GROUNDWATER AND PUBLIC POLICY LEAFLET SERIES

This series of seventeen leaflets is part of a set of educational materials on rural groundwater quality issues developed by the Groundwater Policy Education Project. This ASCII version of the leaflet series contains the complete text, but none of the graphics found in the original. Leaflets may be purchased from the Freshwater Foundation, Spring Hill Center, 725 County Road Six, Wayzata, Minnesota 55391, Telephone: (612) 449-0092. Reproduction and publication, in whole or in part, of adaptation for specific audiences is encouraged. Authors should be properly cited, with the Groundwater Policy Education Project identified as the source.

The Groundwater Policy Education Project is a joint effort of Cooperative Extension, the Freshwater Foundation, and the Soil and Water Conservation Society. These organizations joined together to create educational materials that would increase the abilities of citizens and local and state officials to make informed groundwater policy decisions.

#2: HOW CONTAMINANTS REACH GROUNDWATER

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The movement of contaminants through soil to groundwater is affected by many variables, including properties of the contaminant itself, soil conditions and climatic factors. These combinations of factors make the likelihood of groundwater contamination a very site-specific science. Nevertheless, as thorough an understanding as possible of these processes and variables is critical to effective management of potential groundwater contaminants.

Groundwater is the source of drinking water for 50 percent of the population in the United States. In rural areas, 85-90 percent of residents obtain their drinking water from groundwater. Because the quality of drinking water supplies is important, groundwater merits protection from contamination.

How Contaminants Move Through Soil

Folklore holds that the presence of soil protects groundwater quality by "filtering" contaminants out of recharge water. Present knowledge, however, indicates that the capacity of soils and the intermediate vadose zone (the area below the crop root zone and above the permanent water table) to degrade potential contaminants as they move toward groundwater is limited. The major processes that determine the fate of pollutants in soil and their potential to leach to groundwater are now well understood, and this knowledge can be used to reduce or eliminate contamination of drinking water supplies.

There are two basic processes by which contaminants move from the earth's surface through soils and groundwater. These processes are diffusion and mass flow. Substances diffuse through soils and aquifer materials in response to differences in energy from one point to another. These energy gradients may be caused by differences in concentration or temperature within the system. The principal process of movement of contaminants in soils and groundwater is mass flow. Dissolved constituents in water move through the soil, with the water acting as carrier of the contaminants. Diffusion and mass flow are affected by properties of the contaminants, the soil, the intermediate vadose zone and the aquifer; climatological factors; and vegetation patterns:

- Properties of contaminants that determine their movement and potential threat to water quality include water solubility, tendency to adhere to soil materials, persistency and toxicity.
- Properties of soil, the intermediate vadose zone and the aquifer that affect rate of contaminant movement include infiltration characteristics, pore size distribution, microbial population density and diversity, organic matter content, total porosity, ion exchange capacity, hydraulic properties, pH and oxygen status.

- Climatic factors include temperature; wind speed; solar radiation; and frequency, intensity and duration of rainfall.
- Vegetation may act as a sink for contaminants by uptake or assimilation, thus reducing the amount of contaminant available for transport to groundwater.

All of these properties interact to determine the rate and amount of movement of contaminants in soils and groundwater.

MANAGING SPECIFIC CONTAMINANTS

Since different classes of contaminants interact differently, management of these materials requires different approaches to reducing movement through soil to groundwater. Three such groups that require different approaches include pesticides; nitrogen forms, including fertilizers, manures and septage (organic semisolids pumped out of septic tanks); and pathogens.

Managing Pesticides

The use of pesticides is important to modern agriculture and residential landscapes. During the past several years, however, concern has grown about the presence of pesticides in the environment and the threat they pose to wildlife and humans.

By design, pesticides are poisons and can be particularly dangerous when misused. Fish kills and acute illnesses in humans have been attributed to pesticide exposure or ingestion, usually as a result of misapplication or careless disposal of unused pesticides and containers. Pesticide losses from areas of application, as well as contamination of such nontarget sites as surface water and groundwater, represent a monetary loss to the farmer as well as a threat to the environment. Thus, careful management of pesticides to avoid environmental contamination is desired by both farmers and the general public.

Pathways of Pesticide Loss

There are four pathways by which properly applied pesticides may be removed from the targeted application site:

- vaporization (volatilization) into the atmosphere
- removal in the harvested plant
- runoff - the physical transport of pollutants overland by water or eroded soil, caused by precipitation or irrigation that does not penetrate the soil
- leaching - the process whereby pollutants are flushed downward through the soil by rain or irrigation water that does infiltrate the soil

In areas of the country where soils are sandy and permeable, leaching is likely to be a more serious problem than runoff.

Once applied to cropland, a number of things may happen to a pesticide:

- It may be taken up by plants or ingested and metabolized by animals, insects, worms or microorganisms in the soil.
- It may move downward in the soil and either adhere to soil particles ordissolve.
- It may vaporize and enter the atmosphere.
- It may break down via microbial and chemical pathways into other less-toxic compounds.
- It may be leached out of the root zone or washed off the surface of land by rain or irrigation water.
- It may flow upward with water as a result of evaporation of water at the ground surface. In the United States, this process is not likely to be as important as downward leaching.

In addition to the mass flow components controlled by climate and the water-holding properties of the soil, the fate of a pesticide applied to soil depends largely on two of its properties: persistence and sorption.

Persistence

Persistence defines the life and activity of a pesticide. Most pesticides degrade or become inactive over time as a result of chemical and microbiological reactions in soil:

- Sunlight breaks down some pesticides.
- Soil microorganisms can completely break down many pesticides to carbon dioxide, water and other inorganic constituents.
- Some pesticides produce intermediate substances, called metabolites, as they degrade. The biological activity of these substances may have environmental significance.

Persistence is expressed as a half-life. Half-life is the amount of time it takes for one-half the original amount of a pesticide applied to be deactivated in the soil. Half-life is sometimes defined as the time required for half the amount of applied pesticide to be completely degraded and released as carbon dioxide and water. Usually, the degradation half-life of a pesticide measured by this "complete degradation" factor is longer than that based on deactivation only.

Persistence and Partition Coefficient (PC) of Selected Pesticides in Soils

COMMON NAME, TRADE NAME, PC , and HALF-LIFE (days)	
NONPERSISTENT (half-life 30 days or less)	
dalapon Basfapon, Dowpon 1 30	alachlor Alanex 170 15
dicamba Banvel 2 14	cyanazine Bladex 190 14
chloramben Amiben 15 15	carbaryl Sevin 200 10
metalaxyl Ridomil 16 21	iprodione Rovral 1,000 14
aldicarb Temik 20 30	malathion Cythion 1,800 1
oxamyl Vydate 25 4	methyl parathion Penncap-M, Metacide 5,100 5
propham Ban-Hoe, Chem-Hoe 60 10	chlorpyrifos Lorsban, Dursban 6,070 30
2,4,5-T Dacamine 4T, Trioxone 80 24	parathion Thiophos, Bladan 7,161 14
captan Orthocide, Captanex 100 3	fluvalinate Mavrik, Spur 100,000 30
fluometuron Cotoran, Lanex 100 11	
MODERATELY PERSISTENT (half-life 31-99 days)	
picloram Tordon 16 90	prometryn Caparol, Primatol Q 500 60
chlorimuron-ethyl Classic 20 40	fonofos Dyfonate 532 45
carbofuran Furadan, Curaterr 22 50	chlorbromuron Maloran 996 45
bromacil Hyvar, Bromax 32 60	azinphos-methyl Guthion 1,000 40
diphenamid Enide, Rideon 67 32	cacodylic acid Bolate, Bolls-Eye 1,000 50
ethoprop Mocap 70 50	chlorpropham Beet-Kleen, Furloe 1,150 35
fensulfothion Dasanit 89 33	phorate Thimet 2,000 90
atrazine Attrex 100 60	ethalfluralin Solanan 4,000 60
simazine Princep 138 75	chloroxuron Tenoran, Norex 4,343 60
dichlobenil Casoron 224 60	fenvalerate Extrin, Sumitox 5,300 35
linuron Lorox, Aflon 370 60	esfenvalerate Asana 5,300 35
ametryne Evik 388 60	trifluralin Treflan 7,000 60
diuron Karmex 480 90	glyphosate Roundup 24,000 47
diazinon Basudin, Spectracide 500 40	
PERSISTENT (half-life 100 days or more)	
fomesafen Flex 50 180	fluridone Sonar 450 360
terbacil Sinbar 55 120	lindane Isotox 1,100 400
metsolfuron-methyl Ally, Escort 61 120	cyhexatin Plictran 1,380 180
propazine Milogard, Primatol P 154 135	procymidone Sumilex 1,650 120
benomyl Benlate 190 240	chloroneb Terraneb 1,653 180
monolinuron Aresin, Afesin 284 321	endosulfan Thiodan, Endosan 2,040 120
prometon Pramitol 300 120	ethion Ethion 8,890 350
isofenphos Oftanol 408 150	metolachlor Bicep 85,000 120

Sorption

Probably the single most important property influencing a pesticide's movement with water is its sorptivity, or tendency to stick to soil particles. Soil is a complex mixture of solids, liquids and gases that provides the life-support system for roots of growing plants and such microorganisms as bacteria. When a pesticide enters soil, some of it will stick to soil particles, particularly organic matter, through a process called sorption.

Some of the pesticide will dissolve and mix with the water between soil particles, called soil-water. As more water enters the soil through rainfall or irrigation, the pesticide molecules will move down and may enter soil-water through a process called desorption. The relationship between water flow, sorption and desorption is a dynamic process. The solubility of a pesticide and its sorption on soil are generally inversely related, with increased solubility resulting in less sorption.

One of the most useful indices for quantifying pesticide sorption on soils is the partition coefficient (PC). This PC value is defined as the ratio of pesticide concentration bound to soil organic matter particles to that dissolved in the soil-water. Thus, for a given pesticide application, the smaller the PC value, the greater the concentration of pesticide in soil-water. Pesticides with small PC values are more likely to be leached than those with large PC values.

Pesticide Persistence and Sorption and Potential Impact on Groundwater

- Consideration of persistence and sorption of a pesticide in determining its potential to contaminate groundwater and surface water.
- Persistence Sorption Potential Impact Groundwater Surface water
- Nonpersistent Low-moderate Low
- Nonpersistent Moderate-high Low Moderate
- Moderately Moderate-high Moderate persistent
- Moderately Low-moderate High persistent
- Persistent Moderate-high Moderate High

Moderately persistent and persistent Low-high Site-specific conditions determine groundwater or surface water impacts

Estimating Pesticide Losses

In estimating pesticide losses from soils and their potential to contaminate groundwater or surface water, it is essential to consider simultaneously both persistence and sorption. Quantitative estimation of pesticide losses via runoff or leaching requires complex mathematical models. These models are used to analyze site-specific soil, crop, management and climatological information. In the absence of such information, however, a qualitative assessment of a pesticide's potential to contaminate surface water or groundwater is possible.

Pesticides with high persistence and a strong sorption rate are likely to remain near the soil surface, increasing the chances of being carried to a stream or lake via surface runoff. In contrast, pesticides with high persistence and a weak sorption rate may be readily leached through the soil and are more likely to contaminate groundwater.

For nonpersistent pesticides, the possibility of surface water or groundwater contamination depends primarily on whether heavy rains or irrigation occur soon after pesticide application. Without water to move them downward, pesticides with short half-lives are more likely to remain within the biologically active crop root zone and may be degraded readily. In terms of water quality, then, pesticides with intermediate sorption values and low persistence values may be considered generally nonthreatening to health, because they are not readily leached and are degraded fairly rapidly.

Selecting and Using Pesticides

Agricultural use of pesticides should be part of an overall pest management strategy that includes biological controls, cultural methods, pest monitoring and other applicable practices, referred to altogether as integrated pest management or IPM. When a pesticide is needed, its selection should be based on effectiveness, toxicity to nontarget species, cost and site characteristics, as well as solubility and persistence.

In addition to pesticide sorptivity and soil permeability, it is important that the pesticide+s toxicity to nontarget species be considered. The use of some pesticides is severely restricted due to acute toxicity or long half-lives. These pesticides present serious concerns if they are leached through the soil to groundwater. The U.S. Environmental Protection Agency has issued health advisory levels for pesticides that pose a potential threat to groundwater. Selection of pesticides based on their mobility and persistency should be done only according to instructions on the pesticide label.

Managing Nitrogen

Nitrogen is an essential element in life. It is a normal part of the human environment. The atmosphere consists of approximately 78 percent nitrogen gas. Amino acids, which are nitrogencontaining organic acids, form the building blocks of protein in our bodies. Nitrogen is also an integral part of chlorophyll production. Chlorophyll converts radiant energy from the sun to carbohydrates, which are essential dietary components of human health.

Nitrogen accumulates in soils during the process of soil formation, through deposition from rainfall, and through plant and microbial fixation of nitrogen gas from the atmosphere. Nitrogen accumulated in soil organic matter is produced from decaying plant and animal matter.

Worldwide, nitrogen is the plant nutrient most critical to the production of food and fiber. Throughout recorded history, humans have added nitrogen to crops through animal manures, legume crops or fertilizers.

There are four major factors that affect the behavior of nitrogen in the environment - and subsequently its potential to contaminate drinking water supplies. These factors include:

- the amount and forms of nitrogen entering the soil
- the soils that overlay the aquifers
- assimilation of nitrogen by plants, microbes and other soil organisms
- local climatic conditions and irrigation practices

These factors interact to determine the fate of applied nitrogen fertilizers, animal wastes, sewage sludge and septage.

The most common forms of nitrogen in fertilizers are ammonium, nitrate, urea and natural organics. Forms of nitrogen in septic tank effluent include ammonia, ammonium, organic nitrogen, nitrate and nitrite.

Nitrogen can be lost from the soil by various pathways, some of which reduce the potential for nitrate to contaminate groundwater. Pathways of loss include volatilization as gases to the atmosphere, plant uptake, microbial metabolism and leaching.

How Nitrogen Moves Through Soil

Soils are the medium in which we grow most of our crops. Soils provide a reservoir for the nutrients, water and microbes necessary for economic production of crops. Soils differ in their capacities to retain water and nitrogen and thus must be managed differently to maximize production and minimize water and nutrient leaching.

Deep sandy soils require more frequent water and nutrient applications due to their very limited capacity to retain these inputs. Excessive leaching is the rule rather than the exception, unless very careful management practices are followed. No soil will retain heavy, continuous applications of nitrogen exceeding crop requirements. Thus, highleaching potentials occur under these conditions.

Poorly drained soils, on the other hand, may require artificial drainage to be productive. Leaching to groundwater may occur if confining layers are discontinuous or if drainage or irrigation ditches cut through the confining layer. Medium and heavy textured soils and organic soils have good water and nitrogen retention capacities. Nevertheless, careful management of water and nitrogen application practices is necessary.

How Climate and Irrigation Affect NitrogenLeaching

Rainfall is dissipated by streamflow and groundwater recharge. Rainfall patterns vary with season in different regions of the country. Even in areas with ample annual rainfall, drought can occur, causing production losses or failure unless irrigation is used. Soils with poor water retention capacity also may require frequent irrigation. Managing the soil-water deficit to prevent plant water stress and excess leaching of nutrients from the root zone is an onerous task in these soils.

Whether in arid or humid regions, management practices to reduce groundwater contamination must be based on the following:

- a good understanding of the water-holding capacity of the soil
- a good estimation of soil-water deficits
- irrigation systems that deliver precisely the water required to replenish the soil-water deficit

How Nitrate Contaminates Aquifers

Nitrate is very soluble and mobile in water. Forms of nitrogen fertilizer other than nitrate are transformed readily into nitrate and thus become subject to leaching to groundwater. Consequently, forms of nitrogen fertilizer other than nitrate are seldom found in aquifers.

Studies indicate that such conversion can take place within 30 days in warm, moist soils. Soluble nutrients are carried with the water through soils. Excessive rainfall or irrigation will tend to leach nitrogen below the root zone and ultimately to groundwater. This results in both an economic loss of nitrogen and deterioration of water quality in drinking water supplies. For these reasons nitrogen and water management practices must be considered jointly in farm management decision-making. Soil testing for residual soil nitrogen, crop nutrient requirements, realistic yield goals and irrigation efficiency are concepts that must be integrated to develop a crop production system that avoids excessive nitrogen leaching.

Managing Pathogens

Pathogens (bacteria and viruses) may occur in sewage sludge, septage, animal wastes, some food-processing wastes and septic tank effluent. These waste streams enter the soil environment in several ways. Some are applied to the land as fertilizers, some are disposed into landfills, and others seep into the soil either by design or happenstance.

How Pathogens Move Through Soil

Pathogens are carried in suspension with water through soil. These suspended organisms are removed from the soil-water by filtration and adsorption. Two factors that significantly affect the mobility of bacteria and viruses in the underground environment are the size of the water-filled pores, including cracks, fissures and solution channels; and the actual velocity of the water in those pores. Other factors affecting the survival of pathogens in the vadose zone (the unsaturated zone extending from the earth+s surface to the permanent water table) are pH, temperature and oxygen concentration.

The pore size distribution of soils acts in two ways to reduce pathogen movement. Soils with predominantly small pores will provide greater filtering characteristics and greater residence time to allow adsorption and deactivation than will coarsetextured soils. If the texture is too fine, however, infiltration and internal drainage will be insufficient to permit reasonable loadings of effluent. (Such soils would fail percolation tests.) Coarse sandy soils provide little opportunity for filtration or adsorption due to larger pore sizes, more rapid water movement and less exchange surface for adsorption. Thus, removal of pathogens depends strongly on soil properties, which are known to vary widely, and on controlling rate of flow through the soil.

Methods to reduce contaminant movement to groundwater depend on water management, appropriate loading rates, and soil and vadose zone properties. Some level of contamination occurs in groundwater due to natural processes of precipitation, infiltration and recharge to aquifers. Understanding the processes that control movement of contaminants is necessary for developing any successful strategy to protect groundwater from contamination levels that pose significant health risks.

Groundwater quality and related public policy issues are the theme of the March-April 1990 issue (Volume 45, Number 2) of the Journal of Soil and Water Conservation. This special issue, titled "Rural Groundwater Quality Management: Emerging Issues and Public Policies for the 1990s," may be ordered from the Soil and Water Conservation Society, 7515 N.E. Ankeny Road, Ankeny, Iowa 50021-9764, for $12.

Further Information

For further information on understanding how contaminants reach groundwater, contact your local county Extension office.

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