Watershed Management Above Drinking Water Reservoirs

Published by
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University of Missouri and Lincoln University

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Preface

This manual was developed to help residents, municipalities and agricultural producers understand their roles and responsibilities within a watershed above a drinking water reservoir.

Public water suppliers need to be aware of their legal responsibilities to guarantee safe water. Maximum contamination levels (MCLs) are set by federal regulations, and strict testing procedures must be followed to ensure safe drinking water for the public.

Best management practices (BMPs), outlined in this manual, can be used by farmers within the watershed to reduce pesticide runoff from fields. Understanding how pesticides can contaminate water through runoff, erosion, run-in and leaching is an important step in developing BMP strategies. BMPs can be combined to achieve maximum pollution control and minimize production loss.

Collection and handling of water samples from public drinking water supplies is important for obtaining correct analysis information. Different types of samples may be needed for different types of analyses. For the required sampling of public drinking water supplies, state sampling requirements should be followed. General guidelines for collecting samples are included within these pages.

Development of the manual and educational programs and the demonstrations in the Lewistown/La Belle area were made successful through the collaborative work of the following:

United States Environmental Protection Agency
Missouri Department of Natural Resources
University Extension
MFA Incorporated
Agricultural chemical suppliers
City and county officials
Area agricultural producers

The Rights and Obligations of Missouri's Cities

Does pesticide contamination of public water supplies present a legal concern to city officials?

The fundamental reason for concern is the health of the residents who use the water. However, the legal reason is found in a piece of federal legislation, the 1986 amendments to the Safe Drinking Water Act. This legislation establishes the drinking water quality standards that are now in effect throughout the United States.

What are the obligations of city officials to protect the water supply from pesticide contamination?

It is the legal obligation of city governments and other public water suppliers to ensure that the water they provide to customers meets or exceeds the drinking water standards mandated by the Safe Drinking Water Act.

Each of the regulated pesticides and other regulated contaminants has a set Maximum Contaminant Level (MCL), which is the highest level permitted by law in the drinking water supply. Title 40 of the Code of Federal Regulations (40CFR) sets the water quality standards that drinking water supplies must now meet. 40 CFR 141 specifies MCLs for each chemical. For example, the MCL is three parts per billion for atrazine and two parts per billion for alachlor.

What are the legal rights and options of a city to protect a surface public drinking water supply from pesticide contamination?

Missouri law provides cities with some legal options. These include asking state agencies to intervene to protect the watershed, acquiring property within the watershed and pursuing criminal and civil legal action against people contaminating the water supply. After reviewing the options, it becomes evident that prevention and education are less expensive, better and easier than having to deal with a pesticide contamination cleanup.

Can city or county governments restrict or ban the use of certain pesticides in a watershed to protect the public water supply?

The 1992 amendments made it clear that local governments in Missouri have no regulatory jurisdiction over pesticide use. Instead, the Missouri Attorney General has reserved that right for the state.

Chapter 281 RSMo places regulation of pesticides under the Missouri Department of Agriculture. Section 281.025 RSMo provides that:

> The director (of the Missouri Department of Agriculture) shall administer and enforce the provisions of sections 281.010 to 281.115 and shall have authority to issue regulations … where the director finds that such regulations are needed to carry out the purpose and intent of sections 281.010 to 281.115, such regulations may relate to, but need not be limited to, prescribing the time, place, manner, methods, materials, and amounts and concentrations, in connection with the use of the pesticide, and may restrict or prohibit use of pesticides in designated areas during specific periods of time and shall encompass all reasonable factors which the director deems necessary to prevent damage or injury.

In addition to granting jurisdiction, Missouri's regulations also say that state law shall preempt any local laws regarding pesticide regulation. However, a similar attempt by the federal government to preempt local laws was rejected by the U.S. Supreme Court. In a decision called *Mortier vs. Wisconsin Public Intervenor,* the Court held unanimously that the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) does not preempt the right of local governments to regulate the sale and use of pesticides more strictly than the federal government. The Court further held that if the Congress intends to preempt local regulatory authority, it must expressly say so in the laws it enacts. This issue is still under consideration at the federal level, and interested city officials should contact their Congressional representatives to find out the status of any legislation in this area.

Can a city obtain statutory authority to acquire property in the watershed?

The only way a city currently can have certain control over how pesticides are used in the watershed above its public water supply is to control or own the entire watershed.

Section 91.010 RSMo gives cities, towns and villages the authority to operate waterworks and to "supply the inhabitants of such cities, towns, and villages with water." Chapter 91 RSMo also provides the authority for cities, towns and villages to acquire the lands necessary for this purpose. Several other statutes also deal with the topic of municipal water supplies.

If landowners will not sell, cities have the power to condemn land in the watershed and purchase it through condemnation proceedings. Authorization of condemnation for water supplies is found in section 91.080 RSMo. Additional authorization for this is found in section 81.170 RSMo for special charter cities and towns, section 88.497

RSMo for third class cities, section 88.667 RSMo for fourth-class cities, section 82.240 RSMo for constitutional charter cities and section 80.090 RSMo for towns and villages.

The general provisions for condemnation of private property are found in sections 88.010-077 RSMo. This allows property located outside the city limits to be evaluated and deemed condemned by city officials in a case where the evaluated property may create a necessary condition for purchase by the city or governing institution. It is important to note that section 88.077 RSMo specifies that when the property to be condemned is outside the city limits (as is often the case with a watershed) the condemnation procedure "shall be regulated in all respects as the condemnation of property for railroad purposes and is at the time governed by Chapter 523 RSMo."

Instead of buying all the land in a watershed, the city could buy negative easements or restrictive covenants from the owners, thereby preventing the use of certain pesticides on the land in the watershed. Section 91.080 RSMo empowers cities to acquire easements as well as land by "purchase, donation, or condemnation" for public water supply purposes. Acquiring such easements might be considerably less expensive than acquiring the land itself.

Do cities have the statutory authority to pursue criminal and civil legal action against persons contaminating the water supply?

Section 577.150 RSMo states:

> Whoever willfully or maliciously poisons, defiles or in any way corrupts the water of a well, spring, brook or reservoir used for domestic or municipal purposes, or whoever willfully or maliciously diverts, dams up and hold back from its natural course of flow any spring, brook or other water supply for domestic or municipal purposes, after said water supply shall have once been taken for use by any person or persons, corporation, town or city for their use, shall be adjudged guilty of a misdemeanor, and punished by a fine not less than fifty or more than five hundred dollars, or by imprisonment in the county jail not exceeding one year, or by both such fine and imprisonment, and shall be liable to the party injured for three times the actual damage sustained, to be recovered by suit at law.

This would imply that if a city had made a good-faith effort to inform landowners and/or farm operators that their current pesticide-use practices were contaminating the water supply, and those operators persisted in their current practices, the city would have grounds to sue. The city has the power to charge three times actual damages. This has the potential to be a strong bargaining chip in a city's discussions with uncooperative landowners, even before any formal action begins.

What can happen if a city's public drinking water system fails to meet the drinking water standards?

The Missouri Department of Natural Resources (DNR) is mandated to test for the chemicals regulated under the Safe Drinking Water Act. The city is out of compliance with the law if the average of four quarterly samples taken in one year is above the MCL for a regulated contaminant. Violations can result in the following actions:

The public notification requirements of the Safe Drinking Water Act go into effect. Violations of MCLs are considered Tier 1 violations. For community water systems, public notice of Tier 1 acute violations must be given in the electronic media within 72 hours, in the newspaper within 14 days, and notices given by direct mail, hand delivery, or in water bills within 45 days and repeated quarterly as long as the violation continues. For Tier 1 non-acute violations, public notice must be given through the newspaper within 14 days, and notices given by direct mail, hand delivery, or in water bills within 45 days and repeated quarterly as long as the violation continues. Mandatory health-effects language found in 40 CFR 141.32 must be used in public notification. If a water system fails to comply with this requirement, the Missouri DNR will make sure that the city or county gives public notification.

The Missouri Department of Agriculture and the Missouri DNR also have regulatory options they can pursue if a water system is out of compliance. Under Chapter 281 RSMo, the Department of Agriculture can restrict or prohibit the use of any pesticide. These restrictions can be put in place for a geographic area that the Department of Agriculture believes is necessary "to prevent damage or injury." Where control is needed, the Department of Agriculture will work in cooperation with cities, towns or villages to control or resolve the problem.

The Missouri DNR also has authority under sections 640.418 to 640.423 RSMo to:

> …establish "special water quality protection area" in areas where it finds a contaminant in a public water system in concentration which exceeds a maximum contaminant level established by the Environmental Protection Agency pursuant to the Safe Drinking Water Act, as amended, or a maximum contaminant level established by the department pursuant to this chapter or sections 640.400 to 640.535 or a contaminant in surface or groundwater which exceeds water quality standards pursuant to chapter 644, RSMo, which presents a threat to public health or the environment. In making such a determination, the department shall consider the probable effect of the contaminant or contaminants on human health and the environment, the probable duration of the elevated levels of the contaminant, the quality, quantity, and probable uses of surface or groundwater within the area, whether protective measures are likely to prevent, mitigate or minimize the level of contaminant in the surface or groundwater.

If such an area is established, section 640.420 RSMo provides that:

> When a special water quality protection area has been established, the department shall imple-

ment an area informational program to help prevent, eliminate, mitigate or minimize the continued introduction of the contaminant or contaminants into the surface or groundwater.

More drastic measures also can be taken if necessary. Safe Drinking Water Act regulations require that if a public water system is above the MCL for a contaminant, the community can be required to adopt the Best Available Technology (BAT) to remove that contaminant. BAT is defined in 40 CFR 141, and for most pesticides, the BAT is granular activated carbon filters. These are expensive to install and operate; the cost makes them prohibitive for most small community water systems.

The Missouri DNR can issue an abatement order requiring a water system to install the BAT if necessary. If the water system fails to comply, the Missouri DNR can get a court order requiring compliance. As a last resort, the Missouri DNR can go to court and have a noncomplying water system placed in a trusteeship or state-sponsored receivership.

What can a city government do to prevent pesticide contamination from occurring in the public drinking water supply?

The best solution is prevention and education. This requires the city to deal with the situation before it ever becomes a problem. The city will need to work with city residents, landowners and farm operators in the watershed and state agencies to understand how pesticide contamination can occur. It also will need to develop a plan acceptable to all to minimize the risks of pesticide contamination. Farm operators may need to modify their farming practices within the watershed, and city residents may need safer methods of disposing of hazardous wastes from households and businesses.

These preventive measures will take some time and require spending money. However, they are generally cheaper, easier and safer than trying to pursue any of the legal avenues available or dealing with being found out of compliance. Moreover, there are several agencies that can assist city governments in their efforts.

What agencies can I call on for assistance in protecting surface public drinking water supplies?

The Missouri DNR works closely with your water plant operator and may be able to provide advice and assistance. Contact the department at P.O. Box 176, Jefferson City, MO 65102-0176, or call (573) 751-5331.

The Missouri Department of Agriculture has regulatory authority over pesticides in Missouri. The department also can provide advice and assistance to local officials regarding pesticide contamination. You may contact the Missouri Department of Agriculture, Bureau of Pesticide Control, P.O. Box 630, Jefferson City, MO 65102, or call (573) 751-6808.

University Extension (University of Missouri and Lincoln University) has offices in almost every Missouri county. Extension specialists in agronomy, agricultural engineering, and community development are available to assist you in your educational efforts and your work with agricultural producers. Contact your local University Extension center or Agricultural Engineering, 205 Agricultural Engineering Building, Columbia, MO 65211. Call (573) 882-2731.

The Natural Resources Conservation Service (NRCS)-USDA, in cooperation with your county Soil and Water Conservation District (SWCD), also can assist producers in identifying ways to prevent pesticide runoff into your public drinking water supply. The SWCD may be able to provide cost-share assistance to landowners and farm operators to adopt practices that can reduce the incidence of pesticide runoff. Contact your local office.

The National Drinking Water Clearinghouse, sponsored by the Farmers Home Administration–USDA, has produced many informational materials as well as a newsletter, *On Tap,* to assist community leaders in maintaining high-quality drinking water. These materials are clearly written and contain information on regulations, technologies and case studies of other communities. To reach them, call 1-800-624-8301, or write to National Drinking Water Clearinghouse, West Virginia University, P.O. Box 6064, Morgantown, WV 26506-6064.

Missouri Rural Water Association (MoRWA) provides assistance for training or technical assistance on water systems, regulations and wastewater systems. You may write to Missouri Rural Water Association, 2610 Calvert Drive, Columbia, MO 65202, or call (573) 474-6990.

The U.S. EPA also produces many helpful publications. EPA's Region VII Groundwater Protection office can be reached by calling (913) 551-7033, or writing U.S. Environmental Protection Agency Region VII, Office of Groundwater Protection, 726 Minnesota Ave., Kansas City, KS 66101.

EPA–Drinking Water Branch and the Toxics and Pesticides Branch offer information and assistance concerning public drinking water facilities and can be contacted at (913) 551-7032 and (913) 551-7020, respectively.

How important is public involvement in protecting the drinking water supply from contamination?

Public involvement is critical because the public water supply belongs to the whole community. The entire community's support and cooperation are necessary to protect the water supply from contamination. Without public involvement, a city government cannot achieve the long-term solutions necessary to avoid an expensive and politically unpleasant situation of non-compliance with Safe Drinking Water Act regulations.

Revised Statutes of Missouri, for this publication, is based on Title 40 RSM.

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Pesticides and Their Effects on Health

What is a pesticide?

A pesticide is a chemical used to kill unwanted organisms. Pests can include insects, weeds, fungi, rodents and other types of organisms. Three of the most common types of pesticides used in production agriculture are herbicides, fungicides and insecticides.

What is LD50?

This is the amount of toxin necessary to kill 50 percent of a population of test animals being measured. LD50s are determined in laboratory settings and are stated in milligrams of toxin per kilogram of body weight. For example, knowing that the LD50 for atrazine is 0.75, if 10 men (each 150 pounds) ingested 0.75 pounds of atrazine, we could expect five to die.

What is acute oral toxicity?

This measures the toxicity of a substance if it was swallowed in a single dose. If the acute oral toxicity level is proportionately the same for humans as for laboratory rats, a 150-pound person would have a 50 percent chance of dying after ingesting 0.75 pounds of atrazine. The same would be true of 0.5 pounds of salt or 2.5 ounces of aspirin.

What is chronic toxicity?

This measures the effect of long-term exposure, usually a low dose exposure over a long period of time. It is difficult, if not impossible, to measure because people are transient and because people can expect exposure to many other chemicals during an average lifetime (70 years).

What is MCL?

MCL stands for Maximum Contaminant Level. This is the level at which the contaminant is allowed in the public drinking water supply before the water must be treated for removal of the contaminant.

How are the MCLs determined?

Risk assessments are made for the specific chemical. This includes both a toxicity and an exposure assessment. The toxicity assessment is a dose-response assessment that measures the extent and type of adverse effects of a specific level of exposure. Exposure assessment measures the extent and duration of the exposure that is likely to occur. The risk assessments determine the level at which there is no harmful effect to laboratory animals. This level is then multiplied by a safety factor of 100 to 10,000.

How much is a part per million and a part per billion?

Many of the chemicals are measured in drinking water in either parts per million (ppm) or parts per billion (ppb). Putting one teaspoon of salt in 1,300 gallons of water would result in 1.0 ppm of salt in the water. One teaspoon of salt in 1,300,000 gallons of water would be 1.0 ppb. One part per billion is equal to one inch in 15,783 miles, one second in 32 years or one soybean seed in 6,000 bushels.

What does the MCL really mean?

The MCL for atrazine is 3 ppb. This means an average 150-pound person could drink two liters of water contaminated with atrazine at 3 ppb, every day for 70 years, without any adverse effects.

How do pesticides get into surface water supplies?

Pesticides can enter surface water supplies in three basic ways. First, some may form a solution with rain water and run off after a storm. Second, pesticides can attach to soil particles and be washed into a water body. Third, contamination can occur when accidental spills occur near the water.

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Best Management Practices for Reducing Pesticide Runoff from Agricultural Fields

Pesticides enhance agricultural production while greatly reducing the labor requirement. Their use has helped increase the productive efficiency of today's agricultural producer. By aiding in better weed and insect control, pesticides have enabled producers to try reduced and no-till agricultural practices that have greatly reduced soil erosion. (See Appendix 1, MU publication G 7520 - *Pesticides and the Environment.*)

When pesticides are introduced into the environment, they are subjected to physical, chemical and biological processes that can change their form or availability or carry them out of the application zone. Pesticides can become hazards when they move off target by air movement, (drift) or water movement (erosion, surface runoff or run-in, or leaching).

Best Management Practices (BMPs), or "good farming practices," can be used to reduce erosion, surface runoff and leaching of contaminated surface water while at the same time reducing the contamination of groundwater. To develop effective BMP strategies, the general focus should be on preventing surface water contamination. In order to do this, it is essential to understand how pesticides can spread from the area where they are first applied.

Pesticide movement by water

Water can move pesticides out of the target area by 1) runoff – movement with water over the soil surface, 2) erosion of soil particles to which pesticides are attached, 3) run-in – the direct transport of pesticides into the groundwater through sinkholes or fractures in the bedrock, or 4) leaching of the pesticide down through soil layers.

In northeast Missouri, runoff is the most serious contamination problem associated with water movement. Surface water containing pesticides can run off sloping lands during rainfall. (See Appendix 2, MU publication G 1518 - *Estimating Peak Rates of Runoff From Small Watersheds.*)

Pesticides that are strongly adsorbed (bound) to soils can move out of the soil water and attach to soil particles, silt and clay and organic matter. Physical soil erosion is another major cause of how pesticides move out of the target area.

Pesticide properties

The three most important properties that affect pesticide movement in water are persistence, adsorption potential and solubility.

Persistence

Persistence is the ability of a pesticide to resist degradation. Over time pesticides are degraded or broken down by chemical and microbial processes that result in the end products of carbon dioxide, water and inorganic substances.

The persistence of a pesticide is sometimes expressed in terms of its half-life. The half-life is the length of time it takes for one half of the pesticide in the soil to be broken down. For example if a pesticide is applied at 1 pound per acre and its half-life is 30 days, then 30 days after application only one-half pound of the pesticide will remain. After 60 days, only one-fourth pound will remain.

Adsorption potential

Another important characteristic of a pesticide is its ability to adsorb (bind) onto soil particles, especially clay particles and organic matter. The factor Koc is a soil sorption index. The higher the number (i.e. 100,000 as is the case with paraquat – Gramoxone) the greater the pesticide is bound to the soil; likewise the lower the number (i.e. 2 such as with the pesticide dicamba – Banvel) the less tight the pesticide is bound to the soil.

Solubility

Solubility is the ability of a pesticide to dissolve in soil water. Solubility is measured in ppm. The higher the number in ppm the easier for the pesticide to dissolve in soil water; likewise the lower the number in ppm the more difficult for the pesticide to dissolve. Pesticides that are highly water soluble may move readily with infiltrating water through the soil profile.

The majority of herbicides used today fall into the group with intermediate adsorption and solubility properties and are lost mainly in surface water runoff. Studies have shown that 60 percent to 90 percent of common herbicides, such as atrazine, alachlor and cyanazine, are lost in this manner. Herbicide concentrations are much higher in the eroded sediments but because the water volume is so much greater, water accounts for the majority of the total amount of pesticide transported off the field.

Table 1 lists the major herbicides with their solubility, half-life, soil sorption and surface/leaching characteristics.

Table 1. Herbicide Solubility, half-life, and surface/leaching potential

Trade (Common) name	Solubility in water (ppm) *	Half-life in soil (days)	Soil sorption (Koc)**	Surface/ Leaching ***
Weedone/many (2,4 D ester)	50 (E)	10	1,000(E)	Medium/Small
Weedar/many (2,4 D amine)	300,000	10	1,000(E)	Medium/Small
Lasso (alachlor)	42	14	190	Medium/Small
Aatrex (atrazine)	33	60	160	Medium/Large
Classic (chlorimum ethyl)	500(E)	50	20	Small/Large
Command (clomazone)	1,100	30	100(E)	Medium/Large
Bladex (cyanazine)	171	20	168	Medium/Medium
Dacthal (DCPA)	0.5	30	5,000	Large/Small
Banvel (dicamba)	800,000	14	2	Small/Small
Fusilade (fluazifop)	2	20	3,000(E)	Large/Small
Roundup (glyphosphate)	1,000,000	30	10,000(E)	Large/Small
Scepter (imazaquin)	160,000	60	20(E)	Small/Large
Lorox (linuron)	75	60	863	Large/Medium
Dual (metolachlor)	530	20	200	Medium/Medium
Sencor, Lexone (metribuzine)	1,220	30	41	Medium/Large
Gramoxone (paraquat)	1,000,000	3,600(E)	100,000	Large/Small
Prowl (pendimethalin)	0.5	60	24,300	Large/Small
Assure (quizalofop)	0.3	140	100,000	Large/Small
Poast (sethoxydim)	1,000	5	50(E)	Small/Small
Princep (simazine)	3.5	75	138	Medium/Large
Treflan (trifluralin)	0.3	60	1,400	Large/Small

* E indicates an estimate that could be incorrect by a factor of three.
** Large Koc indicates higher potential for adsorption and less potential for movement, except with soil sediment.
*** Surface loss potential indicates the potential to move with soil sediment.

Best management practices

There are three key factors that influence the amount of pesticide lost in surface runoff.

1. Pesticides are partitioned into the adsorbed (sediment) or solution (water) phase typically based on the solubility or partition coefficient (Koc).
2. There is a narrow zone at the soil surface (mixing zone – about 0.2 inches to 0.8 inches) where overland flow and pesticides intermix to create surface runoff. Once a chemical is leached below the thin mixing zone, it is less susceptible to runoff loss.
3. The first storm/runoff event after application will have a large effect on pesticide loss in surface runoff.

Generally as the solubility of the pesticide increases, the amount of the pesticide loss in the water phase of runoff increases. Exceptions to this general rule are pesticides that are soluble but strongly bound to soil, such as paraquat and Roundup.

Most atrazine lost in surface runoff is associated with the water phase of runoff. Controlling the amount of runoff that leaves the field will be important in controlling atrazine runoff losses.

The key to preventing or reducing the entry of pesticides into surface water is to identify the source and the route to the water. Sources of contaminants can be classified as either "point sources" or "nonpoint sources."

Point source BMPs

"Point sources" refer to situations where movement of a pesticide into water can be traced to a specific site or very small area and not a site such as a total farm. Potential point sources of pesticides could include pesticide storage, mixing, disposal and manufacturing sites as well as transportation spills. Point sources often involve high concentrations of pesticides released into water. In contrast, "nonpoint" sources do not occur at a localized site but occur over a wide area and involve lower concentrations. Soil erosion and water runoff from treated fields are the main nonpoint sources of pesticides in surface water. Point source BMPs described below are also listed in Table 2.

Table 2. Pesticide BMPs to protect surface water from point sources.

Pesticide storage, handling, and disposal
· Store and mix away from surface water
· Watertight containment at storage and mixing sites
· Infield mixing and rinsing
· Injection sprayers and on-board sprayer rinsers
· Triple or pressure rinsing containers
· Recycling or proper disposal of containers
· Use bulk containers

Store and mix away from surface water

Point sources of pesticides into surface water can be reduced by avoiding handling and mixing of pesticides near surface water unless containment systems are in place. If surface sources are used for pesticide spraying, water should be pumped into a nurse tank and hauled to a safe mixing site away from surface water.

Watertight containment at storage and mixing site

Watertight dikes and pads at pesticides storage and handling sites can contain spills or storm water containing pesticides. Sprayer rinsing should be confined to a watertight pad so that rinse water can be collected for proper disposal or conducted in the field so that sprayer rinsate is applied to labeled crop fields.

Infield mixing and rinsing/injection sprayers and on-board sprayer rinsers

Innovation in sprayer designs, such as direct injection sprayers, should greatly reduce the problem of rinsate and excess mix disposal. Water and the pesticides are contained in separate tanks, and the pesticide is injected ahead of the pump. This way, any unused pesticide after the field is sprayed remains undiluted and can be reused. Clean water can be flushed through the boom, and no other rinsing is needed. On-board sprayer rinsers can also make rinsing in the field easier when using conventional sprayers.

Triple-rinse containers

Pesticide containers should be triple-rinsed and recycled or disposed of in approved landfills.

Use of bulk containers

The increased use of pesticides in returnable bulk containers helps reduce the amount of pesticide containers in landfills.

Nonpoint source BMPs

Nonpoint source BMPs can be divided into practices that reduce amounts of pesticides available for runoff and changes in management of land, crops, or pesticides. Nonpoint BMPs are listed in Tables 3a and 3b.

Site selection and matching product to site

Sites for pesticide application should be assessed carefully for risk of surface water contamination. When risk of surface water contamination is high due to factors such as steep slopes and close proximity to water, other pesticides based on lower contamination risks should be chosen, when those alternatives exist.

The new label for atrazine requires no application within 200 feet of a natural impounded lake or constructed reservoir. Another requirement is that atrazine is not to be mixed, loaded or applied within 50 feet of the following:

· Drinking water wells
· Intermittent streams

· Irrigation wells
· Lakes
· Livestock water wells
· Perennial streams
· Abandoned wells
· Reservoirs
· Agriculture drainage wells
· Rivers
· Sinkholes

Also, do not apply atrazine within a 66-foot arc measured from points where surface water runoff enters the following:

· Intermittent stream
· Perennial streams
· Rivers

Pesticide formulation

Pesticide formulation can affect soil and water interactions and runoff potential. Wettable powder formulations may be subject to greater runoff than other formulations.

Starch encapsulation of atrazine has shown reduced risk of leaching with minor reductions on effects of weed control.

Rate selection

You should apply the lowest pesticide rate that provides pest control. In a rate study, a nearly linear relationship was found between atrazine application rate, ranging from one-fourth to four times the recommended rate, and the concentrations in surface runoff and sediment.

New labeled rates for atrazine now limit the amounts applied per acre. Maximum annual pre-emergence rates on “highly erodible soils” (as defined by the Natural Resources Conservation Service) are as follows:

· Fields with 30 percent or more residue:
2 lbs./acre.

· Fields with less than 30 percent residue:
1.6 lbs./acre.

· Maximum annual pre-emergence rate on non “erodible soils”:
2 lbs./acre.

· Maximum annual post-emergence rates:
2 lbs./acre with no soil applied atrazine in same year.
2.5 lbs./acre with soil applied atrazine in same year.

Pesticide substitution

Pesticide substitution may be another alternative in reducing pesticide runoff and surface water contamination. Certain pesticides have a lower water solubility and are less susceptible to surface runoff than other pesticides. If this is the case and the efficacy is similar for both products, then an easy choice can be made. Other pesticides may have a higher MCL for drinking water compared to a similar product with a much lower MCL. In this case, you should use a substitute to avoid the risk to the surface water in the particular watershed. Growers can now choose from a long list of new low-rate herbicides for corn with fewer environmental burdens.

Method of herbicide application

The method of herbicide application can help decrease potential pesticide loss. Incorporation of herbicides under conservation tillage systems, with adequate amounts of crop residues to retard soil erosion (greater than 30 percent), can reduce surface runoff of pesticides.

Post-emergence use of the same herbicides also can reduce potential for pesticide runoff. In the case of atrazine, less herbicide is used but also more of the herbicide is intercepted by plant foliage, and less rainfall is likely to occur at post-emergence application times than when herbicides are applied prior to or at planting. Post-emergence methods of application use many different herbicides that have a short half-life or whose sorption constant is so high that the potential for loss in water runoff is small.

Band application

Band application of pesticides, particular herbicides in conjunction with row cultivation, is one technique that reduces the quantity of herbicides required and reduces pesticide runoff into water. However, timeliness of row cultivation and sprayer calibration are absolutely necessary with band herbicide treatments.

IPM approach

The use of Integrated Pest Management (IPM) methods means that pesticides are used only when the pest population exceeds economic thresholds. The example used in an IPM weed control program is scouting for weed escapes. Weed escapes are those areas within a field that have a high population-density of weeds. Instead of spraying the whole field, only “spot spraying” is required.

In a post-emergence herbicide-application program, weed identification is important so the correct herbicides are used the first time to prevent repeated applications. At

Table 3a. Pesticide BMPs to protect surface water from non-point sources.

Product selection and efficient use

· Site assessment
· Match product to site
· Pesticide formulation and additive selection
· Rate selection
· Pesticide substitution
· Method and timing of application
· Band application
· IPM approach including nonchemical controls
· Sprayer calibration and uniform application

the end of the growing season, a completed scouting report on weed identification and population would map out any problem weeds for the following year.

Sprayer calibration and uniform application

Accurate applicator calibration can avoid excessive rates or poor control. This prevents retreatments due to low rates or nonuniform application. (See Appendix 4, MU publication G 1270 – *Sprayer Calibration: Broadcast Sprayers*; and Appendix 5, G 1273 – *Sprayer Calibration: Granule Applications.*)

Along with an accurate sprayer calibration, it is important to keep accurate records of pesticide applications by field. Accurate record keeping is a recommended practice to protect water quality. Without it, growers cannot systematically apply principles such as rotating herbicides or adjusting rates for specific soils or weeds.

No-till and conservation tillage systems

No-till has sometimes produced dramatic decreases in water runoff and increases in water infiltration, especially with long-term studies. Several small paired watershed studies produced no seasonal runoff from no-till fields, while paired conventional tillage (plowed fields) had significant water runoff, soil erosion and pesticide loss.

The decrease in runoff is attributed to increased infiltration due to development of macropores in the absence of tillage. Cracks, root channels and worm holes allow water to bypass upper soil layers when rainfall exceeds the normal infiltration capacity of the soil. Over a longer period of time, no-till increases organic matter and microbial activity, all of which combine to aid in degradation of the pesticide applied.

Conservation tillage, where at least 30 percent or more of the residue remains on the soil surface, aids in the reduction of water runoff and pesticide loss. However, as the amount of residue increases, the amount of time for water runoff to occur also increases with resulting reduced soil erosion and pesticide loss.

The few natural rainfall studies that have been done with conservation tillage, either chisel plow or ridge-till, indicate that there is less herbicide runoff than with conventional tillage. Herbicide runoff from conventional tillage systems was 58 percent higher than ridge-till and 31 percent higher than chisel plow runoff.

Studies done where the pesticide (herbicide in this case) was placed either below the crop residue or on the crop residue itself indicated that herbicide loss in water runoff was the same. The interception of herbicides by crop residues did not increase herbicide loss in the runoff water.

The tillage system to use may be determined by the soil type and soil conditions. No-till studies done on claypan soils did not always show less water and pesticide runoff when compared to conventional tilled systems. In some cases, on these poorly drained soils, greater water and pesticide runoff occurred under no-till versus conventional tillage. On these soil types, not classified as "highly erodible" with less than a 2-percent slope and with poor internal drainage, some type of reduced tillage with incorporation of the herbicides would be recommended.

Table 3b. Pesticide BMPs to protect surface water from non-point sources.

Land, crop, and pesticide management

· No-till and conservation tillage
· Pesticide incorporation
· Contour farming
· Terraces
· Filter strips and setbacks from water
· Grassed waterways
· Drainage improvement
· Reducing compaction
· Crop rotation
· Narrow row cropping
· Irrigation timing
· Pesticide application timing

Pesticide incorporation

Pesticides are more subject to runoff when they are near the soil surface and can interact with overland flow. After the first few rains following surface application, runoff losses of most pesticides decrease dramatically as the pesticide moves below the soil surface. Most studies comparing incorporation of herbicides with those surface applied, but with all on bare ground (no crop residue), show less herbicide runoff with incorporation of the herbicides. A summary of studies shows that incorporation of herbicides reduced runoff to 38 percent of runoff from surface application.

We know conservation tillage systems, reduced tillage and/or no-till systems reduce pesticide runoff and so does incorporation. However, at this moment, few studies compare herbicide runoff with and without incorporation with crop residue, not bare ground.

Currently, both conservation tillage (reduced tillage and no-till) and incorporation are appropriate BMPs. For highly erodible ground, conservation tillage can reduce pesticide runoff and soil erosion. For fields with gentler slopes that are not "highly erodible," incorporation is an effective BMP to reduce herbicide runoff.

Contour farming

Contour farming is another effective and widely used soil conservation technique, reducing erosion by 65 percent to as much as 81 percent compared to rows up and down the hill. Because of reductions of soil loss and often reductions in water runoff, this technique also has been effective in reducing pesticide runoff.

Terraces

Terraces are effective in reducing soil erosion and can reduce water runoff, depending on their design and soil conditions. Few studies, however, have investigated directly the effect of terraces on pesticide runoff. (See

Appendix 6, MU publication G 1500 – *Choosing Terrace Systems*, and Appendix 7, MU publication G 1503 – *Operating and Maintaining Grassed Outlet Terrace Systems.*)

Concern has been expressed that tile outlet terraces may increase surface water contamination by pesticides as runoff water is carried from the terrace channel by tiles, often directly into streams. This reduces the chance for runoff to flow over soil and vegetation strips, which can reduce pesticide contamination. Current regulations have set an area of 50 feet surrounding tile inlets as pesticide free zones. Pesticides should not be used or sprayed within this 50-foot buffer zone. A vegetation buffer strip around the tile inlet is beneficial in stopping pesticide runoff.

Filter strips and setbacks from water

Another good BMP involves the use of vegetative filter strips and waterways. The terms "filter strip" and "buffer strip" often are used interchangeably to denote an area of land (usually planted to grasses or grass/legumes) in drainage ditches, along the perimeter of cropland or water bodies and used to reduce movement of sediment or other pollutants from field runoff. In some cases they are used in place of a terrace on long, gently sloping fields to reduce sediment movement.

Effective filter strips must be designed to distribute surface water runoff over a large area of the vegetative filter strip. When water flow is concentrated in a narrow area of the filter strip, there is little opportunity for the filtering to take place, especially during high water flow. The width necessary for filter strips to be effective depends, in part, on the length and slope of a given field. As the slope or field length increases, the amount of water and sediment moved across the filter strip increases, requiring a greater width for effectiveness.

The appropriate width of filter strips to effectively control sediment has been determined to be 15 feet to 25 feet. A vegetative buffer strip seeded around each individual field boundary can be used for the following: 1) possible set-aside ground, 2) a substitute for the turn rows or head rows normally planted up and down the hill, and 3) improved hay and forage. A filter strip should be at least 30 feet to 45 feet wide to accommodate the turnaround room needed for today's larger combines. This is a practice commonly observed around Iowa's corn and soybean fields.

Filter strips or riparian zones along streams provide stream bank protection, wildlife habitat and water quality benefits. Eliminating the use of pesticides near water can reduce the amounts of pesticides being transferred by runoff.

Currently, atrazine can not be applied to filter strips ranging from 50 to 200 feet wide, according to the product label. The intent of the increased widths is to reduce the potential of atrazine leaving cropped fields in surface water runoff and moving into streams, rivers and lakes. Research has shown that vegetative filter strips at the base of slopes reduced runoff to an average of 22 percent of the runoff from fields that did not have a filter strip. On "highly erodible" fields, where runoff enters perennial or intermittent streams or rivers, a 66-foot buffer must be planted to the same crop or preferably to a grass or other densely growing vegetation.

Although filter strips adjacent to surface water bodies can be effective in reducing pesticide loads, their effectiveness should not be overestimated. Runoff usually does not enter streams or bodies of water uniformly along their banks but in small areas of concentrated flow. If large loads of pesticide in surface runoff are allowed to reach the immediate vicinity of water bodies, it is not realistic to expect a filter strip of a few hundred feet to effectively trap the pesticides. BMPs further up the watershed will be needed to reduce pesticide loads before they reach the edge of water bodies.

Grassed waterways

Another valuable BMP is the use of grassed waterways. Grassed waterways can reduce runoff velocity, remove some phosphorous from sediment, thereby reducing total phosphorous concentration. Grassed waterways carry concentrated water flow and can be effective in reducing pesticide loads entering streams and rivers. Recent studies indicate that pesticide runoff can be reduced from 70 percent to 96 percent when runoff is diverted through a grassed waterway versus where no waterway exists. (See Appendix 8, MU publication 1504 – *Maintaining Grassed Waterways*; and Appendix 9, MU publication G 1505 – *Design Criteria for Grassed Waterways.*)

Drainage improvement

Installation of drainage tiles can increase water infiltration and reduce surface runoff and pesticide loss. Increased infiltration throughout the plant root zone can increase the availability of nutrients for plant growth. Drainage tile outlets should allow for drainage through a grassed waterway or buffer strip to avoid runoff contamination.

Reducing compaction

Compaction can reduce water infiltration and increase pesticide runoff. Recent studies indicate that herbicide runoff is 3.7 times greater from fields compacted by farm machinery when compared to fields with minimum compaction. To keep compaction to a minimum, use BMPs and avoid driving in fields when the soil is too wet.

Crop rotations

Crop rotations can allow land used for high pesticide crops or highly erosive crops to be planted in rotation with fewer pesticide crops or more soil-conserving crops. The best example for northeast Missouri is the use of small grains – primarily wheat – in the cropping rotation with either soybeans or corn. Wheat normally requires no herbicides or insecticides and is grown during late spring when higher amounts of rainfall occur. Red clover or another legume can be established as a hay or forage crop if overseeded into the wheat during late winter. Establishing a hay or forage crop for one or two years can further reduce soil erosion and water runoff.

Crop rotation results in a greater diversity of pesticides used in a watershed. This can reduce the possible concentration of any single pesticide found in surface water. Crop rotation may reduce the chances of exceeding the pesticide limits of the drinking water standards and limit adverse impacts on aquatic organisms.

Narrow row cropping

Narrowing the row width of row crops may have a positive impact on soil erosion, water runoff and pesticide runoff by increasing ground cover. Drilled soybeans will more often help reduce soil erosion and water runoff under reduced tillage systems and perhaps make no or very little difference under complete no-till systems.

Irrigation timing

Irrigation timing can be used to protect water quality and herbicide runoff. Light irrigation soon after applying a pre-emerge (surface) herbicide will move the herbicide below the soil surface and into the root zone, protecting it from rains that could cause runoff.

Pesticide application timing

Timing of pesticide application also can affect runoff potential. Many studies have shown that pesticide losses are greatest when heavy rains closely follow application. If possible, avoid pesticide application when heavy rain is imminent. Also avoid applying pesticides to frozen ground. Similarly, avoid fall application of pesticides.

References

1. Fawcett, Richard S. and Brian Christensen. 1992. *Best Management Practices to Reduce Runoff of Pesticides into Surface Water: A Review and Analysis of Supporting Research Technical Report: 9-92*, Ciba-Geigy, Environmental and Public Affairs Dept., Greensboro, NC 27419-8300.
2. University of Illinois, 1990. *Illinois Pesticide Applicator Training Manual 39-7, Private Applicator*. Cooperative Extension Service. University of Illinois at Urbana-Champaign, Ill.
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4. University of Wisconsin. 1989. *Nutrient and Pesticide Best Management Practices for Wisconsin Farms.* WDATCP Technical Bulletin ARM-1. Agricultural Bulletin Building, 30 North Murray St., Madison, WI 53706.

Sample Collecting

Introduction

The purpose of any sample is to select a representative portion of a population. When planning for a sample collection, determine why you are collecting the sample. Once you know the reason why, you can determine the best course of action to obtain a representative sample.

The method chosen depends on the reason for sampling, what you are sampling for, the analysis required and the physical arrangement at the sampling site. The sampling should follow state and federal laws and regulations to guarantee a satisfactory representative sample.

Types of sampling

The three main forms of sampling are grab samples, composite samples and automatic wastewater samples. There is no "rule book" that can substitute for good judgment when decisions about sampling are made. Choose the method that fits your needs.

Grab samples are used when you need a representative sample for determining maximum or minimum levels of certain pollutants. An individual grab sample should be collected in less than 15 minutes. This is generally done by submerging the sample container in the water. The sample also can be collected by using a pump, spoon or other suitable device.

In some cases, a single grab sample may not give a total representation of the water body. When this occurs, a composite sample may fit your needs better than a grab sample.

Composite samples are formed by the collection of a series of discrete (grab) samples taken manually and combined into one. Composite samples allow for an approximation of the average water quality over a given time period and is less expensive than analyzing individual grab samples. Composite sampling should be used if a National Pollutant Discharge Elimination System (NPDES) permit or analyses of average concentrations over time are required.

Automatic wastewater samplers are two basic types: the compositor and the sequential or discrete sampler. The compositor automatically deposits every sample into one container. The sequential sampler deposits each sample into individual containers, which can be analyzed individually or manually combined into one container.

When collecting samples, be sure to consider the regulations for sample container, volume of sample, preservatives required, holding times, and shipping procedures.

Method to use

Determine the method of collecting by the reason for sampling and what is being sampled for. Many pesticides remain on the water surface, and a single grab sample can give a good representation of the levels of contamination found in drinking water reservoirs. The grab sample method is recommended for atrazine testing. Check with the Missouri DNR to determine the best possible means of collecting a specific sample. You can reach the DNR - Public Drinking Water Program at P.O. Box 176, Jefferson City, MO 65102-0176, or by calling (573) 751-5331.

Materials needed

The following materials are needed to take a proper sample.

Container:

- 950 ml amber colored glass container (do not use plastic jars)
- plastic lid and seal
- properly cleaned and disinfected (acetone-rinse containers before collecting samples)

Preservative:

(If it will be more than 48 hours before the sample will be analyzed, you may need to add a preservative.)

Procedure for collecting an environmental grab sample

1. Dip or pump a minimum sample of 950 ml of water into a clean glass container. The sample should be taken just below the surface at a location that will give a good representation of the water body. A duplicate sample should be taken for quality control analysis.
2. Avoid collecting sediment or foreign material with the sample.
3. Seal, tag and pack sample(s) to comply with shipping needs. Water samples should be kept on ice and protected from direct sunlight.
4. Send sample(s) to a state-approved laboratory for analysis.

Procedure for collecting a treated water sample

For state approval on drinking water, follow the sampling procedures found in the State Drinking Water Regulations. These can be obtained from the Missouri DNR - Public Drinking Water Program, (573) 751-5331.

Frequency of sampling

The type of sample and the reason for sampling will determine how often you need to take a water sample. Missouri requires samples be taken a minimum of four (4) times during the year, once per quarter. Under state law, a water sample for public drinking water must be tested using the Analytical Method (507,525.1). The Analytical Method, which gives a full analysis of a water sample, must be done in an approved laboratory setting and cost approximately $125 per sample.

Immunoassay testing can be performed in the field as a semi-analytical water sample test. Immunoassay testing costs approximately $5 to $15 per sample. The low cost makes immunoassay feasible for weekly or monthly testing. This allows the tester to determine if particular time periods have more pollutants and can help in pinpointing "problem" tributaries.

Hints for getting effective samples

1. Make sure all containers are well marked.
2. Leave an air space of about 1 inch in the sampling vial or container.
3. Keep ice packets frozen so they are ready when needed.
4. For best sample results, collect the sample on Monday or Tuesday and ship to the laboratory by an overnight service to guarantee a minimal time frame between collecting and analyzing.

References

1. *Instructions for the Use of Division Of Environmental Quality Sample Tags,* March 1984.
2. *General Overview of Sample Collection,* Missouri DNR Field Service Staff Standard Operating Procedures.
3. *Sample Collection, Missouri DNR – Environmental Services Program*.

Appendix A
Additional Information Sources

MU publication G 1270

Sprayer Calibration — Broadcast Sprayers

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Pesticides are effective only if applied at the correct amount per acre. Too much pesticide can injure crops and leave harmful residues; too little can give inadequate and undependable control.

The volume of spray mix applied per acre by a sprayer depends on: 1) nozzle flow rate; 2) width sprayed; and 3) travel speed of the sprayer.

Before you calibrate your sprayer, you must select the nozzles to be used. If your sprayer already is equipped with nozzles, be sure all nozzles are the same. Record the nozzle size number for future use.

For example, suppose you have a tractor-mounted sprayer, with two 200-gallon saddle tanks that apply herbicide while you plant. The spray boom and nozzles will spray the width planted with your 6-row (30-inch row spacing) planter. You are going to apply a tank mix of alachor plus linuron for pre-emergence weed control in soybeans.

We will give more examples using the above situation as we describe appropriate nozzle selection and calibration procedures.

Nozzle selection

Step 1. Select the sprayer application rate. A recommended range of sprayer application rates, in gal/acre, is given on the pesticide label. From that range, choose the rate that best fits your operation.

Example: From the recommended range of application rates on the label of both herbicide containers, you select the rate of 20 gal/acre because that rate is easy to use in computations and is the one you generally use.

Step 2. Select the field speed. Choose a speed that you can maintain at all times in the field because speed affects sprayer application rate greatly.

For example, you are farming bottom land and you select a speed of 5 mph, the speed at which you plant soybeans.

(To preserve its continuity, Table 1 is on the following page.)

Table 1. Nozzle flow rate (gal/minute).

Width sprayed (inches)	Travel speed (mph)	Application Rate (gal/acre) 5	10	15	20	25	30	40
10	3	—	—	0.08	0.10	0.13	0.15	0.20
	4	—	0.07	0.10	0.13	0.17	0.20	0.27
	5	—	0.08	0.13	0.17	0.21	0.25	0.34
	10	0.08	0.17	0.25	0.34	0.42	0.51	0.67
12	3	—	—	0.09	0.12	0.15	0.18	0.24
	4	—	0.08	0.12	0.16	0.20	0.24	0.32
	5	—	0.10	0.15	0.20	0.25	0.30	0.40
	10	0.10	0.20	0.30	0.40	0.51	0.61	0.81
15	3	—	0.08	0.11	0.15	0.19	0.23	0.30
	4	—	0.10	0.15	0.20	0.25	0.30	0.40
	5	—	0.13	0.19	0.25	0.32	0.38	0.51
	10	0.13	0.25	0.38	0.51	0.63	0.76	1.01
20	3	—	0.10	0.15	0.20	0.25	0.30	0.40
	4	0.07	0.13	0.20	0.27	0.34	0.40	0.54
	5	0.08	0.17	0.25	0.34	0.42	0.51	0.67
	10	0.17	0.34	0.51	0.67	0.84	1.01	1.35

Step 3. Determine the width sprayed by each nozzle. The width sprayed by each nozzle on a broadcast spray boom is the distance between nozzles. If a sprayer has nozzles spaced every 20 inches on the boom, the width sprayed by each nozzle is 20 inches. If a sprayer has several nozzles that will be used to spray each row, such as the sprayers used to apply insecticides to row crops, then the width sprayed by each nozzle would be the distance between rows divided by the number of nozzles used to spray each row.

Suppose you have a sprayer that has one nozzle that will be above the row and two that will be between rows. Say the rows are 30 inches apart. Each row will be sprayed with three nozzles. The effective width sprayed by each nozzle would be 30 inches divided by 3 nozzles, or 10 inches.

Example: The width sprayed by each nozzle on a sprayer is 15 inches because the spray boom and nozzles spray the full width of the planter, or broadcast, and the nozzles on the sprayer are 15 inches apart.

Step 4. Determine the nozzle flow rate. The nozzle flow rate can be determined from Table 1 or calculated by the use of Equation 1.

Table 1 gives the nozzle flow rate for four speeds and seven application rates. You can use this table if your spray width, speed, and application rate are among the values listed. For example, if you want to apply 20 gal/acre at a speed of 5 mph with a broadcast boom having nozzles 15 inches apart, you can determine from the table that you will need a nozzle flow rate of 0.25 gal/minute.

If you want to calculate the nozzle flow rate, use Equation 1.

Equation 1.

$$\text{Nozzle flow rate} = \frac{AR \times S \times W}{5{,}940}\text{, where}$$

NFR = nozzle flow rate, gal/min.

AR = sprayer application rate, gal/acre, as selected in Step 1.

S = speed in mph, as selected in Step 2.

W = width sprayed by each nozzle, inches, as determined in Step 3.

5,940 = a constant (instead of 5,940, you can use 6,000 with an error of 1 percent).

Example:

AR = 20 gal/acre, as selected in Step 1.

S = 5 mph, as selected in Step 2.

W = 15 inches, as determined in Step 3; therefore,

$$NFR = \frac{20 \times 5 \times 15}{5{,}940} = 0.25 \text{ gal/min.}$$

Table 2. Example from a typical nozzle catalog.

Nozzle no.	Pressure (psi)	Flow rate (gal/min.)
8812	20	0.14
	25	0.16
	30	0.17
	40	0.20
	50	0.23
	60	0.25
8813	20	0.21
	25	0.24
	30	0.26
	40	0.30
	50	0.34
	60	0.37
8814	20	0.28
	25	0.32
	30	0.35
	40	0.40
	50	0.45
	60	0.49

Step 5. Select nozzles. Use the nozzle manufacturer’s catalog to select a nozzle that will have a flow rate (Step 4) within the range recommended on the pesticide label.

Example: You want to use a flat fan nozzle to apply the herbicides. The nozzle manufacturer’s catalog lists the nozzle number, pressure and flow rate. You don’t find the exact value of 0.25 gal/minute, so you select a nozzle with a flow rate range that includes 0.25. Table 2 is an example from a typical nozzle catalog. You decide to use nozzle 8813 because you observe that 0.25 is within the range of flow rates shown for that nozzle. You install the new nozzles and adjust the boom height so the spray fans overlap about 4 inches above the soil.

Calibration

Step 1. Check general sprayer operation. Fill the supply tank with water and operate the pump. Check for leaks, proper operation of the pressure gauge and clogged nozzles. Place a container, such as a quart fruit jar, under each nozzle and see whether all jars fill in about the same time; or use a watch with a sweep second hand and collect the output from each nozzle for the same amount of time. If the output varies much, check to see whether any nozzles are clogged and whether all nozzles are the same size. Nozzles that continue to have a flow rate greater or less than 10 percent of the average should be replaced. Sometimes nozzles wear and cause the flow rate to change. Nozzle wear depends on the amount of use, nozzle material and type of pesticide used. Most suspended pesticides cause greater nozzle wear than soluble pesticides. Brass and aluminum nozzles wear more than stainless steel or ceramic nozzles. The following list gives the nozzle life for several nozzle materials:

Nozzle material	Nozzle life (years)
Brass or aluminum	1
Stainless steel	2 to 3
Hardened stainless steel	10 to 15
Ceramic	lifetime
Carbides (tungsten, chrome)	lifetime

Example: You have operated the sprayer and checked operation of the shut-off valve and for leaks in the spray system. You've checked the nozzles and found that the flow rate of all is within 10 percent of the average.

Step 2. Check travel speed. Lay out a known distance in the field to be sprayed or in one with similar soil conditions. Use a distance of 176 feet for speeds up to 8 mph and 352 feet for speeds greater than 8 mph. Be sure to use a loaded sprayer and operate the sprayer or tractor with the throttle setting and gear you want to use throughout the spraying operation. Measure, once in each direction, the time to travel the known distance. Average the times in seconds and use Equation 2 or Table 3 to determine the travel speed.

Equation 2.

Travel speed (S) = $\frac{D \times 60}{T \times 88}$, where

S = travel speed — mph

D = distance — feet

T = travel time — sec

60 = a constant — sec/min.

88 = a constant — feet/min. per mph

Be sure to mark your throttle setting and gear after you are satisfied with the speed check. Also use the tachometer as a check.

Example: You place two stakes 176 feet apart in the soybean field. You find it takes 23 sec to drive one way and 25 sec to drive the other way, an average of 24 sec. You can calculate the travel speed using Equation 2.

$$S = \frac{176 \times 60}{24 \times 88} = 5 \text{ mph}$$

You check this speed using Table 3 and find that your calculation is correct. You also note that the tachometer on the tractor indicated a speed of 5.25 mph. The difference between 5.25 mph and 5 mph is probably due to wheel slippage or an incorrect tachometer.

Table 3. Travel speed (mph).

Distance (feet)	Travel time (seconds) 15	17	20	24	27	30
88	4.0	3.5	3.0	2.5	2.2	2.0
176	8.0	7.0	6.0	5.0	4.5	4.0

Step 3. Determine nozzle flow rate. If you have selected nozzles, you have already determined the desired nozzle flow rate in Step 4 of the nozzle selection procedure. If you are going to use the nozzles you now have, you must calculate their flow rate using Equation 1 or the manufacturer’s catalog.

Example: The nozzle flow rate needed for your sprayer was 0.25 gal/minute, as calculated using Equation 1 in Step 4 of the nozzle selection procedure.

Step 4. Measure and adjust nozzle output. Convert the output from gal/minute to ounces/minute because ounces are easier to measure. Multiply the nozzle flow rate in gal/minute by 128, the number of oz/gallon. Collect the nozzle output from several nozzles for 1 minute and calculate the average flow rate. If the nozzle output is within 5 percent of the desired flow rate, the sprayer is calibrated. If not, readjust the pressure and collect the output again. Repeat this procedure until the output is within 5 percent of that desired.

Example: You plan to use a glass kitchen measure that is graduated in ounces to measure the output from the nozzle. Therefore, you multiply the nozzle flow rate of 0.25 gal/min times 128 and find that the rate in ounces is 32 oz/minute. You checked the nozzle catalog and found the approximate pressure needed to obtain a flow rate of 0.25 gal/min with the 8813 nozzle. You found that 0.25 is between 25 and 30 pounds per square inch (psi). You adjust the pressure so that the gauge reads about halfway between 25 and 30. You use a 2-quart glass kitchen measure to collect the output from a nozzle for 1 minute. The amount collected is 38 ounces. That is too much because 38 minus 32 equals 6, which is greater than 5 percent of 32 (32 x 0.05 = 1.6). You lower the pressure and collect the output from three nozzles. This time the average flow rate is 32.5 oz/min. Your sprayer is now calibrated.

Step 5. Recheck the nozzle output. Check the nozzle flow rate frequently. Adjust the pressure, when necessary, to compensate for changes in flow rate caused by nozzle wear and other changes.

To order, request G 1270, *Sprayer Calibration — Broadcast Sprayers* (50 cents).

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MU publication G 1271

Sprayer Calibration — Band Sprayers

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Pesticides are effective only after they have been applied in the correct amount. Too much pesticide can cause crop injury and leave harmful residues. Too little pesticide may cause inadequate and undependable control.

The number of gallons applied per acre depends on nozzle size, pressure of the spray and sprayer ground speed.

Spray calibration is a procedure to determine how much water and chemical is applied per acre.

Calibration

Step 1. Determine width covered by sprayer. The width covered by the sprayer is equal to the number of nozzles multiplied by the band width applied with each nozzle. Divide this number by 12 to get the width covered in feet. Figure 1 shows a typical arrangement of nozzles on a band sprayer.

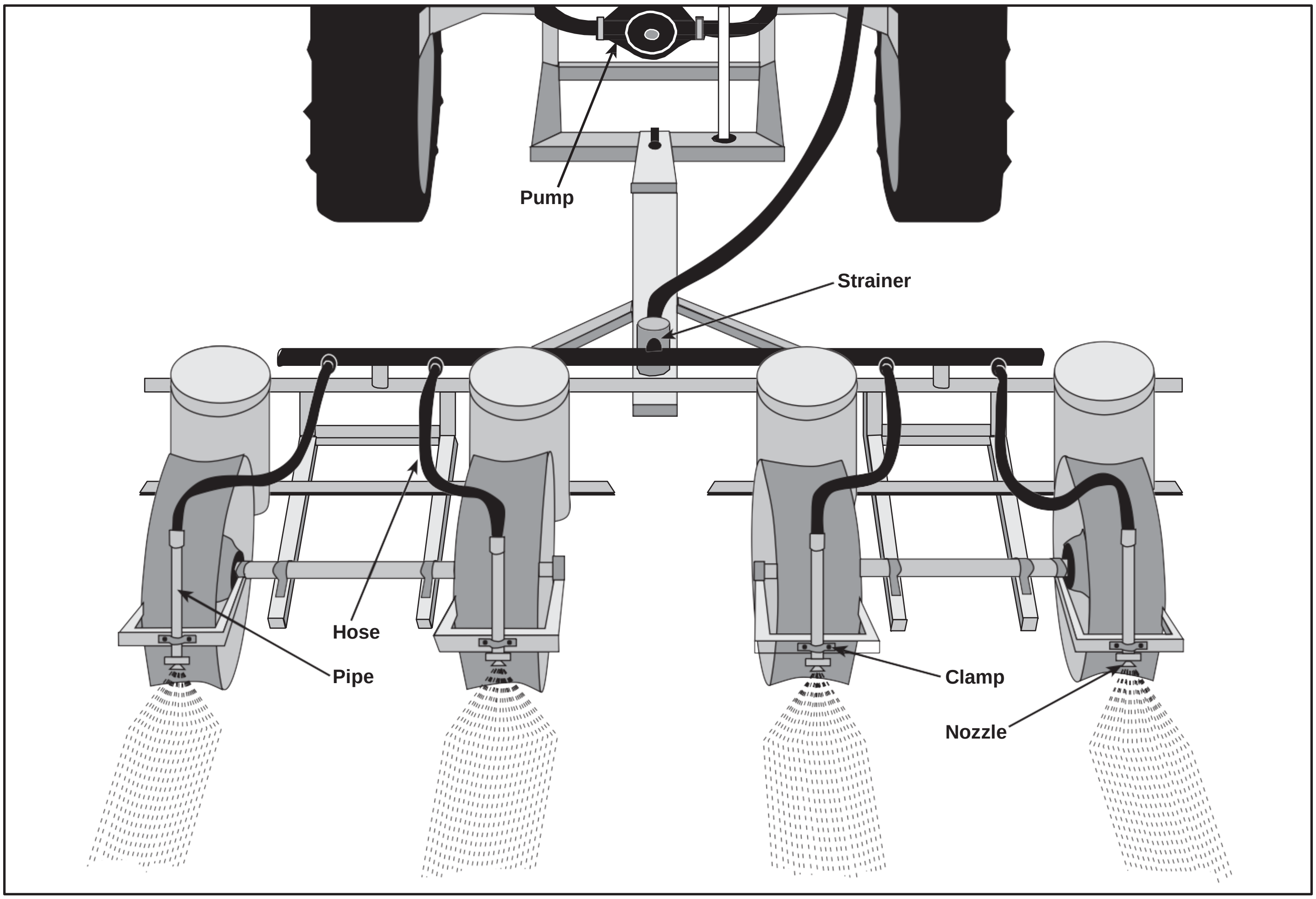

Figure 1. Typical arrangement of nozzles on a band sprayer. The sprayer width (w) is equal to the number of nozzles times the band width.

Step 2. Check general sprayer operation. Fill supply tank with water and operate pump. Check for leaks, proper operation of pressure gauge and for clogged nozzles.

Place a container such as a quart fruit jar under each nozzle and see if all jars fill in about the same time. You may want to use a watch with a sweep second hand and collect the output from each nozzle for the same amount of time. If there is much variation, check for clogged nozzles and that all nozzles are the same size. Nozzles that continue to show a variance greater than 10 percent should be replaced.

Step 3. Time sprayer over a measured course. Measure a 300-foot course in the field where you will be spraying. Operate the sprayer at the field speed you will use. Mark the tachometer and record the tachometer reading for use when spraying. Spray at the same speed as when calibrating. If you do not have a tachometer, mark the throttle setting and gear. Measure the time required to make one round trip (don't include the time required for turning). An ordinary pocket or wrist watch with a second hand is sufficiently accurate. Record this time for use later in Step 5.

Step 4. Refill spray tank. Move the sprayer to a level area near a source of water. With the sprayer in a stationary position, completely fill the tank with water. Be sure that the tank is full so water is just beginning to spill over the edge.

Step 5. Operate sprayer for measured time. Without moving the sprayer, operate it for a period of time equal to that required to make the round trip over the measured course as determined in Step 3. Be sure sprayer is operated at same pressure as will be used when spraying.

Step 6. Measure amount of water required to refill supply tank. Use a bucket graduated in gallons and half gallons. A quart fruit jar can also be used for finer measurements. Record this amount for use in Step 9.

Step 7. Determine area covered. The area covered is equal to the width covered (Step 1) times the round trip distance (skip this step if you use Table 2).

Area covered = Width covered x Round trip distance

Table 1. Acres sprayed for band widths in inches and number of rows when spraying a 600-foot course.

Number of rows	Band width (inches) 10	12	14	16	18	20
2	0.023	0.028	0.032	0.037	0.041	0.046
4	0.046	0.055	0.064	0.073	0.083	0.092
6	0.069	0.083	0.096	0.110	0.124	0.138
8	0.092	0.110	0.129	0.147	0.165	0.184

Step 8. Determine acres covered. Divide area covered (Step 7) by 43,560 (number of square feet in one acre) or:
Equation 1.

$$\text{Acres covered} = \frac{\text{Area covered}}{43{,}560}$$

You can use Table 1, which shows the acres for band widths and number of rows that are common to band sprayers, rather than do the calculation. You must do the calculation if your band width is not listed in Table 1.

Table 2. Multiplication factors for band widths and number of rows when spraying a 600-foot course.

Multiply the number in this table by the gallons required to refill the tank (Step 6) to obtain the gallons per acre (GPA).

Number of rows	**Band width (inches)** 10	12	14	16	18	20
2	43.5	35.8	31.3	27.0	24.4	21.7
4	21.7	18.2	15.6	13.7	12.0	10.9
6	14.5	12.0	10.4	9.1	8.1	7.2
8	10.9	9.1	7.8	6.8	6.1	5.4

Step 9. Determine gallons applied per acre. Divide gallons required to refill tank (from Step 6) by the acres covered (from Step 8) or:

Equation 2.

$$\text{Gallons per acre (GPA)} = \frac{\text{Gallons to refill tank}}{\text{Acres covered}}$$

As an alternative to the formula, you can use Table 2 if your band width and number of rows are listed in this table. Multiply the factor opposite your number of rows and under your band width by the number of gallons required to refill the tank. The answer is the gallons applied per acre.

Example: You have a 6-row planter equipped with six nozzles that apply a 14-inch band per nozzle.

Step 1. Determine swath width.

$$\text{Swath width} = \frac{\text{No. of nozzles x Band width}}{\text{12 inches/foot}} = \frac{6 \times 14}{12} = 7 \text{ feet}$$

Step 2. Check sprayer. Clean any nozzles that need cleaning, and replace those that need replacing.

Step 3. Measure a 300-foot course in the field. You find that it takes 41 seconds to drive in one direction and 39 seconds to drive the other direction or a total of 80 seconds for the round trip.

Step 4. Move the sprayer to a level area near a water supply. Fill the spray tank.

Step 5. Operate the sprayer for 80 seconds with the pressure adjusted for 40 psi.

Step 6. Measure the water required to refill the tank. You find this to be 1-1/2 gallons.

Step 7. Determine area covered (Skip this step if you use Table 2).

Area covered = Width covered (feet) x Round trip distance (feet) = 7 x 600 = 4,200 square feet

Step 8. Determine acres covered.

$$\text{Acres covered} = \frac{\text{Area covered (Step 7)}}{\text{43,560 (feet}^2\text{/acre)}} = \frac{4{,}200}{43{,}560} = 0.096$$

If Table 1 is used for this step, the acres covered can be found by looking up a band width of 14 inches and six rows, which is 0.096 acres. This agrees with our calculation.

Step 9. Determine gallons per acre (GPA).

$$GPA = \frac{\text{Gallons to refill tank (Step 6)}}{\text{Acres covered (Step 8)}} = \frac{1.5}{0.096} = 15.6 \text{ gallons/acre} = 16 \text{ (to nearest gallon)}$$

This answer can be also found much easier if Table 2 is used. Opposite six rows and under the band width of 14 inches, find the factor 10.4. Multiply this number by the gallons measured in Step 6 and find:

GPA = 10.4 x 1.5 = 15.6 = 16 (to nearest gallon) Again, find that this agrees with our calculation. The tables eliminate long division required in sprayer calibration.

Calibration check

You can check calibration in a few minutes if you have a container with ounce graduations and a watch. You must know the speed and be sure the pressure used in the field is the same as used during this check.

Step 1. Place a container, such as a quart fruit jar, under each nozzle and see if all jars fill in about the same time. You may want to use a watch with a sweep second hand and collect the output from each nozzle for the same amount of time. If there is much variation, check for clogged nozzles and that all nozzles are the same size. Replace nozzles that continue to vary more than 10 percent.

Step 2. Collect output from at least three nozzles for 1 minute. Average these amounts and record this for use in the next step.

Step 3. Determine GPA: $$GPA = \frac{46.4 \times \text{oz. per minute}}{\text{Band width} \times MPH}$$

Example: You measure the output from three nozzles and find the average flow rate to be 24 ounces per minute. Each nozzle applies a 14-inch band. You have checked your tachometer/speedometer and know your field speed will be 5 mph.

$$GPA = \frac{46.4 \times 24}{14 \times 5} = 15.9 \text{ gallons/acre} = 16 \text{ (to nearest gallon)}$$

Note: This check can also be used for calibration if you are sure the assumed speed used in Step 3 is the same as you will be using in the field. Check your field speed with this formula:

$$MPH = \frac{\text{distance traveled} \times 60}{\text{time(seconds)} \times 88}$$

Example: $$MPH = \frac{600 \times 60}{80 \times 88} = 5.11 \text{ miles/hour} = 5 \text{ (nearest MPH)}$$

To order, request G 1271, *Sprayer Calibration — Band Sprayers* (25 cents).

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MU Ppublication G 1273

Sprayer Calibration — Granule Pesticide Applicators

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Some pesticides come in granule form. Most granules used for row crops are applied to the soil with either a band applicator or a broadcast applicator. This guide describes the procedures for calibrating broadcast and band applicators. The prediluted granules have a fixed amount of pesticide so there is no need for mixing.

Tractor speed and wind can greatly affect the distribution from granule applicators. Keep the distributors adjusted so that the granules will be deposited uniformly. Empty the granule hoppers each day because moisture affects the metering of granules.

Granule application rates are affected by the following:

- Orifice size (feeder-gate setting)
- Ground speed
- Agitator speed
- Size and nature of granules
- Roughness of the ground
- Humidity
- Temperature.

Calibration — band applicators

Step 1. Determine application rate. Read the label and the operators manual! The recommended range of application rates is on the label. Be sure the rate you use is the right one for your soil and crop conditions. Normally the label will list the total amount of pesticide granules (product) to apply per acre. For example: Apply 40 pounds of product per acre.

The recommended rate may also be expressed in pounds (lb.) of active ingredient. If so, you will need to go to Step 2. If the rate is for total product per acre, then skip Steps 2 and 3 and go to Step 4.

Step 2. Determine concentration of active ingredient. Read the label! The label will show the active ingredient in each container in percentage.

Example: Contains 5 percent 2,4-D.

Step 3. Calculate how much pesticide to apply. If the label expresses the application rate (AR) as pounds of active ingredient per acre, then the amount of total product per acre is calculated as follows:

$$\text{Lb. of pesticide product/acre} = \frac{\text{AR} \times 100}{\text{Concentration (percent)}}$$

Example: You want to apply 2 pounds of active ingredient of 2,4-D per acre, and the label shows that the concentration of the product is 5 percent 2,4-D.

$$\text{Lb. of 2,4-D product/acre} = \frac{2 \times 100}{5} = 40$$

Therefore, you will have to apply 40 pounds of total product per acre to get 2 pounds of 2,4-D per acre.

Step 4. Calculate amount of pesticide to apply per course.

CAUTION!: Sometimes the application rate is based on the total crop acreage, and at other times it is based on the area covered by the bands only.

First, consider the rate based on band area only. You know the application rate you want (example: 40 lbs./acre). You need to calculate how much pesticide should be collected when you have traveled a given distance. Use a distance of 653 feet (about 1/8 mile) because 653 makes the calculations easy and will result in an accurate calibration. The following equation is the weight in ounces (oz.) for each applicator.

$$\text{Ounces} = \frac{\text{Rate (lbs./acre)} \times \text{Width (inches)}}{50}$$

Example: You want to apply 40 pounds of 2,4-D granules per acre on a band that is 15 inches wide.

$$\text{Ounces} = \frac{40 \times 15}{50} = 12$$

Adjust the applicator used in this example until it applies within plus or minus 5 percent of 12 ounces (11 to 13 ounces) on the 653-foot band.

Now consider the rate based on total crop acreage. Use the same equation, but use row spacing instead of band area.

Example: You want to apply 40 pounds of 2,4-D granules per crop acre, and the row spacing is 30 inches.

$$\text{Ounces} = \frac{40 \times 30}{50} = 24$$

Adjust the applicator until it applies within plus or minus 5 percent of 24 oz. for the 653-foot course.

Step 5. Adjust applicator. Read the instruction manual! The instruction manual should be used as a guide for the initial setting. Open and close the metering gate several times to be sure it is operating properly. Move the gate lever from the closed position to the initial setting so slack will always be taken up in the same direction each time you change settings.

Step 6. Add pesticide to hopper. Read the label! Observe handling instructions before opening pesticide container. Wear appropriate protective equipment and clothing. Add pesticide to hopper until it is one-half full.

Step 7. Operate applicators. Turn on the applicators, and while they are operating check to see that all are feeding pesticide.

Step 8. Disconnect feed tubes. Turn off applicators and disconnect each feed tube from the hopper.

Step 9. Attach container to hopper. Attach a container such as a paper or plastic bag to the hopper opening(s).

Step 10. Travel a measured distance. Lay out the 653-foot (1/8-mile) course in the field. Travel that distance at the speed you will use during application.

Step 11. Weigh pesticide collected. Weigh and record the amount collected from each applicator. The weight will often be less than a pound; so a small scale such as a postal scale is needed. Adjust the applicator gate opening until the applicator applies within plus or minus 5 percent of the weight calculated in Step 4.

Calibration — broadcast applicators

Note: Steps 1 through 3, same as for band applicators.

Step 4. Calculate how much pesticide to apply per area.

Pound of pesticide = Pound/acre x Area

The area covered in acres can be calculated by the following equation:

$$\text{Area (acres)} = \frac{\text{Width (feet)} \times \text{Length (feet)}}{43{,}560}$$

Example: You are calibrating a 10-foot applicator, using an area 20 feet wide by 240 feet long. You want to apply 40 lbs. of product per acre.

$$\text{Area} = \frac{20 \times 240}{43{,}560} = 0.11 \text{ acres}$$

Pounds = 40 x 0.11 = 4.4 lbs.

Therefore you want to keep adjusting the spreader until it applies within plus or minus 5 percent of 4.4 pounds on the 20-by-240-foot area.

Step 5. Adjust applicator. Read the instruction manual! The instruction manual should be used as a guide for the initial setting. Open and close the metering gate several times to be sure it is operating properly. Move the gate lever from the closed position to the initial setting so slack will always be taken up in the same direction each time you change settings.

Step 6. Pour granules into hopper. Pour until the hopper is filled to a mark you have made on hopper side with a pencil or other ink marker. The mark should be at least one-third of the distance from the bottom of hopper to the top.

Step 7. Apply pesticide to predetermined acreage. Apply pesticide to the predetermined area in your field. Drive at the speed you want to use during application.

Step 8. Refill hopper to mark. Weigh the container with unused pesticide. Pour more pesticide into the hopper until the level again reaches the mark on the side of the hopper. Then reweigh the container and pesticide. Subtract the two weights to determine the amount applied in Step 7. Compare this amount with the amount calculated in Step 4. If the amount is within plus or minus 5 percent, the applicator is calibrated. If the amount is not within 5 percent, readjust metering gate and start again with Step 6.

To order, request G 1273, *Sprayer Calibration — Granule Pesticide Applicators* (25 cents).

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MU publication G 1500

Choosing Terrace Systems

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Terraces are one way to control soil erosion. Crop rotation and tillage practices also control erosion, but they do not provide control of runoff water after heavy rains. Terraces provide this control and should often be a part of your water management plan for continuous row crops on slopes of 5 percent or more.

Terraces do require high capital investments, however. Costs may range from $100 to $250 per acre, depending on the type of terrace system.

Terraces are intended to intercept and slow the flow of surface water from unprotected slopes. Contour farming by itself is not very effective in controlling water when large storms occur on moderately steep slopes. Terraces capture the water in a channel and control its removal from the field via an erosion-resistant, vegetative waterway or an underground pipe outlet. Design of grassed waterways is described in MU publication G01505, *Design Criteria for Grassed Waterways.*

Your financial position will affect your choice of terracing systems. If you have a definite cash flow problem and little equity, you may consider only a minimal investment in the short term. If you have considerable equity in your land or other sources of capital, you can install a terrace system and still show a profit.

Unfortunately, no one has collected statistics showing significantly increased yields in the first five to 10 years after terracing. Yield loss due to erosion is not easily measured but does definitely occur as the moisture-holding characteristics of the eroded soil decline.

In deciding on which fields to spend money, remember that the best land is usually devoted to high return row crops and needs the maximum protection possible. Therefore, take two steps. First, prepare a plan for the entire farm. This is a must so that travel lanes, terraces, fences and outlets all work together. Then put the practices in place. Put in outlets first and then construct terraces on the best land near the tops of ridges. Careful scheduling will ensure that terraces can be put in place as crop rotation permits.

Terraces are being built today under many of the same constraints that hindered their development 40 years ago. However, advances in technology have provided a wider variety of technical alternatives. Review of terraces is helpful in identifying systems that are useful to Missouri landowners. These terrace methods are listed in order of both increasing cost and increasing design complexity. The simplest systems can be laid out directly in the field. Those developed later require more field measurements and considerable computation; thus, they usually require technical assistance. The overall objective of all the systems, of course, is to produce a cost-efficient and easy-to-farm system that meets the owner's preferences.

A case study of a farm in northeast Missouri illustrates the various types of systems one might adopt. Each of the designs in Figures 1 through 4 includes features that may be important to various landowners.

(Figures 1 through 4 appear on the following page to preserve their continuity.)

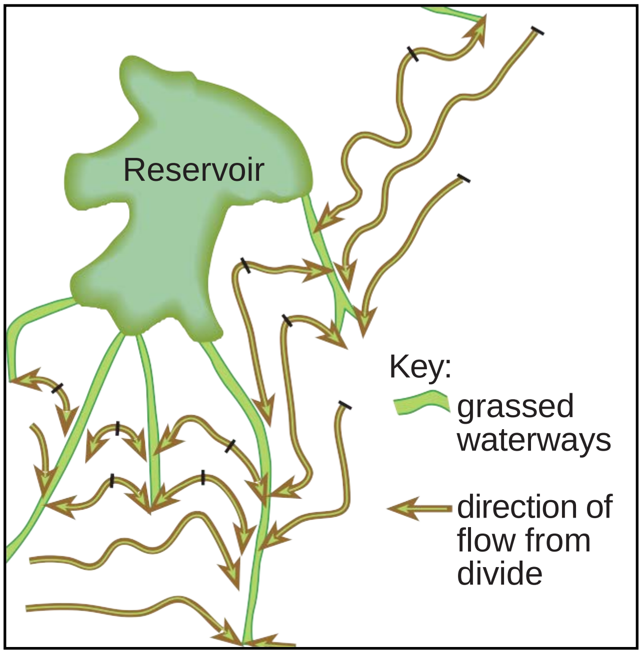

Figure 1. Constant grade channels and grassed waterways are characterized by point rows and sharp curves.

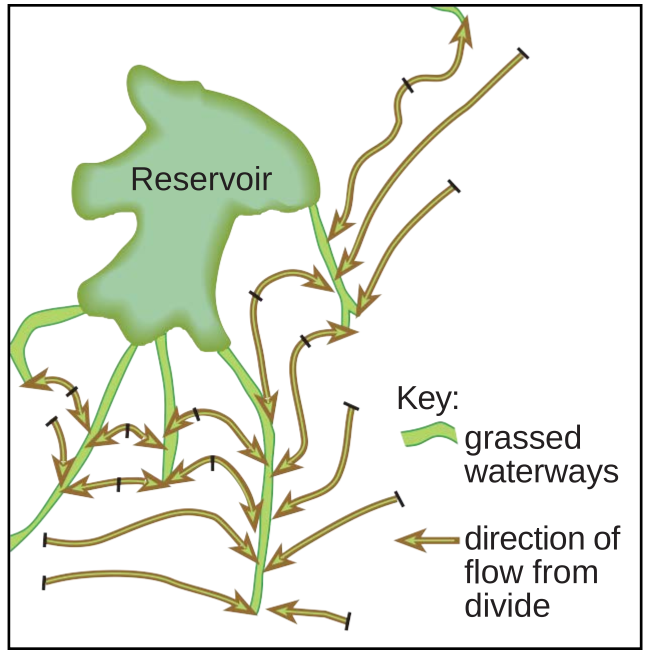

Figure 2. Cuts and fills improve alignment. Note smoother curves.

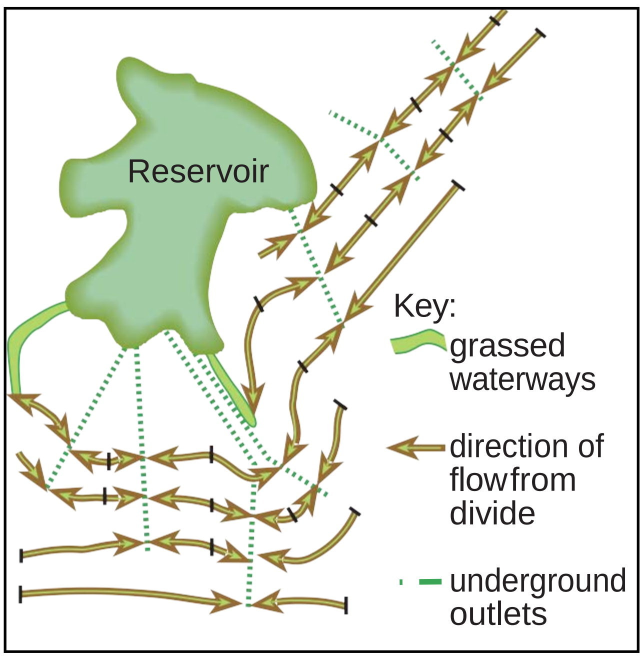

Figure 3. Cuts and fills, a variable grade, plus some underground outlets improve alignment.

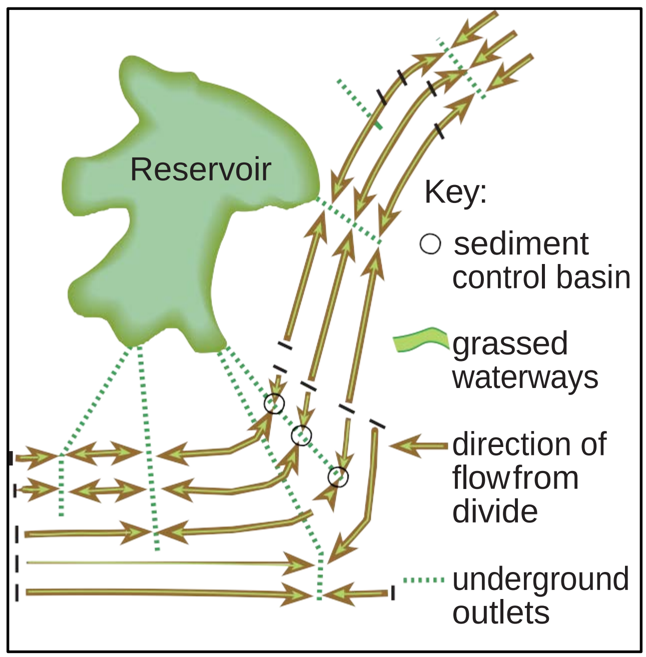

Figure 4. Cuts and fills, a variable grade, underwater outlets, plus water and sediment control basins keep terraces parallel.

Easiest and cheapest

The early constant grade terrace, first constructed during the 1930s and early 1940s, was and continues today as an excellent erosion control device. It is relatively easy to design and lay out in the field. It can be constructed using farm equipment. Grass turn rows or brush along the banks of a ditch or fence row often provide outlets. Two-row farm equipment on 40-inch rows could traverse the sharp turns and point rows that were often necessary to obtain a proper channel grade with no cutting or filling. Heavy earth moving equipment was not readily available when the constant grade terrace was first used; thus, farm equipment had to be used to build the terraces. Many farmers today ignore farming on the contour if they choose this type of terrace, since large equipment is difficult to use on these sharply turning channels. But the terrace ridges are damaged unless the land is farmed on the contour.

Dozers and four-row equipment

As farm equipment began to increase in size, the larger four-row equipment no longer fit the terrace cross-section properly. Sharp turns and point rows caused more concern. The broad-base terrace was developed after World War II along with the practice of cutting a little more or less in the channel to reduce the sharpness of curves in the terrace. Terrace channels have straightened. After World War II, the crawler tractor with dozer blade came to be readily available for hire on the farm. This tractor was necessary for constructing the broad-base terrace. Bending the wire staffs of marking flags became a common way to mark where adjustments to improve terrace alignment were to be made. The bent staff signaled the dozer operator to cut a little deeper than normal at this point. The amount of extra cut was left to the dozer operator's judgment.

The dozer became a valuable tool in the development of agricultural lands. Gullies were cleared and shaped into crossable grassed waterways. Fence rows were cleared and fences were eliminated to create larger fields and longer rows to accommodate even larger more powerful farm machines. The 36-inch crop row width became more common. Cutting through high spots and filling across depressions in the terrace channel reduced curves and point rows. The idea of varying the terrace channel grades within certain limits gained general acceptance and extended the capacity for straightening the terrace without excessive cuts and fills. Operators continued to use dozers to transport cuts to areas of fill.

Terrace system designs became more demanding while layout possibilities became more varied. Cuts and fills required balancing and locating to make transporting fill easier. Guide stakes had to be marked with specific amounts to be cut and filled. Construction was more exacting. The builder had to supplement "seat of the pants" grading with more exact methods. A sequence of construction had to be planned to keep transportation of cuts and fill materials to a minimum.

Modern technology and narrow rows

Modern times are bringing even larger machines and narrower rows. Row widths of 30 inches and six- to eight-row equipment are becoming common. These rows must be traveled by huge, four-wheel drive tractors with like-sized tillage and planting equipment. Self-propelled combines with six- or eight-row headers are commonplace.

Advanced technology has also given us herbicides, pesticides, special planting machines, fertilizers and tillage machines. The construction industry has developed the self-propelled and self-loading scraper, the chain and wheel type trencher and corrugated polyethylene plastic tubing with a complete set of quick-connect fittings. The self-loading scraper is fast becoming the primary machine for constructing terraces. Cuts and fills no longer have to be kept close together or even in the same terrace channel. This scraper is capable of cutting, transporting, filling, shaping and smoothing earth efficiently. The trencher and corrugated plastic tubing have made the underground terrace outlet not only feasible but easier and faster to install than a grassed waterway.

As the self-loading scraper freed the terrace designer of many restrictions on location of cuts and fills, so has the underground outlet added new concepts of design that provide wide latitude in developing a parallel and accessible field terrace system and that satisfy the increased demand for easy-to-farm land. In exchange, the modern day designer of terraces must consider storm runoff quantities, storage capacities of terrace channels, optimum removal rates, pipe flow rates and capacities for varying slopes and proper outletting of underground conduits to minimize the possibilities of plugging by sediment or washouts. Terrace builders must be better able to follow construction plans and handle new installation techniques required to establish a satisfactory system and to reduce the possibilities of component failure. For a given area, the terrace system layout possibilities are many. Special training and field experience are valuable assets in reaching a solution that will give the most functional and economical plan.

Cuts and fills, a variable grade, underwater outlets and water and sediment control basins keep terraces parallel. This is the easiest-to-farm system proposed to date. Farming operations do not always follow the contour in some sections of these terraces. But erosion control should still be effective as long as the affected slope lengths are kept within one terrace spacing. Other areas of the field are protected by water and sediment control basins, which trap the soil and do not let it leave the farm. The terraces use all of the options and much of the technology listed previously. A high priority has been given to ease of farming. Not all landowners would want to consider this system. Proper management of residues is critical if such a design is to succeed.

To order, request G 1500, *Choosing Terrace Systems* (25 cents).

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MU publication G 1503

Operating and Maintaining Grassed Outlet Terrace Systems

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Operating terrace systems properly depends on good farming practices and prompt correction of problems. Terraces should be inspected one or more times each year. Terrace ridge height and shape should be maintained as built. Occasionally, a modification may be required (for example, if you change basic machinery size from 6-row to 8-row).

Erosion and most tillage operations besides plowing tend to fill terrace channels and reduce terrace height. Sediment deposits in the channel reduce the capacity of the channel to carry water off the field. Both effects increase the chances of water flowing over the terrace during heavy rains.

Tillage operations performed over terraces (parallel to a field boundary instead of parallel to the terrace) are especially detrimental to terraces. Tillage tools should not straddle the ridge. The ends of the equipment should operate along the top of the ridge to prevent lowering of the terrace ridge. For information on maintaining grassed waterways, refer to MU publication G01504, *Maintaining Grassed Waterways*.

Conservation tillage and tillage and planting operations that run parallel to the terrace ridge reduce erosion and sediment buildup in terrace channels. Inter-terrace erosion and terrace channel deposits increase as terrace spacing is increased and as terraces deviate from the field's natural contour. Using conservation tillage to reduce erosion becomes even more desirable in such situations. Your goal may be to use a plow only as required for maintaining terrace ridges and not to plow the steeper backslope and the area between the terraces.

Safety

Terrace ridges, especially those with steep backslopes, are potentially hazardous. Perform all farming and maintenance operations with caution and common sense to reduce the chance of injury to the operator and damage to the machine.

Terrace maintenance problems

Common terrace problems include reduced ridge height (which can be local low spots or the entire terrace), decreased channel capacity, sediment bars and ponding of water in the channel. One or more of these problems may cause water from heavy rains to overflow the ridge, causing the terrace system to deteriorate rapidly as ridge height is reduced or gullies cut through the ridge and down to the next terrace. Water overflowing from one terrace frequently causes terraces below to overflow as well.

Ponding may be caused by sediment bars or other channel irregularities. High areas usually must be removed to restore channel grade. Low areas occasionally may require filling. Channel capacity at the discharge into the waterway may be reduced by sediment deposits, tillage operations or crossing the terrace. Changing travel patterns to eliminate crossing terraces may be necessary.

Plowing terrace ridges

Plowing the ridge as part of each tillage/crop sequence normally maintains terrace height and shape if it is done properly. Typically, moldboard plowing with a back furrow at the top of the ridge and leaving a single dead furrow in the terrace channel and at the toe of the backslope maintains proper height and shape. To decrease the furrow depth at the bottom of the backslope or in the channel, make the last trip with the plow with the rear of the plow cutting quite shallowly.

To further increase the channel capacity on neglected terraces, leave a double dead furrow in the terrace channel. This can be done by using a two-way plow to throw all furrows uphill from the ridge top down to the next terrace channel. With a standard one-way plow, a second back furrow between terraces eases the creation of the double dead furrow in the channel. Place the second back furrow parallel to the terrace channel below, leaving the irregular areas on non-parallel terraces below the upper terrace.

Ridge maintenance without plowing

If no-till or conservation tillage is used to reduce the erosion associated with plowing, sediment may have to be removed from terrace channels with earth-moving equipment such as a front-end loader, dozer, blade or scraper. Use any sediment removed to build up low spots on the terrace ridge or in the field.

Additional maintenance for narrow-base and steep backslope terraces

Since the steep slopes of the narrow-base ridges and steep backslope terraces are vegetated and cannot be farmed, additional maintenance may be required.

A vigorous stand of vegetation should be maintained on the steep slopes to help control weeds, trees and brush. This may require periodic fertilizer and herbicide applications. Trap and remove burrowing animals to prevent damage to the terrace ridge.

Maintain the front slope of steep backslope terraces by plowing as you would in building broad-base terraces. You may need to periodically remove sediment accumulation in narrow-base terraces with a front-end loader or scraper.

This guide sheet was written and produced in cooperation with the Natural Resources Conservation Service.

To order, request G 1503, *Operating and Maintaining Grassed Outlet Terrace Systems* (25 cents).

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MU publication G 1504

Maintaining Grassed Waterways

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Grassed waterways are commonly used as an outlet for water from terraces or to prevent gullies, where water flowing down a hillside concentrates. Inspect grassed waterways annually or after unusually large storms. Perform needed maintenance promptly to prevent costly damage to the waterway.

Common maintenance problems with grassed waterways include insufficient grass, weeds and brush, sedimentation, gullies and insufficient capacity.

Insufficient grass

This may be caused by establishment problems, low soil fertility, smothering from lodged growth, accumulated sediment, or competition from weeds, legumes and nearby trees or brush. It may also be caused by not turning off the herbicide sprayer when crossing waterways, from herbicide runoff or from herbicide-laden sediment deposits.

Because of periodic flowing water, it is difficult to re-establish grass in a functioning waterway. Bare spots may be reseeded or sodded. Mulching can help re-establish a grass seeding. Bare spots being reseeded should not be lower than the surrounding channel areas. You may slightly overfill them to divert water while grass becomes established.

Periodic soil tests make a proper soil fertility maintenance program for waterways easier. Waterways can be top-dressed with lime, fertilizer or manure. In extreme cases, a waterway may require a major renovation. In these cases, low fertility may be corrected by moving in topsoil and/or mixing in lime, fertilizer, manure or organic matter to obtain the desired fertility level.

Weeds and brush control

A high fertility program and heavy nitrogen fertilization helps grass compete with weeds and legumes and maintain a vigorous stand. Control trees and brush by cutting and/or with herbicides. Contact your local extension center for recommendations on control herbicides.

To prevent smothering from lodged, accumulated growth, mow and remove hay from the waterway as required to maintain a moderate height. If hay is not desirable, more frequent mowing and/or shredding can prevent smothering without removing the residue.

Delay mowing until after July 15 of each year to avoid destroying wildlife habitats.

Some waterways may not be accessible during the normal cropping/haying season. If necessary, growth may be removed at other seasons. Hay quality may be sacrificed for convenience. Carefully controlled grazing may be permissible when the ground is not too wet or too dry.

Gullies

Gullies may be caused by original construction irregularities, by sediment deposits, by using the waterway as a travelway or by livestock paths. Unstable outlets, which result from a drop-off or an extremely steep slope at the lower end of the waterway, can also cause gullies.

To control unstable outlets, regrade (and reseed) the outlet end or construct a grade stabilization structure. For more details, refer to MU publication G01509, *Types of Stabilization Structures.*

Gullies must be filled and reseeded or sodded. Fill material should be well compacted. Slight overfilling may be desirable to allow for settling and to divert water flow somewhat while the new grass becomes established.

If possible, sediment deposits should be removed before grass is damaged.

Machine travel up and down waterways should be minimal, especially when the area is wet and soft. Machine travel on waterways will be required during haying and other maintenance operations. Waterways except for those located on the field boundary will usually be crossed or used as a turnstrip for normal field machinery operations.

Livestock may have to be fenced out of waterways when they are grazing fields.

After grass is well established, remove temporary dikes (berms) that were built to prevent runoff from entering waterways during the grass establishment period. The objective is to allow runoff to enter the waterway and prevent water from eroding a channel along the side of the waterway. Soil removed from the berms may be used to fill low spots in the field or to build terrace ridges.

Insufficient capacity

Insufficient waterway capacity may result from sediment accumulation in the channel or from loss of side berm height. (Permanent side berms are commonly used to contain the water flow in shallow waterways located on field boundaries or ridges.)

Higher residue tillage systems or more soil-conserving crop rotations can reduce sediment buildup.

Overflow can cause a gully to form along the side of the waterway. Sediment buildup in the waterway can cause water to pond in the lower end of the terrace channel.

In severe cases, sediment must be removed from the channel and the channel must be reseeded. In other cases, the height of the side dikes (for waterways not in natural drainage ways) may be increased and the dikes reseeded.

Spot removal of sediment from the waterway at the terrace discharge may eliminate ponding in the terrace channel with a minimum of waterway reseeding required. In other cases, the lower end of the terrace may be moved downhill to access the waterway at a lower point to obtain adequate terrace channel drainage.

If the waterway has to be rebuilt or reseeded, water from the terraces may have to be diverted outside of the waterway until the grass is established. Small, temporary cross trenches and dikes with a fall of 6 to 12 inches across the waterway that will interrupt the flow of water on long waterways may be useful in establishing grass.

This guide sheet was written and produced in cooperation with the Natural Resources Conservation Service.

To order, request G 1504, *Maintaining Grassed Waterways* (25 cents).

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Design Criteria for Grassed Waterways (abstract only)

Allen Thompson

Department of Agricultural Engineering, University of Missouri-Columbia

Abstract:

This publication describes how to design a grassed waterway for a particular setting. Grassed waterways can be used to dispose of runoff from terraces, diversions, structures and natural water concentrations.

Diagrams, tables and text illustrate how to determine important design factors such as desired shape and width of the waterway, water velocity and waterway capacity.

For further information, refer to MU publications G01506, *Design Criteria for Diversions,* and G01518, *Estimating Peak Rates of Runoff From Small Watersheds.*

Keywords:

dikes, drainage, side dikes, soil erosion, water channels

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MU publication G 1518

Estimating Peak Rates of Runoff from Small Watersheds

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Use the following equation to estimate the peak rates of runoff to be expected from watersheds smaller than 200 acres in Missouri:

$Q = Q_T \times L \times I \times T \times S \times V \times C \times P \times F$ where

Q = Peak rate of runoff, cubic feet per second.
Q_T = Peak rate of runoff from a watershed with a specific set of watershed conditions (see Table 1).
L = Watershed location factor.
I = Soil infiltration factor.
T = Topographic factor.
S = Watershed shape factor.
V = Vegetative cover factor.
C = Contouring factor.
P = Surface storage factor.
F = Runoff frequency factor.

(To preserve its continuity, Table 1 is on the following page.)

Table 1. Peak rates of runoff, in cubic feet per second, to be expected from watersheds in Missouri under the following conditions:

1. **Watersheds located along line 1.00, Figure 1 (see print publication).**
2. **Soils with an average infiltration rate.**
3. **Land slopes average 8 percent.**
4. **A typical watershed shape.**
5. **In row crops, with the crop rows planted across the slope without terraces.**
6. **No appreciable surface storage.**
7. **10-year frequency runoff.**

Size of watershed (acres)	Peak rate of runoff (cu/ft/sec)
5	19
10	36
15	52
20	67
25	81
30	94
35	107
40	120
45	132
50	144
55	155
60	166
65	175
70	185
75	195
80	205
85	215
90	225
95	235
100	245
110	265
120	285
130	304
140	322
150	340
160	356
170	372
180	388
190	404
200	420

Table 1 gives peak rates of runoff to be expected from various sizes of watersheds: (1) located along line 1.00 in Figure 1, with (2) a soil of average infiltration, (3) average land slope of 8 percent, (4) a typical watershed shape, (5) planted to row crops with the crop rows planted across the slope without terraces, (6) with no appreciable surface storage, and (7) in an average 10-year period.

If the watershed for which the peak rate of runoff is being estimated has conditions different from those in Table 1, then multiply the values from Table 1 by the appropriate factor, which can be found in the following information.

Watershed location

Values in Table 1 are for watersheds located along line 1.00, Figure 1. If the watershed is in another location, multiply the value from Table 1 by the appropriate factor obtained from the map in Figure 1.

Soil infiltration

Values in Table 1 are peak rates of runoff to be expected from a soil with an average infiltration rate, such as a Summit silt loam or a Shelby loam. If soil conditions differ from this, multiply the value from Table 1 by an appropriate factor selected from the following:

Soil infiltration rate	**Soil infiltration factor, I**
Very High (coarse textured soils throughout, such as Sarpy sand or Bruno sand)	0.8
Above average (soils with medium to moderately coarse textured surface, well drained as evidenced by bright or nonmottled subsoil colors, such as Marshall or Menfro silt loams)	0.9
Average (soils with medium textured surface and moderately-fine textured subsoils with restricted drainage as evidenced by having gray or mottled subsoil colors, such as Shelby loam or Summit silt loam)	1.0
Below average (soils with medium to moderately fine textured surface with a claypan or fragipan subsoil within 12 inches of the surface, such as Mexico or Lebanon silt loams)	1.1
Very low (soils with fine textured surface or soils eroded into claypan subsoils, such as Wabash clay or severely eroded Mexico silt loam)	1.2

Shape of watershed

The peak rate of runoff will be affected by the maximum distance the runoff must travel in reaching the discharge point. In long, narrow watersheds, the runoff must travel a greater distance than in a compact watershed, hence a lower peak rate of runoff can be expected. If terraces or diversions drain away from the discharge point, the runoff must travel a greater distance and a lower peak rate of runoff can be expected.

Determine the maximum distance the runoff must travel in reaching the discharge point. Find this distance in Table 2 in the number of acres in the watershed and read the corresponding S factor in the right-hand column of the table. Multiply the value from Table 1 by this S factor.

(To preserve its continuity, Table 2 is on the following page.)

Table 2. Determining the maximum distance runoff must travel in reaching the discharge point.

Size of watershed (acres)																
5	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**120**	**140**	**160**	**180**	**200**	**Shape factor,S**
Maximum distance that runoff travels (feet)																
		600	800	1000	1100	1300	1400	1500	1700	1800	1900	2100	2300	2500	2700	1.25
	550	700	900	1100	1200	1400	1600	1700	1800	1900	2100	2400	2600	2900	3100	1.20
	550	800	1000	1200	1400	1600	1800	1900	2000	2200	2400	2700	3000	3300	3500	1.15
400	600	900	1200	1400	1600	1800	2000	2100	2300	2500	2800	3100	3400	3700	3900	1.10
500	700	1000	1400	1600	1800	2100	2300	2500	2700	2900	3200	3600	3800	4100	4300	1.05
600	800	1200	1600	1900	2100	2400	2700	2900	3100	3300	3600	4000	4300	4600	4800	1.00
700	950	1400	1900	2200	2400	2700	3100	3300	3600	3800	4100	4500	4800	5200	5500	0.95
800	1100	1600	2200	2600	2900	3200	3600	3800	4100	4400	4700	5100	5500	5900	6200	0.90
900	1300	1900	2600	3100	3400	3700	4100	4400	4600	5000	5400	5900	6300	6700	7000	0.85
1100	1600	2300	3100	3600	3900	4200	4600	5000	5400	5700	6200	6700	7100	7500	7900	0.80
1300	1900	2800	3600	4200	4600	5000	5400	5800	6200	6600	7100	7600	8000	8400	8800	0.75

Topography

Values in Table 1 are peak rates of runoff to be expected from watersheds with an average land slope of 8 percent. If the average land slope on a watershed differs from this, multiply the value from Table 1 by the following factor:

Average land slope (percent)	Topographic factor (T)
0.5	0.50
1	0.65
2	0.72
3	0.78
4	0.83
5	0.88
6	0.92
7	0.96
8	1.00
9	1.04
10	1.07
12	1.14
14	1.20
16	1.26
18	1.32
20	1.37

Vegetation

Values in Table 1 are peak rates of runoff to be expected from watersheds with the entire watershed in row crops. If different crops are expected on a watershed, multiply the value from Table 1 by the following factor:

Type of cover	Vegetative cover factor (V)
Farmstead	1.2
Row crop	1.0
Small grain, good quality	0.8
Small grain, poor quality	0.9
Pasture, good quality	0.6
Pasture, poor quality	0.8
Meadow, good quality	0.5
Meadow, poor quality	0.7
Timer, good quality	0.5
Timer, poor quality	0.6

If several types of cover are present on a watershed, a weighted vegetation factor should be computed. For example, assume that a 160-acre watershed contains 80 acres of small grain, 40 acres of meadow and 40 acres of timber, all with good quality cover. The weighted vegetation factor would be computed as follows:

80 acres small grain	multiplied by	factor 0.8	equals	64
40 acres meadow	multiplied by	factor 0.5	equals	20
40 acres timber	multiplied by	factor 0.5	equals	20
160				104

104 ÷ 160 = 0.65, the weighted vegetation factor.

Contouring

Values in Table 1 are peak rates of runoff to be expected from watersheds with crop rows planted across the slope without terraces or without contour guide lines.

If the entire watershed is farmed parallel to contour guide lines or terraces, multiply the value in Table 1 by an appropriate factor selected from the following:

Acres in watershed	Contour factor (C)
0-10	0.95
11-40	0.96
41-100	0.97
101-200	0.98

If the entire watershed is not farmed on the contour, make an appropriate adjustment in the contouring factor. For example, if only 20 acres of a 60-acre watershed are farmed on the contour, the contouring factor would be 0.99.

0.97 + [(60-20 ÷ 60) (1.0-0.97)] = 0.99, the weighted contouring factor.

Storage

Any water detained or impounded on the watershed will reduce the peak rate of runoff from the watershed. Values in Table 1 are peak rates of runoff to be expected from a watershed with no appreciable surface storage. If water is impounded on the watershed, multiply the value from Table 1 by an appropriate factor. The storage factor may vary depending on the percent of the watershed that drains into the impoundment, the amount of storage provided and the location of the impoundment on the watershed.

Because of the wide variations in type of impoundments and the many possible locations on the watershed, it is impossible to give specific values for the storage factor that would be applicable for all situations. The following general principles may be helpful in evaluating the storage factor:

1. Impoundments with only an emergency spillway will not reduce the peak rate of runoff an appreciable amount, particularly if they are expected to be full when the design storm occurs.

2. Impoundments with a principal spillway at a lower elevation than the emergency spillway will reduce the peak rate of runoff. The amount of reduction will depend on the percent of the watershed that drains into the impoundment, the rate of flow through the principal spillway, the amount of storage provided between the principal and emergency spillways, and the capacity of the emergency spillway.

3. Impoundments located in the upper part of a watershed give the greatest reduction in the peak rate of runoff; those located in the lower part give the least reduction while impoundments located throughout the watershed will have an intermediate effect.

4. The effect of level terraces on the peak rate of runoff depends on the percent of the watershed terraced and the amount of storage provided.

5. The effectiveness of natural storage such as lakes, swamps and sink holes will depend on their location on the watershed, the percent of the watershed draining into them and the amount of storage available when the design storm occurs.

To obtain the best estimate of the effect of storage on the peak rate of runoff, the design storm should be flood routed through the impoundments. If this is not feasible, the following procedure is suggested:

a. Determine the peak rate of runoff to be expected from the area of the watershed below the impoundments.

b. Determine the expected flow through the spillways of the impounding structures for the frequency of storm being considered.

c. Add the spillway discharge to the discharge to be expected from the area below the impoundments to obtain the total peak rate of runoff.

Storage factor for graded terraces. Water in temporary storage in the channels of graded terraces will reduce the peak rate of runoff from the watershed.

If the entire watershed is terraced, the storage factor P can be selected from the following table:

Storage factor P for graded terraces (average length of terraces, feet)

Acres in watershed	500	1,000	1,600
0-10	0.95	0.90	0.80
11-40	0.97	0.93	0.85
41-100	0.98	0.95	0.90
101-200	0.99	0.97	0.95

If the entire watershed is not terraced, make an appropriate adjustment in the storage factor. For example, if 40 acres of a 50-acre watershed were terraced and the terraces averaged 1,000 feet long, the storage factor would be 0.96.

$0.95 + [(50 - 40 \div 50)(1.0 - 0.95)] = 0.96$

Runoff frequency

Values in Table 1 are the peak rates of runoff to be expected in an average 10-year period. If the peak rate of runoff for a different design frequency is desired, multiply the value from Table 1 by the following factor:

Runoff frequency	Runoff frequency factor (F)
1/2 year	0.2
1 year	0.3
2 year	0.5
5 year	0.8
10 year	1.0
25 year	1.3
50 year	1.5

Combination of several factors

For watersheds that have a number of factors differing from those specified for the watersheds in Table 1, determine the peak rate of runoff by multiplying the value from Table 1 by a succession of factors applicable to the watershed being considered.

For example, estimate the peak rate of runoff to be expected in a 10-year period from a 120-acre watershed located in Andrew County with the following characteristics:

1. A Marshall silt loam soil.
2. Land slopes average 10 percent.
3. The runoff must travel a maximum distance of 4,700 feet in reaching the discharge point.
4. Eighty acres of low cropland in the upper half of the watershed is terraced. The terraces average 1,300 feet in length. The crop rows are planted with the terraces.
5. Forty acres of good quality pasture in the lower half of the watershed are not terraced.
6. There are no impoundments, except terraces, on the watershed.

Condition	Factor
Location, Andrew County	1.03
Marshall silt loam soil	0.9
Land slope, 10 percent	1.07
Maximum distance of water flow, 4,700 feet	0.90
Vegetation, 80 acres row crop (1.0); 40 acres pasture (0.6)	0.87
Contouring	0.99
Storage in gradient terraces	0.97
10-year frequency runoff	1.0

The peak rate of runoff (Qt) for a 120-acre watershed from Table 1 is 285 cubic feet per second.

Substituting in the equation

Q = Qt x L x I x T x S x V x C x P x F

Q = 285 x 1.03 x 0.9 x 1.07 x 0.90 x 0.87 x 0.99 x 0.97 x 1.0
Q = 213 cfs

Compute the peak rate of runoff to be expected from the above watershed in a 25-year period. F = 1.3.

Q = 213 x 1.3 = 277 cfs

This publication was prepared jointly by state and field staffs of the College of Agriculture, University of Missouri, and the Natural Resources Conservation Service. Original MU author was the late R.P. Beasley.

To order, request G 1518, *Estimating Peak Rates of Runoff from Small Watersheds* (50 cents).

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MU publication G 7520

Pesticides and the Environment

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Once a pesticide is introduced into the environment, whether through an application, a disposal or a spill, it is influenced by many processes. These processes determine a pesticide's persistence and movement, if any, and its ultimate fate.

The fate processes can be beneficial. They can move a pesticide to the target area or destroy its potentially harmful residues. Sometimes they can be detrimental, leading to reduced control of a target pest, injury of non-target plants and animals, and environmental damage. Of particular concern today is the movement of pesticides into ground water.

Different soil and climatic factors and different handling practices can promote or prevent each process. An understanding of the fate processes can help every pesticide applicator ensure that applications are not only effective, but are also environmentally safe.

The fate processes

Fate processes fall into three major types: **adsorption** binds pesticides, **transfer** processes move pesticides, and **degradation** processes break them down.

Pesticide adsorption. The adsorption process binds pesticides to soil particles, similar to iron filings or paper clips sticking to a magnet. Adsorption often occurs because of the attraction between a chemical and soil particles. Positively charged pesticide molecules, for example, are attracted to and can bind to negatively charged clay particles.

Many soil factors influence pesticide adsorption. Soils high in organic matter or clay are more adsorptive than coarse, sandy soils, in part because a clay or organic soil has more particle surface area, or more sites onto which pesticides can bind. Moisture also affects adsorption. Wet soils tend to adsorb less pesticide than dry soils because water molecules compete with the pesticide for the binding sites.

Pesticides vary in their adsorption to soil particles. Some pesticides such as paraquat and glyphosate bind very tightly, while others bind only weakly and are readily desorbed or released back into the soil solution.

One problem resulting from pesticide adsorption is reduced pest control. For example, weeds may not be controlled if a herbicide is held tightly to soil particles and cannot be taken up by the roots of the target weeds. Some pesticide labels recommend higher application rates when the chemical is applied to adsorptive soils.

Plant injury can be another problem resulting from adsorption of pesticides to soil particles. Injury can result when a pesticide used for one crop is later released from the soil particles in amounts great enough to cause injury to a sensitive rotational crop. This pesticide "carry over" can also lead to the presence of illegal residues on rotational food or feed crops.

Adsorption is particularly important because it influences whether other processes are able to affect pesticides.

Pesticide transfer. Pesticide transfer is sometimes essential for pest control. For example, for certain pre-emergence herbicides to be effective, they must move within the soil to reach the germinating seeds. Too much movement, however, can move a pesticide away from the target pest. This can lead to reduced pest control, injury of non-target species including humans, and surface water and ground water contamination. Five ways that pesticides can be transferred are through volatilization, runoff, leaching, absorption and crop removal.

Volatilization is the conversion of a solid or liquid into a gas. Once volatilized, a pesticide can move in air currents away from the treated surface. Vapor pressure is an important factor in determining whether a pesticide will volatilize. The higher the vapor pressure, the more volatile the pesticide.

Environmental factors tend to increase volatilization. They include high temperature, low relative humidity and air movement. A pesticide tightly adsorbed to soil particles is less likely to volatilize; soil conditions such as texture, organic matter content, and moisture can thus influence pesticide volatilization.

Reduced control of the target pest may occur due to volatilization because less pesticide remains at the target site. Vapor drift, the movement of pesticide vapors or gases in the atmosphere, can lead to injury of non-target species. Herbicide vapors in particular can injure non-target plants.

To reduce pesticide volatilization, avoid applying volatile pesticides when conditions are unfavorable, such as very hot, dry days or when the soils are wet. Labels often provide warnings if there is a volatility hazard under certain conditions.

Labels of volatile pesticides may suggest adding the pesticide to the soil by tillage or irrigation during or shortly after application. This helps to reduce volatilization by reducing the amount of exposed pesticide on the soil surface. Low-volatile formulations are also available for some pesticides.

Runoff is movement of water over a sloping surface. Runoff occurs when water is applied faster than it can enter the soil. Pesticides can be carried in the water itself or bound to eroding soil particles.

The severity of pesticide runoff depends on the slope or grade of an area; the erodibility, texture and moisture content of the soil; and the amount and timing of rainfall and irrigation. Pesticide runoff usually is greatest when a heavy or sustained rain follows soon after an application. Over-irrigation can lead to excess surface water; it also can lead to pesticide runoff, especially with chemigation.

Vegetation or crop residue tends to slow the movement of runoff water. Certain physical and chemical properties of the pesticide, such as how quickly it is absorbed by plants or how tightly it is bound to plant tissue or soil, are also important.

Herbicide runoff can cause direct injury to non-target plants. Insecticide and nematicide runoff into surface waters such as streams and ponds can be particularly harmful to aquatic organisms. Pesticide runoff also can lead to ground water contamination and can cause injury to crops, livestock or humans if the contaminated water is used downstream.

Practices to reduce pesticide runoff include monitoring weather conditions, careful application of irrigation water, using a spray mix additive to enhance pesticide retention on foliage, and incorporating the pesticide into the soil. Reduced tillage cropping systems and surface grading, in addition to contour planting and strip cropping of untreated vegetation, can slow the movement of runoff water and help keep it out of wells, sinkholes, water bodies and other sensitive areas.

Leaching is the movement of pesticides through the soil rather than over the surface. Leaching depends, in part, on the pesticide's chemical and physical properties. For example, a pesticide held strongly to soil particles by adsorption is less likely to leach. Another factor is solubility. A pesticide that dissolves in water can move with water in the soil. The persistence, or longevity, of a pesticide also influences the likelihood of leaching. A pesticide that is rapidly broken down by a degradation process is less likely to leach because it may remain in the soil only a short time.

Soil factors that influence leaching include texture and organic matter, in part because of their effect on pesticide adsorption. Soil permeability (how readily water moves through the soil) is also important. The more permeable a soil, the greater potential for pesticide leaching. A sandy soil is much more permeable than a clay.

The method and rate of application, the use of tillage systems that modify soil conditions, and the amount and timing of water a treated area receives after application can also influence pesticide leaching. Typically, the closer the time of application to a heavy or sustained rainfall, the greater likelihood some pesticide leaching will occur.

A certain amount of pesticide leaching may be essential for control of a target pest. Too much leaching, however, can lead to reduced pest control, injury of non-target species and ground water contamination.

Monitoring weather conditions and the amount and timing of irrigation can help minimize pesticide leaching. Careful pesticide selection is important because those pesticides that are not readily adsorbed, not rapidly degraded, and highly water soluble are the most likely to leach. Labels must be read carefully for application instructions such as rates, timing and method. The label also may contain statements advising against using the pesticide when certain soil, geologic or climatic conditions are present.

Pesticides can leach through the soil to ground water from storage, mixing, equipment cleaning and disposal areas. Under certain conditions, some pesticides can leach to ground water from normal applications. The section "Pesticides and ground water" provides further discussion on ground water and safe handling practices to prevent contamination.

Absorption or **uptake** is the movement of pesticides into plants and animals. Absorption of pesticides by target and non-target organisms is influenced by environmental conditions and by the chemical and physical properties of the pesticide and the soil. Once absorbed by plants, pesticides may be broken down or they may remain in the plant until tissue decay or harvest.

Crop removal transfers pesticides and their breakdown products from the treatment site. Most harvested food commodities are subjected to washing and processing procedures that remove or degrade much of the remaining pesticide residue. While we typically associate harvesting with food and feed products, it is easy to forget that pesticides potentially can be transferred during such operations as tree and shrub pruning and turfgrass mowing.

Pesticide degradation. Pesticide degradation, or the breakdown of pesticides, usually is beneficial. Pesticide-destroying reactions change most pesticide residues in the environment to non-toxic or harmless compounds. However, degradation is detrimental when a pesticide is destroyed before the target pest has been controlled. Three types of pesticide degradation are microbial, chemical, and photodegradation.

Microbial degradation is the breakdown of pesticides by fungi, bacteria, and other microorganisms that use pesticides as a food source. Most microbial degradation of pesticides occurs in the soil. Soil conditions such as moisture, temperature, aeration, pH, and the amount of organic matter affect the rate of microbial degradation because of their direct influence on microbial growth and activity.

The frequency of pesticide application also is a factor that can influence microbial degradation. Rapid microbial degradation is more likely when the same pesticide is used repeatedly in a field. Repeated applications can actually stimulate the buildup of organisms that are effective in degrading the chemical. As the population of these organisms increases, degradation accelerates and the amount of pesticide available to control the pest is reduced. In extreme cases, accelerated microbial degradation has led to certain products being removed from the marketplace. Microorganisms greatly reduce the effectiveness of these chemicals soon after application.

The possibility of very rapid pesticide breakdown is reduced by using pesticides only when necessary and by avoiding repeated applications of the same chemical. Alternating between different classes, groups or formulations of pesticides can minimize the potential for microbial degradation problems as well as pest resistance.

Chemical degradation is the breakdown of pesticides by processes that do not involve living organisms. Temperature, moisture, pH and adsorption, in addition to the chemical and physical properties of the pesticide, determine which chemical reactions take place and how quickly they occur.

One of the most common pesticide degradation reactions is hydrolysis, a breakdown process in which the pesticide reacts with water. Many organophosphate and carbamate insecticides are particularly susceptible to hydrolysis under alkaline conditions. Some are actually broken down within a matter of hours when mixed with alkaline water.

Product labels may warn against mixing a pesticide with certain fertilizers, other pesticides or water with specific characteristics. Following these precautions can help prevent pesticide degradation and potential incompatibility problems. In some situations, buffers or other additives may be available to modify spray mix conditions and prevent or reduce degradation. Pesticide degradation and possible corrosion of application equipment can be avoided by not allowing a spray mix to remain in a tank for a long period of time.

Photodegradation is the breakdown of pesticides by light, particularly sunlight. Photodegradation can destroy pesticides on foliage, on the surface of the soil, and even in the air.

Factors that influence pesticide photodegradation include the intensity of the sunlight, properties of the application site, the application method and the properties of the pesticide. Pesticide losses from photodegradation can be reduced by adding the pesticide to the soil during or immediately after application.

Pesticides and ground water

More than one third of Missouri's population, including about 95 percent of the state's rural population, relies on ground water as a source of drinking water. Ground water is subject to contamination from many sources, including industrial and municipal waste, leaking underground fuel storage tanks, road salts, agricultural fertilizers and pesticides.

The ground water system. Ground water is water that lies below the soil surface and fills the pore spaces in and around rock, gravel sand and other materials. Contrary to popular belief, ground water does not move through vast underground rivers and lakes, but through water-saturated zones called aquifers.

The upper level of an aquifer is called the water table. The water table level fluctuates throughout the year, lowering as water is removed from wells or discharged at streams and springs. The water table rises through recharge from rain and melting snow that seeps through soil into the aquifer.

For years it was believed that the natural filtering of water during its slow movement through the soil, sand, gravel and rock formations was adequate to cleanse it of contaminants before it reached ground water. Today, many chemicals, including some pesticides, have been detected in ground water. Studies have shown that recharge can carry pollutants down to aquifers. Furthermore, it seems clear that human activities can lead to contamination of the recharge water.

Not all ground water is similarly vulnerable to contamination by pesticides. The deeper the water table is below the soil surface, the less likely that pollutants will reach ground water. A deep aquifer provides more opportunities and time than does a shallow aquifer for pesticide adsorption, degradation and other processes to occur.

The permeability of the geologic layers between the soil surface and the ground water is also important. If the materials above the water table are very coarse, such as sand or gravel or highly fractured rocks, water can move to ground water more readily than if less permeable layers of clay or solid rock are present.

Bedrock such as limestone can make ground water particularly prone to contamination, because it dissolves easily to form channels and depressions in the land surface. The depressions, called sinkholes, can provide a direct connection between the soil surface and the ground water below. Contaminated water that drains into a sinkhole can readily enter ground water, because the soil that lines the bottom of a sinkhole is often thin and provides little filtering of pollutants that enter.

Wells. A well is a direct conduit from the land surface to ground water. The method of well construction, the frequency of well inspection, maintenance, and the proximity of a well to a pesticide source are important factors determining the potential for contamination.

Pesticides can reach ground water by moving along the outside of the well casing or by entering an improperly capped or sealed well. Well casing forms the well's wall. A cement compound of grout is forced into the space between the bore hole and the outside of the well casing to prevent water and contaminants from moving down along the outside of the casing into ground water. Gravel, sand and other permeable materials are not adequate. The top of the casing is capped about 8 inches above the ground or at least high enough to prevent surface water from entering the top of the well.

Potential sources of contamination include storage, mixing, loading, disposal, and equipment cleaning areas and application sites. Wells should be safe from both surface and subsurface contamination from such sources. Soil can be graded, or diversion terraces or ditches can be built upslope to intercept or divert surface runoff from the well head. Monitoring the area around a well can ensure that changes in land use do not increase the risk of contamination. Situating a well at least 10 feet from a building makes it accessible for maintenance and inspection.

Improperly closed or abandoned wells can contribute to ground water contamination. The procedures for proper well closing can depend on site condition, but wells should be filled in such a way as to prevent water movement within the drill hole.

Protecting ground water

It is very difficult to clean ground water once it has become contaminated. Treatment is complicated, time-consuming, expensive, and often not feasible. The best solution to ground water contamination is to prevent it in the first place. The following pest management and pesticide handling practices can reduce the potential for contamination.

Practice Integrated Pest Management. Pesticide application should be timed carefully and combined with other pest management practices. Pests should be identified accurately and pesticide applications made only when necessary, using the least amount needed for adequate pest control. Minimizing pesticide use cuts expenses and reduces potential for environmental problems.

Select pesticides carefully. Those pesticides that are not adsorbed to soil particles, are highly water soluble, and are relatively stable, have the greatest potential to leach through the soil. Read pesticide labels carefully for information and restrictions about the rate, timing, and placement of the pesticide in that container. These factors affect the potential for leaching. Also note any ground water advisories or other water protection guidelines on the label.

Consider the vulnerability of the area. Determine how susceptible soil is to leaching. Soil texture, organic matter content, and permeability affect pesticide movement. Determine as accurately as possible the water table depth and the relative permeability of the geologic layers between the soil surface and the ground water. Sinkholes can be especially troublesome because they allow surface water to quickly reach ground water with little natural soil filtering.

Consider the location and condition of wells. Wells should be properly capped and sealed to prevent ground water contamination. Grade the area around a well head to keep runoff away from the well. Pesticides spilled near wells can move directly and rapidly into ground water. Some recommendations advise against mixing, storing, or disposing of pesticides within 100 feet of a well. Properly close all abandoned wells, and never dispose of wastes in unused wells.

Measure accurately. Carefully calculate how much pesticide concentrate is needed to treat the specific site with the equipment being used. Careful calculations can not only save money by reducing the amount of pesticide used, but can help eliminate disposal problems associated with excess spray mix.

Calibrate accurately. Calibrate equipment carefully and often to be certain the proper amount of pesticide will be applied. Check the equipment for leaks and malfunctions to minimize the potential for accidents or spills.

Mix and load carefully. Handle pesticides carefully to avoid spills. Mix and load pesticides on a concrete surface to avoid saturating the soil. Fill the spray tank as far from the water source as possible. Increase the length of the water hose or fill the tank in the field using an alternative water source. Never leave a spray unit unattended when filling.

Prevent back-siphoning. To prevent pesticides from back-siphoning into the water supply, keep the end of the fill hose above the water level in the spray tank. Use an anti-backflow device (check valve) on the fill hose, especially when siphoning water directly from a pond or stream. Proper well construction includes check-valves to prevent back-siphoning; check-valves can be added to an existing system.

Consider weather and irrigation. If you suspect heavy or sustained rain, delay the pesticide application. Runoff and leaching are favored by rainfall soon after application. The quality of irrigation water should be carefully controlled to minimize the potential for pesticide leaching and runoff.

Store pesticides safely. Minimize your pesticide inventory by buying only what is needed for a season or a specific spray job. The storage area should be away from all water sources. A concrete floor sealed with an impervious material eases cleanup in case of a spill or leak. Inspect containers regularly for leaks and corrosion. Bulk pesticide storage tanks should be inspected frequently and placed on concrete pads with dikes built around them to prevent the movement of pesticides if there is a spill or leak.

Dispose of wastes carefully. Follow all label instructions and restrictions when disposing of pesticides. Triple rinse or pressure rinse containers as soon as they are emptied and pour the rinsate into the spray tank. Excess spray mix and rinsates from equipment cleaning can be sprayed on another site or crop listed on the label. A source of water at the application site makes it easier to rinse equipment and to spray rinsates in the field. Where practical, excess spray mix or rinsates can be held in a tank for use in later spray mix.

Never dispose of pesticides or pesticide containers near a water source, over shallow water tables, in sinkholes or in abandoned wells. Excess pesticide concentrates can be given to another qualified user, safely stored until there is a hazardous waste collection day, or disposed of through a hazardous waste transporter.

Prevent spills. If a spill does occur, it should be contained and cleaned up immediately. Repeated pesticide spills in the same area can exceed the capacity of the soil to adsorb or degrade the chemical and can increase the likelihood of ground water contamination.

Leave buffer zones around sensitive areas. When mixing, applying, storing or disposing (including cleanup) of pesticides, be aware of ground water-sensitive areas. These include springs, streams, ponds, wetlands and other surface waters; wells and ground water recharge areas; and sinkholes. Establishing vegetation or leaving an untreated border are two ways to provide a buffer zone between sensitive areas and pesticide use or handling sites.

The fate of a pesticide and the likelihood of a pesticide moving into ground water are affected by the pesticide's chemical and physical properties, soil and geologic characteristics, climatic conditions, and pesticide handling practices. Each factor must be considered when determining the susceptibility of ground water to pesticide contamination.

Missouri aquifers currently provide a vast supply of water for use in agriculture, homes and industry. They can remain a source of high-quality ground water for future needs only if they are protected now. Be sure to understand how your activities, including your handling and use of pesticides, may affect them. Seek assistance if you have questions or problems.

Checklist for protecting water from pesticides

- Does your storage facility have a concrete floor?
- Do you clean your pesticide application equipment in a way that makes it easier to collect rinsates?
- Does your water hose have a check-valve to prevent back-siphoning?
- Have you graded the area around your well to divert surface runoff?
- Are there abandoned wells near a pesticide handling or application site that are not properly closed?
- Are there dikes around your bulk tanks to prevent off-site movement of pesticides?
- Do you know if the pesticides you use have a potential for leaching?
- Do you delay pesticide applications if rain is forecast?
- Do you always check pesticide labels to learn irrigation practices, rates and application methods?
- Do you leave a border of untreated vegetation between treated and sensitive areas?
- Do you know about the geology and the relative depth of the ground water in your area?

- Do you use pesticides only when necessary and then at the lowest rate needed to control a pest?

The materials in this publication are used with permission from Pennsylvania State University and were originally published in their Extension Agrichemical Fact Sheet Number 8, The Fate of Pesticides In The Environment and Groundwater Protection, *originally prepared by C.L. Brown, project associate and W.K. Hock, professor of plant pathology and pesticides coordinator, Pesticide Education Program.*

To order, request G 7520, *Pesticides and the Environment* (75 cents).

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Appendix B
Additional Information Sources

MU publication DM 464 – *Town Meetings That Work: A Guide to Organizing the Process.*

MU publication G 7512 – *Pesticides: Emergency Planning and Community Right to Know*

MU publication DM 490 – *Working With Resource People*

MU publication CM 304 – *Publicizing the Event*

MU publication G I0016 – *Setting an Organization's Direction and Performing the Entrepreneurial Function – A Checklist for Action.*

MU publication G 1915 – *First Aid for Pesticide Poisoning*

MU publication G 1919 – *Drift of Agricultural Sprays: Causes*

MU publication WM 6001 – *Safe Use, Storage and Disposal of Pesticides*

MU publication G 350 – *Conservation Tillage: Cost and Returns*

MU publication G 355 – *No-Tillage and Reduced-Tillage: Costs and Returns*

MU publication G 4099 – *Analyzing Cropping Systems*

MU publication G 7510 – *Pesticide Dilution Table*

MU publication RP 98 – *Corn Pest Management for the Midwest*

MU publication M 91 – *Demonstration and Research Pest Control*

MU publication M 95 – *General Structural Pest Control: Manual 95*

MU publication MX 328 – *Applying Pesticides Correctly: Missouri Core Manual*

The Worker Protection Standard for Agricultural Pesticides – United States Environmental Protection Agency – EPA 735-B-93-001, July 1993

BMPs for Water Quality – Reducing Herbicide Runoff: Role of Best Management Practices, Conservation Technology Information Center, West Lafayette, Ind. (317) 494-9555

Publications can be ordered from:

Extension Publications
University of Missouri
2800 Maguire Blvd.
Columbia, MO 65211

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