IMPACT OF FOREST CHEMICALS ON WATER QUALITY AND GUIDELINES FOR USE

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Several groups of chemicals used in the management of forests have biological activity with more or less potential for affecting water quality. The EPA's Silviculture Project included a study of silvicultural chemicals and protection of water quality, conducted through a contract with Oregon State University. This presentation is a brief synopsis of our final report[1]. This report has been through the formal review process, and has been accepted as the national guide for forest chemical use near water.

The biologically active chemicals used in the management of forests fall into four broad categories: fertilizers, herbicides, insecticides and rodenticides. These materials are used in rather specific ways so that they, 1) enhance productivity, 2) focus the productive effort in desirable species, and 3) protect the desirable species from consumption. In the course of use, however, it is possible for them to enter water courses inadvertently, where enhanced productivity, controlled vegetation and intoxicated fauna are to be avoided.

The specific purpose of the study of silvicultural chemicals was to develop a "state-of-the-art" summary of the effects of all major classes of silvicultural chemicals on water quality, and to develop guidelines under which continued use of chemicals would not lead to deterioration of quality.

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[1]Silvicultural Chemicals and Protection of Water Quality. 1977. (M. Newton and J. A. Norgren authors). Report EPA 910/9-77-036. 224 p. Available at no charge through the National Technical Information Service, Springfield, VA 22161.

Our approach toward that end was as follows: first, chemical use patterns were identified, together with the nature and basis of the problems for which they are prescribed. In order to include all the major problems, only those practices with signigicant chance of contaminating water were considered. The toxicological nature of each candidate chemical was examined in detail, and clearly defined, water quality criteria were proposed in keeping with the nature of forest watersheds and downstream biota and users. Principles of chemical behavior in and near water were examined to furnish the basis of use prescriptions so as to avoid biologically significant contamination. Finally, a guide was developed from these principles that gives the land manager an array of practices permitting the production and protection of forest crops on virtually every acre without infringing on water quality as judged by the above criteria.

Throughout the report, we attempted to maintain an awareness that the management of forests is necessary, and that restriction of tools leads to substitutions having other, perhaps less well known, impacts. Thus, both chemical and non-chemical effects were considered in an attempt to minimize total <u>impact</u> of implementing a silvicultural prescription.

<u>The nature of chemicals and their use patterns</u>

The major classes of chemicals are used in considerably different patterns. These affect the likelihood of encountering a significant pollution problem resulting from a given dosage. Quantities applied during an application also differ substantially, leading to variations in local deposits. Spectrum of biological activity and inherent chronic and acute toxicities determine whether a given deposit in water will have a significant biological impact.

Fertilizers are generally very low in toxicity. The forms used in forests are all found in nature; the baseline levels in soils are usually much larger than the amounts applied. Fertilizer poses a potential pollution problem only because the materials are soluble at the time of application, leading to a brief period during which nutrients may move into water. The likelihood of contamination actually taking place is tied to deposition directly in open water, or to the occurrence of high-intensity rainfall immediately after application. When contamination does occur, it poses no special water quality problems unless the water is trapped in an impoundment where algal bloom can result from an increase in nutrient concentration over an extended period.

Fertilizers are applied at high rates, but at low frequency and in widely dispersed locations. Treatments have not led to large scale contamination of river systems. Forest fertilization is also done in established stands, where nutrients are utilized by vegetation shortly after application, and are not lost from the forest system. There is no evidence that application of nitrogen fertilizers has ever led to water concentrations of nitrate approaching the 10 ppm (nitrogen equivalent) water standard set by the EPA to respond to human intoxication concerns. In brief, there appears to be no special reason for modifying existing fertilization methods as they pertain to water quality.

Herbicides are much more widely used than fertilizers in forests. These chemicals were quite specific in their effects on plants, and some of the most widely used materials in forests are registered for use in aquatic weed control at much higher concentrations than are encountered in forest watersheds.

Silvicultural herbicides are usually applied by helicopter in small units. They are usually applied no more often than once or twice in the development of a timber crop. Roughly 0.2 percent of the commercial forest land in the United States is treated in any given year.

Aerial applications of herbicides and their effects on water quality have been studied extensively. At no time in studies of silvicultural use of herbicides has water contamination reached concentrations known to affect the most sensitive aquatic plants or fauna. The only contamination known to be potentially harmful is that of picloram when it enters water upstream from irrigated potatoes or tobacco, and thus far, no damage to crops has been recorded as the result of water contamination. Despite widespread publicity, 2,4,5-T and silvex do not pose a special problem, despite their trace contamination with TCDD (2,3,7,8-tetrachlorodibenzo-p-dioxin). These materials have been the subject of very sophisticated toxicology research, and the technological base for their continued use is stronger than that of any other pesticide.

Insecticides and rodenticides are of special interest because of their ability to injure animals at low dosages. For rodenticides, the amounts are so small, and the applications so confined to baits and burrows that specific concerns for water quality have very low priority. Insecticides, conversely, are applied to large areas with application systems designed to project a diffuse pattern. The chance for incidental contamination of waterways is therefore greater than for other types of chemical applications. Moreover, the spectra of activity of insecticides indicates that for most materials, very low levels of contamination in water may result in biological impact. The persistent organo-chlorine compounds have the greatest potential for long term effects.

Insecticides are subject to strict administrative control. Most aerial application projects are cooperatively scheduled over areas large enough to bear the overhead costs of monitoring and careful supervision. Despite this, most of the insecticides in use have the potential for causing serious damage to fish or aquatic insect populations if inadvertently applied directly to open water or if spilled directly into a stream in significant quantities.

In sum, there is abundant evidence that priority for water pollution control in the use of silvicultural chemicals is highest for aerial application of insecticides. Among these, the organochlorine compounds warrent special consideration to keep them from entering waterways.

Water quality targets

The determination of a trace contamination of a chemical in streamwater does not imply that harm will result. Aerial application of any chemical normally results in minute quantities appearing in water for a matter of hours, or perhaps a few days. The alternatives to such applications, however, often have impacts on water quality that last for much longer periods, in the form of siltation, large dumps of organic litter into stream channels, and so forth. Some of these impacts have serious implications for water users as well as aquatic fauna. So it is imperative that rules be established under which chemicals may be continued in use safely. Safety is insured by preventing biologically significant amounts from entering water. Cleanup is clearly impractical.

The establishment of rules for safe use entails first the determination of concentrations of chemicals in water that can be tolerated by all known species of aquatic organisms or water users. Secondly, operating guidelines must be established that insure that water quality targets are not overshot while land management goals are being met.

The toxic principles of chemical action determine the approach taken in setting limits on water concentration. Some chemicals are acutely toxic, meaning that they produce symptoms quickly or not at all. Some are chronically toxic, meaning that symptoms are likely to be delayed until body deposits are accumulated, or until some metabolic function has been decreased until detectable changes occur. In general, the persistent compounds, especially the fat-soluble organochlorine insecticides, are the most likely to be chronically toxic. Virtually all of the herbicides and organophosphorus insecticides are in the acutely toxic category. These chemicals are usually eliminated quickly and non-lethal effects are transient. The principal concern for the acutely toxic materials is short-term evidence of lethal or severe intoxication, whereas chronically toxic materials must be evaluated over much longer periods, and be studied for signs of accumulation through food chains. Food chain magnification appears to be largely a function of fat solubility, and is not a problem for pesticides other than organochlorine insecticides presently registered for use in forests.

Chemicals can be classed according to their degrees of toxicity. Acutely toxic does not imply a high degree of toxicity, but merely that toxic symptoms show up quickly, if at all. Degree of toxicity is an inherent property of a compound once it has entered into a metabolic system. Acutely toxic materials are evaluated according to acute oral feeding or exposure levels that produce some measurable symptom in a population of test organisms. Typical tests for rodents are lethality tests, in which a dosage that kills half the animals is known as the LD_{50} (lethal dose for 50% of a population). Fish are exposed to water having various concentrations of toxicant at various life stages. A typical expression of toxicity is LC_{50} (lethal concentration for 50% of a population).

Test data for most of the silvicultural chemicals are sufficient to determine at which levels of water concentration one can anticipate injurious effects on aquatic insects, fish, plants and on animals using the water for drinking. Data are also available that show at which point chemicals are likely to affect irrigated crops, either by directly affecting the crop, as with a herbicide, or by depositing an illegal residue.

All tests contain an uncertainty factor determined by random variation within test organisms. There is also uncertainty resulting from the use of one species test organism to draw inferences about responses of others. Test data for many species demonstrate the degree of variation among species, and show which groups are the most sensitive. Having such an array of data decreases the likelihood of overlooking potential effects on any major group, and virtually eliminates the likelihood of human or fish sensitivity remaining undetected. "No effect" levels of exposure can be ascertained with adequate precision with these methods, especially for the acutely toxic substances.

Maximum concentrations for all silvicultural chemicals other than dinoseb were established for three classes of stream, and for irrigation or potable use. These target maxima were based on a substantial margin of safety below the lowest concentration known to affect <u>any</u> organism likely to be exposed. Data for insects, fish and birds and mammals were considered. Target water quality standards were given safety factors that provide for maximum exposures 10 to 1,000 times lower than the lowest concentrations known to have caused injury to fauna. The range of margin allowed for safety provides for much larger factors for chronically toxic and persistent chemicals than for acutely toxic and quickly degraded materials.

Table 1 lists the recommended target standards for silvicultural chemicals. It provides for a graduation in allowable concentration downward with increasing size of stream, and discriminates between potable standards, which provide for the safety of all aquatic organisms, and irrigation standards that take into account the special sensitivity of vertain crops to some

Table 1 Recommended concentration maxima for silvicultural chemicals by stream class and user group. Potable waters include safety factors for wildlife and aquatic organisms as well as humans.

Class	Chemical	Most Sensitive Test Species Affected	Test Basis & Concentration	Criteria, PPM 24 hr. Mean Stream Class & User: < 10 cfs Potable	< 10 cfs Irrig.	10 cfs-Navigable Potable	10 cfs-Navigable Irrig.	Navigable Potable	Navigable Irrig.
Fertilizer	Nitrate	Man	No effect, 10 mg/l N	10*	10*	10*	10*	10*	10*
	Phosphate	Algae	Growth response var.	-------inadequate basis for recommendation---------					
Herbicide	Amitrole	Daphnia	LC_{50} 48 hr, 3 mg/l	.15	0.1	.03	.01	.015	.01
	Ammonium ethyl carbamoyl phosphonate	Bluegill	LC_{50} 48 hr, 670 mg/l	5	5	1	1	0.5	0.5
	Arsenicals (organic)	Man	No effect, 0.12 mg/l	.1	.1*	.05*	.1*	.05*	.1*
	Dalapon	Daphnia	LC_{50} 48 hr, 11.0 mg/l	.5	.1	.1	.02	.10	.02
	Dicamba	Bluegill	LC_{50} 96 hr, 23. mg/l	.2	.004	.05	.002	.01	.001
	Dinoseb	----------------------inadequate data----------------------							
	Picloram	Bass	LC_{50} 48 hr, 19.7 mg/l	.5	.001	.05	.0005	.005	.0001
	Silvex[1]	Chinook salmon	LC_{50} 48 hr, 1.2 mg/l	.06	.02	.03	.02	.01*	.01*
	Triazines	Daphnia	LC_{50} 48 hr, 1.0 mg/l	.05	.05	.03	.03	.01	.01
	2,4-D[1]	Bluegill	LC_{50} 48 hr, 1.0 mg/l	.05	.05	.05	.02	.01	.005
	2,4,5-T[1]	Bluegill	LC_{50} 48 hr, 1.4 mg/l	.06	.02	.03	.02	.01	.01

Table 1 (continued)

Class	Chemical	Most Sensitive Test Species Affected	Test Basis & Concentration	Criteria, PPm 24 hr. Mean Stream Class & User < 10 cfs Potable	< 10 cfs Irrig.	10 cfs-Navigable Potable	10 cfs-Navigable Irrig.	Navigable Potable	Navigable Irrig.
Herbicide	TCDD	Coho salmon	No effect 96 hr, .000000056 mg/l	.000000006 for all water					
Insecticide	Carbaryl	Stonefly	LC_{50} 48 hr, .0048 mg/l	.001	.001	.0005	.0005	.0002	.0002
	Diazinon	Daphnia	LC_{50} 49 hr, .0009 mg/l	.0001	.0001	.00005	.00005	.00001	.00001
	Disulfoton	Stonefly	LC_{50} 48 hr, .005 mg/l	.001	.001	.00025	.00025	.00024	.00025
	Endosulfan	Rainbow trout	LC_{50} 96 hr, .0003 mg/l	.00003	.00003	.00001	.00001	.000003	.000003
	Endrin	Coho salmon	LC_{50} 96 hr, .0005 mg/l	.00005	.00005	.00001*	.00001*	.000005	.000005
	Fenitrothion	Atlantic salmon	Behavior test 1 mg/l	.025	.025	.01	.01	.005	.005
	Guthion	Stonefly	LC_{50} 96 hr, .0015 mg/l	.0003	.0003	.0002	.0002	.00007	.00007
	Lindane	Brown trout	LC_{50} 48 hr, .002 mg/l	.0001	.0001	.00005	.00005	.00001*	.00001*
	Malathion	Daphnia	LC_{50} 96 hr, .0018 mg/l	.0005	.0005	.0002*	.0002*	.0001	.0001
	Phosphamidon	Daphnia	LC_{50} 48 hr, .0088 mg/l	.0005	.0005	.0005	.0005	.0002	.0002
	Trichlorfon	Stonefly	LC_{50} 96 hr, .016 mg/l	.002	.002	.0005	.0005	.00005	.00005

* As listed in QCW.

[1] The phenoxy herbicides may occur in water as esters or other forms. The given criteria for potable water may be increased by a factor of 10 for forms other than esters. Criteria for irrigation use are for total phenoxy herbicide.

herbicides. The rationale for decreasing levels with increasing size of stream is that concentration peaks move more slowly downstream in large streams than in small creeks, and more total exposure occurs in large than small watercourses having a specified maximum observed concentration.

It is noteworthy that insecticides, as a group, have much lower tolerance limits than herbicides in potable water. The differences between these groups are much greater than the relative differences in nominal application rates. For this reason more attention must be given to application methods in insecticide work than in herbicide applications.

Chemical behavior in forest applications

Water contamination can result if chemicals are applied directly to water, or if runoff carries them to streams at some time later. For those with post-treatment mobility, wide buffer zones would be in order to provide for maximum tie-up in soils and organic matter prior to runoff entry into streams. For those that do not move readily, and this includes nearly all pesticides, the critical factor is in preventing direct application to water at levels exceeding the accepted criteria.

The limited mobility of most forest chemicals is attributable to their tendency to adsorb to organic material and soil colloids. Most forest soils have relatively high cation exchange capacities and low base saturations. This opportunity to "fix" pesticides in situ is substantially greater than actual amounts applied, with the result that most chemicals never penetrate forest soils substantially below the duff layer. Forest soils normally have high infiltration rates, so surface runoff of chemical in solution is rare. In short, little migration occurs in solution, either through soil or over it.

Disturbed soils are far less stable than those without recent history of machine activity. Scarified or tilled soils subjected to intense rainfall are capable of losing many tons of silt per acre in a single storm. When such soils are treated with a chemical, the adsorbed materials will move in association with the silt. The degree to which it affects stream life is determined by the absolute quantity actually reaching the stream, decreased by the tendency for the material to remain attached to soil. This type of contamination is more difficult to evaluate than that of direct contamination, because the silt tends to form deposits that continue to release small quantities of contaminant as desorption occurs. In particular, this process is especially critical when the chemicals are absorbed and retained by stream biota over an extended period. The persistent organochlorine compounds, and endosulfan used on Christmas trees in particular, warrant close attention in this situation. Silt mobility is also a consideration in the evaluation of non-chemical alternatives for vegetation control.

Direct application to open water accounts for most stream contamination. Accuracy of aircraft guidance and technology of nozzles and solvent systems are the most useful controls over direct placement of chemicals in water. This form of contamination takes the form of a brief concentration spike that cannot provide chronic exposure. If the peak is not harmful no effects occur. Thus elimination of harmful peaks are the first line of water protection.

An aircraft releases chemicals through nozzle systems that break the spray into droplets of an array of sizes. Applications requiring heavy coverage and precise targeting, such as herbicides, are delivered in relatively high volumes of liquid, through large-orofice nozzles that emit large drops. Conversely, insecticides are generally applied in general treatments in which very fine sprays are delivered over large areas. Very low volumes of total liquid per acre are required for logistic efficiency in large projects, yet a deficiency of droplets per square inch of foliage allows escapement of excessively large numbers of insects. The droplet size is therefore reduced so as to increase density of droplets per unit of foliage, and to increase the uniformity of coverage between aircraft swaths. Unfortunately, the very technology that contributes to effective insect control also enhances the difficulty of precise targeting of the spray. Thus, effective insecticide applications near streams are likely to deposit significant amounts of material in the water. Except for certain of the most "selective" of the insecticides and biological agents, such deposits are likely to have some effects on aquatic insects or fish, depending on the specific chemical.

Herbicides are more amenable to technical spray modification without loss of effectiveness. Spray nozzle configurations are available that increase uniformity of droplet size and decrease the proportion of fine droplets with high drift potential. Spray thickeners, emulsification agents and foams all may be used to decrease fine droplet movement away from the target zone. The dependence on helicopters rather than fixed-wing aircraft also improves precision of aircraft control.

For many species of vegetation requiring control, there are several herbicides capable of providing the necessary effects. Some of these are usually lower in impact to aquatic systems than others, and unusually sensitive areas may be treated with some of them by helicopter without having direct impact on water quality. There are some opportunities for substitution of insecticides, as well, but margins of selectivity are not as great.

Herbicides applied with conventional cone-nozzle systems delivering ten gallons of water per acre will usually show a rather precise swath boundary. In the absence of wind drift, deposits 50 feet from the edge of a spray project will approximate five percent of the nominal application rate, or less. Insecticides are applied from greater distances above the canopy of vegetation in smaller droplets, swaths are wider and swath "tails" extend further from the target boundary.

The width of a chemical-free buffer zone along a stream is often expressed in terms of swath widths of the aircraft. The effective swath width (ESW), of a spray aircraft is the maximum distance permissible between successive swaths without having a measurable decrease in dosage between swaths. The actual swath width is much wider, in view of the movement of fine droplets to distances of several boom lengths either side of the aircraft. In practice, every swath consists of a principal application centered on the flight line, plus minor deposits from adjacent swath tails. The elimination of such tails improves ability to avoid minor deposits in water.

Guidelines for protection of water quality

Table 2 provides a list of forest management practices involving the application of chemicals, and outlines the rules for buffer strip treatment and monitoring so as to meet the water quality and productivity goals of this program. Methods used to reduce impact of chemicals (Priority I) include designation of buffer zones of widths in accordance with the potential hazard posed by the chemical. The rationale behind recommendations for buffer strip widths is based on the earlier described 20-fold decrease of contamination with each herbicide swath width away from the stream and five-fold decrease per swath of low-volume insecticides with winds less than 5 mph. Based on experience with various pesticides, the proposed criteria for water concentrations will be met with a margin of safety when registered rates of application are applied as recommended. In those exceptions where buffer strips are defined in terms of absolute width, the problem being addressed is the physical movement overland or through the soil in subsurface flow, a group of processes not affected by application technology.

To achieve the second priority, meeting forest production goals without compromising water quality, emphasis is given to the identification of practices that have adverse impacts near water, and substituting less harmful practices. Exceptional conditions under which untreated buffer zones are recommended are identified so that unnecessary loss of productivity can be avoided.

Monitoring will be needed to insure that the recommendations are a) being observed, and b) effective in maintaining water quality. Monitoring for validation of practices will be the responsibility of state and federal water resources agencies, and operational quality control will be the responsibility of the operator. Monitoring of insecticides in particular, will be necessary by users on a limited scale to provide a record of the consequences of chemical activity at the point of maximum potential trouble. The intensity of monitoring is specified in Table 2.

In conclusion, biologically important direct impacts from herbicides, rodenticides and fertilizers will not occur when used as prescribed. And virtually all commercial forest lands adjacent to streams may be managed in ways that include their use without impairing water quality. Insecticides also may be used, but substantial buffer zones and greater operational quality control and monitoring are in order. By following these rules, management goals may be achieved without major extra cost, and without resorting to non-chemical tools having adverse impacts.

For further details of data and rationale behind the rules and standards proposed in this paper, the reader is referred to the original work.

Table 2 Guidelines for Applying chemicals by aircraft, and water monitoring in silvicultural practices.

Practice	Chemical Used	Minimum Distance Between Nearest Water and Center Line of Nearest Swath	Treatment of Buffer	Suggested Location and Frequency of Water Sampling
Fertilization	Urea	3/4 of an effective swath width (ESW).	Apply by ground rig.	Composite, Day 1, at potable user site, if within 1 mile downstream from project.
	Phosphorus	3/4 ESW* Exceptions: upstream from lake or impoundment.	Apply by ground rig.	None
Forest Site Preparation	Amitrole	1/2 ESW* Exceptions: within a mile of potable users, 50-foot buffer.	a) Apply by ground rig. b) Apply substitute chemical. c) Plant buffer zone with tolerant tree species.	Composite, Days 1 & 2, at potable user site if within 1 mile downstream.
	Ammonium ethyl Carbomyl phosphonate	1/2 ESW*	Can be treated.	Composite, Day 1 at potable user site if within 1 mile of project downstream.
	Atrazine	1/2 ESW* Exceptions: scarified areas, 50 feet.	Do not disturb soil within buffer zone.	None
	Dalapon	1/2 ESW	Do not disturb soil within 50 feet of creek.	None
	Phenoxys	1/2 ESW	Can be treated.	Composite, Day 1, at intake if potable user within 1 mile of project downstream.

Table 2 (continued)

Practice	Chemical Used	Minimum Distance Between Nearest Water and Center Line of Nearest Swath	Treatment of Buffer	Suggested Location and Frequency of Water Sampling
	Picloram	100 feet (200 feet when applied during period of rainfall surplus).	Can be treated with substitute chemical within prescribed limits.	Composite, weekly at irrigation user if within 5 miles of project, and crops include potatoes, tobacco or legumes. Sample after spraying, again in sequence after effective rainfall.
Forest Insect Control				
Biological	Bacillus thuringiensis	None*	Can be treated.	None
	Nuclear polyhedrosis	None*	Can be treated.	None
Chemical	Carbaryl	1 ESW* or 100 feet, whichever is greater.	May treat with biological agent.	Composite each day of spraying immediately downstream from project and above potable user, and 2 days after. Sample at water intake, if within 2 miles of project. Filter samples.
	Diazinon	1 ESW* or 100 feet, whichever is greater.	"	"
	Disulfoton	1 ESW* or 100 feet, whichever is greater.	"	"

Table 2 (continued)

Practice	Chemical Used	Minimum Distance Between Nearest Water and Center Line of Nearest Swath	Treatment of Buffer	Suggested Location and Frequency of Water Sampling
Forest Insect Control (cont.)	Endosulfan	4 ESW* or 300 feet, whichever is greater.	May treat with carbaryl diazinon, fenitrothion or phosphamidon to 1 ESW from water.	Sample as with organophosphorus insecticides, but sample also after each heavy rain for next month.
	Fenitrothion	1 ESW*	May use biological agent.	Same as carbaryl.
	Guthion	3 ESW* or 200 feet, whichever is greater.	"	"
	Malathion	"	"	"
	Phosphamidon	1 ESW* or 100 feet, whichever is greater.	"	"
	Trichlorfon	"	"	"
Rodent Control (Seeding)				
Chemical	Endrin	3/4 ESW	Can be treated by hand.	None

*For definition and discussion of ESW see pages 118 and 119.
Designation of "None" or 1/2 ESW under Buffer Strip Width implies only that buffer strip width is at the discretion of the operator, and that direct impact on water quality is not at issue. Even without a buffer strip, the aircraft should never be operated within a half-ESW of streams that are likely to have fish in them at time of chemical application. For those insecticides requiring one or more effective swath widths, the proposed buffers are for helicopters with droplet size of 200 μ MMD. If droplets are smaller or large fixed-wing aircraft are used, buffers should be 200 feet plus the given swath numbers. Helicopters may be used in conjunction with large aircraft.