PESTICIDES USED IN FORESTRY AND THEIR IMPACTS ON WATER QUALITY. J.L. Michael. USDA Forest Service, Southern Research Station, Auburn, AL 36849.

ABSTRACT

Approximately 2.1 billion kg active ingredient (a.i.) ofpesticides are used in the US annually. Of the 890 a.i.s registered, 20 account for more than 95% of the pesticide used in forest vegetation management. Forest vegetation management, in the broader context, includes such activities as plant protection from animal, insect, bacterial, and fungal damage. It also includes pesticide uses for noxious weed control, conifer and hardwood culture, and improvement of recreational areas and wildlife habitat. Pesticide use is most intensive around home and gardens, followed by agricultural land, governmental and industrial land, and is least intensive on forest land. The most extensive use is on agricultural land. Contamination of surface and ground water have been monitored and observed to occur at relatively low levels. Maximum pesticide concentrations observed in water have been much lower than the maximum levels which EPA considers safe for consumption on a daily basis over a lifetime (HAL). Some studies have applied herbicides at several times the labeled rate directly to surface water in research studies. In some of these studies maximum herbicide concentrations observed in ephemeral to first-order streams exceeded the lifetime HAL, but were ephemeral lasting only a few hours and the highest concentrations did not exceed EPA's 1-day HAL. Even with the widespread use of pesticides in North America, those typically used in vegetation management programs have not been identified in surface or groundwater at sufficiently high concentrations as to impair drinking water quality. Their rapid break-down by physical, chemical, and biological routes coupled with current use patterns precludes the development of significant water contamination problems unless they are applied directly to water. Therefore, their use should be carefully planned and all agency, local, state, and federal laws should be followed. It is especially important to follow all label directions because pesticide labels are legal documents specifying federal laws pertaining to their use. Best management practices should be carefully adherred to and use around drinking water supplies should be avoided, except where permitted by

the label. Wherever pesticides are used, precautions should always be taken to protect drinking water sources from contamination.

INTRODUCTION

On forest and range land, management often must protect desirable vegetation from pathogens, competing vegetation, insects, and animals. Vegetation also is managed to clear road and utility rights-of-way, to improve recreation areas and wildlife habitat, and to control noxious weeds. Pesticides offer inexpensive and effective ways of getting these jobs done.

The Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) allows the registration of pesticides for use in the U.S. The registration process is an extraordinary one which requires years of testing before sufficient efficacy, environmental safety, toxicology, and public safety data can be collected and evaluated in the support of registration of a new pesticide. While this process is designed to assure safety, new and old pesticides, following registration, continue to be studied by researchers in private, state, and federal agencies in an effort to identify any potential environmental or toxicological problems. This extremely thorough process has led to the registration of the safest pesticides possible with the caveat that to maintain this safety they must be applied according to directions approved by the U.S. Environmental Protection Agency (U.S. EPA) and included on the label of every registered pesticide. Currently there are about 890 active ingredients registered under FIFRA, most of which are conventional pesticides. These conventional pesticides represent about 21% of the total quantity of pesticides used annually while the remaining 79% of the 2.1 billion kg are a small group not normally thought of as pesticides (chlorine/hypochlorites, specialty biocides, petroleum, sulfur, and wood preservatives), but which are regulated under the authority of FIFRA (1).

A number of issues surround all pesticide use. Among them are (1) drinking water quality, (2) aquatic ecosystem impacts, (3) health effects of 'inerts', and (4) non-target species effects. In considering the impacts of pesticides on drinking water quality we will consider use patterns, pesticide contamination of surface and ground water, and the toxicology associated with those levels of contamination.

USE PATTERNS

Resistance to pesticide use in forestry generally focuses on perceived risks based on toxicology and stream contamination. The resistance to use of pesticides may arise in part from the writtings of authors concerned over the wide-scale use of pesticides on agricultural and forest sites and their potential adverse environmental impacts. This approach fails to recognize the far more intensive use by individuals and the potential adverse health impacts that accrue from that use. Two reports give similar statistics for pesticide use in the US (1, 28). Approximately 16 percent of the 9.3 million square kilometers of land in the United States is treated with pesticides annually (28). The most intensive use of pesticides occurs on land occupied by households. Households represent 0.4 percent of all land and receive 11-12 percent of all pesticides used in the US. Agricultural land (52 percent of all land) is the next most intensively treated receiving 75-77 percent of all pesticides used. Government and industrial land (16 percent of all land) receives 12 percent of all pesticides. The least intensive use of pesticides occurs on forest land (32 percent of the land). Pimentel and Levitan (28) point out that forest land receives only 1 percent of all pesticides used and that less than 1 percent of all forest land is treated annually. In the United States of America, National Forest System (NFS) land is treated with even smaller amounts of pesticides. Since 1990, less than 0.3 percent of NFS land received some form of pesticide treatment annually. As an example, data from 1997 indicates 120,674 of the 77.7 million ha of NFS land (approximately 0.16 percent) was treated with a total of 91,101 kg of active ingredient (43). The amount of pesticide used and the number of acres treated varies slightly from year to year.

It is difficult to determine exactly how much of each kind of pesticide is used in forest management in the private sector because of the proprietary nature of that information. It is clear that pesticide use, especially herbicide use, is more common on production forests than on NFS land. In the 12 southern states, herbicide use increased 53% from 1996 to 1998 and a total of 256,345 ha were reported treated with herbicides in 1998 (8). Most of this land was aerially sprayed (80 %) while the remainder was treated by mobile ground equipment or backpack sprayer (8).

Pesticide use in the public sector is well documented and the information is readily available. While vegetation management is frequently taken to mean the control of competing vegetation in timber management programs, there are many aspects of the broader context of vegetation management as practiced on NFS land. Nation-wide, 120,552 ha of NFS land were treated with pesticides in 1997 (43) while only 48169 ha were treated with herbicides (including also plant growth regulators and algicides). On NFS land, more area was treated to protect vegetation from animals (26 percent of all treated land) and insects (22.3 percent), and to control noxious weeds (19.5 percent) than for control of competing vegetation (17.9 percent) in FY97. Table 1 lists the use of pesticides on NFS land in 1997 by type and management objective.

PESTICIDE CONTAMINATION OF SURFACE AND GROUND WATER

Pesticides used in forest vegetation management are used around the world in agricultural, forest, range, and urban applications. Some have been found in surface water, shallow groundwater, and even in shallow wells (less than 10 m), but in concentrations far below levels harmful to human health and the occurrence is infrequent. Table 2 summarizes

reports of pesticides most used in forest vegetation management that have been detected in water in the U.S. The 20 pesticides most used on NFS land in vegetation management (Table 3) represent more than 95% of all active ingredient applied to NFS land in 1997.

Reports of pesticide contamination of water are usually from agricultural (14, 15) or urban applications (3), but the potential exists for contamination from forest vegetation management. Water from forests is generally much less contaminated than water from other land uses. However, several studies on forest sites listed in Table 2 present data for water collected directly from treated areas. The concentration of pesticides from some of these sites is high compared to samples taken from large rivers and lakes. Pesticide concentrations are greatly reduced by dilution as they move from the treated sites to downstream locations. Degradation of pesticides by biological, hydrolytic and photolytic routes also contributes to downstream reductions in pesticide concentrations.

Larson and others (16) summarized the results of 236 studies throughout the United States on pesticide contamination of surface water by listing the maximum observed concentrations from each study. These studies were located principally around large river drainage basins and therefore represent cumulative pesticide contributions from a variety of uses. Monitoring results were reported for 52 pesticides approved for agricultural, urban and forestry use and their metabolic byproducts. Only six of the pesticides most used in vegetation management were reported to be present in surface water by Larson and others (16). They were carbaryl, 1 report; hexazinone, 1 report; chlorpyrifos, 3 reports; picloram, 4 reports; dicamba, 5 reports; and 2,4-D, 24 reports.

From 1985 to 1987, Cavalier and others (6) monitored 119 wells, springs, and municipal water supplies for occurrence of pesticides throughout the State of Arkansas. The wells were mostly located in eastern Arkansas, with 8 wells located in the Ouachita National Forest. Only wells considered highly susceptible to pesticide contamination were monitored. They included domestic, municipal, and irrigation wells. The laboratory detection limits for the 3 forestry pesticides (2,4-D, hexazinone, and picloram) were 70 to 800 times lower than their HALs. They did not detect well water contamination from any of the 18 pesticides monitored. Failure to detect pesticides in these high risk wells strongly indicates that ground water is not at risk from forestry pesticides applied according to label directions.

Michael and Neary (20) reported on 23 studies conducted on industrial forests in the South in which whole watersheds received herbicide treatment. Water flowing from the sites was sampled near the downstream edge of the treatments. The watersheds were relatively small (less than 300 acres) and the ephemeral to first-order streams draining these watersheds were too small to be public drinking water sources, but their flow reached downstream reservoirs. The maximum observed hexazinone, imazapyr, picloram, and sulfometuron concentrations in streams on these treated sites did not exceed HALs, except for one case in which hexazinone was experimentally applied directly to the stream channel. Even in this case in which hexazinone was applied directly to the stream at a very high rate, drinking water standards were exceeded for only a few hours. In another study, picloram was accidentally applied directly to streams, but maximum picloram concentrations did not exceed HALs during the year after application.

Bush and others (5) reported on use of hexazinone on two coastal plain sites (deep sand and sandy loam soils) that were monitored for impacts on groundwater. Hexazinone was not detected in groundwater at the South Carolina site for 2 years after application. In Florida, hexazinone was found infrequently in shallow test wells at concentrations up to 0.035 mg/L, much lower than the safe levels for daily exposure (0.400 mg/L). Water from these sites drains into other creeks and rivers, and is diluted before entering reservoirs.

Michael and others (21) reported the dilution of hexazinone downstream of treated sites. One mile below the treated site, hexazinone concentrations were diluted to 1/3 to 1/5 the concentration observed on the treated site. Hexazinone was applied for site preparation at 6 lb ai/ac to clay loam soils, a rate three times the normal, and it was applied directly to a stream segment, resulting in a maximum observed on-site concentration of 0.473 mg/L. This was slightly more than the lifetime HAL but considerably below the longer-term HAL of 9.0 mg/L (36). Following the application, on-site stream concentrations did not exceed the lifetime HAL.

Norris (26) reported contamination of streamflow with dicamba used for control of hardwoods on silty clay loam soils in Oregon. On a 603 acre watershed, 166 acres were aerially sprayed with 1 lb ai/ac of dicamba. A small stream segment was also sprayed causing detectable dicamba residues 2 hours after application began, approximately 0.8 miles downstream. Concentrations rose for approximately 5.2 hrs after treatment began and reached a maximum concentration of 0.037 mg/L, less than a fifth of the HAL (0.200 mg/L). No dicamba residues were detected beyond 11 days after treatment.

Glyphosate and 2,4-D have aquatic labels, which permit direct application to water. Stanley and others (30) found that when 2,4-D was applied to reservoirs for aquatic weed control, about half of water samples from within treatment areas contained 2,4-D, and the highest concentration (0.027 mg/L) was less than half of the HAL (0.070 mg/L). Newton and others (25) aerially applied glyphosate at three times the normal forestry usage rate (4 lbs ai/ac), no buffers were left, and all streams and ponds were sprayed. Initial water concentrations were 0.031 and 0.035 mg/L in Oregon and Georgia, and 1.237 mg/L in Michigan on the day of application. After day 1, glyphosate concentrations dropped to below 0.008 mg/L on all three sites for the duration of the study. HAL was exceeded on only one of three sites and then for only 1 day, the day of application.

There is little information on the movement of metsulfuron to streams. Michael and others (19) found trace residues of metsulfuron in shallow monitoring wells in Florida where 24 wells were sampled to a depth of 6 feet. Metsulfuron was detected (0.002 mg/L) in 1 of 207 samples collected during 2 months after application.

Pesticide movement into streams is well documented, but movement into ground water is not as well researched. Movement of pesticides into ground water should result in much lower concentrations than observed in surface water. Pesticides must pass through several physical barriers or layers before reaching ground water. As pesticides pass through each layer, they are degraded, diluted, etc. Surface water provides a medium for dilution, hydrolysis, metabolism, and photolysis. Aquatic vegetation can also degrade pesticides by metabolism. Microbes associated with coarse and fine particulate organic matter found naturally in streams also metabolize pesticides.

In order for water on the soil surface to carry pesticides into ground water, it must pass through the soil column. Here again, processes work to reduce the potential for pesticides to reach ground water. Pesticides percolating through the soil column are adsorbed to soil particles, reducing the amount reaching the ground water. Pesticides adsorbed onto soil particles may be irreversibly bound, released slowly, or further metabolized by microbes. Once pesticides reach ground water, they may degrade further. Cavalier and others (7) found that naturally-occuring microbes degraded herbicides, including 2,4-D, in ground water.

Thus, ground water concentrations of pesticides should be considerably lower than observed in surface water. Funari and others (11) reviewed the literature and reported the range of maximum concentrations of pesticides in ground water, including those used in forestry, agriculture, home and garden, and on industrial rights-of-way. The maximum range of values for 2,4-D (0.0002-0.0495 mg/L), hexazinone (0.009 mg/L), and picloram (0.00063-0.049 mg/L) are much lower than the HALs for those compounds.

The National Water-Quality Assessment (NAWQA) Program conducted by the U.S. Geological Survey began in 1991. The focus of NAWQA is to identify nutrient and pesticide contamination of the water resource throughout the United States. The 1999 NAWQA report (http://water.usgs.gov/pubs/circ/circ1225/index.html) makes little mention of forest sites or forestry pesticides, but concludes that: "Concentrations of nutrients and pesticides in streams and shallow ground water generally increase with increasing amounts of agricultural and urban land in a watershed." The report focused on more than 50 major river basins and aquifers supplying water to more than 60 percent of the population and approximately half of the United States. Few forestry pesticides other than 2,4-D are mentioned in these basins or aquifers.

Even in dominantly agricultural areas, the report states: "One of the most striking results for shallow ground water in agricultural areas, compared with streams, is the low rate of detection for several high-use herbicides other than atrazine. This is probably because these herbicides break down faster in the natural environment compared to atrazine." Atrazine is principally used in growing corn, but also has applications for general weed control in a host of areas including rangeland, pastures, and turf grass sod. It has not been used on NFS land since 1992. While not directly addressing forestry pesticides and drinking water, these NAWQA conclusions support the above research findings and conclusions that ground water contamination by pesticides should be lower than observed for surface water. Because surface water contamination from forest sites treated according to label directions does not exceed HALs, it is unlikely that ground water contamination would exceed HALs.

Several of the pesticides in Table 3 have not been reported in water. They include chloropicrin, chlopyralid, dazomet, and thiram. Chloropicrin and dazomet are soil fumigants which are gases in their active form and are used only for seedling production. Chlopyralid is a relatively new compound in the U.S. Thiram is a dimethyl dithiocarbamate fungicide, principally used in forestry for seed protection.

There is very little water quality data for pesticides used in nursery disease control and soil fumigation. More than 71 percent of fungicides and fumigants used on NFS land are applied in nurseries. Intense use in a nursery may result in localized groundwater contamination. Three pesticides (chloropicrin, dazomet, and methyl bromide) make up this group of intensively used agents. Chloropicrin is toxic to plants and is used in combination with other chemicals for fumigating seedbeds. Dazomet, a soil fumigant, is a gas and relatively insoluble in water (3 g/L). However, dazomet is unstable in water and quickly breaks down into methyl isothiocyanate (MITC), formaldehyde, monomethylamine, and hydrogen sulfide. All are toxic, but the most toxic is MITC. The RfD for formaldehyde is 0.2 mg/kg/d. EPA has classified formaldehyde as a compound of medium carcinogenic hazard to humans. Methyl bromide is very toxic. Data are insufficient to determine whether frequent use of these three pesticides adversely impacts water quality, either locally or over an expanded area.

TOXICOLOGY

One major issue with pesticide use is the impact on drinking water quality. To adversely impact drinking water, pesticides must (1) be harmful to humans, and (2) reach drinking water at concentrations exceeding toxic levels for humans. The toxicity of a chemical is a measure of its ability to harm individuals of the species under consideration. This harm may come from interference with biochemical processes, interruption of enzyme function, or organ damage. Toxicity may be expressed in many ways. Probably the best known term is LD_{50}, the dose at which 50 percent of the test animals are killed. More useful terms have come into popular usage in the last decade: no observed effect level

(NOEL), no observed adverse effect level (NOAEL), lowest observed adverse effect level (LOAEL), reference dose (RfD), and, relating specifically to water, the health advisory level (HA or HAL). The U.S. EPA uses these terms extensively in risk assessment programs to indicate levels of exposure deemed safe for humans, including sensitive individuals. They are derived from toxicological test data and have built-in safety factors ranging upward from 10, depending on U.S. EPA's evaluation of the reliability of the test data.

The NOEL is determined from animal studies in which a range of doses is given daily; some doses cause adverse effects and others do not (38). NOAEL is derived from the test data where all doses have some effect, but some of the observed effects are not considered adverse to health. When U.S. EPA has data from a number of these tests, the lowest NOEL or NOAEL is divided by a safety factor of at least 100 to determine the RfD. The RfD is an estimate of a daily exposure to humans that is likely to be without an appreciable risk of deleterious effects during a lifetime.

Drinking water standards are calculated for humans by assuming that an adult weighs 70 kg and consumes 2 L of water per day, and a child weighs 10 kg and consumes 1 L of water per day over the period of exposure. HALs are calculated for 1-day, 10-days, longer-term (10 percent of life expectancy), or lifetimes (70 years) by dividing the NOAEL or LOAEL by a safety factor and multiplying the resulting value by the ratio of body weight to amount of water consumed daily (38). The safety factor can range from 1, but is rarely less than 10, and goes as high as 10,000, depending on the available toxicological data. A safety factor of 10 is used when good NOAEL data are based on human exposures and are supported by chronic or subchronic data in other species. When NOAELs are available for one or more animal species but not humans and good data for LOAEL in humans is available, a safety factor of 100 is used. When good chronic data are available identifying an LOAEL but not an NOAEL for one or more animal species, a safety factor of 1,000 is used. For situations where good chronic data are absent, but subchronic data identify an LOAEL but not an NOAEL, the safety factor of 10,000 is used. EPA's estimates of safe levels for daily exposure to the pesticides most widely used in forest vegetation management are summarized in Table 3. Of the pesticides listed in Table 3, only elemental boron (potentially from borax) and methyl bromide are listed in EPA's drinking water contaminant candidate list (CCL) for consideration for possible regulation. Maximum Contaminant Levels (MCLs) have been established for 2,4-D (0.070 mg/L), glyphosate (0.700 mg/L), and picloram (0.500 mg/L) and these are the same as the already established lifetime HALs (Table 3). Additional information on specific pesticides can be retrieved from the National Pesticides Telecommunication Network at http://ace.orst.edu/info/nptn, USEPA site at http://www.epa.gov/epahome/search.html, Extension Toxicology Network at http://www.orst.edu/info/extoxnet, Material Data Safety Sheets at http://siri.uvm.edu/msds, US Forest Service at http://www.fs.fed.us/foresthealth/pesticide, and many others.

None of the pesticide concentrations in water reported in Table 2 exceeded U.S. EPA safe levels for human health (lifetime HAL, Table 3) except where application included placement directly in stream channels, and most were less than 0.002 mg/L. Where concentrations of pesticides in surface water exceeded the lifetime HAL, they lasted only for a few hours and did not exceed the 1-day HAL. Thus, use of these pesticides has not resulted in impairment of drinking water or water that would feed into drinking water systems. It is important to recognize that surface water is not necessarily drinking water. The studies summarized by Larson and others (16) dealt with surface water, principally in lakes, reservoirs, and rivers, which would be treated prior to use for drinking.

DISCUSSION AND CONCLUSIONS

Care must always be exercised in extrapolating data from local studies on drinking water to a regional or larger scale. However three strategies of "worst-case" scenarios used in the studies described by Michael et al. (18, 19, 21), Michael and Neary (20), and Newton et al. (25) mitigate against high levels of uncertainty: (1) several studies have investigated the impacts of pesticides applied directly to surface water, (2) several studies have investigated the impacts on water of pesticides applied at several times the prescribed rate, and (3) most of the studies conducted specifically on forestry sites treated the entire catchment from which water samples were taken, resulting in samples with levels of pesticide contamination greater than are likely to occur anywhere downstream. Research which investigated the impacts of pesticides applied directly to surface water used the worst-case scenario for operational treatments in which pesticide was applied at normal rates directly to surface water (ponds and streams). These studies in forest sites did not find any contamination of water at levels above the HAL for individual chemicals. Research investigating aquatic impacts for pesticides applied at several times the labeled rate used the worst-case scenario for operational treatments where an area might receive multiple applications in error or where small spills occurred. In these studies, HALs were exceeded by only a few percent and then for only a brief period of time, usually less than a few hours. Both worst-case scenarios just described were combined with the third worst-case scenario in which all sampling was conducted on surface water found within the treated area. In this case most of the water was from small pools or ephemeral to first-order streams. While water from ephemeral to first-order streams or pools would not be used for drinking water sources because of the low yield, they do represent the water sources most likely to be severely contaminated during normal forest pesticide applications. However, even these sources were not contaminated at levels exceeding HALs except in the worst-case scenario in which pesticide was applied at several times the labeled rate as indicated above. In addition, data on contamination of water for the pesticides in Table 2 have been taken from a number of studies conducted in North America and the findings are generally similar. These studies have, with a few exceptions, confirmed the absence of significant contamination of drinking water. The exceptions were those cases in which a pesticide was applied directly to water, and the high concentrations observed in those studies were at or only slightly above drinking water standards. These high concentrations lasted only a few hours at most before dropping well below current HALs. It is clear from

the available literature that use of pesticides in strict accordance with label directions on forest land cannot be expected to contribute significantly to groundwater or drinking water contamination. It is also clear that pesticides, unless clearly labeled for aquatic uses, must not be applied directly to water, and that pesticides should be used around water resources which are particularly sensitive only after careful consideration of the ramifications.

Even with the widespread use of pesticides in North America, those typically used in vegetation management programs have not been identified in surface or groundwater at sufficiently high concentrations as to impair drinking water quality. Their rapid break-down by physical, chemical, and biological routes coupled with current use patterns precludes the development of significant water contamination problems unless they are applied directly to water. Therefore, their use should be carefully planned and all agency, local, state, and federal laws should be followed. It is especially important to follow all label directions because pesticide labels are legal documents specifying federal laws pertaining to their use. Best management practices should be carefully adherred to and use around drinking water supplies should be avoided, except where permitted by the label. Wherever pesticides are used, precautions should always be taken to protect drinking water sources from contamination.

LITERATURE CITED

1. Aspelin, A.L.; Grube, A.H. 1999. Pesticides industry sales and usage: 1996 and 1997 market estimates. Report no. 733-R-99-001. United States Environmental Protection Agency, Office of Prevention, Pesticides and Toxic Substances, Wahsington, DC.
2. Bouchard, D.C.; Lavy, T.L.; Lawson, E.R. 1985. Mobility and persistence of hexazinone in a forest watershed. Journal of Environmental Quality. 14:229-233.
3. Bruce, B.W.; McMahon, P.B. 1996. Shallow ground-water quality beneath a major urban center: Denver, Colorado, USA. Journal of Hydrology. 186: 129-151.
4. Bush, P.B.; Neary, D.G.; Taylor, J. W. 1988. Effect of triclopyr amine and ester formulations on groundwater and surface runoff water quality in the coastal plain. Proceedings SouthernWeed Science Society. 41:226-232.
5. Bush, P.B.; Michael, J.L.; Neary, D.G.; Miller, K.V. 1990. Effect of hexazinone on groundwater quality in the coastal plain. . Proceedings SouthernWeed Science Society. 43:184-194.
6. Cavalier, T.C.; Lavy, T.L.; Mattice, J. D. 1989. Assessing Arkansas ground water for pesticides: methodology and findings. Ground Water Monitoring Review. 9: 159-166.
7. Cavalier, T.C.; Lavy, T.L.; Mattice, J. D. 1991. Persistence of selected pesticides in ground-water samples. Ground Water. 29:225-231.
8. Dubois, M.R.; McNabb, K.; Straka, T.J. 1999. Costs and cost trends for forestry practices in the South. Forest Landowner 58:3-8.
9. Edwards, W. M.; Triplett, G. B., Jr.; Kramer, R. M. 1980. A watershed study of glyphosate transport in runoff. Journal of Environmental Quality. 1980. 9: 4, 661-665.
10. Feng, J. C.; Thompson, D. G.; Reynolds, P. E. 1990. Fate of glyphosate in a Canadian forest watershed. 1. Aquatic residues and off-target deposit assessment. Journal of Agricultural and Food Chemistry. 1990. 38: 4, 1110-1118.
11. Funari, E.; Donati, L.; Sandroni, D.; Vighi, M. Pesticide Levels in Groundwater: Value and Limitations of Monitoring. In *Pesticide Risk in Groundwater*, M. Vighi and E. Funari, Eds. (Boca Raton, FL:Lewis Publishers, 1995) 275 pp.
12. Holmes, S. B.; Millikin, R. L.; Kingsbury, P. D. 1981. Environmental effects of a split application of Sevin-2-oil. Rep. FPM-X-46. Sault Ste. Marie, Ontario: Canadian Forestry Service. 58 pp.
13. Johnsen, T. N., Jr. 1980. Picloram in water and soil from a semiarid pinyon-juniper watershed. Journal of Environmental Quality. 9:601-605.
14. Kolpin, D.W.; Kalkhoff, S.J.; Goolsby, D.A.; Sneck-Fahrer, D.A.; Thurman, E.M. 1997. Occurrence of selected herbicides and herbicide degradation products in Iowa's ground water, 1995. Ground Water. 35:679-688.
15. Koterba, M.T.; Banks, W.S.L.; Shedlock, R.J. 1993. Pesticides in shallow groundwater in the Delmarva Peninsula. Journal of Environmental Quality. 22:500-518.
16. Larson, S.J.; Capel, P.D.; Majewski, M.S. 1997. Pesticides in surface water: Distribution, trends, and governing factors. Pesticides in the Hydrologic System series v. 3, Chelsea, MI: Ann Arbor Press. 373 pp.
17. Leveille, P.; Legris, J.; Couture, G. 1993. Results of spot checks in lotic environments after spraying of glyphosate in forests from 1989 to 1991. Quebec, Canada: Ministere des Forets du Quebec. 21 pp.
18. Michael, J.L.; Neary, D.G.; Wells, M. 1989. Picloram movement in soil solution and streamflow from a coastal plain forest. Journal of Environmental Quality. 18:89-95.
19. Michael, J.L.; Neary, D.G.; Fischer, J.B.; Gibbs, H.G. 1991. Metsulfuron in surface groundwater of a North Florida flatwoods. . Proceedings of the Southern Weed Science Society. 44:233-237.
20. Michael, J.L.; Neary, D.G. 1993. Herbicide dissipation studies in southern forest ecosystems. Environmental Toxicology and Chemistry. 12:405-410.
21. Michael, J. L.; Webber, E. C.; Bayne, D. R.; Fischer, J. B.; Gibbs, H. L.; Seesock, W. C. 1999. Hexazinone dissipation in forest ecosystems and impacts on aquatic communities. Canadian Journal of Forest Research. 29:1170-1181.
22. Miller, J.H.; Bace, A.C. 1980. Streamwater contamination after aerial contamination of a pelletized herbicide. New Orleans, LA: USDA Forest Service, Southern Forest Experiment Station. Res. Note SO-255, 4 pp.
23. Neary, D.G.; Bush P.B.; Douglas, J.E.; Todd, R.L. 1985. Picloram movement in an Appalachian hardwood forest watershed. Journal of Environmental Quality. 14:585-592.

24. Neary, D.G.; Bush P.B.; Grant, M.A. 1986. Water quality of ephemeral streams after site preparation with the herbicide hexazinone. Forest Ecology and Management. 14:23-40.
25. Newton, M.; Horner, L.M.; Cowell, J.E.; White, D.E.; Cole, E.C. 1994. Dissipation of glyphosate and aminomethylphosphonic acid in North American forests. Journal of Agricultural and Food Chemistry. 42:1795-1802.
26. Norris, L.A. 1975. Dicamba residues in streams after forest spraying. Bulletin ofEnvironmentalContamination and Toxicology. 13:1-8.
27. Norris, L.A. 1981. Phenoxy herbicides and TCDD in forests. Residue Reviews. 80:65-135.
28. Pimentel, D.; Levitan, L. 1986. Pesticides: Amounts applied and amounts reaching pests. BioScience. 36(2):86-91.
29. Smith, N.J.; Martin, R.C.; St. Croix, R.G. 1996. Levels of the herbicide glyphosate in well water. Bulletin of Environmental Contamination and Toxicology. 57:759-765.
30. Stanley, R. A.; Bates, A. L.; Bedsole, J. A.; Hall, T. F. 1974. Program diversity and control of Eurasian watermilfoil in Tennessee Valley reservoirs. Las Vegas, Nevada. Weed Science Society of America Proceedings. 19 pp.
31. Sundaram, K. M. S.; Szeto, S. Y. 1987. Distribution and persistance of carbaryl in some terrestrial and aquatic components of a forest environment. Journal of Environmental Science and Health, B (Pesticides, Food Contaminants and Agricultural Wastes). B22: 5, 579-599.
32. Thompson, D. G.; Staznik, B.; Fontaine, D. D.; Mackay, T.; Oliver, G. R.; Troth, J. 1991. Fate of triclopyr ester released in a boreal forest stream. Environmental Toxicology and Chemistry. 10 (5): 619-632.
33. U.S. EPA. 1988a. U.S. EPA integrated risk information system substance file-Ally; CASRN 74223-64-6. 30 June 1988. Washington, D.C.: U. S. Environmental Protection Agency. URL: http://www.epa.gov/ngispgm3/iris/subst/0288.htm.
34. U.S. EPA. 1988b. Picloram health advisory. Office of Drinking Water, Washington, D.C.: U. S. Environmental Protection Agency. August, 1988.
35. U.S. EPA. 1989. Drinking waterhealth advisory. Pesticides. Chelsea, MI: U. S. Environmental Protection Agency, Office of Drinking Water Health Advisories. Lewis Publishers, Inc. 819 pp.
36. U.S. EPA. 1990. Drinking water regulations and health advisories. Washington, D.C.: U. S. Environmental Protection Agency Office of Drinking Water. 10 pp.
37. U.S. EPA. 1992. U.S. EPA integrated risk information system substance file- Thiram; CASRN 137-26-8. 1 July 1992. Washington, D.C.: U. S. Environmental Protection Agency. URL: http://www.epa.gov/ngispgm3/iris/subst/0267.htm.
38. U.S. EPA. 1993. Health Advisories for Drinking Water Contaminants. Boca Raton, FL: U.S. Environmental Protection Agency Office of Water Health Advisories, Lewis Publishers.
39. U.S. EPA. 1996. Hexazinone Health Advisory. Office of Drinking Water, Washington, D.C.: U.S. Environmental Protection Agency. September, 1996.
40. U.S. EPA. 1997. Imazapyr (Arsenal) pesticide tolerances: Final rule. Ithaca, NY: Cornell University. Pesticide Management Education Program, Cornell University. URL: http://pmep.cce.cornell.edu/profiles/herb-growthreg/fatty-alcohol-monuron/imazapyr/tol-imazapyr.html#top.
41. U.S. EPA. 1998a. Reregistration Eligibility Decision (R.E.D.) Facts: Triclopyr. Document EPA-738-F-98-007. Washington, D.C.: U.S. Environmental Protection Agency Office of Prevention, Pesticides and Toxic Substances (7508C). Washington, DC. URL: http://www.epa.gov:80/oppsrrd1/REDs/factsheets/2710fact.pdf.
42. U.S. EPA. 1998b. Draft Resource Conservation and Recovery Act; Waste minimization PBT chemical list; Appendix C: Waste Minimization Prioritization Tool Human Noncancer Scores. Washington, D.C.: U.S. Environmental Protection Agency Office of Solid Waste, Waste Minimization Branch. URL: http://www.epa.gov/epaoswer/hazwaste/minimize/chemlist/ap_c.pdf
43. USFS. 1998. Report of the Forest Service Fiscal Year 1997. U.S. Forest Service. Washington, D.C. : USDA Forest Service. 147 pp.
44. Wood, J.A. ; Anthony, D.H.J. 1997. Herbicide contamination of prairie springs at ultratrace levels of detection. Journal of Environmental Quality. 26: 1308-1318.

Table 1. Percent of all treated land and pesticide active ingredient applied by pesticide type and vegetation management objectives for pesticides used on USFS lands in FY97. Data extracted from Table 10 of the Annual Report of the Forest Service (43).

Pesticide type Management objective	Treated Land	Active Ingredient
Fungicides and fumigants		
General disease control	10.7	8.2
Fumigation, nursery disease and fungus control	0.1	30.4
Herbicides, plant growth regulators, algicides		
Noxious weed control	19.5	17.5
Planting site preparation	10.0	21.5
Conifer release	7.2	12.0
Hardwood release	0.4	0.5
Nursery weed and disease control	0.3	0.7
Wildlife habitat	0.8	1.3
Rights-of-way	0.3	1.2
Hardwood control	0.2	0.2
Seed orchard protection, recreation improvement, aquatic vegetation control	0.1	0.3
Rodenticides, repellents, acaricides, insecticides, pheromones, predacides		
Animal damage control	26.0	2.9
Insect control-biological	22.1	NA
Insect control- chemical	0.3	0.6
Vector/plague suppression	0.6	0.03
Seed orchard protection, recreation improvement, fish eradication	0.1	1.5

NA-not applicable. The biological control agents Nucleopolyhedrosis virus and *Bacillus thuringiensis* are measured in terms of billions of international units and not kg.

Table 2. Frequency and occurrence of surface and ground water contamination from pesticide use in North America.

Pesticide	Water Type[1]	Location	Maximum (mg/L)	Range (mg/L)	Comments	Literature Citation
2,4-D	S	Large River Basins Throughout US	0.0075	0.00004-0.0075[2]	24 reports of mainly urban, sub-urban, agricultural sources	16
	S	Streams in Oregon and California	2.0	nd-2.0	Highest concentrations observed from forest areas where no attempt was made to prevent application to water.	27
	G	Saskatchewan, Can	0.0000007	ng	Natural spring flow	44
	G	Connecticut, Iowa, Kansas, Maine, Mississippi, South Dakota	0.049	0.0002-0.049	Well water samples except for South Dakota from shallow sand and gravel aquifer	11
Borax		nr	nr	nr	nr	nr
Carbaryl	S	Mississippi River	0.0001	ng	1 report	16
	S	New Brunswick, Can	0.314	ng	Aerial spray spruce budworm control	11
	S	New Brunswick, Can	0.314	0.123-0.314	Budworm control	12
Chloropicrin		nr	nr	nr	nr	nr
Chlorpyrifos	S	Mississippi River, the Lower Colorado River, rivers and lakes in Kansas, and irrigation ditches in California, Arizona, Nevada	0.00015	0.00004-0.00015	3 reports	16
Clopyralid		nr	nr	nr	nr	nr
Dazomet		nr	nr	nr	nr	nr
Dicamba	S	USFS land near Hebo, OR	0.037	0.006-0.037	Treated 166 ac of 603 ac forest catchment. Highest concentration diluted to 0.006 mg/L 2.2 miles downstream.	26
Glyphosate	S	45 ha Coastal British Columbian catchment	0.162	0.0032-0.162	Highest concentration in streams intentionally sprayed, lowest in streams with smz	10
	S	Quebec	3.080	0.078 to 3.08	9 of 36 streams contained glyphosate after forest spraying	17
	S	Ohio	5.2	ng	No-tillage establishment of fescue	9
	S	Georgia Michigan Oregon	0.035 1.237 0.031	ng ng ng	Forest sites for scrub hardwood control and direct spray of streams	25
	G	Newfoundland, Can	0.045	0.004-0.045	Application of 4 lb ai/ac to power substations resulted in contamination of water in monitoring wells	29
Hexazinone	S	Mississippi River	0.00007	ng	Detected in 5 tributaries	16
	S	Alabama, Florida,	0.037	0.0013-	7 reports, each treated	20

Table 2. Frequency and occurrence of surface and ground water contamination from pesticide use in North America.

Pesticide	Water Type[1]	Location	Maximum (mg/L)	Range (mg/L)	Comments	Literature Citation
		Georgia		0.037	catchment containing ephemeral/first order streams	
	S	Alabama	2.400	ng	Applied directly to ephemeral channel and in first runoff water	22
	S	Alabama	0.473	0.422-0.473	Ephemeral/first order stream in catchments treated with 3X rate of hexazinone in liquid and pellet formulation with accidental application to streams	21
	S	Arkansas	0.014	ng	11.5 ha watershed drained by ephemeral to first order stream	2
	S	Georgia	0.442	ng	Ephemeral/first order stream in treated catchment, pellets applied to stream channel	24
	G	ng	0.009	ng	Only one value reported from a single study	11
Imazapyr	S	Alabama	0.680	0.130-0.680	2 reports, each treated catchment containing ephemeral/first order streams, herbicide accidentally applied to stream channel	20
Methyl bromide		nr	nr	nr	nr	nr
Metsulfuron	S G	Central Florida	0.008 0.002	ng	Water in surface depression in slash pine site and 1 of 207 shallow (6 feet) well samples	19
Picloram	S	Northcentral Arizona	0.32	ng	Pinyon-juniper site	13
		Streams and rivers in N. Dakota, Wyoming, and Montana	0.005	0.00001-0.005	4 reports from mainly range-land uses	16
	S	Alabama	0.442	ng	Pellets accidentally applied directly to forest stream	18
	S	Georgia, Kentucky, Tennessee	0.021	nd-0.021	6 study catchments with ephemeral/first order stream in each treated forest catchment	20
	S	North Carolina	0.01	ng	ephemeral/first order stream in treated forest catchment	23
	G	Saskatchewan, Can	0.000225		Natural spring flow	44
	G	Iowa, Maine, Minnesota, North Dakota	0.049	0.00063-0.049	Fewer than 2% of well samples were positive	11
Strychnine		nr	nr	nr	nr	nr
Thiram		nr	nr	nr	nr	nr
Triclopyr	S	Florida	0.002	ng	Coastal plain	4

Table 2. Frequency and occurrence of surface and ground water contamination from pesticide use in North America.

Pesticide	Water Type[1]	Location	Maximum (mg/L)	Range (mg/L)	Comments	Literature Citation
					flatwoods catchments near Gainesville, FL	
	S	Ontario	0.35	0.23-0.35	Intentional aerial application to boreal forest stream	32
Zinc phosphide		nr	nr	nr	nr	nr

[1] Surface water- S, Ground water- W
[2] Range of maximum values reported as summarized by Larson and others (16)
ng-not given, nr-no reports found in published literature

Table 3. Estimates of safe levels for daily exposure to the 20 pesticides most used on NFS lands in FY97 in the vegetation management program. These pesticides account for more than 95% of all active ingredient applied to NFS land in 1997.

Pesticide	RfD	NOEL	NOAEL	Lifetime HAL	Literature Citation
	mg/kg	mg/kg	mg/kg	mg/L	
Borax	0.09	NA	8.8	0.60[1]	36
Carbaryl	0.1	NA	9.6	0.700	35
Chloropicrin[2]	NA	NA	NA	NA	
Clopyralid	NA	NA	NA	NA	
Chlorpyrifos	0.003	0.03	NA	0.020	38
2,4-D	0.01	NA	1	0.070	35
Dazomet[2]	NA	NA	NA	NA	
Dicamba	0.03	NA	3	0.200	35
Dormant oil	NA	NA	NA	NA	
Glyphosate	0.1	20	NA	0.700	35
Hexazinone	0.05	5	NA	0.400	39
Imazapyr	NA	250	NA	NA	40
Methyl bromide	0.0014	NA	1.4	0.010	36
Metsulfuron	0.25	25	NA	NA	33
Picloram	0.007	7	NA	0.500	34
Putrescent egg solids	NA[3]	NA	NA	NA	
Strychnine	0.0003		NONE	NA	42
Thiram	0.005	5	NA	NA	37
Triclopyr	0.05	5	NA	NA	41
Zinc phosphide	0.0003		NONE	NA	42

NA Not available
[1]HAL for elemental boron.
[2]These fumigants are not expected to get into water.
[3] Made from food products, toxicology was waived by U.S. EPA.

NEW APPLICATIONS OF MULCHING EQUIPMENT FOR FOREST VEGETATION MANAGEMENT. D. Mitchell and Dr. R. Rummer, USDA Forest Service, Southern Research Station, Engineering Research Unit, 520 Devall Drive, Auburn, AL 36839.

ABSTRACT

Mulching machines have been used for clearing land for road and utility right-of-ways, real estate development, and for the seismic industry. These machines are finding their way into forests. Some machines are being used to reduce fuel loading so that fire can be safely re-introduced into an area. Other forest managers are using the machines to perform strip pre-commercial thinnings, while still others are using them to reduce vegetation for wildlife habitat enhancement. Mechanical mulching treatments may be an effective tool in understory vegetation reduction, but little is known about the effects on regrowth, production, or site impacts of using these types of equipment in the southern pine forests.

Mulching machines may be divided into two major types: vertical and horizontal shafts (1). These designations refer to the axial spinning of the shaft that turns the cutting implements. Vertical shafts have been documented as severing the material without much mulching of the stems, while horizontal shaft machines sever and mulch stems. The cutting attachments range from circular sawblade heads to individually fixed teeth to free-swinging teeth. The machines are mounted on a variety of prime movers including modified tractors, harvesters and excavators.