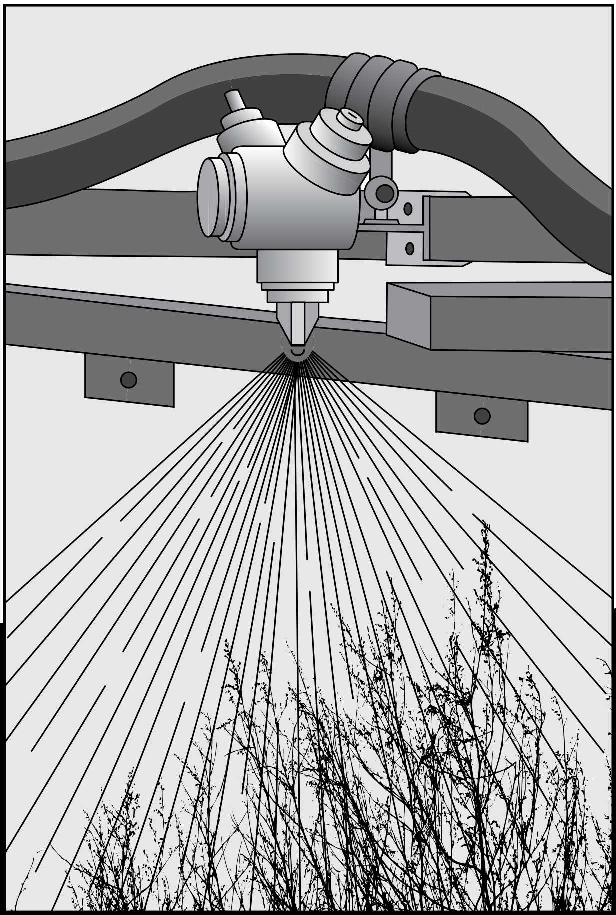
Best Management Practices for Agricultural Pesticide Use to Protect Water Quality



Colorado State University

Extension

Best Management Practices for Agricultural Pesticide Use to Protect Water Quality

February 2010
Bulletin #XCM-177

Principal authors:
Troy Bauder, Water Quality Specialist
Colorado State University Extension
Reagan Waskom, Director
Colorado Water Institute
Robert Pearson, Former Research Associate

In association with:
Colorado Department of Agriculture
Agricultural Chemicals and Groundwater Protection Advisory Committee

The authors and the Colorado Department of Agriculture gratefully acknowledge the extensive input and leadership of the Agricultural Chemical and Groundwater Protection Advisory Committee, representing production agriculture, agricultural chemical dealers and applicators, the green industry, and the general public.

With cooperation from:
USDA Natural Resources Conservation Service, Colorado State Office
Colorado State University, Department of Soil and Crop Sciences
Colorado Department of Public Health and Environment

BMP Technical Review:
Sandra McDonald, Pesticide Education Safety Specialist
Jim Sharkoff, Natural Resources Conservation Service
Robert P. Wawrzynski, Colorado Department of Agriculture

Layout and Design by:
Colorado State University Communications and Creative Services

Published by Colorado State University Extension in cooperation with Colorado Department of Agriculture.

Table of Contents

Best Management Practices for Agricultural Pesticide Use to Protect Water Quality

Pesticides are widely used to protect crops and livestock from losses due to insects, weeds, and diseases. Colorado uses about 1 percent of the 900 million pounds of conventional pesticide applied annually in the United States. The Environmental Protection Agency (EPA) has estimated that 76 percent of the total pesticide use nationally is for agricultural production, with the remaining 24 percent used in the urban, industrial, forest, and public sectors. These chemicals have helped to increase agricultural production with reduced labor, tillage and other inputs. However, problems associated with improper pesticide use have led to human illness, wildlife losses, and water quality degradation.

The major groups of pesticides include insecticides, herbicides, and fungicides. Because herbicides are the most widely used class of agricultural and urban use pesticides, they are the pesticides most frequently found in ground and surface water. The ability to detect pesticides in the environment has greatly improved in recent years. The development of extremely sensitive detection methods has led to the discovery that commonly used management practices may lead to small amounts of pesticides that contaminate ground and surface water supplies. Since we depend on these water supplies for drinking water, pesticide users need to exercise a high level of care and sound pesticide use management to avoid contamination.

This guide addresses Best Management Practices (BMPs) for preventing nonpoint source contamination of water resources by agricultural pesticides. Contamination from normal pesticide application is typically considered nonpoint contamination, since a single point of contamination cannot be identified. Point source contamination would include spills of concentrated chemicals during transportation, or at storage, mixing, or loading sites. These point source problems are addressed in the document *BMPs for Pesticide and Fertilizer Storage and Handling* (Bulletin #XCM-178).

Since pesticides are an important tool for most farming operations, and cleaning up contaminated groundwater is extremely difficult, producers need to evaluate their use of pesticides and adopt BMPs that are appropriate for their crops and site. Fortunately, a number of crop management and pesticide application practices can be used to reduce potential contamination of water supplies.

Government Regulations and Policy

The federal government has enacted several laws to control pollution of water resources. Among these are the Safe Drinking Water Act; the Clean Water Act; the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA); and the Food Quality Protection Act (FQPA). All pesticides are regulated through FIFRA, and producers should understand that the chemical label is, in effect, the law. In most cases, the precautions on the chemical label are adequate to protect water resources from contamination above a regulatory standard. However, it is possible for a pesticide to reach ground or surface water resources even when used according to the label instructions. Chemicals that have a higher potential to move to groundwater

Table 1. Commonly used pesticides with Groundwater Advisory Statements

Trade name	Common name
Propylene dichloride	1,2-Dichloropropane
Weed B Gone	2,4-D, dimethylamine salt
Lasso	Alachlor
Temik	Aldicarb
Aatrex	Atrazine
Quadris	Azoxystrobin
Hyvar	Bromacil
Furadan	Carbofuran
Dacthal	DCPA
Casoron	Dichlobenil
Imidacloprid 4F	Imidacloprid
Benzeneacetic acid	Kreosoxim-methyl
Kilprop	MCPP, DMA salt
Dual	Metolachlor
Sencor	Metribuzin
Solicam	Norflurazon
Vydate C-LV	Oxamyl
Tordon	Picloram, potassium salt
Princep	Simazine
Confirm 2F	Tebufenozide
Sinbar	Terbacil
Platinum	Thiamethoxam
Bayleton 50	Triadimefon

are identified on the label by a “Groundwater Advisory Statement.” This statement is usually located in the precautionary statements on the label. Producers should take special care when using these chemicals on sites with conditions that increase the chance of leaching or runoff (Table 1).

Rather than impose overly restrictive measures on farmers and related industries, Colorado has elected to encourage the voluntary adoption of BMPs that suit the agricultural chemical user’s specific managerial constraints while still meeting environmental quality goals. Voluntary adoption of the appropriate measures by agricultural chemical users will help maintain the quality of water resources, improve public perception of the industry, and perhaps reduce the need for further regulation and mandatory controls.

Groundwater Monitoring

In 1990, the Colorado legislature passed Senate Bill 90-126, which introduced Colorado’s Agricultural Chemicals and Groundwater Protection Act. This Act declares that the public policy of Colorado is to protect groundwater and the environment from impairment or degradation caused by improper use of agricultural chemicals, while allowing for their proper and correct use. The Act also requires the Colorado Department of Agriculture (CDA) to conduct a statewide groundwater monitoring program and aquifer vulnerability analyses. Since 1992, the CDA has been working in cooperation with the Colorado Department of Public Health and Environment (CDPHE) and Colorado State University Extension to implement the Agricultural Chemicals and Groundwater Protection Program (GW Program). The Program acquires groundwater samples from monitoring, irrigation, and domestic wells throughout the state. These samples are analyzed for a suite of over 100 active ingredients from pesticides registered in Colorado. All well samples are also analyzed for nitrate-nitrogen and other inorganic constituents.

Pesticide and nitrate analysis results from the groundwater monitoring program are available on the Agricultural Chemicals and Groundwater Protection Program Water Quality Database, found at http://ids-nile.engr.colostate.edu/webkit/Groundwater/. The database can quickly and easily be queried based on any number of criteria, including county, region, conservancy district, well use, water quality parameters (e.g., nitrate, pesticide, etc.) and year. It also includes a statewide summary of sampling results. The web site features an interactive map of Colorado that displays statewide sampling results for tested water quality parameters. The map below (Figure 1) shows the general location of all wells sampled in the state from 1992 to 2008 by the GW Program.

Pesticide analysis results for monitoring conducted from 1992 to 2008 indicate that the highest numbers of wells with pesticide detections are located in the South Platte River Basin. A total of 225 wells have been monitored in the South Platte River Basin, of which 56 percent are located in Weld County. Of the 125 wells in Weld County, 94 percent have tested positive for pesticide at some point in time. Other areas of the state with a significant number of pesticide detections included the Front Range, Arkansas Valley, and San Luis Valley, with 20 percent, 11 percent, and 11 percent of wells, respectively. The most frequently detected pesticides were atrazine and its breakdown products, prometon, and metolachlor. The EPA has established primary drinking water standards or health advisory levels for a number of pesticides. Primary drinking water standards are referred to as maximum contaminant levels (MCLs) and represent the highest amount of a contaminant allowed in public water systems. Only six of the wells that tested positive for a pesticide exceeded an established human health drinking water standard.

These results seem to be promising, given the small number of pesticide detections that exceeded an established health standard or advisory level. However, the existence of any amount of pesticide in groundwater may be an indication of future problems. Continuation of

Example Groundwater Advisory Label

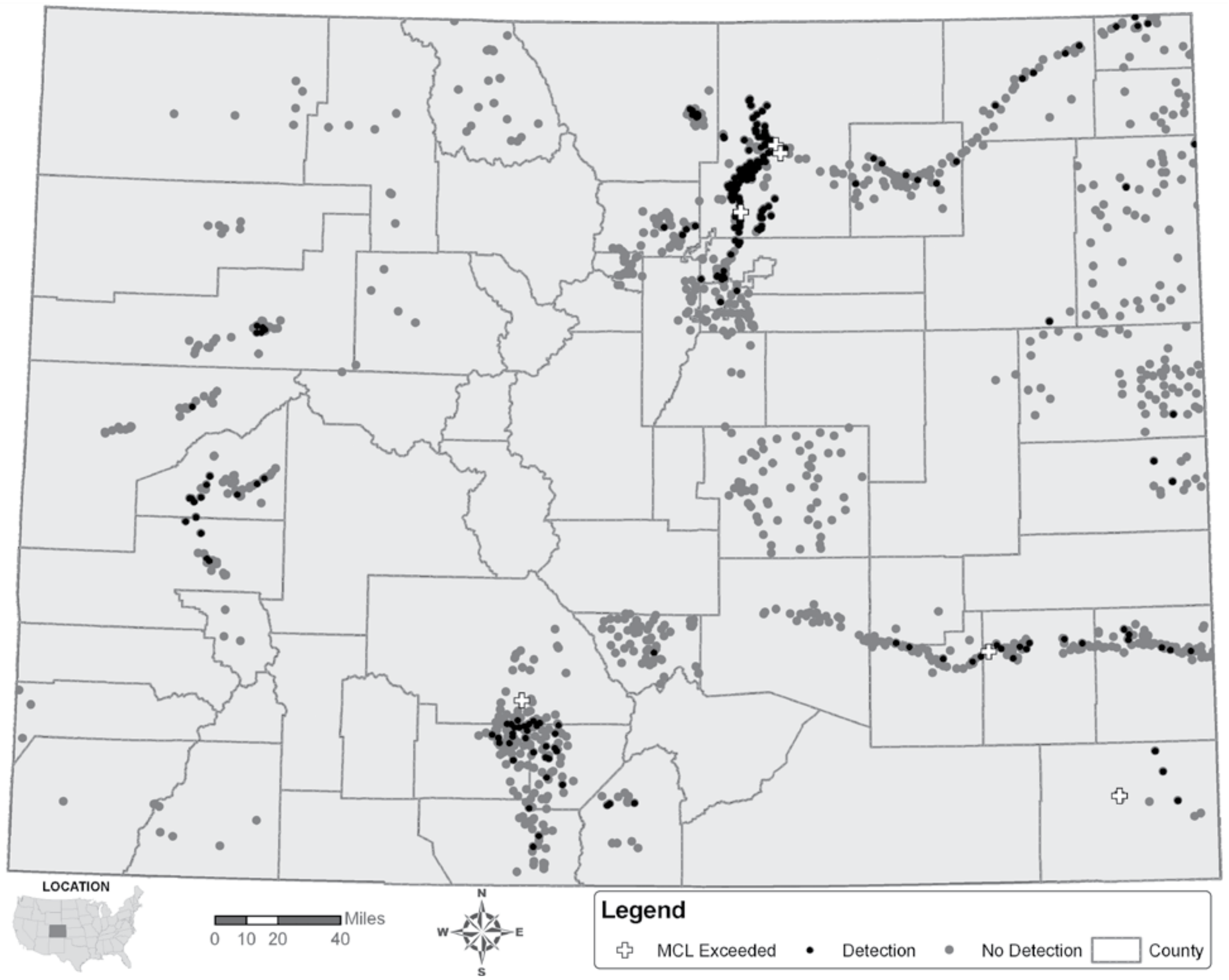
Environmental Hazards

The active ingredient in this product can be persistent for several months or longer and has properties similar to chemicals which are known to leach through soil to ground water under certain conditions as a result of agricultural use. Use of this chemical in areas where soils are permeable, particularly where the water table is shallow, may result in groundwater contamination.

This pesticide is toxic to freshwater and estuarine/marine fish and aquatic invertebrates.

Do not apply directly to water except as specified on this label. For terrestrial uses, do not apply directly to water, or to areas where surface water is present or to intertidal areas below the mean high water mark. Drift and runoff may be hazardous to aquatic organisms in neighboring areas. Do not contaminate water when disposing of equipment washwater or rinsate.

Figure 1. Colorado wells sampled by the Agricultural Chemicals and Groundwater Protection Program from 1992 to 2007.



groundwater sampling and testing by the Program will help to identify present and future problem areas of the state so that stakeholders can focus their educational and management activities in regions where it is most needed.

Pesticide Fate in the Environment

Pesticides meet a variety of fates after application. They may evaporate, be broken down by sunlight, or be carried away to surface water before reaching their targets. After reaching the soil, they may be taken up by plants, adsorbed to soil particles, broken down by soil microorganisms, or, in some cases, be moved off-target to water resources (Figure 2). The fate of pesticides in the environment depends upon a number of factors, including:

- site characteristics
- pesticide properties
- pesticide use practices

Site Features

Soil Features

Soil properties and water management can significantly affect pesticide movement in the environment. The most significant soil properties influencing pesticide behavior are:

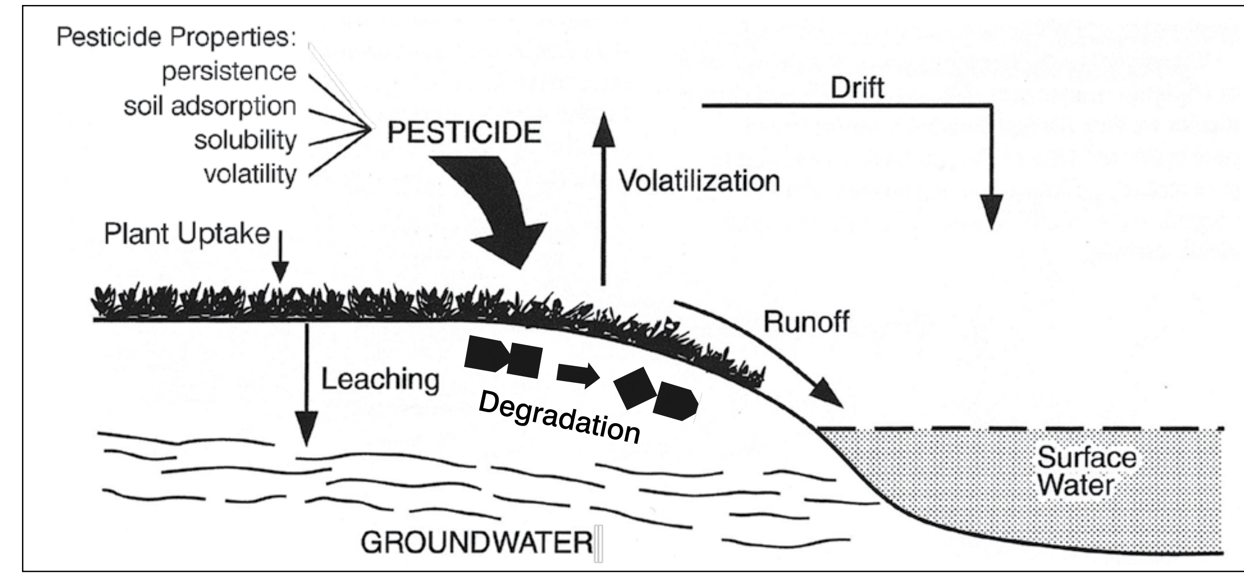


Figure 2. Factors influencing pesticide transport and its impact on water quality.

- organic matter content
- texture
- structure and macropores
- moisture content
- pH

Soil organic matter (SOM) content is an important soil property affecting pesticide adsorption. Adsorption refers to the adherence of a compound in the soil due to opposite charged particles attracting one another. Pesticides can be held in soil onto organic matter or clay particles by the process of adsorption. Pesticides are strongly attracted to the surface of organic matter and are less likely to leach in soils that are high in organic matter. Applicators working on soils with less than 1 percent organic matter should be aware of the possibility of pesticide leaching.

Soil texture refers to the proportion of sand, silt, and clay particles in the soil. Texture affects the surface charge and the surface area for pesticide adsorption. Soils with higher clay content have a greater ability to adsorb pesticides, but they are more susceptible to runoff and need to be managed accordingly. Sandy soils leach more readily and provide fewer sites for pesticide adsorption. Soils with a high sand content

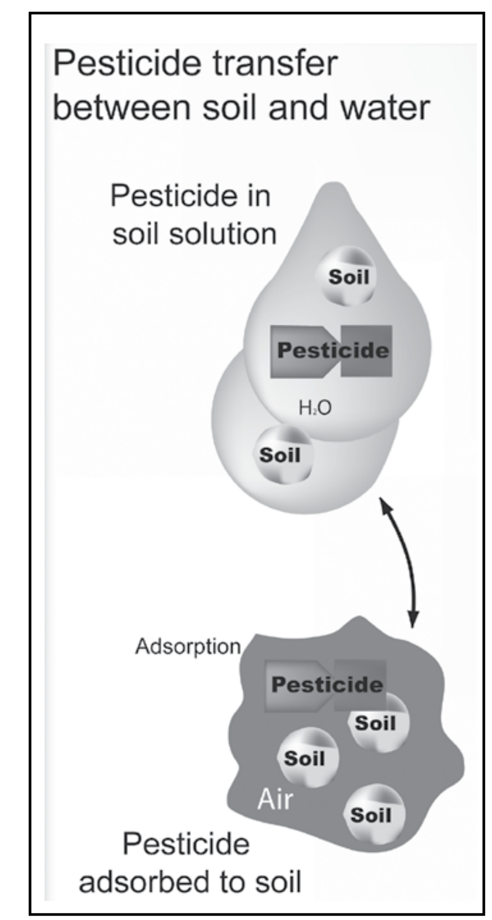


Figure 3. Pesticides will exist in the soil water solution, in soil air, or adsorbed onto soil particles.

should be managed carefully, with minimal use of persistent or very mobile pesticides.

Soil structure – the way soil particles are aggregated – significantly affects water movement and may allow pesticides to move through the profile before they can be adsorbed or degraded. Large soil cracks or openings (macropores) caused by heaving, roots, or soil animals can cause rapid pesticide movement, even in fine-textured soils with high organic matter. Soils characterized by high numbers of macropores are poor candidates for chemigation because the chemical can move rapidly downward below the root zone.

Unfortunately, these soil factors are difficult, if not impossible, for a producer to change. However, specific soil features can alert producers to the likelihood of pesticide runoff or potential leaching at their sites.

One of the most significant factors affecting runoff or leaching is the soil moisture condition at the time of pesticide application. In the semi-arid climate of Colorado, producers often can manage pesticide application and irrigation to avoid conditions leading to pesticide loss. Pesticides with medium or high mobility should not be applied to a saturated soil or just prior to a heavy irrigation. Alternative pest management strategies should be considered when the soil moisture status increases the probability of runoff or leaching.

In addition to soil properties, other features of the application site can affect the potential for pesticide movement. The site characteristics of greatest concern include:

- depth to groundwater
- proximity to surface water
- topography
- aquifer and overburden characteristics
- climate and irrigation

Distance to water is one of the most important site features to consider when evaluating pest management decisions. When the water table is close to the soil surface (less than 30 feet), contamination of groundwater is much more likely than when groundwater resources are deep. Surface water proximity should also

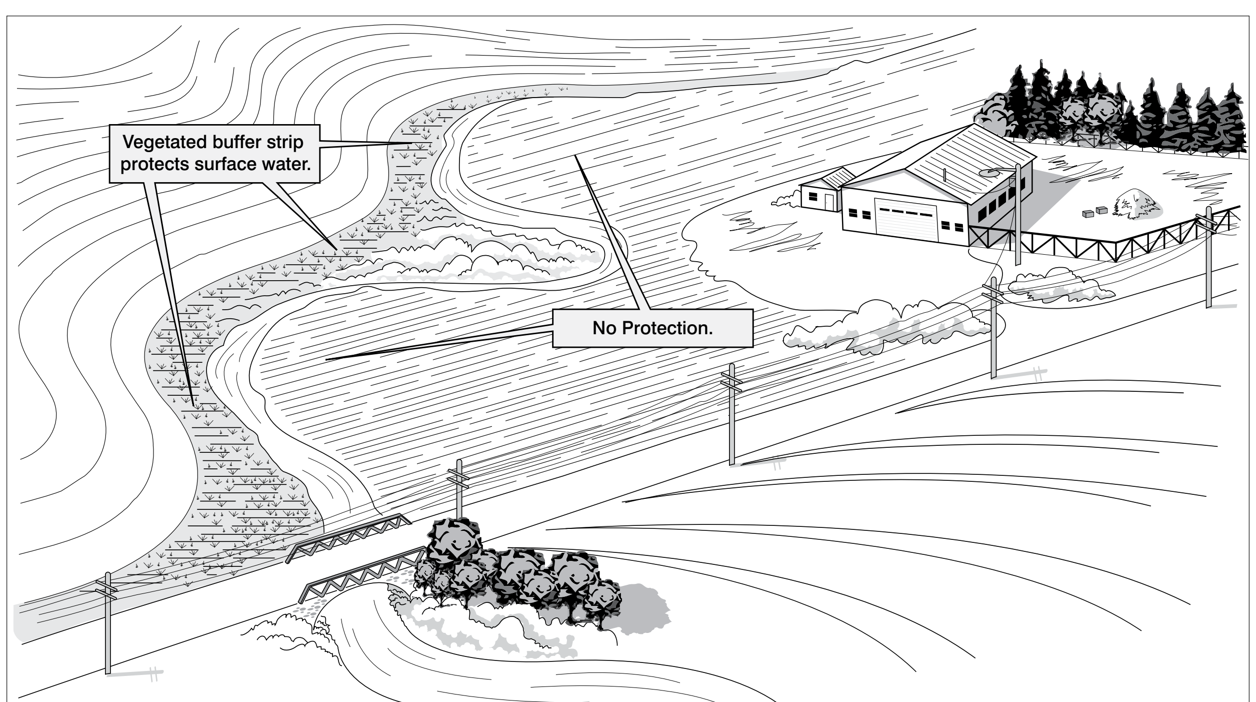


Figure 4. Pesticide application buffer zone to protect surface water.

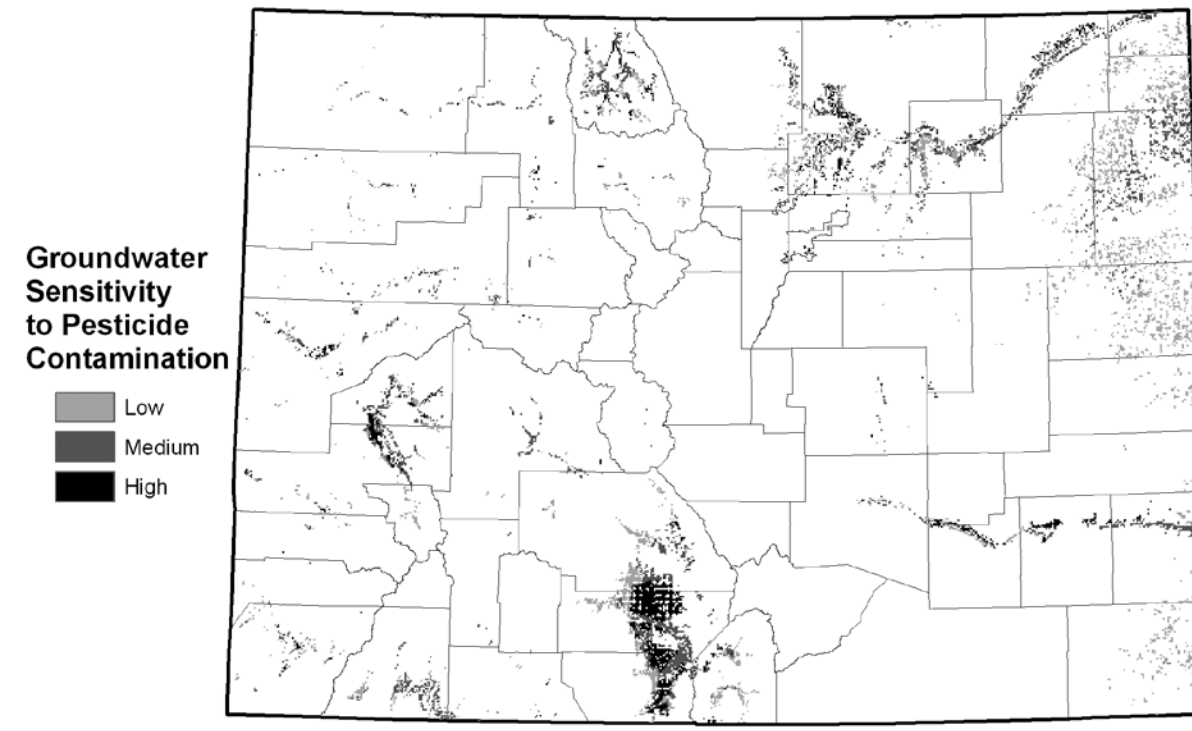


Figure 5. Relative sensitivity of Colorado groundwater to pesticide contamination.

be considered prior to pesticide application. Observe a setback buffer zone between the application site and wells, streams, ponds and lakes (Figure 4). Do not apply pesticides in these zones. The actual setback required will depend on the slope, the mobility of the chemical, and the likelihood of runoff. For sensitive areas directly adjacent to surface water bodies, contact your local USDA Natural Resources Conservation Service (NRCS) office for information regarding buffer strips.

As shown in Figure 5, groundwater sensitivity to pesticide contamination varies greatly across Colorado due to depth to water table, permeability of materials overlying aquifers, and availability of recharge for transport of contaminants (irrigation). The mapped areas are predominately agricultural, where the bulk of pesticides are used in an irrigated setting. Pesticide applicators should exercise caution when mixing and/or applying pesticides in areas mapped as highly sensitive to pesticide leaching. However, because field scale properties can vary, this map should be used only as a starting point for further consideration. In highly sensitive areas, applicators should read and follow all label restrictions and advisories, particularly for those with groundwater advisory statements (See Table 1 for a list of pesticides with groundwater advisory statements).

The permeability of subsurface layers affects the rate of groundwater recharge and subsequent contamination if any pesticide is carried in percolating water. Regions with highly permeable materials, such as those found over alluvial aquifers in Colorado, are particularly susceptible to contamination. These vulnerable areas merit careful pesticide selection and application methods, especially where irrigation may result in excess water for leaching.

Determining Pesticide Loss Potential

Pesticide applicators should evaluate all soil, site, and pesticide properties to determine the relative hazard to water resources that pesticide

Table 2. Factors Influencing Pesticide Leaching Potential

Soil characteristics	Numeric guidelines*
sandy soil	
low organic matter	less than 1% SOM
numerous macropores	
Pesticide properties	
long half-life	greater than 21 days
low adsorptivity	Koc less than 300-500
high solubility	greater than 30 ppm
Site features	
shallow groundwater	less than 30 feet deep
permeable overburden	
excess irrigation water	

* These numeric guidelines are only indicators that a hazard may exist.

Actual leaching depends on the interaction of site and management factors.

applications may pose. Table 2 lists factors that applicators should consider so that they can select pest management measures that are least likely to impact groundwater or surface water.

Pesticide Leaching and Runoff

For sites that are vulnerable to leaching, exercise caution when considering pesticides that are poorly adsorbed or that have long persistence in the environment. When possible, select chemicals with low toxicity, short half-lives, and high adsorption. This information is usually available from your chemical dealer, Extension agent, or crop adviser. Several computer models have been developed to predict pesticide movement and to help applicators select the most appropriate pest management strategy.

A Windows based pesticide-screening tool (WIN-PST) is available through the USDA Natural Resources Conservation Service (NRCS). WIN-PST utilizes pesticide properties and Soil Survey Geographic (SSURGO) Database information to evaluate potential pesticide leaching below the crop root zone and pesticide movement with water and eroded soil off fields. WIN-PST also considers the impact of depth to water table, larger soil pores (macropores), rainfall probability, pesticide application area, method and rate, and effects on non-target organisms. This program is available for download at www.wsi.nrcs.usda.gov/products/W2Q/pest/winpst31.html, and SSURGO soils information is available through the NRCS Soil Data Mart link found at http://soils.usda.gov/. WIN-PST assistance is also available through your local NRCS Field Office.

Runoff

Pesticides have routinely been found in surface waters receiving agricultural runoff, particularly after heavy spring rainfall or surface irrigation. This suggests that the management of pesticides should focus on good practices at the time of application. Additionally, land management practices, such as reduced tillage, strip tillage, and no-till, are important for protecting surface water quality. Grass filter strips and waterways should be established on fields that drain directly to streams and lakes. Contact local NRCS personnel for buffer strip design criteria to protect surface water from pesticide runoff (Figure 4).

Conservation tillage practices that increase the amount of crop residues on the soil surface can reduce runoff volume and velocity, which results in less erosion and less pesticide movement. Strongly adsorbed chemicals, such as paraquat, tend to adhere tightly to soil particles and will move on eroding sediments. Reduced tillage systems are highly recommended on all erosive soils. However, in some cases increased macro porosity and infiltration, coupled with

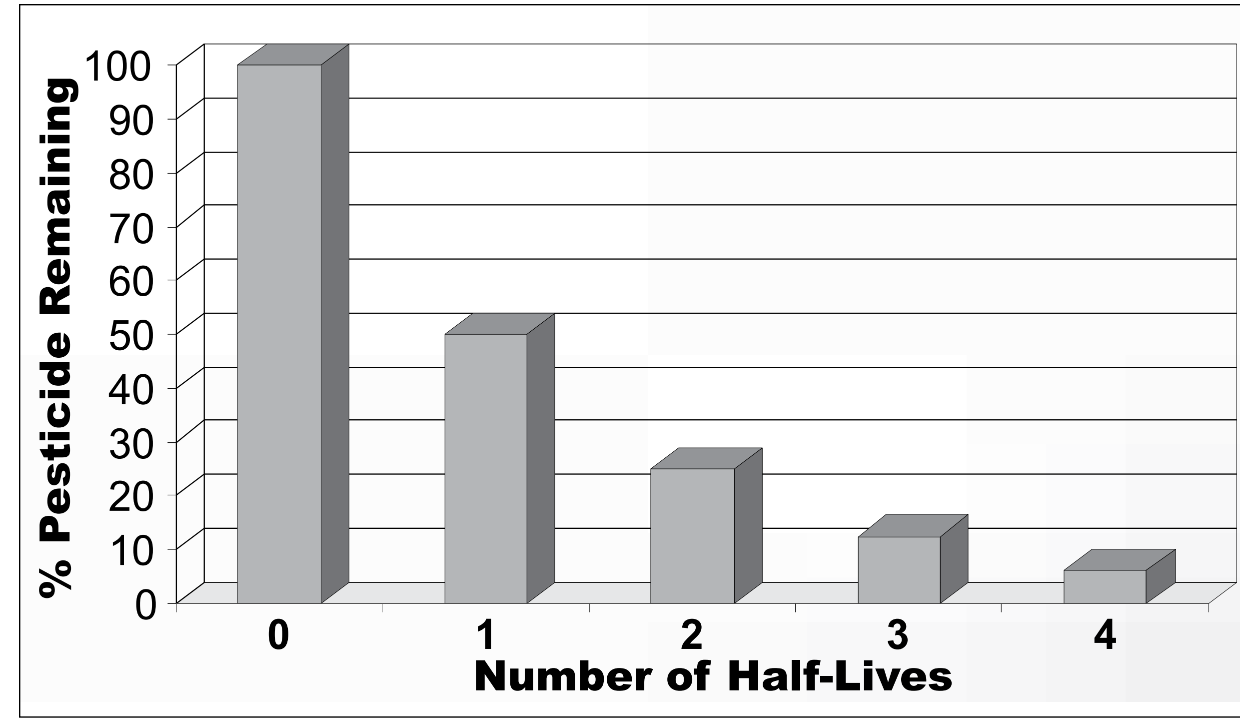


Figure 6. Half-life chart depicting conceptual pesticide degradation.

increased herbicide use, may favor pesticide leaching. Where groundwater is shallow and domestic wells are nearby, these trade-offs should be assessed.

Pesticide Properties

Chemical properties of a pesticide cannot be changed by applicators, but they should be considered in order to select the most appropriate product when chemical control is necessary. Table 3 lists pesticide properties such as solubility, half-life, and soil adsorptivity. Values for these properties are of special interest because they influence the likelihood of off-target effects.

The degradation rate of a pesticide, measured as the half-life, indicates how long the chemical persists in the environment. Persistence is significant, because the longer a chemical remains in the environment the greater the probability the chemical will move to off-target locations (like ground surface and ground water) or injure non-target organisms.

The major pathways of pesticide degradation are microbial breakdown, photolysis (breakdown by sunlight), and hydrolysis (chemical breakdown). These pathways are influenced by the chemical structure of the pesticide compound, as well as by soil temperature, pH, moisture, and microbial populations. Soil microbes, including bacteria, fungi, and actinomycetes, are the major degradation pathway for most pesticides. Because microbes tend to be most active in the upper portions of the root zone, once a pesticide moves below this level it may be stable long enough to reach groundwater.

Adsorptivity is a measure of how strongly a pesticide is attracted to the negative charges on soil particles. Strongly adsorbed pesticides are less likely to leach, especially on soils with high organic matter or high clay content. However, they may be more prone to end up in surface water if soil erosion occurs because of wind or water. Adsorptivity is usually expressed as the Kd or Koc of the compound. The higher the

Table 3. Pesticide properties, risk ratings and groundwater advisory identifications. Source: NRCS Pesticide Database, 2009.

Key:	
PLP = Pesticide Leaching Potential	H = High
PSRP = Pesticide Soluble Runoff Potential	I = Intermediate
PARP = Pesticide Adsorbed Runoff Potential	L = Low
	VL = Very Low

Trade Name	Active Ingredient Name	Ground Water Advisory	Solubility mg/L	Soil Adsoption	Soil Half Life	PLP	PSRP	PARP
			(mg/L)	(Koc mL/g)	days			
Propylene dichloride	1,2-Dichloropropane	X	2700	50	700	H	H	I
Weed B Gone	2,4-D	X	796000	20	10	I	I	L
Harness	Acetochlor		223	150	14	I	I	L
Lasso	Alachlor	X	240	170	15	I	I	L
Temik	Aldicarb	X	6000	30	30	H	I	L
Milestone	Aminopyralid		212	13	26	H	I	L
Aatrex	Atrazine	X	33	100	60	H	H	I
Quadris	Azoxystrobin	X	6.7	1590	65	L	H	H
Bifenthrin	Bifenthrin		0.1	24000	26	VL	L	I
Hyvar	Bromacil	X	700	32	60	H	H	I
Buctril	Bromoxynil		0.08	192	8	L	L	I
Sevin	Carbaryl		120	300	10	L	I	L
Furadan	Carbofuran	X	351	22	50	H	H	I
Bravo	Chlorothalonil		0.6	1380	30	L	I	I
Lorsban	Chlorpyrifos		0.4	6070	30	L	L	I
Telar	Chlorsulfuron		7000	40	160	H	H	I
Curtail	Clopyralid		300000	6	40	H	H	L
Ro-Neet	Cycloate		95	430	30	I	H	L
Dacthal*	DCPA	X	0.5	5000	100	L		H
Dazzel	Diazinon		60	1000	40	L	H	H
Banvel	Dicamba		400000	2	14	H	I	L
Casoron	Dichlobenil	X	21.2	400	60	I	H	I
Dimethoate	Dimethoate		39800	20	7	I	I	L
Acrobat WP	Dimethomorph		19	428	92	I	H	I
Disyston	Disulfoton		25	600	30	I	H	L
Dynex	Diuron		42	480	90	I	H	I
Endosol	Endosulfan		0.32	12400	50	VL	I	H
Eptam	EPTC		344	200	6	L	I	L
Asana	Esfenvalerate		0.002	5300	35	L	I	I
Sonalan	Ethalfluralin		0.3	4000	60	L	I	H
Roundup	Glyphosate		900000	24000	47	VL	H	H
Velpar	Hexazinone		33000	54	90	H	H	I
Assert	Imazamethabenz-methyl		1113.5	51	35	H	I	L
Plateau	Imazapic	X	2150	137	232	H	H	I
Arsenal	Imazapyr		11000	100	90	H	H	I
Pursuit	Imazethapyr		200000	10	90	H	H	I
Imidacloprid 4F	Imidacloprid	X	580	440	127	H	H	I
Benzeneacetic acid	Kreosoxim-methyl	X	2	100	4	L	I	L
Karate	Lambda-Cyhalothrin		0.005	180000	30	VL	L	I
Lindane	Lindane		7	1100	400	I	H	H
Linex	Linuron		75	400	60	I	H	I
Malathion	Malathion		130	1800	1	L	L	L
Manzate 200	Mancozeb		6	2000	70	L	H	H
Manzate	Maneb		6	2000	70	L	H	H
MCPA Amine	MCPA		825	110	25	I	I	L
Kilprop	MCPP, DMA salt	X	660000	20	21	H	I	L
Ridomil	Metalaxyl		8400	50	70	H	H	I
Dual	Metolachlor	X	530	200	90	H	H	I
Sencor	Metribuzin	X	1220	60	40	H	H	L
Ally	Metsulfuron-methyl		9500	35	120	H	H	I
Solicam	Norflurazon	X	28	600	90	I	H	I
Vydate C-LV	Oxamyl	X	282000	25	4	L	I	L
Gramoxone	Paraquat		620000	1000000	1000	VL	L	H
Methyl Parathion	Parathion		24	5000	14	L	I	I
Prowl	Pendimethalin		0.275	5000	90	L	I	H
Permethrin	Permethrin		0.006	100000	30	VL	L	I
Tordon	Picloram	X	200000	16	90	H	H	I
Primatol	Prometon		720	150	500	H	H	I
Comite	Propargite		0.5	4000	56	L	I	H
Pyridate	Pyridate		1.5	190	6	L	I	L
Princep	Simazine	X	6.2	130	60	H	H	I
Confirm 2F	Tebufenozide	X	0.83	389	348	H	I	I
Sinbar	Terbacil	X	710	55	120	H	H	I
Platinum	Thiamethoxam	X	4100	245	111	H	H	I
Bayleton 50	Triadimefon	X	71.5	300	26	I	H	L
Amber	Triasulfuron		800	60	60	H	H	I
Garlon 3A	Triclopyr	X	435	27	155	H	H	I
Treflan	Trifluralin		0.3	8000	60	L	I	H

For more information, including a complete list of pesticides, contact your local NRCS office or visit http://www.wsi.nrcs.usda.gov/products/W2Q/pest/winpest31.html.

* Groundwater advisory for Dacthal is based upon possible leaching of a breakdown product.

number, the more strongly adsorbed the pesticide will be.

Solubility, usually expressed in parts per million (ppm), describes the tendency of a pesticide to dissolve in water. While solubility may influence the amount of a chemical carried in macropore flow, it is generally not as significant as the adsorptivity of a chemical in predicting chemical movement through soil.

Volatility is the rate at which a chemical evaporates when in contact with air. Volatile pesticides can vaporize and move by vapor drift. Pesticides can injure non-target organisms and impact surface waters when they vaporize and move off-target.

Pesticide properties only indicate the probability of leaching or runoff; soil, site, and management factors must also be considered. Even if pesticide properties indicate very little environmental risk, they may still end up in water supplies if other factors favor movement. However, in most cases good management will keep water contamination to a minimum. Pesticide information and application risk criteria can also be acquired from http://www.pw.ucr.edu.

Pesticide Use Practices

Although pesticide use is a standard practice in most agricultural operations, most producers are adopting an Integrated Pest Management (IPM) approach. IPM combines chemical control with Prevention, Avoidance, Monitoring and Suppression (PAMS) activities to form a comprehensive program for managing pests. This approach emphasizes preventive measures to maintain pests below the economic threshold while using the minimum amount of pesticide necessary.

Prevention is the practice of keeping a pest population from infesting a field or site and includes such tactics as using pest-free seeds and transplants, preventing weeds from reproducing, irrigation scheduling to avoid situations conducive to disease development, cleaning tillage and harvesting equipment between fields or operations, using field sanitation procedures, and eliminating alternate hosts or sites for insect pests and disease organisms.

Avoidance may be appropriate when pest populations exist in a field or site, but a cultural practice avoids pest impact to the crop. Examples include crop rotation, choosing cultivars with genetic resistance to pests, using trap crops or pheromone traps, choosing cultivars with maturity dates that may allow harvest before pest populations develop, and not planting areas of fields where pest populations are likely to cause crop failure.

Monitoring and identification of pests should be performed as the basis for suppression activities. Monitoring can include surveys or scouting programs, trapping, or weather monitoring and soil testing where appropriate. Records should be kept of pest incidence and distribution to help determine the most appropriate crop rotation, economic thresholds, and suppressive action. Proper pest identification and using the correct pesticide at the time of maximum pest susceptibility is foundational to an effective IPM program.

Suppression of pest populations becomes necessary to avoid economic loss if monitoring indicates that prevention and avoidance tactics are not successful. Suppression activities include cultural, physical, biological and chemical controls.

Changing your pest management strategy to an IPM program may involve modifying tillage, fertility, cropping sequence, and sanitation practices. This may require some experimentation and perhaps even professional advice. Additional information, practical guidelines and tools for using IPM are available in the High Plains IPM Guide (http://highplainsipm.org) and at the Western IPM Network (http://www.wrpmc.ucdavis.edu/).

Pesticide Application Practices

When pesticides are required to control pests, it is important to use application techniques that minimize potential water quality impacts. All commercial applicators should be certified through the Colorado Department of Agriculture (CDA) and remain current in new pest management techniques and developments. Certification through CDA is required for all commercial applicators and for distribution and application of Restricted Use Pesticide (RUP) products. Information about CDA's Pesticide Applicator Program is available at: http://www.colorado.gov/cs/Satellite/Agriculture-Main/CDAG/1167928159784.

A separate licensing category exists for private applicators who apply an RUP. Any person who uses or supervises the use of an RUP on property owned or leased by the applicator or the applicator's employer must be a licensed private applicator. A licensed private applicator may apply RUP's for another producer for agricultural commodity production only if the compensation is limited to the trading of personal services between the applicator and the other producer. Certification for private applicators is conducted by CDA.

Pesticides should be applied at a time when they will be most effective against the crop pest. Pest cycles are influenced by temperature and moisture conditions. In many cases, pests under dormant or stressed conditions may not be susceptible to pesticide treatments. Lower pesticide rates reduce the total amount of chemicals in the environment; therefore, apply the lowest labeled pesticide rate that adequately controls pests. Rotate pesticides among chemical families to minimize pest resistance. IPM does not rely on continuous use of a single pesticide or pesticide family (Table 4). Avoid pesticide applications during adverse weather, especially windy and wet conditions. Do not apply volatile chemicals such as 2,4-D ester or methyl parathion under high temperature conditions.

The application method used to apply pesticides can influence leaching or runoff potential. Soil injection or incorporation makes the pesticide more available for leaching, but less likely to cause surface water contamination. In general, pre-plant and pre-emergence treatments on clean tilled soil are more subject to surface loss than post-emergence treatments, when crop cover reduces runoff. Foliar insecticide and post-emergence herbicide treatments may reduce the potential for chemical movement because of rapid absorption by plants. Additionally, many of the foliar or post-emergence chemicals are less persistent and can sometimes be used effectively at lower rates.

Banding herbicides over the crop row is a BMP that can significantly reduce chemical costs while maintaining yields. Many producers are using a 10- to 15-inch band, reducing total herbicide use by 50 percent or more. Banding may require an extra cultivation and slightly more management, but it does not involve sophisticated equipment or a large investment. Existing application and tillage equipment usually can be modified. Spot pesticide treatments in the pest-affected areas of a field can also control pests to within economic levels with much less chemical than broadcast applications. The reduced amount of pesticide used under band and spot applications can result in higher returns and less pesticide for potential leaching or runoff.

Precision Farming Technology

Precision farming systems include information, technology, and decision support. In pest management, information can include the collection and mapping of pest populations in fields. Mapping of pests can be done manually or using technology such as a global positioning system (GPS) and geographic information

Table 4. Herbicide Families and Selected Herbicides*

Family	Common name	Trade name(s)
Amino acid synthesis inhibitors:		
Imidazolinones	Imazamethabenz	Assert
	Imazapyr	Arsenal
	Imazethapyr	Pursuit
	Imazamox	Raptor
Sulfonylureas	Chlorsulfuron	Glean
	Metsulfuron	Ally, Escort
	Prosulfuron	Peak
	Thifensulfuron+Tribenuron	Harmony Extra
	Triasulfuron	Amber
	Tribenuron	Express
Amino Acid Derivatives	Glyphosate	Roundup Ultra
Cell Membrane Disruptors:		
Bipyridyliums	Paraquat	Gramoxone, Cyclone
	Diquat	Reglone
Growth Regulators:		
Phenoxy-acetic Acids	2,4-D	2,4-D Amine
	MCPA	MCPA Amine
Benzoic Acid	Dicamba	Banvel
Pyridines	Clopyralid	Stinger, Curtail
	Picloram	Tordon
Lipid Synthesis Inhibitors:		
Aryloxyphenoxypropionate	Diclofop	Hoelon
	Fluazifop	Fusilade
	Fenoxaprop	Acclaim
	Quizalofop	Assure II
Cyclohexanedione	Sethoxydim	Poast
	Clethodim	Select
Photosynthetic Inhibitors:		
Triazine	Atrazine	Aatrex
	Simazine	Princep
	Ametryn	Evik
	Prometon	Pramitol
Triazinone	Metribuzin	Sencor
	Hexazinone	Velpar
Uracil	Terbacil	Sinbar
	Bromacil	Hyvar
Phenylurea	Linuron	Lorox, Linex
	Diuron	Karmex, Diurex
	Tebuthiuron	Spike
Benzothiadiazole	Bentazon	Basagran
Benzonitriles	Bromoxynil	Buctril, Bronate, Bison, Moxy
Phenyl-pyridazine	Pryidate	Tough
Seedling Growth Inhibitors:		
Shoot Inhibitors (Carbamothioates)		
	Triallate	Buckle, Far-Go
	Butylate	Sutan+ 6.7 E
	Cycloate	Ro-Neet
	EPTC	Eradicane, Eptam
Shoot and Root Inhibitors (Acetamide)		
	Alachlor	Lasso
	S-metolachlor	Dual
	Propachlor	Ramrod
	Acetochlor	Harness, Surpass
Microtubule Assembly Inhibitors (Dinitroanilines)		
	Trifluralin	Treflan
	Ethalfluralin	Sonalan
	Pendimethalin	Prowl

* Chemicals within the same family have similar modes of action and should be rotated to avoid weed resistance. Information about herbicide families is available at: http://www.hracqlobal.com

systems (GIS) software. These maps, combined with known economic threshold levels for each crop, can be used to determine where spraying is necessary. A tractor equipped with the software, corresponding map, and a GPS unit can then be used to selectively spray the field. This requires that the GIS map, the GPS unit, and the tractor's sprayer unit all be connected so the boom will turn on and off as needed. A primary benefit of using GPS/GIS technology includes application maps for record keeping.

Lightbar navigation and/or auto-steer are another form of precision farming technology that can be used when applying pesticides. The lightbar consists of a row of LEDs (light-emitting diodes), a GPS receiver, and a microprocessor. This technology helps guide the applicator and reduces application overlap, overspray, and application costs.

Application Technology

Advances in pesticide application technology reduce pesticide use and increase application efficiencies. Precision farming technology enables accurate pesticide applications using GPS-controlled navigation. Modern electronics has improved application accuracy with electronic flow meters, pressure gauges, speed sensors, and system computers. Application rate efficiencies are also improved with advanced boom flotation, nozzle design, sprayer electronics and controls, and computer control with GPS and GIS.

Advances in Nozzles

Advances in nozzle design allow pesticide applicators to choose nozzles that match their needs. Application rate improvements are influenced by increases in plant coverage and more effective crop canopy penetration and pesticide adherence to plant surfaces. Air induction (inclusion) nozzles increase spray droplet size by mixing air into the spray solution, which lowers drift potential. When these droplets strike the spray target they release energy stored in bubbles, spreading out the droplet onto the target surface. This increases application efficiency and effectiveness. Angled nozzles enable under-canopy pesticide applications, making targeted applications effective. Advances in broadcast nozzle designs provide more uniform coverage with a broad range of operating pressures. Also, spray droplet size and spray patterns can now be adjusted from the cab to match application types and environmental conditions.

Modern materials used in boom construction allow for lighter-weight equipment with greater strength and flexibility. Boom suspension controls allow the operator to adjust boom float to match field conditions, which isolates the boom from the sprayer and allows flotation. This improves application efficiency by providing a more even application.

Chemical Mixing

Chemical mixing for spray applications has been a source of operator chemical exposure. Modern equipment designs offer chemical induction systems to enable liquid and dry chemical to be loaded into the system via a separate chemical tank as opposed to traditional tank mixing procedures. This enhances operator safety by improving chemical handling procedures, and it decreases carryover from improper cleaning of mixing tanks when changing rates or products.

Advances in sprayer technologies have improved pesticide application efficiencies and effectiveness, reduced operator exposure to chemicals, and reduced over applications of product. Operator safety should be paramount in any IPM program; advances in equipment design and functionality facilitate operator safety.

Broadcast Sprayer Calibration Formula

Gallons per acre = Gallons/nozzle/minute x 12 x 43560/nozzle spacing x speed (in feet per second)

Gallons/nozzle = Ounces collected in 1 minute from 1 nozzle/minute/128

Nozzle spacing = Distance in inches between nozzles on spray boom

Speed = mph x 88

Calibration and Equipment Maintenance

Effective pesticide use requires uniform application of the correct amount of chemical and carrier. Under-application usually results in poor control, which may require retreatment. Over-application of pesticide is illegal, seldom increases control and may result in crop damage and needless environmental risk.

Calibrate spray equipment prior to each application season and maintain all equipment according to the manufacturer's recommendation. Monitor rate accuracy throughout the year and check calibration as needed. Check hoses, booms, tanks, and nozzles regularly for uneven wear and leaks or drips.

Information on proper calibration of field sprayers is available from a number of sources. Check with your local chemical dealer, crop consultant, or Extension agent for help calibrating your equipment properly. Also, the following links will direct you to equipment calibration and maintenance web sites:

Equipment calibration:

http://wsprod.colostate.edu/cwis435/WQ/pestrecordbook.htm

Equipment cleaning/maintenance:

http://www.ianrpubs.unl.edu/epublic/pages/publicationD.jsp?publicationId=865

Recordkeeping

Keeping accurate records of all agricultural chemicals applied on your site will help you make informed management decisions. By law, records of all restricted use pesticides (RUP) must be maintained by operators for at least three years in Colorado (see http://www.ams.usda.gov/Science/prb/prbfacts.htm). You can maintain records of non-restricted chemicals on the same form as the required records with minimal additional effort. This information has further value for use with crop and pest modeling programs and economic analyses. Records must be kept for all RUP applications and must include:

- brand or product name
- EPA registration number
- total quantity of pesticide applied
- application date
- location of restricted use pesticide applications (not farm address)
- crop commodity, stored product, or site treated
- size of treatment area
- name of the certified private applicator performing and/or supervising the application
- certification number of the private applicator

Other useful information to record includes:

- weather data and irrigation water applied
- description of pest problems
- application rate of chemical and carrier
- equipment calibration data

Colorado State University Extension and several other organizations have developed record-keeping forms for restricted use pesticides. Computer software is also commercially available to help producers and applicators maintain high-quality records. Please visit http://wsprod.colostate.edu/cwis435/WQ/pestrecordbook.htm for pesticide record-keeping forms and spreadsheets.

Summary

Pesticides are currently an important component of most agricultural pest management strategies. The IPM approach can help producers minimize water quality impacts and manage pests economically. A number of BMPs are effective in reducing pesticide runoff and leaching. Additional benefits of these BMPs include reduction of soil erosion and nutrient losses.

Selection of least toxic chemical controls should be coupled with knowledge of site and chemical interactions. Sites with vulnerable water resources require selection of pesticides least likely to move off-target, or alternative pest management measures. Proper management of soils, water, and pesticides by agricultural producers can help reduce adverse water quality impacts.

Note: The pesticide label always supersedes any educational material such as this publication. Always read and follow label instructions precisely. Data presented in this publication on commercial products are for educational purposes only. Reference to commercial products does not imply endorsement, nor is criticism implied of products not mentioned.

Best Management Practices for Agricultural Pesticide Use to Protect Water Quality

General BMPs

1. Obtain thorough training and the appropriate certification prior to applying any pesticide.
2. Always follow pesticide label directions and read all instructions, particularly precautionary statements, prior to chemical mixing and application. All pesticide applications must follow label specifications and must be applied only to the crops for which the product is registered for use.
3. Keep accurate and timely pest and pesticide records. See Pesticide Recordkeeping Form for suggested format (Page 22).
4. Consider the effects of pest control measures on the environment and non-target organisms. Minimize chemical reliance by rotating crops and using physical, biological, or cultural pest management controls whenever feasible.
5. Follow refuge requirements for biotech cultivars to avoid resistance development in target pests.

Pesticide Selection BMPS

6. Avoid the overuse of preventive pesticide treatments. Base pesticide application decisions on site-specific pest scouting and indicators of economic return.
7. Select least toxic and less persistent pesticides when feasible.
8. Avoid overuse of herbicides with common modes of action (Table 4). Chemicals within the same family have similar modes of action and should be rotated to avoid weed resistance particularly with herbicide tolerant cultivars.
9. Consider pesticide and target site characteristics to determine suitability of the pesticide at that location. Knowledge of pesticide persistence, mobility, and adsorption should be included in pesticide selection (Table 3). Chemical applicators should know the characteristics of the application site, including soil texture, organic matter, topography, and proximity to ground and surface water. Contact your local NRCS office for further information about the soils on your site and possible pesticide interactions.

Pesticide Application BMPs

10. Maintain application equipment in good working condition and calibrate equipment frequently to ensure that pesticides are applied at recommended rates. Replace all worn components of pesticide application equipment, especially nozzles, prior to application.
11. Ensure that the pesticide applicator knows the exact field location to be treated. Post warning signs around fields that have been treated, in accordance with local, state, and federal laws. Follow the established re-entry interval as stated on the pesticide label.
12. Employ application techniques that increase efficiency and allow the lowest effective labeled application rate. Use band and spot applications of pesticides where appropriate to reduce environmental hazards and treatment costs.

13. Avoid unnecessary and poorly timed application of pesticides. Optimize pesticide rate, timing, and placement to avoid the need for re-treatment.
14. Avoid overspray and chemical drift, especially when surface water is in close proximity to treatment area. Avoid applications if wind speed favors drift beyond the intended application area. Increasing nozzle size and/or lowering boom pressure will increase droplet size and help reduce drift. Always recalibrate following equipment adjustments or modifications.
15. Time pesticide application in relation to soil moisture, anticipated weather conditions, and irrigation schedules to achieve the greatest efficiency and reduce the potential for off-site transport. Avoid pesticide application when soil moisture status or scheduled irrigation increases the possibility of runoff or deep percolation. After application, manage irrigation to reduce the possibility of erosion, runoff and/or leaching, which may transport pesticide from the target site.
16. Establish buffer zones so pesticide is not applied within 50-100 feet of wells and surface water.
17. Apply pesticides in a manner that will minimize off-target effects.
18. Avoid repetitive use of the same pesticide or pesticides of similar chemistry and modes of action to reduce the potential for pesticide resistance development and shifts in the pest spectrum.
19. Ensure that backflow prevention devices are installed and operating properly on irrigation systems used for applying pesticides.
20. Use GPS/GIS technology, where appropriate, to aid in pest mapping, pesticide application precision and record keeping.

Pesticide Safety BMPs

21. Read and follow label safety directions, maintain appropriate Material Safety Data Sheets (MSDS), and become certified prior to applying restricted use pesticides.
22. Wear the appropriate protective equipment specified on the pesticide label to minimize unnecessary exposure to pesticide. Be sure to clean protective gear after each day's use.
23. Provide emergency hand and eye wash facilities for personnel working in chemical storage, mixing, and treatment areas. Develop a safety plan that includes information about poison centers and emergency treatment centers. Post emergency response phone numbers in highly visible places near areas where chemical handling occurs.
24. Know what to do in case of accidental pesticide poisoning. Have an emergency response kit available when handling pesticides. Check the product label for instructions and call the nearest poison center in the event a pesticide is swallowed or when pesticide exposure has occurred. Product labels often include a telephone number where expert information is also available. Take the pesticide label to the attending physician if you need treatment.
25. Follow all Worker Protection Standard (WPS) requirements and postings as specified by the

label under "Directions for Use or Agricultural Use Requirements," which includes requirements for personal protective equipment, restricted entry and posting.

26. Program emergency response numbers into your cell phone when involved with pesticide handling.

Rocky Mountain Poison and Drug Center

Denver, Colorado

303-629-1123

1-800-222-1222

www.rmpdc.org

For more information about pesticide management or specific inquiries about BMPs, contact Colorado State University Extension or visit www.csuwater.info. CSU publications, programs, and specialists are available to help you answer questions about water quality.

Related source material from Colorado State University Extension

Fact Sheet 5.003, Sprayer Calibration Fundamentals

Fact Sheet 5.021, Agricultural Protective Equipment

XCM-178, Best Management Practices for Pesticides and Fertilizer Storage and Handling

XCM-176, Best Management Practices for Crop Pests

XCM-202, Pesticide Record Book for Private Applicators

Colorado Pesticide Information Retrieval System
http://state.ceris.purdue.edu/doc/co/stateco.html

CEPEP Fact Sheet: The Pesticide Label
http://www.cepep.colostate.edu/

CEPEP Fact Sheet: Understanding the Material Safety Data Sheet
http://www.cepep.colostate.edu/

Colorado Department of Agriculture
http://www.colorado.gov/ag
303-239-4179

Glossary

Adsorption – The process by which atoms, molecules, or ions are taken up from the soil solution or soil atmosphere and retained on the surfaces of solids through chemical or physical binding. Defined by an adsorptivity constant called Koc.

Backflow – Flow in the reverse direction of normal or desired flow.

Buffer zone – An area set aside from chemical applications and designed to hold influx of substances due to wind and water erosion by physical and chemical detainment.

Calibration – The process of adjusting equipment to deliver the desired amount of a substance when application occurs.

Chemigation – The application of pesticide through an irrigation system.

Conservation tillage – A tillage system that uses specially designed equipment to retain crop residue on the soil surface to lower erosion potential and aid in water conservation.

Fungicide – A chemical product or biological organism used to kill or inhibit fungi or fungal spores.

Half-life – Length of time it takes for the quantity of a substance to decay to half its original mass.

Herbicide – A chemical product designed to kill unwanted plants.

Insecticide – A chemical product designed to kill unwanted insects.

Leaching – Movement of a chemical downward through the soil.

Macropores – Large soils pores formed by cracks, root holes, worm channels or other physical or biological mechanisms that can be responsible for rapid infiltration and percolation of water and dissolved chemicals below the rootzone.

Nonpoint contamination – Contamination that occurs when a single identifiable point of contamination is not defined.

Nontarget organism – An organism, such as a plant, insect, animal, or microbe, that is not the target of pesticide application but is present within the management area.

Off-target location – An area that is not within the application management area but is still impacted by the pesticide.

Overspray – Pesticide application that occurs where not intended or planned in an area adjacent to a treatment area.

Pesticide detection – The detection of a pesticide in a sample.

Percolating water – Water moving or seeping downward through the soil from precipitation and/or irrigation.

Point-source contamination – Contamination that occurs where a single point of contamination can be identified.

Post-emergence treatment – The application of pesticide to an emerged crop.

Pre-emergence treatment – The application of pesticide to the soil or plant residue prior to crop emergence.

Restricted Use Pesticide (RUP) **–** A pesticide product that is not available for use by the general public due to its acute human toxicity, accident history, potential for or history of groundwater contamination, toxicity to vulnerable nontarget plants or animals, or is a fumigant or carcinogenic or mutagenic product.

Solubility – A measure of how much substance can solubilize in a given amount of water.

Vapor drift – The movement of a pesticide in its gaseous state from the point of application.

Volatility – The measure of a pesticide's proneness to vaporize through evaporative processes as influenced by temperature, relative humidity, and solar radiation.

Pesticide Recordkeeping Form

Name ________________________________ Pesticide Applicator's Certification Number ____________________

Certification Expiration Date ______________________________

Required RUP Pesticide Application Records for an Individual Field

Field Name and Location ____

Crop____ Variety: (optional) ______________________________

Application Date:						
Brand Name:						
EPA Reg. Number:						
Acres Treated:						
Total Amount:						

Optional RUP Pesticide Application Records for an Individual Field

Application time:						
Restricted Entry Interval:						
Rate:						
Gallonage:						
Surfactant:						
Nozzle:						
Wind:						
Other:						