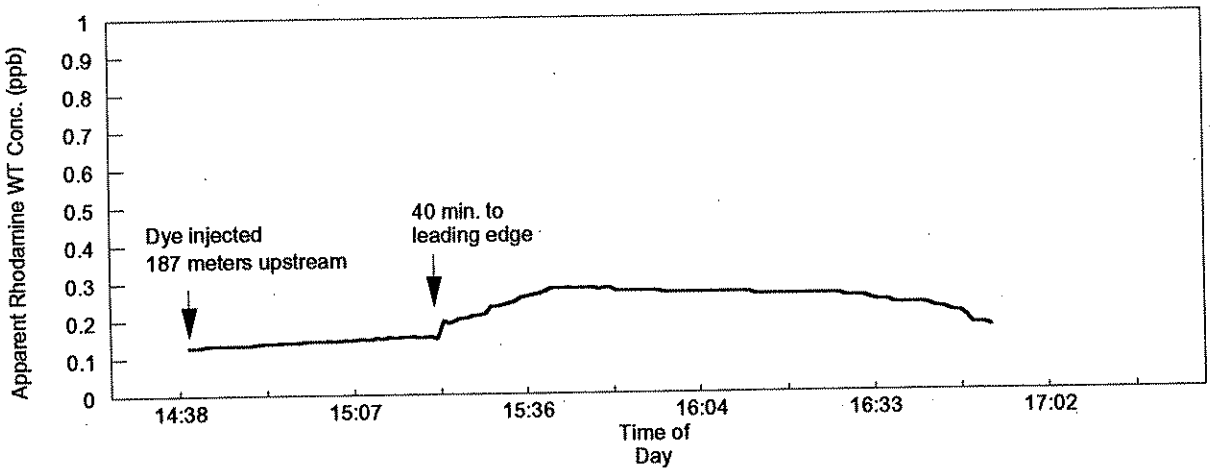


Figure 5: Time-of-Travel Study Results for Site SH1-Tributary to Bigwater Creek

Table 4: Weather Data for Time of Application at Site SH1-Bigwater Creek Unit.
(All data recorded as 15 minute averages.)

DATE	TIME	WIND SPEED (km/hr)	WIND DIRECTION (azimuth)	AIR TEMP. (°C)	SOLAR RADIATION (watts/sqm)	RELATIVE HUMIDITY (%)	RAIN-FALL (mm)
4/18/91	10:45	1.0	345	11.1	541	53.7	0
4/18/91	11:00	1.0	305	12.5	565	51.0	0
4/18/91	11:15	1.3	285	13.9	588	49.4	0
4/18/91	11:30	1.8	284	15.3	606	46.7	0
4/18/91	11:45	2.7	289	15.8	624	45.5	0
4/18/91	12:00	3.5	288	15.8	641	46.3	0

Table 5: Operational Summary for Site SH1

Target Vegetation: Vine Maple

Active Ingredient Herbicide: Triclopyr (Garlon 4E)

Surfactant added: none
Other additives: Bivert TME
Carriers used: diesel
water

Application Rate:
liters/ha: 2.3
Active Ingedient Application Rate in kg/ha: 1.1
liters/ha: none
liters/ha: 0.7
liters/ha: 37.4
liters/ha: 71.8
Application Rate for Final Spray Mix: 112.2 liters/ha
Approximate Area Sprayed: 37 ha

Helicopter Model: Bell 206 Jet Ranger
Flight Altitude: 8 meters Airspeed: 64 km/hr
Flight Centerline Offset from Edge of Buffers: 9 meters
Nozzle Type: hollow-cone Nozzle Size: D10 with #46 whirlplate
Nozzle Orientation Angle: 45°

Boom Length: 11.0 meters total
Effective Swath Width: 18 meters
# of Nozzles: 48
Operating Pressure: 138 kPa (20 psi)

Site SH2: Gibson Creek Unit

Site SH2 was an early foliar conifer release spray applying a 2,4-D ester formulation (Weedone LV4®) with water as a carrier at an application rate of 2.1 kg a.i./ha (see Table 7). A drift control additive (NALCO-TROL®) was used for swaths applied adjacent to buffers. The 105 hectare spray unit includes a 73 hectare block north of Gibson Creek and a 32 hectare block south of Gibson Creek (see Figure 6). We monitored the block north of Gibson Creek, which had a Type 3 stream and several Type 5 or untyped tributaries traversing the unit. We sampled the Type 3 stream downstream of the unit after it had traversed a stand of mature forest for about 200 meters. This stream had several tributaries within the spray unit, many of them quite small and not shown on DNR Water Type Maps. There were spray areas on both sides of the stream, and no Riparian Management Zones or other riparian leave areas, although the alder growth along the stream was quite dense with crown heights of 4-5 meters. The topography of this unit was varied, with slope gradients predominately in the 25 to 35% range, and ranging from 10 to 80%. As shown in Figure 6, parallel flight paths were used along most of the streamside buffers. Swaths were flown perpendicular to some of the smaller tributaries. Single (half) boom applications were used for some of the near-stream spray swaths.

A runoff producing rainfall event began about 39 hours after the spray, and we sampled the runoff period with 24-hour composite samples as well as grab samples. Cumulative rainfall was about 30 mm over the 62-hour period during which we had our tipping bucket rain gage deployed (see Figure 8).

All samples were analyzed for 2,4-D and 2,4-DCP. The 2,4-D was detected in all 32 post-spray samples, seven of which represented the surface runoff event, at concentrations ranging from 0.03 to 2.49 μg/L (see Figure 7 and Appendix E). It was not detected in either of the two pre-spray control samples or the equipment blank. The breakdown product 2,4-DCP was not detected in any samples (detection limits ranged from 0.63 to 0.81 μg/L). Levels of 2,4-D peaked at 1.31 μg/L within the first three hours after swaths adjacent to the stream were sprayed (about 1 hour after spraying the entire unit), then tapered off to less than 0.20 μg/L about 6 hours after the start of spraying (see Figure 7). The pattern of 2,4-D concentrations that occurred before the runoff event is consistent with the results of our time-of-travel study, which indicated substantial dispersion over the length of the stream (note the dye peak followed by a prolonged declining tail in Figure 9). Levels of 2,4-D then increased during the runoff event, with the highest level we detected (2.49 μg/L) occurring 48 hours after spraying. After the first day our grab sampling interval was 24-28 hours. At this low resolution we were probably not able to identify the peak concentration of 2,4-D that occurred during the runoff event. However, based on our 24-hour composite samples (see Figure 7), we know that the highest levels occurred between 24 and 48 hours after the spray, when the first-flush of runoff occurred.

The applicator indicated the entire length of the mainstem of our sampling stream was buffered, as were the lower portions of its primary tributaries (see Figure 6). His assessment

was that the other portions of the tributaries were not flowing at the time of spraying. Based on our reconnaissance, which included walking the mainstem and checking the mouths of each tributary and inspecting each culvert along the road that traversed the drainage, we agreed with his assessment. However, we cannot be certain that there was no surface flow in some of the apparently dry segments, as minor amounts of flow could only be detected by walking the length of each stream channel. On the day of spraying, streamflow was 12 L/s at the sampling site and 9 L/s at a road crossing in the upper portion of the unit, 730 meters upstream of the sampling site. Roughly 25 percent of the flow entered the stream from tributaries or groundwater seepage within the unit. As illustrated in Figure 8, stream discharge at the sampling site had increased to 28 L/s four days later. Based on discharge measurements and 24-hour composite sample concentrations, we estimate cumulative loading of 2,4-D in the stream we sampled was about 187 mg/day on the day of spraying (before runoff), and about 864, 789, and 605 mg/day on the second, third, and fourth days, respectively. This corresponds to about 0.0001, 0.0006, 0.0005, and 0.0004 percent of the 153 kg a.i. of 2,4-D applied on the 73 hectare portion of this unit that is north of Gibson Creek on the first, second, third, and fourth days, respectively, or about 0.0002 percent over the four-day period. However, we only sampled one stream and additional, unaccounted for amounts were likely exported via other tributaries and/or mainstem Gibson Creek. It is unlikely that the 32 hectare block south of Gibson Creek could have contributed the levels of 2,4-D in the stream we sampled due to prevailing wind direction.

Some portions of the small tributary streams that were oversprayed may have had some minor amount of surface flow intermingled with shallow subsurface flow at the time of spraying. However, we believe most of the direct entry of 2,4-D that we detected at our sampling site prior to runoff was due to off-target swath displacement and drift into the mainstem and flowing tributaries of the stream we sampled. Excluding runoff samples, the peak concentration of 2,4-D corresponds to the time of initial swath deposition in near-stream areas. Wind conditions were variable at the time of spraying, with 15-minute average wind speeds up to 9.5 km/hr (see Figure 6 and Table 6), the second highest among the seven case studies. Wind direction ranged from SW to NW, and we observed downwind displacement of some of the spray clouds. Spot checks with a hand-held wind meter revealed gusts of 16 km/hr or more. The highest stream concentrations of 2,4-D occurred during runoff, after the stream network had expanded into areas (most of them not flowing at the time of application) where the drainage channels and near stream areas had been intentionally oversprayed. As mentioned earlier, the BMPs do not require buffering of small streams that have no surface flow at the time of spraying.

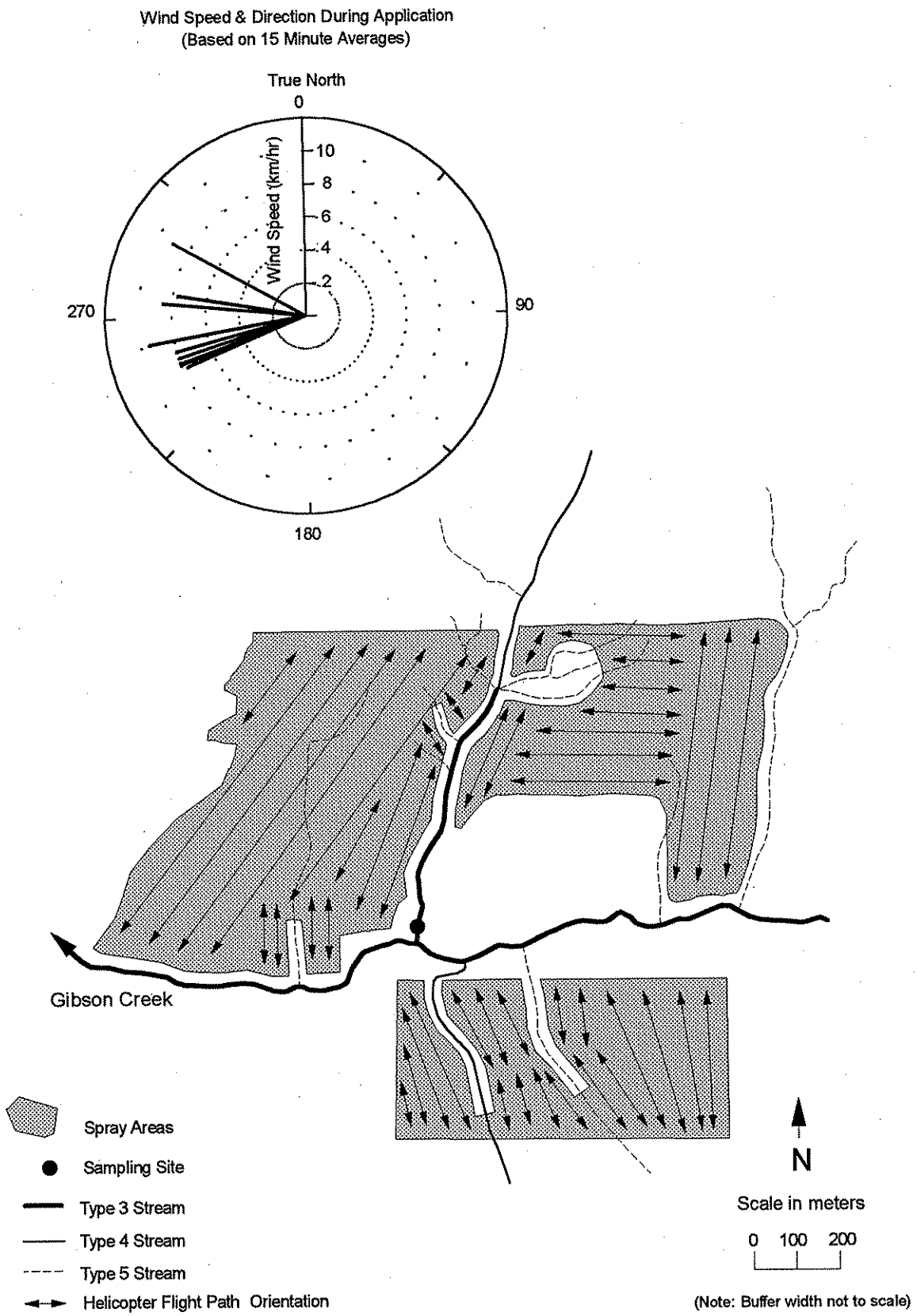
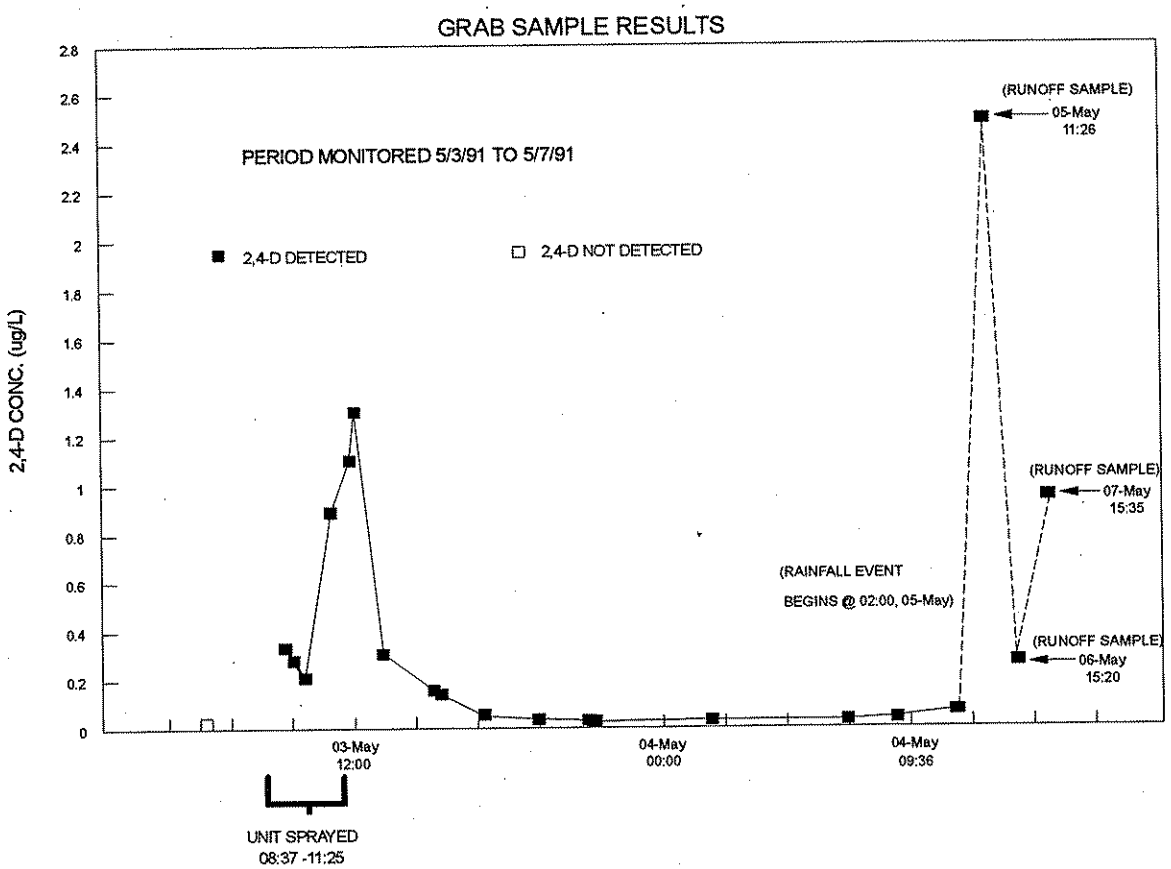


Figure 6: Map of Study Site SH2 - Gibson Creek Unit



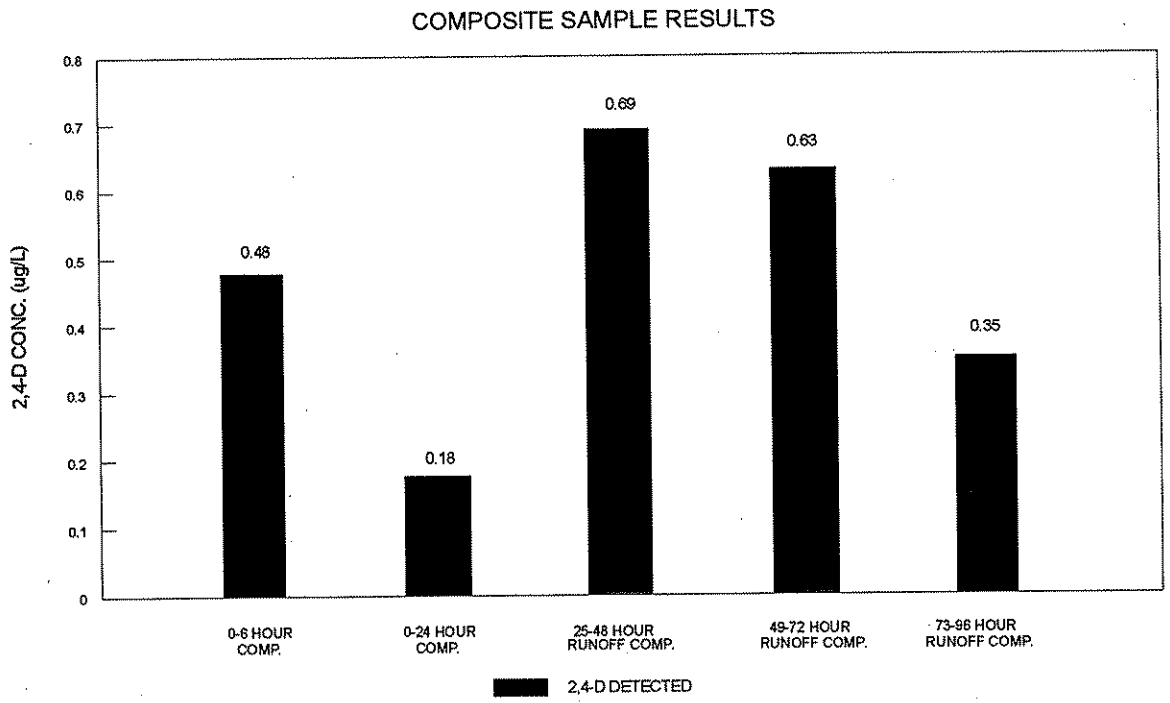


Figure 7: 2,4-D Levels at Site SH2 - Gibson Creek Unit

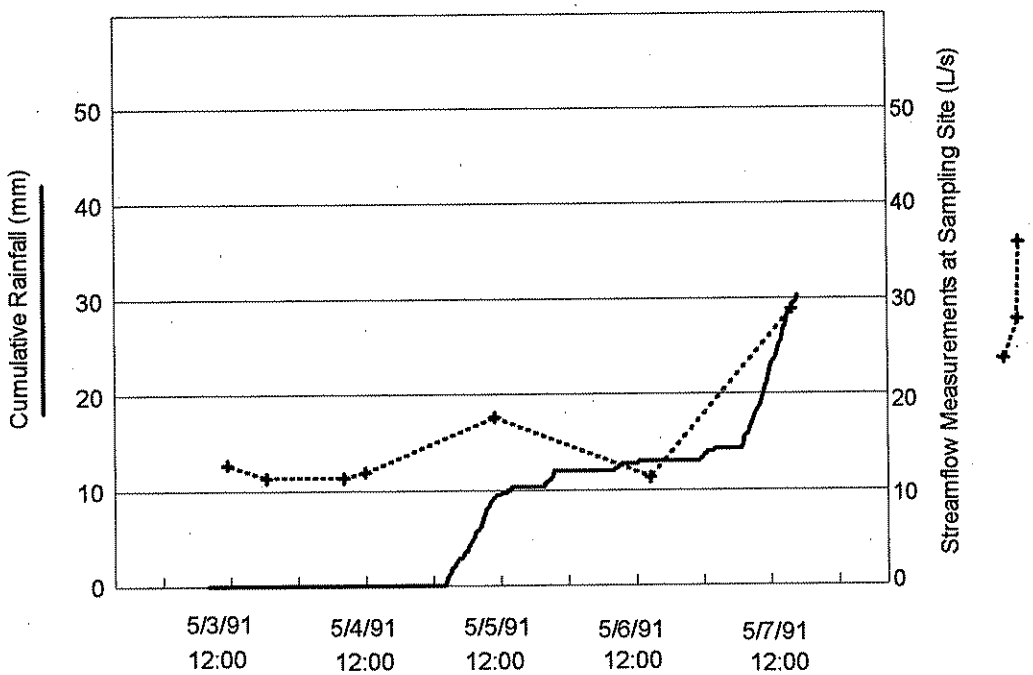


Figure 8: Rainfall and Streamflow at Gibson Creek Tributary

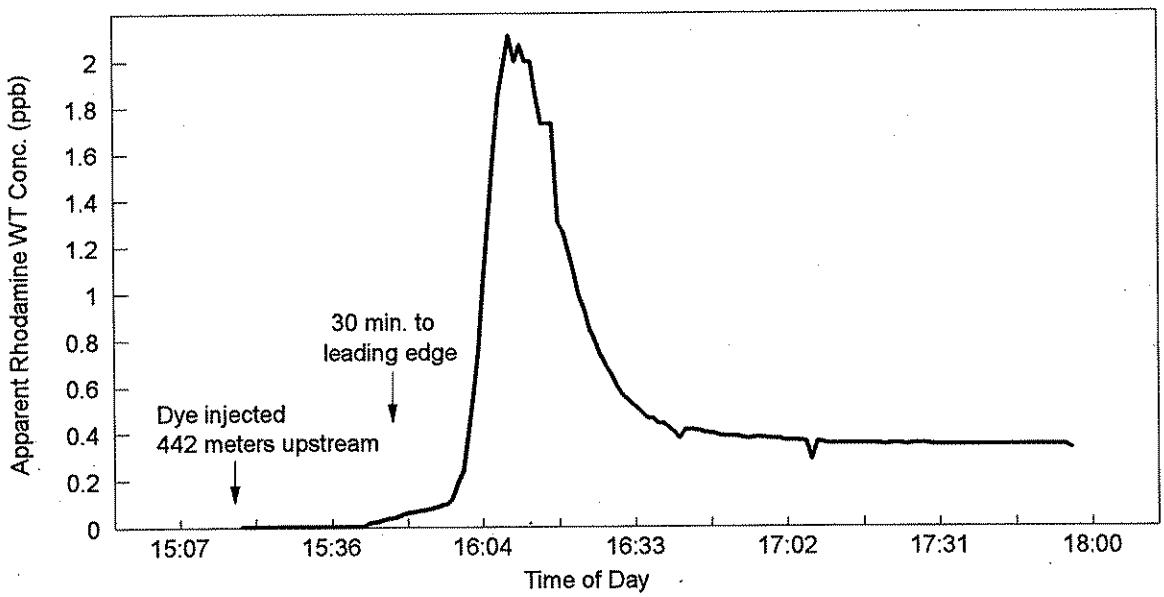


Figure 9: Time-of-Travel Study Results for Site SH2-Tributary to Gibson Creek

Table 6: Weather Data for Time of Application at Site SH2-Gibson Creek Unit.
(All data recorded as 15-minute averages.)

DATE	TIME	WIND SPEED (km/hr)	WIND DIRECTION (azimuth)	AIR TEMP. (C)	SOLAR RADIATION (watts/sqm)	RELATIVE HUMIDITY (%)	RAINFALL (mm)
5/3/91	08:45	8.5	276	8.7	94	70.2	0
5/3/91	09:00	8.0	260	8.7	106	69.4	0
5/3/91	09:15	9.5	260	9.0	159	67.5	0
5/3/91	09:30	8.0	252	9.2	165	66.3	0
5/3/91	09:45	7.7	247	9.5	147	66.7	0
5/3/91	10:00	7.7	250	9.5	153	67.1	0
5/3/91	10:15	8.0	250	9.8	194	66.3	0
5/3/91	10:30	8.0	249	10.1	194	64.7	0
5/3/91	10:45	6.8	260	10.1	206	64.3	0
5/3/91	11:00	8.0	255	10.9	288	62.4	0
5/3/91	11:15	7.7	280	11.1	276	60.8	0
5/3/91	11:30	9.0	300	11.4	335	60.4	0

Table 7: Operational Summary for Site SH2

Target Vegetation: Red Alder

Active Ingredient Herbicide: 2, 4-D (LV Ester 4)

Surfactant added: none
Other additives: NALCO-TROL
Carrier used: water

Application Rate:
liters/ha: 4.7
Active Ingredient Application Rate in kg/ha: 2.1
liters/ha: none
liters/ha: 0.1
liters/ha: 88.8
Application Rate for Final Spray Mix: 93.6 liters/ha
Approximate Area Sprayed: 105 ha

Helicopter Model: Bell 47 Soloy
Boom Length: 10.1 meters total
Flight Altitude: 5 meters
Airspeed: 60 km/hr
Effective Swath Width: 12 meters
Flight Centerline Offset from Edge of Buffers: 6-7 meters
Nozzle Type: hollow-cone
Nozzle Size: D8 with #46 whirlplate
# of Nozzles: 30
Nozzle Orientation Angle: 45°
Operating Pressure: 207 kPa (30 psi)

Site SH3: McCoy Creek Unit

Site SH3 was an early foliar conifer release spray using a combination of 2,4-D ester (Weedone LV4®, applied at the rate of 1.7 kg a.i./ha) and triclopyr ester (Garlon 4®, applied at the rate of 0.5 kg a.i./ha) with water as a carrier (see Table 9). A drift control additive (STA-PUT®) was used for swaths applied adjacent to buffers. The 38 hectare spray unit was adjacent to McCoy Creek, a Type 3 stream (see Figure 10). Slopes on the unit ranged from 10 to 80%, but were predominantly in the 15 to 30% range. There were no streams traversing the spray unit. However, there was a wetland area in the northeast corner of the unit. (Note: it is our interpretation that this area would be classified as a forested wetland under current forest practice wetland rules, hence it would not require buffering.) Although there was no standing water in the wetland and no well-defined channels on the unit, subsurface drainage from this area was apparent along the adjacent banks of McCoy Creek. Spraying occurred on only one side of the creek, which had a Riparian Management Zone (RMZ) between it and the unit. The RMZ was generally about 15 to 20 meters wide, which is about the same as the spray buffer width required by the BMPs. However, in a couple of areas the RMZ widened to as much as 60 meters. We established our sampling site on McCoy Creek just downstream of the reach that was adjacent to the spray unit.

All samples were analyzed for 2,4-D and triclopyr as well as 2,4-DCP. Triclopyr was detected in 3 of 27 post-spray samples at a concentration of 0.02 μg/L, which was the limit of detection for the other samples (see Figure 11 and Appendix E). Triclopyr was detected in grab samples collected at 30 minutes and 1 hour after the swaths adjacent to the buffer were sprayed, and once again in a grab sample collected 24 hours after the spray. Neither 2,4-D nor its degradation product 2,4-DCP were detected in any of the samples. None of the analytes were detected in 6-hour or 24-hour composite samples, pre-spray control samples, or the equipment blank.

Unlike most of the other streams in our study, which were smaller and had a morphology that resulted in considerable longitudinal dispersion of streamflow, water in this reach of McCoy Creek moves downstream relatively rapidly. During the time-of-travel study, most of the dye was recovered at the sampling site within 35 minutes of the leading edge (see Figure 12). On the day of spraying, streamflow was about 283 L/s at the sampling site, and this remained fairly constant throughout the sampling period. Based on streamflow measurements taken at the upstream unit boundary, there was no discernable increase or decrease in discharge within the study reach. We cannot determine cumulative loading to the stream since the 24-hour composite samples did not have detectable levels of either pesticide, but based on detection limits and stream discharge we know that daily loads were less than 978 mg/day for 2,4-D and less than 489 mg/day for triclopyr. These results indicate that losses of pesticides to McCoy Creek did not exceed 0.002 percent of the 2,4-D applied (64.6 kg a.i.) or 0.003 percent of the triclopyr applied (19.0 kg a.i.) on 38 hectare spray unit.

The very low concentrations detected in McCoy Creek soon after spraying probably represent the effects of swath displacement and drift onto the stream surface, which was quickly

transported downstream to the sampling site. We believe pesticide concentrations were minimal in this case primarily because of three factors: favorable weather conditions, interception of drift by the forest canopy and ground deposition within the relatively wide RMZ, and dilution by streamflow. Winds were calm to slight, with average wind speeds of less than 3 km/hr (see Figure 10 and Table 8). As illustrated in Figure 10, the spray unit was located generally downwind of the stream. Relative humidity was high, averaging 80-100 percent during the spraying. We observed relatively rapid settling of spray clouds, with minimal swath displacement. Because of the mature mixed forest within the wider than average RMZ, drifting spray droplets that did move in the direction of the stream would potentially be intercepted by the foliage. Also, the relatively large volume of water in the stream would have quickly diluted any herbicide concentrations. The identification of triclopyr in the 24-hour sample is somewhat puzzling, but it may have been due to subsurface seepage from the wetland area, which was oversprayed (as mentioned earlier, we observed subsurface flow from this area into McCoy Creek).

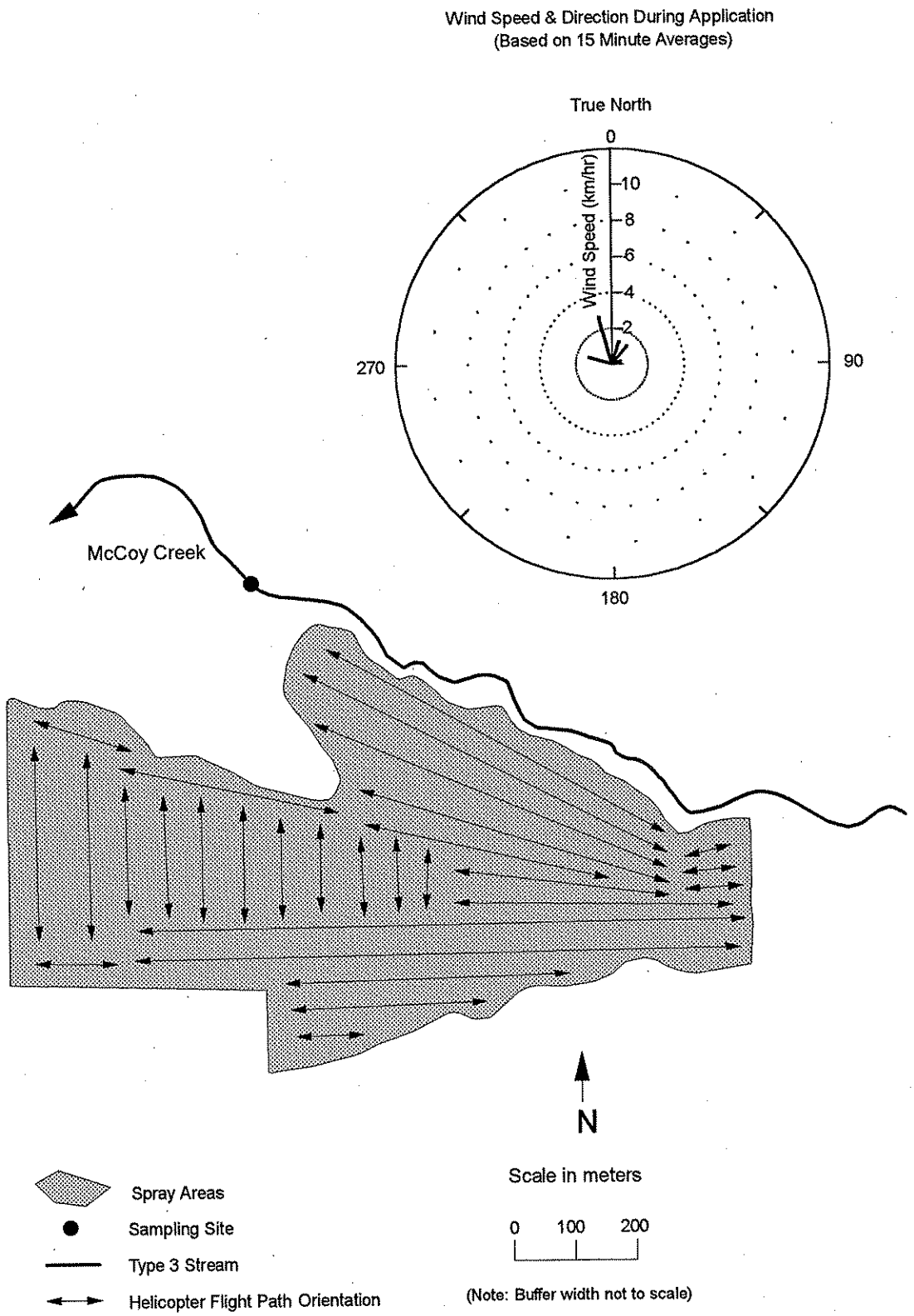
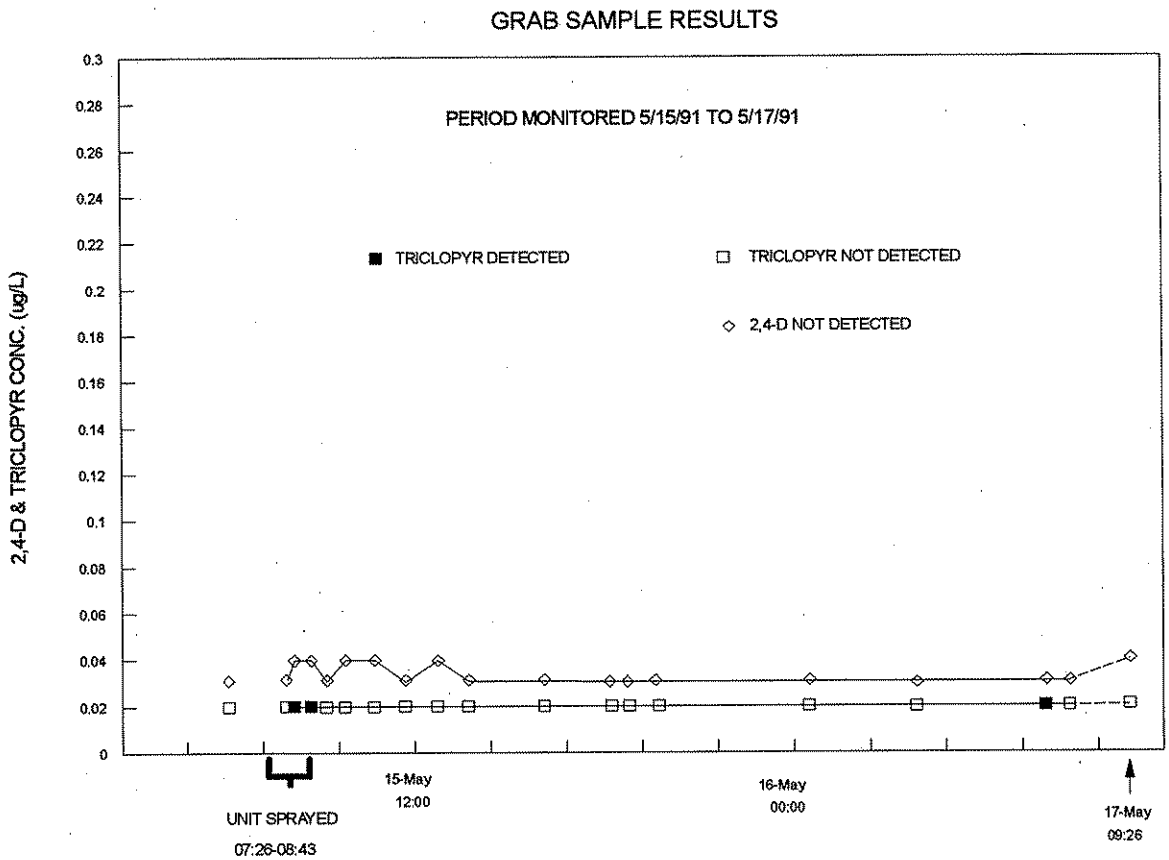


Figure 10: Map of Study Site SH3 - McCoy Creek Unit



2,4-D AND TRICLOPYR WERE NOT DETECTED
IN THE 0-6 HOUR, 0-24 HOUR, OR 25-48 HOUR
COMPOSITE SAMPLES.

Figure 11: 2,4-D and Triclopyr Levels at Site SH3 - McCoy Creek Unit

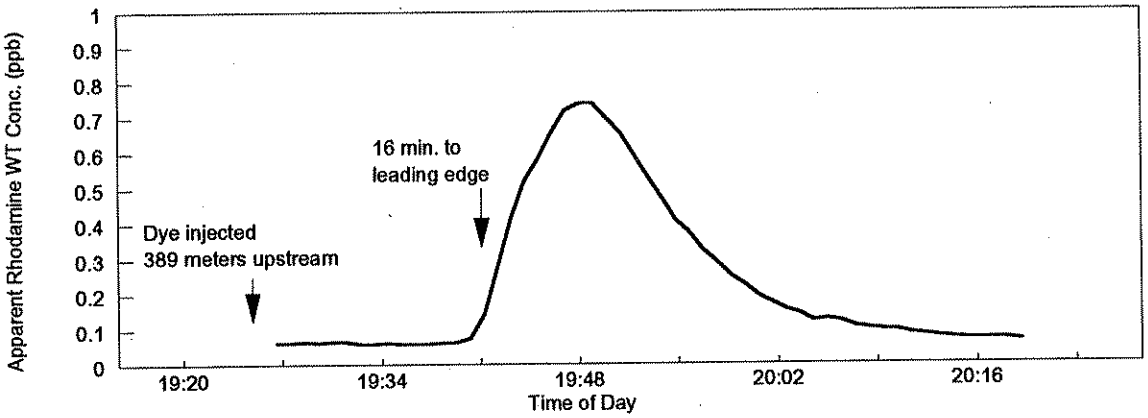


Figure 12: Time-of-Travel Study Results for Site SH3-McCoy Creek

Table 8: Weather Data for Time of Application at Site SH3-McCoy Creek Unit.
(All data recorded as 15-minute averages.)

DATE	TIME	WIND SPEED (km/hr)	WIND DIRECTION (azimuth)	AIR TEMP. (C)	SOLAR RADIATION (watts/sqm)	RELATIVE HUMIDITY (%)	RAINFALL (mm)
5/15/91	07:30	0	- -	6.7	176	100.0	0
5/15/91	07:45	0.5	72	7.6	176	100.0	0
5/15/91	08:00	1.3	40	8.1	218	100.0	0
5/15/91	08:15	2.7	345	8.4	247	96.5	0
5/15/91	08:30	1.3	18	8.7	288	90.6	0
5/15/91	08:45	1.3	287	10.1	318	80.4	0

Table 9: Operational Summary for Site SH3

Target Vegetation: Red Alder

Application Rate:

Active Ingredient Herbicides: 2,4-D (LV Ester 4) liters/ha: 3.7
Active Ingredient Application Rate in kg/ha: 1.7
Triclopyr (Garlon 4E) liters/ha: 0.9
Active Ingredient Application Rate in kg/ha: 0.5

Surfactant added: none liters/ha: none
Other additives: STA-PUT liters/ha: 0.7
Carrier used: water liters/ha: 88.8
Application Rate for Final Spray Mix: 94.1 liters/ha
Approximate Area Sprayed: 38 ha

Helicopter Model: Bell 47-B-1 Boom Length: 10.7 meters total
Flight Altitude: 3 meter Airspeed: 64 km/hr Effective Swath Width: 12 meters
Flight Centerline Offset from Edge of Buffers: 9 meters
Nozzle Type: hollow-cone Nozzle Size: D10 with #46 whirlplate # of Nozzles: 20
Nozzle Orientation Angle: 45° Operating Pressure: 152 kPa (22 psi)

Site IN1: Foster Creek Unit

Site IN1 was a pest-control spray on a Christmas tree plantation using the insecticide metasystox-R (Metasystox-R®, applied at the rate of 0.6 kg a.i./ha) and the fungicide chlorothalonil (Daconil®, applied at 2.3 kg a.i./ha) with water as a carrier (see Table 11). Foster Creek is a Type 3 stream which traverses diagonally across the 15 hectare spray unit. There were no other natural streams on the unit, but there were several drainage swales, a few of which had very minor amounts of standing water. (In our opinion, the applicable BMPs did not require spray buffers on the drainage swales because they were not flowing, and the amount of standing water was so minor that it would not reasonably be considered "open water, such as ponds or sloughs.") The topography of the unit was flat, with slope gradients less than 1%. Spraying occurred on both sides of the creek, which did not have a Riparian Management Zone. The stream was quite exposed; there was no slash or woody debris and essentially no streamside vegetation other than grasses to intercept spray drift. We established our sampling site on Foster Creek just downstream of and across a county road from the unit. About two hectares at another Christmas tree plantation, located near Foster Creek about 900 meters upstream (see Figure 13), was sprayed with the same pesticides shortly after the application on the study unit was completed.

All samples were analyzed for metasystox-R and chlorothalonil, and the results are depicted in Figure 14 and tabulated in Appendix E. Metasystox-R was detected in 10 of 26 post-spray samples at concentrations ranging from 2.4 to 4.1 μg/L. Chlorothalonil was detected in all post-spray samples, at concentrations of 0.01 to 1.72 μg/L. Neither pesticide was detected in the pre-spray control sample (collected the day before the application) or the equipment blank. Levels of both pesticides peaked within 30 minutes of spraying the streamside buffers, accounting for the estimated travel time for stream water from the middle portion of the spray unit to reach the sampling site. Within three hours from the start of spraying, stream concentrations had tapered off to below detectable levels (about 2.5 μg/L) for metasystox-R, and less than 0.5 μg/L for chlorothalonil.

This was a very slow-moving stream, with an average velocity of around 0.03 meters/second and a travel time of over 2 hours from mid-unit to the sampling site. The time-of-travel study indicated substantial dispersion over the length of the stream (see Figure 15), and this was reflected in the pattern of chlorothalonil levels, which persisted throughout the 48-hour sampling period. Stream levels of metasystox-R that resulted from the application are difficult to evaluate, due in part to the relatively insensitive levels of detection (as compared to chlorothalonil analyses), which ranged from 2.4 to 4.1 μg/L. (The higher quantification levels of 4.1 μg/L were associated with two samples that had less volume due to splitting for duplicate matrix spikes.) Detection of metasystox-R in the two 25-48 hour composite samples at an average concentration of 3.25 μg/L indicates that this pesticide was also present in the stream throughout the sampling period, although it was below detectable levels in samples collected from three to twenty-four hours after the spray. Detectable levels of metasystox-R were found in the hand-composite sample made up of equal parts of the 15-minute, 4-hour, 8-hour, and 24-hour grab samples.

The lower level of analytical resolution makes it difficult to ascertain the actual pattern of metasystox-R occurrence in the stream. It is somewhat puzzling that peak and average concentrations of metasystox-R appear to exceed levels of chlorothalonil, particularly since chlorothalonil was applied at a higher rate. Possible explanations for higher stream levels of metasystox-R relative to the amount applied include: the higher water solubility (330 mg/L versus 0.6 mg/L) and/or mobility of metasystox-R; differences in spray droplet deposition patterns or fate; greater attenuation of chlorothalonil to particulate matter or sample containers, or other matrix effects; or, unknown interferences or quantification problems with the analytical techniques. The laboratory noted that analysis of metasystox-R required a secondary oxidation reaction, after the initial extract broke down during chromatography.

On the day of spraying, streamflow was 11 L/s at the sampling site and 7 L/s at the upper unit boundary (approximately 520 meters upstream). This indicates that roughly one-third of the streamflow came from groundwater seepage within the unit. A shallow water table was indicated by minor amounts of standing water observed in drainage swales on the unit. Based on 24-hour composite sample results, cumulative loading of chlorothalonil in Foster Creek was about 171 mg/day on the day of spraying. This corresponds to about 0.0005 percent of the 34.5 kg a.i. applied on the 15 hectare unit. The cumulative load of metasystox-R for the day of application cannot be ascertained since it was not detected in the 0-24 hour composite sample, but based on detection levels it was less than 2471 mg/day, or less than 0.03 percent of the amount applied (9 kg a.i.).

We believe that the pesticides entered Foster Creek primarily by off-target swath displacement and drift at the time of spraying. As with most of the other sites, we observed some swath displacement during the spray. Wind conditions were very light at the time of spraying, with no perceptible winds at times and maximum wind speeds of 3-4 km/hr (see Figure 13 and Table 10). As mentioned previously, the peak pesticide concentrations correspond to the time of initial swath deposition in near-stream areas, but off-target deposition of the spray does not explain the presence of pesticides in the stream up to 48 hours later. The persistence of detectable levels of chlorothalonil in Foster Creek may reflect some subsurface transport via the shallow groundwater system. Another possible source of persistent levels of pesticides is the two hectare spray area located about 900 meters upstream of the study unit, near a tributary of Foster Creek (see Figure 13). This Christmas tree plantation was sprayed with the same chemicals immediately following the application on the study unit. Using an average stream velocity of 0.03 meters/second, water in the vicinity of this other unit would have taken roughly 14 hours to begin reaching our sampling site. If any of the spray from this unit entered the stream system, downstream transport could have contributed to the levels we found in our later samples.

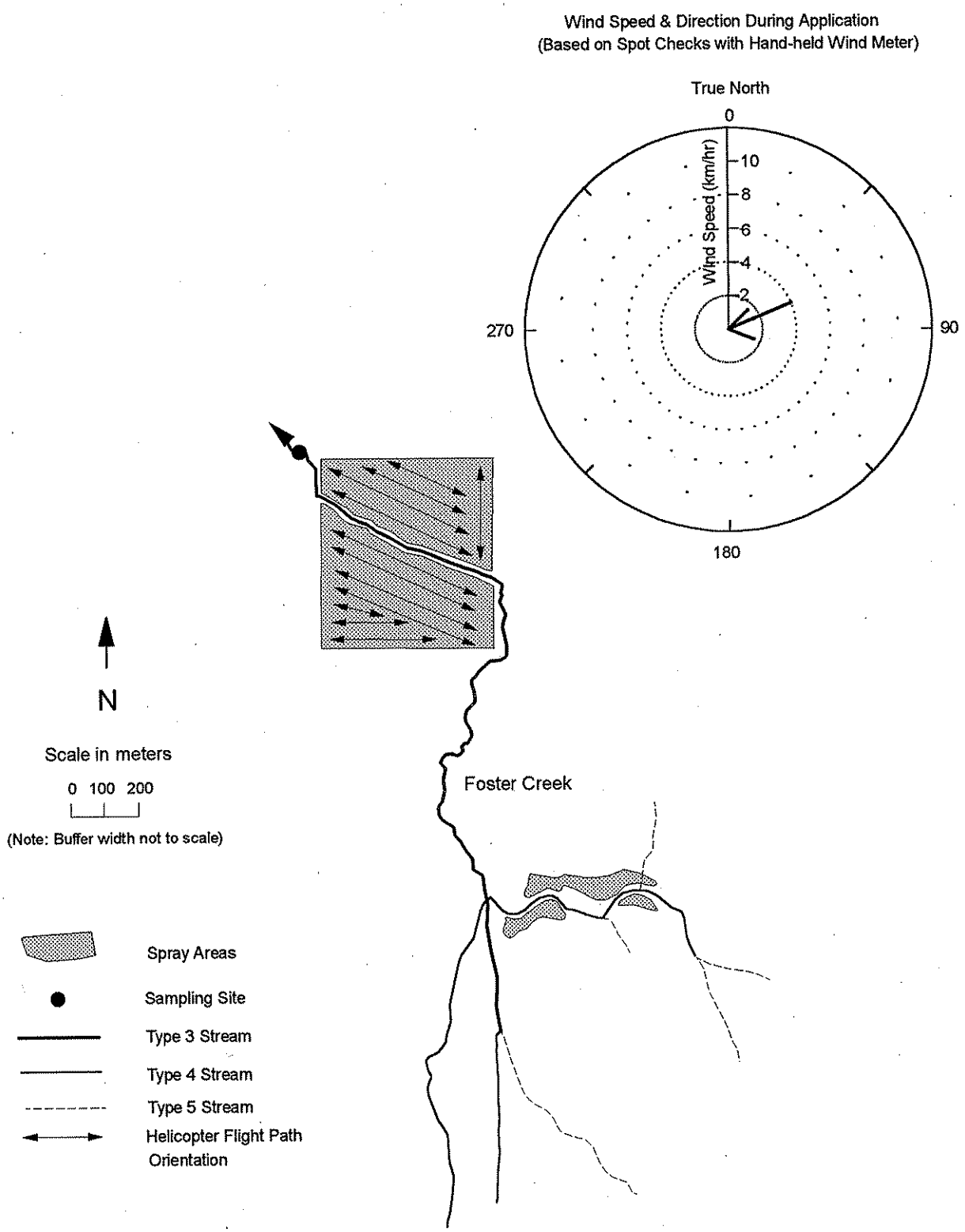
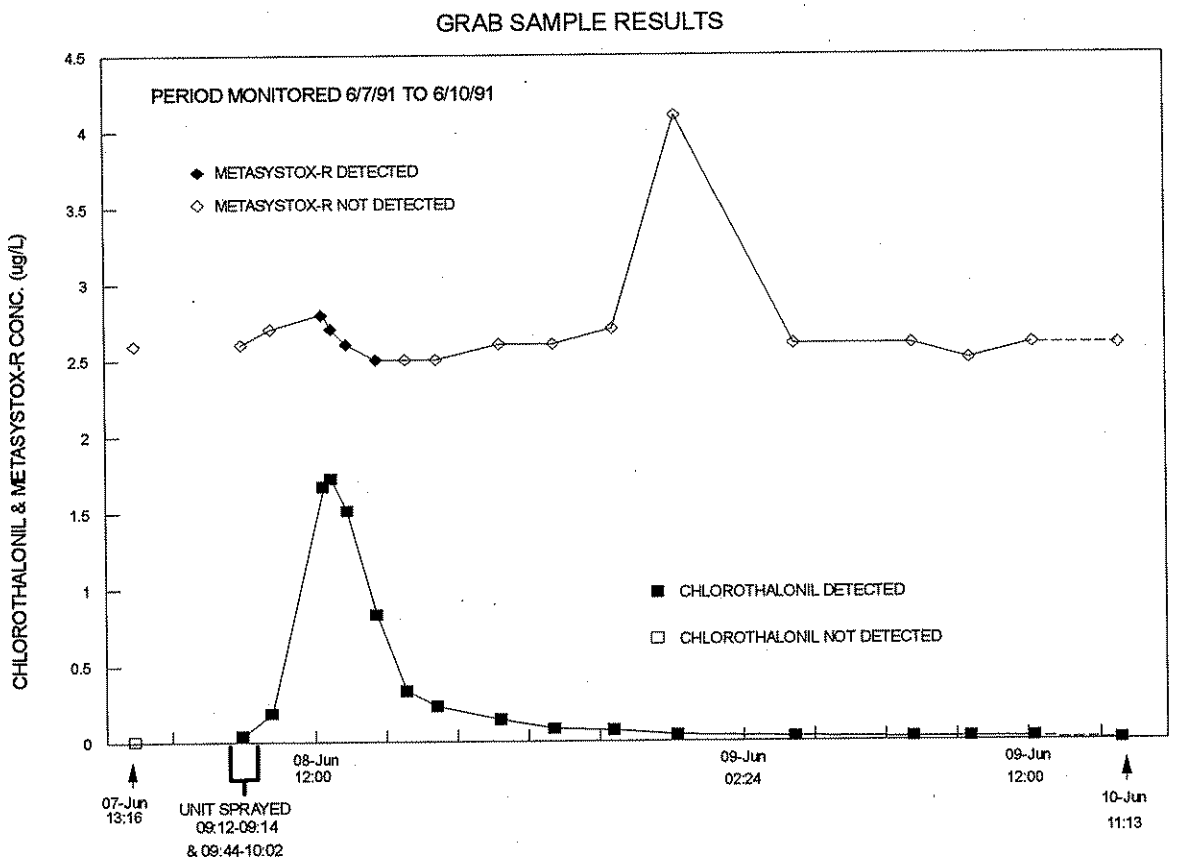


Figure 13: Map of Study Site IN1- Foster Creek Unit



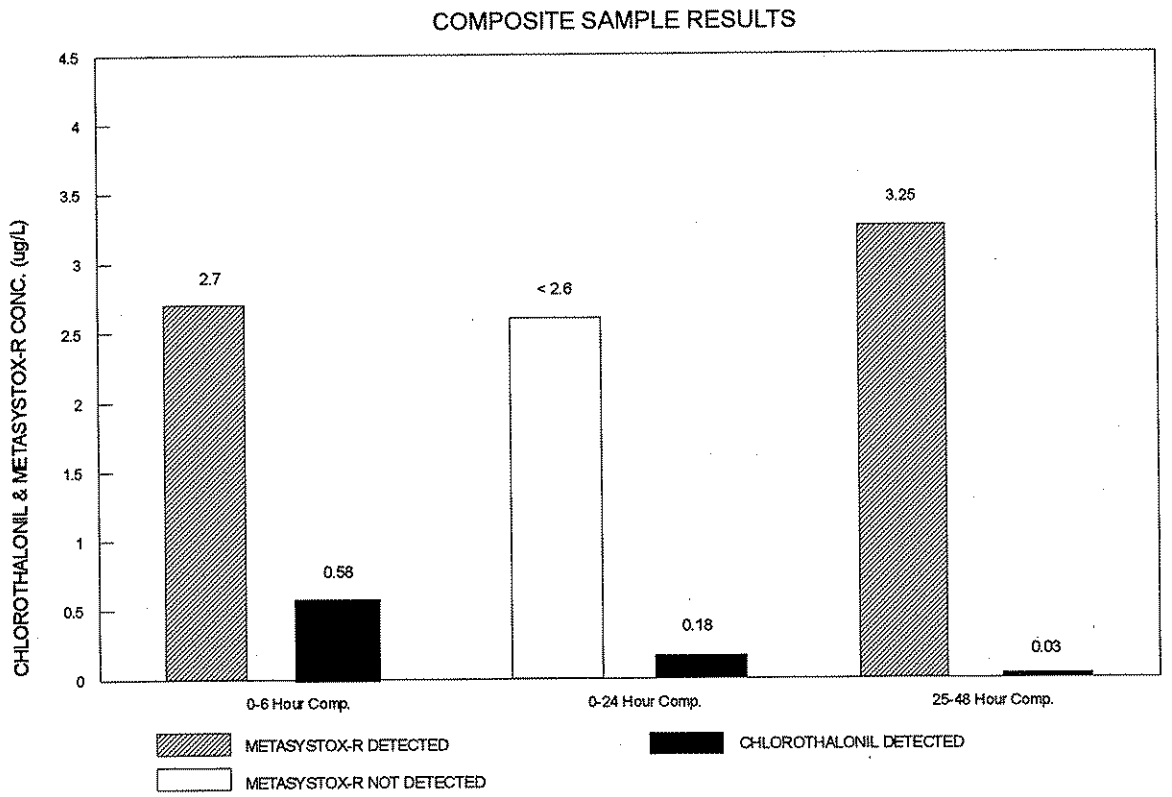


Figure 14: Chlorothalonil and Metasystox-R Levels at Site IN1 - Foster Creek Unit

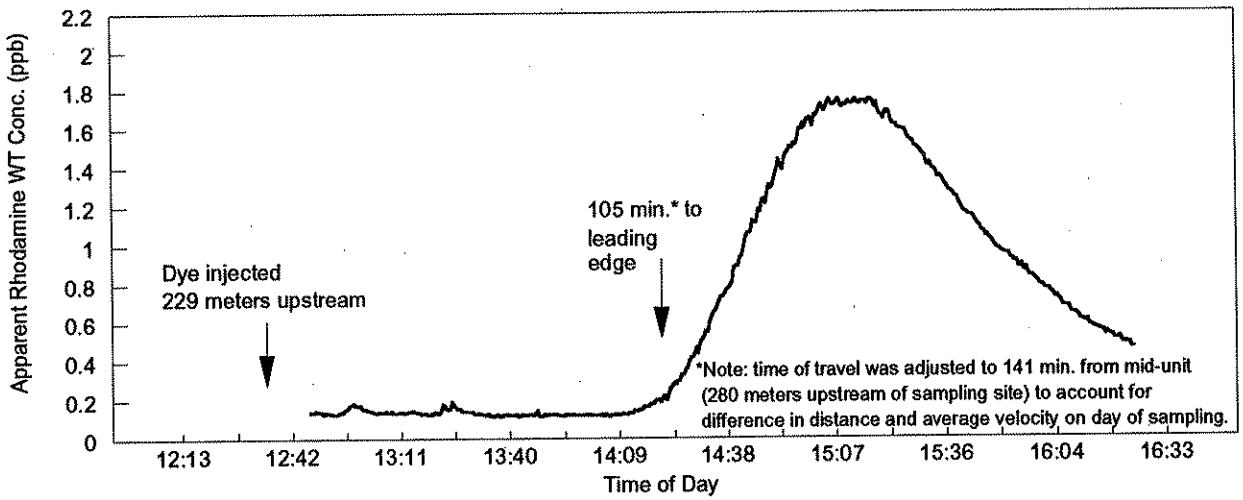


Figure 15: Time-of-Travel Study Results for Site IN1-Foster Creek

Table 10: Weather Data for Time of Application at Site IN1-Foster Creek Unit. (Data collected using hand-held wind meter; no data available for relative humidity or temperature.)

DATE	TIME	WIND SPEED (km/hr)	WIND DIRECTION (azimuth)	RAINFALL (mm)
6/8/91	09:45	<3	112	0
6/8/91	09:55	<3	112	0
6/8/91	09:57	<3	45	0
6/8/91	09:58	4	67	0
6/8/91	10:00	<3	67	0

Table 11: Operational Summary for Site IN1

Target Pests: Swiss needlecast fungus and aphids

Application Rate:

Active Ingredient Insecticide: Metasystox-R — liters/ha: 2.3

Active Ingredient Application Rate in kg/ha: 0.6

Active Ingredient Fungicide: Chlorothalonil (Daconil) — liters/ha: 4.7

Active Ingredient Application Rate in kg/ha: 2.3

Surfactant added: none — liters/ha: none

Other additives: none — liters/ha: none

Carrier used: water — liters/ha: 86.5

Application Rate for Final Spray Mix: 93.5 liters/ha

Approximate Area Sprayed: 15 ha

Helicopter Model: Bell 47 Soloy — Boom Length: 10.4 meters total

Flight Altitude: 5 meters — Airspeed: 60 km/hr — Effective Swath Width: 14 meters

Flight Centerline Offset from Edge of Buffers: 7-8 meters

Nozzle Type: hollow-cone — Nozzle Size: D8 with #46 whirlplate — # of Nozzles: 30

Nozzle Orientation Angle: 45° — Operating Pressure: 207 kPa (30 psi)

Site FH1: Mitchell Creek Unit

Site FH1 was a late foliar conifer release spray using glyphosate (Accord®, applied at the rate of 1.3 kg a.i./ha) and imazapyr (Arsenal®, applied at 0.1 kg a.i./ha) with R-11® surfactant and water as a carrier (see Table 13). The spray unit was adjacent to Mitchell Creek, with Type 4 and 5 tributaries traversing the unit (see Figure 16). Our sampling site was on Mitchell Creek about 130 meters downstream of the unit. Spraying was conducted on only one side of Mitchell Creek, which had a Riparian Management Zone. As shown in Figure 16, this was a spot spray, with about 30 percent or 12 hectares of the unit treated. The forester on the unit indicated that buffers of at least 15 meters were left along all typed waters. The unit was relatively steep, with predominant slope gradients of 35-45%, but ranging from 25 to 75%. Parallel flight paths were used along streamside buffers.

All samples were analyzed for glyphosate and AMPA, and four of the post-spray samples were analyzed for imazapyr. Glyphosate was detected in 14 of 27 post-spray samples, at concentrations ranging from 0.25 to 2.39 μg/L (see Figure 17 and Appendix E). Glyphosate levels peaked sharply within 30 minutes of the spray, then tapered off to undetectable levels within 3 hours. It was not detected in either of the two pre-spray control samples, the equipment blank, or the transfer blank. AMPA and imazapyr were not detected in any samples.

During our field reconnaissance a week prior to the spray, we determined that there was a minor amount of surface flow in the tributary on the east side of the unit, but did not see any surface flow in the other tributaries flowing through the unit. We also noted a flowing seep along the upper streambanks on the unit side. We estimate that about 15 percent of the streamflow at the downstream end of the unit may have come from surface and subsurface discharges from the unit, based on comparison of upstream and downstream flow measurements. Another 7 percent of the flow comes from a southeast flowing tributary that drains a valley across Mitchell Creek from the spray unit. On the day of spraying, streamflow was about 50 L/s at the sampling site. Cumulative loading of glyphosate in Mitchell Creek on the day of spraying was about 1380 mg/day, which corresponds to about 0.009 percent of the glyphosate applied at this unit (15.6 kg a.i.) exported via Mitchell Creek on the day of spraying. Cumulative loading of imazapyr cannot be determined because it was not detected in the 0-24 hour composite sample. However, based on detection limits, we know that the cumulative load of imazapyr did not exceed 2160 mg/day, or 0.2 percent of the 1.2 kg a.i. applied, on the day of application.

As with the other sites, we believe the majority of pesticide introduction was due to off-target swath displacement and drift because the timing of the peak concentration corresponds to the initial settling of near-stream spray swaths. As shown in Figure 18, the time-of-travel study results indicate a fairly rapid travel time to the sampling site of 32 minutes for the initial peak, followed by a prolonged declining tail. Winds were light during the brief spray operation, which lasted only about 6 minutes. The average wind speed during this period was 1.3 km/hr (see Table 13). Relative humidity was 95 percent during the spray, which is almost ideal.

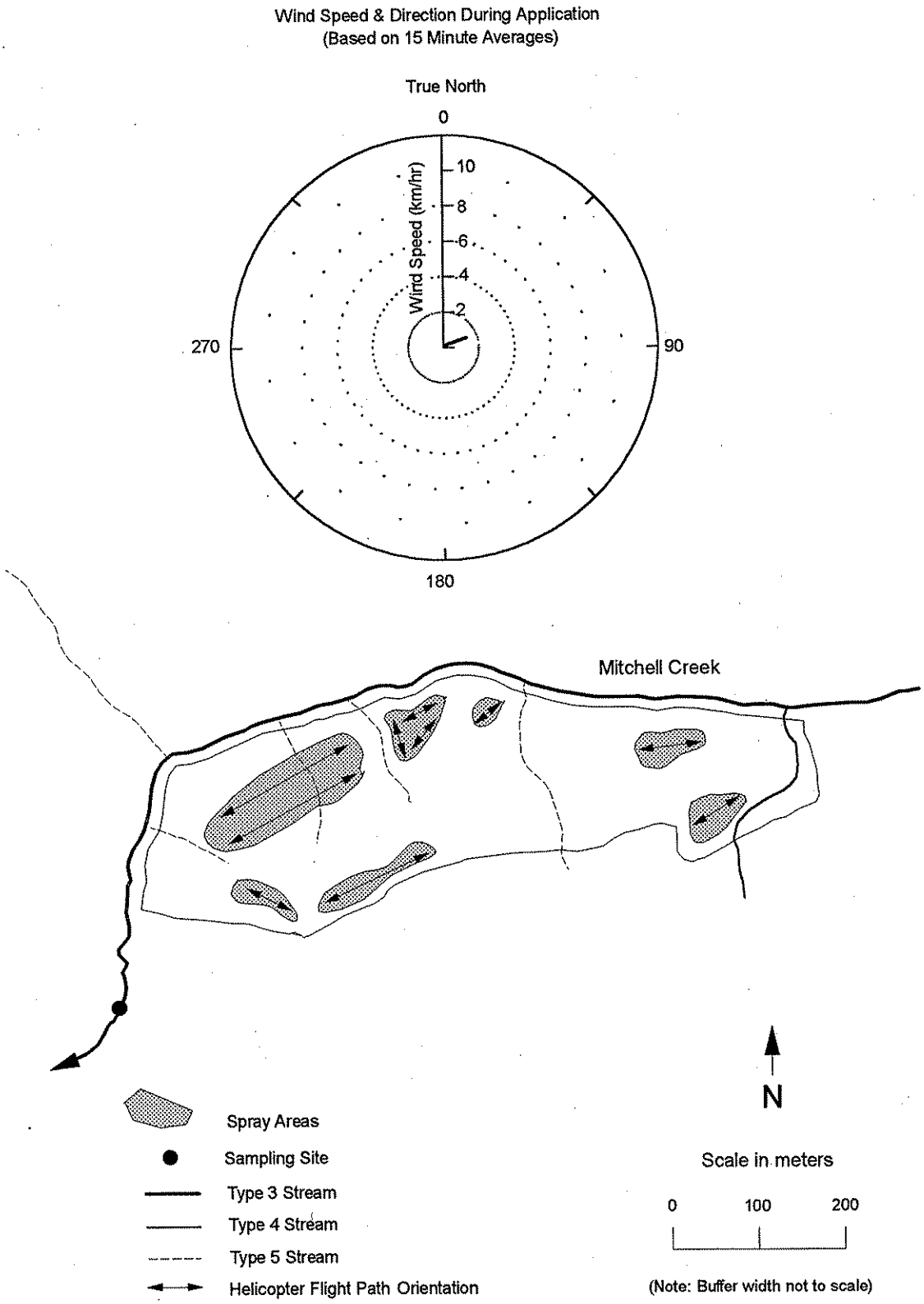
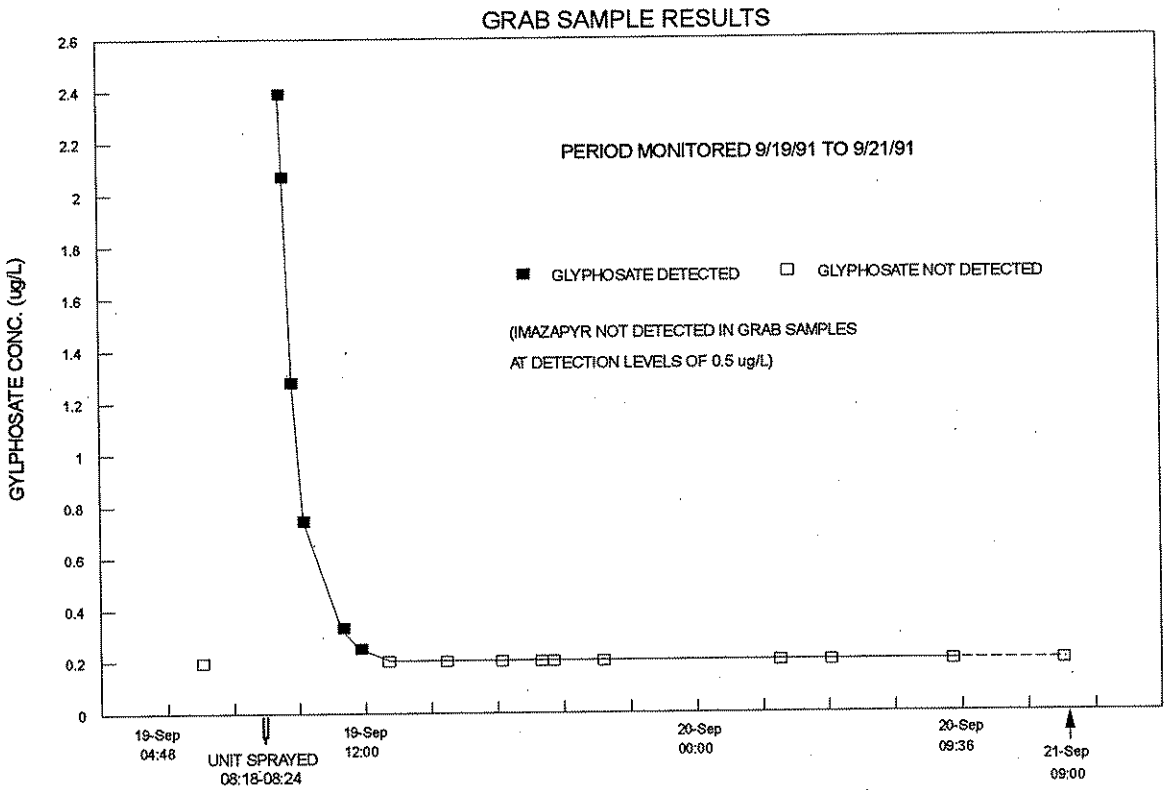


Figure 16: Map of Study Site FH1 - Mitchell Creek Unit



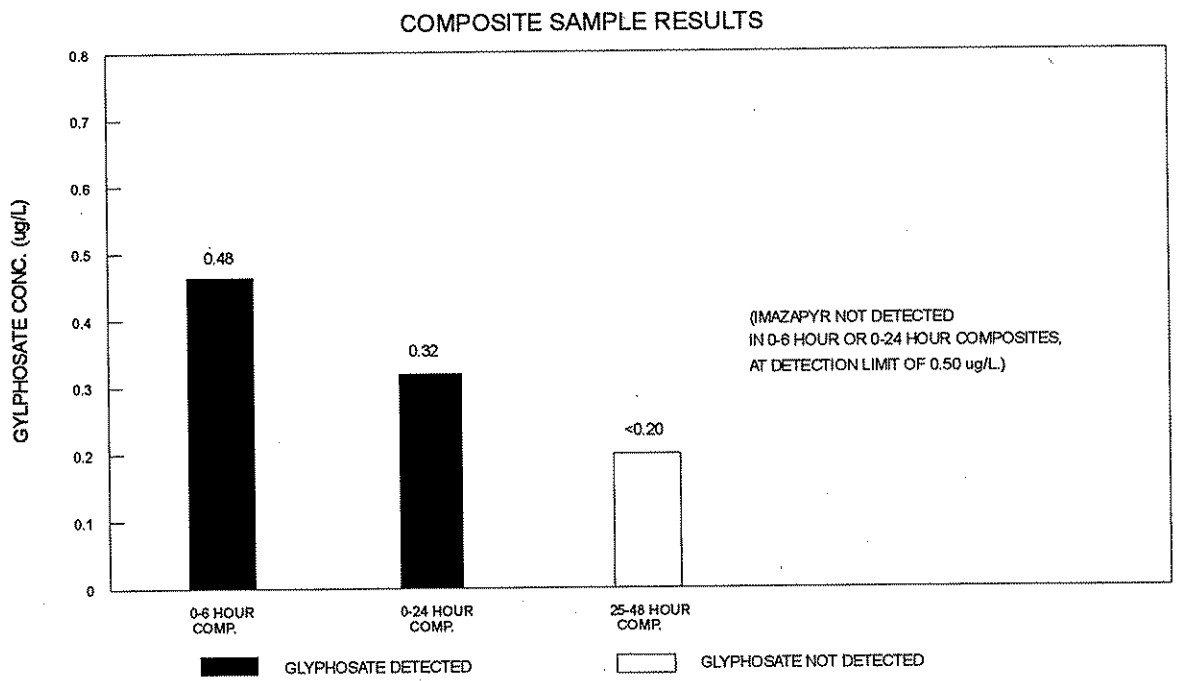


Figure 17: Glyphosate Levels at Site FH1 - Mitchell Creek Unit

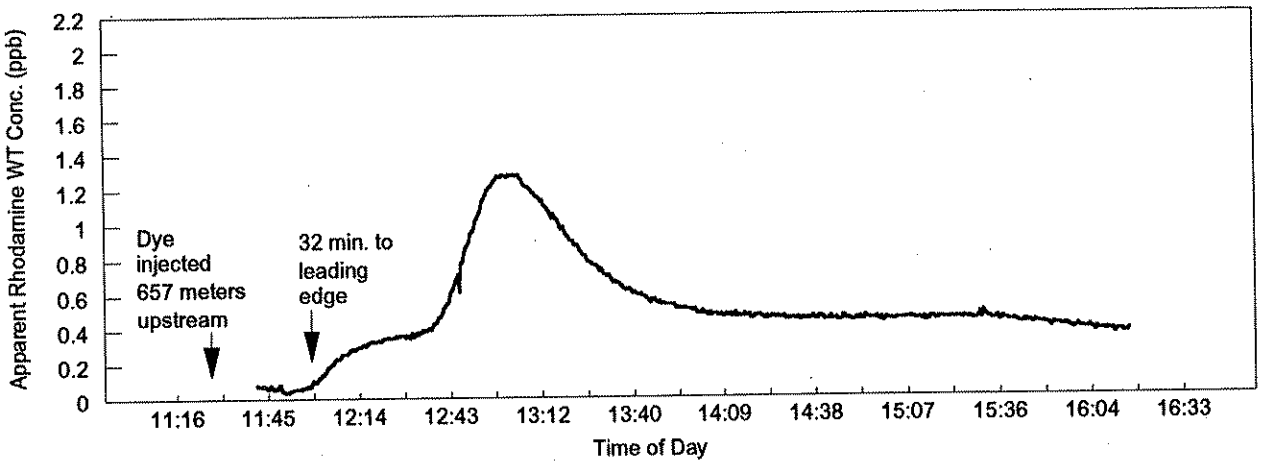


Figure 18: Time-of-Travel Study Results for Site FH1-Mitchell Creek

Table 12: Weather Data for Time of Application at Site FH1-Mitchell Creek Unit. (All data recorded as 15-minute averages.)

DATE	TIME	WIND SPEED (km/hr)	WIND DIRECTION (azimuth)	AIR TEMP. (C)	SOLAR RADIATION (watts/sqm)	RELATIVE HUMIDITY (%)	RAINFALL (mm)
9/19/91	08:30	1.3	71	10.6	35	94.5	0

Table 13: Operational Summary for Site FH1

Target Vegetation: Vine Maple, Salmonberry, Big Leaf Maple

Application Rate:

Active Ingredient Herbicides: Glyphosate (Accord) — liters/ha: 3.6; Active Ingredient Application Rate in kg/ha: 1.3

Imazapyr (Arsenal) — liters/ha: 0.2; Active Ingredient Application Rate in kg/ha: 0.1

Surfactant added: R-11 — liters/ha: 0.3

Other additives: none — liters/ha: none

Carrier used: water — liters/ha: 89.4

Application Rate for Final Spray Mix: 93.5 liters/ha

Approximate Area Sprayed: 12 ha

Helicopter Model: Bell 212 — Boom Length: 14.6 meters total

Flight Altitude: 9 meters — Airspeed: 64 km/hr — Effective Swath Width: 24 meters

Flight Centerline Offset from Edge of Buffers: 12-15 meters

Nozzle Type: hollow-cone — Nozzle Size: D12 with #46 whirlplate — # of Nozzles: 62

Nozzle Orientation Angle: 90° — Operating Pressure: 138 kPa (20 psi)

Site FH2: Bush Creek Unit

Site FH2 was a site preparation spray using glyphosate (Accord®, applied at the rate of 1.7 kg a.i./ha) and imazapyr (Arsenal®, applied at 0.2 kg a.i./ha) with R-11® surfactant and water as a carrier (see Table 15). A drift control additive (STA-PUT®) was used in the application. This was a 57 hectare spray unit that contained the headwaters of a Type 4 stream, with several tributaries originating on the unit (see Figure 19). Slopes on the unit ranged from 10 to 40%, with the predominant slope gradient being about 15%. Our sampling site was on the main branch of the Type 4 tributary to Bush Creek, about 70 meters downstream of the unit boundary. There were broadcast spray areas on both sides of stream we sampled and on areas drained by its tributaries within the unit. None of the streams in the unit had Riparian Management Zones or other riparian leave areas. As illustrated in Figure 19, parallel flight paths were used along streamside buffers on the mainstem. This resulted in flight paths that were generally perpendicular to its tributaries, which were not buffered except for their lower portion where they joined the mainstem.

The first significant precipitation event occurred 18 days after the spray. Two weather stations located within 15 kilometers of the unit reported an average of 10 mm of rain over a two-day period. This may have produced a first flush of runoff on the spray unit, but we were unable to sample this event. A second storm beginning 24 days after the spray produced 25 mm of rain over a two-day period. We sampled this runoff event with two grab samples (plus one replicate grab) collected about 5 hours apart.

All samples were analyzed for glyphosate and AMPA, and 12 of the samples were analyzed for imazapyr. Glyphosate was detected in 22 of 27 post-spray samples at concentrations ranging from 0.26 to 7.55 μg/L (see Figure 20 and Appendix E). Glyphosate was not detected in the three runoff samples. AMPA was detected only in the hand-composite sample, at an estimated concentration of 0.5 μg/L. Imazapyr was detected in 9 of 11 post-spray samples, including all three runoff samples, at levels ranging from 0.36 to 1.25 μg/L (see Figure 20 and Appendix E). No herbicides were detected in either of the two pre-spray control samples or the equipment blank.

For this site, the sample collection schedule was modified to include two "early" grab samples to cover the period before the regular sampling schedule began. This was done because of the large area sprayed and the long travel time for this stream. Because the stream traversed such a long distance through the unit (about 1400 meters), we based the sampling schedule on time-of-travel from one-third of the stream distance above the sampling site instead of the unit mid-point. Even with this modification, the time-of-travel delay was still 1.75 hours from the start of spraying to the beginning of the sampling schedule. The first "early" sample, collected 36 minutes after the streamside buffer was sprayed, had no detectable levels of either herbicide. The peak glyphosate concentration of 7.55 μg/L was found in the second "early" sample, collected 68 minutes after spraying along streamside buffers. Glyphosate levels remained above 1.0 μg/L for 4 hours after stream water from the lower third of the unit had first arrived at the sampling site, then tapered off to less than

0.5 μg/L 18 hours after the application. Based on time-of-travel study results (see Figure 21), we would have expected the herbicides to become dispersed along a considerable length of the stream, and it appears that they did. The "early" samples containing the most glyphosate were not analyzed for imazapyr, so levels of imazapyr that may have occurred soon after the spray began are not known. The highest stream levels we found on the day of spraying (1.15 μg/L) occurred 30 minutes after the application was completed. However, one of the runoff samples analyzed was reported to have 1.25 μg/L of imazapyr (a field replicate collected at the same time had 0.36 μg/L, yielding an average value of 0.81 μg/L).

With the exception of some road drainage, the entire drainage area of the stream we sampled was within the boundaries of the spray unit. At the time of spraying, the uppermost reaches of all streams were dry on the surface, but within a short distance (150 to 200 meters) of the drainage divide surface flow was beginning, at times intermingled with subsurface flow. All tributaries to the stream had minor amounts of surface flow at their confluence with the mainstem during our reconnaissance survey four days before the application. On the day of spraying, streamflow was about 4 L/s at the sampling site. Based on 24-hour composite sample concentrations, the cumulative load was about 194 mg/day for glyphosate and about 124 mg/day for imazapyr on the day of spraying. This corresponds to about 0.0002 percent of the 96.9 kg a.i. of glyphosate applied, and about 0.001 percent of the 11.4 kg a.i. of imazapyr applied, exported via the stream we sampled during the first 24 hours following the spray. On the day we sampled runoff, streamflow was 18 L/s when the first runoff sample was collected. This had dropped to 12 L/s about 5 hours later when we collected the second grab sample, indicating that we were sampling the falling limb of the hydrograph. Because of the timing of our runoff sampling, it is unlikely that we characterized the peak levels of runoff-related herbicides at this site.

The timing of peak concentrations lead us to believe that the majority of pesticide entry to streams at this site was due to off-target swath displacement and drift into the mainstem of the stream we sampled. Stream entry due to unintentional off-target deposition likely occurred both in the lower portion along the mainstem of the sampling stream, as indicated by the early peak levels, and in the upper reaches as indicated by the persistence of low levels of glyphosate up to 24 hours following the spray. Buffers were left along the mainstem of the sampled stream, as well as the lower 15 meters or so of its tributaries. Most areas of the small tributaries were oversprayed based on the assessment of the forester and applicator that they were dry. As mentioned previously, these tributaries had minor amounts of surface flow along at least a portion of their length. We believe that the effect of such overspray is primarily seen in the later samples, rather than the early peak concentrations. With the possible exception of the lowermost tributary, considerable time would have been required for herbicides to have been transported to the sampling site after entering the stream system due to overspray of reaches that had been assessed as dry, and therefore were not buffered. As in some of the other cases, we believe it was not possible for the forester or applicator to detect the presence of minor amounts of surface flow in small streams obscured by logging slash using typical surveillance techniques .

Of the seven spray operations monitored, this site had the highest average wind speed. Winds were moving up the stream valley out of the west-southwest, with 15-minute average speeds of 8-11 km/hr (see Figure 19 and Table 14). Average relative humidity ranged from about 85 to 77 percent during the spray, which lasted about 1.2 hours.

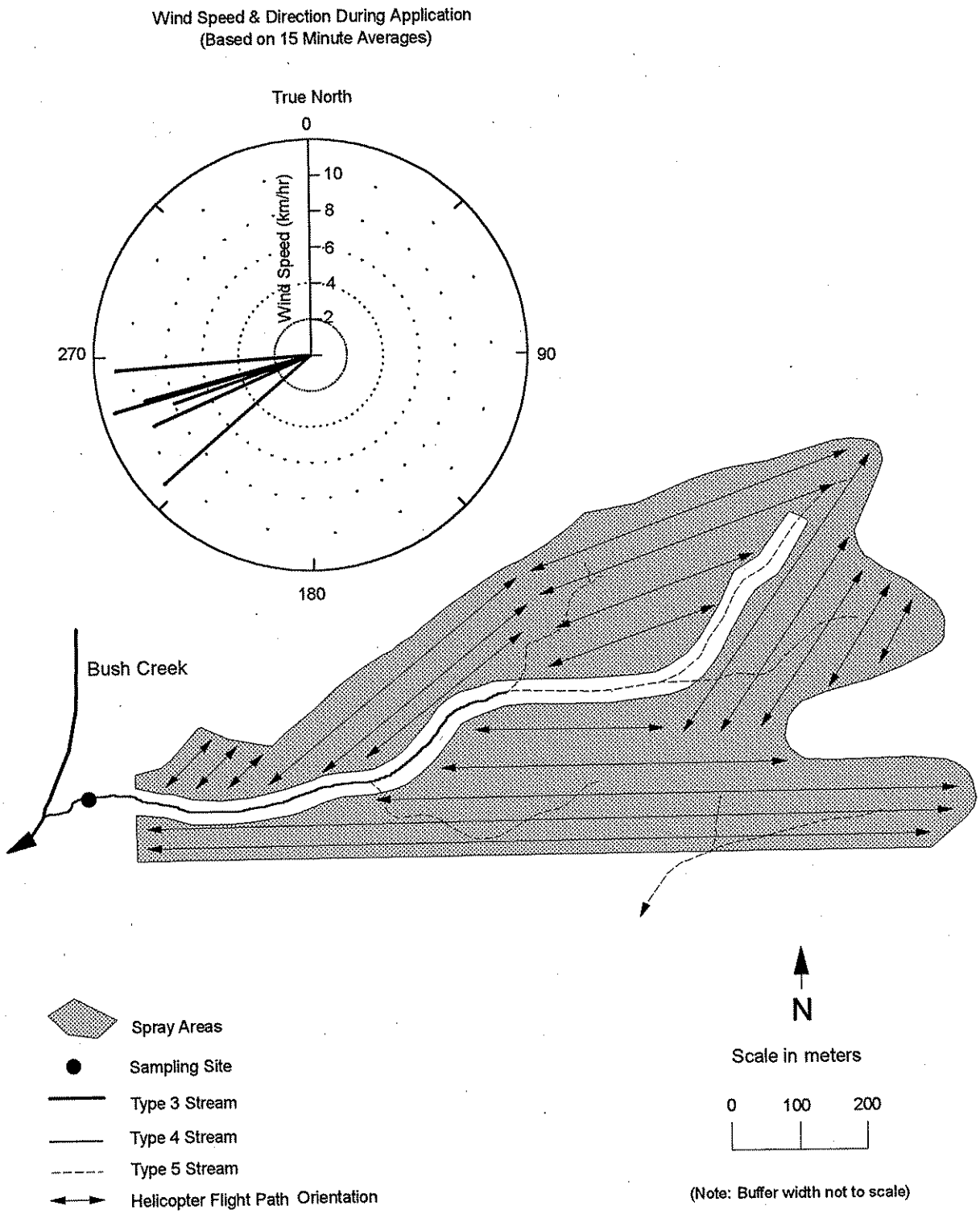
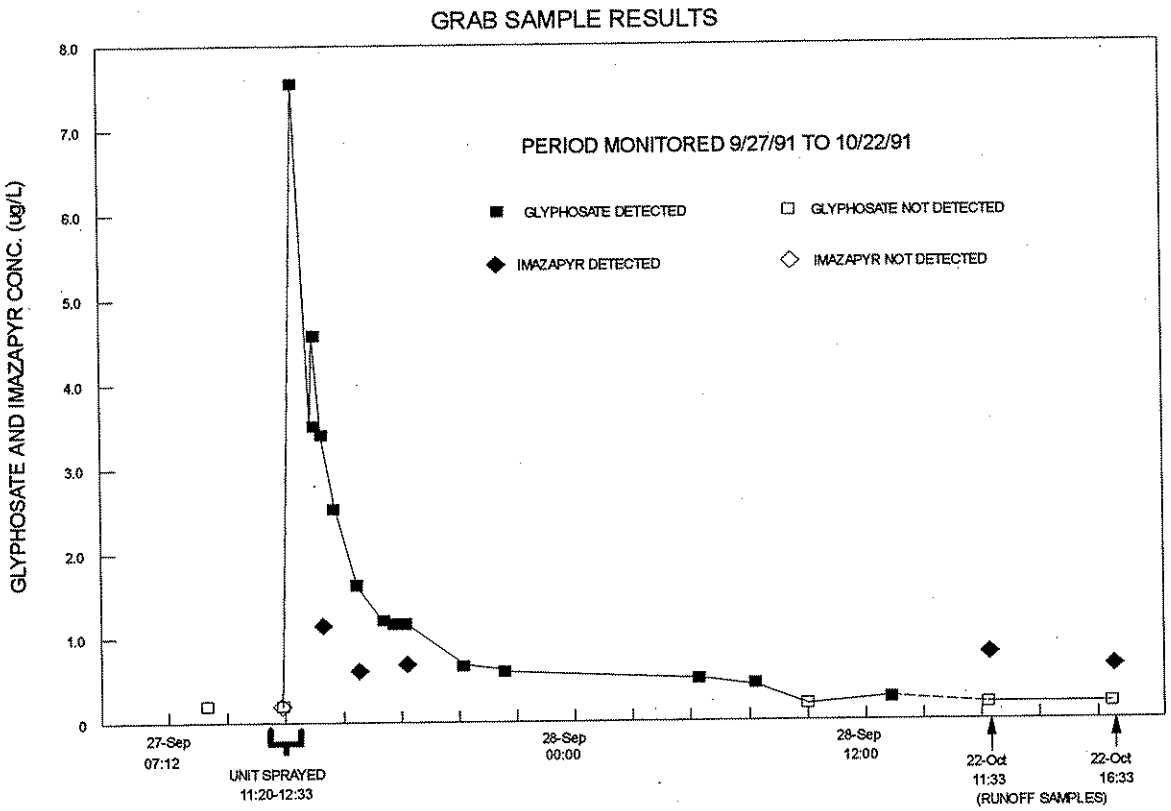


Figure 19: Map of Study Site FH2 - Bush Creek Unit



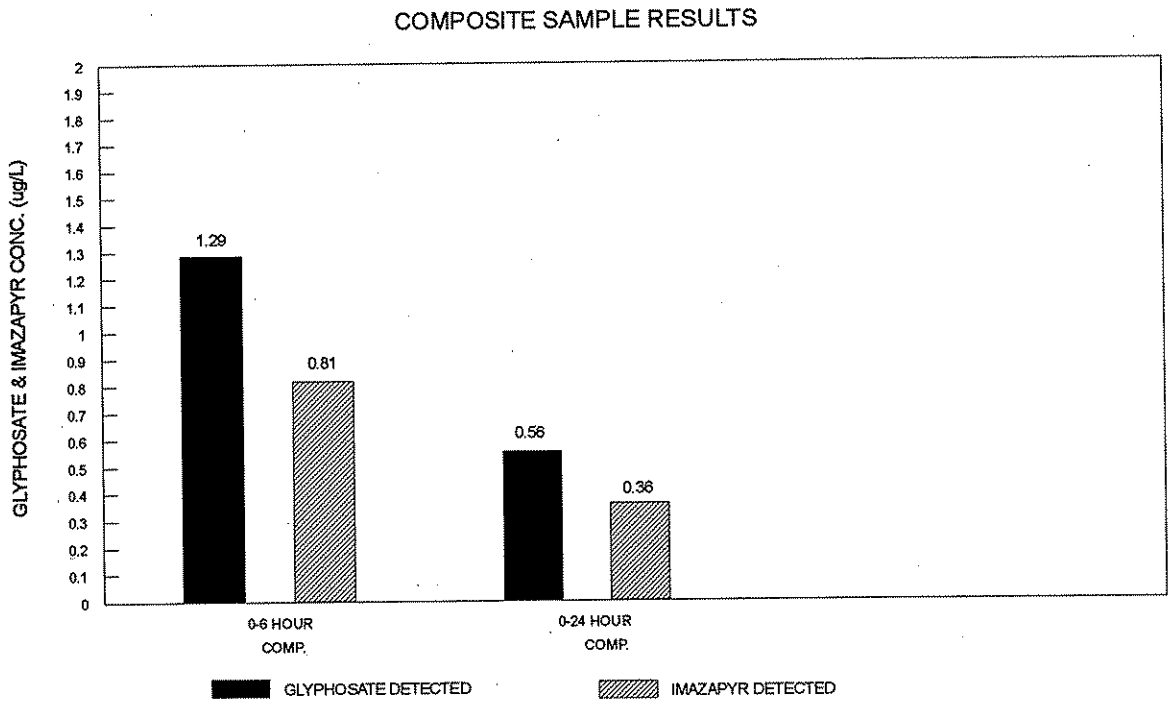


Figure 20: Glyphosate and Imazapyr Levels at Site FH2 - Bush Creek Unit

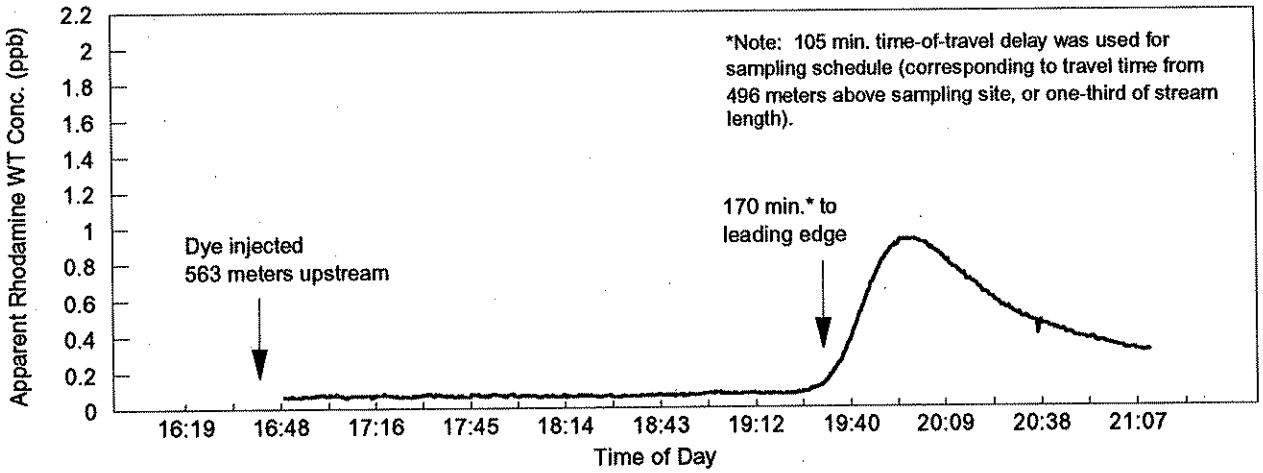


Figure 21: Time-of-Travel Study Results for Site FH2-Tributary to Bush Creek

Table 14: Weather Data for Time of Application at Site FH2-Tributary to Bush Creek Unit. (All data recorded as 15-minute averages.)

DATE	TIME	WIND SPEED (km/hr)	WIND DIRECTION (azimuth)	AIR TEMP. (C)	SOLAR RADIATION (watts/sqm)	RELATIVE HUMIDITY (%)	RAINFALL (mm)
9/27/91	11:30	10.8	266	14.7	94	84.7	0
9/27/91	11:45	9.5	255	14.7	100	84.3	0
9/27/91	12:00	8.0	251	15.0	118	83.1	0
9/27/91	12:15	11.3	254	15.3	135	80.4	0
9/27/91	12:30	10.8	229	15.6	147	78.4	0
9/27/91	12:45	9.5	246	15.8	153	76.9	0

Table 15: Operational Summary for Site FH2

Target Vegetation: Vine Maple, Salmonberry, Red Alder

Application Rate:

Active Ingredient Herbicides: Glyphosate (Accord) — liters/ha: 4.7
Active Ingredient Application Rate in kg/ha: 1.7

Imazapyr (Arsenal) — liters/ha: 0.5
Active Ingredient Application Rate in kg/ha: 0.2

Surfactant added: R-11 — liters/ha: 2.3
Other additives: STA-PUT — liters/ha: 0.5
Carrier used: water — liters/ha: 86.0

Application Rate for Final Spray Mix: 94.0 liters/ha
Approximate Area Sprayed: 57 ha

Helicopter Model: Hillier 12E — Boom Length: 9.5 meters total
Flight Altitude: 8 meters — Airspeed: 81 km/hr — Effective Swath Width: 17 meters
Flight Centerline Offset from Edge of Buffers: 9 meters
Nozzle Type: hollow-cone — Nozzle Size: D10 with #45 whirlplate — # of Nozzles: 32
Nozzle Orientation Angle: 90° — Operating Pressure: 221 kPa (32 psi)

Site FH3: North Fork Rabbit Creek Unit

Site FH3 was a late foliar conifer release spray applying glyphosate (Accord®, at the rate of 1.3 kg a.i./ha) with R-11® surfactant and water as a carrier (see Table 17). A drift control additive (STA-PUT) was used. The 61 hectare spray unit had several streams traversing it, including North Fork Rabbit Creek, a Type 3 stream with a Riparian Management Zone (see Figure 22). This stream was flowing within the unit; however, the flow went subsurface about 100 meters downstream from the unit boundary. We set up our primary sampling station on Rabbit Creek about 40 meters downstream of the unit boundary (Station A in Figure 22). The topography of most of the spray unit was characterized by gentle slopes of less than 10%; slope gradients ranged from 3 to 40%. We did not conduct a fluorometric time-of-travel study at this site. Average stream velocity as determined by current meter was used to estimate time-of-travel from mid-unit to the primary sampling site.

Secondary sampling stations were set up on a spring-fed stream/wetland complex (Stations B1, B2, and B3 in Figure 22), and on a Type 5 stream that traverses the eastern side of the unit (Station C). Two of the springs that feed the stream/wetland complex emanate from the base of a slope along the southern boundary of the unit. These springs were not buffered, as their presence was not known to the forester or applicator. They were not identified on maps of the area, and would have been difficult to see from the air. Station B1 was on a well-defined channel in an alder forest about 45 meters downstream from the largest spring. The spring actually surfaces about 15 meters into the spray unit. Station B2 was about 60 meters downstream from B1 on a flowing channel that incorporates flow from at least three distinct springs and a ponded wetland area. Station B2 is downstream of the first two of numerous beaver dams that impound portions of the stream/wetland complex. Station B3 was about 500 meters downstream of B2, on a flowing reach just upstream of the point at which the flow recharges into the subsurface. Station C is about 15 meters downstream of the unit boundary. The Station C stream was flowing and was buffered. Glyphosate levels at the secondary sampling stations were evaluated by grab sampling at irregularly spaced intervals. As illustrated in Figure 22, parallel flight paths were used along streamside buffers on both North Fork Rabbit Creek and the Station C stream.

The first significant precipitation event occurred 19 days after the spray. Two weather stations located within 15 kilometers of the unit reported an average of 14 mm of rain over a two-day period. This storm may have produced a first flush of runoff, but we were unable to sample this event. A second storm fives later (25 days after the spray) produced 23 mm of rain over a two-day period. We sampled this runoff event by collecting one grab sample each at stations A, B1, and C.

All samples were analyzed for glyphosate and AMPA. We collected a total of 32 post-spray samples at all stations within the first 48 hours, and glyphosate was detected in 25 of them at concentrations ranging from 0.22 to 4.36 μg/L (see Figure 23 and Appendix E). Of the three runoff event samples, glyphosate was only detected in the one collected from the spring (Station B1) at an estimated concentration of 0.32 μg/L. Glyphosate was not detected in the

three pre-spray control samples collected from Station A or in a field transfer blank. However, glyphosate was detected in a pre-spray sample collected at Station B3, at an estimated concentration of 0.27 μg/L. After verifying with the laboratory that this was not the result of an analytical or data management mistake, we considered possible environmental sources of trace levels of glyphosate. Station B3 is at the downstream end of an extensive spring-fed stream/wetland complex that flows through a unit that was treated with glyphosate (Roundup®) in September of 1990. This application one year earlier is a possible source of the residues found in the sample. Although glyphosate generally does not persist in surface waters for long periods of time, and its terrestrial fate is thought to be dominated by microbial degradation in the surface layers of organic soils (Feng and Thompson, 1989), it has been shown to persist for up to a year in the organic bottom sediments of certain aquatic systems (Feng *et al.*, 1989). It is possible that resuspension of bottom sediments in this extensive wetland complex could be a source of transient trace levels of glyphosate in the water column. Pre-spray control samples were not collected at Stations B1, B2 or C. AMPA was detected in only one sample, collected at Station C, at an estimated concentration of 0.38 μg/L.

At the primary sampling site, glyphosate levels peaked within an hour of spraying the streamside buffer, which was 30 minutes before the application had been completed. Within eight hours of spraying the streamside areas, glyphosate had dropped off to undetectable levels in grab samples from Station A, however, it was present at detectable levels in the 25-48 hour composite sample. At Stations B1, B2, and C, low levels of glyphosate were found in grab samples up to 48 hours following the spray. Discharges from the spring had similar glyphosate levels 25 days after the application. Although other studies have concluded it is unlikely that leaching from forest soils could be a source of glyphosate to aquatic systems (Feng and Thompson, 1989), our spring sampling indicates that it behaved differently in the gravelly soils at this site.

Streamflow at the primary sampling site was only about 3 L/s during the initial sampling period. Streamflow on North Fork Rabbit Creek was about 5 L/s at the upstream edge of the spray unit, (*i.e.* this is a loosing reach within the spray unit). Based on stream discharge at the sampling site and 24-hour composite sample concentrations, cumulative glyphosate loading in North Fork Rabbit Creek ranged from 60-75 mg/day on the first two days after the spray. Based on a total of 79.3 kg a.i of glyphosate applied at this site, these loading rates correspond to about 0.00007 percent and 0.00009 percent of the amount applied exported via North Fork Rabbit Creek on the first and second days following the spray, respectively. However, there are three other streams draining the spray area, and it is not known what additional amounts were exported via cumulative loading to these waterbodies. Streamflow at this station had increased to 11 L/s during the runoff event sampling. The stream at Station C had a discharge of about 2 L/s during the initial sampling period, and this was only slightly higher during the runoff sampling. At Station B1, the spring discharge was about 2 L/s during the spray sampling period. Measurements taken at B1 during the runoff sampling event indicated a slight decrease in discharge, to just over 1 L/s.

The highest concentrations observed at the Rabbit Creek site and at Station C indicate that most if not all of the pesticide entry to these streams was due to off-target swath displacement and drift during the application. There were no small tributary streams where direct overspray would have been a source of glyphosate to North Fork Rabbit Creek (Station A). Weather conditions were generally favorable. Winds during the spray were from the southwest, with average speeds less than 5 km/hr (see Figure 22 and Table 16). Relative humidity was high, ranging from about 84-100 percent (see Table 22).

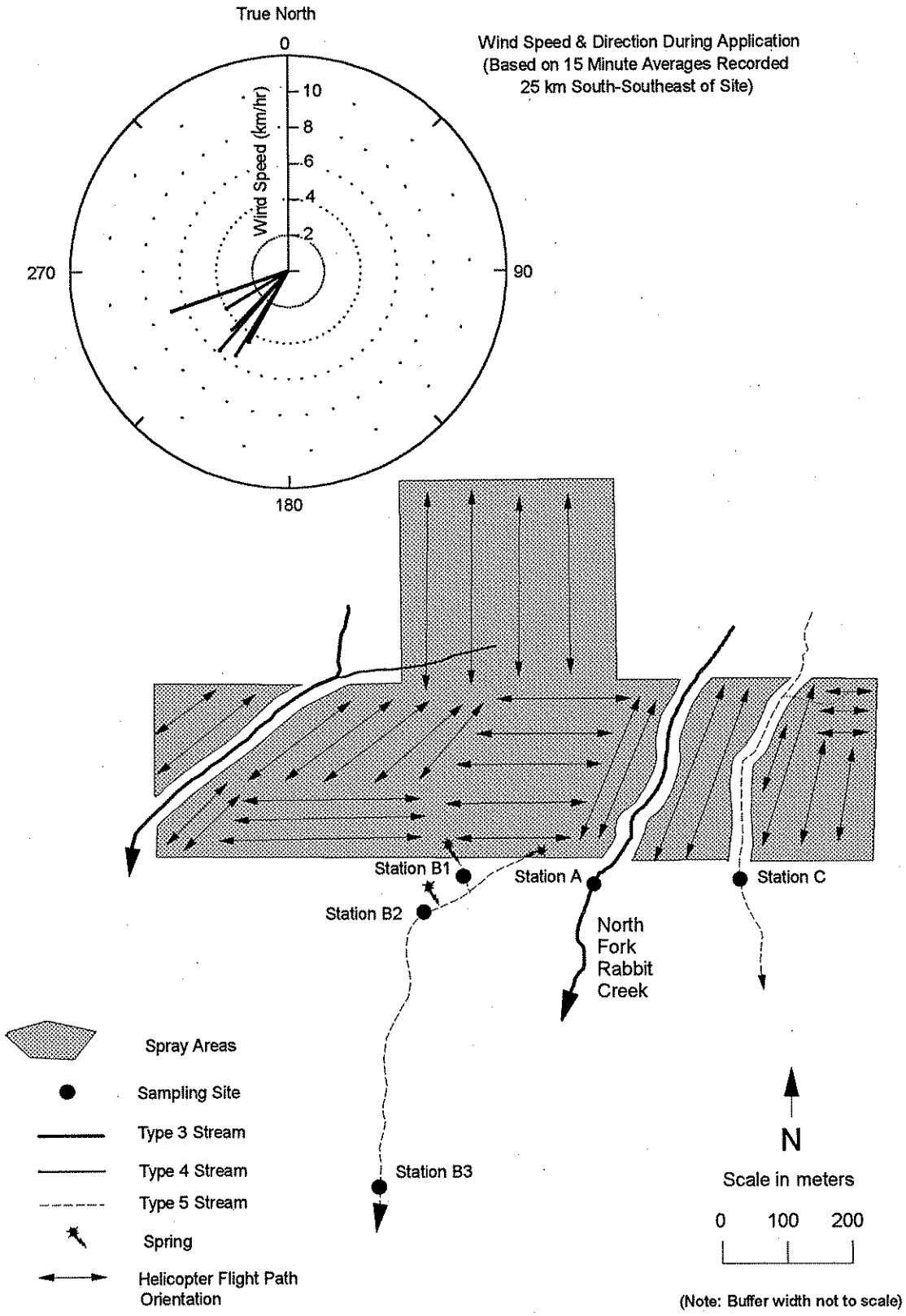
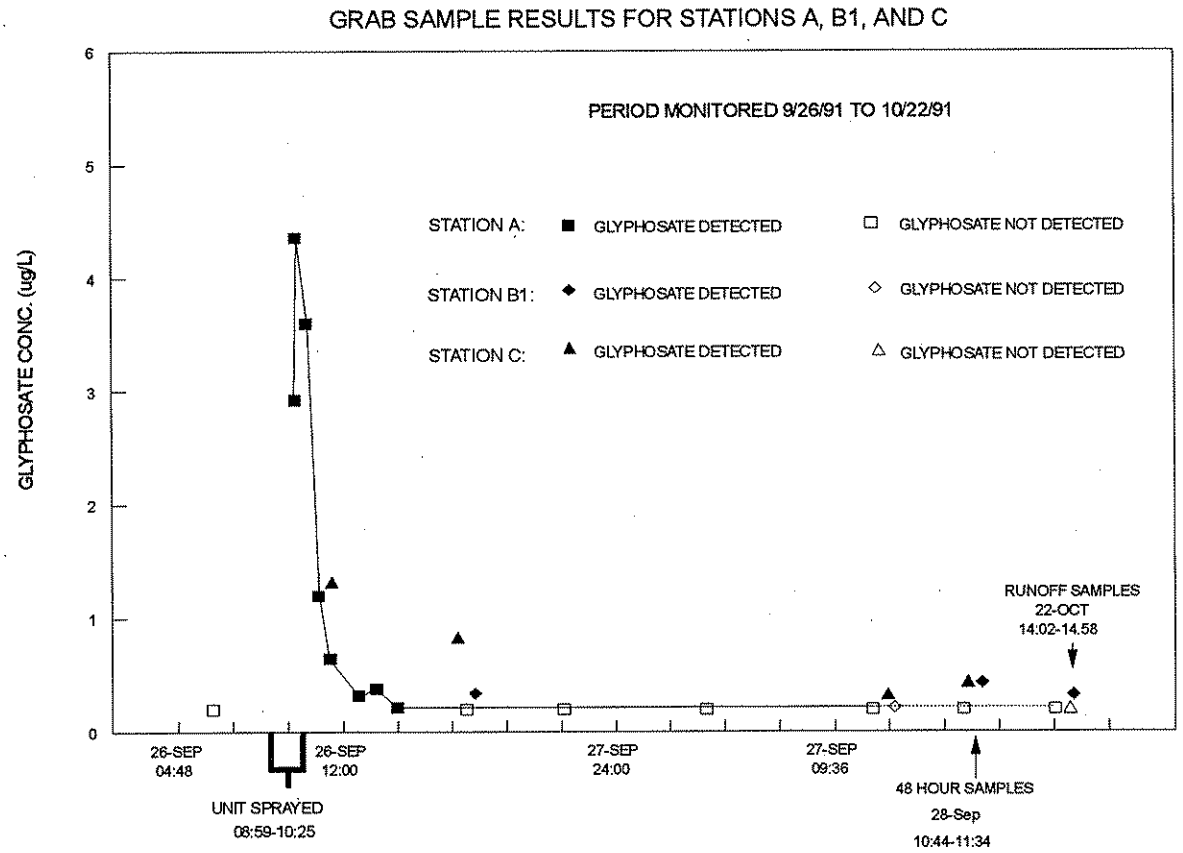


Figure 22: Map of Study Site FH3 - North Fork Rabbit Creek Unit



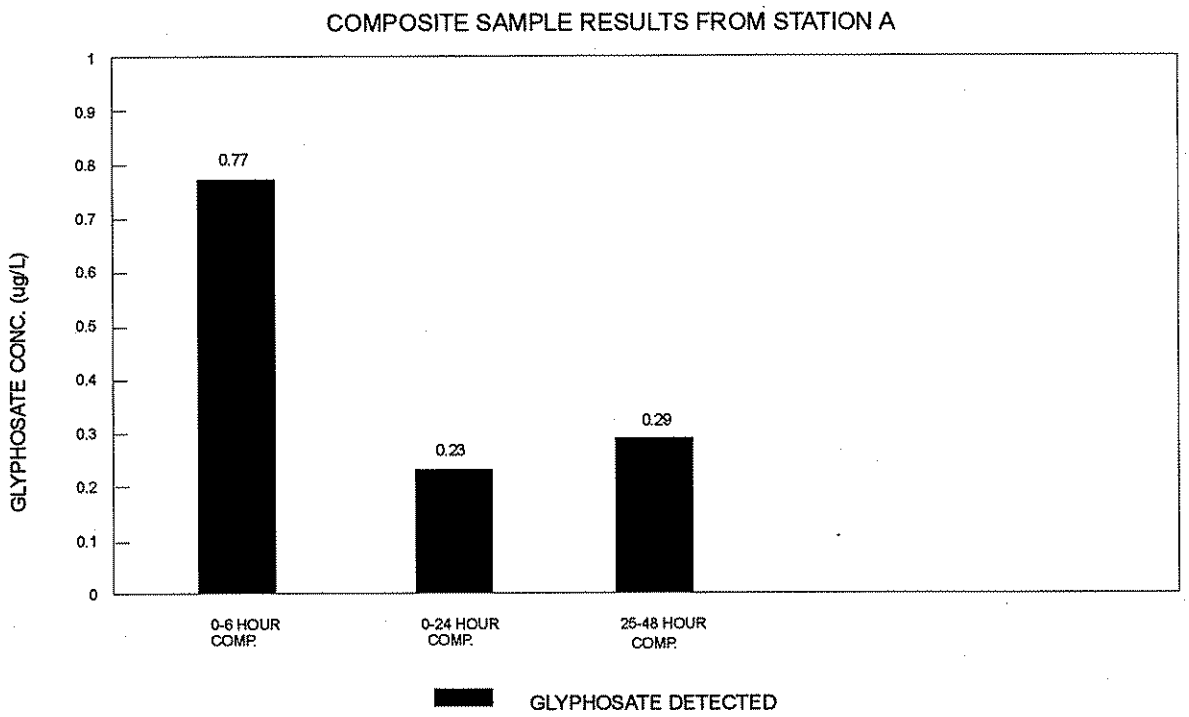


Figure 23: Glyphosate Levels at Site FH3 - North Fork Rabbit Creek Unit

Table 16: Weather Data for Time of Application at Site FH3-North Fork Rabbit Creek Unit.

DATE	TIME	WIND SPEED (km/hr)	WIND DIRECTION (azimuth)	AIR TEMP. (C)	SOLAR RADIATION (watts/sqm)	RELATIVE HUMIDITY (%)	RAINFALL (mm)
Data recorded as 15-minute averages, collected by weather station installed 25 km SSE:							
9/27/91	09:00	4.5	209	13.1	59	98.0	0
9/27/91	09:15	4.5	210	13.3	65	94.9	0
9/27/91	09:30	4.5	224	13.9	76	93.3	0
9/27/91	09:45	5.5	212	14.2	94	91.0	0
9/27/91	10:00	5.8	221	14.5	106	89.0	0
9/27/91	10:15	4.0	239	14.7	100	88.2	0
9/27/91	10:30	6.8	251	14.7	88	87.5	0
Data collected on-site using hand-held wind meter and sling psychrometer:							
9/27/91	08:52	0-3.2	225	12.2		100.0	
9/27/91	09:13	0-3.2	270	12.8		90.0	
9/27/91	10:15	1.6-4.8	270	14.5		84.0	

Table 17: Operational Summary for Site FH3

Target Vegetation: Vine Maple, Salmonberry

Application Rate:

Active Ingredient Herbicides: Glyphosate (Accord) — liters/ha: 3.5

Active Ingredient Application Rate in kg/ha: 1.3

Surfactant added: R-11 — liters/ha: 0.2

Other additives: STA-PUT — liters/ha: 0.5

Carrier used: water — liters/ha: 89.8

Application Rate for Final Spray Mix: 94.0 liters/ha

Approximate Area Sprayed: 61 ha

Helicopter Model: Hillier 12E — Boom Length: 9.5 meters total

Flight Altitude: 8 meters — Airspeed: 81 km/hr — Effective Swath Width: 17 meters

Flight Centerline Offset from Edge of Buffers: 9 meters

Nozzle Type: hollow-cone — Nozzle Size: D10 with #45 whirlplate — # of Nozzles: 32

Nozzle Orientation Angle: 90° — Operating Pressure: 221 kPa (32 psi)

DISCUSSION

Determination of BMP Effectiveness

In this section, we present our evaluation of BMP effectiveness from the standpoint of meeting the provisions of the water quality standards, forest practice rules, and Department of Agriculture regulations, including those regarding EPA-approved pesticide label restrictions. The monitoring results are compared to various decision criteria for applying the above regulations. The BMPs are considered effective if all applicable requirements are met. Although one of the key objectives of BMPs is to ensure that water quality standards are met, in the case of forest pesticide use there are other tests of BMP effectiveness to consider. In some cases the water quality standards may be the most restrictive requirement, while in other cases provisions of the forest practice rules or EPA-approved pesticide labels may provide the ultimate test of BMP effectiveness.

Water Quality Standards

The first test of BMP effectiveness is whether pesticide applications result in levels of pesticides or other substances in streams that violate water quality standards. Other substances of concern might include certain non-pesticidal ingredients in the pesticide formulations, spray adjuvants (e.g., surfactants), or carriers. As mentioned earlier, there are no specific numeric criteria for the chemicals of concern which have been adopted into the water quality standards. However, the narrative criteria regarding toxic substances apply. We have taken the approach of considering reasonable water quality criteria which have been recommended for protecting beneficial uses from the toxic effects of the chemicals of concern. We have chosen the most protective of such criteria for applying narrative water quality standards as a test of BMP effectiveness.

In selecting which criteria to apply, we reviewed the following sources of recommended water quality criteria: 1) "Proposed Surface Water Quality Criteria for Selected Pesticides Used for Forest Management and Management of Forest Tree Seedling Nurseries and Christmas Tree Plantations in Oregon and Washington" (Norris and Dost, 1992); 2) "Canadian Water Quality Guidelines" (Canadian Council of Resource and Environment Ministers, 1991); and 3) "Water Quality Criteria 1972" (National Academy of Sciences, 1973). We are not aware of any other sources, including state or EPA criteria documents, which present water quality criteria for our chemicals of concern that are any more protective than those presented in these sources. Norris and Dost (1992) developed their recommendations for water quality criteria for the Oregon State Department of Forestry and the TFW Cooperative Monitoring Evaluation and Research Committee, specifically for use in evaluating the results of forest pesticide monitoring projects such as this one. The other sources developed pesticide criteria for the purpose of applying water quality standards.

Recommended water quality criteria have been developed separately for protection of human health and aquatic life. For application of water quality standards, the most sensitive use

must be protected. If criteria for the most sensitive use are applied, other uses will be protected as well. For all pesticides monitored in this study, the most protective criteria were those developed for aquatic life. The available criteria for protection of aquatic life are based on toxicity to fish or invertebrates. However, in the case of herbicides it is possible that the most sensitive aquatic species may be plants such as macrophytes, phytoplankton, or periphyton. Hopefully, as more toxicity studies on herbicides are conducted using aquatic plants, these can be incorporated into future water quality criteria.

Table 18: Water Quality Criteria for Forest Pesticides
(All criteria values are in $\mu g/L$)

	Source of Criteria:					
	Norris & Dost (1992)		National Academy of Sciences (1973)	Canadian Water Quality Guidelines (1991)	Selected Criteria:	
Pesticide	Inst.[1]	24-Hr Ave.	Inst.[1]	Inst.[1]	Inst.[1]	24-Hr Ave.
triclopyr (ester)	30.0	3.0	--	--	30.0	3.0
2,4-D (ester)	10.0	1.0	4.0	4.0	4.0	1.0
glyphosate (Roundup®)	130.0	13.0	--	65.0	65.0	13.0
imazapyr	10,000	1,000	--	--	10,000	1,000
chlorothalonil	1.0	0.1	--	--	1.0	0.1
metasystox-R	--	--	0.4	--	0.4	None

1: Recommended instantaneous concentration not to be exceeded at any time or place.

The criteria we reviewed and those we selected for applying the water quality standards are summarized in Table 18. The pesticide criteria provided in Canadian Council of Resource and Environment Ministers (1991) and National Academy of Sciences (1973) are recommended as maximum concentrations not to be exceeded. Norris and Dost (1992) provide separate aquatic life criteria for instantaneous and 24-hour exposure scenarios, based on safety factors of 0.1 and 0.01, respectively, applied to acute toxicity test results (LC_{50} values). The National Academy of Sciences (1973) uses a 0.01 safety factor in establishing their recommended criteria for pesticides. The Canadian Water Quality Guidelines use a safety factor of 0.01 for 2,4-D and 0.05 for glyphosate (as Roundup®). Reasons for using a more conservative safety factor include protecting aquatic life from

sublethal effects and accounting for uncertainties regarding maximum stream concentrations that might occur. In the conclusion of their report, Norris and Dost (1992) present a single criteria, based on the 24-hour exposure scenario for aquatic life protection, for each use scenario (forest management and Christmas Tree plantation/nursery). These more conservative criteria may be appropriate for comparison to monitoring results when one cannot be reasonably certain that peak concentrations have been characterized.

We chose to apply the criteria developed for the Roundup® formulation (glyphosate plus a surfactant) to glyphosate levels found in this study, even though the product used was Accord®. This is because the Accord® applications used R-11® surfactant, which has a LC_{50} of 3.8 mg/L (Monsanto, 1992), similar to the toxicity of the surfactant used in Roundup® (LC_{50} of 2 to 3 mg/L according to Norris and Dost (1992)). Since it appears that applications of Accord® typically use a surfactant, which has greater toxicity than the herbicide itself, it is reasonable to apply the criteria for Roundup®.

Use patterns and resulting exposure of aquatic systems are important aspects to consider in choosing which water quality criteria to use. Forest management applications of herbicide may occur once during the forest rotation (about 40 to 60 years on commercial forest land), and applications to the same area more than three times during a rotation are rare (Norris *et al.*, 1991), resulting in a relatively limited exposure duration. Christmas tree plantations generally use pesticides more frequently because of the much shorter rotation (five plus years) and different pest control objectives. Norris and Dost (1992) developed two different sets of criteria for use with forest management and Christmas Tree plantation applications, respectively. Because they were developed with a specific use pattern in mind, these criteria should not be assumed to be appropriate for other uses of the same chemicals, such as agricultural or residential uses.

Monitoring results are compared to criteria in Table 19. Both instantaneous and 24-hour average concentrations of chlorothalonil and instantaneous concentrations of metasystox-R at site IN1 (the Christmas tree application) exceeded our criteria. At the six forest management sites, maximum instantaneous and 24-hour herbicide levels found at our monitoring locations were lower than the respective criteria. However, as noted in the case summary for site SH2, instantaneous concentrations of 2,4-D during the runoff event probably exceeded the 2.49 μg/L found in the 48-hour grab sample, and may have exceeded the criteria of 4.0 μg/L. Also, we believe that the peak concentrations found at sites FH2 and FH3 (both of which exceeded 4.0 μg/L of glyphosate) indicate a potential for exceeding the instantaneous criteria for 2,4-D when using current BMPs under similar application scenarios. This concern is discussed further in the section "**Factors Influencing BMP Effectiveness.**"

In addition to pesticides, we also considered whether water quality criteria for diesel (used as a carrier at site SH1) were exceeded. Norris and Dost (1992) have recommended criteria of 19 μg/L (instantaneous) and 1.9 μg/L (24-hour average) for diesel used in forest management applications. Although diesel was below detection limits in all samples, we are fairly certain it did not exceed the instantaneous criterion at this site, since it was not detected at levels

ranging from about 16-20 μg/L. It is not known whether 24-hour average concentrations of diesel exceeded the criterion, since detection levels are at least an order of magnitude above the recommended level.

Pesticide levels found at our downstream monitoring stations represent the effects of dilution and dispersion of the chemicals by streamflow following pesticide introduction at one or more upstream sites. Actual maximum concentrations that may have occurred upstream of our sites are not known, but transient levels in small tributaries are likely to be higher than those found downstream since the volume of stream water available to dilute the inputs is less. In explaining apparent sublethal effects on coho salmon fingerlings, Holtby and Baillie (1989) speculated that concentrations in upstream areas of an oversprayed tributary may have been four times the levels observed at the mouth of the tributary. They noted that measured glyphosate concentrations at the outlet of the tributary were probably a poor indication of concentrations in the upper portion of the stream where fish stress was observed.

Upstream areas are subject to pesticide introduction by small droplet drift, swath displacement (larger droplets), overspray, or mobilization in ephemeral streams during runoff. In several studies of the fate of forest herbicides in aquatic systems, levels found in streams that had been oversprayed were many times greater than levels we found in this study. For example, Feng *et al.* (1989) found levels up to 162 μg/L of glyphosate in a small oversprayed stream within two hours of application, and levels of 37 μg/L 16 hours post-application. The first post-spray runoff event resulted in stream levels of 109 μg/L. In a study of the fate of glyphosate in Oregon following forest application, Newton *et al.* (1984) found a peak concentration of 270 μg/L in an oversprayed stream. Thompson *et al.* (1991) found peak triclopyr concentrations ranging from 230 to 350 μg/L following overspray of a stream in Ontario. We have concluded that overspray of small streams which may be mistakenly assumed to be dry does not contribute greatly to peak levels found downstream. However, such overspray could be a source of toxic levels at the point of introduction which could adversely affect the resident biota in small streams (e.g., amphibians and macroinvertebrates), and this would be prohibited by narrative water quality standards.

Forest Practice Rules

It is important to determine whether the BMPs, when applied in typical forest practice operations, are effective at meeting the specific provisions of the forest practices rules. The provision in the rules that requires applicators to "avoid applications that might result in drift causing direct entry of pesticides into ... all Typed Waters, except segments of Type 4 and 5 Waters with no surface waters" is conceptually one of the most protective in terms of water quality, and perhaps the most restrictive in terms of pesticide application. (The wording of this provision was apparently developed to replace and clarify the "Do not allow direct entry of chemicals into any Type 1,2,3 or flowing Type 4 and 5 Waters" provision of the 1988 rules.) Our interpretation is that only certain EPA-approved label restrictions are more restrictive than this provision. We interpret this provision to refer to any entry of pesticides into surface waters that is related directly to the spraying and initial settling of the spray

Table 19: Comparison of Monitoring Results to Water Quality Criteria

Site ID	Pesticide	Maximum Instantaneous Conc. (μg/L)[1]	Maximum 24-Hour Average Conc. (μg/L)[1]	Water Quality Criteria(μg/L) Inst.	Water Quality Criteria(μg/L) 24-Hour Ave.	Criteria Exceeded At Site?
SH1	triclopyr	1.29	0.13	30.0	3.0	No
SH2	2,4-D	2.49[2]	0.69[2]	4.0	1.0	No
SH3	2,4-D	<0.04	<0.04	4.0	1.0	No
	triclopyr	0.02	<0.02	30.0	3.0	No
IN1	chlorothalonil	1.72	0.18	1.0	0.1	Yes
	metasystox-R	2.80	3.25	0.4	--	Yes
FH1	glyphosate	2.39	0.32	65.0	13.0	No
	imazapyr	<0.50	<0.50	10,000	1000	No
FH2	glyphosate	7.55	0.56	65.0	13.0	No
	imazapyr	1.15	0.36	10,000	1000	No
FH3	glyphosate	4.36	0.29	65.0	13.0	No

1: Maximum levels at sampling sites located downstream of spray areas. Value shown may be an average of two analytical results where duplicate or replicate samples were analyzed (see Appendix E); "<" indicates compound not detected at the level shown.

2: Represents a runoff event. Higher instantaneous concentrations may have occurred, possibly exceeding the criterion for 2,4-D, but were not detected by grab samples spaced 24-28 hours apart during runoff.

droplets. Direct entry includes entry to surface waters that is related to intentional or unintentional overspray, inadequate buffering, and swath displacement or drift into streams. It does not include entry associated with surface runoff or subsurface seepage. This "no drift causing direct entry" provision of the forest practice rules provides an important margin of safety which, if achievable, adds to overall BMP efficacy at meeting water quality standards.

Because of the way the forest practice rules are worded, it is not necessary to make a distinction between "direct entry" and "drift"; the rules prohibit *drift that causes direct entry*. Unfortunately, neither term is defined in the regulations to aid in interpretation. Unintentional off-target transport of spray droplets is commonly referred to as drift. According to our interpretation of the rules, such off-target transport to streams is considered direct entry caused by drift if it is related to the initial settling pattern of the spray. Some

evaluations have distinguished between drift of the smallest spray droplets and swath displacement, which refers to movement of larger droplets (University of Arizona, 1983). While we believe that such a distinction is useful, for purposes of interpreting the forest practice rules, we will consider "drift" to be a near-field settling phenomena that results in unintentional off-target deposition of spray droplets, regardless of their size. We believe it is not a reasonable interpretation to assume that "direct entry" could only refer to overspray, since horizontal swath displacement from the flight path is a normal phenomena that is accounted for in the application, and small droplet drift is also common (University of Arizona, 1983). Drift onto a nearby stream surface that was intended to be buffered is therefore just as direct as is spray deposition onto target surfaces. Our interpretations are consistent with the intent of the Forest Practices Rules, according to the Department of Natural Resources (Robinson, 1993).

According to the forest practice rules test of avoiding "drift causing direct entry," the BMPs are not effective. The timing of elevated pesticide levels at our monitoring sites indicates that there was direct entry into flowing streams in all seven of our case studies (as well as direct entry into Riparian Management Zones). The Forest Practice Rules also require that pesticides be applied in accordance with all provisions of EPA-approved pesticide product labels and Department of Agriculture regulations. As we discuss in the following section, the BMPs were not always effective at meeting this requirement either.

Department of Agriculture Regulations and Pesticide Labels

The Washington State Department of Agriculture (WDA) has primary regulatory authority over pesticide applications. The WDA regulations for protecting humans and the environment from adverse impacts due to pesticide use prohibit: 1) use contrary to label directions; 2) faulty, careless, or negligent application; and 3) applications which ". . . endanger humans and their environment" or "pollute water supplies or waterways . . ." The provisions related to polluting waterways and endangering the environment are generally covered by the water quality criteria discussed earlier. For the purposes of enforcing the regulations with regard to drift, WDA uses the Model Drift Enforcement Policy of the Association of Pesticide Control Officials (APCO). This policy defines drift as "the physical movement of pesticide through the air at the time of pesticide application or soon thereafter from the target site to any non- or off-target site." Based on their regulations and enforcement policy, the WDA has interpreted EPA-approved pesticide registration labels, and we apply their interpretations as a test of BMP effectiveness. These interpretations and the drift enforcement policy are presented in Appendix C.

EPA-approved pesticide product labels vary among the products used in this study. In terms of entry to waterbodies, the most restrictive label is that for the triclopyr product Garlon 4®. This label states "Keep out of lakes, ponds or streams." According to WDA, if detectable levels in a stream can be tied directly to a specific application it would be considered use contrary to label directions. Both applications that used this product resulted in detectable levels in streams, therefore the BMP was not effective in these cases.

The labels for the 2,4-D, metasystox-R, and chlorothalonil products used in this study have the following directions: "Do not apply directly to water or wetlands . . ." and "Do not apply when weather conditions favor drift from treated areas." WDA's interpretation of "direct application" is one made directly over the site in question. (Note that this is different from our interpretation of "direct entry.") The official interpretation of the labels for these products is that an application directly over water (*i.e.*, overspray) or application in weather conditions that obviously favor drift would be considered use contrary to label directions.

This interpretation is significant in terms of decisions that foresters and applicators make on buffering small streams. If a stream that appears dry based on a general surveillance does in fact have surface water and is not buffered, this would be use contrary to label directions. We believe that this happened at site SH2, since detectable levels of 2,4-D remained in the stream for 24 hours before any runoff occurred. (We are fairly certain that overspray also occurred in at least two other forest management herbicide applications conducted in accordance with typical BMP implementation, but using products other than 2,4-D.) Therefore we believe that current practices are not effective at adhering to the "do not apply directly to water" instructions included in the label for 2,4-D in the context of forest management operations. This is because current practices do not, in our opinion, reliably detect the presence of surface water in small streams within forestry spray units. However, at the chlorothalonil/metasystox-R application we monitored, direct overspray did not occur, therefore the label instructions were adhered to in this case. We would expect that for most Christmas tree applications, unintentional overspray of water would be less of a problem, since streams are more exposed (*i.e.*, less obscured by brush or slash) and aerial reconnaissance would be more reliable at detecting surface water.

In terms of the provision on weather conditions, the interpretation is ambiguous because it relies on a judgement call on which conditions "obviously favor" drift. We do not believe that any of the applications we monitored were made in a negligent manner with respect to weather conditions, yet it could be said that any wind direction that is unfavorable (*i.e.*, blowing away from target areas) may favor drift.

The 2,4-D label also includes the instruction "Do not apply with hollow-cone type insecticide or other nozzles that produce fine spray droplets." As discussed later, the 2,4-D applications we studied were made with hollow-cone nozzle configurations that produce fine spray droplets. However, these sprays were not made using insecticide configurations *per se*; they were made using hollow-cone type herbicide configurations which produce fine droplets, albeit a lower proportion of fine droplets than would typically be produced for certain types of insect control applications.

The label for the glyphosate product Accord® states "Avoid drift - do not apply during inversion, when winds are gusty, or under any other condition which will allow drift . . . do not use nozzles or nozzle configurations which dispense spray as fine droplets." The WDA interprets this to mean that if drift can be proved it would constitute use contrary to label directions, but points out that the primary concern with this product is drift-related damage to

terrestrial vegetation, not entry to water. We have concluded that drift (as defined by APCO) did occur at the three sites that used this product. Drift was not avoided, therefore we conclude the BMPs were not effective by this test. (Note: in these cases we did not verify whether damage to off-target vegetation occurred, only that off-target deposition occurred in streams and riparian buffers.) Also, the Accord® applications we monitored used hollow-cone nozzle configurations and nozzle orientations that are known, and in fact intended, to produce fine droplets. It is not clear whether this would constitute use contrary to label directions, since most common application equipment would produce some amount of fine droplets.

The label for the imazapyr product Arsenal Applicator's Concentrate® states "Do not apply directly to water or wetlands" and "Maintain adequate buffer zones to ensure that drift does not occur off the target site." WDA's interpretation of this is that if off-target drift did occur, adequate buffer zones were not maintained, therefore use was contrary to label directions. Our monitoring results show the BMPs were not effective at maintaining adequate buffer zones to prevent drift of imazapyr at site FH2.

Factors Influencing BMP Effectiveness

Streamflow Regimes

The streamflow regimes in the vicinity of an application can have a profound influence on concentrations and cumulative loads of pesticides that result, and hence affect the effectiveness of BMPs. For a given amount of pesticide entry due to swath displacement, drift, or overspray, the resulting stream concentrations will vary inversely with stream discharge, while the cumulative load of pesticide in the stream will tend to vary directly with the amount of discharge. These relationships can be seen in our results. Of the sites where we were able to estimate the cumulative 24-hour loads, the site with the highest pesticide load was the site with the greatest discharge (site FH1). The two sites with the highest instantaneous concentrations (FH2 and FH3) were the two sites with the lowest stream discharge. We believe this is due in part to there being a lower volume of water in the stream to dilute the introduced pesticide. Thus, other factors such as pesticide toxicity and application rate being equal, the greatest risk of exceeding water quality criteria and experiencing toxicity problems will occur in streams with minimal flow. The worst case for potential toxicity problems is a shallow but wide stream, because it will have a greater surface area for pesticide deposition but a low volume for dilution due to its shallow depth. Other aspects of streamflow also influence pesticide concentrations. As the stream water moves downstream, the degree to which longitudinal dispersion occurs will influence the dilution of introduced pesticides, affecting both the intensity (*i.e.*, concentration) and duration of exposure for aquatic life. Longitudinal dispersion is related to roughness elements in the stream channel (such as woody debris resulting in plunge pools) that disturb the flow of water, causing back-eddies where dilution can occur. Groundwater inflow or recharge regimes may also influence dilution processes and pesticide concentrations, and hence affect BMP effectiveness from the standpoint of water quality.

Application Equipment and Operating Parameters

The application equipment used in the case studies evaluated was typical of forest pesticide applications. Spray nozzle configurations are a major controlling factor on the size of spray droplets produced. Minimizing the size (diameter) of spray droplets increases the efficiency of the application (Newton and Norgren, 1977), but with the unwanted side effect of increasing the susceptibility of the spray to off-target movement. In operational practice, the size of spray droplets produced is not uniform, thus the size characteristic is referred to as a droplet size spectrum. The proportion of droplets produced which are less than 100 microns in diameter (the size most susceptible to drift) is one of the most important characteristics of spray nozzle configurations (University of Arizona, 1983). Nozzle type, size, and orientation are the primary factors influencing the droplet size spectrum. Aircraft flying speed and operating pressure also have an influence on droplet size.

The operations monitored in this study employed nozzles with orifice sizes D8, D10, and D12, backed up by a #46 or #45 whirlplate. This configuration is referred to as a hollow-cone nozzle. (The whirlplate is a disc set into the nozzle that produces a hollow-cone form as the spray leaves the nozzle; the #45 whirlplate produces a greater proportion of fine drops relative to the #46.) Using the same nozzles without the whirlplates is referred to as a jet spray nozzle configuration. The use of whirlplates increases the proportion of fine spray droplets. For example, a D6 jet spray nozzle configuration (without whirlplates), oriented straight back (0°), produces a droplet size spectrum with a volume median diameter (VMD) of 1190 microns with 0.07 percent of the volume in droplets <100 microns in diameter. In contrast, a D6-46 hollow-cone nozzle configuration (orifice size D6 nozzle backed up by a #46 whirlplate) with the same orientation produces a spectrum of 435 micron VMD, with 0.1 percent of the volume made up of droplets <100 microns in diameter (University of Arizona, 1983).

Nozzle orientation for our study sites was either straight down (90°) or 45° back. The 90° orientation is not actually straight down, since the helicopter typically flies at a tilt (tail up, nose down) of up to 20°. Any configuration that is oriented into the airstream produces wind shear, which increases the amount of fine droplets produced. For example a D6-46 nozzle oriented straight back produces a droplet size spectrum of 420 to 450 microns VMD, whereas the same nozzle oriented straight down produces a spectrum of 280 to 300 microns VMD (Gratkowski, 1974). In a study of the effectiveness of drift control adjuvants, high wind shear atomization configurations (e.g., D6 or D6-46 nozzles oriented down) were not recommended where drift control is desired (Yates *et al.*, 1976). High wind shear or high operating pressure tends to cancel out the intended effects of viscosity (drift control) agents (University of Arizona, 1983).

The University of Arizona Cooperative Extension project brought together experts in the field of agricultural engineering to develop a manual for applicators to minimize drift (University of Arizona, 1983). The project resulted in recommendations which are pertinent to our Forest Practice BMPs. These recommendations include:

1) Leave a buffer of at least 300 feet (92 meters) downwind between aerial applications and any sensitive situation. They note that the 300 foot buffer will accommodate swath displacement but cannot protect against small droplet drift, for which buffers are practically ineffective.

2) Use the largest droplet size compatible with the coverage required. For herbicides use jet spray nozzles size D4-D10 directed with the airstream, with no fan or cone producing disc in the nozzle, to produce a droplet size spectrum of 800-1000 microns VMD. For insecticides and fungicides use D4-D10 orifices with a #46 whirlplate or larger, directed not more than 45 degrees into the airstream, to produce a droplet size spectrum of 300-350 microns VMD.

3) Do not direct any nozzles greater 45 degrees into the airstream.

4) Only operate when the wind is at least 2-3 miles/hour (3-5 km/hr), but not over 8-10 miles/hour (13-16 km/hr).

Relationships of Streamflow and Operating Factors to Pesticide Levels in Streams

We believe that streamflow regime and certain operating parameters (particularly nozzle configurations) are the two most important factors influencing the effectiveness of current BMPs from a water quality standpoint. In our opinion, only the width of the buffer itself has a greater influence on stream levels of pesticides. This is because pesticide concentrations in streams are controlled largely by the streamflow regime and the amount of off-target deposition, which is heavily influenced by the proportion of small droplets in the spray. Specifically, the volume of water in the stream and amount of longitudinal dispersion affect the resulting pesticide concentration by controlling the dilution that may occur. This is important to consider in pesticide application practice since the water quality criteria for protecting aquatic life from toxic effects are developed in terms of concentration. Whatever volume of water exists in the stream, it is the operating parameters (particularly nozzle type, size, and orientation) that control the proportion of fine droplets in the spray, and thus the amount of off-target deposition that may potentially enter streams.

The combined effects of these two controlling factors on pesticide concentration in streams is illustrated by the comparisons in Table 20. This table lists the maximum instantaneous stream concentrations which resulted from off-target deposition due to swath displacement and drift (*i.e.*, excluding samples from runoff periods). The concentrations are converted to maximum instantaneous loads (in kilogram per second) in order to normalize pesticide amounts to stream discharge, thus elucidating the effects of operating parameters, particularly nozzle configurations. Maximum instantaneous concentrations and loads are then shown in proportion to pesticide application rates, to facilitate a more meaningful comparison of the influence of stream discharge and operating parameters.

Table 20: Relationship of Monitoring Results to Streamflow and Operating Parameters

Study Site & Pesticide Applied	Maximum Instantaneous Conc.(μg/L)[1]	Average Stream Discharge (L/sec)	Maximum Instantaneous Loading (kg/sec)	Active Ingredient Application Rate (kg/ha)	Maximum Load as Proportion of Appl. Rate (kg-sec/kg-ha)	Ratio of Maximum Conc. to Appl. Rate (μg-L/k-ha)	Nozzle Size and Orientation[2]	Operating Pressure (kPa)
SH1								
triclopyr	1.29	18	2.32×10^{-8}	1.1	2.11×10^{-8}	1.17	D10-46/45°	138
SH2								
2,4-D	1.31	12	1.57×10^{-8}	2.1	7.62×10^{-9}	0.62	D8-46/45°	207
SH3								
2,4-D	<0.04	283	$<1.13 \times 10^{-8}$	1.7	$<6.65 \times 10^{-9}$	<0.02	D10-46/45°	152
triclopyr	0.02	"	5.66×10^{-9}	0.5	1.13×10^{-8}	0.04	"	"
IN1								
chlorothalonil	1.72	11	1.89×10^{-8}	2.3	8.22×10^{-9}	0.75	D8-46/45°	207
metasystox-R	2.80	"	3.08×10^{-8}	0.6	5.13×10^{-8}	4.67	"	"
FH1								
glyphosate	2.39	50	1.20×10^{-7}	1.3	9.23×10^{-8}	1.84	D12-46/90°	138
imazapyr	<0.50	"	$<2.50 \times 10^{-8}$	0.1	$<2.50 \times 10^{-7}$	<5.00	"	"
FH2								
glyphosate	7.55	4	3.02×10^{-8}	1.7	1.78×10^{-8}	4.44	D10-45/90°	221
imazapyr	1.15	"	4.60×10^{-9}	0.2	2.30×10^{-8}	5.75	"	"
FH3								
glyphosate	4.36	3	1.31×10^{-8}	1.3	1.01×10^{-8}	3.35	D10-45/90°	221

1: Levels corresponding to the initial sampling period following application at primary sampling stations, excluding runoff sampling. Value shown may be an average of two analytical results where duplicate or replicate samples were analyzed (see Appendix E); "<" indicates compound not detected at the level shown.

2: Indicates nozzle orifice diameter, whirlplate size, and orientation. For example: D10-46/45° indicates a D10 nozzle orifice (10/64ths inch in diameter) with a #46 whirlplate (hollow-cone producing disc) oriented 45° into the airstream (i.e. angled down and facing back); a 90° orientation is oriented straight down.

From the comparison in Table 20, it can be seen that the highest concentrations (glyphosate at sites FH2 and FH3) occurred in streams with the lowest discharge *and* where operating factors would tend to produce the highest proportion of fine spray droplets. When concentrations are set relative to application rates, the highest levels are again seen at sites FH2 and FH3, as well as for metasystox-R levels in Foster Creek (site IN1). When instantaneous loadings as a proportion of application rate are compared, the highest relative level is for glyphosate at site FH1, followed by metasystox-R at site IN1 and imazapyr at FH2. Although not included in Table 20, we also compared 6-hour and 24-hour average concentrations and loads in the same manner and found similar patterns. The highest 6-hour concentrations relative to application rates were found at sites IN1, FH2, and FH3, in that order, while the highest 6-hour load relative to application rate was found at IN1, followed by FH1, and FH2. The highest 24-hour relative concentration was found at FH2, followed by FH1 and FH3, while the highest relative 24-hour load was found at FH1 followed by FH2.

We believe the primary reason for the high relative concentrations at sites FH2 and FH3 is low stream discharge, resulting in less initial dilution of introduced pesticides. We attribute the high relative loads at sites FH1 and FH2 primarily to the effects of a higher proportion of small droplets produced by high wind-shear nozzle configurations (oriented straight down). In addition, the #45 whirlplate used at sites FH2 and FH3 is known to produce a greater proportion of fine spray droplets than the #46 whirlplate used at the other sites, and higher operating pressures were used at sites FH2 and FH3 as well. We cannot readily explain the high concentration and load of metasystox-R relative to its application rate, and relative to chlorothalonil levels at the same site. Although streamflow at this site was the third lowest in the study, it was similar to that at site SH2 which did not have a particularly high relative concentration. One possible explanation for the high relative levels of metasystox-R is that the stream was more exposed (*i.e.*, free of brush or canopy) at this site than at the forest management sites. In contrast, sites FH1 and FH3 had Riparian Management Zones (RMZs), and even those that didn't have RMZs, such as FH2, had considerable amounts of logging slash or brush that could intercept pesticide deposition.

As mentioned earlier, it is our opinion that the monitoring results from sites FH2 and FH3 indicate a potential for exceeding the instantaneous water quality criterion for 2,4-D in certain situations. While 2,4-D was not applied at these two sites, our results indicate that pesticide introduction due to drift and swath displacement can result in stream concentrations that exceed the 4.0 μg/L criterion for 2,4-D under existing practices given certain streamflow conditions. Norris *et al.* (1991) concluded that the phenomena of drift and direct entry are largely mechanical processes that should not vary appreciably among different herbicides. If we make this assumption, then the results from sites FH2 and FH3 indicate a potential for exceeding the instantaneous criterion for 2,4-D in cases where it is applied using high shear nozzle configurations (high wind-shear orientation and/or #45 whirlplates) in the vicinity of streams with critical flow regimes.

Buffering Decisions

One of the most important aspects of BMP implementation is the area of operator decisions. Specifically, the decision made by the landowner representative, typically the forester in charge of the spray program, about which streams require buffers. This decision is often made in consultation with the pesticide applicator, or in some cases it may be made solely by the applicator. Provisions in the Forest Practice Rules assume that the person making this decision knows with some certainty which portions of the Type 4 and 5 streams have surface water. Yet neither the rules nor the Forest Practices Board manual specify what steps are to be taken to determine the presence of surface water. Larger typed waters are often simply delineated on aerial photos or maps and the applicator is told to buffer them. For smaller streams, an attempt is made to observe streamflow conditions. In current practice, foresters assessing small streams typically rely on: 1) on-site inspection, generally limited to easily accessible areas such as road crossings of streams; 2) aerial surveillance during fly-overs with the applicator; and 3) personal knowledge of the unit gained from previous activities such as site preparation, reforestation, logging, etc.

As we have already stated, we believe that current practices are not effective at reliably determining the presence of surface water in small streams. A large portion of the stream channel length within a spray unit may not be accessible by ground inspection of culverts, or the culvert will often not be in a suitable location to make the call. Aerial surveillance is not reliable because the smaller channels are often obscured from view by brush or slash. Prior knowledge of streams or hydrologic regimes is very helpful in guiding the overall assessment. However, flow conditions in small streams can change so rapidly that such familiarity cannot be relied upon for the application of BMPs that require a determination of flow conditions on the day of spraying. If certainty in the determination of whether streams have surface water is important to implementation of the BMP, then many small streams of the type which are currently being assessed remotely will need to be walked. It is our interpretation that the BMP does rely a good deal on certainty in making this call.

Weather

The primary weather factors that influence pesticide applications are those which affect spray droplet size or movement. Relative humidity and temperature affect droplet size by influencing the drop evaporation rate. Atmospheric boundary layer stability and wind speed and direction affect droplet movement. Rainfall that produces runoff affects pesticide movement into aquatic systems following the application. Stable air conditions, such as during an inversion, are worst case conditions for pesticide drift. Conditions during the sprays we monitored ranged from relatively stable to neutral.

Wind speeds during the applications we monitored ranged from barely perceptible to 15-minute averages of about 11 km/hr, with higher gusts. According to Payne *et al.* (1989), the worst case conditions with respect to wind speeds are to spray in light winds, but not calm conditions. The reasoning for this is that increased wind speed increases spray drop

impaction efficiency on vegetation surfaces, thereby decreasing the drop concentration available for deposit onto stream surfaces. Since most of our study sites had applications made on both sides of the sampled stream or flowing tributaries, wind direction was unfavorable at least some of the time during the applications. It is of note that in the one case where wind direction was favorable (*i.e.*, the application was made downwind of the stream), pesticides were barely detectable in the stream. Favorable wind direction probably contributed to the relative effectiveness of the BMPs in this case (Site SH3), although other factors such as a wide RMZ and a large dilution effect from upstream flows were also important.

Relative humidity and temperature conditions both have a potential effect on spray droplet size following release from the helicopter where water is used as a pesticide carrier. Because drop evaporation rate is inversely related to relative humidity, drift potential increases as relative humidity drops and droplet size decreases more rapidly. Likewise, air temperature has an effect on drop evaporation rate and drift potential. We do not believe that temperature or relative humidity were particularly unfavorable in their influence on the applications we monitored.

Site SH2 was interesting from the standpoint of weather. We observed some of the highest winds of the study during this application, and suspected that substantial displacement of some spray swaths may have occurred. We surveyed the unit later in the summer after the sprayed vegetation had turned brown and observed distinct buffers along the mainstem, but there was also dead vegetation very near some of the tributary streams where buffers were intended. We believe that this represents unintentional off-target deposition due to miscalculation of swath displacement or an unexpected gust of wind. Another weather factor, precipitation, had obvious effects on in-stream levels of 2,4-D at site SH2, where runoff resulted in higher levels than did swath displacement or drift.

Chemicals Used

Because pesticides and pesticide formulations vary in their toxicity and application rates necessary to control pests, the choice of products to apply may influence BMP effectiveness from a water quality standpoint. For example, using the water quality criteria effectiveness test, an application using a 2,4-D herbicide product would have less tolerance for swath displacement or drift than would one using glyphosate or imazapyr because of the greater toxicity of 2,4-D. However, as Norris and Dost (1992) emphasize in recommending their criteria, water quality criteria should not be seen as permissible levels, but rather as levels not to be exceeded when appropriate best management practices are applied.

Pesticides also vary in their environmental fate characteristics such as persistence, mobility, and water solubility, which affect the way chemicals partition between air, water, sediment, soils, and biota in the environment. This in turn will affect the intensity and duration of exposure for aquatic organisms when pesticides are introduced to surface waters via off-target deposition or overspray, runoff, or leaching from soils. Differences in environmental

fate characteristics may explain the differences we see in relative levels of pesticides (*i.e.*, concentration or load per kilogram a.i. applied) used at the same site. For example, the differences in relative levels of metasystox-R and chlorothalonil at site IN1, and glyphosate and imazapyr at site FH2, could be due to different environmental fates of these chemicals. Since achievement of water quality standards is determined largely by stream concentrations, environmental fate characteristics can influence BMP effectiveness.

The pesticide formulations chosen also influence carriers used and the degree to which adjuvants are necessary or desirable. Adjuvants in turn may influence pesticide introduction to surface waters. For example, surfactants and drift control additives can affect droplet size uniformity and the proportion of fine spray droplets, which affects off-target deposition. Surfactants can also be a significant source of toxicity, as can diesel where it is used as a carrier, decreasing the tolerance for off-target deposition from a water quality standpoint.

Another effectiveness test that may vary with the choice of pesticide products is that of adhering to EPA-approved product label directions. As discussed earlier, the language on the labels varies considerably. Unfortunately, there is no consistent relationship between label language and toxicity of the product. In fact, the most toxic herbicide used in this study, 2,4-D, appears to have some of the most lenient label restrictions, largely because of their ambiguity. Triclopyr, on the other hand, has the most restrictive label for applications made near water: "Keep out . . ." indicating zero tolerance. Also, labels are subject to change as products go through re-registration processes, so this test of BMP effectiveness may be a "moving target."

Topography and other Site Factors

One of the most important site factors in BMP effectiveness is the drainage network. Because of the difficulty in determining whether small streams have surface waters and therefore must be buffered, overspray of streams with minor amounts of flow is more likely on sites which have more highly dissected terrain. Even if an attempt is made to leave buffers on all streams, the difficulty of achieving accurate swath deposition in highly dissected terrain increases the likelihood of stream entry. This is underscored by our observation that site SH3, which had relatively little pesticide entry into McCoy Creek, is the only site that did not have tributaries within the spray unit.

Site topography also influences the buffering practice. On excessively steep terrain, small streams cannot be buffered parallel because of pilot safety considerations, yet parallel swaths are probably the most effective method of buffering. Steeper sites also require greater release heights, which increases susceptibility to drift (University of Arizona, 1983). Conceptually, the BMPs should have been more effective on flat sites where the aircraft could fly at lower altitudes. However, we found no relationship between slope steepness and BMP effectiveness in terms of pesticide levels in streams. This is probably because other factors such as streamflow regimes and wind direction or speed offset the effects of favorable topography.

The presence of Riparian Management Zones (RMZs) is conceptually an important factor influencing pesticide levels in streams, as there is a potential for the forest canopy to intercept airborne pesticides. Three of our sites had RMZs, and one of these was SH3, where the BMP was most effective. At the other two RMZ sites, the width of the RMZ was more typical (8 to 15 meters wide as opposed to 15 meters plus), and did not appear to influence BMP effectiveness. A lack of streamside vegetation (including brush and slash) that could intercept deposition may be an important factor in some cases. As mentioned previously, the high levels of metasystox-R (relative to the amount applied) that were found in Foster Creek (site IN1) may be due in part to the almost complete lack of woody streamside vegetation and woody debris at this site.

Improvements to the BMPs

This analysis has shown that improvements to the BMPs are necessary to ensure achievement of water quality standards, and to adhere to provisions of the forest practice rules and pesticide product label restrictions. Possibilities for improvements include changes in buffering provisions, more effective procedures for determining the presence of surface water in Type 4 and 5 streams, specifications on the type of nozzle configurations and orientations used, and operational restrictions based on weather conditions.

Various studies have evaluated stream buffer effectiveness and downwind deposition of pesticide sprays. As a part of the Carnation Creek herbicide project, Payne *et al.* (1989) found that drift distances and buffer effectiveness varied widely depending on the type of application equipment used, and they recommended stream buffers tiered to type of application equipment. However, even the most protective buffers cannot prevent drift of the smallest droplet sizes. Droplets less than 100 microns in diameter have been displaced up to 800 meters off-target even under favorable atmospheric boundary layer stability conditions, and small droplets can travel several kilometers during inversion conditions (University of Arizona, 1983). Markin (1982) studied the effects of cold air drainage, a common phenomena in mountainous areas, on forest insecticide sprays in the east slope of the Cascades. He found that almost as much spray was deposited 100 meters below and downwind of the target plot as was recovered in the target area, and some ground deposition was found up to 1,500 meters downgradient. As a practical matter, buffers should not be established with the goal of preventing small droplet drift, but rather to prevent off-target deposition of larger droplet sizes which flare out in a downwind direction immediately after release (*i.e.*, the extended swath) and to reduce drift into streams. Buffers are also needed in the upwind direction to accommodate the portion of the extended swath that flares out due to aircraft-induced turbulence, or wake. Drift minimization can be best accomplished by focusing on the application technology and technique.

Payne *et al.* (1989) recommended buffer widths to protect streams which were based on measurements of downwind deposition following forest glyphosate applications and predicted stream concentrations from a multiple swath application. They present predicted stream concentrations of Roundup® (applied at the rate of 2.1 kg a.i./ha) for three different

application technologies and three different stream depths for streams located 25, 50, and 75 meters downwind of a hypothetical 100 hectare forest spray unit. Their analysis indicates that with the D8-46 hollow-cone nozzle configuration (commonly employed in forest spraying in Washington), buffer widths of 75 meters will produce predicted stream concentrations of 2.2, 0.89, and 0.46 μg/L, respectively, for stream depths of 0.1, 0.25, and 0.5 meters. If a Microfoil® boom application system were used, similar levels would be produced with a 25 meter buffer. Predicted concentrations for the D8-46 application with a 50 meter buffer were 82, 32, and 16 μg/L, respectively, for stream depths of 0.1, 0.25, and 0.5 meters. For the D8-46 nozzles with a 25 meter buffer, predicted stream concentrations were 590, 240, and 120 μg/L, respectively, for stream depths of 0.1, 0.25, and 0.5 meters. They do not recommend buffer widths of less than 25 meters due to concerns with swath displacement.

If we assume that other pesticides will behave similar to Roundup® with respect to the physical processes involved in swath displacement and drift, we can use the analysis of Payne *et al.* (1989) to develop buffer recommendations for achieving water quality standards. Based on their analysis, we believe that downwind buffers of greater than 75 meters are needed to ensure that stream concentrations of the more toxic pesticides (e.g. insecticides and fungicides used in Christmas tree applications) do not exceed the water quality criteria we employed in this evaluation. For herbicides used in forest management, the 75 meter buffer would be expected to be effective for keeping 2,4-D concentrations below the instantaneous criterion of 4.0 μg/L for streams at least 0.1 meter deep, and acceptable for keeping instantaneous concentrations of triclopyr and glyphosate (with surfactant) below their respective criteria of 30 μg/L and 65 μg/L. A 50-meter buffer would appear to be adequate around deeper streams for pesticides of intermediate to low toxicity, however, stream depths of less than 0.25 meters are common in the vicinity of forestry sites.

In terms of spray application technology, we believe there is a need to encourage nozzle configurations that reduce the production of droplets less than 100 microns. Requiring that jet spray nozzles be used instead of hollow-cone nozzles would be one way to accomplish this. However, there may be an environmental trade-off to increasing the droplet size: a greater application rate may be needed to achieve the pest control objective, potentially resulting in greater environmental exposure if swath displacement results in deposition to streams, wetlands, or other sensitive environments. Using the current nozzle types but increasing buffer widths and minimizing wind shear by not orienting nozzles more than 45° into the airstream may be an appropriate compromise between the conflicting concerns about droplet size and application rate.

A specialized type of application equipment, the Microfoil® boom, produces a uniformly larger droplet. This equipment is effective at buffering streams and has been demonstrated to greatly improve the accuracy of deposition. The Microfoil® boom was used experimentally in the Carnation Creek herbicide study in British Columbia, and the results of that research suggest that streamside buffers may be reduced when this technology is used (Payne *et al.*, 1989). Based on our conversations with pesticide applicators, the Microfoil® boom is not

used in Washington, but it is used in the Southeastern United States. This is probably due to the limitations for using this technology in steep terrain. Another type of nozzle that may have practical application for reducing drop size in forest management is the Raindrop® nozzle, which has been referred to as a large, low velocity hollow-cone nozzle. Data presented in Yates *et al.* (1984) indicates that a size D8-45 Raindrop® nozzle (RD-7) oriented straight back (0°) at an airspeed of 80 km/hr produces a droplet size spectrum of 993 microns VMD, versus 384 microns VMD for a standard D8-45 hollow-cone nozzle at the same airspeed and orientation. This is a substantial reduction in small droplets for a nozzle type that can be used with conventional spray booms.

Another issue which may need to be considered in the establishment of revised BMPs is the water quality standards issue of antidegradation. Even where water quality criteria related to pesticide toxicity are met, the introduction of pesticides to natural stream systems would represent a degradation to existing water quality. Since it is not reasonable to expect that any aerial application of pesticides in the vicinity of surface waters can achieve zero introduction of pesticides to the water, the requirements of the antidegradation provisions come into play. According to these provisions, the entry of pesticides, even in amounts below toxic levels, can only be allowed if: 1) "all known, available, and reasonable best management practices" are used; and 2) " it is clear, after satisfactory public participation and intergovernmental coordination, that overriding considerations of the public interest will be served" by allowing the degradation to occur. In order for any revised BMPs to fully comply with this aspect of the standards, it may be necessary to demonstrate the public interest provision based on the results of a public participation process. It may be appropriate to undertake such a process after the Department of Ecology has adopted an antidegradation implementation policy which is scheduled for the next triennial water quality standards revision.

Development of Recommended Monitoring Protocol

One of the objectives of this project was to develop a recommended protocol for monitoring stream concentrations which result from forest pesticide applications. As stated earlier, the sampling protocol for this study mimicked both the Oregon (Oregon State Department of Forestry, 1989) and DNR (Washington State Department of Natural Resources, 1990) protocols. The monitoring protocol we have recommended is a composite of these two protocols and the more intensive sampling schedule we employed in this study. We have excluded from the protocol the use of automatic pump samplers, since many investigators won't have access to such equipment. Taking into consideration the need to limit monitoring costs while maintaining quality control checks, we have recommended a schedule for collection of grab samples that should be effective at characterizing peak concentrations and estimating 24-hour average levels in most situations. The recommended monitoring protocol is presented in Appendix G.

We found that in some cases the DNR protocol, which times sample collection from the completion of spraying, was very similar to the Oregon protocol, which times sample

collection from the beginning of spraying with allowance for stream time-of-travel. In other cases, such as very large spray units, the two protocols were very different in their ability to detect the initial spike of pesticide in the stream. Borrowing the most effective components from the two approaches, our recommended protocol provides for a different basis for timing of sample collection for large and small spray units.

The protocol we recommend focuses most of the sample collection on the initial four hours following the application. This is consistent with other published monitoring results and our findings that, except in cases where runoff occurs very soon after spraying, the highest stream concentrations occur within the first four hours. In fact, in five of our seven case studies, the peak concentration occurred within the first thirty minutes following application (accounting for stream time-of-travel). Samples beyond the first four hours are included primarily to allow the investigator to estimate the 24-hour average concentration. The recommended protocol presented in Appendix G includes a schedule for collection of a pre-spray control sample, a series of timed post-spray grab samples, and a procedure for calculating a 24-hour average concentration. The protocol incorporates field replicates and duplicate matrix spikes as quality control samples. It addresses planning, preparations, quality control considerations for sample collection and handling, and the collection of supporting data as well. In developing the protocol, we had to make some trade-offs between the costs (particularly analytical costs) and efficacy of monitoring. Our recommended protocol involves analysis of ten samples, including the pre-spray control and three other quality control samples. The level of resolution would be enhanced considerably if the monitoring budget allows collection of additional samples within the first four hours following the spray, and we have specified two optional samples in the protocol. We also recommend runoff sampling, especially in cases where a runoff event occurs within 72 hours of the application.

From a water quality standpoint, both peak (*i.e.*, maximum instantaneous) and 24-hour average levels are important. In lieu of using automatic pumping samplers to obtain a 24-hour composite, there are at least two approaches for estimating a 24-hour concentration: hand-composites of grab samples and calculated average concentrations. The Oregon protocol incorporates a hand-composite sample, made of equal parts of the 15-minute, 4-hour, 8-hour, and 24-hour grab samples, which is intended to approximate the 24-hour average concentration. This hand-composite is used as a screening sample; if pesticide is detected in it, then the individual grab samples are analyzed. From our study results, we found that the 4-sample hand-composite results overestimated the concentrations found in 24-hour composites taken by automatic pump samplers by factors of 2 to 6 in five of the six sites where pesticides were detected in composite samples (see Appendix E). At one site the concentrations were essentially the same.

In our monitoring protocol, we do not recommend use of a hand-composited screening sample. One problem with using a screening sample is that by the time screening results are available, the individual grab samples will likely have exceeded the recommended holding time between collection and analysis. This was a common problem noted in a recent

monitoring program report (Oregon State Department of Forestry, 1992). Compliance with recommended holding times is an important aspect of quality control. Another problem with the hand-composited screening sample is that using equal parts of the timed grab samples tends to significantly over-estimate the true 24-hour concentration, as noted above. While this could be overcome by preparing a volume-weighted composite (with the volume of each aliquot determined by the proportion of time it represents), preparation of such a composite would introduce additional sources of potential contamination or bias (contact with glassware, etc.).

In the Oregon protocol, a calculated 24-hour average concentration is derived from the individual grab sample results, in cases where they are analyzed. The calculation uses time-proportionate weighting of the concentrations found in the 15-minute, 4-hour, 8-hour, and 24-hour grab samples. When we calculated the time-weighted 24-hour concentration from our individual grab sample results according to the Oregon protocol, the calculated values were similar to concentrations in the automatic compositor samples (calculated values are given in Appendix E). Calculated concentrations ranged from about 0.5 to 2 times the 24-hour composite concentrations, with relative percent differences of 11% to 67% (average RPD of 42%). This indicates that the calculated 24-hour concentration, which represents a crude integration of the time-concentration curve, is an acceptable surrogate for the true 24-hour concentration (provided that the individual samples are analyzed in a timely manner).

We have adopted a calculated 24-hour average into the recommended monitoring protocol presented Appendix G. This calculated average is based on a time-proportionate weighting of the concentrations found in the 30-minute, 1-hour, 2-hour, 4-hour, 6-hour, and 24-hour grab samples. When applied to the results from this study, our formula produced calculated 24-hour average values which ranged from about 0.9 to 1.8 times the true concentrations, performing slightly better than the Oregon protocol calculation (calculated values are given in Appendix E). Relative percent differences between the calculated and actual values ranged from 12% to 57% (average of 33%). Table 21 shows a comparison of these two approaches to calculating the 24-hour average concentration.

Aside from the differences in the grab sampling schedule, the primary difference between the Oregon protocol calculation and the one in our recommended protocol is the way in which we deal with values reported as less than detection limits. In the Oregon protocol, samples reported as less than detection limit are assumed to have a value of zero for purposes of calculating a 24-hour average (Oregon State Department of Forestry, 1992). In our opinion, this approach increases the potential to underestimate the average. We believe that a concentration of zero is unlikely if an application occurred in the vicinity of the stream. Since the concentration is unknown in such samples, we have chosen to assume a value of one-half the detection limit for purposes of calculating the 24-hour average. By choosing the halfway point between the reported detection limit (which is generally a quantification limit rather than an absolute limit of detection) and zero, we stand an equal chance of being above or below the true value. The exceptions to this are situations where 50% or more of the samples, including the 24-hour grab sample, are reported as less than detection limit, in which case we report the calculated 24-hour average as less than the detection limit.

Table 21: Comparison of Two Approaches for Calculating the 24-Hour Average Concentration

Site ID	Pesticide	Actual[1] 24-Hour Average Conc. (µg/L)	Calculated 24-Hr Ave: Recommended Protocol (µg/L)	Percent of Actual	RPD[2]	Calculated 24-Hr Ave: Oregon Protocol (µg/L)	Percent of Actual	RPD[2]
SH1	triclopyr	0.05	0.09	180%	57%	0.10	200%	67%
SH2	2,4-D	0.18	0.16	89%	12%	0.11	61%	48%
SH3	2,4-D	<0.03	<0.03	NA	NA	0	NA	NA
	triclopyr	<0.02	0.02	NA	NA	0.01	NA	NA
IN1	chlorothalonil	0.18	0.22	122%	20%	0.20	111%	11%
	metasystox-R	<2.60	<2.60	NA	NA	0.22	NA	NA
FH1	glyphosate	0.32	<0.20	NA	NA	0.17	53%	61%
FH2	glyphosate	0.56	0.70	125%	22%	0.84	150%	40%
FH3	glyphosate	0.23	0.39	170%	52%	0.30	130%	26%

1: Composite sample from first 24 hours following the application.

2: Relative Percent Difference (range expressed as a percent of the mean) between actual and calculated 24-hour average.

CONCLUSIONS AND RECOMMENDATIONS

In this section we summarize our conclusions and make recommendations for changes to the Best Management Practices to improve their effectiveness. Our recommendations are based on the results of our case studies as well as published information regarding pesticide application and avoidance of off-target deposition.

Conclusions

1. Based on results from our case studies which served as examples of typical BMP implementation, current BMPs are partially effective at meeting water quality standards regarding toxic levels of pesticides, but are not effective at complying with certain Forest Practice Rules provisions and Department of Agriculture provisions for adhering to EPA-approved label directions. These conclusions are summarized below in Table 22, which shows the results of the three effectiveness tests as applied to each study site.

Table 22: BMP Effectiveness Summary According to Three Tests of Effectiveness

Study Site	Adherence to Water Quality Criteria	Adherence to Forest Practice Regulations[1]	Adherence to EPA-Approved Pesticide Labels[2]
SH1	Effective	Not Effective	Not Effective
SH2	Effective[3]	Not Effective	Not Effective
SH3	Effective	Not Effective	Not Effective
IN1	Not Effective	Not Effective	Effective
FH1	Effective	Not Effective	Not Effective
FH2	Effective	Not Effective	Not Effective
FH3	Effective	Not Effective	Not Effective

1: Adherence to the provision on avoiding drift causing direct entry to waters (including Type 4 and 5 streams with surface water) or Riparian Management Zones.
2: Adherence to applicable label instructions regarding entry to waters (direct or indirect, depending on the product), avoidance of drift, and leaving adequate buffers, as determined by applying Washington State Department of Agriculture label interpretations.
3: Possible exceedance of criteria during runoff event.

2. Water quality criteria for two pesticides were exceeded in one of the seven case studies. This case was an application of a pesticide and fungicide at a Christmas tree plantation. In the six forest management herbicide applications studied, herbicide levels found in streams did not exceed water quality criteria. However, we believe the maximum concentrations observed in two of these six cases indicate that current forest pesticide application practices may result in peak stream concentrations that exceed the 2,4-D criterion of 4.0 μg/L when applied under similar conditions. These conditions are applications made with nozzle configurations that produce a relatively large proportion of fine spray droplets at sites where stream depth and discharge are critically low. In addition, it is our opinion that criteria for 2,4-D and other pesticides applied under current practices may be exceeded during runoff events that occur soon (within about 72 hours) after applications, or as a result of overspray of small streams mistakenly assumed to be dry. Therefore we conclude that current forestry BMPs are only partially effective at achieving water quality standards regarding pesticide toxicity.

3. The provision in the Forest Practice Rules on avoiding drift causing direct entry of pesticides into surface waters or Riparian Management Zones was not met in all seven cases. This provision may provide an important margin of safety to ensure that toxic levels of pesticides do not occur, but it is difficult to achieve as a practical matter.

4. In six of the seven cases, EPA-approved label directions on entry to surface waters and avoiding off-target drift were not adhered to according to Department of Agriculture regulations.

5. The most important factors influencing BMP effectiveness are:

   - proximity of spray swaths to streams (*i.e.*, buffer widths);
   - streamflow regimes (*i.e.*, the depth, surface area, and volume, and dispersion of surface water) as they affect dilution of pesticides;
   - application equipment configuration and operation, and resulting spray droplet size (*i.e.*, susceptibility to drift);
   - the ability of operators to identify surface flow in small streams;
   - weather factors including wind speed and precipitation (wind direction is an important factor where applications are made on only one side of streams, but it often turns out to be both favorable and unfavorable at the same spray unit);
   - pesticide toxicity and environmental fate characteristics;
   - topographic factors affecting release height and flight patterns; and
   - the presence of riparian vegetation and slash as they affect the degree to which stream surfaces are exposed to deposition.

6. Pesticide levels found in streams in this study were substantially lower than those found in several earlier studies where buffer zones were not used in application practices, indicating that buffer zones are an effective way to reduce pesticide entry to streams.

7. Entry of pesticides into streams in amounts which exceed recommended water quality criteria, Forest Practice Rules provisions, and/or pesticide label restrictions may occur even where 15-meter (50-foot) buffers, as delimited by a lack of effective herbicidal action, are left. Achieving buffer zones which are absolutely free of pesticides is probably not technologically feasible if an area is to be sprayed. However, wider buffer zones may eliminate the entry to streams of larger spray droplets, thereby ensuring that water quality criteria are not exceeded.

8. The majority of pesticide introduction into buffered streams was attributed to swath displacement and drift, with secondary contributions from overspray of small tributaries mistakenly assessed as not flowing and therefore not in need of buffers. In addition, runoff associated with precipitation events occurring soon after sprays can result in pesticide concentrations in streams which exceed levels caused by entry due to drift or swath displacement.

9. Overspray of small tributaries mistakenly thought to be dry at the time of spraying probably does not contribute greatly to peak concentrations observed downstream, but may be significant in terms of cumulative pesticide loading to streams and 24-hour average concentrations. Furthermore, overspray could result in acutely toxic concentrations of some pesticides in small tributaries with minor amounts of surface flow due to the small volume of water available for dilution. Although they are generally not fish-bearing, small headwater streams still harbor aquatic life, such as macroinvertebrates and amphibians, which are protected under state water quality standards.

10. In order to ensure that applications comply with Forest Practice Rules and label directions for products that prohibit direct application to water, as well as instantaneous water quality criteria, a more definitive determination that Type 4, 5, or untyped streams have no surface flow must be made before overspray can be authorized. On forest management units, it is generally not sufficient to rely on inspection of areas accessible by road or aerial surveillance to make this determination.

11. Application technologies and practices exist which minimize the production of small spray droplets, thereby minimizing off-target deposition. Using conventional jet spray type nozzles (without whirlplates), directed straight back (0°) has been shown to minimize the proportion of droplets $< 100\ \mu m$. This configuration may be used with commonly available equipment. Use of Raindrop® nozzles (large, low velocity hollow-cone nozzles) produces a droplet size spectrum that is intermediate between standard hollow-cone and jet spray type nozzles. Use of Raindrop® nozzles for herbicide applications would offer a distinct advantage over current practices (standard hollow-cone nozzles) in terms of minimizing small droplets most susceptible to drift. Use of specialized equipment such as the Microfoil® boom may be feasible for spraying near-stream areas on some sites, and helicopters could be adapted (*i.e.*, made convertible) for using different delivery systems on different portions of treatment areas, subject to

operational constraints such as topography. The use of different application systems for different zones of sensitivity is not currently an operational practice for forest pesticide application in Washington. There could be an environmental trade-off in that increasing droplet size reduces drift, but may require an increase in pesticide application rates.

Recommendations

1. Stream buffers should be established which will be more effective at meeting water quality standards and other applicable regulations. Different buffer widths should be used for upwind (*i.e.*, where the spray swath is upwind of the stream) and downwind applications. Spray swaths which are not directly downwind of streams (e.g., where wind direction is neutral) should be treated as upwind applications for the purposes of buffers. We recommend that minimum buffers of 15-25 meters for downwind applications and 75 to 90 meters for upwind applications be left along all flowing streams, including those with minor or intermittent flows. Wider buffers may be needed on steep terrain where spray release height exceeds 6 meters. These recommended buffers are intended to eliminate the introduction of larger spray droplets to streams, and are based on published studies of swath displacement, off-target deposition, and buffer effectiveness. These recommended buffers will not totally eliminate drift to streams.

   If feasible from a regulatory standpoint, it may be appropriate to specify different buffers for application of different pesticides, with buffer width based on pesticide toxicity. For forest and Christmas tree insecticides and Christmas tree fungicides, upwind buffers of 90 meters are recommended to ensure water quality criteria are met. For the herbicide 2,4-D and sprays where diesel is used as a carrier (e.g., dormant sprays), upwind buffers of 75 meters should be maintained to ensure water quality criteria are met. If the objective is to ensure that water quality criteria are not exceeded, buffers for less toxic herbicides may be less than 75 meters for upwind applications provided streamflow regimes are not critically low. Published studies of off-target downwind deposition indicate that 50-meter buffers may be adequate to meet water quality criteria for upwind applications of less toxic herbicides such as imazapyr, and for herbicides of intermediate toxicity such as triclopyr and glyphosate (with surfactant) where stream depth is about 0.25 meters or greater. (Note that these recommendations are based on avoidance of toxic levels of pesticides, and do not take into account the anti-degradation provisions of the water quality standards.)

   However, provisions of the Forest Practices Rules and/or label instructions regarding drift avoidance and entry to streams may dictate maintaining 75-90 meter buffers regardless of water quality criteria. Final buffer requirements should be established based on input from experts in the fields of agricultural engineering, forestry, pesticide application, and water quality. Computerized pesticide drift models may be useful in the evaluation of alternative practices. In addition to technical considerations, policy

guidance is needed to clarify goals regarding drift to surface waters, and what levels of drift are acceptable in RMZs, wetlands, and other sensitive areas. For example, it may be appropriate to re-evaluate or clarify the Forest Practices Rules provision requiring avoidance of "drift causing direct entry" to make it more consistent with technical realities. The preponderance of evidence indicates that drift (of the smallest droplets) is essentially unavoidable, while avoiding off-target deposition of larger droplets and swath displacement are achievable goals.

2. Buffers should be measured as a horizontal distance between the streambank and the edge of the effective swath. The purpose of the buffer is to accommodate deposition of the extended swath (the portion of the swath which flares out due to wind and/or aircraft-induced turbulence beyond the target swath), in order to achieve no entry of medium and large droplets and minimize the entry of small droplets within the active stream channel. The terms "buffer," "effective swath," and "extended swath" should be clearly defined in the Forest Practice rules. If the terms "drift" and "direct entry" continue to be used in a regulatory context, they should also be clearly defined in the rules and/or Forest Practices Board Manual.

3. The BMPs should include specifications for nozzle configurations and operating parameters which minimize the production of small droplets. Specifically, nozzle orientations of greater than 45° should not be allowed. Other specifications such as restrictions on the use of whirlplates and limitations on operating pressure may be appropriate, especially where needed for adherence to label instructions regarding aerial application equipment. The use of half-boom applications for swaths nearest streams may be another way to minimize introduction of pesticides to streams. Equipment or operational specifications such as these should be determined based on input from appropriate experts and evaluation of alternatives using computer models. In addition, some means of encouraging proper calibration of application equipment should be developed, either through regulatory requirements or educational outreach and applicator training.

4. There is a need to develop some consistency in label directions between different pesticide products, particularly with regard to entry to waters, drift avoidance, and application equipment. Ideally, the level of restrictions on entry to waters should correspond to aquatic toxicity of the pesticide formulation (including surfactants which are used), with the most stringent label language applied to the most toxic products. This is not currently the case. Inter-agency communication and cooperation may be the best way to achieve such consistency. Additionally, the Washington State Department of Agriculture should clarify its interpretations of label language regarding use of nozzles that produce small drops, specifically whether standard hollow-cone type nozzles are acceptable.

5. The feasibility and availability of alternate nozzles such as jet spray type or Raindrop® nozzles, or using alternate application systems such as the Microfoil® boom to apply

pesticides in the vicinity of streams, should be fully evaluated. If technologies proven to minimize the production of small droplets are used, the buffer widths recommended above may be reduced, but upwind buffers of at least 50 meters for hydraulic nozzles or 25 meters for Microfoil® boom applications should be maintained to accommodate the extended swath.

6. Develop more effective procedures for determining whether streams are dry or flowing at the time of spraying. Consider requiring applicators to assume that all streams are flowing and buffer accordingly unless direct observation of the channel is made (e.g., by walking). This requirement should apply to all streams, regardless of whether they are typed on DNR water type maps.

7. Consider establishing specific weather restrictions for wind, atmospheric boundary layer conditions, relative humidity, and temperature. Restrict applications when precipitation events can be reasonably expected to occur within 72 hours in order to avoid peak and 24-hour average concentrations which may be toxic to aquatic life. Specific weather restrictions should be developed based on input from appropriate experts on pesticide drift and swath displacement and/or evaluation of alternative restrictions using computer models.

8. As more information on the toxicity of herbicides to aquatic plants or other aquatic life such as amphibians becomes available, this should be incorporated into recommended water quality criteria. Ultimately, the criteria used to evaluate pesticide levels should be based on the most sensitive species potentially affected by the pesticide applied. This might be fish, macroinvertebrates, amphibians, or aquatic plants.

9. Although this study evaluated BMP effectiveness from the standpoint of impacts to surface waters, focusing primarily on forest management applications, there is a need to consider effects on the ground water resource for pesticide use on Christmas tree plantations. The toxicity of some of the pesticides, greater frequency of use, and application sites which are sometimes in the vicinity of domestic water supplies indicate a need to evaluate the potential for human health effects through well sampling and perhaps additional surface water monitoring.

REFERENCES

Bernhardt, J., J. Praveza, and H. Tracy. 1978. Aquatic Monitoring of the 1977 Spruce Budworm Sevin-4 Oil Aerial Spray Project in Washington State. Department of Ecology, Tech. Report DOE 78-4. 22 pp. Olympia, Washington.

Canadian Council of Resource and Environment Ministers. 1991. Canadian Water Quality Guidelines. Environment Canada, Water Quality Objectives Division. Ottawa, Ontario.

Feng, J.C., D.G. Thompson, and P.E. Reynolds. 1989. Fate of Glyphosate in a Forest Stream Ecosystem. *In* Proceedings of the Carnation Creek Herbicide Workshop., pp. 45-64. P.E. Reynolds, ed. Forest Pest Management Institute, Forestry Canada. Sault Ste. Marie, Ontario.

Feng, J.C. and D.G. Thompson. 1989. Persistence and Dissipation of Glyphosate in Foliage and Soils of a Coastal Canadian Forest Watershed. *In* Proceedings of the Carnation Creek Herbicide Workshop., pp. 65-87. P.E. Reynolds, ed. Forest Pest Management Institute, Forestry Canada. Sault Ste. Marie, Ontario.

Fredriksen, R.L., D.G. Moore, and L.A. Norris. 1975. The Impact of Timber Harvest, Fertilization, and Herbicide Treatment on Streamwater Quality in Western Oregon and Washington. *In* Forest Soils and Forest Land Management. pp. 283-313. B. Bernier and C.H. Winget, eds. Les Presses de l'Universite', Laval, Quebec.

Gratkowski, H. 1974. Herbicidal Drift Control: Aerial Spray Equipment, Formulations, and Supervision. General Technical Report PNW-14. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. 12 pp. Portland, Oregon.

Graves, R.L. 1989. Method 515.1 Determination of Chlorinated Acids in Water by Gas Chromatography with an Electron Capture Detector, Revision 4.0. U.S. Environmental Protection Agency, Environmental Monitoring Systems Laboratory, Office Of Research and Development. Cincinnati, Ohio.

Holtby, L.B. and S.J. Baillie. 1989. Effects of the Herbicide Roundup on Coho Salmon Fingerlings in an Oversprayed Tributary of Carnation Creek, British Columbia. *In* Proceedings of the Carnation Creek Herbicide Workshop., pp. 273-285. P.E. Reynolds, ed. Forest Pest Management Institute, Forestry Canada. Sault Ste. Marie, Ontario.

Markin, G. 1982. Drift of Insecticidal Spray by Cold Air Drainage Winds in Western Mountains. Research Note PSW-360. USDA Forest Service, Pacific Southwest Forest and Range Experiment Station. Berkeley, California.

Monsanto Company. 1992. Unpublished toxicity test data provided to Department of Ecology. Monsanto Company, St. Louis, Missouri.

National Academy of Sciences. 1973. Water Quality Criteria 1972. EPA/R3-73-033. National Academy of Sciences. Washington, D.C.

NCASI. 1992. The Effectiveness of Buffer Strips for Ameliorating Offsite Transport of Sediment, Nutrients, and Pesticides from Silvicultural Operations. Tech. Bulletin No. 631. National Council of the Paper Industry for Air and Stream Improvement. 48 pp. New York, New York.

Newton, M. and J.A. Norgren. 1977. Silvicultural Chemicals and Protection of Water Quality. EPA 910/9-77-036. U.S. Environmental Protection Agency, Region 10. Seattle, Washington.

Newton, M. K.M. Howard, B.R. Kelpsas, R. Danhaus, C.M. Lottman, and S. Dubelman. 1984. Fate of Glyphosate in an Oregon Forest Ecosystem. Journal of Agricultural and Food Chemistry, Vol. 32, No. 5:1144-1151.

Norris, L.A., H.W. Lorz, and S.V. Gregory. 1991. Influences of Forest and Rangeland Management on Salmonid Fishes and Their Habitats, Chapter 7: Forest Chemicals. American Fisheries Society special Publication 19:207-296.

Norris, L.A. and F. Dost. 1992. Proposed Surface Water Quality Criteria for Selected Pesticides Used for Forest Management and Management of Forest Tree Seedling Nurseries and Christmas Tree Plantations in Oregon and Washington. Oregon State University. Corvallis, Oregon.

Oppenhuizen, Mark E. and John E. Cowell. 1991. Liquid Chromatographic Determination of Glyphosate and Aminomethylphosphonic Acid (AMPA) in Environmental Water: Collaborative Study. J. Assoc. Off. Anal. Chem. Vol. 74, No. 2.

Oregon State Department of Forestry. 1989. Water Sampling Procedures for Use in Enforcement, Complaint Investigation and Monitoring, Revised 2/28/89. Salem, Oregon.

Oregon State Department of Forestry. 1992. Forest Herbicide Application Water Sampling Study. Forest Practices Program, Oregon Department of Forestry. Salem, Oregon.

Payne, N., J. Feng and P. Reynolds. 1989. Off-Target Deposit Measurement and Buffer Zones Required Around Water for Various Aerial Applications of Glyphosate. *In* Proceedings of the Carnation Creek Herbicide Workshop., pp. 88-109. P.E. Reynolds, ed. Forest Pest Management Institute, Forestry Canada. Sault Ste. Marie, Ontario.

PTI Environmental Services. 1991. A Project Manager's Guide to Requesting and Evaluating Chemical Analyses. EPA 910/9-90-024. U.S. Environmental Protection Agency, Region 10, Office of Coastal Waters. Seattle, Washington.

Rashin, E. 1992. Evaluation of the Effectiveness of Best Management Practices for Aerial Application of Forest Herbicides and Insecticides--Scope of Work. Washington State Department of Ecology. Olympia, Washington.

Robinson, T. 1993. Personal communication (telephone) to Ed Rashin, January 27, 1993. Forest Practices Division, Washington Department of Natural Resources. Olympia, Washington.

Thompson, D.G., B. Staznik, D.D. Fontaine, T. Mackay, G.R. Oliver, and J. Troth. 1991. Fate of Triclopyr Ester (Release) in a Boreal Forest Stream. Environmental Toxicology and Chemistry, Vol. 10:619-632.

Tracy, Harry B., John Bernhardt, Douglas Freeman, and Bill Purvis. 1977. A Report on Aquatic Monitoring of the 1976 Spruce Budworm Control Project in Washington State. Department of Ecology, Tech. Report DOE 77-3. 50 p. Olympia, Washington.

University of Arizona. 1983. Reducing Pesticide Application Drift Losses. Cooperative Extension Service, College of Agriculture, University of Arizona. 27 pp. Tucson, Arizona.

U.S. Environmental Protection Agency. 1986. Test Methods for Evaluating Solid Waste (SW- 846): Physical/Chemical Methods. U.S. Environmental Protection Agency, Office of Solid Waste. Washington, D.C.

U.S. Food and Drug Administration. 1975. Pesticide Analytical Manual, Volume 2, Pesticide Reg. Sec. 180.33. U.S. Department of Health and Human Services, Food and Drug Administration. Washington, D.C.

Washington Administrative Code. 1992. Water Quality Standards for Surface Waters of the State of Washington. Chapter 173-201A WAC. Olympia, Washington.

Washington State Department of Ecology. 1992. Total Petroleum Hydrocarbons Analytical Methods for Soil and Water (Method WTPH-D for Diesel in Water). *In* Guidance for Remediation of Releases From Underground Storage Tanks, Appendix L (pp. 131). Washington State Department of Ecology. Olympia, Washington.

Washington State Department of Natural Resources. 1990. Controlling Competing Vegetation Guideline, Appendix K--Water Monitoring and Spray Cards. Forest Land Management Division. 8 pp. Olympia, Washington.

Washington State Forest Practices Board. 1988. Washington Forest Practices Rules and Regulations. Title 222 WAC. November 1, 1988. pp. 48-50. Olympia, Washington.

Yates, W.E., N.B. Akesson, and D. Bayer. 1976. Effects of Spray Adjuvants on Drift Hazards. Transactions of the ASAE 1976, pp. 41-46.

Yates, W.E., N.B. Akesson, and R.E. Cowden. 1984. Measurement of Drop Size Frequency from Nozzles Used for Aerial Application of Pesticides in Forest. U.S.D.A. Forest Service, Equipment Development Center. Missoula, Montana.

APPENDIX A
1991 BMPs for Aerial Application of Forest Pesticides: 1988 Forest Practices Rules

(b) Lands being acquired by public agency for construction within 10 years of a project inconsistent with timber production, if at the time of completion of harvest the public agency has entered into a binding contract for the purchase of the lands or initiated legal proceedings for the condemnation of the lands.

Chapter 222-38 WAC
FOREST CHEMICALS

WAC

222-38-010 Policy—Forest chemicals.
222-38-020 Handling, storage, application.

Reviser's note: For an explanation of the rules marked with an asterisk (*), see WAC 222-12-010.

WAC 222-38-010 Policy—Forest chemicals. Chemicals perform important functions in forest management. The purpose of these regulations is to regulate the handling, storage and application of chemicals in such a way that the public health, soils, wildlife and aquatic habitat will not be endangered by contamination. This section in no way modifies the state department of agriculture regulations governing chemicals. (NOTE: OTHER LAWS AND REGULATIONS AND/OR PERMIT REQUIREMENTS MAY APPLY. SEE CHAPTER 222-50 WAC.)

WAC 222-38-020 Handling, storage, application.

*(1) **No pesticide leakage, contamination, pollution.**
(a) No person shall transport, handle, store, load, apply, or dispose of any pesticide, pesticide container or apparatus in such a manner as to pollute water supplies or waterways, or cause damage or injury to land, including humans, desirable plants, and animals.
(b) The department or the department of agriculture may suspend further use of any equipment responsible for chemical leakage, until the deficiency has been corrected to the satisfaction of the department suspending its usage.

*(2) **Streams, lakes and public waters.** No person shall pollute streams, lakes, and other public water supplies in their pesticide loading and mixing operation. Use devices or procedures to prevent "back siphoning" such as providing an air gap or reservoir between the water source and the mixing tank.

*(3) **Mixing and landing areas.**
(a) Mix chemicals and clean tanks and equipment only where any accidental spills would not enter any water types.
(b) Landing areas should be located where accidental spillage of chemicals will not cause them to become a contaminant. If any chemical is spilled, immediate appropriate procedures should be taken to contain or neutralize it.

*(4) **Riparian management zone.** Chemical treatments within the riparian management zone shall be by hand unless the department has approved a site specific plan with another method of treatment.

*(5) **Aerial application.**
(a) To keep chemicals out of the water, leave a 50 foot buffer strip on Type 1, 2, 3 and flowing Type 4 and 5 Waters and other areas of open water, such as ponds or sloughs. Do not spray chemicals in buffer strips or riparian management zones. Provided that fertilizers may be applied to within 25 feet of the water.
(b) Apply the initial swath parallel to the buffer strip in (a) of this subsection on Type 1, 2, 3 or flowing Type 4 and 5 Waters. Parallel flight adjacent to all buffer strips shall be required unless a deviation is approved in advance by the department. Drift control agents shall be required adjacent to buffer strips.
(c) Use a bucket or spray device capable of immediate shutoff.
(d) Shut off chemical application during turns and over open water.
(e) Do not allow direct entry of chemicals into any Type 1, 2, 3 or flowing Type 4 and 5 Waters.
(f) Leave at least 200 foot buffer strip around residences and 100 foot buffer strip adjacent to lands used for agriculture unless such residence or farmland is owned by the forest landowner or the aerial application is acceptable to the resident or landowner.
(g) The landowner shall identify for the operator the units to be sprayed and the untreated areas within the units so they are visible from the air. Before application of the chemical an over-flight of the area shall be made by the pilot and a responsible agent of the landowner.
(h) Aerial chemical application areas shall be posted by the landowner by signing at significant points of regular access at least 5 days prior to treatment. Posting shall remain at least 15 days after the spraying is complete. Posting at formal, signed trailheads that are adjacent to aerially treated units is required. The signs will contain the name of the product used, date of treatment, and a contact telephone number.
(i) Any water purveyor of a certified Class 1, 2 or 3 system, as defined in WAC 248-54-015, may request the department to designate lands within the watershed upstream of the surface water intake of the affected water supply as an "area of water supply interest." Prior to requesting such designation, the purveyor shall personally or by certified mail deliver to each landowner of record within such area, a copy of the request, a map showing proposed area boundaries and the name and address of the purveyor. The department may designate an "area of water supply interest" in such area(s) where it determines that the aerial application of pesticides may adversely impact the affected water supply. Where the department has designated an "area of water supply interest," it shall notify the purveyor of any Class IV Forest Practices for the aerial application of pesticides.

*(6) **Stream protection - ground application with power equipment.**
(a) Leave a 10 foot buffer strip on each side of every Type 1 and 2 Water and each flowing Type 3 Water.
(b) Do not allow entry of chemicals into any water.

(c) Do not exceed allowable dosages.

*(7) **Stream protection – hand application.** Apply only to specific targets, such as a stump, burrow, bait or trap.

*(8) **Limitations on application.** Chemicals shall be applied only in accordance with all limitations:

(a) Printed on the United States Environmental Protection Agency container registration label, and/or

(b) Established by regulation of the state department of agriculture.

(c) Established by state and local health departments (in municipal watersheds).

(d) Established by the Federal Occupational Safety and Health Administration, or the state department of labor and industries, as they relate to safety and health of operating personnel and the public.

*(9) **Container disposal.** Chemical containers shall be either:

(a) Removed from the forest and disposed of in the manner consistent with label directions; or

(b) Removed and cleaned for reuse in a manner not inconsistent with any applicable regulations of the state department of agriculture or the state or local health departments.

*(10) **Daily records – aerial application of pesticides.** On all aerial applications of pesticides, the operator shall maintain for 3 years daily records of spray operations as required by the state department of agriculture WAC 16-228-190.

*(11) **Reporting of spills.** All potentially damaging chemical spills shall be immediately reported to the department of ecology.

Chapter 222-42 WAC
SUPPLEMENTAL DIRECTIVES

WAC

222-42-010 Supplemental directives.

WAC 222-42-010 Supplemental directives.

(1) **Purpose of supplemental directives.** The department may issue supplemental directives to the forest landowner, timber owner and operator, advising them to take or not take as part of any forest practice operations specified actions the department determines to be preferred courses of action or minor changes in the operation to provide greater assurance that the purposes and policies set forth in RCW 76.09.010 of the act will be met.

(2) **Content of supplemental directives.** Supplemental directives shall indicate the reason for their issuance.

(3) **Form, service.** All supplemental directives shall either be in writing, or be confirmed in writing. The supplemental directive shall be given to the operator and a copy mailed promptly to the forest landowner and to the timber owner if different than the forest landowner.

(4) **Directive constitutes approval.** No other approval of the department shall be necessary to conduct forest practice operations in compliance with the terms of a supplemental directive.

(5) **Informal discussions.** The department shall provide an opportunity for an informal discussion before issuing, withdrawing or modifying a supplemental directive.

Chapter 222-46 WAC
ENFORCEMENT

WAC

222-46-010 Policy—Enforcement.
222-46-020 Informal conferences.
222-46-030 Notice to comply.
222-46-040 Stop work orders.
222-46-050 Corrective action.
222-46-060 Civil penalties.
222-46-070 Injunctions, civil suits,
222-46-080 Criminal penalty.

WAC 222-46-010 Policy—Enforcement. It is the policy of the act and the board to encourage informal, practical, result-oriented resolution of alleged violations and actions needed to prevent damage to public resources. It is also the policy of the act and the board to provide, consistent with the principles of due process, effective procedures for enforcement. This part of these regulations provides the following enforcement procedures: Informal conferences; notices to comply; stop work orders; corrective actions by the department; civil penalties; injunctions and other civil judicial relief; and criminal penalties. The enforcement procedure used in any particular case shall be appropriate in view of the nature and extent of the violation or the damage or risk to public resources and the degree of bad faith or good faith of the persons charged.

WAC 222-46-020 Informal conferences.

(1) **Opportunity mandatory.** The department shall afford the operator or his representative reasonable opportunities to discuss proposed enforcement actions at an informal conference prior to taking further enforcement action, unless the department determines that there may be imminent damages to the public resource. Informal conferences may be used at any stage in enforcement proceedings, except that the department may refuse to conduct informal conferences with respect to any matter then pending before the appeals board or a court.

(2) **Reports required.** Department personnel in attendance at informal conferences shall keep written notes of the date and place of the conference, the persons in attendance, the subject matter discussed, and any decisions reached with respect to further enforcement action.

APPENDIX B

Current BMPs for Aerial Application of Forest Pesticides: Forest Practice Rules Adopted June 26, 1992

Chapter 222-38 WAC
Forest Chemicals

WAC

222-38-010 Policy--Forest chemicals.
222-38-020 Handling, storage and application of pesticides.
222-38-030 Handling, storage and application of fertilizers.
222-38-040 Handling, storage and application of other forest chemicals.

NOTES:
Reviser's note: For an explanation of the rules marked with an asterisk (*), see WAC 222-12-010.

WAC 222-38-010 Policy--Forest Chemicals.

Chemicals perform important functions in forest management. The purpose of these regulations is to regulate the handling, storage and application of chemicals in such a way that the public health, lands, fish, wildlife, aquatic habitat, and water quality will not be endangered by contamination. This section in no way modifies the state department of agriculture regulations governing chemicals.
(NOTE: OTHER LAWS AND REGULATIONS AND/OR PERMIT REQUIREMENTS MAY APPLY. SEE CHAPTER 222- 50 WAC.)

WAC 222-38-020 Handling, Storage, and Application of Pesticides.

*(1) NO PESTICIDE LEAKAGE, CONTAMINATION, POLLUTION. Transportation, handling, storage, loading, application, and disposal of pesticides shall be consistent with applicable label requirements and other state and federal requirements.

*(2) MIXING AND LOADING AREAS.
(a) Mix pesticides and clean tanks and equipment only where any accidental spills would not enter surface water or wetlands.
(b) Storage and loading areas should be located where accidental spillage of pesticides will not enter surface water or wetlands. If any pesticide is spilled, immediate appropriate procedures should be taken to contain it.
(c) Use devices or procedures to prevent "back siphoning" such as providing an air gap or reservoir between the water source and the mixing tank.

This chapter has been restructured to address chemicals in three separate groupings; pesticides, fertilizers, and other forest chemicals. The chapter has been simplified. The application of chemicals must be conducted in compliance with the instructions found on the EPA label and in compliance with the rules established by the Washington Department of Agriculture. The "area of water supply interest" has been replaced with a more comprehensive determination method described in the new WAC 222-16-050(1) (a) and WAC 222-16-070.

*(3) RIPARIAN MANAGEMENT ZONE. PESTICIDE treatments within the riparian management zone shall be by hand unless the department has approved a site specific plan with another method of treatment.

*(4) WETLAND MANAGEMENT ZONE. Pesticide treatment within the wetland management zone shall be by hand unless the department has approved a site specific plan with another method of treatment.

*(5) AERIAL APPLICATION OF PESTICIDES.

(a) To keep pesticides out of the water, leave a 50 foot buffer strip on all Typed Waters, except segments of Type 4 and 5 Waters with no surface water and other areas of open water, such as ponds or sloughs.

(b) Apply the initial swath parallel to the buffer strip in (a) of this subsection unless a deviation is approved in advance by the department. Drift control agents shall be required adjacent to buffer strips. Avoid applications that might result in drift causing direct entry of pesticides into riparian management zones, Type A and B Wetlands, wetland management zones, and all Typed Waters, except segments of Type 4 and 5 Waters with no surface water.

(c) Use a bucket or spray device capable of immediate shutoff.

(d) Shut off spray equipment during turns and over open water.

(e) Leave at least a 200 foot buffer strip around residences and 100 foot buffer strip adjacent to lands used for agriculture unless such residence or farmland is owned by the forest landowner or the aerial application is acceptable to the resident or landowner.

(f) The landowner shall identify for the operator the units to be sprayed and the untreated areas within the units with appropriately marked aerial photos or detailed planimetric maps. Before application of the pesticide an over-flight of the area shall be made by the pilot with the marked photos or maps.

(g) Aerial chemical application areas shall be posted by the landowner by signing at significant points of regular access at least 5 days prior to treatment. Posting shall remain at least 15 days after the spraying is complete. The department may require an extended posting period in areas where human use or consumption of plant materials is probable. Posting at formal, signed trailheads that are adjacent to aerially treated units is required. The signs will contain the name of the product used, date of treatment, a contact telephone number, and any applicable restrictions.

*(6) GROUND APPLICATION OF PESTICIDES WITH POWER EQUIPMENT.
Leave a 25-foot buffer strip on each side of Type A or B Wetland and all typed waters, except segments of Type 4 and 5 Waters with no surface water.

*(7) HAND APPLICATION OF PESTICIDES. Apply only to specific targets, such as vegetation, trees, stumps, and burrows, or as bait or in traps.

Check pesticide E.P.A. labels to determine whether the chemical is approved for wetland use. The change regarding streams with "no evidence of surface water" is intended to protect these streams that may run below the gravel with emergent pools for some portion of the year, the pooled water must be protected.

This subsection is intended to comply with F.A.A. flight regulations regarding passengers in spray ready aircraft.

This posting requirement is intended to provide information to individuals who may inadvertently enter a recently sprayed unit.

*(8) LIMITATIONS ON APPLICATION. Pesticides shall be applied only in accordance with all limitations:

(a) Printed on the United States Environmental Protection Agency container registration label, and/or

(b) Established by regulation of the state department of agriculture.

(c) Established by state and local health departments (in municipal watersheds).

(d) Established by the Federal Occupational Safety and Health Administration, or the state department of labor and industries, as they relate to safety and health of operating personnel and the public.

(e) The department or the department of agriculture may suspend further use of any equipment responsible for chemical leakage until the deficiency has been corrected to the satisfaction of the department suspending its usage.

*(9) CONTAINER DISPOSAL. Pesticide containers shall be either:

(a) Removed from the forest and disposed of in the manner consistent with label directions; or

(b) Removed and cleaned for reuse in a manner consistent with any applicable regulations of the state department of agriculture or the state or local health departments.

*(10) DAILY RECORDS - AERIAL APPLICATION OF PESTICIDES. On all aerial applications of pesticides, the operator shall maintain daily records of spray operations as required by the state department of agriculture WAC 16-228-190.

*(11) REPORTING OF SPILLS. All potentially damaging chemical spills shall be immediately reported to the department of ecology. Emergency telephone numbers for reporting spills shall be available at the department's regional offices.

The department's regional offices must make the appropriate emergency telephone numbers available to the staff and the public. For spill information contact the Department of Ecology. For Pesticide applications violations contact the Washington Department of Agriculture.

New Section
WAC 222-38-030 Handling, Storage, and Application of Fertilizers.

***(1) Storage and Loading Areas. Storage and loading areas should be located where accidental spillage of fertilizers will not enter surface water or wetlands. If any fertilizer is spilled, immediate appropriate procedures shall be taken to contain it.**

***(2) Riparian Management Zone. Fertilizer treatments within a riparian management zone shall be by hand unless the department has approved a site specific plan with another method of treatment.**

***(3) Wetland management zone. Fertilizer treatments within a wetland management zone shall be by hand unless the department has approved a site specific plan with another method of treatment.**

The TFW Cooperative Monitoring Evaluation and Reasearch Committee sponsored a research and monitoring effort on the application of urea fertilizer and its impacts on water quality. These rules are based on the results of that study.

APPENDIX C

Department of Agriculture Policy Regarding Pesticide Drift and Adherence to EPA Pesticide Product Registration Labels

C. ALAN PETTIBONE
Director

STATE OF WASHINGTON
DEPARTMENT OF AGRICULTURE
P.O. Box 42560 • Olympia, Washington 98504-2560 • (206) 753-5063

July 17, 1992

Mr. Ed Rashin
Watershed Assessments Section
Department of Ecology
7171 Cleanwater Lane, Bldg. 8
P.O. Box 47710
Olympia, WA 98504-7710

Dear Mr. Rashin:

In response to your letter dated June 23, I am sending you a copy of the American Association of Pesticide Control Officials (AAPCO) Drift Enforcement Policy. The Department of Agriculture will use this policy in enforcement situations, particularly as it applies to the definition of drift.

I am also including the following excerpt from a 1990 letter written by the Director of the Department of Agriculture in which he explains the departments policy of pesticide drift enforcement:

"...Every pesticide application that results in regulatory action must present a set of evidence that places the application in violation of a specific law or administrative code. Two statutory sections and two administrative code sections come into play when investigating complaints of pesticide drift. The pertinent sections are as follows:

RCW 15.58.150(2)(c) It shall be unlawful...for any person to use or cause to be used any pesticide contrary to label directions or to regulations of the director (of agriculture) if those regulations differ from or further restrict the label directions...

RCW 17.21.150(4) A person who has committed any of the following acts is declared to be in violation of this chapter...(4) operated in a faulty, careless, or negligent manner...

WAC 16-228-160(1) No person shall handle, transport, store, display, apply, dispose of or distribute pesticides in such a manner as to endanger humans and their environment...

WAC 16-228-185(2) No person shall transport, handle, store, load, apply, or dispose of any pesticide container or pesticide apparatus in such a manner as to pollute water supplies or waterways, or cause damage or injury to land, including humans, desirable plants and animals, or wildlife...

These sections are the basis of investigating any complaint of pesticide drift. The evidence collected by WSDA investigators is tested against these laws and rules to determine if a violation has occurred. We question:

-were the label instructions violated,
-was the application faulty, careless or negligent,
-was there endangerment, and
-did damage or injury occur.

If the answer to one or more of these is yes, a violation has occurred."

Hopefully, the above information will answer your question regarding the department's definition of and enforcement policy regarding drift.

The department interprets "direct application" literally. Whether the application is made intentionally or inadvertently, it is a "direct application" if made immediately over the site in question. Direct application would not include off-target drift.

In response to your questions regarding specific pesticide products, I have the following comments:

1. Garlon 4 (EPA Reg. No. 464-554) - Under Environmental Hazards, the label states "Keep out of lakes, ponds or streams." If detectable levels of a pesticide in a stream can be tied directly to a specific application, enforcement action would be indicated based on use contrary to label directions.

2. Weedone LV-4 (EPA Reg. No. 264-20) - Under Environmental Hazards, the label states "Do not apply directly to water or wetlands..." "Do not apply when weather conditions favor drift from treated areas." If, during an investigation, it could be proved that the pesticide was applied <u>directly</u> over water or applied in weather conditions that <u>obviously</u> favored drift onto water, enforcement action would be indicated based upon use contrary to label directions.

3. Accord (EPA Reg. No. 524-326) - The label allows the use of this material in and around water. Under Application Equipment and Techniques, the label states "Avoid drift..." Again, if drift can be proved, enforcement action would be indicated; however, the main concern with this pesticide is drift and subsequent damage to desirable vegetation, not drift onto water.

4. Arsenal Applicators Concentrate (EPA Reg. No. 241-299) - Under Environmental Hazards, the label states "Do not apply directly to water or wetlands." Under Mixing and Application Instructions, the label states "Maintain adequate buffer zones to insure that drift does not occur off the target site." Although the label does not specify what an adequate buffer zone is, it would seem reasonable to assume that if off-target drift did occur, the buffer zones were not adequate.

5. Metasystox-R (EPA Reg. No. 3125-111) - Same general wording as the Weedone LV-4 label. Same response.

6. Bravo (EPA Reg. No. 50534-188) - Same general wording as Weedone LV-4 and Metasystox-R. Same response.

I have addressed only the question of "use contrary to label directions". Because the department does not find an application to be contrary to label directions, does not necessarily mean that no enforcement action will be taken. As stated earlier, there are other factors involved, such as whether the application was performed in a faulty, careless or negligent manner, whether endangerment occurred, or whether the application resulted in damage or injury.

If you have any further questions, please call me at 206-753-5064.

Sincerely,

PESTICIDE MANAGEMENT DIVISION

Ted Maxwell

Ted Maxwell
Chief, Registration and Services

TCM:c

MODEL AAPCO PESTICIDE DRIFT ENFORCEMENT POLICY
Adopted at the March 11-13, 1991 AAPCO Spring Meeting

Definitions.

(1) "Pesticide drift" means the physical movement of pesticide through the air at the time of pesticide application or soon thereafter from the target site to any non- or off-target site. Pesticide drift shall not include movement of pesticides to non- or off-target sites caused by erosion, migration, volatility or windblown soil particles that occurs after application unless specifically addressed on the pesticide product label with respect to drift control requirements.

(2) "Sufficient quantity to cause injury" means an amount of pesticide which will:

(a) cause a pesticide residue in excess of the established tolerance for the pesticide on the particular non-target agricultural commodity or that otherwise prevents the lawful marketing of the commodity; and/or

(b) endanger or cause injury to the off-target environment, including persons, desirable vegetation, animals or wildlife; and/or

[Option] (c-1) cause a measurable amount of pesticide which is objectionable to the owner or resident of the non-target site and/or otherwise disrupts the normal use of the non-target site.

[Option] (c-2) cause a measurable amount of pesticide which results in disruption of the normal use of the non-target site.

(3) "Due care" means conduct in such a manner that all reasonable and prudent precautions are taken to avoid the possibility of pesticide drift. The following factors should be considered: the pesticide formulation, toxicity and labeling; type and condition of the application equipment; weather conditions; location of target site; location, nature and use of the surrounding non-target sites; and other related factors.

Prohibited or violative act. No person shall make an application of a pesticide:

(1) inconsistent with its label or labeling, FIFRA Sec. 2(ee) recommendation, or rules of this state; or

(2) under conditions that result in pesticide drift of sufficient quantities to cause injury; or

(3) in such a manner that the person failed to exercise due care to prevent pesticide drift.

APPENDIX D
Operator Questionnaire

OPERATOR QUESTIONNAIRE
FOREST CHEMICALS MONITORING PROJECT

Landowner: _____

Person(s) completing questionnaire: _____

Name of Unit: _____ Legal Description: _____

Date of Application: _____

Please fill in your measurements of:

	TIME	TIME	TIME	TIME	TIME	TIME	TIME	TIME	TIME
	____	____	____	____	____	____	____	____	____
WIND SPEED:	____	____	____	____	____	____	____	____	____
WIND DIRECTION:	____	____	____	____	____	____	____	____	____
RELATIVE HUMIDITY:	____	____	____	____	____	____	____	____	____

Start Time of Spraying: _____

Stop Time of Spraying: _____

Approximate Acres Sprayed: _____ % of Unit: _____

Please indicate which streams were buffered (considered flowing) and which were not (considered dry) and show flight paths and directions on the attached unit map; please indicate the order of spraying as well.

Target Vegetation: _____

Active Ingredient Herbicide(s): _____ Amount/acre: _____

Secondary Herbicide: _____ Amount/acre: _____

Surfactant added: _____ Amount/acre: _____

Other additives: _____ Amount/acre: _____

_____ Amount/acre: _____

Carrier used: _____ Amount/acre: _____

_____ Amount/acre: _____

Application Rate for Final Spray Mix: _____

Batch Volume (Capacity of Tank): _____

Helicopter Model: _____ Effective Swath Width: _____

Flight Altitude: _____ Airspeed: _____ Boom Length: _____

Flight Centerline Offset from Buffers: _____

Nozzle Type: _____ Nozzle Size: _____ # of Nozzles: _____

Nozzle Orientation Angle: _____ Operating Pressure: _____

APPENDIX E
Laboratory Results

Notes on Data Qualifiers:

Some of the individual results in this appendix have been given data qualifiers by the reviewing chemist from Manchester Laboratory. The most common qualifier is "J". According to EPA's Contract Laboratory Program (CLP), this qualifier indicates that the analyte was positively identified, but the associated numerical value is an estimate and may not be consistent with the actual amount present in the sample (PTI Environmental Services, 1991). Still, the data are useable for most purposes. The most common reason for data receiving a "J" qualifier in this study is for values near the detection limit (this is the case with many of the glyphosate analysis results). In addition, all positive results for metasystox-R were flagged with a "J" because the recommended time lapse between extraction and analysis (i.e. holding time) was exceeded by about 25% (although holding time recommendations for time from collection to extraction were met). The chemist indicated that the holding time exceedance probably did not effect the results, but that CLP guidelines called for the data qualifier. Two of the triclopyr sample results were flagged with a "J" because of surrogate spike recoveries less than 25%. Other than these two samples, none of the data was qualified based on quality control sample results. These "J" qualifiers are indicated in Appendix E, but not in the graphical displays presented in the case summaries.

Another common data qualifier is "U", meaning "undetected", or "less than". This qualifier is given when the analyte was not present in concentrations at or above the associated numerical value, which indicates the approximate concentration necessary to detect the analyte in that sample. For individual samples, it is possible to detect concentrations below the typical detection level for a batch of samples, where the "noise level" for that particular sample is lower. Such results are given a "J" qualifier. In some of the glyphosate and imazapyr data sets, the undetected results are given a "UJ" qualifier. Like the "U" qualifier, this indicates an undetected result, but in this case the numerical value of the detection limit is itself an estimate, meaning it may not accurately or precisely represent the concentration necessary to detect the analyte in that sample. This qualifier was given by Manchester Laboratory's reviewing chemist in cases where the detection limit reported by A&S Environmental Testing Laboratory was lower than the lowest calibration standard used for that batch of samples.

Calculated 24-hour Average Values:

The tables in this appendix contain calculated 24-hour average values in addition to analytical results. These are time-proportionate averages calculated according to two monitoring protocols discussed in the report: the "Recommended Protocol" and the "Oregon Protocol". Time weighting factors are applied to discrete grab sample results to obtain the averages.

For the Recommended Protocol, the 24-hour average is calculated by the formula:

$$\textbf{24-hr Average} = \textbf{30-min}(0.03) + \textbf{1-hr}(0.03) + \textbf{2-hr}(0.06) + \textbf{4-hr}(0.08) + \textbf{6-hr}(0.30) + \textbf{24-hr}(0.50)$$

In the Recommended Protocol, grab sample results reported as less than detection limits are assumed to have a value of one-half the detection limit. The exception to this are cases where 50% or more of the grab samples, *including* the 24-hour grab, are less than detection limits, in which case the 24-hour average is determined to be "less than" the detection level reported for the grab samples.

For the Oregon Protocol, the 24-hour average is calculated by the formula:

$$\textbf{24-hr Average} = \textbf{15-min}(0.08) + \textbf{4-hr}(0.17) + \textbf{8-hr}(0.25) + \textbf{24-hr}(0.50)$$

In the Oregon Protocol, grab sample results reported as less than detection limits are assumed to have a value of zero for purposes of the calculation.

SH1 – Bigwater Creek Unit

UNIT SPRAYED 4/18/91 FROM 10:30 TO 11:51. STREAMSIDE BUFFER UPSTREAM OF STATION A SPRAYED @ 11:12. TIME–OF–TRAVEL FROM MID–UNIT TO STATION A = 40 MINUTES. GRAB SAMPLES TIMED FROM 11:52; COMPOSITORS TIMED FROM 12:21. FOR STATION B, STREAMSIDE BUFFER SPRAYED 10:50–10:53 (WEST SIDE) AND 11:20–11:30 (EASTSIDE) AND COMPOSITORS TIMED FROM 12:06.

SAMPLE DESCRIPTION	FIELD ID #	LAB ID #	DATE	TIME	TRICLOPYR (ug/L)	Q*	MEAN** VALUE	DIESEL (ug/L)	Q*
Compositor Control Sample–St B	SH1B–09	168289	18–Apr–91	06:20	0.01	U		34.2	U
Control Grab Sample–St A	SH1A–08	168288	18–Apr–91	07:00	0.01	U		16	U
15 Minute Grab	SH1A–01	168281	18–Apr–91	12:15	0.78			17.5	U
30 Min. Grab (= 30'Plus Grab)	SH1A–02	168282	18–Apr–91	12:28	1.37			20.2	U
Duplicate of 30 Min. Grab	SHIA–06	168286	18–Apr–91	12:28	1.21		1.29	16	U
1 Hour Grab	SH1A–03	168283	18–Apr–91	12:55	0.74			15.8	U
Replicate of 1 Hour Grab	SH1A–11	168291	18–Apr–91	12:55	0.44		0.59	16.9	U
2 Hour Grab	SHIA–04	168284	18–Apr–91	13:55	0.31			16.2	U
Replicate of 2 Hour Grab	SH1A–17	168297	18–Apr–91	13:55	0.27		0.29	15.7	U
3 Hour Grab	SHIA–05	168285	18–Apr–91	14:55	0.14			16	U
4 Hour Grab (= 4 Hr Plus Grab)	SHIA–07	168287	18–Apr–91	15:55	0.09			18.6	U
6 Hour Grab	SH1A–10	168290	18–Apr–91	17:55	0.02			16.3	U
8 Hour Grab	SH1A–15	168295	18–Apr–91	19:55	0.07			16.4	U
10 Hour Grab (= 10 Hr Plus Grab)	SH1A–16	168296	18–Apr–91	21:55	0.01	U		16	U
12 Hour Grab	SH1A–18	168298	18–Apr–91	00:07	0.01	U		16.3	U
16 Hour Grab	SH1A–27	168307	18–Apr–91	04:33	0.01	J		16.8	U
20 Hour Grab	SH1A–28	168308	18–Apr–91	08:06	0.01	U		33.6	U
24 Hour Grab (= 24 Hr Plus grab)	SH1A–19	168299	18–Apr–91	11:55	0.01	UJ		16.9	U
48 Hour Plus Grab	SH1A–32	168312	18–Apr–91	12:21	0.01	U		16.6	U
Runoff Grab – St A	SH1A–33	168313	18–Apr–91	17:05	0.17			17.2	U
0–6 Hr Composite–St A	SH1A–12	168292	18–Apr–91	18:45	0.19			32.8	U
Duplicate of 0–6 Hr Composite–St A	SH1A–14	168294	18–Apr–91	18:45	0.16		0.18	33.2	U
0–6 Hr Composite–St B	SH1B–13	168293	18–Apr–91	19:00	0.14	J		81.5	U
0–24 Hr Composite–St A	SH1A–24	168304	18–Apr–91	13:00	0.05			34.6	U
0–24 Hr Composite–St B	SH1B–25	168305	18–Apr–91	13:45	0.13	J		197	U
4–Sample Hand Composite (24 Hr)–St A	SH1A–26	168306	18–Apr–91	12:00	0.33			18	U
Calc. 24–hr Ave. (Recommended Prot.)					0.09				
Calc. 24–hr Ave. (Oregon Prot.)					0.10				
25–48 Hr Composite–St A	SH1A–29	168309	18–Apr–91	12:30	0.01	U		32.6	U
25–48 Hr Composite–St B	SH1B–30	168310	18–Apr–91	13:30	0.01	U		168	U

*DATA QUALIFIERS:

U = The analyte was not detected at or above reported value.

J = The analyte was positively identified; the value reported is an estimate.

UJ = The analyte was not detected at or above the reported estimated value.

**MEAN VALUE: For Duplicate and Replicate sample pairs, the mean value reported is used in Results and Discussion sections of the report; "NA" indicates that the mean could not be calculated because one or both results were below detection levels. In such cases, single values reported as detected were used in the report, or the sample was referred to as less than detection limit if neither sample had detectable amounts.

Site SH2 – Gibson Creek Unit

UNIT SPRAYED 5/3/91 FROM 08:37 TO 11:25. STREAMSIDE BUFFER SPRAYED 08:37.
TIME–OF–TRAVEL FROM MID–UNIT TO SAMPLING SITE = 30 MINUTES. GRAB SAMPLES TIMED FROM 09:07, EXCEPT "PLUS" SAMPLES TIMED FROM 11:25. COMPOSITORS TIMED FROM 09:16.

SAMPLE DESCRIPTION	FIELD ID #	LAB ID #	DATE	TIME	24–D (ug/L)	Q*	MEAN** VALUE	24–DCP (ug/L)	Q*
Compositor Blank (Rinse)	SH2–00	188280	03–May–91	05:10	0.03	U		0.67	U
Compositor Control Sample	SH2–09	188289	03–May–91	06:05	0.03	U		0.64	U
Control Grab Sample	SH2–08	188288	03–May–91	06:18	0.03	U		0.63	U
15 Minute Grab	SH2–01	188281	03–May–91	09:23	0.33			0.64	U
30 Min. Grab	SH2–02	188182	03–May–91	09:41	0.28			0.68	U
1 Hour Grab	SH2–03	188283	03–May–91	10:07	0.21			0.63	U
2 Hour Grab	SH2–04	188284	03–May–91	11:09	1.00			0.63	U
Replicate of 2 Hour Grab	SH2–16	188296	03–May–91	11:09	0.74		0.87	0.64	U
30 Minute Plus Grab	SH2–19	188299	03–May–91	11:55	1.06			0.66	U
Replicate of 30 Min. Plus Grab	SH2–06	188286	03–May–91	11:55	1.23		1.15	0.66	U
3 Hour Grab	SH2–05	188285	03–May–91	12:07	1.23			0.67	U
Duplicate of 3 Hour Grab	SH2–11	188291	03–May–91	12:07	1.39		1.31	0.64	U
4 Hour Grab	SH2–07	188287	03–May–91	13:09	0.31			0.65	U
6 Hour Grab	SH2–10	188290	03–May–91	15:08	0.16			0.64	U
4 Hour Plus Grab	SH2–20	188300	03–May–91	15:25	0.14			0.65	U
8 Hour Grab	SH2–13	188293	03–May–91	17:07	0.06			0.66	U
10 Hour Grab	SH2–15	188295	03–May–91	19:13	0.04			0.8	U
12 Hour Grab	SH2–17	188297	03–May–91	21:09	0.03			0.65	U
10 Hour Plus Grab	SH2–21	188301	03–May–91	21:25	0.03	J		0.67	U
17 Hour Grab	SH2–25	188305	04–May–91	01:56	0.03	J		0.67	U
22 Hour Grab	SH2–26	188306	04–May–91	07:12	0.03	J		0.67	U
24 Hour Grab	SH2–18	188298	04–May–91	09:08	0.04			0.66	U
24 Hour Plus Grab	SH2–22	188302	04–May–91	11:25	0.07			0.65	U
48 Hour Plus Grab (Runoff)	SH2–28	188308	05–May–91	11:26	2.49			0.68	U
72 Hour Grab (Runoff)	SH2–31	198311	06–May–91	15:20	0.27			0.7	U
100 Hour Grab (Runoff)	SH2–32	198312	07–May–91	15:35	0.95			0.64	U
Replicate of 100 Hour Grab	SH2–34	198314	07–May–91	15:35	0.92		0.94	0.71	U
0–6 Hour Composite	SH2–12	188292	03–May–91	15:16	0.48			0.67	U
Duplicate of 0–6 Hour Composite	SH2–14	188294	03–May–91	15:16	0.47		0.48	0.66	U
0–24 Hour Composite	SH2–23	188303	04–May–91	09:30	0.20			0.63	U
Duplicate of 0–24 Hour Composite	SH2–29	188309	04–May–91	09:30	0.15		0.18	0.69	U
4–Sample Hand Composite (24 Hr)	SH2–24	188304	04–May–91	09:20	0.19			0.63	U
Calc. 24–hr Ave. (Recommended Prot.)					0.16				
Calc. 24–hr Ave. (Oregon Prot.)					0.11				
25–48 Hour Composite (Runoff)	SH2–27	188307	05–May–91	11:30	0.69			0.81	U
49–72 Hour Composite (Runoff)	SH2–30	198310	06–May–91	15:20	0.63			0.7	U
73–96 Hour Composite (Runoff)	SH2–33	198313	07–May–91	15:20	0.35			0.7	U

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U = Analyte not detected at or above reported value.

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**MEAN VALUE: For Duplicate and Replicate sample pairs, the mean value reported is used in Results and Discussion sections of the report; "NA" indicates that the mean could not be calculated because one or both results were below detection levels. In such cases, single values reported as detected were used in the report, or the sample was referred to as less than detection limit if neither sample had detectable amounts.

SH3 – McCoy Creek Unit

UNIT SPRAYED 5/15/91 FROM 07:26 TO 08:43; FIRST SWATH ALONG CREEK SPRAYED AT 07:26. TIME–OF–TRAVEL FROM MID–UNIT TO SAMPLING SITE = 16 MINUTES. GRAB SAMPLES TIMED FROM 07:42, EXCEPT "PLUS" SAMPLES TIMED FROM 08:43; COMPOSITORS TIMED FROM 07:44.

SAMPLE DESCRIPTION	FIELD ID#	LAB ID#	DATE	TIME	2,4–D (ug/L)	Q*	MEAN** VALUE	2,4–DCP (ug/L)	Q*	TRIC–LOPYR (ug/L)	Q*	MEAN** VALUE
Compositor Blank (Rinse)	SH3–00	208280	15–May–91	06:18	0.03	U		0.68	U	0.02	U	
Compositor Control Sample	SH3–09	208289	15–May–91	06:30	0.03	U		0.67	U	0.02	U	
Control Grab Sample	SH3–08	208288	15–May–91	06:08	0.03	U		0.68	U	0.02	U	
15 Minute Grab	SH3–01	208281	15–May–91	07:57	0.03	U		0.69	U	0.02	U	
30 Min. Grab	SH3–02	208282	15–May–91	08:12	0.04	U		0.71	U	0.02		
1 Hour Grab	SH3–03	208283	15–May–91	08:43	0.04	U		0.69	U	0.02		
Duplicate of 1 Hour Grab	SH3–11	208291	15–May–91	08:43	0.04	U	NA	0.71	U	0.02	U	NA
30 Minute PLUS Grab	SH3–18	208298	15–May–91	09:13	0.03	U		0.68	U	0.02	U	
Replicate of 30 Min. PLUS Grab	SH3–06	208286	15–May–91	09:13	0.03	U	NA	0.69	U	0.02	U	NA
2 Hour Grab	SH3–04	208284	15–May–91	09:48	0.04	U		0.69	U	0.02	U	
Replicate of 2 Hour Grab	SH3–16	208296	15–May–91	09:48	— —	LAC	NA	— —	LAC	— —	LAC	NA
3 Hour Grab	SH3–05	208285	15–May–91	10:44	0.04	U		0.69	U	0.02	U	
4 Hour Grab	SH3–07	208287	15–May–91	11:42	0.03	U		0.68	U	0.02	U	
4 Hour PLUS Grab	SH3–19	208299	15–May–91	12:43	0.04	U		0.69	U	0.02	U	
6 Hour Grab	SH3–10	208290	15–May–91	13:42	0.03	U		0.68	U	0.02	U	
8 Hour Grab	SH3–13	208293	15–May–91	16:07	0.03	U		0.69	U	0.02	U	
10 Hour Grab	SH3–15	208295	15–May–91	18:14	0.03	U		0.66	U	0.02	U	
10 Hour PLUS Grab	SH3–20	208300	15–May–91	18:49	0.03	U		0.66	U	0.02	U	
12 Hour Grab	SH3–17	208297	15–May–91	19:45	0.03	U		0.69	U	0.02	U	
17 Hour Grab	SH3–22	208302	16–May–91	00:30	0.03	U		0.66	U	0.02	U	
20 Hour Grab	SH3–23	208303	16–May–91	03:53	0.03	U		0.66	U	0.02	U	
24 Hour Grab	SH3–24	208304	16–May–91	07:57	0.03	U		0.68	U	0.02	J	
24 Hour PLUS Grab	SH3–21	208301	16–May–91	08:43	0.03	U		0.66	U	0.02	U	
48 Hour PLUS Grab	SH3–28	208308	17–May–91	09:26	0.04	U		0.84	U	0.02	U	
0–6 Hour Composite	SH3–12	208292	15–May–91	13:55	0.03	U		0.69	U	0.02	U	
Duplicate of 0–6 Hour Composite	SH3–14	208294	15–May–91	13:55	0.03	U	NA	0.67	U	0.02	U	NA
0–24 Hour Composite	SH3–25	208305	16–May–91	08:55	0.03	U		0.66	U	0.02	U	
Duplicate of 0–24 Hour Composite	SH3–30	208310	16–May–91	08:55	0.03	U	NA	0.69	U	0.02	U	NA
4–Sample Hand Composite	SH3–26	208306	16–May–91	08:30	0.04	U		0.70	U	0.02	U	
Calc. 24–hr Ave. (Recommended Prot.)					<0.03					0.02		
Calc. 24–hr Ave. (Oregon Prot.)					0					0.01		
25–48 Hour Composite	SH3–27	208307	17–May–91	10:00	0.03	U		0.69	U	0.02	U	
Duplicate of 25–48 Hour Composite	SH3–29	208309	17–May–91	10:00	0.04	U	NA	0.69	U	0.02	U	NA

*DATA QUALIFIERS:

U = Analyte not detected at or above reported value.

J = The analyte was positively identified; the value reported is an estimate.

LAC = Laboratory accident resulted in loss of sample.

**MEAN VALUE: For Duplicate and Replicate sample pairs, the mean value is used in Results and Discussion sections of the report; "NA" indicates that the mean could not be calculated because one or both results were below detection levels. In such cases, single values reported as detected were used in the report, or the sample was referred to as less than detection limit if neither sample had detectable amounts.

Site IN1 – Foster Creek Unit

UNIT SPRAYED FROM 09:12 TO 10:02; FIRST SWATH (EAST EDGE OF UNIT NEAR HELIPORT ONLY) SPRAYED FROM 09:12–09:13. SPRAYING RESUMED @ 09:44, WITH FIRST SWATH ALONG STREAMSIDE BUFFER SPRAYED @ 09:44. TIME–OF–TRAVEL FROM MID–UNIT TO SAMPLING SITE = 141 MINUTES. GRAB SAMPLES TIMED FROM 12:05, EXCEPT "PLUS" SAMPLES TIMED FROM 10:02; COMPOSITORS TIMED FROM 11:44.

SAMPLE DESCRIPTION	FIELD ID#	LAB ID#	DATE	TIME	META–SYSTOX–R (ug/L)	Q*	MEAN** VALUE	CHLORO–THALONIL (ug/L)	Q*	MEAN** VALUE
Compositor Blank (Rinse)	IN1–00	238280	07–Jun–91	13:16	2.60	U		0.01	U	
Composite Control Sample	IN1–09	238289	07–Jun–91	14:00	2.60	U		0.01	U	
"Early" Grab Sample	IN1–08	238288	08–Jun–91	09:32	2.60	U		0.04		
30 Minute PLUS Grab	IN1–18	238298	08–Jun–91	10:32	2.70	U		0.19		
15 Minute Grab	IN1–01	238281	08–Jun–91	12:18	2.60	U		1.62		
Replicate of 15 Min. Grab	IN1–06	238286	08–Jun–91	12:18	2.80	J	NA	1.72		1.67
30 Min. Grab	IN1–02	238282	08–Jun–91	12:34	2.70	J		1.72		
1 Hour Grab	IN1–03	238283	08–Jun–91	13:05	2.60	J		1.47		
Duplicate of 1 Hour Grab	IN1–11	238291	08–Jun–91	13:05	2.60	J	2.60	1.55		1.51
2 Hour Grab	IN1–04	238284	08–Jun–91	14:05	2.50	J		0.83		
Replicate of 2 Hour Grab	IN1–16	238296	08–Jun–91	14:05	2.50	J	2.50	0.81		0.82
3 Hour Grab	IN1–05	238285	08–Jun–91	15:05	2.50	U		0.33		
4 Hour Grab	IN1–07	238287	08–Jun–91	16:08	2.50	U		0.23		
6 Hour Grab	IN1–10	238290	08–Jun–91	18:16	2.60	U		0.14		
8 Hour Grab	IN1–13	238293	08–Jun–91	20:05	2.60	U		0.08		
10 Hour Grab	IN1–15	238295	08–Jun–91	22:05	2.70	U		0.07		
12 Hour Grab	IN1–17	238297	09–Jun–91	00:12	4.10	U		0.04		
16 Hour Grab	IN1–22	238302	09–Jun–91	04:10	2.60	U		0.03		
20 Hour Grab	IN1–23	238303	09–Jun–91	08:10	2.60	U		0.02		
24 Hour PLUS Grab	IN1–21	238301	09–Jun–91	10:05	2.50	U		0.02		
24 Hour Grab	IN1–24	238304	09–Jun–91	12:13	2.60	U		0.02		
48 Hour PLUS Grab	IN1–29	238309	10–Jun–91	11:13	2.60	U		0.01		
0–6 Hour Composite	IN1–12	239292	08–Jun–91	18:30		LAC		0.56		
Duplicate of 0–6 Hour Composite	IN1–14	239294	08–Jun–91	18:30	2.70	J	NA	0.60		0.58
0–24 Hour Composite	IN1–25	238305	09–Jun–91	11:45	2.50	U		0.16		
Duplicate of 0–24 Hour Composite	IN1–27	238307	09–Jun–91	11:45	2.60	U	NA	0.19		0.18
4–Sample Hand Composite	IN1–26	238306	09–Jun–91	12:47	2.70	J		0.38		
Calc. 24–hr Ave. (Recommended Prot.)					<2.60			0.22		
Calc. 24–hr Ave. (Oregon Prot.)					0.22			0.20		
25–48 Hour Composite	IN1–28	238308	10–Jun–91	12:16	2.40	J		0.03		
Duplicate of 25–48 Hour Composite	IN1–30	238310	10–Jun–91	12:16	4.10	J	3.25	0.03		0.03

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LAC = Laboratory accident resulted in loss of sample.

**MEAN VALUE: For Duplicate and Replicate sample pairs, the mean value reported is used in Results and Discussion sections of the report; "NA" indicates that the mean could not be calculated because one or both results were below detection levels. In such cases, single values reported as detected were used in the report, or the sample was referred to as less than detection limit if neither sample had detectable amounts.

Site FH1 – Mitchell Creek Unit

UNIT SPRAYED 9/19/91 FROM 08:18 TO 08:24; STREAMSIDE BUFFER SPRAYED 08:20.
TIME–OF–TRAVEL FROM MID–UNIT TO SAMPLING SITE = 32 MINUTES.
GRAB SAMPLES TIMED FROM 08:52, EXCEPT "PLUS" GRAB SAMPLES TIMED FROM 08:24. COMPOSITORS TIMED FROM 09:04

SAMPLE DESCRIPTION	FIELD ID#	LAB ID#	DATE	TIME	GLYPHO–SATE (ug/L)	Q*	MEAN** VALUE	AMPA (ug/L)	Q*	IMAZAPYR (ug/L)	Q*
Compositor Blank (Rinse)	FH1–00	388180	19–Sep–91	06:40	0.20	UJ		0.20	UJ		
Composite Control Sample	FH1–09	388189	19–Sep–91	06:56	0.20	UJ		0.20	UJ		
Control Grab Sample	FH1–08	388188	19–Sep–91	06:14	0.20	UJ		0.20	UJ		
30 Minute PLUS Grab	FH1–19	388199	19–Sep–91	09:03	2.39			0.20	UJ		
15 Minute Grab	FH1–01	388181	19–Sep–91	09:09	2.07			0.20	UJ	0.50	U
Replicate of 15 Min. Grab	FH1–06	388186	19–Sep–91	09:09	2.07		2.07	0.20	UJ		
30 Minute Grab	FH1–02	388182	19–Sep–91	09:24	1.28	J		0.20	UJ		
1 Hour Grab	FH1–03	388183	19–Sep–91	09:52	0.78	J		0.20	UJ	0.50	U
Duplicate of 1 Hour Grab	FH1–11	388191	19–Sep–91	09:52	0.72	J	0.75	0.20	UJ		
2 Hour Grab	FH1–04	388184	19–Sep–91	11:14	0.33	J		0.20	UJ		
Replicate of 2 Hour Grab	FH1–17	388197	19–Sep–91	11:14	0.31	J	0.32	0.20	UJ		
3 Hour Grab	FH1–05	388185	19–Sep–91	11:53	0.25	J		0.20	UJ		
4 Hour PLUS Grab	FH1–20	388200	19–Sep–91	12:25	0.50	U		0.20	UJ		
4 Hour Grab	FH1–07	388187	19–Sep–91	12:53	0.20	UJ		0.20	UJ		
6 Hour Grab	FH1–10	388190	19–Sep–91	15:00	0.20	UJ		0.20	UJ		
TRANSFER BLANK	FH1–14	388194	19–Sep–91	16:35	0.20	UJ		0.20	UJ		
8 Hour Grab	FH1–13	388193	19–Sep–91	17:00	0.20	UJ		0.20	UJ		
10 Hour PLUS Grab	FH1–21	388201	19–Sep–91	18:25	0.20	UJ		0.20	UJ		
10 Hour Grab	FH1–16	388196	19–Sep–91	18:52	0.20	UJ		0.20	UJ		
12 Hour Grab	FH1–18	388198	19–Sep–91	20:39	0.20	UJ		0.20	UJ		
18 Hour Grab	FH1–23	388203	20–Sep–91	03:04	0.20	UJ		0.20	UJ		
20 Hour Grab	FH1–24	388204	20–Sep–91	04:55	0.20	UJ		0.20	UJ		
24 Hour Grab	FH1–25	388205	20–Sep–91	09:19	0.20	UJ		0.20	UJ		
48 Hour PLUS Grab	FH1–31	388211	21–Sep–91	09:00	0.20	UJ		0.20	UJ		
0–6 Hour Composite	FH1–12	388192	19–Sep–91	15:15	0.36	J		0.20	UJ	0.50	U
Duplicate of 0–6 Hr Composite	FH1–15	388195	19–Sep–91	15:15	0.60		0.48	0.20	UJ		
0–24 Hour Composite	FH1–26	388206	20–Sep–91	09:30	0.20	UJ		0.20	UJ	0.50	U
Duplicate of 0–24 Hour Composite	FH1–28	388208	20–Sep–91	09:30	0.32	J	NA	0.20	UJ		
4–Sample Hand Composite	FH1–27	388207	20–Sep–91	13:00	0.54			0.20	UJ		
Calc. 24–hr Ave. (Recommended Prot.)					<0.20						
Calc. 24–hr Ave. (Oregon Prot.)					0.17						
25–48 Hour Composite	FH1–29	388209	21–Sep–91	09:40	0.20	UJ		0.20	UJ		
Duplicate of 25–48 Hour Composite	FH1–30	388210	21–Sep–91	09:40	0.20	UJ	NA	0.20	UJ		

*DATA QUALIFIERS:

U = Analyte not detected at or above the reported value.

J = Analyte was positively identified; the value reported is an estimate.

UJ = Analyte was not detected at or above the reported estimated value

**MEAN VALUE: For Duplicate and Replicate sample pairs, the mean value reported is used in Results and Discussion sections of the report; "NA" indicates that the mean could not be calculated because one or both results were below detection levels. In such cases, single values reported as detected were used in the report, or the sample was referred to as less than detection limit if neither sample had detectable amounts.

Site FH2 – Bush Creek Unit

UNIT SPRAYED 9/27/91 FROM 11:20 TO 12:33; STREAMSIDE BUFFER SPRAYED @ 11:20. TIME–OF–TRAVEL FROM MID–POINT OF UNIT TO SAMPLING SITE = 205 MINUTES; TIME–OF–TRAVEL FROM LOWER ONE–THIRD OF UNIT TO SAMPLING SITE = 105 MINUTES. GRAB SAMPLES TIMED FROM 13:05, EXCEPT "PLUS" SAMPLES TIMED FROM 12:33. COMPOSITORS TIMED FROM 13:07.

SAMPLE DESCRIPTION	FIELD ID#	LAB ID#	DATE	TIME	GLYPHO–SATE (ug/L)	Q*	MEAN** VALUE	AMPA (ug/L)	Q*	IMAZ–APYR (ug/L)	Q*	MEAN** VALUE
Compositor Blank (Rinse)	FH2–00	398130	27–Sep–91	08:58	0.20	UJ		0.20	UJ			
Composite Control Sample	FH2–09	398139	27–Sep–91	09:26	0.20	UJ		0.20	UJ	0.20	UJ	
Control Grab Sample	FH2–08	398138	27–Sep–91	08:49	0.20	UJ		0.20	UJ			
Early Sample #1	FH2–34	398164	27–Sep–91	11:56	0.20	UJ		0.20	UJ	0.20	UJ	
Early Sample #2	FH2–35	398165	27–Sep–91	12:28	7.55			0.20	UJ			
30 Minute PLUS Grab	FH2–19	398149	27–Sep–91	13:17	3.51			0.20	UJ			
15 Minute Grab	FH2–01	398131	27–Sep–91	13:20	4.27			0.20	UJ			
Replicate of 15 Min. Grab	FH2–06	398136	27–Sep–91	13:20	4.91		4.59	0.20	UJ			
30 Minute Grab	FH2–02	398132	27–Sep–91	13:36	3.40			0.20	UJ	1.15		
1 Hour Grab	FH2–03	398133	27–Sep–91	14:04	2.52			0.20	UJ			
Duplicate of 1 Hour Grab	FH2–17	398147	27–Sep–91	14:04	2.43		2.48	0.20	UJ			
2 Hour Grab	FH2–04	398134	27–Sep–91	15:05	1.86			0.20	UJ	0.20	UJ	
Replicate of 2 Hour Grab	FH2–11	398141	27–Sep–91	15:05	1.42	J	1.64	0.20	UJ	0.60		NA
3 Hour Grab	FH2–05	398135	27–Sep–91	16:07	1.20	J		0.20	UJ			
4 Hour PLUS Grab	FH2–20	398150	27–Sep–91	16:33	1.16	J		0.20	UJ			
4 Hour Grab	FH2–07	398137	27–Sep–91	17:02	1.16	J		0.20	UJ	0.70		
6 Hour Grab	FH2–10	398140	27–Sep–91	19:25	0.66	J		0.20	UJ			
8 Hour Grab	FH2–13	398143	27–Sep–91	21:08	0.59	J		0.20	UJ			
16 Hour Grab	FH2–23	398153	28–Sep–91	05:11	0.50	J		0.20	UJ			
18 Hour Grab	FH2–21	398151	28–Sep–91	07:30	0.44	J		0.20	UJ			
20 Hour Grab	FH2–24	398154	28–Sep–91	09:38	0.20	UJ		0.20	UJ			
24 Hour Grab	FH2–25	398155	28–Sep–91	13:07	0.26	J		0.20	UJ			
Runoff Grab #1	FH2R–01	438060	22–Oct–91	11:33	0.20	UJ		0.20	UJ	1.25		
Replicate of Runoff #1	FH2R–02	438064	22–Oct–91	11:33	0.20	UJ	NA	0.20	UJ	0.36	J	0.81
Runoff Grab #2	FH2R–03	438065	22–Oct–91	16:35	0.20	UJ		0.20	UJ	0.63	J	
0–6 Hour Composite	FH2–12	398142	27–Sep–91	19:40	1.16	J		0.20	UJ	0.75		
Duplicate of 0–6 Hour Composite	FH2–15	398145	28–Sep–91	19:40	1.42	J	1.29	0.20	UJ	0.87		0.81
0–24 Hour Composite	FH2–26	398156	28–Sep–91	13:20	0.38	J		0.20	UJ	0.36		
Duplicate of 0–24 Hour Composite	FH2–28	398158	28–Sep–91	13:20	0.74	J	0.56	0.20	UJ			
4–Sample Hand Composite	FH2–27	398157	28–Sep–91	15:30	1.84	J		0.50	J			
Calc. 24–hr Ave. (Recommended Prot.)					0.70							
Calc. 24–hr Ave. (Oregon Prot.)					0.84							

*DATA QUALIFIERS:

J = Analyte was positively identified; the value reported is an estimate.

UJ = Analyte was not detected at or above the reported estimated value.

**MEAN VALUE: For Duplicate and Replicate sample pairs, the mean value reported is used in Results and Discussion sections of the report; "NA" indicates that the mean could not be calculated because one or both results were below detection levels. In such cases, single values reported as detected were used in the report, or the sample was referred to as less than detection limit if neither sample had detectable amounts.

Site FH3 – North Fork Rabbit Creek Unit

UNIT SPRAYED FROM 8:59 TO 10:25; STREAMSIDE BUFFER SPRAYED @ 9:00.

TIME–OF–TRAVEL FROM MID–UNIT TO SAMPLING SITE = 28 MINUTES. GRAB SAMPLES AT STATION A TIMED FROM 09:28, EXCEPT "PLUS" SAMPLES TIMED FROM 10:25. COMPOSITORS TIMED FROM 10:05.

SAMPLE DESCRIPTION	FIELD ID#	LAB ID#	DATE	TIME	GLYPHOSATE (ug/L)	Q*	MEAN** VALUE	AMPA (ug/L)	Q*
Composite Control Sample	FH3–08	398178	26–Sep–91	06:35	0.20	UJ		0.20	UJ
Composite Control Sample	FH3–29	398199	26–Sep–91	06:43	0.20	UJ		0.20	UJ
Control Grab Sample	FH3–07	398177	26–Sep–91	06:21	0.20	UJ		0.20	UJ
Station A Grab Samples:									
15 Minute Grab	FH3–00	398170	26–Sep–91	09:57	2.92			0.20	UJ
30 Minute Grab	FH3–01	398171	26–Sep–91	09:59	4.36			0.20	UJ
1 Hour Grab	FH3–02	398172	26–Sep–91	10:28	3.64			0.20	UJ
Duplicate of 1 Hour Grab	FH3–10	398180	26–Sep–91	10:28	3.54		3.59	0.20	UJ
30 Minute PLUS Grab	FH3–18	398188	26–Sep–91	10:59	1.20			0.20	UJ
2 Hour Grab	FH3–03	398173	26–Sep–91	11:28	0.58	J		0.20	UJ
Replicate of 2 Hour Grab	FH3–16	398186	26–Sep–91	11:28	0.71		0.65	0.20	UJ
3 Hour Grab	FH3–04	398174	26–Sep–91	12:42	0.27	J		0.20	UJ
Replicate of 3 Hour Grab	FH3–05	398175	26–Sep–91	12:42	0.36	J	0.32	0.20	UJ
4 Hour Grab	FH3–06	398176	26–Sep–91	13:30	0.38	J		0.20	UJ
4 Hour PLUS Grab	FH3–19	398189	26–Sep–91	14:25	0.22	J		0.20	UJ
8 Hour Grab	FH3–12	398182	26–Sep–91	17:28	0.20	UJ		0.20	UJ
TRANSFER BLANK	FH3–13	398183	26–Sep–91	18:56	0.20	UJ		0.20	UJ
12 Hour Grab	FH3–17	398187	26–Sep–91	21:45	0.20	UJ		0.20	UJ
18 Hour Grab	FH3–15	398185	27–Sep–91	04:01	0.20	UJ		0.20	UJ
24 Hour Grab	FH3–22	398192	27–Sep–91	11:17	0.20	UJ		0.20	UJ
48 Hour PLUS Grab	FH3–28	398198	28–Sep–91	10:44	0.20	UJ		0.20	UJ
Runoff Grab–Station A	FH3R–01	438061	22–Oct–91	14:02	0.20	UJ		0.20	UJ
Grab #1–Station B1	FH3–39	398119	26–Sep–91	17:49	0.33	J		0.20	UJ
Grab #2–Station B1	FH3–41	398121	27–Sep–91	12:14	0.20	UJ		0.20	UJ
Grab #3–Station B1	FH3–43	398123	28–Sep–91	11:34	0.43	J		0.20	UJ
Runoff Grab–Station B1	FH3R–03	438063	22–Oct–91	14:58	0.32	J		0.20	UJ
Grab #1–Station B2	FH3–44	398124	28–Sep–91	11:26	0.43	J		0.20	UJ
Pre–Spray Grab–Station B3	FH3–36	398116	26–Sep–91	07:10	0.27	J		0.20	UJ
Post–Spray Grab–Station B3	FH3–45	398125	28–Sep–91	13:15	0.20	UJ		0.20	UJ
Grab #1–Site C	FH3–37	398117	26–Sep–91	11:50	1.31			0.20	UJ
Grab #2–Site C	FH3–38	398118	26–Sep–91	17:07	0.82			0.38	J
Grab #3–Site C	FH3–40	398120	27–Sep–91	11:59	0.32	J		0.20	UJ
Grab #4–Site C	FH3–42	398122	28–Sep–91	11:01	0.43	J		0.20	UJ
Runoff–Site C	FH3R–02	438062	22–Oct–91	14:19	0.20	UJ		0.20	UJ
NOTE–All Composite Samples From Station A:									
0–6 Hour Composite	FH3–11	398181	26–Sep–91	16:45	0.82			0.20	UJ
Duplicate of 0–6 Hour Composite	FH3–14	398184	26–Sep–91	16:45	0.71		0.77	0.20	UJ
0–24 Hour Composite	FH3–23	398193	27–Sep–91	11:30	0.23	J		0.20	UJ
Duplicate of 0–24 Hour Composite	FH3–25	398195	27–Sep–91	11:30	0.23	J	0.23	0.20	UJ
4–Sample Hand Composite	FH3–24	398194	28–Sep–91	14:30	0.99	J		0.20	UJ
Calc. 24–hr Ave. (Recommended Prot.)***					0.39				
Calc. 24–hr Ave. (Oregon Prot.)					0.30				
25–48 Hour Composite	FH3–26	398196	28–Sep–91	11:50	0.32	J		0.20	UJ
Duplicate of 25–48 Hour Composite	FH3–27	398197	28–Sep–91	11:50	0.26	J	0.29	0.20	UJ

Station A is on North Fork Rabbit Creek, just downstream of the spray unit.
Station B1 is a spring which emanates from the toe of a slope at the south edge of unit.
Station B2 is a flowing wetland about 60 meters downstream from Station B1.
Station B3 is at the downstream end of a large springfed wetland about 500 meters south of the spray unit.
Station C is an unnamed type 5 stream about 100 meters east of N.F. Rabbit Creek, within the same spray unit.

*DATA QUALIFIERS:
J = Analyte was positively identified; the value reported is an estimate.
UJ = Analyte was not detected at or above the reported estimated value.

**MEAN VALUE: For Duplicate and Replicate sample pairs, the mean value reported is used in Results and Discussion sections of the report; "NA" indicates that the mean could not be calculated because one or both results were below detection levels. In such cases, single values reported as detected were used in the report, or the sample was referred to as less than detection limit if neither sample had detectable amounts.

***In this case, the calculated 24–hour average was determined by substituting the 8–hour result for the 6–hour result, since a 6–hour sample was not available for this site.

APPENDIX F
Quality Control Results

Quality Control Results and Discussion

The following table presents the analytical results and the relative percent difference (RPD) for all blind field replicate and duplicate pairs for which the analyte was detected. RPD describes the range as a percent of the mean. The table also presents matrix spike recovery results, showing the recoveries for each analyte and the RPDs for matrix spike duplicate pairs. These results and other quality control considerations are discussed below for each pesticide.

Triclopyr: On blind quality control samples (field duplicates and replicates), RPDs ranged from 12% to 51% for sample pairs. 4 additional pairs had less than detection limit (DL) results, and one pair had one duplicate reported as <DL with the paired sample showing detection at the DL. Average RPD for field replicates and duplicates was 23.5%. This level of precision is acceptable.

Matrix spike recovery ranged from 16.0% to 134%, and averaged 77.4%. RPDs for matrix spike duplicate pairs ranged from 1% to 98%, and averaged 43.5%. Spiked sample 208308 had very low recovery in one of the duplicate matrix spikes, resulting in a high RPD of 98% for this pair. The laboratory reported that either poor extraction efficiency or losses during the concentration step may have contributed to the low recovery in this sample. Overall, the recovery results for triclopyr are acceptable.

Surrogate spike recovery ranged from 8% to 130%. Two sample results were qualified ("J") based on low surrogate spike recoveries (<25%).

All holding times guidelines were met, and no data were qualified based on quality control concerns, other than the two mentioned above.

2,4-D: On blind quality control samples (field duplicates and replicates), RPDs ranged from 2% to 30% for 6 sample pairs. 5 additional pairs had less than detection limit (DL) results. Average RPD for field replicates and duplicates was 15.2%. This level of precision is acceptable.

The laboratory noted a problem with the matrix spikes for 2,4-D. The stock 2,4-D standard that the laboratory used to spike samples was apparently contaminated with a compound that eluted similarly to 2,4-D and caused chromatographic interference. In the absence of meaningful recovery results for 2,4-D, duplicate matrix spikes of the chemically similar compound 2,4,5-TP (obtained from a different standard mixture) were used as a surrogate. Average recovery for 2,4,5-TP was 64.4%, ranging from 9.5% to 97.5%. RPDs for matrix spike duplicate pairs ranged from 12% to 126%, and averaged 47.5%. Spiked sample 208308 had very low recovery in one of the duplicate matrix spikes, resulting in a high RPD of 126% for this pair. The laboratory reported that either poor extraction efficiency or losses during the concentration step may have contributed to the low recovery in this sample. Overall, the recovery results for 2,4,5-TP are within the acceptable range.

Surrogate spike recovery ranged from 26.4% to 130%. No samples were qualified based on low surrogate recoveries.

All holding times guidelines for collection to extraction were met. For 14 samples, the recommended 40 day holding time for extraction to analysis was exceeded by one day. No data were qualified based on holding times or other quality control concerns.

Chlorothalonil: On blind quality control samples (field duplicates and replicates), RPDs ranged from 0% to 17% for 6 sample pairs. Average RPD for field replicates and duplicates was 6.2%. This level of precision is acceptable.

For chlorothalonil, the laboratory recovery efficiency cannot be definitively quantified, because the laboratory inadvertently neglected to spike the matrix samples with the compound. Recoveries for the surrogate compound dibutylchlorendate (DBC) ranged from 48% to 131%, however, and averaged 90%, indicating no major problems with the analytical technique or equipment.

All holding times guidelines were met, and no data were qualified based on quality control concerns.

Metasystox-R: On blind quality control samples (field duplicates and replicates), RPDs ranged from 0% to 52% for 3 sample pairs. One additional pair had less than detection limit (DL) results, and one pair had one replicate reported as <DL with the paired sample showing detection at slightly above the DL. Average RPD for field replicates and duplicates was 17.3%. This level of precision is acceptable.

Matrix spike recovery ranged from 29% to 53%, and averaged 39.8%. RPDs for matrix spike duplicate pairs ranged from 34% to 59%, and averaged 46.5%. Low matrix spike recovery for metasystox-R may indicate that extraction of metasystox-R was inefficient or that the secondary oxidation reaction was incomplete when it reached equilibrium. The secondary oxidation step became necessary when it was discovered that the metasystox-R broke down in the gas chromatograph under normal organo-phosphorus pesticide analysis conditions. This required the samples to be solvent exchanged to acetone, oxidized with potassium permanganate, and re-extracted for GC analysis. These extra steps probably contributed to low spike recoveries, and also resulted in higher detection and quantification levels as compared to other pesticide analyses conducted for this study.

Surrogate spike recovery ranged from 51% to 131%. The laboratory noted that the normal organo-phosphorus surrogate compound triphenyl phosphate would have functioned as a reasonable surrogate for the extraction and analysis steps, but would not undergo the same oxidation reaction, and thus would not necessarily be representative of metasystox-R.

All holding times guidelines for collection to extraction were met, but the extra steps required for analysis resulted in a delay that exceeded the recommended 40 day extraction to analysis

guideline by about 29%. All data were qualified ("J") due to exceeding holding times per EPA Contract Laboratory Program (CLP) guidelines, however, the reviewing chemist noted that the delay should not have any significant effect on sample results since it was only 11-12 days.

Glyphosate: On blind quality control samples (field duplicates and replicates), RPDs ranged from 0% to 64% for 15 sample pairs. Two additional pairs had less than detection limit (DL) results, and 1 pair had one duplicate reported as <DL with the paired sample showing detection at slightly above the DL. Average RPD for field replicates and duplicates was 18.7%. This level of precision is acceptable.

Matrix spike recovery ranged from 88.5% to 104.5%, and averaged 99.3%. RPDs for matrix spike duplicate pairs ranged from 0% to 4%, and averaged 1%. Surrogate spikes were not used for glyphosate analyses.

All holding times guidelines were met, and no data were qualified based on quality control concerns. Several results were qualified ("J") based on levels near the detection limit.

Imazapyr: On blind quality control samples (field replicates), the RPD was 111% for one sample pair. This discrepancy was for a replicate pair collected during a runoff event, and the level of precision the laboratory achieved on matrix spike duplicates suggests field rather than lab variability. One additional pair had one replicate reported as <0.20 with the paired sample showing detection at 0.60.

Matrix spike recovery ranged from 94.0% to 107.6%, and averaged 98.6%. RPDs for two matrix spike duplicate pairs were 3%. Surrogate spikes were not used for imazapyr analyses.

All holding times guidelines were met, and no data were qualified based on quality control concerns.

Summary of Quality Control Results (Page 1 of 3)

Pesticide	Study Site	Field Duplicates Sample ID #	Field Duplicates Results in ug/L	Field Duplicates RPD*	Field Replicates Sample ID #	Field Replicates Results in ug/L	Field Replicates RPD*	Duplicate Matrix Spikes Sample ID #	Duplicate Matrix Spikes Results in % Recovery	Duplicate Matrix Spikes RPD*
triclopyr	SH1	168282	1.37		168283	0.74		168282	84.4%	
		168286	1.21	12%	168291	0.44	51%	168282	85.6%	1%
		168292	0.19		168284	0.31		168305	88.0%	
		168294	0.16	17%	168297	0.27	14%	168305	134.0%	41%
	SH3	208283	0.02		208298	<0.02		208291	96.0%	
		208291	<0.02	NA	208286	<0.02	NA	208291	68.1%	34%
		208292	<0.02		(Second replicate lost due to			208308	16.0%	
		208294	<0.02	NA	laboratory accident.)			208308	47.0%	98%
		208305	<0.02							
		208310	<0.02	NA						
		208307	<0.02							
		208309	<0.02	NA				Average triclopyr recovery:		77.4%
2,4-D**	SH2	188285	1.23		188284	1.00		188295	88.4%	
		188291	1.39	12%	188296	0.74	30%	188295	66.0%	29%
		188292	0.48		188299	1.06		188307	97.5%	
		188294	0.47	2%	188286	1.23	15%	188307	86.1%	12%
		188303	0.20		198312	0.95				
		188309	0.15	29%	198314	0.92	3%			
	SH3	208283	<0.04		208298	<0.03		208291	70.1%	
		208291	<0.04	NA	208286	<0.03	NA	208291	55.7%	23%
		208292	<0.03		(Second replicate lost due to			208308	9.5%	
		208294	<0.03	NA	laboratory accident.)			208308	42.0%	126%
		208305	<0.03							
		208310	<0.03	NA						
		208307	<0.03							
		208309	<0.04	NA				Average 2,4,5-TP recovery:		64.4%

* RPD = Relative Percent Difference: The range of the two results, divided by their mean; "NA" means RPD could not be calculated due to unquantified results in one or both samples.

** 2,4,5-TP was used as a surrogate for matrix spike results.

Summary of Quality Control Results (Page 2 of 3)

Pesticide	Study Site	Field Duplicates Sample ID #	Field Duplicates Results in ug/L	Field Duplicates RPD*	Field Replicates Sample ID #	Field Replicates Results in ug/L	Field Replicates RPD*	Duplicate Matrix Spikes Sample ID #	Duplicate Matrix Spikes Results in % Recovery	Duplicate Matrix Spikes RPD*
chlorothalonil	IN1	238283	1.47		238281	1.62		(No matrix spikes were run on chlorothalonil.)		
		238291	1.55	5%	238286	1.72	6%			
		238292	0.56		238284	0.83				
		238294	0.60	7%	238296	0.81	2%			
		238305	0.16							
		238307	0.19	17%						
		238308	0.03							
		238310	0.03	0%						
metasystox-R	IN1	238283	2.6		238281	<2.6		238310	29.0%	
		238291	2.6	0%	238286	2.8	NA	238310	53.0%	59%
		238305	<2.5		238284	2.5		238297	45.0%	
		238307	<2.6	NA	238296	2.5	0%	238297	32.0%	34%
		238308	2.4							
		238310	4.1	52%				Average metasystox-R recovery:		39.8%
imazapyr	FH1							388183	94.9%	
								(No duplicate analysis)		NA
								388192	94.0%	
								(No duplicate analysis)		NA
	FH2				398134	<0.20		398132	96.7%	
					398141	0.60	NA	398132	94.0%	3%
					438060	1.25		438060	104.6%	
					438064	0.36	111%	438060	107.6%	3%
								Average imazapyr recovery:		98.6%

* RPD = Relative Percent Difference: The range of the two results, divided by their mean; "NA" means RPD could not be calculated due to unquantified results in one or both samples.

** 2,4,5-TP was used as a surrogate for matrix spike results.

Summary of Quality Control Results (Page 3 of 3)

Pesticide	Study Site	Field Duplicates Sample ID #	Field Duplicates Results in ug/L	Field Duplicates RPD*	Field Replicates Sample ID #	Field Replicates Results in ug/L	Field Replicates RPD*	Duplicate Matrix Spikes Sample ID #	Duplicate Matrix Spikes Results in % Recovery	Duplicate Matrix Spikes RPD*
glyphosate	FH1	388183	0.78		388181	2.07		388182	88.5%	
		388191	0.72	8%	388186	2.07	0%	388182	88.5%	0%
		388192	0.36		388184	0.33		388183	103.3%	
		388195	0.60	50%	388197	0.31	6%	388183	103.3%	0%
		388206	<0.20					388192	102.5%	
		388208	0.32	NA				388192	104.2%	2%
		388209	<0.20							
		388210	<0.20	NA						
	FH2	398133	2.52		398131	4.27		398132	98.4%	
		398147	2.43	4%	398136	4.91	14%	398132	98.4%	0%
		398142	1.16		398134	1.86		398133	102.4%	
		398145	1.42	20%	398141	1.42	27%	398133	102.4%	0%
		398156	0.38		438060	<0.20		398142	101.6%	
		398158	0.74	64%	438064	<0.20	NA	398142	101.6%	0%
								438060	95.2%	
								438060	91.9%	4%
	FH3	398172	3.64		398173	0.58		398171	95.7%	
		398189	3.54	3%	398186	0.71	20%	398171	95.7%	0%
		398181	0.82		398174	0.27		398172	100.0%	
		398184	0.71	14%	398175	0.36	29%	398172	103.9%	4%
		398193	0.23					398181	104.5%	
		398195	0.23	0%				398181	104.5%	0%
		398196	0.32							
		398197	0.26	21%				Average glyphosate recovery:		99.3%

* RPD = Relative Percent Difference: The range of the two results, divided by their mean; "NA" means RPD could not be calculated due to unquantified results in one or both samples.

** 2,4,5-TP was used as a surrogate for matrix spike results.

APPENDIX G
Recommended Monitoring Protocol

Recommended Monitoring Protocol to Determine Stream Levels of Pesticides Following Aerial Application on Forest Lands

This protocol was developed as a part of the CMER Forest Pesticides BMP Effectiveness Study. The objective of this monitoring protocol is to allow the investigator to characterize peak and average concentrations of pesticides in streams following aerial application of forest pesticides in a cost effective manner. By following these protocols, TFW cooperators and others can effectively monitor forest chemical aerial applications with a minimum commitment of time and equipment. Monitoring conducted according to this protocol will require approximately two days commitment by the investigator for site reconnaissance, data gathering, and sample collection.

STUDY SITE SELECTION AND RECONNAISSANCE:

Spray units selected for monitoring should have one of the following configurations:

1) units which have a flowing stream adjacent or nearby with no tributaries in the spray unit;

2) units which have a flowing stream adjacent or nearby with multiple tributaries within the spray unit; or

3) units which have one or more flowing stream located within (rather than adjacent to) the spray unit.

Large (e.g. Type 1 or Type 2) streams with high background flows may not be suitable as sampling sites because of large dilution effects which would mask small amounts of chemical in the water. Also, it is preferable that there are no tributaries entering the stream to be sampled within the study area, except those which cross or run adjacent to the spray unit.

Once a unit has been selected that satisfies the study objectives, investigators should visit the site to determine access to the spray unit, streamflow regimes, and stream locations relative to spray areas. Any factors which may interfere with study results such as upstream pesticide use, should be noted.

Two to three weeks lead time is generally necessary to coordinate laboratory services. This will allow the assigned laboratory to determine laboratory protocols and plan their work schedules accordingly. Time is also needed to order sample containers, and finalize sampling schedule and laboratory analysis plans. All chemicals to be used, including herbicide/insecticide products, surfactants, drift control agents, and carriers, must be clearly identified ahead of time. For assistance in dealing with analytical laboratories, investigators may wish to consult "A Project Manager's Guide to Requesting and Evaluating Chemical

Analyses" (Document # EPA 910/9-90-024), published by the Puget Sound Estuary Program and available from the U.S. Environmental Protection Agency, Region 10, in Seattle. This document has guidance on appropriate levels of quality control and other information on what to expect from a laboratory.

It will be necessary to measure or estimate stream lengths during site reconnaissance or after. This includes the length of small streams within the spray unit, and the distance from the upstream unit boundary to the downstream unit boundary for streams which traverse or run adjacent to the spray unit. It is also necessary to measure the distance from the downstream unit boundary to the sampling site. Stream length may be measured using a string box or measuring tape following the stream centerline or bank. Direct measurement is the most accurate and takes into account stream meanders. Another method is to use aerial photos and/or maps and a map wheel to estimate stream distances. While walking, information about the stream should be noted. Especially important are the location of beaver dams or large deep pools, springs and/or seeps along the stream banks, and the location and estimated flow or relative size of tributaries flowing into the measured stream. The distances, tributary positions, and sampling site should be noted on a unit map for future reference.

It is desirable but not absolutely necessary to have streamflow (discharge) estimates. A place to take flow measurements should be selected within about 50 meters (165 feet) downstream of the sampling site. The flow site should have a relatively uniform, unrestricted channel. If possible, stream discharge should also be determined at the upstream unit boundary, the downstream unit boundary, and at the sampling site on the same day. This will help determine groundwater influence (flow loss or gain in the reach), incoming flows from tributaries, stream velocity, and cumulative pesticide loading to the stream. Optimally, these flows should be taken within a few days of the spray. In addition to determining the discharge, average stream velocity should be determined from flow measurements taken at one or more representative cross-sections. If a current meter is not available, average velocity may be approximated by timing a floating object along a measured stream distance.

The flowing length of the mainstem of the stream to be sampled and the average stream velocity are used to estimate stream time-of-travel from spray areas to the sampling site (i.e. meters/second X meters of stream = seconds of travel). Time-of-travel is used to adjust the sample collection schedule for larger spray units, as discussed later. Time-of-travel from the midpoint of the stream length that traverses or runs adjacent to the spray unit should be used, except when the length of stream affected is very long (e.g. over about 900 meters or 3000 feet). In the case of very long streams, it may be advisable to time sample collection based on travel time from about one-third of the affected distance, otherwise peak levels may be missed.

It is recommended that the sampling site be at least 65 meters (200 feet) downstream of the nearest spray boundary to avoid possible contamination of personnel and equipment, up to a maximum of 300 meters (1000 feet). The optimum distance is in the 65 to 150 meter range.

The exact location for a sampling site will be determined based on access, the presence of tributaries which would interfere with the study, and other local considerations.

A small step/waterfall or deep riffle area located in the center of the sample creek presents the best opportunity to take water samples. A waterfall or other turbulence tends to mix the sample well and facilitates rapid filling of the sample bottle.

Another consideration is that sampling equipment must be carried into and out of the sampling site. Once the sampling starts, all access to the stream must be from below (downstream of) the sampling site to avoid contamination. Therefore, it is important to mark the access route and sampling site before the day of spray. The spray unit itself must not be entered after the start of spray.

PROCEDURES ON THE DAY OF APPLICATION

There are a lot of details to keep track of, so an equipment list and procedure check off list should be developed prior to sampling. Since the person doing the sampling (sampler) will be preoccupied with the sampling protocol, someone else (e.g. landing forester) will be required to take care of the helicopter and batch truck activities on the unit landing.

The sampler should get to the sampling site at least one or two hours before the start of spray. This will allow time to set up the sampling site, cover equipment with plastic to keep it from being contaminated, take a control sample, and leave to an observation point before start of spray.

It is important for the landing forester and sampler to synchronize their watches prior to the start of spray. The sampler should avoid the landing site after the helicopter or batch truck arrive to avoid contamination.

The sampler also needs to coordinate with the landing forester on a means to signal the sampler on the starting and ending times of spraying. The signal could be by CB or 2-way radio, or it could be a visual or audio signal from the helicopter. In some cases, the sampler might not be able to observe the entire spraying operation due to local topography, but will need to know the starting and ending times to finalize the sample collection schedule.

The attached questionnaire should be filled out by the applicator and/or landing forester . This questionnaire will be used on the day of spraying to record information on wind speed and direction, temperature, relative humidity, aircraft characteristics and flight patterns, characteristics of application equipment (nozzle and boom configuration, operating pressure, etc.), locations of chemical mixing and landing areas, timing of spraying, and other pertinent information and observations. Where appropriate, the information will be displayed on a map of the unit.

In addition, it is critical for the applicator or landing forester to indicate the areas of the unit sprayed (especially for spot sprays) and which streams are buffered on a copy of the unit map. Note the width of all buffers with input from the pilot. This information should also be documented by the sampler if he or she is in a location to observe the spray operation. Also, note helicopter flight paths on the map. For large units, note the approximate times that portions of the unit were sprayed. Where possible, the sampler should also record wind speed and direction from the observation point, as well as the time of the start of spray and end of spray based on his/her own observations.

Follow the protocol on timing of grab samples described in the following section. If possible, streamflow should gaged periodically on the day of sampling by the sampler.

SAMPLING PROCEDURES

Water sampling will include a collection of timed grab samples. A control grab sample is collected prior to chemical spraying, on the same day the unit is sprayed. If not possible to collect the control sample on the same day as spraying, it may be collected the day before.

Timing of sample collection for smaller units (where less than 20 hectares or 50 acres are sprayed) should start from the completion of spraying. This will start the sample schedule described below.

For larger units (where greater than 20 hectares or 50 acres are sprayed), the sampling should be timed from the beginning of spraying *plus time-of-travel from the center or lower portion of the spray unit to the sampling site*. This will start the sampling schedule described below. Time-of-travel must be estimated ahead of time using average stream velocity and stream length.

The final schedule for taking grab samples will be determined as soon as possible after spraying begins or ends and noted in the "Planned Sample Collection" column on the attached Sampling Schedule Form. The schedule for collection of grab samples is presented in Figure 1. These will be collected at 30 minutes, 1 hour, 2 hours, 4 hours, 6 hours, and 24 hours from either the completion of all spray operations for small spray units or the start of spraying plus stream time-of-travel for larger units. Optional grab samples taken at 15 minutes, 3 hours, and 48-hour can be included in the sampling schedule to provide greater resolution of data, depending on budget constraints and the availability of sampling personnel. The 15-minute and 3-hour samples will increase monitoring effectiveness for characterizing the peak concentrations that occur, and will also improve the calculation of a 24-hour average level. A sample collected at 48 hours will help evaluate the persistence of pesticide levels in the stream.

One pair of **field replicate samples** will be collected at each study site to assess sampling and analytical variability. These quality control samples should be sent to the laboratory as

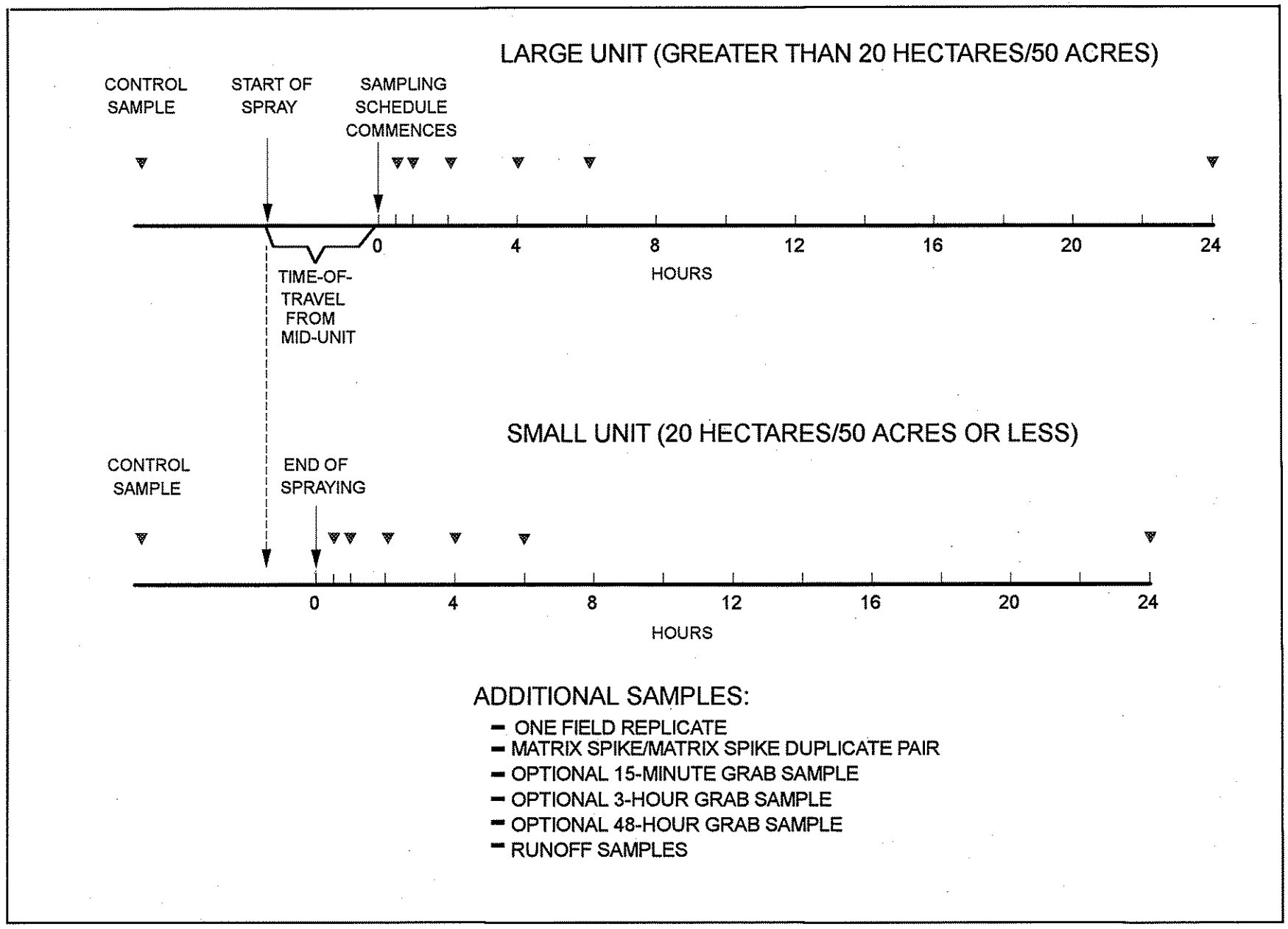

FIGURE 1: SAMPLING SCHEDULE

"blind" samples (i.e. handled so the lab will not know they are replicates). The schedule for collection of replicates is determined by the investigator prior to sampling and may vary from site to site. In addition, the lab will spike a selected sample with a known concentration of the chemical sprayed, and this **matrix spike** will be analyzed in duplicate as an additional quality control check. The grab sample to be spiked will be predetermined, and a larger volume will need to be collected for this sample to facilitate spiking.

All samples collected should be analyzed for the primary active ingredient pesticide. Samples may also be analyzed for primary degradation products, carriers (where diesel is used), and/or secondary pesticides.

Some of the key considerations in sample collection are:

1. The sample bottle itself should be labeled with a preassigned Sample ID Number (usually supplied by the lab) and Field ID Number (identifying the sampling station and/or sequence) and date (**but not time**) of collection. (The time will be recorded on the Sampling Schedule Form but not on the sample bottle as this would give away the "blind" replicates.) Samples will generally be collected in containers supplied by the laboratory and will be preserved and handled per laboratory instructions.

2. All samples should be consistently taken at the same place in the stream cross-section and water column, except that field replicates may be taken at slightly different locations at the cross-section.

3. The sampler should stand downstream of the sample site and avoid disturbing sediment or other materials that could reach the sample bottles. The samples themselves should be taken with the bottle lip just below the surface, pointing upstream, with the bottom held firmly, **avoiding contact with the bottle rim or inside of the bottle cap**. The samples bottles should be filled up to the bottle shoulder (where the container begins to narrow).

4. After taking the sample, the Sample ID Number, Field ID Number, and date (but not time) of the sample will be noted on a sample label that is then securely attached by rubber band or other method, and the date **and time** of collection are entered on the Sampling Schedule Form next to the Sample ID Number.

5. When collecting field replicates, both containers should be filled from the **same location** at the **same time** (or one immediately after the other). If two samplers are available the replicate samples should be taken simultaneously at slightly different locations on the same cross-section using the same procedure. Give each replicate a unique Sample and Field ID Number in order to make them "blind" replicates.

6. Additional containers may also need to be filled for the matrix spike sample, however, it is preferable to use a single oversized container (two to three times normal sample

size) to collect the extra sample volume for splitting by the laboratory. If unsure about collecting matrix spike samples, ask the laboratory for advice. Containers for matrix spike samples should be labeled identically to the scheduled sample; these are **not** sent in "blind".

7. Grab samples taken in glass bottles should be wrapped in bubble rap or other padding to protect the bottles, and iced in coolers immediately upon collection.

8. Samples need to be transported to the laboratory as soon as possible after the 24-hour sample has been taken. Ask the lab for recommended collection-to-analysis holding times (usually seven days maximum for pesticides), and make sure these are adhered to. Make sure all laboratory paperwork is filled out completely and clearly. Once the samples leave your hand the "paper trail" is critical to ensuring the results are assigned to the correct samples.

COLLECTING THE 24-HOUR SAMPLE

Before going out to collect the final 24-hour grab sample, coordinate with the lab representative to determine sample delivery details. At the sampling site note any observations such as precipitation, temperature, weather conditions. Take your grab sample and then take a streamflow measurement (if possible) at the sample site.

RUNOFF SAMPLING

Sampling the same stream is recommended during the first runoff-producing rainfall event in order to characterize pesticide levels associated with runoff. This is especially important when the rainfall occurs within the first 72 hours after the spray. In such cases, peak pesticide levels associated with runoff may exceed those that occurred shortly after spraying. Runoff should be evaluated by one or more grab samples taken at the same locations as the original samples. The schedule of collection will depend on the availability of personnel and funds for laboratory analysis, but the first 12 hours after runoff begins is probably the most important period to sample.

CALCULATING THE 24-HOUR AVERAGE CONCENTRATION

A calculated 24-hour average concentration is derived from the grab samples collected during the first 24 hours after the spray. Time proportionate weighting is used to approximate the actual time-concentration curve. This has been shown to do a good job of approximating the true 24-hour average levels (as might be determined by compositing 15-minute grabs over the entire 24-hour period). The values obtained by the following formula should be within a

factor of 2 of the actual 24-hour average level. This formula applies a time-proportionate weighting factor to each grab sample result:

24-hour ave. conc. = 30-min(0.03) + 1-hr(0.03) + 2-hr(0.06) + 4-hr(0.08) + 6-hr(0.30) + 24-hr(0.50)

If the optional 15-minute and/or 3-hour samples are collected, this should improve the approximation of the 24-hour average, and the above formula should be modified as follows:

24-hour ave. conc. = 15-min(0.015) + 30-min(0.015) + 1-hr(0.03) + 2-hr(0.04) + 3-hr(0.04) + 4-hr(0.06) + 6-hr(0.30) + 24-hr(0.50)

The result should be rounded off to the same number of decimal places that were reported for each grab sample. For grab sample results that are reported as "less than" a specified detection limit, use one-half the detection limit in the above formulas. However, if 50% or more of the grab sample results, *including* the 24-hour grab sample, are reported as "less than" values, then the calculated 24-hour average should be reported as "less than" the average detection limit reported for the data set. (If the 24-hour grab sample has detectable levels of the pesticide, calculate the 24-hour average using one-half the detection limit for any grabs where the result was reported as less than detection limits.)

OPERATOR QUESTIONNAIRE
FOREST CHEMICALS MONITORING PROJECT

Landowner: _____

Person(s) completing questionnaire: _____

Name of Unit: _____ Legal Description: _____

Date of Application: _____

Please fill in your measurements of:

	TIME	TIME	TIME	TIME	TIME	TIME	TIME	TIME	TIME
	_____	_____	_____	_____	_____	_____	_____	_____	_____
WIND SPEED:	_____	_____	_____	_____	_____	_____	_____	_____	_____
WIND DIRECTION:	_____	_____	_____	_____	_____	_____	_____	_____	_____
RELATIVE HUMIDITY:	_____	_____	_____	_____	_____	_____	_____	_____	_____
TEMPERATURE:	_____	_____	_____	_____	_____	_____	_____	_____	_____

Start Time of Spraying: _____

Stop Time of Spraying: _____

Approximate Acres Sprayed: _____ % of Unit: _____

Please indicate which streams were buffered and which were not, and show flight paths and directions on a map of the unit; please indicate the general order of spraying the various sections of the unit.

Target Vegetation/Pest: _____

Active Ingredient Pesticide: _____ lbs/acre applied: _____
Additional Pesticides Used: _____ lbs/acre applied: _____

Surfactant added: _____ amount/acre: _____

Other additives: _____ amount/acre: _____
_____ amount/acre: _____

Carrier(s) used: _____ amount/acre: _____
_____ amount/acre: _____

Application Rate for Final Spray Mixture: _____

Helicopter Model: _____ Effective Swath Width: _____
Flight Altitude: _____ Airspeed: _____ Boom Length: _____
Flight Centerline Offset from Edge of Buffers: _____
Nozzle Type: _____ Nozzle Size: _____ Whirlplates Used: _____
# of Nozzles: _____ Nozzle Orientation Angle: _____ Operating Pressure: _____

SAMPLING SCHEDULE FORM

SITE ID #: FC____: STREAM SAMPLED: _____

PESTICIDE OF CONCERN: _____

SPRAY TIMES: Begin Unit:____:____ Stream Buffer:____:____ End of Spraying:____:____

TIME-OF-TRAVEL ESTIMATE: ____:____ TIME GRAB SAMPLES FROM: ____:____

SAMPLE DESCRIPTION	PLANNED SAMPLE COLLECTION DATE	PLANNED SAMPLE COLLECTION TIME	ACTUAL SAMPLE COLLECTION DATE	ACTUAL SAMPLE COLLECTION TIME	FIELD ID NUMBER	SAMPLE ID NUMBER
Control Grab					FC____-01	
15 Minute Grab *OPTIONAL*					FC____-02	
30 Minute Grab **MS/MSD--COLLECT EXTRA SAMPLE VOLUME**					FC____-03	
1 Hour Grab					FC____-04	
Duplicate of 1 Hour Grab					FC____-05	
2 Hour Grab					FC____-06	
3 Hour Grab *OPTIONAL*					FC____-08	
4 Hour Grab					FC____-09	
6 Hour Grab					FC____-10	
24 Hour Grab					FC____-11	
48 Hour Grab *OPTIONAL*					FC____-12	
Runoff Sample #1 *OPTIONAL*					FC____-13	
Runoff Sample #2 *OPTIONAL*					FC____-14	
Runoff Sample #3 *OPTIONAL*					FC____-15	

NOTES: * Optional samples to be collected, depending on monitoring objectives and budget.

** Collect additional sample volume and/or container labeled with same ID numbers for Matrix Spike & Matrix Spike Duplicate (MS/MSD).

***Collect replicate sample to be labeled seperately and sent to the lab "blind".