

NATURAL RESOURCES

CORNELL COOPERATIVE EXTENSION

Groundwater: What It Is and How to Protect It

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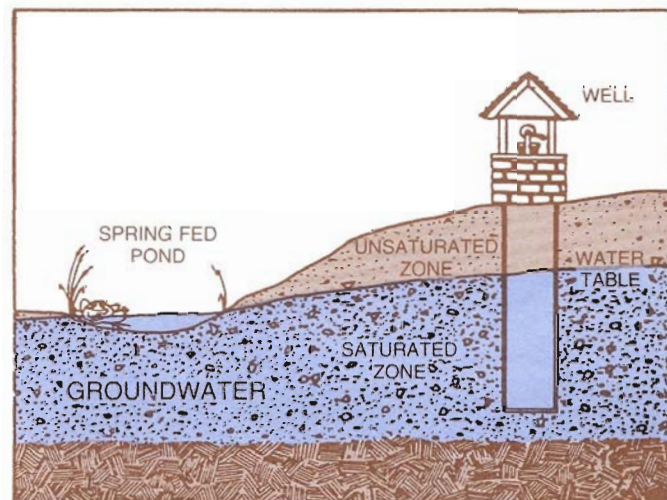
Groundwater is the source of water for wells and springs. It is found underground, within cracks in bedrock or filling the spaces between particles of soil and rocks. The groundwater layer in which all available spaces are filled with water is called the *saturated zone*. The dividing line between the saturated zone and overlying unsaturated rock or sediments is called the *water table*.

Why Groundwater Is Important

Groundwater can be found under most of the land in the Northeast and is widely used for household and other water supplies. Approximately half the population of the United States relies on groundwater for drinking water, and more than 90 percent of rural residents obtain their water from groundwater through wells or springs.

There are good economic reasons for this widespread dependence on groundwater. In its natural state groundwater is usually of excellent quality and can be used with no costly treatment or purification. It can be inexpensively tapped adjacent to the point of use, thereby saving the costs of transporting water long distances. In addition, costly storage facilities such as water tanks or towers are not needed. Surface water, on the other hand, usually requires storage and treatment, which are relatively expensive and difficult

to manage without technical resources. For rural residents relying on individual wells, groundwater often is the only available water supply, and for many communities it is by far the least expensive option for public water supply systems.



Until recently, groundwater quality has been taken for granted. Although some wells and springs were known to contain naturally high levels of sulfur or salts, and others were known to be contaminated by sewage bacteria, groundwater was generally thought to be immune from contamination by the many chemicals we use for industrial, agricultural, and household purposes. Only within the past decade have we made the link between what we do at the land surface and what we find in our groundwater supplies.

In dealing with threats to groundwater resources, communities and individuals need knowledge and understanding of groundwater:

Dependence of northeastern states on groundwater as a source of drinking water

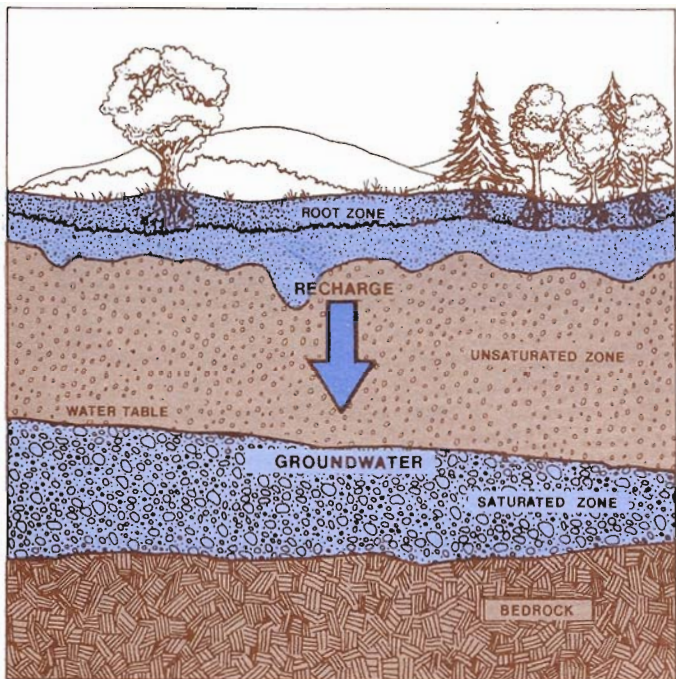
State	Total population (thousands)	% of total population relying on groundwater	Population served by groundwater from public supplies (thousands)	Population served by groundwater from rural supplies (thousands)	% of public supply population relying on groundwater	% of rural population relying on groundwater
Connecticut	3032	37	590	531	24	98
Delaware	548	65	217	138	53	100
Maine	994	37	153	219	20	91
Massachusetts	5689	31	1464	286	27	100
New Hampshire	738	61	261	191	48	98
New Jersey	7168	53	3032	746	47	100
New York	18191	32	4152	1734	25	100
Pennsylvania	11794	30	1351	2144	14	100
Rhode Island	950	33	213	103	25	100
Vermont	445	56	100	150	35	96
U.S. TOTAL	205897	48	60600	38568	37	94

Source: V.I. Pye, R. Patrick, and J. Quarles, 1983, *Groundwater Contamination in the U.S.*, Univ. of Pennsylvania Press, Philadelphia.

where it comes from, how it flows, and how it can be protected. This bulletin explains these principles in nontechnical language, with emphasis on the information necessary to protect groundwater quality.

Where Groundwater Comes From

Water entering the soil gradually percolates downward to become groundwater if it is not first taken up by plants, evaporated into the atmosphere, or held within soil pores. This percolating water, called *recharge*, passes downward through the root zone and unsaturated zone until it reaches the water table. Effective programs for protection of groundwater focus primarily on the recharge process because this controls both the quantity and the quality of water reaching the saturated zone. Water is far easier and less expensive to manage at the land surface than after it becomes less accessible and more dispersed underground.



The quantity of recharge in any particular location depends on the amount of precipitation or irrigation, the type of soil, and the topography and geology of the site. Seasonal fluctuations occur in the quantity of recharge, leading also to fluctuations in depth of the water table. In winter and early spring when snow is melting and plants are not yet taking up much water, the water table may be close to or at the ground surface. Evidence of this includes wet basements and agricultural fields that are too wet for cultivation or planting. As the summer progresses, the water table commonly drops because evaporation and plant uptake exceed recharge. During dry periods this drop may cause water shortages in shallow wells, as well as drying up of some springs, wetlands, and small streams.

Recharge is the only natural means of replenishing groundwater supplies, and the water table will drop if the amount of water withdrawn exceeds the amount recharged. This is not a common problem in the Northeast except during drought periods. In more arid parts of the country, though, where groundwater is the sole source of water supply for large cities or agricultural operations, groundwater depletion can be a serious and continuing problem.

How Groundwater Moves

Groundwater does not generally consist of large underground lakes or streams. Rather, it is water that fills irregular spaces within rock fractures or between particles of sand, gravel, or clay. Whereas water in a stream may move several feet per second, groundwater may move only a few feet per month or even per year. The major exception to this general rule is in limestone areas, where groundwater may flow rapidly through large underground channels and caverns.

The geologic formation through which groundwater moves is called an *aquifer*. This can be a layer of sand, gravel, or other soil materials, or a section of bedrock with fractures through which water can flow. Drilling a hole into the ground in most areas of the Northeast will yield some water. Only the major aquifers, though, will have sufficient flow to maintain community water systems. In New York State, the most productive aquifers consist of sand and gravel deposits, which generally are found in river valleys. The quantity and quality of recharge they receive depend on their depth from the ground surface, on the geology of the overlying materials, and on the climate, land uses, and water management practices in their recharge areas.

Recharge water generally moves downward through the soil until it reaches the water table, then travels in a more horizontal direction, following the contours of the aquifer. Eventually groundwater resurfaces, producing springs or feeding water into streams, wetlands, or other surface water bodies.

Groundwater Contaminants

One of the most familiar reasons for problems with well water is contamination by bacteria, viruses, or parasites, which can seep into the groundwater from sources such as septic systems, leaky sewer lines, barnyards, or fields spread with manure. Water contaminated with sewage-related microorganisms can transmit diseases such as cholera, typhoid, and hepatitis. These diseases kill many people worldwide, but have been almost eliminated in the United States by chlorination of public water supplies and regulation of septic system placement. Of greater concern for groundwater contamination in this country are two broad classes of chemicals: (1) inorganic minerals, salts, and metals and (2) synthetic organic compounds.

Inorganic Chemicals

All groundwater contains natural salts, minerals, and other inorganic compounds. These usually are found at concentrations higher than those in surface water because groundwater dissolves inorganic substances as it seeps through the ground. Most inorganic compounds are harmless at the concentrations commonly found in unpolluted groundwater, and some, such as potassium, magnesium, and calcium, are even beneficial to human health. Others, such as arsenic, barium, or mercury, can occur naturally in concentrations that are considered harmful. Naturally high concentrations of hydrogen sulfide or salt make some groundwater unpalatable, although not a health hazard.

Human activities are another source of inorganic substances in groundwater. Chloride levels, for example, can become elevated by leaching of highway deicing salts or effluent from septic systems. In coastal areas groundwater supplies become high in chloride if pumping exceeds recharge, causing salt water to intrude into what had been a fresh water aquifer. Salt water intrusion is a problem in some Cape Cod and Long Island communities, as well as in other coastal areas with heavy pumping of groundwater. Chloride levels can also be elevated naturally by flow of groundwater through areas with natural salt deposits.

Nitrate is another groundwater contaminant of concern in drinking water because at high enough concentrations it can cause methemoglobinemia, or "blue baby syndrome." (Fact Sheet 400.02, *Nitrate: Health Effects in Drinking Water*, in this series gives more information about the health effects of nitrates in drinking water.) Typical sources of high nitrate concentrations include septic systems that are spaced too close together, fertilizers that leach from lawns or agricultural fields, and liquids that percolate into the ground in areas where animal manures are concentrated.



Organic Chemicals

Organic compounds are chemicals containing carbon and other elements such as hydrogen, nitrogen, or chlorine. Many occur in nature, and many others are manufactured for a wide range of purposes, including cleaning fluids, wood preservatives, and pesticides. The production of synthetic organic compounds has increased more than 10-fold in the past 40 years, and some of these chemicals have become significant groundwater contaminants. In many cases these can be traced to improper disposal of chemicals in lagoons, landfills, or leaking storage tanks. Presence of synthetic organic compounds in groundwater is a matter of serious concern because of their potential health effects in drinking water. A few are known to be carcinogenic, and others can cause problems such as liver damage, neurological disorders, or birth defects. (Fact Sheet 400.03, *Pesticides: Health Effects in Drinking*

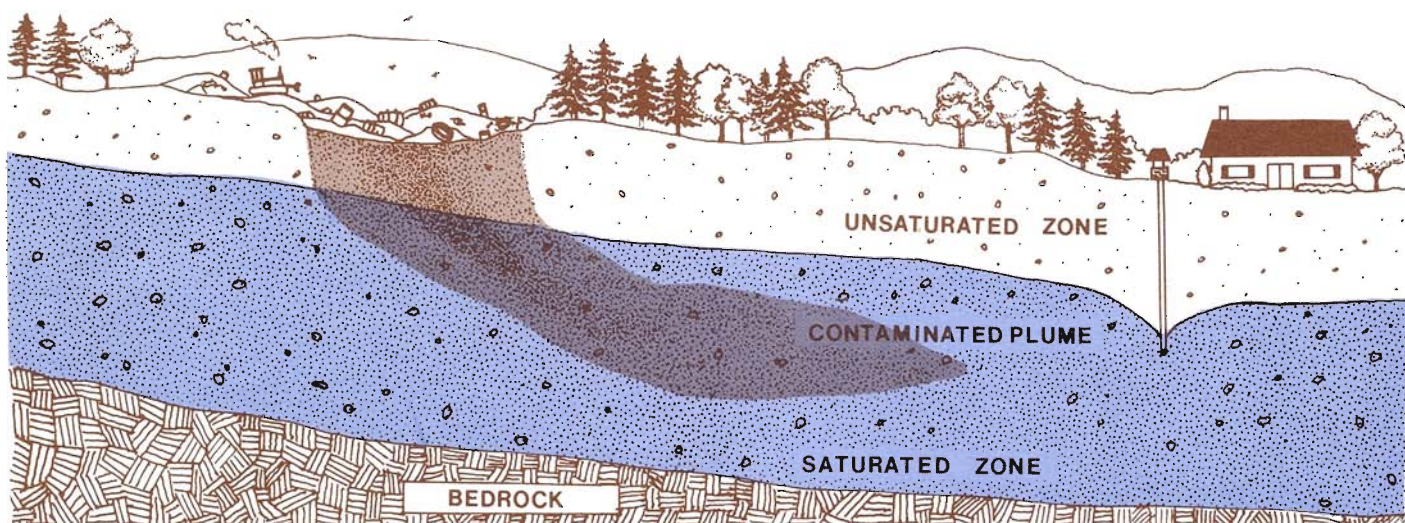
Water, in this series gives more information about the health effects of pesticides and other synthetic organic compounds in drinking water.)

Not all chemicals will leach to groundwater. Which ones will do so and in what quantities depend on the original quantity of the chemical, how soluble it is, how strongly it is held by the soil, and how quickly it breaks down in the root zone. Soil type and climatic conditions also affect leaching potential. One example is aldicarb (brand name Temik), a pesticide widely used throughout the country for a variety of crops including cotton, peanuts, potatoes, and citrus fruits. In most areas aldicarb has been used without significant leaching to groundwater. This has not been the case, though, on Long Island and in several other locations with sandy, acidic soils and a shallow water table. As a result, over 2,000 Long Island wells exceed the New York State drinking water guideline for aldicarb. On Long Island carbon filtration units have had to be installed in each affected household, and plans are being made to replace individual wells with expensive community water supply systems.

Movement of Contaminants

Groundwater becomes contaminated when water percolating through the soil carries pollutants downward to the water table. Gasoline or other liquids that seep into the ground or leak from underground storage tanks can also become groundwater contaminants. Once in the saturated zone, these chemicals move with the groundwater, forming a region of contaminated water called a *plume*. Because contaminants flow with groundwater through the saturated zone, the quality of water in a particular well depends on the land areas, perhaps miles away, from which this part of the aquifer was recharged.

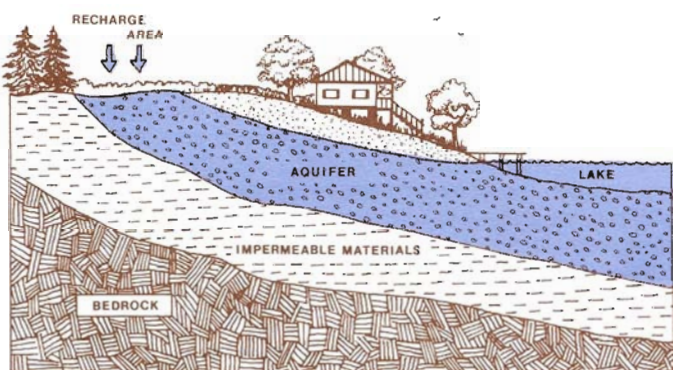
It may be some years before a contaminant plume originating at the land surface appears in a well some distance away. By the time this is detected, the contamination is likely to be widespread, and it may take decades or even centuries for the aquifer to purify itself naturally. In rivers and streams dissolved contaminants are rapidly swept downstream, diluted, and subjected to biological and chemical decay. Groundwater conditions, in contrast, act to preserve contaminants. The slow water movement means that flushing of contamination from an aquifer may take many years. Dilution does occur, but to a limited extent, because mixing takes place only gradually as water moves through small cracks or pores. Biological and chemical decay of chemicals are slow in groundwa-



ter because of the cold temperatures, low oxygen levels, and limited microbial activity. Because contaminants in groundwater tend to be preserved rather than degraded, diluted, or rapidly swept away, the best way to protect groundwater quality is to keep contaminants out of recharge waters.

Protection of Groundwater Quality

Protection of groundwater quantity and quality can best be accomplished by controlling potential contaminant sources and by managing land uses in prime recharge areas. Using knowledge of local geology and groundwater flow directions, estimates can be made of the land areas contributing recharge to a particular well or to an aquifer as a whole. Controls can then be established to ensure appropriate land uses and chemical practices within the recharge areas. The best protection is provided through land acquisition. Massachusetts recently has initiated an Aquifer Land Acquisition Program, which provides state funding for purchase of important recharge areas. Where acquisition is not feasible, conservation easements and transfer of development rights are alternative means of protecting recharge quality.



In many cases recharge areas cannot be set aside in their natural states. Groundwater protection efforts then must focus instead on management of the diverse potential contaminant sources. Possible techniques include public education, inventory and monitoring of potential contaminant sources, and tailoring of zoning ordinances and other local land use regulations for protection of community groundwater supplies. Connecticut and Vermont have established programs to assist communities in protecting recharge quality within specially designated aquifer protection areas (see Mullikin 1984; Harrison and Dickinson 1984).

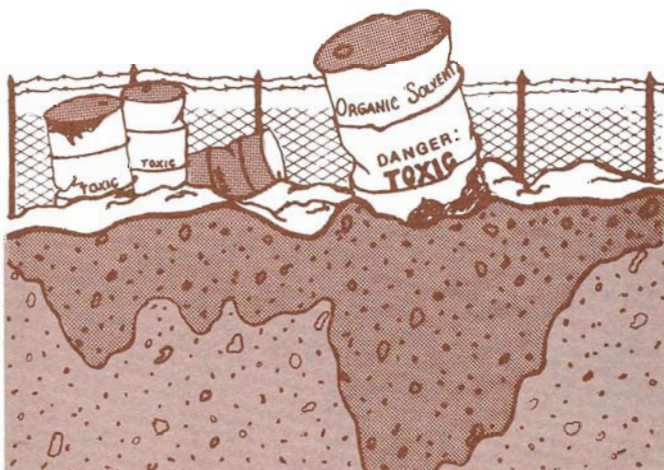
Residential areas, commercial operations, and industries all require careful design and management for protection of groundwater supplies. Potential contaminants from residential areas include nitrates from lawn fertilizers or septic systems, pesticides from lawn or household treatments, and synthetic organic chemicals from septic tank cleaners and other household products ranging from paint thinner to drain cleaners. Commercial operations can contaminate groundwater through chemical spills or inadequate disposal practices. Substances such as waste motor oil or used dry cleaning fluid can cause well closures if they are dumped down a drain or onto the ground rather than handled appropriately as toxic wastes. Similarly, industrial discharges to ground or surface waters can make the water undrinkable unless toxic components receive proper treatment or alternative disposal.

One means of reducing the chances of groundwater contamination from residential areas is to limit the allowable housing density. Most houses in rural areas have septic systems rather than public

sewers, so wastewater is disposed of in the ground. This wastewater is high in nitrogen and may also contain other contaminants such as the synthetic organic chemicals found in

Some potential groundwater contaminant sources and methods for control

Source	Contaminants	Control methods
Septic systems	Bacteria, viruses, synthetic organic compounds, nitrate	Regulation of siting and installation. Requirement of periodic inspection or pumping. Education about hazardous household chemicals.
Underground fuel storage	Gasoline and other petroleum products	Periodic inspection of tanks, including pressure testing. Monitoring of fluid levels and inflow/outflow comparisons.
Sanitary landfills	Heavy metals, synthetic organic compounds, nitrate	Careful siting to protect groundwater. Regulation of construction and operation, including prohibition of hazardous wastes.
Road salt storage and use	Sodium chloride or other salts	Protection of stockpiles from precipitation and runoff. Minimization of salt use.
Fertilizers and pesticides	Nitrate, synthetic organic compounds, heavy metals	Efficient nitrogen application to meet crop needs. Use of integrated pest management or other means of minimizing pesticide needs. Regulation of disposal of used containers.
Hazardous waste spills, leaks, or improper disposal	Industrial chemicals	"Cradle to grave" accounting of hazardous materials. Mandatory inspection of transportation equipment. Heavy fines for spills. Storage regulations for hazardous materials.



Community action for groundwater protection

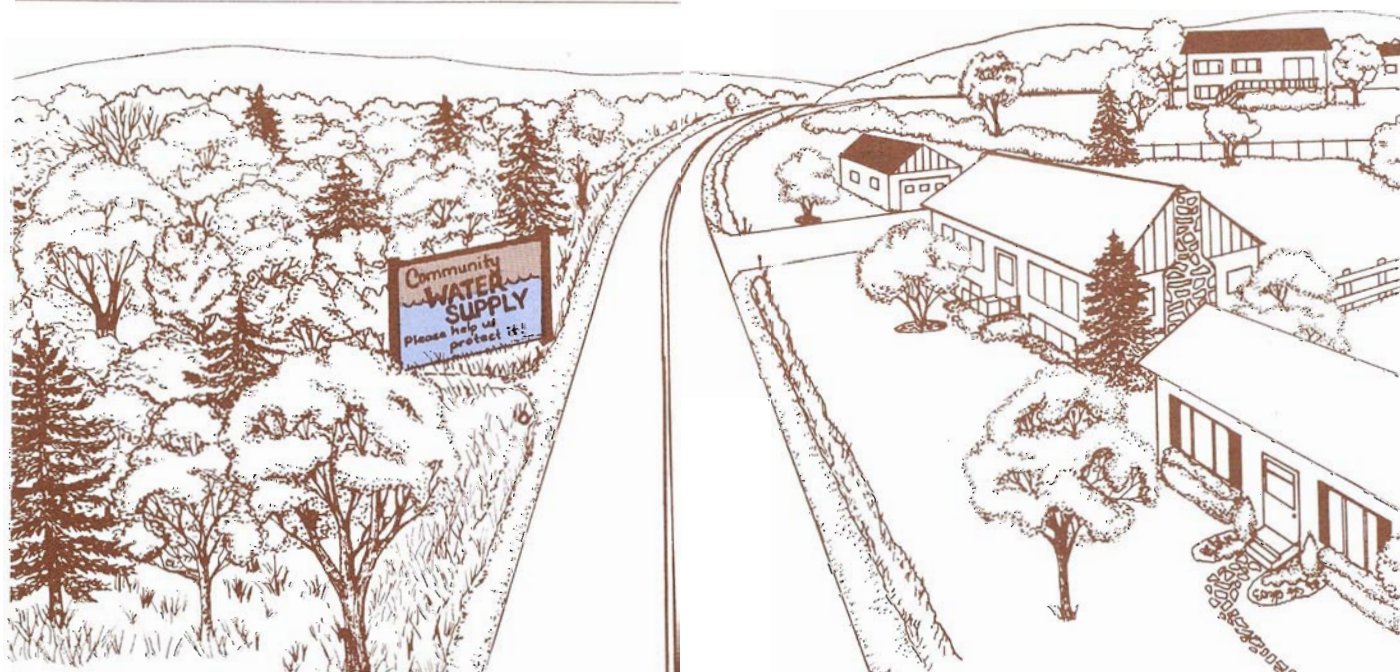
Action	References for further information
Identify groundwater resources and recharge areas.	O'Donnell 1984 Pacinka et al. 1984 STCRPDB 1985
Inventory existing local programs.	Harrison and Dickinson 1984 STCRPDB 1985
Inventory present and future groundwater resources, land uses, and water supply demands.	Harrison and Dickinson 1984
Identify inadequacies of existing programs.	Harrison and Dickinson 1984 STCRPDB 1985
Choose and draft protection mechanisms.	
Zoning techniques	Dawson 1984
Aquifer protection districts	MAPC 1982
Watershed protection districts	STCRPDB 1985
Nonzoning regulatory techniques	
Development review	Dawson 1984
Underground fuel storage	O'Donnell and White 1984
Hazardous material handling	MAPC 1982
Storage and use of road salt	STCRPDB 1985
Maintenance of septic systems	
Nonregulatory techniques	
Education	Dawson 1984
Conservation restrictions	Harrison and Dickinson 1984
Transfer of development rights	MAPC 1982
Land acquisition	Mullikin 1984
Groundwater monitoring	

cleaning agents, petroleum products, or household pesticides. The farther apart the houses, the wider the separation between possible contaminant sources, and therefore the more the dilution they receive in groundwater.

Other possible groundwater protection techniques include sewerage of sensitive areas, mandatory inspection of septic systems, reduction of the amount of salt used on roads, and regulation of chemical waste disposal practices of local industries and commercial establishments.

Prohibitions or limits imposed on specific chemicals have been adopted by some communities. Suffolk County on Long Island, for example, prohibits use of septic tank cleaners because these products contain synthetic organic compounds that have been detected in local wells at concentrations exceeding the N.Y.S. drinking water guidelines. If nitrate levels are a problem in water recharging from residential areas, then community ordinances can be established to limit either the area used for lawns or the amount of fertilizer that can be applied to them. The towns of Southampton and Easthampton on Long Island have recently developed ordinances limiting the allowable turf area per lot, and the town of Oyster Bay requires that any new lawns be made up of low maintenance turf varieties so that fertilizer requirements will be reduced.

In some parts of the country, agricultural fertilizers and pesticides have become significant groundwater contaminants. Farmers have a wide range of choices in how to manage their farms, and these choices determine the efficiency of chemical use as well as the success of the harvest. Pesticides and fertilizer applications can be designed to efficiently meet crop needs while minimizing losses to groundwater. The types of chemicals used, the amounts and timing of applications, and a variety of other farm management practices all interact to affect crop yields and leaching losses. Further bulletins in this series will address farm chemical management in greater detail.



Conclusions

Groundwater, historically, has been taken for granted, especially in the Northeastern states where it tends to be plentiful and easily obtained. In recent years, however, many communities have discovered how valuable their groundwater supplies can be. Once groundwater becomes contaminated, the options for treating it or for finding alternative supplies tend to be very expensive, and the prospects for cleaning up the aquifer may be many years in the future.

Both the quantity and the quality of groundwater supplies depend on the recharge water that continually filters down through the soil to the saturated zone. Any chemicals at the ground surface or within the soil profile can become groundwater contaminants if they are carried downward by this recharge water.

The first step in protecting groundwater quality is to determine the locations of prime recharge areas. The second step is to identify management options which would help to protect the quality of recharge in these areas. The level of management appropriate to a particular area depends on the vulnerability of the aquifer, the extent to which it is relied on for high quality water supplies, and the number and type of potential contaminant sources. Action for protection of recharge quality can be as simple as not dumping used motor oil down the drain or as comprehensive as a communitywide aquifer protection plan incorporating land-use and contaminant source control regulations. Recharge protection is the key to any effective groundwater protection program.

For Further Reading

- Dawson, A. 1984. Local authority for groundwater protection. Massachusetts Audubon Society, Groundwater Information Flyer #4. Available from Massachusetts Audubon Society, Public Information Office, Lincoln, MA 01773.
- Gordon, W. 1984. A citizen's handbook on groundwater protection. Natural Resources Defense Council, Inc. Available from NRDC, Inc., 122 East 42nd Street, New York, NY 10168.
- Harrison, E.Z., and M.A. Dickinson. 1984. Protecting Connecticut's groundwater: A guide to groundwater protection for local officials. Connecticut Department of Environmental Protection, Hartford, Conn.
- Metropolitan Area Planning Council. 1982. Groundwater protection: A guide for communities. Available from MAPC Resource Library, 110 Tremont Street, 5th Floor, Boston, MA 02108.
- Mullikin, E.B. 1984. An ounce of prevention: A groundwater protection handbook for local officials. Available from Vermont Department of Water Resources, State Office Building, Montpelier, VT 05602.
- O'Donnell, A. 1984. Mapping aquifers and recharge areas. Massachusetts Audubon Society, Groundwater Information Flyer #4. Available from previously cited address.
- O'Donnell, A., and L. White. 1984. Underground storage tanks and groundwater protection. Massachusetts Audubon Society Groundwater Information Flyer #4. Available from previously cited address.
- Pacinka, S.P., et al. 1984. Protecting ground-water supplies in river valley communities. Cornell Cooperative Extension Miscellaneous Bulletin 131. Available from Distribution Center, 7 Research Park, Cornell University, Ithaca, NY 14850.
- Southern Tier Central Regional Planning and Development Board. 1985. Final report of the Central Southern Tier Groundwater Critical Recharge Area Project. Corning, N.Y.
- White, L. 1983. An introduction to groundwater and aquifers. Massachusetts Audubon Society, Groundwater Information Flyer #1. Available from previously cited address.
- . 1984. Groundwater and contamination: From the watershed into the well. Massachusetts Audubon Society, Groundwater Information Flyer #2. Available from previously cited address.

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