PROTECTING SURFACE WATER SYSTEMS ON FOREST SITES THROUGH HERBICIDE USE

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ABSTRACT

Sediment, nutrients, and pesticides are universally accepted as the greatest threats to surface water quality world-wide. Sedimentation in surface waters is a natural phenomenon, but is magnified by human activities. Intensive forest management practices, particularly road building, harvesting and planting site preparation, result in the greatest increases in erosion from forest sites. Significantly more sedimentation occurs on steeper slopes, finer-textured soils, and where episodic storms occur most frequently. Research has shown extreme events are more important than average events or streamflow levels in determining annual losses of sediment and other non-point pollutants. Factors important in reducing erosion and resultant sedimentation include percent groundcover and number of rooting stocks remaining intact to hold soil in place. Herbicides used in the Southern United States (South) in forest vegetation management programs typically kill residual vegetation leaving plant residues and root stocks in place. Use of these herbicides has been demonstrated to reduce erosion and when used in conjunction with streamside management zones greatly reduce sedimentation in streams. While stream contamination by forest herbicides is often cited as a threat to surface water systems, research in the South has demonstrated that these herbicides used according to label directions do not result in adverse impacts on aquatic ecosystems. Further, extensive monitoring of offsite movement of herbicides in stormflow and baseflow shows drinking water standards in the USA are not exceeded on the treated sites. Downstream dilution further reduces the potential for adverse impacts. Herbicide movement from treated sites to streams draining treated catchments can not be detected after 3-6 months. Thus herbicides, properly used in intensive forest management, have the potential to greatly reduce the sedimentation of streams and protect surface water.

INTRODUCTION

Sediment in surface water is a problem world-wide. Sediment is the direct result of the movement of soil particles, dislodged in the process of erosion, to the water resource. Thus any activity which decreases the energy required for dislodging of soil particles or which increases the erosive energy reaching soil will increase erosion. The primary energy source in erosion is rainfall and runoff and it has been shown that the impact of falling rain is the greatest force of moving water in most watersheds (Satterlund and Adams 1992). Because most raindrops achieve terminal velocity after free fall of around 8 m, tall forest canopies provide little in the way of protection from erosion. Indeed, because kinetic energy associated with raindrops increases as drop size increases (kinetic energy is proportional to one half the product of mass and the square of the velocity), and because drip from foliage is usually in larger drops than falling rain, throughfall may contain more erosive energy than natural rain drops (Satterlund and

Adams 1992). Low vegetation and litter covering the soil surface provide the greatest protection against erosion and therefore sediment production. It is also clear that sedimentation is a natural process. Natural sedimentation rates for forested watersheds vary around the world and range from a trace to 2000 kg/ha/yr (Balci et al. 1986, Doty et al. 1981, Johnson 1993, Lal 1984, Malmer 1996, Yoho 1980). Natural sedimentation rates may vary considerably from year to year within a given site. Beasley and Granillo (1988) reported small undisturbed watersheds with less than 3 percent slope in Arkansas flatwoods area had annual sediment losses between 1981 and 1985 that ranged fro 4 to 52 kg/ha. Natural wildfires also increase sedimentation rates. Ewing (1996) reported postfire seasonal daily sediment averages increased 32% for the Lamar River and 58% for the Yellowstone River after wildfires in 1988 burned 568900 ha of the Greater Yellowstone Area.

Every activity that affects vegetation cover or soil condition (use of all-terrain vehicles, hiking, camping, hunting, wildfires, road construction, thinning, harvesting, planting site preparation, and regeneration practicies) can interact with soil characteristics, vegetation characteristics, site topography, and weather to produce erosion culminating in sedimentation of streams, lakes, reservoirs, etc. Ranges of values for some of these management activities have been reported in the literature. Patrick et al. (1984) report sediment yields on completely forested small watersheds vary widely within a region and among regions in the USA. Annual sediment yields ranged from 22 to 1166 kg/ha in the Western USA (n=80 watersheds) and from 22 to 2444 kg/ha in the Eastern USA (n=65 watersheds). The highest sediment yields reported by Patrick et al. (1984) occurred in the small forested watersheds along the California and Oregon Pacific Coasts (45-43562 kg/ha, n=26 watersheds). On a regional basis, Yoho (1980) reported clearcut forests in the Southern USA could produce up to 3027 kg/ha/yr and mechanically site prepared lands could produce up to 14259 kg/ha/yr. Blackburn et al. 1990 reported annual sediment production from undisturbed watersheds ranged from 2 kg/ha to 275 kg/ha in east Texas watersheds over a 8 year period. Clearcutting with chopping for site preparation increased sediment production to 57-262 kg/ha per year and clearcutting with shearing for site preparation increased sediment production to 112-306 kg/ha.

Comparisons of sediment from undisturbed and disturbed forest watersheds have been reported for a number of research watersheds. Binkley and Brown (1993) reviewed reports of 13 researchers and found sediment concentrations from clearcut watersheds increased 16% to 333% over control watersheds located on coastal plain sites in the Eastern USA, 934% in Texas, and 234% to 2567% in Western USA. Beasley and Granillo (1988) reported annual sediment losses for small clearcut watersheds with less than 3 percent slope in Arkansas flatwoods increased 228% to 8354% during 1981-1985.

REDUCING SEDIMENT YIELD

Barrier Method

Methods of protecting the water resource from the effects of sediment fall into two categories. They either provide barriers to movement of eroded material to water bodies or they attack the mechanism by which sediment is produced. The use of streamside management zones, buffer strips, or filter strips (SMZs) is the most common approach to the barrier method. While the barrier method has been considered in the USA since the mid-1950s, there is still no simple method to determine the most effective size or design of barriers for specific sites (Comerford et al. 1992). However, it has been shown that nearly all barriers are partially effective. Arthur et al

(1998) found 25-100 kg/ha sediment loss annually from undisturbed eastern Kentucky watersheds and 400-550 kg/ha per year for clearcut sites using Best Management Practices (BMPs), principally a 15 m SMZ on each side of the stream while 700-1100 kg/ha were lost from clearcut sites without SMZs or use of BMPs. During the year post harvest, the watershed with no SMZ produced 1.5 times as much sediment as the one with an SMZ.

Herbicides For Reducing Sediment

Another approach to reduce sediment is to attack the mechanism by which it is produced. Erosion on forest sites occurs when sufficient energy is applied to the soil surface to dislodge soil particles and when there is sufficient runoff to move those particles to the water resource. Herbicides kill unwanted vegetation but leave plant residue on site and leave root systems in place. Plant residues intercept rainfall and reduce the impact energy on soil thereby reducing erosion potential. In addition, stems of dead plants and their root systems increase infiltration rates for rain by providing a vehicle for stemflow and rapid movement of water into soil.

Very few studies have looked carefully at the role herbicides play in reducing sediment yield on forest sites. Beasley et al. (1986) studied sediment movement on 9 watersheds on the Athens Plateau of southwest Arkansas. They found mechanical site preparation following clearcutting resulted in 3.88, 3.52 and 3.45 times as much sediment as observed in control watersheds in the 3 years post-treatment. The increase was significant ($p=0.05$) while the increase of sediment yield for watersheds chemically site prepared of 2.6, 1.01 and 1.4 over controls was not significant.

In a study in the upper coastal plain of Alabama, USA we tested for sediment movement from clearcut watersheds without the protection of SMZs. Study watersheds were selected for similarity in size, topography, and vegetation. All watersheds, except the control, were clearcut in late March of 1995 and site prepared with herbicide (HSP) or mechanically by shearing, rootraking and windrowing of debris (MSP) in late August of 1995. Sediment concentrations were monitored in samples collected by automatic samplers during each storm over a two year period. Prior to any disturbance, average stormflow sediment concentrations from the MSP watershed were 2.25 times that from the HSP watershed. Following clearcut harvesting of both watersheds, sediment from the MSP was only 1.7 times that from the HSP watershed. Site preparation was conducted in late August 1995 and the first post site preparation storm came 1 month later in September 1995. Sediment concentrations in flow from the MSP increased to 4.98 times that from the HSP indicating the mechanical site preparation greatly increased sediment yield over the herbicide site preparation. Not only were individual sample sediment concentrations higher on the MSP, they did not decrease as rapidly as those from the HSP watershed during storms.

Streamside management zones and herbicide use have the potential, individually, to reduce sediment yield. Together they can significantly decrease sediment from managed forest sites, but there has been considerable resistance to full implementation of herbicide use on nearly all forest lands in the USA (including National Forests and Rangelands, State and National Parks, and managed private and industrial forest lands).

CONCERNS OVER HERBICIDE TOXICITY HAS LIMITED THEIR USE

Herbicide Use

Resistance to herbicide 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 increased use of pesticides and their potential adverse environmental impacts, but fails to recognize the extensive use by individuals and the benefits that accrue from that use. Approximately 16 percent of the 3.6 million square miles of land in the United States is treated with pesticides annually The most intensive use of pesticides occurs on land occupied by households. Households represent 0.4 percent of all land and receive 12 percent of all pesticides used in the US. Agricultural land (52 percent of all land) is the next most intensively treated receiving 75 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 (1986) 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 Unites 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. NFS pesticide use data is available from the Annual Report of the Forest Service. As an example, data from 1997 indicates 297,880 of the 191.8 million acres of NFS land (0.16 percent) was treated with a total of 200,841 pounds of active ingredient (USFS 1998). The amount of pesticide used and the number of acres treated varies slightly from year to year.

Toxicity

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. Enivronmental Protection Agency (USEPA) 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 USEPA'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 (USEPA 1993). 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 USEPA 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 adults weigh 70 kg and consume 0.95 L of water per day, and a child weighs 10 kg and consumes 0.47 L. HALs are calculated for one-day, ten-day, longer-term (10 percent of life expectancy), or lifetime (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 (U.S.EPA 1993). 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. EPA's estimates of safe levels for daily exposure to the most widely used pesticides on NFS lands are summarized in Table 1.

Table 1. Estimates of safe levels for daily exposure to the herbicides most used on NFS lands in 1997 in the vegetation management program.

Pesticide	RfD	NOEL	NOAEL	Lifetime HAL	References
	mg/kg	mg/kg	mg/kg	mg/L	
Hexazinone	0.05	5	NA	0.400	U.S. EPA, 1996
Glyphosate	0.1	20	NA	0.700	U.S. EPA, 1989
2,4-D	0.01	NA	1	0.070	U.S. EPA, 1989
Picloram	0.007	7	NA	0.500	U.S. EPA, 1988b
Triclopyr	0.05	5	NA	NA	U.S. EPA, 1998a
Imazapyr	NA	250	NA	NA	U.S. EPA, 1997
Dicamba	0.03	NA	3	0.200	U.S. EPA, 1989
Metsulfuron	0.25	25	NA	NA	U.S. EPA, 1988a

NA Not available

Occurrence In Water.

Pesticides used in forest vegetation management programs 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 30 ft), usually in concentrations far below levels harmful to human health and the occurrence is infrequent (Larson et al. 1997). Reports of pesticide contamination of water are usually from agricultural (Kolpin et al. 1997; Koterba et al. 1993) or urban applications (Bruce and McMahon 1996), but the potential for contamination from forest vegetation management programs exists.

Norris (1975) 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 resulting in 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 (Table 1). No dicamba residues were detected beyond 11 days after treatment.

Glyphosate and 2,4-D have aquatic use labels, which permit direct application to water. Stanley et al. (1974) 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. Newton et al. (1994) 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 one day.

There is little information on the movement of metsulfuron to streams. Michael et al. (1991) 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.

Michael and Neary (1993) 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 streams 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, 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.

Michael et al (1999) 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 3 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 (10 percent of life expectancy or about 7 years) HAL of 9.0 mg/L (USEPA 1990). Following the application, on-site stream concentrations did not exceed the lifetime HAL.

Ecosystem Impacts.
The issue of ecosystem impacts has been addressed by Miller (1996). Adverse impacts to wildlife from the use of herbicides in forest management do not generally extend beyond those normally seen in harvesting. Toxicological studies have shown there is insufficient exposure of wildlife to forest-use herbicides to cause health problems. Indeed, in 1997 a approximately 2% of all herbicide used on National Forests was applied for improvement of wildlife habitat (USFS, 1998).

Michael et al. (1999) have described the impacts of hexazinone on aquatic communities. When applied to forest sites for planting site preparation at three times the prescribed rate, benthic community structure, even pollution-sensitive insects, in streams draining the treated site were unaffected.

In another study, application of imazapyr to cypress domes in Florida at 100 times the expected environmental concentration did not affect benthic communities. In that same study, chironomid mouthpart deformity was studied as an indicator of herbicide pollution, but there was no correlation evident in the data (Michael and Crisman 1999).

CONCLUSIONS

Studies reviewed and reported in this paper have demonstrated the use of mechanical planting site preparation methods result in 20 to 400% more sediment than observed on paired sites which were site prepared with herbicides. Although short-term low-level stream contamination has been observed for ephemeral to first-order streams draining treated sites, levels of herbicides in these streams has been neither of sufficient concentration nor of sufficient residence time to cause observable impacts on aquatic ecosystems. These studies have, with a few exceptions, confirmed the absence of significant contamination of surface 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. Thus herbicides used properly can help protect water quality in the reduction of sediment in streams while accomplishing forest management goals.

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