

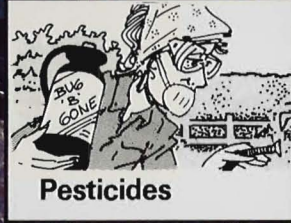
Septic Systems



Nitrates



Underground Injection



Pesticides



Spills



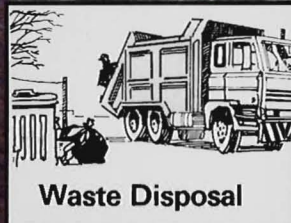
Abandoned Wells



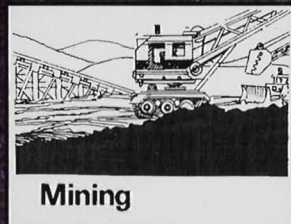
Natural Constituents



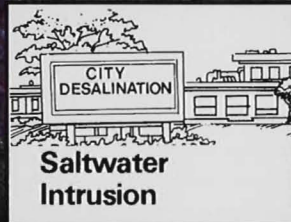
Underground Storage Tanks



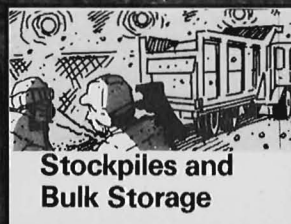
Waste Disposal



Mining



Saltwater Intrusion



Stockpiles and Bulk Storage

Threats to Virginia's Groundwater

We Can Make a Difference in Protecting Groundwater

THIS is a book about groundwater problems in Virginia and the nation. The focus on problems may seem a pessimistic approach, but, unfortunately, many activities threaten both the quality and quantity of groundwater.

However, for every act that endangers groundwater, at least one preventive or alternative action can be taken to protect this valuable hidden resource. We want to emphasize these positive actions because restoring the quality of water in a polluted aquifer is complex and costly. This brings us to the central message of this book: Preventing contamination is the best strategy for protecting groundwater. Your everyday actions can make a difference.

Below are the major threats to Virginia's groundwater and a brief review of what you can do to prevent contamination from each source or activity. Turn to the page number in parentheses for more information.

Septic Systems (page 11): The proper siting, installation, and maintenance of home septic systems can prevent not only the surface ponding of raw wastes but also the contamination of groundwater by nitrates, fecal coliform bacteria, and other wastes.

Fertilizers and Pesticides (pages 13, 14): If you must use fertilizers or pesticides, be sure to follow directions carefully and use them as efficiently and safely as possible.

Underground Storage Tanks (page 17): If your well is contaminated by petroleum products, your own underground fuel oil tank may be leaking. Any suggestion of an oil leak or spill — any change in the taste or smell of your water — should be reported to the Virginia Water Control Board.

Waste Disposal (page 19): The less waste society has to dispose of, the lower the danger of contaminating groundwater with landfill leachate. Limit the amount of waste you generate by recycling, reusing, and repairing instead of discarding. Support efforts promoting the proper disposal of wastes.

Mining (page 27): Groundwater damage from mining can be minimized by using the best available technology and best management techniques. Coal mining site problems should be reported to the Department of Mines, Minerals, and Energy, Division of Mined Land Reclamation, Abandoned Mines Land Group.

Saltwater Intrusion (page 30): The over-withdrawal, or mining, of groundwater can be the cause of saltwater intrusion, and the best individual response to this problem is water conservation.

Underground Injection (page 32): Underground injection is the placement of fluids into the ground through a well. Examples are cesspools, cooling water return flow wells, and stormwater drainage wells. All injection wells in Virginia should be reported to the Environmental Protection Agency's Region III office.

Spills (page 33): Spills of oil or chemicals should be reported immediately to the National Response Center at (800) 424-8802 or the Virginia Emergency Response Council at (804) 786-5999.

Abandoned Wells (page 33): Wells no longer in use should be capped and sealed and should never be used as trash pits. Abandoned wells should be reported to the Virginia Water Control Board.

We hope that you will find this book informative and useful. If you have comments or questions, please write to the authors in care of the Virginia Water Resources Research Center, Virginia Tech, 617 North Main Street, Blacksburg, Virginia 24060-3397.

D.L.W.
C.J.K.

Threats to Virginia's Groundwater

by
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Blacksburg

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Contents

Acknowledgments	iv
Introduction	1
ABCs of Hydrogeology	3
Threats to Groundwater	8
Septic Systems	11
Nitrates	13
Pesticides	14
Underground Storage Tanks	17
Waste Disposal	19
Mining	27
Saltwater Intrusion	30
Stockpiles and Bulk Storage	31
Underground Injection	32
Spills	33
Abandoned Wells	33
Natural Constituents	34
Protecting Your Water Supply	35
A Final Thought	38
Appendices	39
Appendix A: Laws Protecting Groundwater	39
Appendix B: Virginia's Superfund Sites	39
Appendix C: References	40
Appendix D: Units of Measurement	42
Appendix E: Agency Programs	42
Glossary	43

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Introduction

*Water, water everywhere,
And all the boards did shrink;
Water, water everywhere
Nor any drop to drink.*
— Samuel Taylor Coleridge

FORTUNATELY, most Virginians are not faced with the dilemma of Coleridge's Ancient Mariner. Although several urban coastal areas suffered water scarcity during the droughts of the 1970s and 1980s, Vir-

ginia seems to have sufficient supplies to provide citizens with an abundance of water to drink. A turn of the faucet provides water for cooking, drinking, and other everyday activities as well as for business, industry, and agriculture.

Although much of the 5.6 billion gallons of water used by Virginians each day comes from rivers, streams, and lakes, a significant portion of it comes from another source: groundwater, or water under the ground. In fact,

Virginians on public water systems in 64 of 95 counties rely on this underground water source to supply 50 percent or more of their drinking water. Residents of 37 counties and five of the state's 41 independent cities rely wholly on groundwater. Overall, 41 percent of Virginia's 5.3 million residents depend on groundwater year around. Across the United States, groundwater is the source of drinking water for about half the population.

Groundwater provides Virginians with more than drinking water. Agriculture, an important part of Virginia's economy, maintains its high productivity with the help of this hidden resource. According to U.S. Geological Survey estimates for 1980, almost one-third of the 27 million gallons of water used per day for irrigation of Virginia's crops is derived from groundwater. Nationwide, irrigation accounts for 68 percent of total annual groundwater use. Two Eastern Shore counties, Northampton and Accomack, account for about 70 percent of the total groundwater used for irrigation in Virginia. Benefiting from irrigation are Virginia crops such as flue-cured tobacco, peanuts, corn, soybeans, apples, peaches, and vegetables.

Industries and businesses in Virginia also use groundwater. A papermaking company in Franklin uses about 35 million gallons of groundwater a day, and another in West Point withdraws 20 million gallons a day. In many cases, the development of groundwater resources is far less costly than the development of surface water, where the cost of transporting water over great distances can be high. Surface water facilities with dams, reservoirs, and pipelines must be planned to take into account future needs for additional capacity and must be built as a unit, but supply facilities relying on groundwater can be constructed in stages with later expansion to keep pace with demands. Once a well is dug and a pump installed, a penny's worth of electricity can lift 83.3 gallons or 1,333 cups of groundwater, an excellent return for a small investment.

The supply of groundwater in the 48 adjoining states has been estimated at 65 quadrillion gallons. That's about 3,600 times the amount of water in the Chesapeake Bay. Because of the vastness of its supply, groundwater has been regarded as a limitless resource. And because it is hidden beneath layers of soil and rocks, groundwater has been thought to be protected from human activities.

Edward Born



BEDFORD COUNTY

Unfortunately, groundwater is vulnerable. Widespread contamination of groundwater by pesticides is being discovered in many areas of the United States, and synthetic chemicals, heavy metals, and other contaminants are being found in the groundwater near Superfund cleanup sites across the

country. Once contaminated, groundwater is very expensive to clean up. Pinpointing the source of contamination is often difficult, as is removing contaminants from water. Preventing groundwater contamination from occurring is the best way to protect this valuable resource.

This book is designed to help Virginians protect the state's groundwater. Because groundwater is hidden, many people find it difficult to understand the factors which affect its occurrence, movement, and contamination; we've devoted the next chapter to a general overview of hydrogeology, the study of groundwater. Then we present the most common threats to Virginia's groundwater, providing information about the extent of the problem nationwide as well as in Virginia and about what citizens can do to help protect groundwater. Another chapter describes well water testing and methods for purifying your well water if it does become contaminated. Appendices list the Virginia state agencies concerned with groundwater protection, state and federal laws protecting groundwater, publications which provide additional information about groundwater and threats to groundwater, and units of measurement used throughout the book. A glossary defines the words that appear in italics in the text.

We wrote this book to inform you about Virginia's groundwater and to encourage wise use of this irreplaceable resource. According to water resources experts, Virginia's groundwater is generally of good quality. Let's make a statewide effort to keep it that way.

ABCs of Hydrogeology

Before learning how substances and land-use practices threaten groundwater, let's look at its origin, occurrence, and movement

BEFORE describing the threats to Virginia's underground waters, we want to introduce the water cycle and basic *hydrogeology* — the study of groundwater. Because it is hidden beneath the earth's surface, many people have trouble visualizing groundwater and understanding its origin, occurrence, and movement. The study of groundwater is a complex science, and we do not have the space to present a complete description of that science here. However, we hope this brief and general introduction to groundwater will help readers understand some of the factors influencing groundwater contamination. For readers who want more information, we have listed a number of texts and reference books in Appendix D.

Hydrologic Cycle

THE constant movement of water above, on, and under the earth's surface is known as the *hydrologic cycle*. Water molecules move among "water compartments" of the cycle: fresh waters on the surface (lakes, rivers, and glaciers), living organisms, underground waters, the oceans, and atmospheric water. Although the movement through these components of the cycle is continuous, the span of time it takes to totally replace water in the atmosphere — nine days — is very different from the 37,000 years needed to totally renew the large volumes of water stored in the oceans. The hydrologic cycle has neither a beginning nor an end, but we'll select moisture-laden clouds in the atmosphere to begin our explanation.

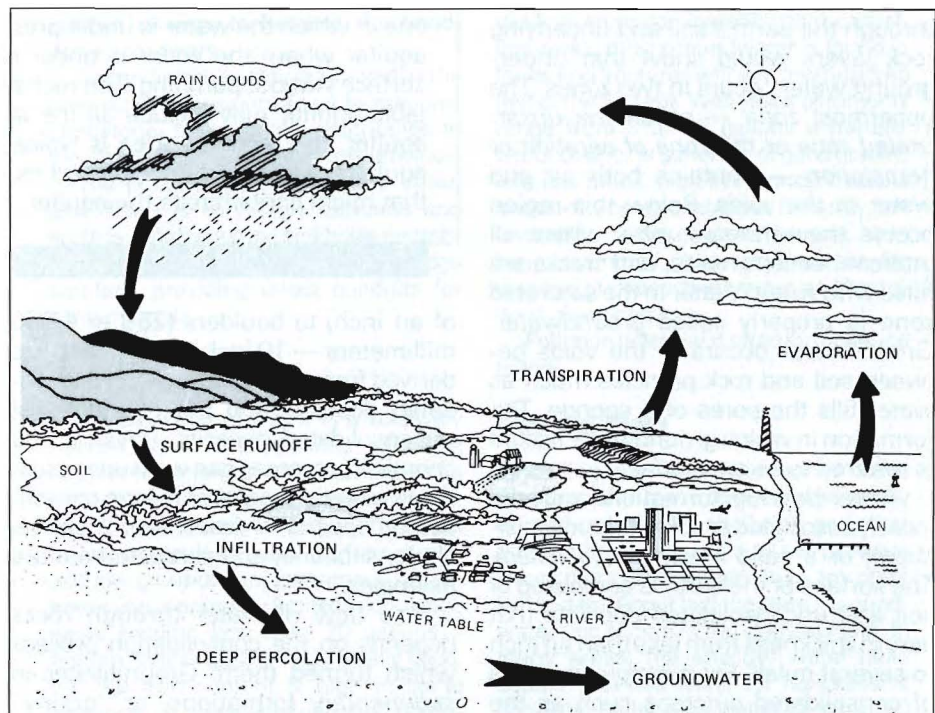
Clouds release moisture, or *precipitation*, commonly as snow or rain. In Virginia, about 30.5 trillion gallons of

water fall on the state's 40,817 square-mile area every year, according to estimates by the U.S. Geological Survey. The average annual precipitation ranges from 36-50 inches a year, with extreme southeastern and southwestern portions of the state receiving the most. Much atmospheric moisture evaporates before it reaches the earth, but that which falls to land can moisten the soil.

Once the surface of the soil is moist, water may begin to *infiltrate*, or penetrate, to deeper subsurface zones. The rate at which water moves laterally and downward through soil layers depends on soil type, land use, amount and duration of precipitation, and extent of vegetation. When the rate of precipitation exceeds the rate of infiltration,

water flows over the surface of the land as *runoff*. Precipitation and surface runoff supply some of the water that feeds streams, lakes, rivers, and oceans.

These surface bodies of water are also fed by water from underground. The water that seeps down through the soil's surface layer to the underlying soil and rocks is known as subsurface water, or underground water. This underground water reappears aboveground as springs and seeps and is an important source of supply to surface waters. Every year, about a billion gallons of groundwater discharge into the Atlantic and Pacific oceans, and according to the U.S. Geological Survey, 30 percent of the annual average flow of streams in Virginia is derived from groundwater.



A Cycle without Beginning or End . . .

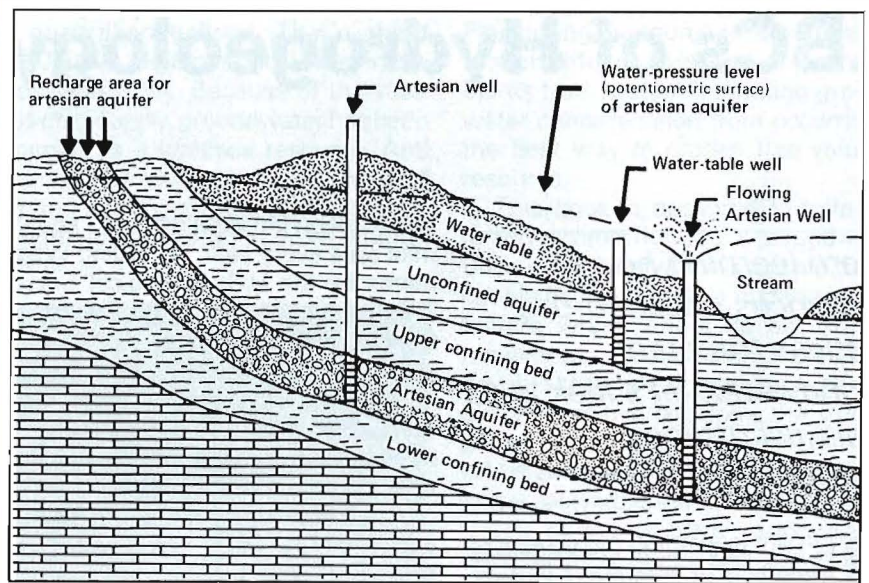
Scientists call the constant movement of water from the atmosphere to earth to river to ocean the hydrologic cycle. How long it takes water that falls from the clouds to return to the atmosphere varies tremendously. After a short summer shower, it may be only a matter of minutes before most of the rainfall has evaporated into the atmosphere. A drop of rain falling on the ocean may take as long as 37,000 years before it returns to the atmosphere, and some water has been in the ground for millions of years.

Most moisture entering the soil is returned to the atmosphere through simple evaporation or through a more complex process known as *transpiration*. This latter process occurs when plant roots in the soil take up water, some of which eventually escapes into the atmosphere through the plant's leaves. The combined loss of water through evaporation and transpiration is known as *evapotranspiration*. The evapotranspiration of water — from the oceans and other surface waters, the land, and vegetation — and its return to the atmosphere where it reforms clouds completes the hydrologic cycle.

Basic Hydrogeology

MOST of the soil and rock formations within a half-mile of the earth's surface consist of solid rocks and minerals and the empty spaces between and within them. The empty spaces are called voids or pores. These voids can hold gases or fluids, including the underground water that supplies wells and springs. A deep vertical cut down through the earth's soil and underlying rock layers would show that underground water occurs in two zones. The uppermost zone — called the *unsaturated zone* or the *zone of aeration* or *percolation* — contains both air and water in the voids. Below this region occurs the *saturated zone*, where all interconnections, voids, and cracks are filled with water. Water in the saturated zone is properly called *groundwater*. Groundwater occurs in the voids between soil and rock particles much as water fills the pores of a sponge. The formation in which groundwater occurs is referred to as an *aquifer*.

Water-bearing formations may be loosely associated or soil-like (*unconsolidated*) or a solid mass (*consolidated*). The surface of the earth is composed of soil and unconsolidated deposits that vary in thickness from less than an inch to several miles. For example, in areas of consolidated outcrops such as the Canadian Shield, a plateau which extends over half of Canada, the soil at the surface may be only a few millimeters (less than a tenth of an inch) deep — or lacking altogether. Below the Mississippi River delta, on the other hand, soil and unconsolidated deposits extend to more than 12,000 meters (7.4 miles) below the surface of the earth. The particles in unconsolidated deposits, ranging in size from clay (0.004 millimeters or less — less than a thousandth



A Word about Aquifers and Artesian Wells

Aquifers can be confined or unconfined. A confined or artesian aquifer is one in which the water is under pressure. A flowing artesian well taps an aquifer where the water is under enough pressure to rise to the land surface without pumping. The recharge area for an unconfined or water-table aquifer may include all the land surface above it; for a confined aquifer, the recharge area is typically less extensive. For both types of aquifers, it is important to protect recharge areas from land-use activities that might contaminate the aquifer.

of an inch) to boulders (256 to 4,096 millimeters — 10 inches to 13 feet) are derived from the weathering of consolidated deposits and the reworking of unconsolidated deposits. Physical and chemical processes can weld unconsolidated materials together to form consolidated deposits — *limestone*, *dolomite*, *shale*, *siltstone*, and *conglomerate* are examples.

The flow of water through rocks depends on the consolidation process which formed them. Groundwater in *sedimentary* formations, or "grainy" rocks formed by sediments deposited in layers, flows between grains, much as it does in an unconsolidated deposit such as a layer of sand. *Limestone* and *sandstone* are both sedimentary rocks. *Crystalline rocks*, formed by great heat, pressure, or chemical reactions into solid masses, usually lack pore spaces. *Metamorphic rocks*, such as *slate*, and *igneous rocks*, such as *granite*, are both types of crystalline formations. In metamorphic rocks, water flow and storage

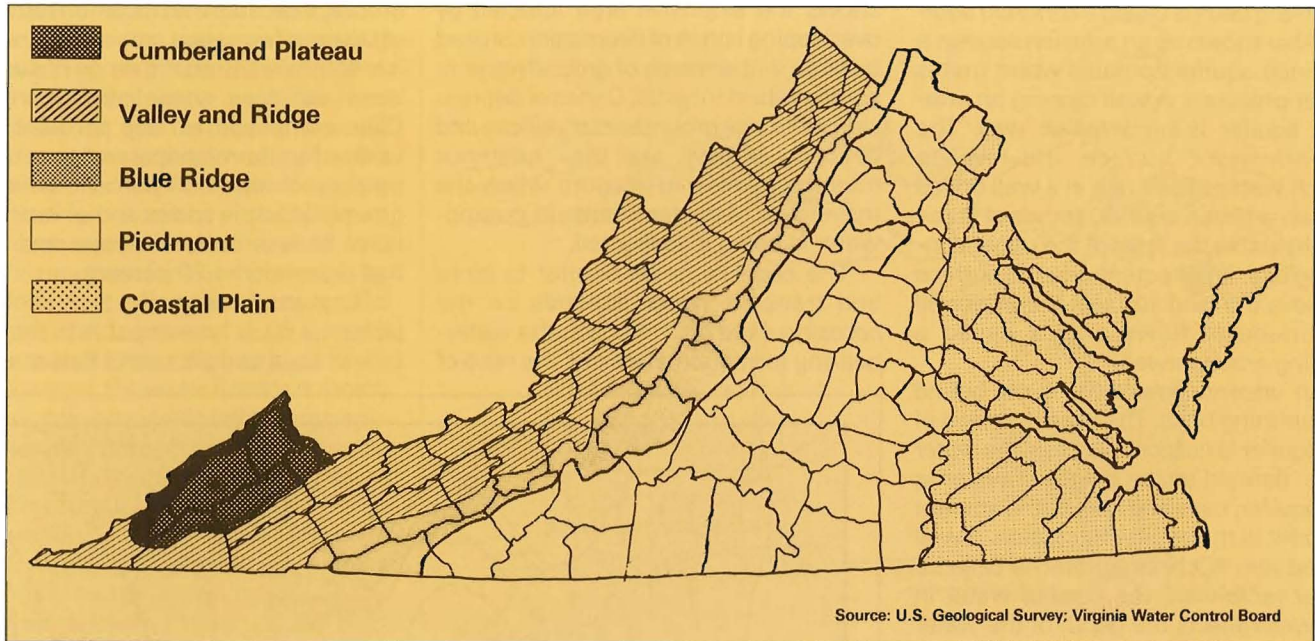
can occur both between grains and within fractures. Groundwater flow and storage in igneous rocks is usually via fractures, faults, and cracks.

Pores formed at the same time the rock is formed, such as those found in sand, gravel, and lava, are called primary openings. Openings created after the rock is formed, such as cracks in granite or solution channels in limestone, are called secondary openings. Many sandstones and limestones and other sedimentary rocks have both primary and secondary openings, and groundwater may be stored in both types of openings.

Aquifers: Confined and Unconfined

Most formations beneath the unsaturated zone can be considered either an aquifer, a water-bearing consolidated or unconsolidated unit, or a *confining bed* or *aquitard*, a rock or soil unit that restricts the movement of groundwater into or out of adjacent aquifers. Aquifers can be confined or unconfined.

An aquifer completely filled with



Geologists Find Virginia Fascinating Place

To a geologist, Virginia is a fascinating place because of its geologic diversity. The Commonwealth has five distinct areas — called *physiographic provinces* — of similar geologic structure and climate. The geology of each province affects the quantity and quality of groundwater in it. The descriptions below are based on information from the Virginia Water Control Board.

Cumberland Plateau

The Cumberland Plateau is underlain by sandstone, shale, and coal. Groundwater is generally of poor quality, tending to be sulfurous and iron-rich. Naturally saline waters occur at depths greater than 300 feet. In coal mining areas, some groundwater has become acidic and is unsuitable for most uses. Wells generally yield from 10 to 50 gallons a minute. The potential for groundwater pollution is moderate in the Cumberland Plateau.

Valley and Ridge

Limestone, dolomite, shale, and sandstone are the common rock types in the Valley and Ridge province. Where limestone dominates, groundwater yields may be as high as 3,000 gallons a minute. Ridges and upland areas are often underlain by sandstone and shale, which yield only enough water for domestic use.

The relationship between groundwater and surface water is easily recognized here. In limestone areas, sizable surface streams disappear into underground

channels and, conversely, some large springs emerge to become the headwaters for rivers.

Groundwater quality is affected by the chemical composition of rock formations. Limestone, for example, contributes to the "hardness" of water in this province.

The pollution potential in the Valley and Ridge is very high. Streams and surface runoff entering sinkholes contribute to the recharge of Valley and Ridge aquifers, providing direct conduits for contaminants.

Blue Ridge

The Blue Ridge province is a relatively narrow zone of mountains with the highest elevations in the state. The rocks underlying the area are granite, gneiss, and marble. Steep terrain and thin soil covering result in rapid surface runoff and low groundwater recharge. Groundwater use is primarily limited to domestic wells yielding less than 20 gallons a minute. Water quality is generally good, but the iron content is high in some locations. Groundwater pollution potential is low.

Piedmont

The Piedmont extends from the fall line — an imaginary line passing through Emporia, Petersburg, Richmond, Fredericksburg, and Fairfax — to the Blue Ridge Mountains.

The subsurface geology of the Piedmont province is diverse, resulting in wide

variations in groundwater quality and well yields. In areas dominated by hard, crystalline rocks, most groundwater is found in faults and fractures within a few hundred feet of the surface. Well yields commonly range from 3 to 20 gallons a minute. Groundwater is generally of good quality; in a few areas, high iron concentrations and acidity cause problems. Recently, the crystalline rocks of the Piedmont have been examined as a potential site for disposal of radioactive wastes and hazardous chemicals.

Pollution potential is rated as moderate to low.

Coastal Plain

Extending from the fall line to the coast, the Coastal Plain is composed primarily of sand, gravel, clay, shell rock, and other unconsolidated deposits. This province stores more groundwater than any other in the state. About half the state's groundwater use occurs in the Coastal Plain. In many areas, the shallow water-table aquifer provides water for hundreds of domestic wells with yields of 10 to 50 gallons a minute. The deeper system of artesian aquifers is the primary source of water for municipal and industrial use. Some large production wells yield 2,000 to 3,000 gallons a minute. Water quality is good, except in a few areas where salt water, iron, and hydrogen sulfide occur.

The highly permeable soils in the Coastal Plain and the high population density result in a high pollution potential, especially for the shallow aquifers.

water and surrounded on all sides by confining beds is called a *confined aquifer*. Also known as an *artesian aquifer*, a confined aquifer contains water that is under pressure. A well tapping an artesian aquifer is an *artesian well*. The *potentiometric surface*, the level to which water would rise in a well drilled into an artesian aquifer, stands at some height above the level of the upper confining bed. If the potentiometric surface is above the land surface, then the well continuously flows and is called a flowing artesian well.

An *unconfined aquifer* is not bound by confining beds. The upper surface of the aquifer is not confined, and the *water table*, defined as the height of water in the aquifer, rises and falls as the amount of water in the aquifer fluctuates. A well drilled into such an aquifer is called a *water table well*; the level of water in the well reflects the depth of the water table in the surrounding aquifer. In some areas, relatively small volumes of water may occur above the water table. This water, collected on top of an unsaturated soil or rock layer above the main body of groundwater, is called *perched water*. The water table is not usually level; more often it reflects the surface topography above it and has "hills" and "valleys" just as the land surface does. In general, the water table is at depths of zero to twenty feet in humid areas and can be hundreds of feet underground in desert areas.

The depth of the water table beneath the land surface influences land use and development of water supplies. Where the water table is close to the surface, land is marshy or "water-logged" during wet weather and unsuitable for residential and other uses. Alternately, the cost of constructing wells and pumping water may be prohibitively expensive where the water table is far beneath the surface.

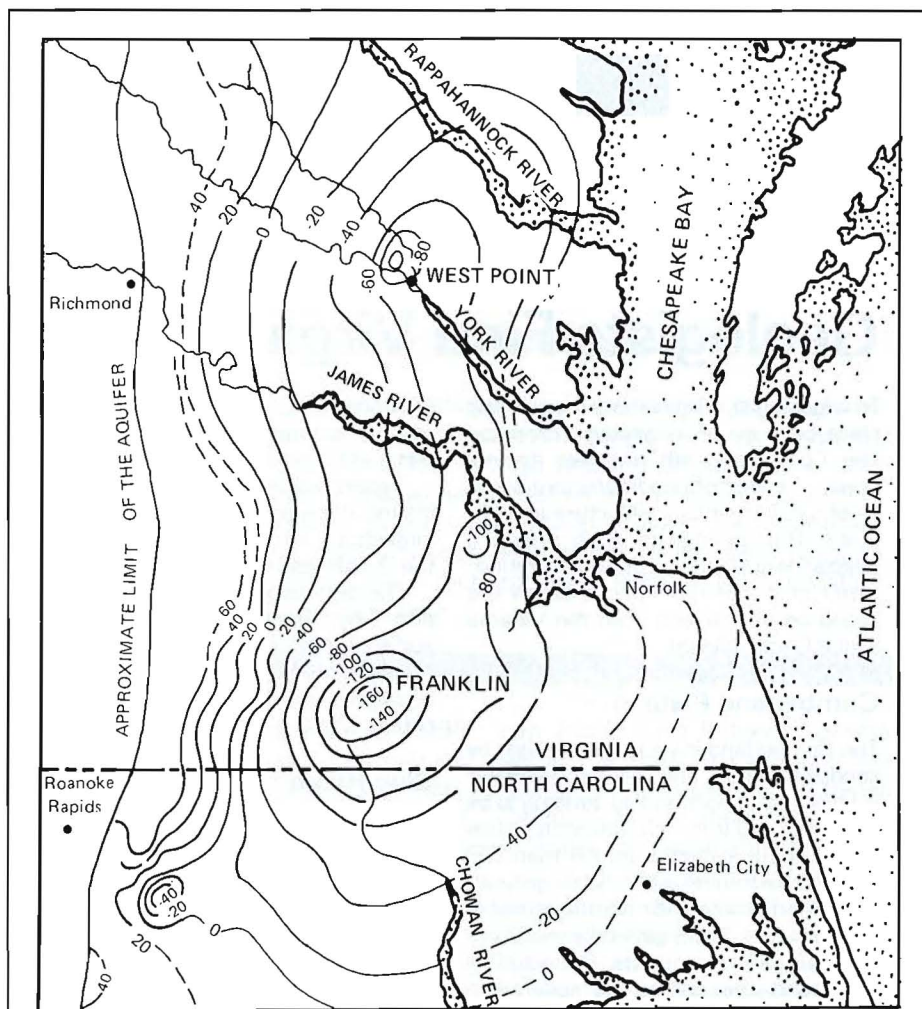
Cones of Depression Wells tapping both confined and unconfined aquifers can cause the formation of *cones of depression*, or "valleys," in the aquifer. This decline in water level in the vicinity of a well may extend for just a few feet or hundreds of feet around a well in an unconfined aquifer, but in a confined aquifer a cone of depression may be miles in diameter. Wells that are close together may have overlapping cones of depression. Because the "drawdown" effect is additive, water level decline in an aquifer is greater where overlapping cones of depression occur than where

there is a single cone. The map below shows the extensive area affected by overlapping cones of depression caused by large withdrawals of groundwater in southeastern Virginia. Cones of depression influence groundwater velocity and direction of flow, and their existence must be taken into account when the movement of contaminants in groundwater is being investigated.

The capacity of an aquifer to store and transmit water depends on the *porosity* of the rock or soil in the water-bearing formation. Porosity, the ratio of

voids or pores to the total volume of soil or rock, indicates the maximum amount of water a formation can contain when it is saturated. Both the range of particle sizes and their shape affect porosity. Clay, composed of tiny particles and voids of uniform shape and size, has a porosity of about 50 percent, whereas gravel, which is composed of rock particles of less uniform shape and size, has a porosity of 20 percent.

For water in an aquifer to be useful to people, it must be pumpable to the surface at a reasonable rate of flow and at a



Source: U.S. Geological Survey

That Sinking Feeling in the Coastal Plain

Withdrawals of about 73 million gallons a day from well fields have caused two giant cones of depression to form in an extensive confined aquifer in Virginia and North Carolina. Pumping by papermaking industries in Franklin and West Point, Virginia, is responsible for more than 60 percent of the daily withdrawal. In this area, such cones of depression can result in saltwater intrusion or the collapse of the water-bearing formation and land above it. The numbers on the map represent height in feet of the aquifer's potentiometric surface relative to mean sea level. Around Franklin, the depth to groundwater below the land surface had declined 165 feet since the 1930s but has recently stabilized.

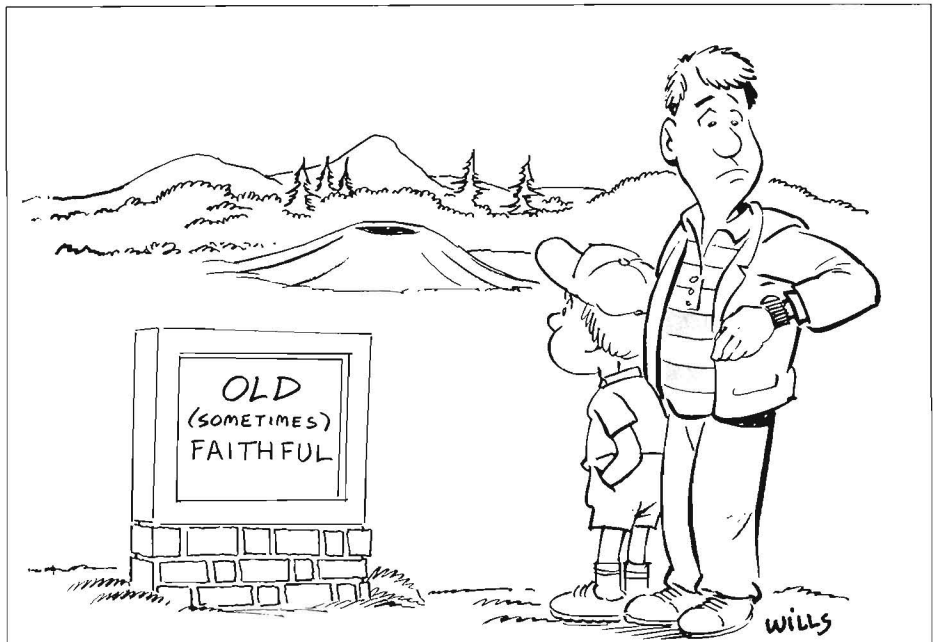
reasonable cost. Although an aquifer may have a high storage capacity, or porosity, its water may not be easily available. The term *specific yield* refers to the amount of water available from an aquifer for use by people. *Specific retention* refers to the amount of water unavailable for use because it is tightly bound to the rock unit by physical forces. Measurements of specific yield and specific retention for a particular aquifer equal its total storage capacity. For example, clay's porosity of 50 percent indicates that it has a high storage capacity. However, the water it holds is mostly unavailable; clay yields little water (specific yield of 2 percent) because physical forces bind the water to the clay particles (specific retention of 48 percent).

Materials with high specific retention have low *hydraulic conductivity* and are commonly termed *impermeable*. Materials have a low hydraulic conductivity or a low ability to transmit water because the pores and voids in the material are not interconnected. Interconnections of openings in limestone and granite allow these rock units to yield much of their available water.

An ideal aquifer for a water supply would have a high storage capacity, high specific yield, high hydraulic conductivity, and good water quality. Unconsolidated sand and gravel aquifers generally are highly productive because they have both high permeability and porosity. In fact, sand and gravel aquifers are the main source of water for most wells in the United States. Unfortunately, their high permeability (high hydraulic conductivity) also makes them more vulnerable to contamination.

Recharge and Discharge Aquifers can be thought of as porous conduits filled with sand and other materials that transmit water from *recharge* to *discharge* areas. Any addition to the groundwater supply is recharge and any removal from this supply — whether it be to pumping wells, springs, seeps, streams, or marshes — is discharge. In the eastern United States, precipitation exceeds evapotranspiration, and annual average recharge of aquifers generally equals or exceeds discharge. In the arid southwestern United States, annual precipitation is less than 10 inches; rates of evapotranspiration are potentially 4 to 20 times greater than precipitation, and recharge may not balance discharge for years or even centuries.

The values for annual precipitation and recharge in Virginia can be used to



No Longer Faithful

Old Faithful, the Yellowstone National Park geyser so named because of its dependability, can no longer be trusted to erupt on schedule. An earthquake in Idaho disrupted its groundwater system. Eruptions which used to occur 65 minutes apart now average 78, with as long as 90 minutes between bursts.

estimate the impact of human use on the state's groundwater. Assuming about 10 percent — a conservative value — of Virginia's total annual precipitation (30.5 trillion gallons) is available as recharge to groundwater, this would equal an annual statewide recharge of 3 trillion gallons. In 1980, total annual groundwater use was about 142 billion gallons (389 million gallons per day for 365 days), according to the Virginia Water Control Board and the U.S. Geological Survey. Based on these estimates, the total groundwater supplied to all users — domestic, agricultural, industrial, and thermoelectric — was only 4.5 percent of the annual average recharge. However, large withdrawals of groundwater in specific locations in Virginia have caused the water table to drop locally, forming extensive cones of depression around the withdrawal points. The use of groundwater which results in discharge exceeding recharge is referred to as overpumping or mining.

Many people greatly overestimate the rate of groundwater's movement from regions of recharge to discharge because they mistakenly think groundwater flows at rates similar to those of streams and rivers. The average rate of water move-

ment through an aquifer composed of coarse sand is 0.3 meters per day (360 feet per year), whereas the average rate through a clay confining bed is 0.00002 meters per day (less than half an inch per year). Only in limestone caverns, open lava tubes, or large rock fractures can the rates of groundwater movement resemble those of streams and rivers on the surface. The movement of contaminants through such formations is likewise very rapid.

Because the movement of water from recharge to discharge areas is generally so slow, groundwater at any one place may be very old. According to the U.S. Geological Survey, groundwater within 800 meters (half a mile) of the land surface has been underground for an average of 200 years. For aquifers deeper than 800 meters, that average is 10,000 years. This slow movement means groundwater contamination can have long-term effects. Toxic chemicals spilled into surface streams often are quickly "flushed" from the area and diluted by the large volumes of water moving rapidly over the streambed. The same chemicals spilled into an aquifer could remain for hundreds or thousands of years.

Threats to Groundwater

The amount of groundwater and the complexity of monitoring and sampling it make protecting this vital resource difficult

THE vastness of our nation's groundwater reserves and the complexity of sampling for all possible pollutants make the task of protecting groundwater quality an enormous one. Groundwater contamination, the introduction of substances and *pathogens* that make the water unfit for present and future uses, is hard to detect until the water is brought to the surface. Indicators of surface water pollution — such as dead fish, smell, and discoloration — do not serve as warning signals for groundwater. Except for gasoline and certain other petroleum products that humans can smell at infinitesimally low concentrations — less than 0.005 parts per million — most commonly occurring contaminants are odorless and colorless and occur in low concentrations. As long as the water remains in the ground and is not brought to the surface by springs or wells, pollution usually is undetected. Consequently, measurable effects of pollution generally are noticed long after the actual contamination has occurred. This lag between occurrence and detection can allow pollutants to spread and contaminate large volumes of groundwater.

That human activities can have a negative and long-term influence on groundwater is now well recognized, but measuring the effects of those activities is hard. In 1984, the Environmental Protection Agency surveyed the nation's 48,000 public water systems that use groundwater. Synthetic chemicals were detected in about one-third of the systems serving more than 10,000 people. However, in all but 3 percent, the concentrations of contaminants were below the standards that the federal agency is considering establishing for drinking water. Little or no information exists on

contamination in the nation's 160,000 noncommunity systems which rely on groundwater or the 40 million individual wells.

Activities that can affect groundwater quality include improper land disposal of liquid and solid waste, using improperly functioning *septic systems*, spills and leaks of petroleum products, misapplication of fertilizers and pesticides, and spreading salt mixtures for highway deicing. The possible impact of these threats to groundwater supplies across the United States could be very large. Consider the pollution potential of the following:

- 23 million septic tank systems

- 9,000 municipal *landfills*
- 190,000 surface *impoundments*
- An estimated 3 million to 10 million underground storage tanks of which 1.8 million store petroleum and hazardous materials
- The annual application of pesticides to 280 million acres of cropland
- 50 million tons of fertilizer applied yearly to crops and lawns
- 548,000 active and 1.2 million abandoned oil and gas wells
- 15,000 active and 67,000 inactive coal mines as well as mines for phosphates, lead, zinc, iron, gold, uranium, and other substances
- The annual storage of 600 to 900

Groundwater Policy

Puddle of Prevention Worth Ocean of Cures

RESTORING a badly contaminated aquifer to drinking water quality is seldom attempted or achieved. Most of the corrective efforts involve the removal of the primary contamination source — a leaking surface impoundment, rusted underground tank, or spill of petroleum. Afterward, an attempt is made to measure the extent of contamination and to monitor and prevent the spread of contaminated groundwater. The large volumes of water that would have to be pumped from underground and then purified make the complete renewal of aquifers economically impossible. Instead, devices to remove contaminants are placed at the water supply well. Present costs for treating public water supplies that have been contaminated with organic compounds are about \$1.50 to \$4.50 a month for each family served.

Containing groundwater contamination is expensive at all levels. Initial hydrological and geological studies to determine the extent of pollution may cost as much as \$25,000 to \$250,000. Litigation may double the costs of these initial investigations. The smallest cost of the groundwater phase of partial cleanup and containment is typically \$500,000. Costs for cleaning up more complex types of contamination can be as high as \$5 to \$10 million. According to a survey of consulting firms and other groups that deal with aquifer restoration, restoring a heavily contaminated aquifer to drinking water quality could cost hundreds of millions of dollars and take decades or centuries to complete.

Society today is bearing the costs of pollution that took place decades ago. Although restoring the quality of polluted groundwater is exceedingly complex and costly, unwillingness to restore aquifers now imposes the risks associated with groundwater contamination on future generations. Groundwater protection and pollution prevention today is the best insurance against exorbitantly expensive cleanup problems tomorrow.

million metric tons of materials (coal, sand, gravel, copper, iron ore, uranium ore, potash, titanium, phosphate rock, salt, and gypsum)

- Over 10 million tons of dry salt and 2 million gallons of liquid salt applied to highways each winter

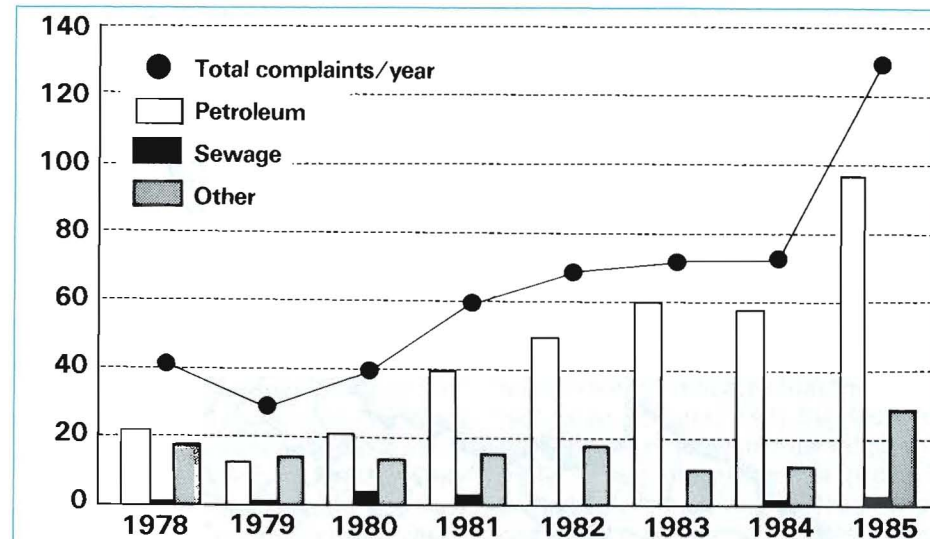
In a 1984 groundwater strategy report, the Environmental Protection Agency stated that groundwater pollution could not yet be adequately measured because data collection on certain chemicals believed to be harmful to human health has just begun. The extent of contamination from any source depends on the geology of an area, and that further complicates the assessment of groundwater contamination. Contaminants may be found in one water-bearing rock formation but not in another, only a short distance away, if the two areas are separated by tightly packed shale or some other impermeable rock. In an area underlain by limestone, on the other hand, contamination can spread over a much wider area. Incomplete understanding of local geology often limits human ability to predict the direction and extent of groundwater contaminant movement.

Despite these difficulties in assessing groundwater pollution, the Environmental Protection Agency and others estimate that only about 1 to 2 percent of the aquifers used nationwide have been contaminated by industrial impoundments, landfills, septic systems, and mining. At the time of these calculations in 1980, no estimates were made of the potential impact of other activities unrelated to waste disposal.

Virginia's Groundwater

MUCH of the information about groundwater contamination in Virginia comes from citizen complaints. For rural dwellers, a change in the taste or smell of well water signals a problem. For an urban dweller, the odor of gasoline in the basement may mean a storage tank or line at a nearby service station is leaking. The domestic well and basement, though not designed for the purpose, can serve as monitoring wells.

The Virginia Water Control Board's Pollution Response Office, which cleans up groundwater pollution and takes action against individuals or firms responsible for contamination, began recording citizen complaints about groundwater problems in 1978. The number of complaints increased sharply over the next



Source: Virginia Water Control Board

From 1978 through 1985 complaints of groundwater pollution reported to the Virginia Water Control Board rose from 41 to 129. Only a small percentage of the complaints require cleanup but the effect of each pollution event is cumulative on the resource; that is, this year's events are added to last year's because many of last year's events are still polluting groundwater.

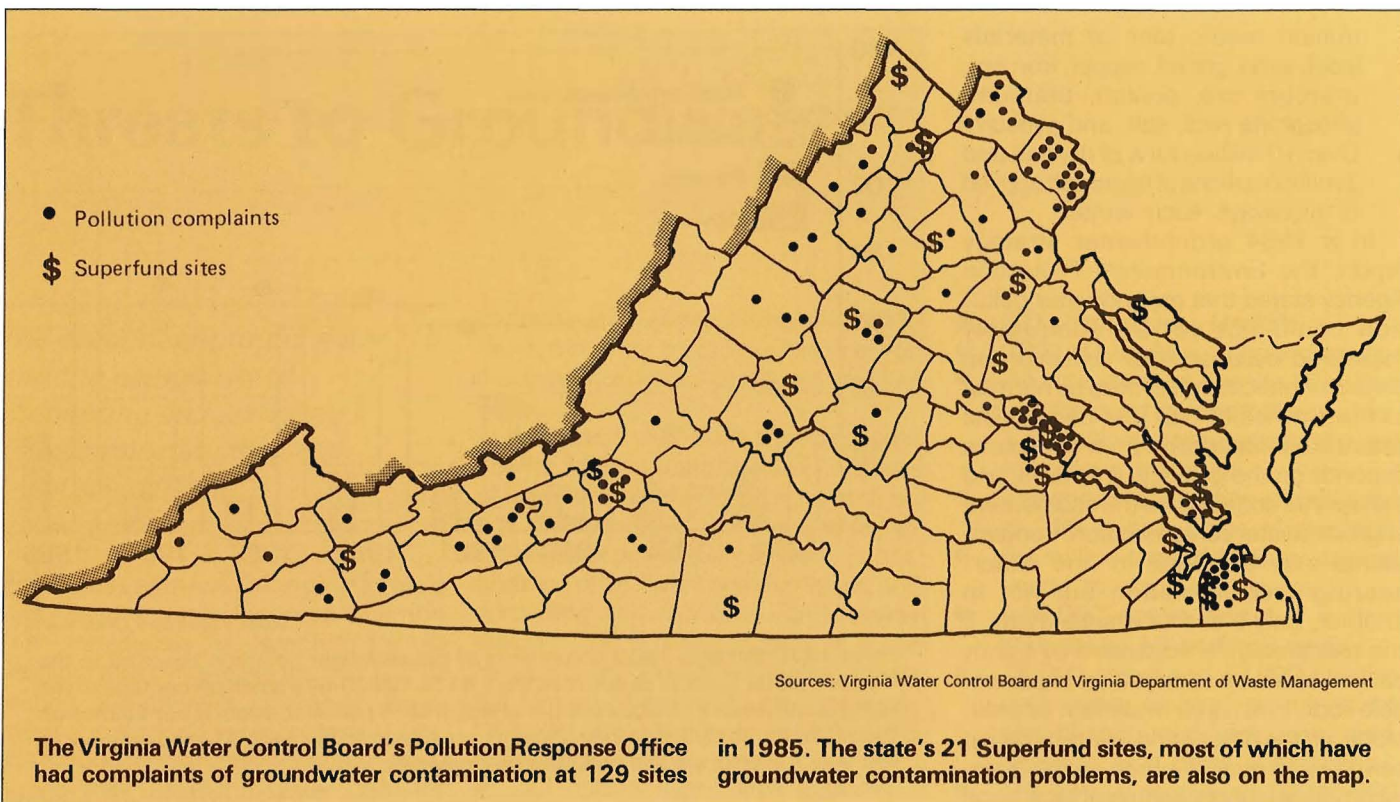
several years. In 1978, the Pollution Response Office received 41 complaints; by 1985 the annual total had jumped to 129. Although this information may reflect increasing citizen awareness, it also provides some indication of the extent of groundwater problems in the state. While the number of complaints has increased, the proportion of complaints in each category — petroleum products, sewage, and other — has remained about the same throughout the reporting period.

In spite of this increase in complaints, the extent of groundwater pollution in Virginia is thought to be small by state officials. Pollutants appear to be concentrated in aquifers near the spill or production site. The Virginia Water Control Board has estimated that a very low percentage of the state's aquifers are contaminated. If this sounds like hedging, that's because it is. Groundwater is, by definition, out of sight. Without an extensive network of monitoring wells and a program of sample analysis, it is only possible to make approximations about groundwater quality.

Petroleum Complaints Lead List Analysis of Virginia Water Control Board records can provide some idea of statewide trends in groundwater pollution, however. More than 620 pollution complaints have been received during the nine years — FY 1978 to 1987 — the

pollution response program has been operating. About 75 percent of the complaints concerned groundwater contaminated by petroleum products — gasoline, diesel fuel, heating fuel, kerosene, motor oil, and others. Complaints about contamination by human and animal wastes amounted to only 3 percent, but this percentage may be deceptively low. The Virginia Department of Health receives most complaints about sewage and bacterial contamination. These complaints are not available for all areas of the state and are not included in the Virginia Water Control Board's summation. The remaining complaints involve contamination by pesticides; diverse kinds of *synthetic organic compounds*, some known to be *carcinogenic* or *mutagenic*; fertilizers; *leachate* from landfills; *heavy metals*; and natural contaminants, such as iron, fluoride, sulfate, manganese, and radon.

Does this mean that petroleum products pose the major threat to aquifers in Virginia? Based on present information, accidental spills and leaking storage tanks and lines are major problems, especially in urban areas. As the map of Virginia illustrates, most contamination complaints during 1985 occurred in urban areas. However, other equally serious but undocumented threats to Virginia's groundwater may exist. Although the information collected by the Virginia Water Control Board is sound, it



is incomplete. Data based on citizen complaints about drinking water provide evidence only of sites where groundwater smells or tastes peculiar. At present, little is known of the extent of contamination by compounds that transmit no taste or odor to water but may affect the health of those drinking it regularly.

Citizen complaints can serve as indicators of obvious contamination problems in the state, but monitoring for chemicals that are not smelled or tasted by humans could provide valuable information. Groundwater is not routinely monitored for synthetic compounds; these hard-to-detect man-made chemicals can cause extensive damage before their presence is noted. For example, storage tanks at an IBM plant in Manassas, Prince William County, leaked synthetic and volatile organic chemicals into groundwater for years before the contamination was detected. The contamination of a public water supply affected 20,000 households. The concern raised by that contamination event led the Prince William County Health Department to test groundwater at a number of sites. This monitoring — the most extensive program in the state —

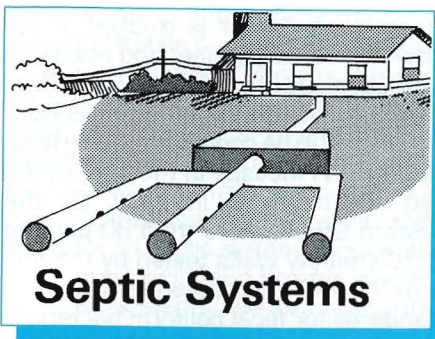
revealed trichloroethylene, carbon tetrachloride, and other synthetic organic compounds in at least four wells. At one industrial site, the water contained 3,046 micrograms per liter (parts per billion) of trichloroethylene, 600 times higher than the level used as a guideline by the health department.

Although the Virginia Water Control Board does not extensively monitor contaminants statewide, it does monitor *pH*, *alkalinity*, *hardness*, *conductivity*, and concentrations of phosphorus, nitrogen, sulfate, fluoride, calcium, copper, iron, chloride, magnesium, manganese, sodium, and potassium. However, these indicators of groundwater quality are often more a reflection of the surrounding geologic formations than of human activities, although some human activities influence levels of naturally occurring substances.

Groundwater Protection Strategy In May of 1987, a document describing Virginia's groundwater protection strategy was sent to the Governor, cabinet secretaries, and state agency heads. The 80-page document resulted from a year of work and study by the state's Groundwater Protection Steering Committee.

Chaired by a member of the Virginia Water Control Board, the committee included members of nine state agencies whose programs affect groundwater quality, including the Department of Health and the Department of Waste Management.

Titled *A Groundwater Protection Strategy for Virginia*, the document identifies major threats to Virginia's groundwater as well as problems that affect specific regions of the state. We have organized this book in a similar fashion. The sections which follow describe the major threats identified by the Steering Committee: septic tanks, fertilizers, pesticides, underground storage tanks, landfills, and lagoons. In each section, we describe the threat, its source, the extent of the problem in Virginia, the Steering Committee's recommendations for protecting groundwater from each threat, and what individuals can do to help protect groundwater. We also provide information on other sources of groundwater contamination: mining, water withdrawal and saltwater intrusion, stockpiles and bulk storage, spills, underground injection, abandoned wells, and natural substances found in groundwater.



Septic Systems

ACCORDING to the U.S. Environmental Protection Agency, septic systems are the major source of groundwater contamination. Designed to dispose of wastes and to prevent wastewater from ponding on the surface, septic tank systems were not designed to prevent groundwater contamination. Unfortunately, as the leading contributor to the total volume of waste discharged directly into the ground — more than a trillion gallons annually from residences — septic systems have a high potential to pollute groundwater with contaminants, including nitrates, *coliform bacteria*, viruses, and a variety of organic and inorganic chemicals from household products. Sixty percent of the 23 million residential septic tanks in the United States are believed to be operating improperly.

Inappropriate siting and poor design, construction, and maintenance of septic systems can cause pollution of underlying groundwater. The potential for groundwater pollution is affected by the amount of time wastewater stays in the soil, the kinds of waste in the effluent, and the type of soil through which it moves. When many septic tank systems occur in an area, the soil's capacity to filter impurities from the effluents may be exceeded. The design life of septic systems averages 10 to 15 years. Many septic systems installed in the 1960s, though still in use, have exceeded their design life and may no longer be functioning properly.

An appropriate soil for a septic tank field should absorb all effluent generated, provide a high level of treatment before the effluent reaches the groundwater, and have a long, useful life. Sand lets wastewater run through it too quickly, and heavy clays impede wastewater movement, allowing it to pool or pond on the surface instead of moving through the soil. In some areas of Virginia, fractured rock or interconnected solution channels in limestone

allow concentrated wastewater to travel long distances underground; eventually groundwater or surface water is contaminated. To prevent siting in soils that will allow ponding of raw sewage, the Virginia Department of Health requires "perk tests," measurements of the rate at which clean water percolates through saturated soil, to be done before septic system permits are issued.

Septic tank problems are frequently magnified because people who use subsurface on-site waste disposal often rely on wells for drinking water. Improper siting and system failures allow wastewater to collect near the surface and be transported to inadequately sealed wells or to lakes and streams. Wells may be contaminated when wastewater enters an aquifer.

Contaminants Insecticides, herbicides, and metals can enter groundwater from a septic field through normal household disposal practices and through corrosion of old plumbing. Nitrates from a failing septic system can contaminate groundwater. Even products used to clean septic tanks may contaminate groundwater. One of the most often found *volatile*, or gas-forming, organic contaminants in groundwater is a septic tank cleaner, trichloroethylene. A known carcinogen, trichloroethylene also is used as a degreaser and industrial *solvent*.

Contamination of drinking water supplies by malfunctioning septic systems can cause outbreaks of waterborne contagious diseases, such as

infectious hepatitis. System overflows can transmit other pathogens and diseases — typhoid, cholera, streptococci, salmonella, protozoans, tapeworms, roundworms, and viruses. Some of these pathogenic organisms can travel long distances and live for a long time in the soil outside a host animal, especially in moist soil. Intestinal bacteria have been reported to survive for 100 days, and viruses may remain capable of reproducing in a host after 170 days in soil.

The presence of fecal coliform bacteria in a well indicates that the water has been polluted with the feces of humans or other warm-blooded animals. Wells often are not properly sealed or grouted, and surface runoff carrying these bacteria from cattle feedlots, septic systems, or other sources can enter a well. Fecal coliforms also may be transported through soil to groundwater supplies in effluent from faulty septic systems. Because coliform bacteria from the intestines of humans cannot be distinguished from those of other warm-blooded animals, coliforms in well water cannot pinpoint the source of contamination. Water contaminated by fecal coliform bacteria is identified as potentially hazardous because it can contain infectious pathogenic viruses and bacteria from fecal discharges of diseased persons.

Septic systems are the major source of groundwater contamination



Edward Born

Outhouses lining the bank of a stream running through Vansant, Virginia, pose a threat to the stream's water quality and to the groundwater that feeds the stream.

According to the Virginia Water Project, more than 200,000 Virginians relied on unsanitary water sources and waste disposal methods in 1985

Primary drinking water standards enacted by EPA — these apply to public water systems that have at least 15 service connections or regularly serve an average of 25 or more individuals daily at least 60 days of the year — have maximum contamination levels for microbes of one fecal coliform bacterium per 100 milliliters (ml). Coliform bacteria, such as *Escherichia coli*, and fecal streptococci (enterococci) average about 50 million organisms per gram of human waste. Untreated domestic sewage contains more than three million coliforms per 100 ml. The fecal coliforms in domestic sewage far outnumber the pathogens, because everyone contributes fecal coliforms and only those with illnesses contribute pathogens. Pathogens outside of the alimentary canal (digestive tract) die off more quickly than nonpathogenic coliforms, so treatment and residence time in the water proportionally reduce the number of pathogens more than the number of nonpathogens. Water that meets the standard of one organism per 100 ml is “statistically” safe for human use because of the improbability of consuming bacterial pathogens. The effectiveness of this bacterial standard in preventing viral diseases is not known.

Since the introduction of septic systems in the United States in 1884, these systems have become the most widely used method of on-site sewage disposal. About one-third of all households nationwide use septic tank systems to dispose of nearly a trillion gallons of domestic wastewater, and 25,000 industrial systems annually discharge an additional 1.2 billion to 1.9 billion gallons of waste into the soil.

In Virginia, about 650,000 households, 34 percent of all year-round housing units, use on-site sewage systems to dispose of household wastes. In rural areas of Virginia, more than 70 percent of all households use on-site sewage disposal. One in ten households has no plumbing in 16 Virginia counties, and in 14 counties more than 20 percent of households use out-

houses. According to the Virginia Water Project, Inc., more than 200,000 Commonwealth citizens in 79,000 households relied on unsanitary water and waste disposal methods in 1985.

Community Problems A number of localities in Virginia have been plagued by septic system problems. A 1982 survey of the Piney River community in southern Nelson County found that 80 percent of the town’s population relied on wells and springs that were contaminated with fecal coliforms. The soil in much of the area is too hard and clayey to absorb wastewater, and the groundwater of nearly the entire community is contaminated with coliform bacteria. A new community well that went on-line in April 1984 supplied 350 households with clean water for the first time since 1979.

In McGaheysville, Rockingham County, nearly 1,000 people have been instructed for more than two years to boil their water. Groundwater samples entering the town’s well were found to have up to nine times the allowable limit of fecal coliforms in 1984. Although a chlorination system lowers

these levels, water is trucked to the local elementary school and residents have been told to boil local water before drinking it. Botetourt County wells were discovered to be contaminated by fecal bacteria in Fincastle in the mid-1970s and in Blue Ridge in 1982. On the Eastern Shore, more than 80 percent of 70 shallow wells tested by the Virginia Water Project failed to meet state standards for fecal coliform bacteria.

Septic System Regulation The Virginia Department of Health regulates individual household septic systems and mass drain field systems, those serving schools, institutions, and clusters of houses. The primary concern of the Virginia Department of Health has been to protect public health from the problems caused by ponding of sewage in soils that do not percolate. The protection of groundwater has received less attention; septic systems have been permitted in areas of highly permeable soils and high water tables that can allow contamination of groundwater. The Virginia Water Control Board regulates commercial and industrial septic systems. It has approved

Septage

A Mess of Grit, Grease, and Hair

GROUNDWATER contamination also can result from improper disposal of septage, the mixture of sludge, fatty materials, and wastewater removed during the pumping of septic systems. Septage is highly malodorous, has concentrations of organisms resembling that of primary wastewater sludge, and contains large quantities of grit, grease and hair.

In Virginia, septage was essentially unregulated before 1982. Now septage is subject to on-site sewage handling and disposal regulations requiring pumpers to take septage to approved facilities, such as municipal treatment plants or state-approved lagoons, where it is aerobically digested by bacteria. Regulations for handling and disposal are currently being revised and will be promulgated by 1989. Septage can be directly applied to land in counties with population densities of less than 100 persons per square mile with the approval of the board of supervisors, local health officials, and the Virginia Water Control Board.

In early 1985, a Septage Management Task Force found that approximately one-third of Virginia’s septage was taken to unapproved disposal sites. Certain counties have no approved septage facilities, so licensed septage haulers must travel to distant approved disposal sites. The illegal dumping of septage in open fields, rivers, and underground tanks has been difficult to control, particularly in these counties with no approved facilities. Improperly storing sludges in unlined excavations and trenches can contaminate groundwater and prohibit the land from being used for agriculture or other purposes.

many systems under the general provisions of a state no-discharge program.

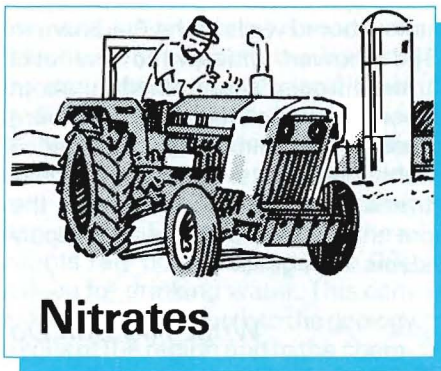
A Groundwater Protection Strategy for Virginia recommends that the Virginia Department of Health and the Virginia Water Control Board form an interagency committee to consider ways to implement water quality standards for all septic systems: residential, mass drain field, and commercial and industrial systems. The *Strategy* further recommends that the agencies strengthen domestic, industrial, and commercial septic system regulations, ban septic cleaners that can contaminate groundwater, educate the public about septic systems and groundwater protection, and suggest to local officials that housing density be controlled or alternative waste disposal methods be used in areas unfavorable for septic system use.

What You Can Do

IF you are building a new home, be sure your septic system is properly planned, sited, and installed. Groundwater typically moves from areas of high water table to low water table. The direction groundwater moves cannot always be predicted from surface topography, but it is generally recommended that septic tanks and drain fields be located downhill from wells or springs and at least 100 feet away. If you're moving to another residence, test the well water and examine the septic system before you begin using it — or even before you agree to buy or rent. The Virginia Water Resources Research Center's *A Homeowner's Guide to Septic Systems* provides information on installing and maintaining septic systems. Having your septic tank pumped out every three to five years, or more often if needed, will help reduce the potential for groundwater contamination. Because excessive amounts of water entering the drain field reduce the soil's capacity to absorb wastewater, water conservation in your home can extend the life of your septic system. Household hazardous wastes should not be poured down the drain and into the septic system. Once in the soil, these chemicals have the potential to contaminate groundwater; they also may kill the bacteria necessary to decompose wastes in the septic tank. The sudden illness of a guest in your home may indicate that your well is contaminated by sewage; often people who regularly drink water contami-

nated with fecal coliforms become "immune" and exhibit no symptoms. Such an illness should prompt you to have your water tested for fecal bacteria.

In small towns and rural areas where soil conditions prevent the use of septic systems and connecting to or constructing a community sewer system is prohibitively expensive, other methods of wastewater disposal may have to be employed. Information about such methods may be available from your local health department.



SINCE the early 1950s, the annual use of fertilizers has increased nationwide from 20 million tons to 40 million tons. Between July 1985 and June 1986, fertilizer sales in Virginia totaled 611,394 tons. In addition to total use of fertilizers increasing, nitrogen in fertilizers has increased from 6.1 to 20.4 percent. The increased nutrient concentrations in soil due to fertilizer use have resulted in greater nutrient absorption and higher crop yields. However, high levels of nutrients also remain in the soil. On the average, only about half of the nitrogen applied as fertilizer is harvested with the crops, and the excess may enter groundwater.

Large amounts of fertilizers are also used in residential areas, parks, and golf courses.

Chemical fertilizers are not the only source of nitrates. Septic tanks located in sandy, permeable soils or in areas where fractures or solution channels communicate directly with shallow aquifers also can release nitrates to groundwater. (Another section, "Septic Systems," provides more specific information about this source of nitrates.)

Animal wastes from feedlots or improperly constructed or leaking manure storage tanks and pits also can contaminate groundwater with nitrates and bacteria. Hog, chicken, and turkey pro-

duction may be associated with groundwater contamination by nitrates. Although these animals often are raised indoors, their wastes and litter are generally stored in piles outdoors or spread on fields as fertilizer.

Cattle feedlots may be a major source of nitrates in certain areas. A one-acre feedlot with an average density of animals (360) could produce more than 12 tons of nitrogen, an amount 383 times greater than the average application rate per acre of nitrogen in commercial fertilizers to cropland in the United States in 1980.

However, these estimates are never realized under normal conditions. Most of the formation of nitrate occurs when the feedlot is not being used—the surface seal of the soil breaks down, oxygen enters the underlying soil layers, the soil becomes more acidic, and nitrate is produced from the accumulated ammonia. Although the concentration of nitrate in a feedlot may be high, the total nationwide acreage devoted to feedlots is small — 130,000 acres or 203 square miles — and feedlots are located primarily in the corn belt and high plains of the United States.

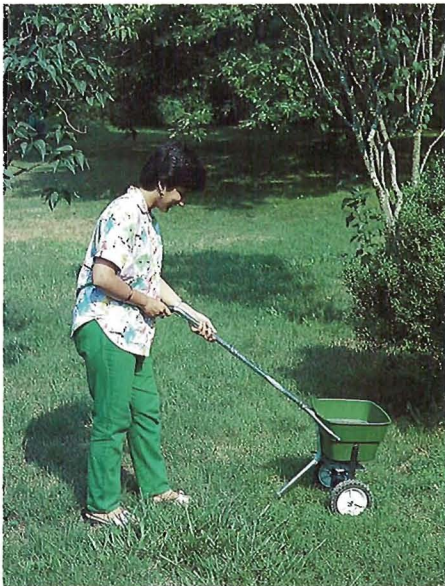
Nitrates also may enter groundwater from natural sources such as decomposing organic material, precipitation, or geologic deposits containing organic materials.

Of the potential sources of nitrates, commercial fertilizers are most likely to have the greatest impact on groundwater because of their high concentrations of nitrogen and high application rates over vast tracts of land. The total nitrogen applied annually in commercial chemical fertilizers is about 2.6 times greater than the total amount of nitrogen in all poultry and livestock manure produced annually.

What Makes Nitrate a Problem? Nitrate is a form of nitrogen and a normal body ingredient. We take in an average of 22.5 milligrams (mg) of nitrate a day. About 90 percent of this amount is derived from such vegetables as spinach, lettuce, beets, and carrots, each of which contain high concentrations of nitrates.

However, consuming too much ni-

Consuming too much nitrate can have fatal results, especially for infants, who can develop "blue-baby syndrome"



Carolyn J. Kroehler

Excessively fertilizing lawns can lead to nitrate contamination of groundwater in many areas of the country.

trate can have fatal results. For infants during their first six months and particularly for infants with diarrhea, ingesting excessive nitrate can produce methemoglobinemia — “blue-baby syndrome.” This occurs when nitrate is reduced to nitrite and is absorbed into the circulatory system. Death from asphyxiation can occur when nitrite reacts with hemoglobin to produce a compound that does not carry oxygen.

Newborns and early infants appear to be particularly sensitive because their stomachs and upper intestines are not strongly acidic, allowing bacteria that convert nitrate to nitrite to colonize these organs. Diarrhea intensifies this by making the stomach and upper intestine even less acidic. The acidity found in older infants and adults discourages such bacterial colonization and growth and prevents methemoglobinemia.

Methemoglobinemia was more common in the United States 30 to 40 years ago than it is today, and the decline in the number of cases is primarily due to water system improvements, such as digging deeper wells.

But methemoglobinemia has not disappeared. In 1986, a South Dakota baby died from nitrate-induced deprivation of oxygen. Nitrate levels in well water were significantly higher than the federal drinking water standard of 10 parts per million.

High levels of nitrates in water also may be dangerous to animals other than humans. Ruminants, especially cattle,

can be poisoned by nitrates. Their first stage of digestion is bacterial fermentation in the rumen; conversion of nitrate to nitrite can occur in this organ. Cattle and other livestock can drink water containing 100 ppm of nitrate-nitrogen with no ill effects to themselves or their offspring, but higher levels may cause problems.

A 1984 nationwide survey by the U.S. Geological Survey showed that 20 percent of all wells had some nitrate-nitrogen contamination. More than 6 percent had levels exceeding Environmental Protection Agency limits. A Virginia Department of Health study of shallow bored wells in the Piedmont in 1983 showed widespread low-level nitrate-nitrogen contamination: about 59 percent of the wells surveyed were contaminated, and 4 percent exceeded established limits. However, excess nitrates have not been found in the more than 2,000 public water supply systems in Virginia.

What You Can Do

REDUCING the amount of nitrogen fertilizer being applied is the most effective way to reduce nitrate contamination in groundwater. Although large amounts of fertilizers are used in agriculture, the over-fertilization of residential and park lawns and gardens also plays a significant role in groundwater contamination. Some approved practices for reducing levels of unused nitrates are using slow-release fertilizers, applying nitrogen fertilizer in small amounts during the growing season as it is needed, and rotating crops with legumes.

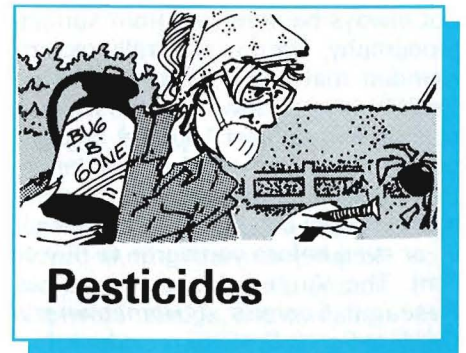
Legumes, plants such as alfalfa, clover, and soybeans, may add as much as 200 pounds of nitrogen to the soil per acre per year. Bacteria that can convert atmospheric nitrogen to a form usable by plants colonize the roots of legumes, provide them with the nitrogen they need, and add extra nitrogen to the soil. Alfalfa adds so much nitrogen to the soil that nitrate fertilizer added the following year does not increase the productivity of a crop such as corn.

Using soil tests to determine the need for fertilizers in different soil types and for various crops can save farmers and homeowners money in addition to reducing the risk of groundwater contamination. Call the Soil Testing and Plant Analysis Laboratory at Virginia Tech for information about testing your soil: (703) 961-6893. A U.S. Department of Agriculture Extension Service program,

Appropriate Technology Transfer for Rural Areas, provides advice about crop rotation, decreased fertilizer use, and other farming practices. Its toll-free information hotline number: (800)346-9140.

The siting of wells on farms also can help reduce the potential for nitrate contamination. Department of Health guidelines for well location should be followed to prevent contamination from this source. Septic system failure can result in nitrate contamination of well water. Testing domestic well water for nitrates is an important defense against nitrate poisoning, as is educating citizens, doctors, and health officials about the symptoms of nitrate-induced health problems.

If well water exceeds the 10 ppm nitrate-nitrogen standard, doctors recommend the use of bottled water. In addition to causing methemoglobinemia, excess nitrate in drinking water may be related to cancer, birth defects, and nervous system damage. The role of nitrates in these human health problems has not been adequately documented, but nitrate levels in well water should be monitored, especially in wells with a history of nitrate contamination.



MODERN agriculture relies on insecticides, herbicides, and fungicides to maintain its phenomenally high levels of production. In 1983, 1.1 billion pounds of pesticides were sold in the United States, and 68 percent were used for agricultural purposes. Home and garden use accounted for 8 percent, government for 7 percent, and industry and business for 17 percent. In Virginia, insecticides were applied to over 900,000 acres and herbicides to over 1 million acres in 1982.

The potential for contamination of aquifers by agricultural pesticides occurs not necessarily because these chemicals are misapplied but because the chemicals are applied repeatedly to vast tracts of land. Through time, some pesticides accumulate in the soil. Con-

The threat of groundwater contamination from pesticides comes more from their repeated application than their misapplication

tamination of groundwater from these sources can occur as water percolates through the soil. Soil erosion can compound the problem; surface runoff can carry pesticides with soil into surface waters which feed underground supplies. In 1977, 22 pounds of soil were washed off the land for every one pound of food eaten in the United States. Unfortunately, practices to reduce erosion, such as no-till farming, may require heavy use of pesticides. Reducing surface runoff and retaining water on the land increases the likelihood that these surface-applied or subsurface-injected pesticides will enter groundwater.

Applying pesticides with irrigation water creates another potential hazard for groundwater: problems with the irrigation pump can allow the pesticide-water mixture to flow backward into the well. A third potential for groundwater contamination comes from the disposal of pesticide containers. Annually, nearly 250 million pesticide containers — usually containing varying amounts of pesticide — are buried, thrown in open dumps, or sent to landfills. As the containers break down, the pesticide is released to the soil and from there can make its way to the groundwater.

Although the potential for contamination exists wherever pesticides are used, the chemical structure of the pesticide can reduce this danger. Pesticides that are volatile — that is, form gases — and have a low solubility in water generally do not travel through soil to groundwater. Those degraded by sunlight and those that react with water to produce new compounds that lack the pesticidal properties of their parents also are not likely to contaminate groundwater. Pesticides easily decomposed by microorganisms and plant enzymes are also improbable candidates as groundwater contaminants. However, pesticides slow to decompose in soil and highly soluble and therefore highly mobile in water have a high potential to pollute groundwater.

Soil type and geological structure also

affect the potential for groundwater contamination by pesticides. Soils rich in organic matter may absorb and firmly bind pesticides, preventing their downward transport. Clayey soils have a high capacity to retain water, and this slows the movement of water and its associated contaminants. Highly permeable soils, such as sand and gravel, have large interconnected pore spaces between the particles, facilitating the rapid, downward movement of surface water. Rapid and deep movement of pesticides can occur along cracks, animal burrows, root channels, and passageways in limestone. Caves, sinkholes, and underground streams in limestone areas allow contaminants to enter groundwater rapidly and travel long distances with little dilution.

In Virginia, one pesticide — the insecticide aldicarb or Temik (trade name) — has been detected in drinking water on the Eastern Shore, where residents rely on wells less than 300 feet deep for drinking water. This contamination is related both to the geology and soils of the region and to the chemical nature of the pesticide. Surface water derived from precipitation and irrigation can move rapidly through the sandy, coarse soils of the Eastern Shore.

Because aldicarb is inexpensive, easy to apply, and effective, it has been used extensively on some vegetable crops. Potato growers on the Eastern Shore use it to control nematodes and potato beetles. Aldicarb is highly soluble and mobile in water. It has a half-life of four to eight weeks in the upper

soil layers where microorganisms are plentiful, but the persistence of aldicarb in groundwater is unknown.

Another area where geology has affected groundwater contamination by pesticides is Clarke County. Very thin and rocky soil there is underlain by rock containing numerous solution channels. Herbicides, phenols (often associated with pesticides), and nitrates were discovered in the town wells of Berryville in 1981. Investigators believe the heavy use of pesticides in orchards was the cause.

More than 60 pesticides have been found in the groundwater of 30 states, including Virginia

Pesticides are developed to kill "pests," and their effects on the health of humans and nonpest animals and plants are of concern in regulating their use. About 435 of the 1,450 U.S. registered active pesticidal ingredients have been tested and approved for use on food crops. More than 60 of those have been detected in the groundwater of 30 states, including Virginia. The application of three — dinoseb (dinitrophenol), 1,2-dibromo-3-chloropropane (DBCP), and ethylene dibromide (EDB) — is now banned in the United States. Dinoseb, an inexpensive herbicide used on soybeans, peanuts, potatoes, and cotton, was banned in the fall of 1986 after laboratory evidence demonstrated irreversible nerve and skeletal malfor-

Table 1. Pesticides Found in Drinking Water Wells and Suggested Health Advisory Concentrations

Pesticide	Health Advisory Level, ppb
Alachlor (H)	700
Aldicarb (I,N)	10-50
Atrazine (H)	150
Bromacil (H)	7.5
Carbofuran (I,N)	50
DCPA (and metabolites) (H)	5000
DBCP (1,2-dibromo-3-chloropropane) (N)	0.05
DCP (1,2-dichloropropane and relations) (N)	5-10
EDB (1,2-dibromoethane) (I,N)	0
Dinoseb (H)	12.5
Oxamyl (I,N)	250
Simazine (H)	1500

H = Herbicide

I = Insecticide

N = Nematicide

(adapted from Cohen *et al.* 1984)

Most pesticides in use today were registered before stricter regulations took effect in 1972

mations of test animals. The hazard to health posed by a pesticide after it enters the environment depends primarily on its toxicity and the extent of human exposure to it.

The maximum amount of pesticide an average human can consume with no observable damaging effect — called the no-observable-effect-level (NOEL) — is determined by dosing laboratory animals over their lifetimes with different amounts of the pesticide being evaluated. Curves representing the response of the animals at each dose (dose-response curves) are plotted, and the maximum dose demonstrating no harmful effects is determined. Two different species are tested, and the NOEL for the most sensitive species is divided by a generous safety factor to establish the acceptable daily intake (ADI). If, for example, a safety factor of 100 were chosen, then humans with the same tolerance as the most sensitive test species could consume 100 times more than the ADI before any observable harmful effect should occur. Suggested “health advisory levels” of pesticides are based on the daily intake of 1.06 quarts of water by a 22-pound child or 2.12 quarts by a 154-pound adult. Table 1 provides some health-advisory levels of commonly used pesticides in the United States.

Pesticide Laws Laws covering the use of pesticides include the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), approved in 1947 and amended in 1972 and 1978, and the Virginia Pesticide Law and associated regulations. Unfortunately, most pesticides in use today were registered before the stricter revisions of FIFRA became law in 1972. The 1972 revision ordered retesting of pesticides in use; however, only 16 of the ingredients in 40,000 pesticides had been reregistered by 1984. According to the National Academy of Sciences, the government had sufficient data in 1984 to assess the health risks of only 10 percent of the pesticides in use. A proposed 1986 federal revision had an accelerated timetable for EPA reexamination of pesticides now in wide use,

but much of the health information needed to make this examination was lacking.

Since 1975, urban water systems have been required to monitor for six pesticides: endrin, lindane, methoxychlor, toxaphene, 2,4-D, and 2,4,5-T. EPA is now conducting a nationwide survey of private and community wells, testing for more than 70 pesticides. As part of the survey project, it has developed health advisory levels for 62 pesticides with high leaching potential. Nontechnical summaries of the advisories are being prepared to provide well owners with information on the health implications of pesticide contamination. Results of the survey, scheduled for completion in 1990, should determine the degree to which the drinking water wells of the United States are contaminated by pesticides.

Additional restrictions on the use of carbofuran, noted in drinking water wells in Wisconsin and New York, are currently under consideration. Bald eagles, reduced to low numbers before

the ban on DDT in the 1970s, have been making a comeback, but the deaths of two bald eagles in eastern Virginia have been linked to granular carbofuran, or Furadan. The pesticide is suspected in the deaths of three other eagles. Small birds mistake granular Furadan as seed and die after eating one grain; eagles prey on these contaminated carcasses and are likewise poisoned. Officials estimate that more than 3 million pounds of Furadan are used annually on more than 400,000 acres in Virginia. Carbofuran is one of the pesticides for which EPA has developed health advisory levels because of their high potentials to leach into groundwater.

During fiscal year 1985, five of the 129 complaints received by the Virginia Water Control Board concerned possible herbicide and insecticide contamination of wells and springs. In four cases, pesticides appeared not to be a problem because concentrations were within the no-observable-effects-level (NOEL). In the fifth case, 2,4-D and

Telephone Numbers for Pesticide Information

Animal Poison Control Center 24-hour hotline for information and advice on chemical contamination of animals: (217) 333-3611

Chemical, Drug, and Pesticide Unit, Cooperative Extension Service, Virginia Tech, for general information: (703) 961-6543

Chemical Transportation Emergency Center (CHEMTREC) for industry assistance in cleanup of spills and other emergencies: (800) 424-8802

EPA hotline (Region III) to report hazardous waste dumping in Virginia: (800) 438-2474

EPA Small Business Hotline: (800) 368-5888

Interpretation and assistance with compliance for those affected by Resource Conservation and Recovery Act (RCRA) and Superfund (CERCLA): (800) 424-9346

National Pesticide Telecommunications Network with 24-hour medical advisories on pesticide poisoning and information on pesticides: (800) 858-7378

National Pollution Response Center for spills into water (EPA regulations and Clean Water Act): (800) 424-8802

Virginia Department of Agriculture and Consumer Services for general consumer information and complaints: (800) 552-9963

Virginia Department of Agriculture and Consumer Services, Office of Pesticide Regulation, for regulatory information: (804) 786-3798

Virginia Department of Health, Bureau of Toxic Substances Information: (804) 786-1763

Integrated Pest Management is an alternative to relying solely on pesticides

triazine herbicides were measured in a shallow well used for irrigation of nursery plants in Rockingham County. During this same reporting period, a truck carrying 628 gallons of herbicides and fertilizers and 150 pounds of lime overturned in Prince William County. Because of the area's geology and the low concentration of chemicals, this spill was not considered to endanger the underlying groundwater, but such accidents can cause contamination.

What You Can Do

AS with the threat of contamination by fertilizers and nitrate, the best way to reduce the threat of groundwater contamination by pesticides is to reduce their use in agriculture, forestry, and lawn and garden care. Application of these products no longer protects crops as effectively as when pesticides were first introduced. "Pest" organisms have evolved mechanisms to detoxify and resist the chemicals designed to kill them. In less than 50 years, about 450 insect and mite species have acquired resistance to pesticides. Most of the world's major pests are in this resistant group. In the last 15 years, about 50 weed species have gained resistance to herbicide use.

Integrated Pest Management, an alternative to relying solely on pesticides, includes use of biological control (natural pest predators), cultural practices (patterns of planting), genetic manipulation (developing pest-resistant crop varieties), and limited use of chemicals to protect crops. Crop rotation, pest monitoring, and soil analysis and conditioning can help promote healthy crops.

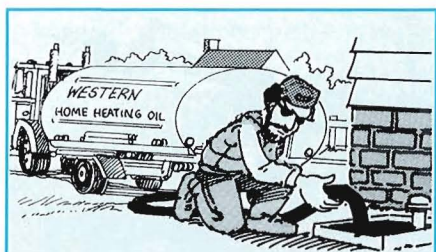
The Virginia Integrated Pest Management guide, published by the Virginia Cooperative Extension Service as 18 separate guides, outlines the latest recommendations for control of insects, diseases, and weeds on economically important crops, ornamentals, livestock, and pets. Information on alternatives to pesticide use also is available from a U.S. Department of Agriculture program, Appropriate Technology Transfer for Rural Areas, which has a toll-free hotline: (800) 346-9140.

Read the Label If you must use pesticides, always follow label directions when applying, storing, handling, and discarding them. Overapplication or improper disposal can contaminate groundwater. Dispose of empty pesticide containers in such a manner that they pose no threat to humans, pets, valuable plants, livestock, or wildlife. Triple rinse empty containers and dispose of pesticide in the rinse water by following instructions on the label.

According to EPA's *Suggested Disposal Guidelines for Homeowners*, small amounts of waste pesticides can be safely sent to a sanitary landfill. Liquids in quantities of a gallon or less should be left in original containers, tightly capped, and wrapped in several layers of newspaper. Dry compounds in bags of ten pounds or less should be securely wrapped in paper or placed in a box or carton and taped securely. These can be placed in a trash receptacle for routine collection with municipal refuse. Small quantities, when handled as described, do not endanger trash collectors.

Be sure to check local ordinances before you dispose of pesticides in a landfill or trash receptacle. The Virginia Department of Waste Management (800-552-2075) can answer questions about hazardous and nonhazardous classifications of waste.

If you suspect your drinking water supply has been contaminated by pesticides, call the Virginia Water Control Board's 24-hour pollution response program: (804) 257-0080.



Underground Storage Tanks

RANDOM sampling of 800,000 underground storage tanks containing gasoline and diesel fuel by the Environmental Protection Agency has revealed for the first time the dimensions of a public health problem potentially more serious than

leaking toxic waste dumps. Based on the survey, the agency estimates that up to 35 percent of the nation's five million underground storage tanks are leaking. This is a substantial increase over the 2 to 5 percent total leakage reported by major oil companies during an earlier study. The Environmental Protection Agency reported that 21 percent of the estimated 280,000 leaking tanks in its survey were at or below the water table and were discharging their toxic contents directly into groundwater.

The average leaking tank in the survey was 16 years old and was leaking about one-third of a gallon (1.2 liters) an hour. Nationwide, approximately one million of the steel tanks currently in the ground are more than 16 years old and lack either double liners or cathodic protection, precautions required under new regulations.

About 40 percent of all steel gasoline storage tanks underground belong to gasoline stations owned by the major oil

Gasoline stations account for 65 percent of the underground storage tank leaks reported nationwide

companies. The other 60 percent belong to small companies, wholesalers, industries, and individual station owners. Unlike the major companies, most of these businesses have not set up general protection and replacement programs, which helps explain why gasoline stations account for about 65 percent of the leaks reported nationwide. Replacement of tanks is expensive. According to the Virginia Petroleum Council, members are replacing tanks at a cost of \$4,500 to \$5,600 a tank and replacement for an entire service station can range from \$35,000 to \$80,000.

Many small leaks from tanks are not detected even when the tanks are checked regularly. Nature cleans up some of this petroleum before it can cause harm. Petroleum products can attach to clay and organic material in the soil, and naturally occurring bacteria can decompose these products over time in shallow, well aerated soil layers. Larger leaks or leaks from tanks in very permeable sandy soils can easily result in contaminated groundwater. Because gasoline floats on the surface of water, it may be carried into sewers, wells,

The Water Control Board estimates that 20,000 underground petroleum storage tanks are leaking in Virginia

springs and basements. Many groundwater contamination events in urban areas are discovered by homeowners smelling gasoline in a basement. Leaks also are detected when petroleum products are seen or smelled in storm-water sewage systems and other utility lines.

Petroleum products themselves affect the taste and *potability* of groundwater, but they also contain other compounds. Gasoline contains between 225 and 250 separate chemicals, some of which are hazardous to human health and safety. Certain of them, such as benzene and toluene, are considered priority pollutants by the Environmental Protection Agency and are carcinogenic and toxic at low concentrations. In confined areas, vapors from these petroleum products can explode.

New state and federal laws require that new tanks meet certain construction specifications and that all tank owners show their financial capability to pay for corrective action or property or personal damage from any leaks. The Environmental Protection Agency is developing regulations for leak detection and prevention, recordkeeping and reporting, tank closure, and corrective action.

The Situation in Virginia

THE most common groundwater contamination complaint reported to the Virginia Water Control Board concerns leaking underground petroleum storage tanks and lines. The Virginia Water Control Board estimates that up to 20,000 tanks may be leaking. Amendments to the federal law covering hazardous wastes (1984 Hazardous and Solid Waste Amendments to the Resource Conservation and Recovery Act of 1976) require owners of underground storage tanks in Virginia to notify the Virginia Water Control Board. Virginia officials have received more than 22,000 forms reporting some 58,000 tanks, and nearly 90 percent of the tanks store some type of petroleum product.

Many other potentially rusting tanks, such as heating oil tanks of less than

5,000 gallon capacity and farm and residential tanks storing less than 1,100 gallons, are exempt from regulation at this time. Local governments are beginning to register the smaller tanks, much as the Virginia Department of Health registers septic tanks.

Contamination of well waters by oil or gasoline frequently is traced to a leaking underground storage tank on the well owner's property. Officials at the Virginia Water Control Board estimate that residential heating oil tanks, most of which are exempt from regulation at this time, may be the greatest threat to groundwater.

Testing Tests for leaks in tanks are expensive: \$300 to \$500 for a precision test. Because testing is not done routinely by residents, leaks often are not discovered until an unusually high water table forces water to enter the tank. By the time a leak is discovered this way, the tank may have been slowly losing oil for months or even years.

The Issue of Liability One of the biggest problems associated with residential heating oil tank leaks is liability. Once a leak is reported to the Virginia Water Control Board, the tank owner may be required to dig a test well—for approximately \$1,000. If it is determined that the tank is leaking and has contaminated groundwater, the tank owner is legally liable for cleanup costs. To avoid

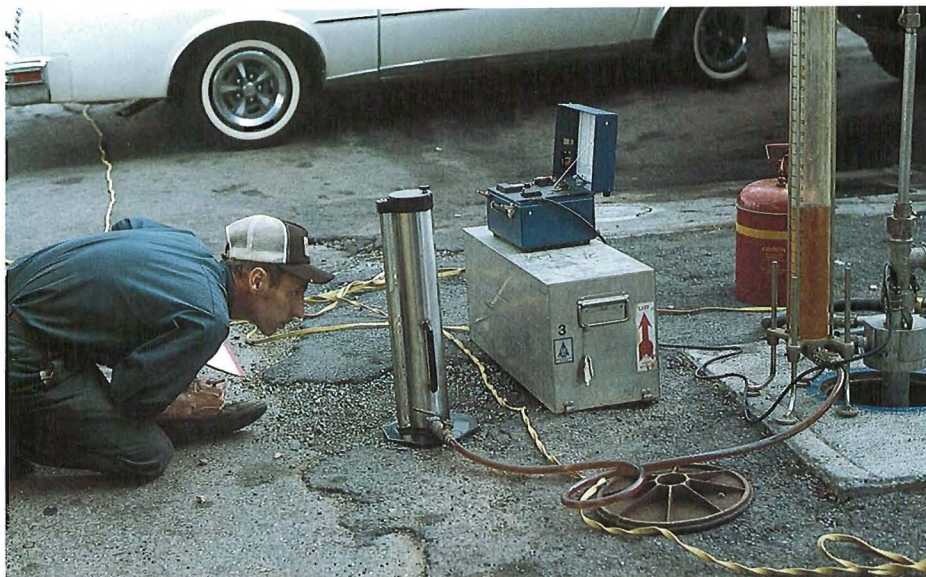
such expense, the typical reaction of people who discover water in their tanks is to remove all the oil they can and abandon the tank in place. The number of unreported residential leaking tanks in the United States is inestimable.

Solving the problems created by groundwater contamination is often difficult, and in the past some leaks have had serious consequences. Petroleum contamination in Montgomery County has caused the loss of three wells capable of producing more than 800,000 gallons of water a day. Another example is provided by Stone Robinson Elementary School in Albemarle County, which was built 10 to 15 years ago. During construction, a fuel line was cut. The school's well became contaminated by petroleum products soon after the school was opened, and a second well had to be dug. The second well also became contaminated, and officials decided to treat the water with an activated carbon filter. This treatment did not entirely solve the problem, but it took more than three years of parental complaints and a reporter from the Charlottesville *Daily Progress* to persuade local officials to take further action. A third well was dug, but it came up dry. A fourth well produced water, but it was put on-line before the health department did bacteriological testing. Testing showed that the water contained excess levels of fecal coliforms, an indication that bacteria capable of



Diana L. Weigmann

Because leaking underground petroleum storage tanks are a major source of groundwater contamination, most major oil companies are replacing their old bare steel tanks with either fiberglass or cathodically protected steel tanks. Most independents have not followed suit, however, because of the cost.



Virginia Water Control Board

A worker using a precision test to check for leaks in an underground storage tank. While very accurate, such tests cost \$300 to \$500 a tank.

producing diarrhea and other intestinal disorders especially harmful to children may have been present. After a chlorinator was installed, the water was safe for drinking.

In another situation in Virginia, a family got more than it bargained for when it bought the Annex Grocery Store in Staunton in 1985. While drilling a new well for the family, the driller hit gasoline at 35 feet. A 3½-foot column of gasoline formed in the well. The previous owner of the grocery, who had leased the tanks from an oil company, told the company about the leaking tanks, and the company removed the tanks without cleaning up the spilled petroleum. During cleanup, gasoline was pumped out of the well periodically. Monthly monitoring of the original well and nearby test wells has indicated a substantial decrease in the amount of gasoline in the groundwater. As of September 1987, the only indication of the spill was a slight odor in two of the wells.

Even minor spills of petroleum products can lead to costly and complicated cleanup. In Buena Vista, Reeves Brothers Construction lost about 5,000 gallons of No. 6 fuel oil when a storage tank leaked. About 100 gallons leaked into Indian Gap and the Maury River, causing a heavy sheen for half a mile downstream. The company recovered six to eight 55-gallon drums of product plus all of the contaminated soil. The pit remaining after this excavation took 100 dumploads of clay to fill. The oil-contaminated soil was mixed with saw-

dust and landfilled; No. 6 heating oil is not considered a hazardous waste.

Two New Laws The 1987 Virginia General Assembly enacted two laws concerning underground storage tanks, authorizing the Virginia Water Control Board to implement federal regulations and establishing both financial responsibility provisions and state cleanup funds for underground storage tank contamination problems. *A Groundwater Protection Strategy for Virginia* recommends that new and old tanks be registered and that federal exemptions be amended so that a greater number of tanks are regulated. Some of this was accomplished by 1987 laws, and additional regulations are being written.

What You Can Do

IF you can smell or taste a petroleum product in your water, the water should not be used for drinking or cooking until it has been tested. If you suspect that your drinking water is contaminated by a petroleum product, contact the Virginia Water Control Board.

Residents have a source of help when private wells are contaminated by petroleum products. The Virginia Water Control Board is charged with seeking a party responsible for the pollution and overseeing the cleanup of state waters, including those underground. Individual homeowners can use the information collected by the Virginia Water Control Board in civil suits to force provision of alternate water sources or cleanup of

private wells. Previously, residents had to dig new wells or hook up to city water at their own expense.

Most often, though, residents who report contamination of well water by oil or gasoline discover that their own leaking fuel tanks are responsible.

Individual citizens can minimize groundwater contamination by leaking storage tanks in several ways. If you're building a house, locate the new tank above ground in a basement or garage. Leaks in aboveground tanks are easier to detect and fix, and groundwater is less likely to be threatened. If your oil storage tank is old and underground, check for the unexplained loss of oil. For example, if your oil tank is used only for heating your home, check the gauge in late spring and in fall before you begin to use your furnace again.

The presence of water in your tank also indicates a leak. If you're willing to spend \$300 to \$500, a precision test for leaks can be done. A leaking tank should be pumped dry and removed from the ground; underground storage tanks will rust out eventually and could collapse, causing a cave-in above.



Waste Disposal

EACH year, 150 million tons of municipal solid waste and 240 million tons of industrial solid waste are deposited in more than 16,000 landfills throughout the United States, according to a 1986 survey by the Environmental Protection Agency. A typical family of two adults and two children disposes of 5,200 pounds of waste a year.

In Virginia, 10,000 tons of solid waste per day are generated. At least 299 legal solid waste landfills exist in the state, more than a third of them owned and operated by local governments. Virginia also has approximately 7,000 inactive landfills.

Across the country, more than 10

In 1984, fewer than 10 states required groundwater monitoring near landfills. Proposed federal regulations would require it for all new sites

trillion gallons a year of liquid industrial wastes are disposed of in nearly 192,000 surface impoundments. In Virginia, 430 industrial waste lagoons, 1,200 animal waste lagoons, and a small number of municipal waste lagoons were identified in 1985.

The disposal of waste can pose serious threats to groundwater. An estimated 90 billion gallons of liquid from landfills and 100 billion gallons from liquid impoundments annually leak into groundwater in the United States.

Landfills and Open Dumps

LANDFILLS are typically soil excavations filled with "solid" wastes, defined by federal waste regulations as being solid, semi-solid, liquid, or containerized gas. Although daily coverings of soil help to prevent odors, disease, and colonization by rats and other pests, the soil does not prevent precipitation and surface water from contacting the wastes. Water can dissolve various materials to form leachate, or "garbage juice," and liquids in the waste can add to the leachate. In unlined landfills, substances in the leachate can percolate through the soil and contaminate aquifers below the landfill.

In 1984, fewer than ten states were requiring groundwater monitoring near landfills. Proposed federal regulations would require installation of monitoring wells as part of the permitting process for new landfills.

Although regulations are stricter now, and permits are required by the Virginia Department of Waste Management, earlier landfills were sited without regard to geology and hydrology. Landfills were typically located on what was considered low-quality land, such as marsh lands, abandoned sand and gravel pits, old strip mines, and limestone sinkholes. Unfortunately, many of those "low quality" sites were groundwater recharge areas. To further compound the problem, operators at many of these sites accepted unknown types and quantities of wastes. Today, these sites with their concentrated, unknown



Virginia Water Control Board

Leachate oozing from a landfill. Nationwide, an estimated 90 billion gallons of "garbage juice" leak into groundwater every year.

pollutants pose a great threat to groundwater.

A landfill on top of a mountain in Russell County caused groundwater contamination when some of its refuse fell into caves beneath the landfill. Nearby well water was contaminated with mercury, lead, and arsenic.

Rainwater percolating through "Mount Trashmore," the landfill in Virginia Beach, has leached ammonia, chlorine, and iron into the groundwater below. A clay cap for the top now prevents rainwater from entering this mountain of waste.

A landfill operated from 1972 to 1985 near Richmond has leaked organic compounds and chlorinated solvents into groundwater. Sited in a swampy area with a high water table, the landfill's contaminants were first detected in monitoring wells in 1984.

Older and abandoned landfills can cause worse problems. More than 350 of Virginia's 7,000 inactive landfills are on the Environmental Protection Agency's waiting list for cleanup money.

Open dumps, where household trash, construction materials, automobiles and tires, old appliances, and numerous other waste items are discarded, are illegal in Virginia. Unfortunately, many open dumps are still in use throughout the state. Most of them have land-clearing and construction debris, and the predominant problem areas are high-development localities.

Open dumps of household garbage, old appliances, and furniture are also common in Virginia. For example, Rock-

bridge County operates a waste collection system and sanitary landfill for the disposal of residential, commercial, and industrial wastes. At the time this disposal system was initiated in 1973, seven major open dumps and at least 59 roadside dumps were located in the county—all of them illegal. A survey of the county in 1985, 12 years after the initiation of an efficient waste disposal system, showed that 61 unapproved,

Illegal open dumps are all too common in Virginia. They pose a threat to groundwater, especially in the mountains

open dump sites were still operating.

Portions of this county are particularly sensitive to groundwater pollution because of the underlying limestone with associated sinkholes, solution channels, and open cracks that provide a direct conduit to groundwater. Almost 80 percent of the illegal dumps were in limestone areas and 40 percent on sites which were considered sensitive to groundwater contamination.

Open dumps and legally nonhazardous solid waste landfills may be more of an environmental threat over the long run than well-regulated hazardous waste sites. Each year cleaning solvents, pesticides, paints, varnishes, photographic chemicals, and other household hazardous wastes are sent

Virginia's 1986 Waste Management Act has brought more control over siting, design, management and closing of landfills

to landfills unequipped for managing hazardous wastes or are discarded in open dumps. And although leachate from "sanitary" landfills may not fit the Environmental Protection Agency definition of hazardous waste, it remains a potential groundwater contaminant.

In Virginia, the Department of Waste Management regulates landfills, and the state's 1986 Waste Management Act has given new emphasis and coordination to waste management activities. A substantial revision of Virginia's solid waste management regulations has resulted in more control over siting, design, management, and closing of solid waste landfills.

Waste Ponds and Lagoons

THE liquid wastes produced by rendering plants, coal-fired power plants, fertilizer production operations, and a wide variety of other commercial activities are often disposed of in surface impoundments. These ponds and lagoons vary in depth from 2 to 30 feet and in size from a fraction of an acre to thousands of acres.

Seventy percent of these sites nation-

wide are located in hydrologically vulnerable areas. About 37 percent of municipal and industrial impoundments are located over aquifers supplying drinking water. Liquid wastes can leak into this groundwater.

Although these surface impoundments for treating, holding, and disposing of hazardous and nonhazardous wastes can easily contaminate groundwater, until recently many of them have been constructed with insufficient liners or no lining at all. Under the new federal regulations of the 1984 Hazardous and Solid Waste Amendments to the Resource Conservation and Recovery Act of 1976, such surface impoundments must have a double liner of synthetic material and clay with a leachate collection system.

Chemical wastes stored in lagoons at Avtex Fibers in Front Royal leaked into groundwater, migrated under the Shenandoah River, and contaminated well water on the other side of the river. In Alleghany County, the practice of pouring liquid wastes down the drain and burying solid wastes "out back" came back to haunt the Pantasote plant. Although the company began sealing wastes in drums for shipping to disposal sites in 1980, a 1986 test of groundwater found so much contamination by old solvents that prospective buyers refused to purchase the land surrounding the plant.

A permit is required to discharge wastes into surface water or groundwater in Virginia. Because wastes held

in lagoons are not discharged, Virginia requires any establishment producing liquid wastes of this nature to apply for a "no-discharge" certificate. The certificate includes conditions for operation and maintenance of lagoons and limited design specifications. *A Groundwater Protection Strategy for Virginia* recommends revising and strengthening this certificate program so that it includes siting standards, design and performance standards, monitoring requirements, and regulations covering existing facilities as well as newly constructed ones. State agencies have begun making some of these revisions.

What makes hazardous waste hazardous? If it's ignitable, corrosive, reactive, or toxic, it is hazardous

Hazardous Waste

BOTH landfills and lagoons were once used to dispose of hazardous waste without regulation, but since 1976 the federal Resource Conservation and Recovery Act (RCRA) has required "cradle-to-grave" management of hazardous wastes. RCRA required persons generating 2,200 or more pounds of hazardous waste per month to follow a set of specific guidelines in waste disposal. Amendments to RCRA in 1984 prohibited generators of 220 or more pounds of hazardous waste per month from disposing of it in landfills and required the EPA to provide states with guidelines for permitting solid waste landfills. Approximately 700 landfills at 136 facilities and 3,200 hazardous waste treatment, storage, or disposal impoundments at 400 facilities accept the hazardous waste generated in the United States.

What makes a hazardous waste hazardous? A hazardous waste possesses one or more of the following characteristics: 1) ignitability (poses a fire hazard during routine management), 2) corrosivity (can dissolve toxic contaminants and must be stored separately or requires special containers since it destroys standard ones), 3) reactivity (may react spontaneously or vigorously in combination with air and water, or may be unstable to heat and shock), and 4) toxicity (when improperly managed, releases toxicants



Carolyn J. Kroehler

The Wayne Kenny family received a 1986 Governor's Clean Water Farm Award for the design and operation of a state-of-the-art manure storage pit on their farm in Carroll County. It is emptied twice a year and the contents are spread on crop and pasture lands, reducing the need for chemical fertilizers.

The Department of Waste Management regulates nearly 2,000 generators of hazardous waste who produce an estimated 25 million tons a year

in sufficient concentrations to endanger human health or the environment). The disposal of hazardous wastes poses a great danger to human health and the environment.

In Virginia, 81 facilities have permits to store, treat, or dispose of hazardous wastes. The Hazardous Waste Facilities Siting Act governs the siting of Virginia's hazardous waste facilities. It prohibits such facilities in wetlands, 100-year floodplains, dam failure flood zones, areas with limestone and sinkholes, and areas designated as natural landmarks or in the public trust. The process of certifying a site and issuing operating permits for a hazardous waste storage or transfer facility can take a year to complete. Public hearings are held to allow comment before a firm is granted a final permit. Under the Virginia Hazardous Waste Facilities Siting Act, the state can overrule local objections if the proposed operation is consistent with local zoning and permitted uses and meets local, state, and federal requirements.

The Virginia Department of Waste Management regulates 581 large quantity generators of hazardous waste, 1,374 small quantity generators, and 319 transporters of hazardous wastes. In Virginia, most of the estimated 25 million tons of hazardous waste produced each year is spent solvents and acids or bases. Most of this waste is treated on-site by recycling and reuse or by burning and using the energy generated. Many acids and bases can be safely disposed of once they are neutralized.

The short-term costs to a business for illegally disposing of hazardous wastes are much less than the costs of following Environmental Protection Agency-approved practices (see Table 2). EPA estimates that in the United States 90 percent of the total hazardous waste is disposed of by environmentally unsound means (see Table 3).

The long-term cost of improperly disposing of hazardous waste can be very high. Liquid wastes from the Matthews Electroplating Company

near Roanoke contaminated seven nearby residential wells with high concentrations of chromium and cyanide, and a water system costing \$1.45 million had to be constructed to serve area residents. In York County, aquifers were contaminated by fly ash containing copper, nickel, beryllium, vanadium, selenium, and arsenic from the residue of coal and refinery coke burned at Yorktown Power Plant. About 30 domestic well users had to attach to the public water supply, and ash pits are scheduled to be capped, sealed, or drained at a cost of \$14 million.

Contamination cleanup problems are complicated by the difficulty in assigning responsibility to a single person or business. Landfills and lagoons constructed and used before federal and state regulations controlled hazardous waste disposal may contribute to groundwater contamination years later. Forty years after the burial of wastes from various World War II supplies at the Defense General Supply Center dump in Richmond, wastes from rusted and leaking drums are contaminating groundwater. Sometimes the exact source of contamination cannot be detected. When it can be, it's often impossible to determine when the waste causing the pollution was discarded or by whom.

In Buckingham County, the well water of a family living near a con-

demned landfill is contaminated with chromium, zinc, beryllium, and cyanide. The landfill had served as a private trash collection service's dump, a public landfill, and a chemical waste dump during its nearly 20 years of operation. Now on the priority Superfund list for cleanup, the site was closed by the county in 1981. The family has been carrying water in plastic jugs from a neighbor's house since 1982.

Superfund The Federal Comprehensive Emergency Response, Compensation, and Liability Act of 1980 (CERCLA), commonly called Superfund, was designed to assist in just such cases. Administered by the Environmental Protection Agency, it covers the identification and remediation of waste disposal sites, emergency cleanup of chemical spills and releases, financing of cleanup operations, and assumption of liability for disposal sites closed under regulations of the Resource Conservation and Recovery Act.

Any hazardous substance, pollutant or contaminant presenting an immediate and substantial threat to public health or the environment is covered by Superfund (petroleum products and natural and synthetic gas products are not covered). Cleanup costs are shared by responsible parties, and the Superfund Amendments and Reauthorization Act of 1986 (SARA) reauthorized the

Table 2. Cost per Metric Ton of Five Disposal Methods for Hazardous Wastes

Method	Dollars per Metric Ton
Land spreading	2 - 25
Surface impoundments	14 - 180
Chemical fixation	5 - 500
Lined chemical landfill	50 - 400
Incineration (land-based)	75 - 2,000

Table 3. Disposal of Hazardous Wastes

Disposal Method	Percent of Total
Unacceptable to the Environmental Protection Agency:	
Unlined surface impoundments	48
Land disposal	30
Uncontrolled incineration	10
Other	2
Acceptable to the Environmental Protection Agency:	
Controlled incineration	6
Lined landfills	2
Recovered	2



Thomas W. Simpson

Treated Sewage Sludge

Land Application Gaining Acceptance

VIRGINIA has more than 200 publicly owned wastewater treatment plants, and nearly two-thirds of the state's households make use of a community sewer service. In rural areas, only one in six households is linked to a community sewer system, but in urban areas the number rises to nine in ten. What happens to all that wastewater?

Sewage treatment plants process wastewater to remove organic matter, pathogens, and some dissolved nutrients. Once it is cleaned up to meet certain requirements, the treated wastewater is discharged into a river or stream. The solids removed during water treatment (sewage *sludge*) can be incinerated, landfilled, or applied to land.

The land application of sewage sludge is gaining wide acceptance in Virginia as an environmentally and economically sound disposal method. All the sludge produced in Richmond, Roanoke, and several other localities is used on land across the state. About 50 percent of the sludge generated in Virginia is land applied.

The decrease in landfill space and the air pollutants and concentrated heavy metals that can be produced by incineration combine to make land application of sludge an attractive alternative. Properly treated sludge applied in appropriate amounts improves soil by adding organic material and inorganic nutrients, con-

ditioning soil, and improving water holding capacity.

The economic benefits of land application of sludge have been significant. Virginia treatment plants that contract sludge for land application save \$12 million a year. Savings in fertilizers for the 85,000 acres that have had sludge instead of chemical fertilizers applied have totaled \$2 million annually.

The Virginia Water Control Board, the Virginia Department of Health, and the Virginia Department of Agriculture and Consumer Services share the regulation of sludge application in the commonwealth. Before sludge is spread on land, it undergoes treatment (stabilization) to eliminate or greatly reduce pathogens and odors. Dewatering increases the solids content and decreases the total volume to be handled. Although organisms such as bacteria, algae, protozoans, rotifers, flukes, viruses, and worms can be found in sludge, no cases of harm to human health have been attributed to sludge application in Virginia. Sludges containing hazardous materials are not approved for agricultural land application.

Virginians also have found other sludge disposal alternatives. In addition to contracting its sludge for land application, Hampton Roads Sanitation District began composting sludge in 1982 and selling this product as Nutri-Green Compost.

"hazardous substances superfund" to pay costs not assumed by these parties.

The "right-to-know" provision under SARA requires states to organize emergency response commissions. These commissions are responsible for making information available to the public about hazardous substances present in communities and for designing emergency response plans based on those specific hazardous materials.

Because the number of sites to be cleaned up exceeds the Superfund budget, identification of the worst sites is an important part of the program. Inactive waste management sites are reported both to the EPA and the states for possible inclusion in the National Priorities List. This cleanup list uses the actual or potential threat posed by the site to human health and the environment for ranking sites nationwide. Sites designated by individual states as their single most serious uncontrolled waste sites are automatically included in the first 100 sites selected for the National Priorities List.

As of July 1987, the Environmental Protection Agency had placed 951 landfills, impoundments, and other waste sites on the National Priorities List. The agency estimates that the list will grow to not more than 2,500 sites and that cleanup costs may total about \$23 billion. Virginia currently has 15 sites on the National Priorities List; most sites have contaminated groundwater. These sites are listed in Appendix B.

Radioactive Waste

VIRGINIA has neither high-level nor low-level nuclear waste disposal facilities, but radioactive wastes are generated in the Commonwealth. According to 1982 estimates, the state produces 100,000 to 150,000 cubic feet of low-level radioactive waste per year. This includes contaminated clothes and tools used around reactors as well as supplies, clothing, and equipment used for research in hospitals and universities. The low-level waste generated in Virginia has been shipped to Barnwell, South Carolina, for many years. A federal act requiring states to be responsible for their own wastes spurred the formation of the Southeast States Low-Level Radioactive Waste Compact, which in 1986 selected North Carolina as the low-level waste "host state" to serve for 20 years after the Barnwell facility closes.

A substantial amount of the radio-

The federal government has yet to designate a national repository for high-level nuclear waste. Until it does, spent fuel rods from the state's two nuclear plants will be stored on site

active waste generated at research facilities in Virginia is disposed of "on-site." Waste contaminated by certain *radioisotopes*, radioactive chemicals with half-lives shorter than 90 days, can be stored for a period of time equivalent to 10 half-lives, surveyed for radioactivity, and discarded as "clean trash" at a local landfill.

Animal carcasses containing less than 0.05 *microcurie* per gram of a radioactive form of carbon (carbon-14) or tritium (radioactive hydrogen) can be incinerated. The radioisotopes are released to the atmosphere as carbon dioxide, carbon monoxide, and water vapor.

Municipal wastewater facilities can receive limited amounts of radioisotopes. Acceptable levels are based on total volumes of water passing through the facility and available for diluting the radioactive waste.

The containment and burial of low-level radioactive wastes is subject to strict regulations aimed at stabilizing waste. All wastes must be in a form such that even if containment drums rust or break down after a period of time, the waste will remain in place. Liquid wastes cannot be disposed of as liquid in drums but must be solidified in concrete or by some other approved method. Animal carcasses and other biological waste must be layered in lime and absorbent and "double drummed" — for example, a 30-gallon drum can be placed inside a 55-gallon drum with the space between packed with absorbent.

The state's high-level radioactive waste is generated at nuclear power facilities. Spent fuel rods from the state's two nuclear power stations, the Surry County and North Anna (Louisa County) facilities, are stored on-site in underground pools. In July 1986, the Nuclear Regulatory Commission approved the storage of spent fuel rods in aboveground dry storage casks at the Surry plant. Fuel rods had not been stored in aboveground dry casks else-

where in the United States when a Virginia utility received permission to do so. The rods are cooled in underground pools for five years before transfer to casks.

Storage space for spent fuel rods has been a problem at both plants, and the casks, approved for transportation of high-level waste, should facilitate movement to a national repository when one is designated.

Household Hazardous Waste

MORE than 61,000 chemicals are marketed in the United States, and several hundred new chemicals are added each year. Many are found in products used in homes and fit the Environmental Protection Agency definition of "hazardous." These ordinary household products can be harmful to human health and the environment if improperly stored and discarded.

Although no federal law regulates

Common hazardous materials around a home include gasoline, varnishes, weed killers, and even nail polish and polish remover

the disposal of household hazardous waste in landfills, the ingredients of many products commonly used by homeowners are dangerous to consume, inhale, or touch. These products include cleaning agents, drain openers, polishes, wood stains and varnishes, paints and thinners, solvents, gasoline, motor oil, photography chemicals, glues and adhesives, yard and garden chemical products such as insect and weed killers or fertilizers, batteries, swimming pool chemicals, and even beauty products such as nail polish and polish remover.

Few people are aware that their homes contain hazardous chemicals or wastes. Here are some simple ways to identify such products: First, read the label. If products are labeled with warnings such as "Flammable," "Corrosive," "Poisonous," "Use in well-ventilated area," or "Wear gloves while using," the product will provide as much hazard when discarded as it does while you're using it. And use common sense. Ask yourself these questions: Would you eat or drink it? Would you light a match around it? Would you mix it with

other materials? If the answer to any of these questions is no, chances are good that you should take extra care in disposing of the material.

Because many people don't realize which products in their homes can be harmful, leftovers are sometimes simply poured on the ground or through drains into septic fields where they can contaminate soil, air, and water. More commonly, these household hazardous wastes are thrown away with other trash and sent to the local sanitary landfill. If the landfill is not properly sited, constructed, and maintained, the wastes may seep into groundwater and contaminate it. The "average" American family discards at least a pound each year of poisons such as lead, cadmium, arsenic, and mercury. A landfill serving 30,000 families receives 15 tons of household hazardous waste a year.

An alternative disposal method for potentially harmful home products has been used in Virginia in Fairfax and Chesterfield counties: these counties sponsored special collection programs for household hazardous wastes. Participants were asked to bring household hazardous wastes to a central collection site for identification, packing, and shipment to a certified hazardous waste facility. In Virginia, these collection programs were organized locally. Seven other states have laws regarding household hazardous waste collection programs. Some states provide total funding for collections, while others provide matching grants.

Local government organizations, public interest groups, or private firms can sponsor household hazardous waste

A landfill serving 30,000 families receives 15 tons of household hazardous waste a year

programs in your community. The following people helped initiate the household hazardous waste collection programs in Chesterfield and Fairfax counties and can provide information and assist persons interested in starting such a program in their own communities: Melanie Pearson, Hazardous Material Section of the Fire Prevention Division of Fairfax County, (703) 691-2331; and Suzan Craik, Extension Service, Chesterfield County, (804) 751-4401. A seven-minute videotape describing Fairfax

Identification and Disposal of Common Household Hazardous Wastes

The following list of potentially hazardous products commonly used in homes and suggestions for disposing of them was taken from *Hazardous Wastes from Homes* (Lord 1986), which provides more detailed information about how to store and dispose of household hazardous wastes. The full reference to this book is in Appendix C.

Key:

1. Waste should NOT be placed in the trash. In particular, containers of liquid hazardous wastes or aerosol cans that have not been completely emptied should never be placed in the trash.
2. Waste should NOT be poured down the drain.
3. Waste can be recycled or returned to manufacturer.
4. Waste should be given to a hazardous waste collection program.
5. Waste can be flushed down the drain with lots of water IF you are connected to a public sewage system. If your home has a septic tank, large quantities of any hazardous waste should NOT be poured down the drain.
6. Waste may be placed in the trash after special treatment. For materials that have resin and hardener components, mix together and let solidify before discarding. For paints and polishes, let dry in a well-ventilated area and discard the solids. For glazes, solidify by firing before placing in the trash. Oils should be mixed with an absorbent (cat litter, saw dust, or commercially available absorbent kits) before being placed in the trash.

In the Garage or Workshop

Automotive Supplies

- 1,2,3,4,6 Used motor oil, light lubricating oil, automatic transmission fluid, kerosene, lamp oil, diesel fuel, brake fluid—take to used oil recycling center.
- 1,5 Antifreeze, coolant
- 1,2,4 Gasoline
- 1,3 Auto batteries
- 1,5 Windshield washer solution concentrate
- 1,2,4 Engine degreaser, carburetor cleaner, car wax, chrome polish containing petroleum distillates or solvents
- 1,2,4,6 Auto body filler

Painting and Decorating Supplies

- 1,2,6 Latex-base paint, other paint whose spills are cleaned up with water
- 1,2,4,6 Oil-base paint, alkyd enamel, epoxy enamel, varnish, other paint whose spills must be cleaned up with thinner
- 1,4 Synthetic auto enamel, model airplane paint
- 1,2,3 Paint thinner, turpentine, mineral spirits
- 1,5 Paint stripper containing sodium hydroxide (lye)
- 1,2,4 Paint stripper containing methylene chloride
- 1,5 Brush cleaners containing TSP
- 1,3 Brush cleaners containing solvents

Building and Woodworking Supplies

- 1,4 Mercury batteries (from smoke detectors)
- 1,4 Fluorescent lamp ballasts
- 1,3 Broken smoke detectors (ionization type)
- 1,2,4 Wood preservatives
- 1,4 Wood that has been treated with preservative
- 1,2,4,6 Glues and cements containing solvents other than water
- 4,6 Asbestos

Garden Supplies

Follow directions on label for use and disposal:

- 1,2,4 Insecticides, soil fumigants, nematocides, fungicides, weed killers, herbicides, vegetation killers, molluscicides, snail and slug poisons, and rat, mouse, and gopher poisons.

Cleaners

- 4 Septic tank degreasers, cesspool cleaners containing organic solvents
- 1,5 Rust removers, aluminum cleaners containing phosphoric acid

Swimming Pool Supplies

- 1,2,4 Pool acid

Pets, Hobbies, Toys

- 1 Flea powder
- 1,2,4 Chemistry sets
- 1 Ammunition, powder, primer
- 1,2,4 Gun cleaning solvent
- 1,3 Antistatic brushes
- 1,4 Photographic chemicals (unmixed)
- 5 Photographic solutions
- 2,6 Ceramic glazes
- 4 Artists' oils, acrylics
- 4 Artists' mediums, thinners, fixatives
- 1,2,4 Rubber cement thinner
- 1,2,4,6 Fiberglass resins, epoxy resins
- 6 Aerosol cans of all types: only completely empty cans should be placed in the trash.

In the Kitchen

Food

- 5 Extracts such as vanilla and peppermint; hard liquor

Housecleaning Supplies

- 1,2,4,5 Lye; oven cleaner, drain opener containing sodium hydroxide
- 1,2,4 Rug cleaners, furniture polish, wooden floor polish containing solvents or petroleum distillates
- 6 Metal polish
- 1,2,5 Cleaners containing ammonia
- 6 Aerosol cans of all types: only completely empty cans should be placed in the trash.

Laundry Supplies

- 1,5 Chlorine bleach
- 1,2,4 Spot remover, dry cleaning solvent for clothing
- 1,2,4 Moth balls, moth flakes

Miscellaneous

- 1,2,4 Lighter fluid
- 1,2,3 Lamp oil
- 6 Shoe polish
- 1,2,4 Shoe dye

In the Bathroom

- 1 Infectious wastes

Medical Supplies

- 1,5 Expired prescriptions, other medicine
- 1,2,4 Shampoo for head lice
- 1,2,3,4 Mercury from broken thermometer
- 1,3 Hearing aid batteries
- 1,5 Rubbing alcohol

Cosmetics

- 1,5 Waving lotions in home permanents, relaxer in hair straighteners, depilatory, cuticle remover containing sodium or potassium hydroxide or thioglycolate
- 1,5 Perfume, cologne, aftershave, preshave
- 2,6 Nail polish
- 1,2,5 Nail polish remover

Cleaners

- 1,5 Tub, tile, shower stall cleaners containing phosphoric acids
- 1,4,5 Disinfectants
- 1,4,5 Toilet bowl cleaners containing sodium hydroxide

Recycling could reduce the volume of trash in landfills by as much as 75 percent

County's Hazardous Materials Clean-Up Day is available from Pearson. The Virginia hazardous waste hotline, (800) 552-2075, is staffed by people who can provide advice about the proper disposal of various hazardous wastes, referral to other state agencies, and information on household hazardous waste collection programs. The federal Resource Conservation and Recovery Act (RCRA) hotline is another source of information about proper disposal of household hazardous wastes: (800) 424-9346. Information about proper disposal of some common household products is provided in the inset box.

What You Can Do

ALTHOUGH it may seem as if individuals can't do much about groundwater pollution from the disposal of liquid and solid hazardous and nonhazardous waste, you can make a significant contribution to the solution of this problem.

Recycling instead of discarding can significantly reduce the volume of trash taken to landfills. Anywhere from 30 to 75 percent of the materials discarded at municipal landfills can be recovered and recycled for use in industry or agriculture. Industry is increasingly employing recycled materials because of the savings in energy and transportation. For example, estimates suggest that the amount of aluminum waste annually disposed of in landfills could fill one quarter of the yearly demand for aluminum.

Landfill "trash" consists primarily of cardboard, paper, plastics, textiles, rubber, leather, wood, glass, metals, food wastes, dirt, ashes, and brick. A large percentage of that can be reused or recycled.

Recycling the maximum amount of waste possible has several benefits: it helps to solve the waste disposal problem, it offers an alternative to the use of new resources, and it conserves energy. Although a curbside collection and recycling program may cost \$20 to \$30 a ton, the costs of "traditional" waste management are also high: \$40 to \$60 a ton to haul trash to a landfill and \$70 to \$120 a ton to burn trash. Some municipalities in Virginia are

beginning separate curbside pickup services for glass, aluminum, and newspapers.

A study done for EPA showed that preparing household glass, cans, aluminum, and newspaper for recycling required an average of three minutes a day for residents. If you don't know where to take recyclable materials in your community, call the Virginia Division of Litter Control recycling hotline, 800-KEEP-ITT. For more information on recycling, write the division at 1215 Washington Building, Capitol Square, Richmond, VA 23219.

Corrugated cardboard (packing boxes) makes up a major part of a city's waste. About 40 percent of the total commercial and 10 percent of the total household waste is cardboard. Recycling old boxes and making new ones out of the recycled cardboard has been successfully practiced by the recycling industry. A collector can make \$15 to \$50 a ton on loose corrugated cardboard. Paper generated by today's businesses accounts for more than 80 percent of their total office waste. This paper, mostly high-grade and worth \$50 or more a ton, makes up 6 percent of city waste.

Glass and metals have been successfully recycled. Aluminum, copper, brass, and silver are more valuable than iron and steel. The recycling of plastic is just beginning, but with the appropriate market, sorted plastics are worth 5 to 40 cents a pound. Cotton and woolen cloth

may be recycled, and charitable organizations or thrift stores can use discarded clothes. Garden and household tools, appliances, and toys are among the commonly discarded items that could be repaired and used.

Organic yard waste, vegetative debris, and sewage sludge can be composted into humus that sells for \$3 a cubic yard. The large amounts of wood the construction and demolition trades generate can be used as fuel to generate heat and energy. Methane produced during the natural breakdown of organic material has been tapped to provide heat and energy for local farms, homes, and industry.

The state's used motor oil recycling program helps protect ground and surface water

A Virginia project targeted specifically at the protection of surface water and groundwater is the automotive oil recycling program. Organized by the Division of Energy within the Virginia Department of Mines, Minerals, and Energy, the program provides collection centers across the state for the safe disposal of waste oil. Used oil currently has no value and collection is a problem in some areas. Improperly discarded oil can cause serious problems for groundwater. A single quart of oil can dissolve



Oliver Services, Inc.

Through the cooperation of Roanoke County and the Clean Valley Council, residents may recycle glass, aluminum, and newsprint. Each type of material goes in a different part of this colorful truck. Recycling extends the life of landfills.



Dennis Slifer

Illegal roadside dumps such as this one on route 601, north of Goshen, Virginia, threaten both surface and ground water. The river in the photo is the Little Calpasture.

and disperse to contaminate up to 2 million gallons of drinking water. And research shows that over 4.4 million gallons of used oil are improperly disposed of by do-it-yourself oil changers in Virginia each year. For information about the used oil collection site closest to you, call (800) 552-3831.

Appropriate disposal of other types of home hazardous waste is another contribution individuals can make. About one pound of the refuse a typical family sends to a landfill or open dump every year is hazardous waste. Proper disposal practices can help reduce the amount of hazardous material available to contaminate groundwater.

Another way to help reduce the threat to groundwater is to avoid using illegal dumps and to help clean up such dumps in your community. Roadside littering is illegal. The Virginia Department of Waste Management depends largely on citizen reports of open dumps to identify these sites and begin the cleanup process. Support of local and state waste management programs contributes to solving the waste disposal problem.

If you own or work at a business that is a "small quantity" generator of hazardous waste — dry cleaners, printers, auto repair shops, laboratories, and many others—the Governmental Refuse Collection and Disposal Association Clearinghouse can provide technical assistance and advice about waste disposal: GRCDAC, P.O. Box 7219, Silver Spring, Maryland 20910; telephone (800) 458-5886.

An increasingly popular alternative to disposal of industrial wastes is waste exchange, the direct shipment of wastes to other companies which can use the waste material. The Southern Waste Information Exchange (SWIX), a nonprofit clearinghouse for waste exchange and management information, sends a quarterly catalog to more than 10,000 firms in a 12-state area from Virginia to Florida and west to Texas. The catalog lists materials wanted and materials available, and SWIX also actively searches for buyers and sellers through telephone referrals. For more information about this program or for subscriptions to the SWIX catalog, write SWIX, P.O. Box 6487, Tallahassee, Florida 32313; telephone (904) 644-5516.

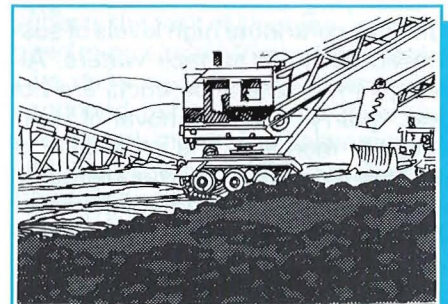
In Virginia, resource recovery facilities (trash-to-energy incinerators) are being built to decrease the amount of trash sent to landfills and to supply energy in the form of steam or electricity for local use. For example, the municipal facility in Galax, a town of about 6,500 inhabitants, burns about 50 tons of garbage a day. The steam produced is used by the Hanes Knitwear Company. In Portsmouth, a public housing project will be heated with fuel derived from garbage, saving the community about \$50,000 a year.

Other local governments and groups in Virginia are considering incineration as a possible option for saving land and reducing garbage disposal costs. The Virginia Department of Waste Management regulates 15 incineration facilities

Integrated waste management is becoming the solution of choice in many localities across the country

across the state. Although incineration can reduce the refuse sent to landfill by about 80 percent, it can create other problems. Harmful materials such as heavy metals may be concentrated in the ash and may require special handling for disposal. Poisonous gases given off may add to air pollution problems. And dioxin, a known carcinogen, is a by-product of the combustion process.

Integrated programs of waste management — the use of incineration, waste reduction, energy and waste recovery, and recycling in addition to traditional landfilling — are becoming more popular nationwide. Environmental laws on air and water pollution, cost and difficulty in obtaining appropriate sites for sanitary landfills and incineration facilities, and new technologies for cost-effective recovery and recycling continue to stimulate new solutions to the long-term disposal of waste.



Mining

A litany of environmental problems is associated with mining. Although mining does not always cause all these problems, mining can create toxic products, lower the water table, disrupt aquifers, affect the movement and recharge of groundwater, cause land subsidence (sinking), and completely alter the landscape.

The disposal of mining wastes also can cause environmental problems. As much as eight tons of rock are removed for every ton of ore, mineral or fossil fuel produced. This waste rock, called

Poisons leaching from the tailings of a titanium mining operation killed hundreds of thousands of fish in the Piney and Tye rivers

spoil, is stored above ground, as are tailings, finely ground rock created in the ore extraction and cleaning process. Mining operations in the United States annually produce approximately 2.3 billion tons of waste spoil and tailings.

Some of these mining wastes may not be hazardous and may be useful as an inexpensive road or construction material. However, others may be hazardous. Sometimes spoil and tailings are subject to erosion, and sediment from them finds its way into a river or lake. Precipitation on uncovered spoil piles and tailings can allow the release of lead, zinc, copper, other heavy metals, sulfuric acid, and radioactive wastes, such as uranium and thorium. Metal mines, particularly uranium and copper mines, produce one of the most serious threats to groundwater. Wastes from these operations are high in toxic dissolved materials — arsenic, sulfuric acid, copper, molybdenum, selenium — and radioactive wastes.

Quarrying for stone, lime, and gypsum may contribute high levels of suspended solids to surface waters. Although these waste products are not toxic, quarrying and removal of overlying soil increases the probability of local contamination of groundwater in another way. The remaining thin layer of soil cannot effectively filter contaminants, increasing the potential for groundwater contamination, especially in areas of fractured *bedrock*.

When mines intersect aquifers, large amounts of water must be pumped to the surface. This dewatering of mines can drain aquifers, lower the water table below the intake of producing wells, and reduce the amount of water supplied to regional well users. In areas with underlying salt water or areas near the ocean, this withdrawal of water can result in saltwater intrusion. The section "Water Withdrawal and Saltwater Intrusion" provides more information about this problem.

Mining and ore processing caused one of Virginia's worst cases of pollution. From 1945 to 1973, American Cyanamid mined titanium to produce titanium dioxide, the sub-

stance that gives white paint its whiteness. The plant was near the Piney River and the town of the same name. As part of the processing, more than 100 tons of copperas (iron sulfate) and other wastes were dumped each day on a hillside. With each rain and snowfall, poisonous substances *leached* from the pile and were carried toward the river. Hundreds of thousands of fish killed in the Piney and Tye rivers provided evidence of contamination from the mining site. The highly acidic copperas had contaminated groundwater, soil, and surface water; cadmium, zinc, chromium, arsenic, and nickel had leached from the waste pile. Estimates of cleanup costs ran as high as \$5 million. In 1985, after an eight-year legal battle, American Cyanamid was found liable for the cleanup of 80,000 tons of the toxic waste.

Coal Mining

DESPITE the decrease in total use of coal in the United States, its use for generating electrical energy has increased slightly in recent years. Its overall use is expected to pick up more as the world's oil reserves near depletion and the availability of cheap gas and oil decreases. The United States now has 15,000 active and 67,000 inactive coal mines covering a total surface area of four million acres. Between one-third and one-half of the world's total reserves of coal are located in the United States. Southwest Virginia has more than 750 active coal mining operations in seven counties.

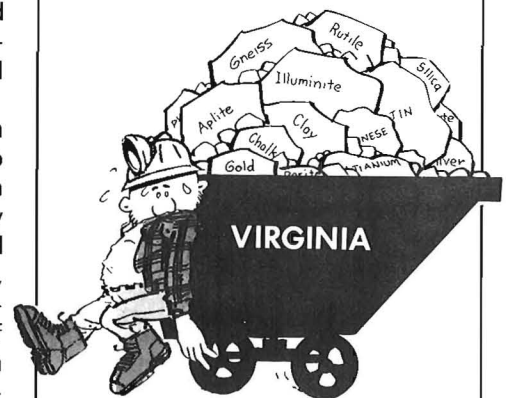
Coal is surface and deep mined in Virginia, and both pose threats to groundwater. Strip mining began in Virginia in the mid-1940s, and nearly 100,000 acres were surface mined during the next 40 years. However, deep mines account for most of Virginia's coal tonnages. For example, of the 40.7 million tons of coal mined in 1987 (estimate based on coal shipments, National Coal Association), deep mining accounted for about 80 percent of the total tonnage. Longwall mining, a German deep mining method that requires few miners and allows companies to shear coal off in slices, is becoming popular in Virginia. The number of mines in Virginia decreased from more than 800 in 1982 to 681 in 1985, but the operation of 12 longwall mines brought total coal production to 44.3 million tons in 1985.

Coal mining can create two major

problems for groundwater. First, interruption of the aquifer by blasting or subsidence can cause loss of water in nearby wells. Mine shafts honeycombing mountains can result in land subsidence and cave-ins of overlying material, allowing the introduction of surface materials into aquifers. Longwall mining machinery removing coal hundreds of feet below the surface can cause cracking of rock and sinking of nearby homes. Second, contamination of groundwater can occur from acid mine drainage and from the washing of chemicals and minerals from mines and mine wastes. Coal is frequently found with iron pyrites and other sulfides. Dewatering causes these minerals to be exposed to oxygen; reintroducing the minerals to water results in

Minerals Mined in Virginia

Amphibolite	Kyanite
Aplite	Limestone
Basalt	Marble
Diabase	Marl
Dolomite	Quartz
Fill	Sand
Fuller's earth	Sandstone
Gemstones	Shale
Gneiss	Slate
Gold	Soapstone
Granite	Starolite
Gravel	Talc schist
Greenstone	Traprock
Iron Oxide	Vermiculite



Minerals Formerly Mined in Virginia

Arsenic	Mica
Barite	Platinum
Chalk	Pyrite
Copper	Rutile
Feldspar	Silica
Illuminite	Silver
Iron	Tin
Manganese	Titanium

Source: Virginia Division of Mineral Resources

Because of mining, some residents of Powell River have been without well water for three years

very acidic groundwater with high levels of iron and sulfates. Approximately 3.6 million tons of acid are generated from the disposal of coal mining wastes in this country every year, and an estimated 360,000 to one million tons of that acid enter the groundwater.

Mining coal has provided the livelihood for many residents of Southwest Virginia, and this area displays the scars of such activity. In particular locations, such as Powell River, Wise County, some citizens have been without well water for three years. First the water was noticeably discolored — dingy brown from sulfur and iron and containing specks of black coal — and then the water in many wells disappeared. Evidently, the stripping on the surface and the tunneling below the surface contaminated and disrupted the groundwater supply. Nearly everyone in this community of 70 individuals has drilled a second well of at least 100 feet in the last year. Others have had to drill as many as four wells in the last 12 years to maintain a producing well. The residents cannot sue for negligence because the area has been mined by many different companies. The nearby town of Norton will extend water lines to Powell River, but they will not be operational until 1988 because of required modernizing of the Norton system. For now, residents of Powell River must continue to collect drinking water from the public spring several miles distant. Even so, Powell River residents seem fortunate when their plight is compared to the isolated Virginians scattered along mountain ridges in other areas, who have no alternative source of drinking water. Because it is not cost effective to extend water lines to the areas, these communities with polluted water or no water at all have little hope for a future solution to their problems.

Mining Laws and Reclamation

ALTHOUGH mining can be restricted in particularly sensitive areas, mining must occur where the metals and ores are located. The federal

Surface Mining Control and Reclamation Act of 1977 regulates surface coal mining and reclamation and requires applying techniques to minimize the draining of aquifers and to prevent acid mine drainage from reaching groundwater. The Virginia Coal Surface Mining Control Reclamation Act of 1979 (Chapter 19 of Code of Virginia) is the state law that regulates surface mining. In 1981, Virginia received federal approval to conduct permanent regulatory and abandoned mine land reclamation programs, and the Department of Mines, Minerals, and Energy's Abandoned Mine Lands Group was created within the Division of Mined Land Reclamation specifically to address Virginia's abandoned mine problem. The federal Surface Mining Control and Reclamation Act established a

In 1986, Virginia received \$3.8 million from the federal government to reclaim 13 abandoned mine sites

fund financed with fees assessed on coal production (35 cents per ton on surface mined and 15 cents per ton on deep mined) to reclaim and rehabilitate land previously used for strip mines. The law provides that Virginia will receive at least 50 percent of the abandoned mine land taxes collected in the state. In 1986, for example, Virginia received \$3.8 million from the federal government to reclaim 13 abandoned mine sites in Southwest Virginia.

In 1982, Virginia had an estimated 72,000 acres of abandoned, disturbed land, including surface mined lands, refuse piles, and sites for loading and preparation. Investigations continue on the best methods to reclaim and use strip-mined land. The Powell River Project, a cooperative venture between business and Virginia Tech, was started in 1979 to analyze reclamation techniques. Restoration of mined land may consist of simple revegetation or of massive earth moving, which can cost more than \$20,000 an acre.

The Abandoned Mine Lands Group recently completed an inventory update of Virginia's problems with abandoned mine lands and identified 345 problem areas with reclamation costs of \$217 million to \$471 million. Most problems occur in Virginia's southwestern coalfields, but about 700 abandoned shafts and pits were located in Chesterfield,

Henrico, Powhatan, and Goochland counties near Richmond. The deepest shaft found was 1,000 feet.

Over 77 million tons of noncoal minerals are annually mined in Virginia, contributing \$380 million and about 5,000 jobs to the state's economy. Lands where noncoal products and minerals were mined are typically among the last sites to be considered for reclamation. Virginia legislation was enacted in 1978 to establish a noncoal orphaned land reclamation program managed by the Department of Mines, Minerals, and Energy's Division of Mineral Mining. Funds for reclamation of these mines are received from interest earned on a state-managed industry program. Payments are made by participating owners to the Minerals Reclamation Fund based on acreage disturbed by the operations. This fund assures the reclamation of active mines and is a requirement of Virginia's Minerals Other Than Coal Surface Mining Law.

The special fees on coal established by the federal Surface Mining Control and Reclamation Act will expire in 1992, and funds will not be available to correct all of Virginia's coal mining problems. J. Steven Griles, assistant secretary for land and minerals management (U.S. Department of the Interior), suggests the task of cleaning up abandoned mine sites in Virginia may have to be done by the coal industry; the abandoned mine land fund does not have enough money for reclamation of all old sites. The federal Office of Surface Mining indicated in its 1986 report, *Encouraging Abandoned Mine Land Reclamation via Remining: A Federal, State, and Industry Initiative*, that only an estimated 10 percent of the nation's abandoned mine land problems will be corrected by 1992.

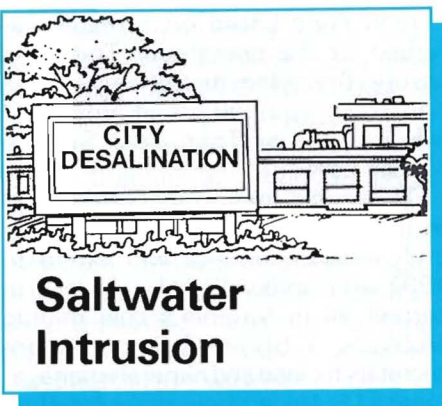
What You Can Do

GROUNDWATER damage can be minimized by employing the best management techniques and the best technology. In many cases, federal and state permits are required for mining activities, well drilling, and disposal of mine wastes. Threats to groundwater quality can be reduced by neutralizing acid mine drainage and sealing aquifers affected by mining activities. Tailings lagoons should be lined with impermeable liners and reclaimed by covering with topsoil and planting grass. In some cases it may be necessary to cap

tailings lagoons or piles with impermeable materials.

If you are aware of an orphaned noncoal mine site in your area or want additional information on "Virginia's Orphan Land Program," contact the Commonwealth of Virginia Department of Mines, Minerals, and Energy, Division of Mineral Mining, P.O. Box 4499, Lynchburg, Virginia 24502; telephone (804) 239-0602.

To report locations of abandoned coal mining sites or problems associated with abandonment, contact the Department of Mines, Minerals, and Energy's Abandoned Mine Lands Group at the Division of Mined Land Reclamation, P.O. Drawer U, Big Stone Gap, Virginia 24219.



THE map below shows the areas in Virginia that have potentially salty aquifers. Some salty groundwater occurs naturally in geologic formations. Wells and pumping can cause its intrusion into fresh-

water aquifers. Modifications of land surfaces, estuaries, and shorelines can cause saltwater intrusion from the ocean. Surface salting, such as on roads in winter, can cause artificial contamination. "Natural Constituents" provides more information about salt in groundwater.

In the southwestern Cumberland Plateau of Virginia, naturally occurring salt water may be found in deposits within 150 feet of valley bottoms. Beds of shale generally prevent deeper salty water from entering freshwater aquifers; however, abandoned and improperly plugged gas wells and coal exploration wells can serve as vertical conduits for the upward movement of waters. Extensive areas of groundwater in Wise, Dickenson, and Buchanan counties have been contaminated by such poor well management.

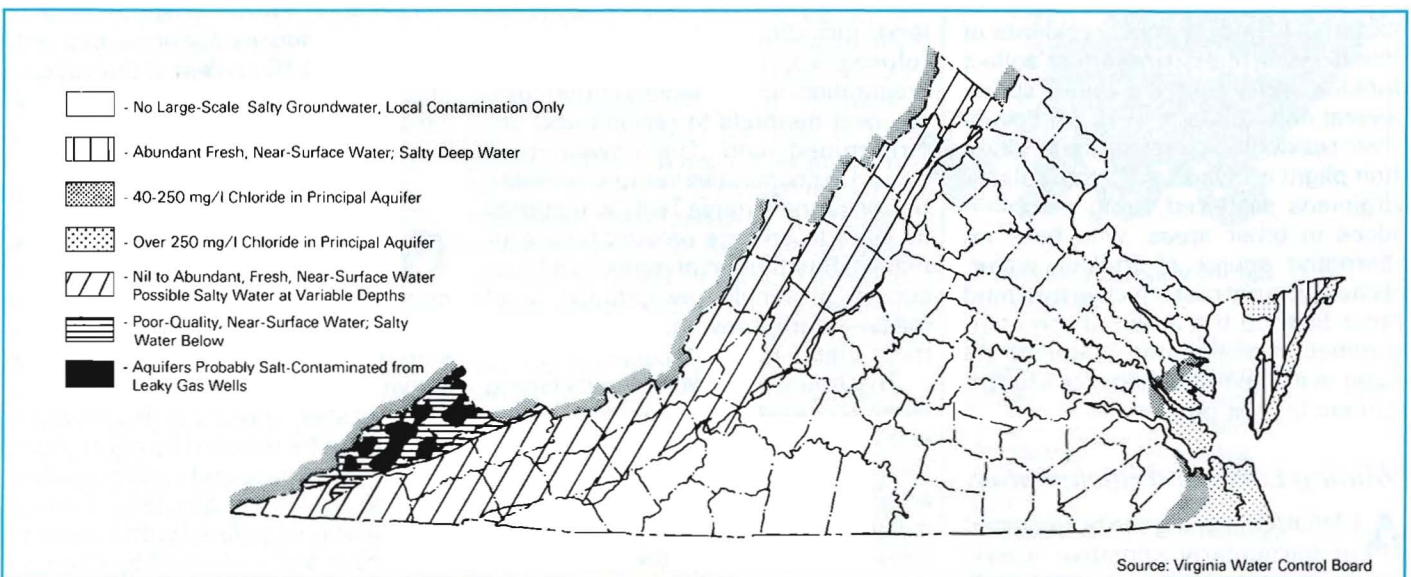
The Valley and Ridge Province has some of the most productive aquifers in the state, but even they can be contaminated by salt. Wells are generally less than 300 feet deep and usually do not encounter salty water at this depth, but shallow aquifers in limestone areas with solution channels and sinkholes can become contaminated by surface applications of salt.

In the coastal area of Virginia, salt water underlies Virginia Beach, Norfolk, and parts of Chesapeake and Portsmouth and extends westerly in a wedge to the eastern parts of Isle of Wight and Southampton Counties. Concentrations of 250 milligrams per liter (mg/l) of chloride, the limit for safe drinking water, can be found at 100

Indirect evidence suggests overpumping of groundwater is causing salt water to move inland at the rate of 30 to 40 feet a year

feet below sea level in extreme southeastern Virginia to 1,400 feet below sea level in the Northern Neck. The entire Eastern Shore area of Virginia has salt water at depths of 300 feet or more. Before extensive development on land, salty groundwater was probably flushed out of the system by the natural seaward movement of fresh water from the fall line. Increased human pumping of groundwater has allowed salt water to move inland, although thus far it is only being detected in scattered wells. Indirect evidence suggests that salt water is moving inland along the Coastal Plain at the rate of 30 to 40 feet a year.

Because that rate may be much faster near major pumping centers, the Coastal Plain of Virginia could develop one of the most serious saltwater intrusion problems in the state. Withdrawal of groundwater in the Coastal Plain for industry and public water supply began about 40 years ago and increased steadily for 30 years before it stabilized. Water levels have declined, and cones of depression have developed around centers where major withdrawals occur. Such a cone exists around Franklin where the Union Camp Corporation withdraws about 35 million gallons a



Source: Virginia Water Control Board

Areas in Virginia having salty groundwater potential

day for its papermaking operation. Another cone of depression has formed around West Point, where another papermaker withdraws 20 million gallons a day. The potentiometric surface of the Potomac Aquifer, the major aquifer used throughout the Coastal Plain, was originally about 20 feet below the land surface near Franklin; today that depth — the cone of depression — is about 190 feet below the land surface. In the West Point area, the potentiometric surface of the Aquia aquifer has dropped an additional 30 feet below the land surface in just 20 years.

Virginia Beach residents are risking saltwater intrusion for the sake of residential landscaping

Although the withdrawal of fresh water can induce the upconing of salty water from underlying aquifers or its lateral movement from the bay or ocean, significant saltwater intrusion into those portions of aquifers supplying drinking water in coastal Virginia has not yet been documented. Wells have shown negligible increase in saltiness over the last 70 years. A U.S. Geological Survey study revealed that freshwater recharge has kept pace with the rate of pumping in coastal areas of Virginia.

Virginia's Groundwater Act of 1973 protects the quantity of groundwater in the state, and the Virginia Water Control Board can declare groundwater management areas if groundwater quantity at these sites is threatened. The Eastern Shore Peninsula and southeastern Virginia (counties and cities east of the fall line and south of the James River) have been designated as groundwater management areas. Within these management areas, industrial and municipal withdrawals of more than 300,000 gallons a month must be reported to the Water Control Board.

One area of Virginia is increasing its potential for saltwater intrusion for the sake of residential landscaping. The Great Neck and Little Neck areas of Virginia Beach are withdrawing huge amounts of water during the summer for watering grass and shrubs. The areas withdraw only 1.5 million gallons a day for heat pumps and drinking water, but they withdraw 11 million gallons a day for landscape watering.

Shallow wells were installed in large numbers after the droughts of 1977 and 1980 to circumvent restrictions on city water use and to lower water and sewer bills. This drilling of landscaping wells continues to increase. In Virginia Beach, an estimated 75,000 people own wells in 129 neighborhoods; only 4,000 of the wells are used for drinking water. Throughout Hampton Roads, more than 100,000 people own wells.

Wells for watering lawns tap the same aquifer as wells for drinking water. Two hundred wells went dry in this coastal area during the drought of 1985. The drain on the aquifer is evidenced by the depth of new wells; 40 to 150 feet is typical now, whereas wells of only 10 to 15 feet previously produced water. Industrial wells in the area take water from aquifers at 1,000 to 2,000 feet below the surface.

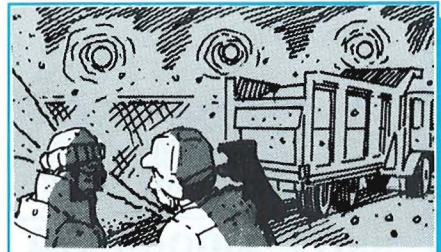
The inadequate recharge of aquifers in this area may be attributed to a number of factors. Much of the land is being paved over as development increases, and water is further diverted from recharge areas by storm sewers. Droughts in recent years have added to the problem. Even lawn choices may have contributed: fescue grass requires twice the amount of moisture as Bermuda grass.

What You Can Do

If you live where saltwater intrusion is a potential or already existing problem, water conservation is probably the best contribution you can make to solving the problem. Limiting "luxury" water use and adopting conservation measures, such as turning off faucets while brushing teeth, shampooing, shaving, or washing can help.

If lawns and gardens must be watered, don't use spray irrigation; much of that water evaporates before reaching the plants that need it. Drip irrigation, a method which delivers small amounts of water throughout the day to meet the plant's water requirements, minimizes the loss of water through evaporation.

Higher fees for water and community emphasis on water conservation may encourage residents and industries to significantly reduce the amount of water they use, lessening the effects of major withdrawals and allowing aquifers more time to recharge. Once an area has lost its groundwater to saltwater intrusion, developing new water supplies can be very expensive.



Stockpiles and Bulk Storage

STORING large quantities of materials at convenient locations allows the materials to be efficiently transported and used. Coal, sand, gravel, potash, gypsum, copper ore, iron ore, and uranium commonly are stored in stockpiles. Across the country, approximately 700 million tons of materials are stockpiled each year.

Unfortunately, even a product seemingly as harmless as common salt (sodium chloride) can contaminate aquifers if it is improperly stored, rendering the water unfit for humans and livestock to drink. Salt used in winter to melt ice on roads in rural and municipal areas poses a threat when it is washed into surface waters or percolates through soil into aquifers.

Because of its low cost, salt is often stored outdoors in uncovered piles. Other chemicals added to road salt to reduce caking (sodium ferrocyanide) and corrosiveness (chromate and phosphate) can find their way into groundwater with the sodium chloride. Sodium ferrocyanide is soluble in the rain and melted snow that infiltrate unprotected stockpiles. Solutions of this compound can enter groundwater and result in concentrations of cyanide above safe levels. The Virginia Department of Highways and Transportation is aware of the dangers of storing road salt improperly and has issued guidelines for the storage and use of deicing materials in the Virginia Water Control Board's *Best Management Practices Handbook 318*.

Earlier methods of storing salt outdoors caused the Department of Highways and Transportation to provide a new well to a rural family in Franklin County after sodium and chloride from the nearby Snyder'sville highway yard salt pile contaminated their drinking water. This stockpile was put into operation in 1972, and salt was stored in uncovered piles outdoors until 1982.

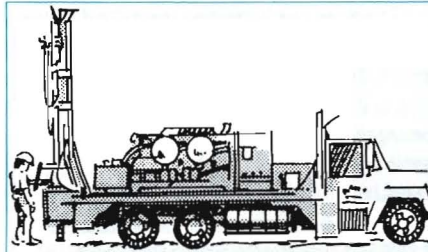
A combination of geology and quick action by officials prevented Virginia's "great tire fire" from becoming a groundwater catastrophe

The pile was then moved to a storage building, but salt still seeped into groundwater and entered surface runoff because large amounts of salt spilled on the ground when the trucks were loaded.

Groundwater on-site and off-site far exceeded the allowable concentration of chloride in drinking water, 250 milligrams per liter (mg/l): the family's contaminated well had chloride concentrations of 730 mg/l, and observation wells near the stockpile had chloride concentrations of more than 7,000 mg/l and sodium concentrations of more than 5,000 mg/l. In 1985, the highway and transportation department designed and built a better storage facility for the salt pile to prevent future groundwater contamination.

Stockpiles of another product related to automotive travel — used tires — might have caused extensive groundwater contamination in Virginia. On October 31, 1983, about seven million used tires stored on four acres in western Frederick County near Winchester were set on fire. An oily product of combustion was released at the rate of 100,000 gallons a day for a total release of 800,000 gallons. Some of this oily product was lost during initial cleanup because of heavy rains. An unnamed tributary and Hogue Creek, which received runoff, were degraded and depopulated of aquatic organisms. Fortunately, the contaminants were not able to move quickly through the soil at the storage site, and the effectiveness of containment techniques employed by state agencies and the Environmental Protection Agency served to minimize groundwater contamination. Only one of seven on-site wells showed contamination by the tire pyrolysis product. The contamination was minor and the Virginia Water Control Board ceased its monitoring program of this Superfund site in late 1986.

The Environmental Protection Agency spent \$1.7 million to control and monitor the pollution from the fire. Six other federal and state agencies, including the Coast Guard, which is responsible for controlling oil spills that endanger water, were also involved.



Underground Injection

UNDERGROUND injection is the placement of fluids into the ground through a well. According to the Environmental Protection Agency, more than 280,000 of these wells are in operation nationwide. Of the hazardous waste disposed on or in land, nearly 60 percent is injected.

Properly constructed, injection wells provide for the safe disposal of liquid wastes that might otherwise be stored less securely

Injection wells that are properly constructed, sited, and operated contribute to groundwater protection by providing a receptacle for wastes that might otherwise be stored less securely. To protect aquifers from contamination, these wells should be constructed so that wastes are injected below the deepest geological structures containing groundwater.

The Safe Drinking Water Act established a national program in 1980 to prevent underground injections that endanger drinking water. This program, the Underground Injection Control program, was created specifically to ensure that disposal of fluids in injection wells does not threaten present and future drinking water sources. Injecting hazardous wastes into or above underground sources of drinking water is prohibited. Injecting these wastes below drinking water aquifers is regulated by provisions of the Underground Injection Control program, as are most other types of injection wells.

The Environmental Protection Agency is required to prescribe an Underground Injection Control program for each state that does not have its own; it has done so for Virginia. Of the five classification

categories of injection wells recognized by the Environmental Protection Agency, termed Class I through V, Virginia has only two. Nearly all Virginia's injection wells are Class V.

More than 32 types of injection wells fit into this category. Examples of these are cesspools, cooling water return flow wells, heat pump exchange wells, drainage wells, sand backfill wells, septic system wells, subsidence control wells, spent brine return wells, and solution mining wells. Virginia's Class V wells include thousands of air conditioning/cooling water return wells and more than a hundred stormwater drainage wells. The state also has 14 Class V waste disposal wells, three recharge wells, and eight wells used to store liquid propane.

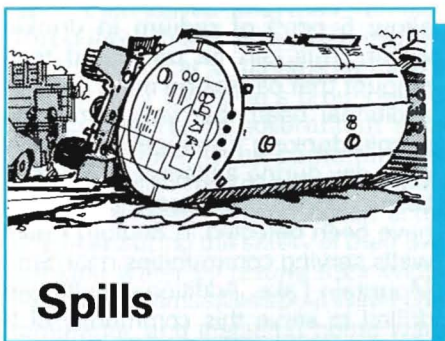
Although no permitting regulations exist for Class V wells in Virginia, such underground injection wells can have a variety of negative effects on underground drinking water sources. Stormwater runoff drainage wells collect deicing salts; lead, grease, and road oil; animal wastes, fertilizers, and pesticides; and other substances that can migrate to groundwater. Waste disposal wells may introduce contaminants directly to groundwater. Cesspools that are excessively deep or excavated in an area with a high water table provide a direct conduit for contaminants to reach groundwater. Injection wells used as return wells for heat pumps or air conditioning systems can cause groundwater problems with "thermal breakthrough," which occurs when the water discharged from the return well does not have time to return to the temperature of the aquifer before being drawn into the supply well.

Under the Underground Injection Control program for Virginia, owners or operators of Class V wells must report the existence of the wells to the Environmental Protection Agency to provide the federal agency with information for its inventory of Virginia underground injection wells. Although permits are not required for Class V wells, immediate action will be taken by the Environmental Protection Agency or the state on any Class V well that poses a risk to human health. Responses may include closing wells, civil or criminal penalties, or requirements to apply for a permit.

Builders of injection wells other than those in Class V must apply for permits before construction. At this time, the only injection wells in Virginia which do not fit into the Class V category are 24

abandoned solution mining wells used to inject water or other fluids underground to dissolve minerals. Virginia does not have injection wells for hazardous or nuclear waste injection, for production of gas and oil, or for converting oil shale and coal.

Two publications, *Fact Sheet on EPA's Underground Injection Control Program in Virginia* and *UIC Class V Injection Wells, Public Information Bulletin for EPA Region III*, are available to interested persons from The Drinking Water/Groundwater Protection Branch, U.S. Environmental Protection Agency, Region III, 841 Chestnut Street, Philadelphia, Pennsylvania 19107; telephone (215) 597-8227.



Spills

PROSPECTS of hazardous materials emergencies are great in Virginia, where an estimated 18 percent of the trucks on highways carry dangerous materials.

Nationwide, approximately four billion tons of hazardous waste a year are transported to treatment, storage, or disposal facilities. Every year, 10,000 to 16,000 spills of 14 million tons of hazardous waste occur.

During 1983-85, oil spills accounted for nearly a third of the pollution complaints received by the Virginia Water Control Board

In Virginia, spills of petroleum products are the most common. The Virginia Water Control Board responded to 1,399 pollution complaints from July 1, 1983, through June 30, 1985. Of this total, 425, or 30 percent, were surface oil spill complaints. The U.S. Coast Guard, which regulates oil spills in tidal waters,

documented 505 oil spills in Virginia's tidal waters during this same period. An estimated 281,277 gallons of petroleum products were spilled, and 19 percent (53,575 gallons) reached state waters. In August 1984, a tanker truck crashed on Warm Springs Mountain, near Warm Springs, Bath County, and spilled 2,300 gallons of diesel fuel. Three springs supplying Virginia Hot Springs, Inc., were contaminated.

Trains carrying hazardous materials were involved in seven accidents in Virginia during 1984, and three caused spills. One of these train accidents caused 26,000 gallons of a hazardous industrial solvent — dimethyl formamide — to be released into a Montgomery County creek that flows into the New River. Although massive fish kills occurred, surface and groundwater drinking sources were not contaminated. Late autumn floods washed away all traces of the solvent from Stroubles Creek and the New River.

In 1982, a spill of liquid arsenic acid close to a school near Rocky Mount forced the evacuation of 1,200 students. The top three feet of soil in the spill area had to be removed to prevent contamination of groundwater and a nearby stream.

Although spills that occur during transportation may be more widely publicized, spills at fixed facilities are probably much more common. In 1987, three thousand gallons of sulfuric acid were spilled into the Potomac River from a plant in Alexandria. A broken line that provided oil to an industry in Smyth County spilled approximately 2,000 gallons of oil into the Middle Fork of the Holston River and caused the town of Marion to have to switch temporarily from surface water to a spring for its drinking water.

What You Can Do

YOU can report spills by calling the 24-hour National Response Center at (800) 424-8802. Government agencies will respond immediately to contain and lessen the effects of a chemical spill on land, in the air, or in water. In Virginia, chemical spills and emergency response are handled by the Hazardous Material Branch (Operations Division, Office of Emergency Services), 7700 Midlothian Turnpike, Richmond, Virginia 23235, telephone (804) 323-2300; and by the Virginia Emergency Response Council, telephone either (804) 786-5999 or (804) 225-2667.



Abandoned Wells

IMPROPERLY constructed and abandoned wells are considered by health officials to be a threat to public safety and the most significant source of groundwater contamination in Virginia.

Although the total number may never be known, several million wells are thought to have been abandoned since the nation was colonized. The sites of many of these wells are unknown; wells may be leveled and the casings and seals broken during demolition of houses and surrounding buildings. In Virginia, old homesites may have one or more abandoned wells. Eastern Virginia and the Piedmont in particular have many dug or bored large-diameter wells.

An improperly abandoned well can provide a direct conduit for surface substances to pollute groundwater

Improperly sealed abandoned wells can provide a direct conduit for surface runoff carrying pollutants. Abandoned wells also are used as convenient sites to dispose of wastes, some of which may be hazardous and may enter groundwater from the well.

Abandoned wells used as garbage dumps pose threats other than groundwater contamination. For example, a 13-year-old Bassett, Henry County, youth died after he was overcome in an abandoned well by large amounts of carbon dioxide, propane, gasoline or kerosene, and possibly methane. The 40-foot well was filled with 24 feet of garbage. The rescue worker who attempted to save the boy survived but had to be hospitalized to recover from the toxic gases.

Improperly abandoned oil and gas wells in the state also pose a threat to groundwater. Early wells often lacked casing and were frequently closed by

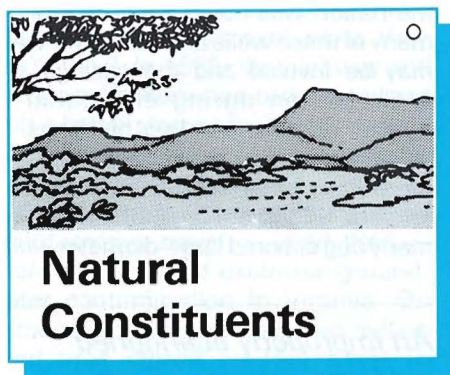
plugging with a tree stump and a few shovels of dirt. In some areas of the state, these wells allow salt water to leak into freshwater aquifers.

What You Can Do

If you use well water, be sure your down well is properly located, built, and sealed. If you move or change to a different water system, be sure that you cap and seal your well properly.

The Virginia Water Resources Research Center's publication *A Homeowner's Guide to Domestic Wells* provides information about well location, drilling, construction, maintenance, and abandonment.

If you know of any abandoned wells, report them to your local health official or the Virginia Water Control Board.



WATER does not exist anywhere with absolutely nothing in it. So much is soluble in water that it is known as "the universal solvent." Groundwater is no exception, and the materials it contains reflect the soil and rock types through which it seeps or flows.

Throughout Virginia, aquifers exist naturally with levels of sodium and chloride high enough to cause the water to taste salty (see map on page 30). The state's anti-degradation policy provided by the Water Control Law reflects differences in the levels of sodium and chloride occurring in groundwater across Virginia. To provide guidance in preventing groundwater pollution, the Virginia Water Control Board has set recommended limits for sodium of 100 milligrams per liter (mg/l) in the Coastal Plain and 25 mg/l elsewhere in the state. Similarly, the state has recommended criteria of 50 mg/l of chloride in the Coastal Plain and 25 mg/l for the remainder of the state. The limits are not enforceable standards but serve as guidelines to prevent the degradation of

groundwater through use by industry and agriculture.

Enforceable drinking water standards for these elements have not yet been set. A concentration of 250 mg/l of chloride is the Environmental Protection Agency's recommended safe limit in drinking water. Although the federal agency has not set limits for sodium in drinking water yet, sodium concentrations of more than 100 mg/l may be dangerous to people with circulatory and kidney problems. Concentrations exceeding 200 mg/l are generally dangerous to human health. As a point of reference, ocean water contains about 19,000 mg/l of chloride and 11,000 mg/l of sodium.

High levels of iron (above the recommended level of 0.3 mg/l) and manganese (above the recommended level of 0.05 mg/l) can be found in groundwater across the state. High concentrations of these metals are not dangerous, merely unpleasant. They stain laundry appliances, plumbing fixtures and clothes and give food and beverages a metallic taste.

Sulfate, another unpleasant natural constituent, is found associated with various rock types, particularly those with pyrite or gypsum. The recommended level of sulfates is 250 mg/l; higher concentrations have a laxative effect and can give water an "off" flavor. Water samples in the Piedmont have contained sulfates in excess of 2,500 mg/l.

High levels of fluoride are found in Coastal Plain groundwater, and barium, zinc, lead, and copper in local deposits throughout the state can result in concentrations in water exceeding recommended levels. Fluoride provides a good example of the way that different concentrations of a substance can cause different human health effects. At a low concentration in drinking water, fluoride is thought to help prevent tooth decay. At higher concentrations, however, it can weaken and damage teeth and bones and cause mottling of the teeth.

Radon, an invisible, odorless, radioactive gas produced from the decay of uranium and radium, occurs in fractured bedrock and soils throughout the Appalachian-Piedmont region. Sufficient doses of radon and its products can result in lung cancer. Radon is believed to be responsible for most of the lung cancer risk to the nonsmoking public. Radon easily escapes from water into the air, and the danger of

radon-contaminated water is not from drinking the water but from breathing in the radon that escapes. According to the Environmental Protection Agency, radon in drinking water causes between 30 and 600 cases of lung cancer in the United States each year.

The EPA recommends that homeowners take corrective action when indoor radon levels exceed 4 picocuries per liter of air (4 pci/l), but a maximum contaminant level for drinking water has not yet been set. Simple techniques such as aeration or filtration through activated charcoal filters can remove radon from water. Because the filters concentrate the radioactivity, care must be taken in disposing of them.

Radon's parent elements, radium and uranium, have been linked to bone cancer. Federal and state regulations allow 5 pci/l of radium in drinking water. This can be translated to an amount that causes no more than one additional death per year per million people drinking a half-gallon of water each day during a lifetime of 70 years. Levels of radium exceeding that limit have been detected in Bedford County wells serving communities near Smith Mountain Lake. Additional wells were drilled to serve this community of 80 people, but the new wells were also contaminated. Nearby Franklin County developments had similar problems with radium in drinking water. High levels of radium also have been found in wells in Culpeper and Pittsylvania counties.

Two types of naturally occurring bacteria may cause problems in drinking water systems. Iron bacteria combine mineral iron or manganese in the water with oxygen to produce rust-colored deposits. A brown slime building up on well screens, pipes, and plumbing fixtures indicates that high levels of these bacteria are contaminating the water. Although they don't cause health problems, they can cause odors, reduce well yields by clogging screens and pipes, and corrode plumbing.

Sulfur bacteria, which also occur in soil and geological formations and can easily get into groundwater, use sulfur to produce some of the same effects caused by iron bacteria. One type of sulfur bacteria converts sulfur compounds into hydrogen sulfide, the gas best known for its "rotten egg" smell. It also can corrode metal, concrete, and other materials. Another type converts sulfide into sulfur; the result is a slime that can clog wells, plumbing, and irrigation systems.

Protecting Your Water Supply

Knowledge about specific contaminants is critical in selecting the best purification system for your water

PEOPLE everywhere want clean and safe drinking water for themselves and their families. Throughout this book, we've presented information that Virginians can use to help protect the state's groundwater. Despite efforts by government at all levels, groundwater contamination problems won't be solved immediately.

Many citizens are taking an active role in ensuring the safety of their own drinking water by testing their water, educating themselves about water contaminants, and installing home water treatment systems if necessary. In this chapter we provide information about water testing and about providing yourselves with safe water if it turns out that your supply is unsatisfactory.

Well Water Testing

NO agency in Virginia has the legal authority to regulate water quality in a private well once it has been drilled and put in operation. The state may take samples from a private well during investigations of health problems or groundwater degradation; otherwise it is up to the well owner to have water tested. The health department can now effectively regulate the location and construction of new wells but not wells constructed before 1986.

Virginia's public water systems are required to do bacteriological analyses at least monthly and a chemical analysis at least once every three years. Virginians who rely on private wells for drinking water are not protected by these requirements. If you want to become better informed about the safety of your drinking water, you'll need to design a sampling schedule.

If you're installing a new well and a septic system at the same time, the

Virginia Department of Health requires a bacterial test. The state's Division of Consolidated Laboratory Services conducts this test, and results are provided free of charge. If you already have a well, the test is not required, but you can get it done for \$10. The Virginia Department of Health recommends private wells on property proposed for Federal Housing Authority or Veterans Administration loans be tested for bacterial contamination, and bacteriological testing of private well water should be done yearly.

Chemical tests may be as necessary and meaningful as biological tests. Water that is free of coliform bacteria might still contain nitrates and chloride

at concentrations that exceed the Environmental Protection Agency's maximum contaminant levels. You should have a test for corrosivity and inorganic chemicals done at least once, preferably before you even begin using your water. An ideal time to have well water tested is before you move into a new residence. Corrosive or "aggressive" water will eat away at pipes, releasing copper, lead, zinc, or even chromium into your drinking water. Tests for naturally occurring minerals, such as manganese and iron, can be performed by water softener dealers.

In addition to the yearly bacteriological analysis and an initial test for pH, corrosivity, and a few metals, your

Health Department Survey Reveals

High Incidence of Poor Water in Piedmont

THE importance of testing your water can be seen from the results of a 1983 survey of households with *bored well* water sources in the south-central Piedmont. Bored wells were chosen for sampling because they are often less than 20 feet deep and they tap aquifers easily contaminated by surface activities. Conducted by the Virginia Department of Health, the survey revealed that 72.5 percent of 200 household water systems sampled had serious water quality problems when standards for bacterial and chemical contamination set by the Environmental Protection Agency were applied. Samples were collected from indoor taps of 200 homes in 14 counties — Brunswick, Charles City, Chesterfield, Dinwiddie, Greensville, Hanover, Henrico, Lunenburg, Mecklenburg, New Kent, Nottoway, Surry, Prince George, and Sussex.

About 17 percent of the households had levels of naturally occurring iron and manganese in their water that exceeded the recommended levels of 0.3 mg/l for iron and 0.05 mg/l for manganese. These recommendations apply to aesthetics and not human health. High concentrations of these metals stain laundry appliances, plumbing fixtures, and clothes; they also give foods and beverages a metallic taste. Except in three homes where barium, lead, and chromium concentrations were high, heavy metal contamination was not encountered.

Water was found to be highly corrosive (pH of 5.9 or less and alkalinities as calcium carbonate of 30 mg/l or below). Water with these characteristics can corrode plumbing and cause copper, zinc, and lead to be released into the water.

About 5 percent of the households had water contaminated by organic compounds, but the analysis of total organics did not distinguish among petroleum products, pesticides, solvents, or living or previously living material. Excess total fecal coliforms accounted for 58 percent of the violations of Environmental Protection Agency standards.

Wells should be tested yearly for bacterial contamination

well water should be tested if you notice any change in its smell or taste. Humans can detect petroleum by taste or smell at very low concentrations. Although many pesticides are odorless, they often are suspended in petroleum products that humans can smell. If you suspect that your well water is contaminated by gasoline, pesticides, or other toxins, either the Virginia Water Control Board or the Virginia Department of Health will investigate the situation.

The first step in getting your water tested is to contact the local or state health department and talk to people there about the tests you want done. If they can't do the tests, ask them for a list of certified analytical laboratories. EPA regulates state certification programs, so a "certified" lab is approved at both the state and federal level. Private laboratories may analyze samples and produce results faster than state laboratories, but you should ask for a certification number to be sure they are certified.

When you contact a lab, ask about turnaround time (it should be approximately two weeks) and about information provided with test results. Unless you're a water pollution specialist, raw numbers probably won't tell you much about your water. A good lab should help you understand the results. Water is never "pure," but you need to know whether the impurities are dangerous and whether they are present in dangerous amounts.

You'll need to tell the lab what tests you want done. The bacterial test is the least expensive one. Chemical analysis can cost between \$150 and \$300 or higher, depending on the type of tests performed. Water can be assayed for inorganic chemicals and minerals, volatile organic chemicals, pesticides and herbicides, and radioactive substances. For enough money, you could have your water completely analyzed. However, it is probably more cost-effective to have your water tested for the specific contaminants that may be there. For example, if you suspect that pesticides have contaminated your well water, you should contact a local extension agent or state pesticide control agency to find out which pesticides are used in your area. With this information, the

lab that collects your water sample can test for specific pesticides instead of testing for every possible contaminant.

Providing Safe Water

SUPPOSE you've tested your water and discovered it is tainted by some sort of contaminant. Now what?

One alternative to using contaminated water is to buy bottled water. However, only bottled water that is marketed across state lines has to meet federal drinking water standards, so it may not be as "pure" as you think.

"Mineral water" is exempt from drinking water regulations altogether. And just changing the water you drink may not solve the problem. New evidence on volatile organic compounds suggests that certain of these chemicals may be inhaled or absorbed through the skin while showering or bathing. Breathing the vapors may endanger human health, and absorption of organic contaminants through the skin may cause the same problems as drinking them in your water.

Another option is to purchase "point-of-use" or home water systems. Many techniques are being developed to remove contaminants from water:

- Chlorination kills microorganisms
- Ultraviolet radiation also kills microorganisms and can be used instead of chlorination.
- Activated carbon filters are effective in removing a number of potentially carcinogenic organic chemicals including trichloroethylene, trihalomethanes, and many pesticides. These filters also solve many taste and odor problems. The Environmental Protection Agency has found granulated activated carbon (GAC) to be the best available technology for removal of synthetic organic compounds at public water works.
- Adsorption filters remove asbestos fibers and other particles.
- Distillation units remove toxic metals, radiological contaminants, and some organic contaminants.
- Water softeners remove magne-

and is the most widely used technique for disinfection of municipal wastewater. Chlorination of surface waters may produce potentially carcinogenic trihalomethanes (THMs), such as chloroform. Groundwater, however, has low concentrations of the organic materials that combine with chlorine to produce THMs. These compounds are rarely formed in the chlorination of well water.

Table 4. Household Water Cleanup Options and Estimated Costs

Option	Estimated Costs
Water treatment system	
Activated carbon filtration	Faucet-mounted: \$25-\$50 Under the sink: \$50-\$300 Whole house: \$500-\$800
Distillation	Countertop: \$300-\$350 Automatic: \$600-\$800
Anion exchange	Whole house: \$500-\$800
Reverse osmosis	Single tap: \$400-\$600
Bottled water	\$7-\$15 weekly for a family of four
New well	\$3.50-\$4.50 per inch diameter per foot of depth, plus casing and pump costs
Public system hookup	\$12,000 + per household depending on distance to water main, plus monthly water payments

(Adapted from *The Magnitude and Costs of Groundwater Contamination from Agricultural Chemicals* by E.G. Nielsen and L.K. Lee)

Contaminants in Water: How Much Is Too Much?

IN 1987, Monsanto was ordered to pay \$16.2 million in punitive damages for a chemical spill in Sturgeon, Missouri. At issue were 19,000 gallons of a raw material used in a wood preservative that included, according to newspaper accounts, "less than a teaspoon" of the carcinogen dioxin. A teaspoon seems like a negligible amount, especially diluted by 19,000 gallons. How do you decide if it will be harmful?

Tests for carcinogenicity, or the ability of a substance to cause cancer, have allowed scientists to predict that a lifetime exposure to 2.2×10^{-7} microgram per liter ($\mu\text{g}/\text{l}$) of dioxin will result in one "extra" cancer death for every million people.¹ A gram in a liter is roughly equivalent to two thousandths of a pound in a quart. A microgram is a *millionth* of a gram. And the number 2.2×10^{-7} microgram is equal to 0.00000022 — less than a *millionth* — of a microgram. That's not much dioxin. If everyone in Virginia were exposed to that concentration, however, six of Virginia's nearly six million residents would die from dioxin-induced cancer. Exposure to higher concentrations of dioxin would result in even more cancer deaths.

A concentration of $2.2 \times 10^{-7} \mu\text{g}/\text{l}$ is not easy to imagine. An example using ordinary table salt, a familiar substance, may help to illustrate. Suppose that salt, instead of being a flavor enhancer for food, were a carcinogen as powerful as dioxin. One teaspoon of table salt weighs about 7 grams, or a quarter of an ounce. If you mixed a teaspoon of salt into 840,600 gallons of water — more than 23,000 bathtubs full — it would be far too dilute to taste salty. In fact, you'd have no reason to suspect you weren't drinking "pure" water. But a teaspoon of salt in 840,600 gallons would be a *million times* more concentrated than $2.2 \times 10^{-7} \mu\text{g}/\text{l}$, dioxin's cancer risk level. In other words, you'd have to put your spoonful of salt into 840,600,000,000 gallons — more than 840 *trillion* gallons — just to dilute it to the same concentration as dioxin's cancer risk level.

How is it possible that such a little bit of something dissolved in so much water can endanger human health? Salt — like all substances — is composed of very small individual particles, or atoms. The number of individual atoms in a teaspoon of salt is enormous. When that teaspoonful is added to water, the atoms spread until they're evenly distributed throughout all the available water, no matter how large the volume. If you took a quarter of a cup — just a gulp — of water containing our imaginary carcinogenic salt at the very low concentration set as the cancer risk level for dioxin, you'd drink more than 100 million atoms of salt!

What usually happens in an aquifer is more complicated. Near the spill, the concentration of contaminant is quite high, but the concentration decreases as the contaminant moves away from the spill site into cleaner water. Contaminant movement is affected by solubility, the type of rock or soil making up the aquifer, the number and location of wells tapping the aquifer, and other factors. When and where contaminants will appear in an aquifer or a well is difficult to predict because so many factors influence their direction and rate of movement in groundwater.

At first glance, a penalty of \$16.2 million to a company that spilled a teaspoon of a substance diluted by 19,000 gallons may seem unreasonably harsh. We hope these calculations help to show that "a little can go a long way" — and with highly carcinogenic or toxic substances, a little going a long way can be a real threat to human health.

¹ The cancer risk level for dioxin was being reassessed by the Environmental Protection Agency in 1988.

A poorly maintained water purifier can be worse than none at all

sium and calcium, which cause water hardness.

- *Reverse osmosis* systems remove dissolved minerals, toxic metals, and radiological contaminants.
- *Anion exchange* systems reduce levels of nitrates.
- Limestone chip filters can be used to raise pH and reduce corrosivity.
- Replacement of metal pipes with plastic can solve problems caused by acidic water reacting with metal pipes and solder and releasing toxic metals.

"Point-of-use" systems can be installed in a variety of places, depending on how you want to use the water. If the contaminant is a problem only for drinking water, a filter can be added at the cold water faucet of the kitchen sink. To treat all kitchen water, units can be installed beneath the sink. A unit installed where your water enters the house can purify water for the whole household. Unplumbed units are available for treating small quantities of water as needed for use. If you install a home water treatment system, you need to follow directions for changing filters, cleaning the unit, and otherwise maintaining it. Improperly maintained systems are ineffective, and in certain cases they may actually cause water quality problems.

If your well is contaminated by iron or sulfur bacteria, chlorine treatment of the well and associated plumbing is recommended. Your local health department or sanitarian may be able to give you advice or refer you to other experts. If you want to test for radon in your water or home, information is available from the Virginia Bureau of Radiological Health radon hotline: (800) 468-0138.

While water softeners and filters of various types originally were designed to remove natural contaminants, they also may be effective in cleaning up water contaminated by human activities. Knowledge about specific contaminants is critical in selecting the best purification system for your water.

A Final Thought



THE groundwater that flows every day to Virginia's homes, farms, businesses, and industries also has been sculpting the state's caves over millions of years by the imperceptibly slow dissolving and redeposition of limestone. Stalactites, stalagmites, and many other intriguing and fragile formations have long delighted and mystified us. Without protection, these spectacular natural displays can be destroyed and lost to future generations.

Virginians are beginning to understand the importance of protecting all of the state's groundwater, not just that

associated with cave formation, because it, too, can be irreparably harmed. We'd like to take this opportunity to emphasize the individual's role in groundwater protection. State and federal regulations ultimately succeed only with the cooperation and support of individuals: homeowners, local government officials, businessmen and women, industrialists, students, farmers, gardeners, voters, and legislators.

Virginia's groundwater is a vital, valuable, and vulnerable resource. We've tried to show throughout this book that many human activities affect both the

quantity and quality of groundwater. The "What You Can Do" sections that follow the descriptions of most groundwater threats provide information and advice for individuals. The staff of the Water Center and other governmental agencies can answer specific questions or refer callers to other sources of information. What you do — from using pesticides sparingly to reporting illegal dumps or abandoned wells — does make a difference. We encourage your individual efforts and urge you to make a personal commitment to protect Virginia's groundwater.

Appendices

Appendix A: Laws Protecting Groundwater

Federal

Three programs under the federal Safe Drinking Water Act relate specifically to the protection of groundwater: the Sole-Source Aquifer program, the Underground Injection Control program, and the Wellhead Protection program. The Sole-Source Aquifer program permits citizens to petition the Environmental Protection Agency to designate an area a sole-source aquifer if it is a principal water supply. Once designated, the area is protected to the extent that the Environmental Protection Agency reviews all federally funded projects that may affect the quality of groundwater in the area. The Underground Injection Control program was created to ensure that disposal of fluids in injection wells does not threaten present and future drinking water sources. According to provisions of the Wellhead Protection program, each state must submit a proposed wellhead protection program to the Environmental Protection Agency by 1989. The proposal must describe how the state intends to protect its drinking water aquifer recharge areas. The Environmental Protection Agency has established a toll-free hotline to provide information about the Safe Drinking Water Act and its 1986 amendments. Staff members are on hand to answer questions Monday-Friday, 8:30 a.m. to 4:30 p.m., at (800) 426-4791 or (in Washington, D.C.) (202) 382-5533.

A number of other federal laws directly or indirectly affect groundwater quality. The Resource Conservation and Recovery Act provides "cradle-to-grave" management of hazardous wastes. The Comprehensive Environmental Response, Compensation and Liability Act, or Superfund, calls for a national inventory of inactive hazardous waste sites and the establishment of a program for environmental response action. The 1986 Superfund Amendments and Reauthorization Act (SARA) reauthorized the hazardous substances superfund to pay cleanup costs not assumed by responsible parties. The Federal Insecticide, Fungicide and Rodenticide Act manages pesticide use and disposal and gives the Environmental Protection Agency the power to regulate pesticides. The Toxic Substances Control Act authorizes the EPA to control the manufacture, use, and disposal of toxic chemicals. The Clean Water Act provides a management structure for state water quality programs, including groundwater quality. Under the Clean Water Act, the National Pollutant Discharge Elimination System authorizes the Environmental Protection Agency to specify limits on the discharge of pollutants into any United States waters. For more information about the EPA's Resource Conservation and Recovery Act/Superfund programs, call (800) 424-9346 or (in Washington, D.C.) 382-3000.

State

At the state regulatory level, Virginia has two major laws protecting groundwater. The Virginia Water Control Law helps to protect all existing high quality waters and to restore other state waters to a quality high enough to permit "all reasonable public uses." This "anti-degradation" policy applies to groundwater as well as to surface water. In addition, the law states that Virginia's water policy is to reduce existing pollution and prevent any increase in

pollution; to safeguard clean state waters from pollution; and to promote water resources conservation and management. The state's Groundwater Act of 1973 protects the quantity of groundwater. The Virginia Water Control Board is responsible for declaring sites groundwater management areas if groundwater quantity becomes threatened. The board is also responsible for setting and enforcing groundwater quality standards.

In practice, the state's central mechanism for groundwater protection is a set of permit programs. For example, a permit is required to operate a hazardous waste facility, an industrial waste lagoon, a solid waste landfill, or a septic tank. In 1987, a committee made up of personnel from a variety of Virginia agencies drafted *A Groundwater Protection Strategy for Virginia*, a set of policy recommendations for state groundwater protection. The committee concluded that "setting terms and conditions for siting and operating facilities with the potential to pollute groundwater provides the state's best opportunity to minimize future contamination problems." Copies of the *Strategy* are available from Terry Wagner, Virginia Water Control Board, Groundwater Program, 2111 N. Hamilton Street, Richmond, Virginia 23230; (804) 367-6304.

Local

Local officials can help protect groundwater in a number of ways. Appropriate siting and management of municipal waste lagoons and landfills, zoning restrictions and local ordinances to protect areas particularly vulnerable to contamination, and monitoring of local groundwater quality and quantity are all important steps toward groundwater protection. Local officials can also help protect groundwater by educating and informing citizens about groundwater, threats to groundwater, and protection. Detailed information about the role local officials can play in groundwater protection is available in the Virginia Water Resources Research Center's publication *Protecting Virginia's Groundwater: A Handbook for Local Government Officials*.

Appendix B: Virginia's Superfund Sites

Fifteen hazardous waste sites in Virginia are on the National Priorities List for Superfund-assisted cleanup. Another six sites are proposed for listing and as proposed sites undergo the same Superfund cleanup processes. The following, listed alphabetically by county or city, are the Virginia sites included on the Superfund National Priorities List or proposed for listing. The sites also are indicated on the map on page 10. Descriptions were provided by the Environmental Protection Agency and Virginia Department of Waste Management.

Albemarle County: The Greenwood Chemical Plant in a rural area east of Waynesboro has contaminated groundwater and surface water with toluene, benzene, chlorobenzene, chloroform, and other compounds. Contaminant sources include unlined waste lagoons and broken, leaking drums. During the 1970s, fish kills and the deaths of cattle in the area were traced to the waste lagoons. Wells within three miles of the site are the sole source of drinking water for approximately 1,600 people.

Buckingham County: Love's Container Service landfill was used to dispose of municipal waste, chemical wastes from

furniture manufacturing, and hazardous wastes during a 20-year period. On-site groundwater samples contain chromium and beryllium. Approximately 1,100 people within three miles of the site use groundwater for drinking water.

Chesterfield County: Groundwater around the Defense General Supply Center, two miles south of Richmond, is contaminated with chloroform, di-, tri-, and tetrachloroethylene, dichlorobenzene, and chromium from wastes and spills at the site.

Culpeper County: Culpeper Wood Preservers treats wood with chromated copper arsenate. A 100,000-gallon spill of waste from a surface impoundment in 1981 contaminated groundwater and soil with arsenic and chromium. Approximately 8,800 residents depend on the contaminated aquifer for drinking water.

Front Royal: Rayon has been manufactured at this site for more than 45 years, most recently by Avtex Fibers, Inc. Wastes disposed of in unlined basins have contaminated groundwater with phenols, carbon disulfide, sulfates, and arsenic. The company has bought most of the lots in a nearby subdivision affected by the pollution and is supplying water to residents who remain.

Hanover County: The H&H, Inc., Burn Pit near Farrington was used between 1960 and 1976 to burn printing inks, paint manufacturing wastes and various solvents in a shallow unlined pit. Toluene, xylene, and benzene are present in monitoring wells, and polychlorinated biphenyls (PCBs) have been found in surface drainage. Private wells within three miles of the site serve approximately 2,700 people.

Nelson County: An abandoned titanium dioxide processing plant near the town of Piney River is the source of groundwater and surface water contamination. Runoff from the piles of waste generated by processing has caused several fish kills. These piles of coppers have since been buried; however, acidic leachate continues to be released to groundwater and surface water adjacent to the site.

Pittsylvania County: First Piedmont Route 719 site was a rock quarry before being used as a disposal site, primarily by a tire and rubber company. Sampling on- and off-site has detected elevated levels of metals and organic compounds in surface water and sediment. Chromium, zinc, and lead have been detected in domestic well water near the site and in nearby Lawless Creek.

Portsmouth: A creosote lumber preserving company, Atlantic Wood Industries, Inc., in operation for 60 years, has contaminated air, groundwater, and the south branch of the Elizabeth River. The parties responsible have agreed to work toward stabilization and long-term remediation of the problems caused by the contamination.

Portsmouth: Abex Corporation, a site that operated for years as a brass foundry making fittings for railroad cars, released large amounts of molten lead into the air and disposed of lead slags and lead dusts near the plant. A public housing project has since been built on nearby soil heavily contaminated with lead. Groundwater may be contaminated, but the immediate threat is direct contact with contaminated soils.

Richmond: A Rentokil wood treatment facility that used creosote, pentachlorophenol (PCP), and chromated copper arsenate has discovered these chemicals in surface runoff, soils, and an on-site monitoring well. Pentachlorophenol has been detected in on-site groundwater. Ninety-two residential water wells are located within about a half mile of the site.

Roanoke County: The Dixie Caverns landfill in Salem accepted industrial sludge, municipal refuse, solvents, and other wastes from 1961 to 1976. Intermittent streams have been contaminated by leachate and fly ash, which contains high levels of lead and cadmium. Groundwater in the area provides approximately 2,000 people with drinking water. Dixie Caverns, a tourist attraction, is one mile "downgradient" from the site.

Roanoke County: Liquid electroplating wastes from the Matthews Electroplating Company near Roanoke contaminated seven nearby residential wells with high concentrations of chromium and cyanide. A water system costing \$1.45 million, 10

percent from the county and 90 percent from Superfund, has been constructed to serve area residents.

Smyth County: A chemical production complex operating in Saltville from 1859 to 1970 polluted nearby North Fork Holston River with mercury that settled and accumulated in river sediments.

Spotsylvania County: L.A. Clarke & Sons, in the vicinity of Fredericksburg, preserves wood with creosote. Spills and leaks since operations began in the late 1930s have contaminated surface water, soil, and groundwater with creosote-derived compounds. The aquifer of concern provides drinking water to approximately 3,000 Virginians within three miles of the site.

Suffolk County: Saunders Supply Company in Chuckatuck has preserved wood with pentachlorophenol, fuel oil, and chromated copper arsenate since 1964. Environmental Protection Agency tests in 1984 showed high levels of chromium in Godwin's Mill Pond Reservoir, a source of drinking water for more than 30,000 people in Suffolk and in the underlying aquifer.

Suffolk County: The Suffolk landfill was used for the disposal of pesticides damaged in a fire at a store that sells agricultural chemicals. The pesticides have not broken down and have leached into groundwater, contaminating monitoring wells at the landfill and at least one well off-site.

Westmoreland County: An electroplating process at Arrowhead Associates-Scovill Corporation in Montross resulted in massive contamination within buildings, and disposal of wastes in drums and lagoons led to contamination problems outside the plant. Removal actions have minimized the health threats, but cleanup of metals contamination and acidity problems remains.

Winchester: A massive tire fire at this site burned for more than a year and was brought under control by Superfund's Emergency Response branch. The site is now under evaluation to determine whether soil, surface water, or groundwater has been permanently damaged.

York County: Aquifers and surface waters in the Chisman Creek drainage basin have increased levels of copper, nickel, beryllium, vanadium, selenium, and arsenic from the residue of coal and refinery coke burned at the nearby Yorktown Power Plant. About 30 domestic well users had to attach to the public water supply, and ash pits are scheduled to be capped, sealed or drained at a cost of \$8.5 million.

The booklet *National Priorities List Fact Book* provides a description of the listing process. It is available from the Environmental Protection Agency's Public Information Center, PM-211B, 401 M Street SW, Washington, D.C. 20460; telephone (202) 382-2080.

Appendix C: References and Sources for Further Information

- Agriculture and Groundwater Quality*. 1985. Council for Agriculture, Science and Technology. Report No. 103. Iowa State University, Box 1550, Ames, IA 50010-1550.
- Aller, Linda, Truman Bennett, Jay H. Lehr, and Rebecca J. Petty. 1985. *DRASTIC: A Standardized System for Evaluating Ground Water Potential*. Robert S. Kerr Environmental Research Laboratory. Office of Research and Development. U.S. Environmental Protection Agency. Ada, Oklahoma.
- Bio Cycle: Journal of Waste Recycling*. 1987. Vol. 28, No. 2.
- Carter, Larry W. and Robert C. Knox. 1985. *Septic Tank System Effects on Ground Water Quality*. Lewis Publishers, Inc., 121 South Main Street, Chelsea, MI 48118.
- Carter, Larry W. and Robert C. Knox. 1985. *Ground Water Pollution Control*. Lewis Publishers, Inc., 121 South Main Street, Chelsea, MI 48118.
- Cederstrom, D.J., E.H. Boswell, and G.R. Tarver. 1979. *Summary Appraisals of the Nation's Ground-Water Resources — South Atlantic-Gulf Region*. Geological Survey Paper 813-0.
- Cohen, S.Z., S.M. Creeger, R.F. Carsel, and C.G. Enfield. 1984. "Potential Pesticide Contamination of Groundwater from Agri-

- cultural Uses." In *Treatment and Disposal of Pesticide Wastes*. R.F. Krueger and J.N. Seiber, eds. ACS Symposium Series 259, American Chemical Society 297, Washington, D.C. 325.
- Council on Environmental Quality. 1981. *Contamination of Ground Water by Toxic Organic Chemicals*. Government Printing Office, Washington, D.C.
- Diehl, Jack. 1986. *How to Comply with Hazardous Waste Regulations: A Step-by-Step Method*. Hazardous Waste Management Education Program, Bureau of Hazardous Waste Management, Virginia Department of Health, Richmond.
- Drinking Water: A Community Action Guide*. 1986. Concern, Inc., 1794 Columbia Road, N.W., Washington, D.C. 20009.
- Gordon, Wendy. 1984. *A Citizen's Handbook on Groundwater Protection*. Natural Resources Defense Council, Inc., 122 East 42nd Street, New York, NY 10168.
- Ground Water and Wells: A Reference Book for the Water-Well Industry*. 1966. Edward E. Johnson, Inc. St. Paul, Minnesota.
- Groundwater: A Community Action Guide*. 1984. Concern, Inc., 1794 Columbia Road, N.W., Washington, D.C. 20009.
- Groundwater Protection*. 1987. Conservation Foundation, 1255 23rd Street, N.W., Washington, D.C. 20037.
- Heath, Ralph C. 1984. *Basic Ground-Water Hydrology*. U.S. Geological Survey Water Supply Paper No. 2220. Alexandria, Virginia.
- Henderson, Timothy R., Jeffrey Trauberman, and Tara Gallagher. 1984. *Groundwater: Strategies for State Action*. Environmental Law Institute, Suite 600, 1346 Connecticut Avenue, N.W., Washington, D.C. 20036.
- Hrezo, Margaret and Pat Nickinson. 1986. *Protecting Virginia's Groundwater: A Handbook for Local Government Officials*. Virginia Water Resources Research Center. Virginia Polytechnic Institute and State University, Blacksburg.
- Joint Subcommittee to the Governor and General Assembly. 1987. *The Laws of the Commonwealth Related to Sewage Handling*. Senate Document No. 27. Richmond, VA.
- Jones, R. Christian, and Beatrice H. Holmes. 1985. *Effects of Land Use Practices on Water Resources in Virginia*. Virginia Water Resources Research Center Bulletin 144. Virginia Polytechnic Institute and State University, Blacksburg.
- Larson, J.D. 1981. *Distribution of Saltwater in the Coastal Plain Aquifers of Virginia*. U.S. Geological Survey Open File Report 81-1013.
- Lord, John. 1986. *Hazardous Wastes from Homes*. Enterprise for Education, 1320A Santa Monica Mall, Santa Monica, CA 90401.
- Metropolitan Area Planning Council. 1982. *Groundwater Protection: A Guide for Communities*. MAPC Resource Library, 110 Tremont Street, 5th Floor, Boston, MA 02108.
- National Academy of Sciences, National Research Council. 1986. *Groundwater Protection: State and Local Strategies*. National Academy Press, Washington.
- Nickinson, Pat. 1986. *Sandcastle Moats and Petunia Bed Holes: A Book about Groundwater*. Virginia Water Resources Research Center. Virginia Polytechnic Institute and State University, Blacksburg.
- Nielsen, E.G. and L.K. Lee. 1987. *The Magnitude and Costs of Groundwater Contamination from Agricultural Chemicals: A National Perspective*. USDA Economic Research Service, Natural Resource Economics Division. Staff Report AGES870318. Washington, D.C.
- Office of Technology Assessment. 1984. *Protecting the Nation's Groundwater from Contamination*. OTA-O-233. Government Printing Office, Washington, D.C.
- Postel, Sandra. 1987. *Defusing the Toxics Threat: Controlling Pesticides and Industrial Waste*. Worldwatch Paper No. 79. Worldwatch Institute, 1776 Massachusetts Avenue, N.W., Washington, D.C. 20036.
- Powell, John D. and Joseph M. Abe. 1985. *Availability and Quality of Ground Water in the Piedmont Province of Virginia*. U.S. Geological Survey Water Resources Investigations Report 85-4235.
- Protecting Our Groundwater: A Grower's Guide*. American Farm Bureau Federation, National Agricultural Aviation Association, National Agricultural Chemicals Association, and U.S. Department of Agriculture Extension Service.
- Pye, Veronica I., Ruth Patrick, and John Quarles. 1983. *Groundwater Contamination in the United States*. University of Pennsylvania Press, Philadelphia.
- Raymond, Lyle S., Jr., ed. 1981. *Groundwater Use Management in the Northeastern States: Conference Proceedings*. Center for Environmental Research. Cornell University, 468 Hollister Hall, Ithaca, NY 14853.
- Raymond, Lyle S., Jr. 1986. *Chemical Hazards in Our Groundwater: Options for Community Action*. Center for Environmental Research. Cornell University, 468 Hollister Hall, Ithaca, NY 14853.
- Rice, Rip G., ed. 1985. *Safe Drinking Water: The Impact of Chemicals on a Limited Resource*. Drinking Water Research Foundation, Alexandria, Virginia.
- Scalf, Marion, William J. Dunlap, and Jones F. Kreissl. 1977. *Environmental Effects of Septic Tank Systems*. Robert S. Kerr Environmental Research Laboratory. U.S. Environmental Protection Agency, Ada, Oklahoma.
- Sevebeck, Kathryn P., Jacob H. Kahn, and Torsten D. Sponenberg. 1985. *A Homeowner's Guide to Domestic Wells*. Virginia Water Resources Research Center. Virginia Polytechnic Institute and State University, Blacksburg.
- Sponenberg, Torsten D., Jacob H. Kahn, and Kathryn P. Sevebeck. 1985. *A Homeowner's Guide to Septic Systems*. Virginia Water Resources Research Center. Virginia Polytechnic Institute and State University, Blacksburg.
- State Programs for Groundwater Quality Management*. 1985. Edison Electric Institute. Groundwater Task Force, 1111 19th Street, N.W., Washington, D.C. 20036-3691.
- State of the Environment: A View toward the Nineties*. 1987. Conservation Foundation, 1250 24th Street, N.W., Washington, D.C.
- Tomboulion, Paul. 1984. *Well Water Testing Guide: Information for Well Owners*. East Michigan Environmental Action Council, 21220 West Fourteen Mile Road, Birmingham, MI 48010.
- Turnquist, Susan. 1985. *Community Guide to Groundwater Protection and Management: An Annotated Bibliography*. 2nd ed. Publication No. 38. Northeast Regional Center for Rural Development, Cornell University, Ithaca, NY.
- U.S. Environmental Protection Agency. 1986. *A Survey of Household Waste and Related Collection*. Office of Solid Waste and Emergency Response. Government Printing Office, Washington, D.C.
- U.S. Environmental Protection Agency. 1987. *Groundwater*. EPA/625/6-87/016. Office of Research and Development. Government Printing Office, Washington, D.C.
- U.S. Environmental Protection Agency. 1987. *Measures to Mitigate Ground Water Contamination by Pesticide Use in Crop Production*. Office of Ground Water Protection, 401 M Street, N.W., Washington, D.C. 20460. Government Printing Office.
- U.S. Environmental Protection Agency. 1986. *National Priorities List Fact Book*. USEPA HW-7.3. Office of Emergency and Remedial Response. Government Printing Office, Washington, D.C.
- U.S. Environmental Protection Agency. 1985. *Overview of State Ground Water Program Summaries*. 2 Vols. Office of Ground Water Protection. Government Printing Office, Washington, D.C.
- U.S. Environmental Protection Agency. 1985. *Protection of Public Water Supplies from Ground Water Contamination. Seminar Publication*. Center for Environmental Research Information, 26 West St. Clair, Cincinnati, Ohio 45268.
- U.S. Environmental Protection Agency. *Public Information Bulletin for EPA Region III: UIC Class V Injection Wells*. U.S.

- EPA Region III, 841 Chestnut Street, Philadelphia, PA 19107.
- U.S. Environmental Protection Agency. 1986. *Radon Reduction Techniques for Detached Houses: Technical Guidance* EPA/625/5-86/019. Center for Environmental Research Information, 26 West St. Clair, Cincinnati, Ohio 45268.
- U.S. Environmental Protection Agency. *Septic Systems and Ground Water Publication: An Executive's Guide*. Office of Ground Water Protection, Government Printing Office, Washington, D.C.
- U.S. Environmental Protection Agency. 1986. *Solving the Hazardous Waste Problem: EPA's RCRA Program*. Office of Solid Waste, USEPA EPA/530-SW-86-037. Government Printing Office, Washington, D.C.
- Virginia Board of Health. 1982. *Sewage Handling and Disposal Regulations*. Virginia Department of Health, Richmond.
- Virginia Water Control Board. 1987. *A Groundwater Protection Strategy for Virginia*. Groundwater Steering Committee. Richmond.
- Virginia Water Control Board. 1979. *Sources Affecting Groundwater (Best Management Practices Handbook)* Planning Bulletin No. 318. Richmond.
- Virginia Water Control Board. 1986. *Virginia Water Quality Assessment*. 2 Vols. Information Bulletin No. 565. Richmond.
- Virginia Water Control Board. 1986. *Water Quality Standards*. Richmond.
- Virginia Waste Management Board. 1987. *Solid Waste Management Regulations*. Draft No. 3. Richmond.

Appendix D: Units of Measurement

Length

meter (m) = 39.37 inches = 1.09 yard
 millimeter (mm) = 0.001 meter = 1.0×10^{-3} meter = 0.03937 inch

Mass

gram (g) = 0.03527 ounces (28.25 grams in one ounce)
 milligram (mg) = 0.001 = 1.0×10^{-3} gram
 microgram (μ g) = 0.000001 gram = 1.0×10^{-6} gram
 ton = 2,000 pounds
 metric ton = 2,205 pounds

Volume

gallon = 3.78 liters
 liter (l) = 0.264 gallon = 1.056 quarts
 milliliter (ml) = 0.001 liter = 1.0×10^{-3} liter = 1 cubic centimeter
 acre-foot = the volume that would cover one acre to a depth of one foot

Radioactivity

curie = 3.7×10^{10} disintegrations per second
 microcurie (μ Ci) = 0.000001 curie = 1.0×10^{-6} curie (3.7×10^4 disintegrations per second)
 picocurie (pCi) = 0.000000000001 curie = 1.0×10^{-12} curie (3.7×10^{-2} disintegrations per second)
 half-life = the time required for half the atoms of a radioactive substance to disintegrate

Area

acre = 43,560 square feet (one square mile = 640 acres)

Concentration

parts per million (ppm) = (approximately) milligrams per liter (mg/l)
 parts per billion (ppb) = (approximately) micrograms per liter (μ g/l)
 parts per thousand (ppt) = (approximately) grams per liter (g/l)

Numbers

million = 1,000,000 = 1.0×10^6
 billion = 1,000,000,000 = 1.0×10^9
 trillion = 1,000,000,000,000 = 1.0×10^{12}
 quadrillion = 1,000,000,000,000,000 = 1.0×10^{15}

Appendix E: Agency Programs with Potential Groundwater Impacts:

Virginia Cooperative Extension Service

- pollution education programs
- agricultural groundwater-use data collection
- soil nutrient testing service
- agricultural technical assistance

Virginia Council on the Environment

- interagency environmental coordination

Virginia Department of Agriculture and Consumer Services

- regulation of pesticide and herbicide applicators
- integrated pest management

Virginia Department of Conservation and Historic Resources, Division of Soil and Water Conservation

- agricultural nonpoint source pollution control (fertilizers and pesticides, animal waste management)
- urban nonpoint source pollution control (stormwater management)

Virginia Department of Health

- on-site sewage disposal permits (septic systems)
- public water supply
- water well construction standards
- municipal wastewater treatment (joint program with Virginia Water Control Board)

Virginia Department of Housing and Community Development

- land-use planning assistance

Virginia Department of Mines, Minerals, and Energy

- geologic mapping, drill cutting, and core analysis
- mine regulation
- oil and gas well regulation

Virginia Department of Waste Management

- solid waste management (landfill permits)
- hazardous waste management (Resource Conservation and Recovery Act permits; Superfund program)
- radioactive waste management

Virginia Water Control Board

- statewide groundwater resource management
- regulation of nonhazardous waste pits, ponds, and lagoons; land application of nonhazardous waste; commercial and industrial drainfield systems; underground storage tanks; animal waste lagoons
- groundwater monitoring, data collection, and management
- groundwater modeling
- municipal wastewater treatment (joint program with Virginia Department of Health)
- municipal water treatment residue disposal

from *A Groundwater Protection Strategy for Virginia*

Glossary

- Activated carbon filter:** A filter made of carbon particles containing numerous pores and channels which trap contaminants as water passes through; not effective for heavy metals, bacteria, nitrates, and dissolved minerals; most effective for organic compounds and general taste and smell problems.
- Adsorption:** Adherence of one particle, ion, or molecule to the surface of another.
- Aerated:** Supplied with air or oxygen.
- Alkalinity:** A measurement of acid neutralization capacity (acid buffering capacity).
- Anion exchange:** Process in which negatively charged ions, or chemicals, attach to a filter medium as water passes through.
- Aquifer:** A water-bearing formation composed of sand, gravel, permeable rock, or rock with cracks and fractures that occurs beneath the earth's surface.
- Aquitard:** An impermeable layer of consolidated or unconsolidated material that restricts the movement of water into or out of a confined aquifer; also called *confining bed*.
- Artesian aquifer:** A formation beneath the earth's surface that is saturated with water and enclosed by less permeable layers; the water is under pressure and will rise above the overlying *confining bed* if given an opportunity to do so. Also called *confined aquifer*.
- Artesian well:** A well tapping an artesian aquifer. Because the water is under pressure, it rises above the top of the aquifer. The height of the water in the well represents the *potentiometric surface* of the aquifer.
- Bedrock:** The consolidated rock underlying unconsolidated surface materials such as soil.
- Bored well:** A relatively shallow well installed by a mechanically driven auger; commonly 18 to 24 inches in diameter; lined with concrete casing to prevent collapse.
- Brackish:** Somewhat salty; specifically, water containing salt at concentrations from 0.5 to 17 parts per thousand.
- Carcinogenic:** Capable of producing or inducing cancer.
- Chlorination:** The process of treating water with chlorine to kill bacteria and ensure satisfactory disinfection.
- Coliform bacteria:** A group of bacteria from (or like those from) the colon or digestive tract of humans and other warm-blooded animals. The presence of coliform bacteria in well water may indicate contamination by surface water or faulty septic systems.
- Conductivity:** The quality or power of conducting or transmitting electrical current; in water, a measure of the dissolved ions.
- Confined aquifer:** A formation beneath the earth's surface that is saturated with water and enclosed by less permeable layers; the water is under pressure and will rise above the overlying *confining bed* if given an opportunity to do so. Also called *artesian aquifer*.
- Confining bed:** An impermeable unit that lies over or under an aquifer and prevents or impedes movement of water into or out of the aquifer.
- Consolidated:** Formed into a compact mass; firm and rigid because of the natural interlocking and/or cementation of mineral grain components.
- Curie:** A measurement of radioactivity equal to 3.7×10^{10} disintegrations per second.
- Crystalline rock:** Rock made up of minerals in a clearly crystalline state; igneous and metamorphic rock, as opposed to sedimentary rock.
- Discharge:** The movement of water from an aquifer to springs, seeps, marshes, streams, or flowing or pumping wells.
- Distillation:** A process to purify water in which water is heated to steam and the steam is collected and condensed back to water. Some contaminants are left behind when the water turns to vapor, but others may condense with the steam.
- Drilled well:** A well which penetrates fractured bedrock, drilled with a rotating bit; lined with steel or polyvinylchloride casing.
- Dug well:** A large diameter well (30 inches or more) excavated by shovel, usually to a depth just below the water table; commonly lined with brick, stone, or wood to prevent collapse.
- Evapotranspiration:** The release of water from the earth's surface to the atmosphere by evaporation from soil and surface waters and by transpiration from plants.
- Fall line:** A line joining the waterfalls on numerous rivers that marks the point where each river descends from the upland to the lowland. In Virginia, the fall line passes through Fairfax, Fredericksburg, Richmond, Petersburg, and Emporia.
- Groundwater:** Water beneath the earth's surface in a layer of rock or soil called the *saturated zone* because all openings are filled with water; the water that supplies wells and springs.
- Hardness:** A measure of dissolved calcium and magnesium salts in water, usually reported in milligrams per liter (mg/l) or grains per gallon.
- Heavy metals:** Metals with a specific gravity of 5.0 or higher, including cadmium, chromium, copper, lead, and zinc.
- Hydraulic conductivity:** The rate of flow of water in gallons per day through a cross section of one square foot at a standard temperature; a measure of permeability.
- Hydrogeology:** The science that deals with subsurface waters and related geologic aspects of surface waters.
- Hydrologic cycle:** A continuous sequence of processes in which water passes from the atmosphere to the land or oceans and back to the atmosphere.
- Igneous rock:** Rock produced through the cooling of molten mineral material.
- Impermeable:** Not permitting passage — impermeable rocks do not allow water to move through them.
- Impoundment:** A body of water formed by being confined; a reservoir for liquid wastes.
- Infiltration:** Process of water moving into the ground, subsurface soil, and rocks from the surface.
- Landfill:** A system of trash and garbage disposal in which waste is buried between layers of earth.
- Leachate:** A solution formed when water percolates through soluble material; often used in reference to the liquid formed from the percolation of precipitation through landfill wastes.
- Leach:** To dissolve by the action of a percolating liquid, such as rainwater seeping through soil and carrying pesticides, fertilizers, or chemical wastes with it.
- Limestone:** A general name for rocks composed primarily of the mineral calcite (calcium carbonate).
- Metamorphic rock:** Rock that has undergone changes caused by pressure, temperature, sheering stress, or water to result in a more compact and highly crystalline form; gneiss, schist, and marble are examples.
- Mutagenic:** Can cause a relatively permanent change in hereditary material, such as a physical change in the chromosomes.
- Pathogen:** A specific agent that causes disease, such as a bacterium or virus.
- Perched water:** Groundwater that occurs above the water table, "perched" above a layer of unsaturated rock or soil.
- Percolation:** Liquid moving through a permeable substance.
- Permeability:** The ability of a rock to transmit water (per unit of

- cross section).
- pH:** A measure of alkalinity or acidity. The pH scale ranges from 0 to 14, with 7 representing neutrality, numbers higher than 7 indicating alkalinity, and numbers lower than 7 indicating acidity. The number is the negative logarithm of the concentration of hydrogen ions.
- Porosity:** The quality of being porous, or full of pores or openings; a measure of the amount of open space in a material or of the water storage capacity of a substance.
- Potability:** The quality of being suitable for drinking.
- Potentiometric surface** (in reference to artesian or confined aquifers, in which water is under pressure): An imaginary surface defined by the level to which groundwater will rise if released from its confining bed by a well or conduit. This surface, signifying the height of water in confined aquifers, is similar to the *water table* that denotes the height of water in unconfined aquifers.
- Precipitation:** A deposit on the earth of hail, mist, rain, sleet, or snow; all of the forms of water, liquid and solid, that fall from the atmosphere and reach the earth's surface.
- Radioisotope:** An isotope (or element) exhibiting radioactivity, an unstable condition in which an element is transformed into another element and radiation is given off.
- Recharge:** The flow of water into the saturated zone; the return of water to an aquifer.
- Reverse osmosis:** A filter process which forces water through membranes that allow water but not dissolved chemicals to pass through. The process is used to remove contaminants in water and can be used to desalinate salty groundwater.
- Runoff:** The water from rain or melted snow that does not infiltrate the soil but flows over the land surface; precipitation drainage.
- Saturated zone:** The part of water-bearing material where voids are filled with water; the zone in which groundwater occurs.
- Sedimentary rock:** A rock formed from particles (sediment) deposited by water.
- Septic system:** A wastewater and sewage disposal system in which solids settle to the bottom of a tank and liquids are discharged to the soil through a series of lines in a drain field.
- Sludge:** Semi-solid waste matter produced by water and sewage treatment processes.
- Solvent:** A usually liquid substance capable of dissolving one or more other substances.
- Specific retention:** The amount of water tightly bound by physical forces in an aquifer; the amount of water unavailable for use.
- Specific yield:** The amount of water in an aquifer available to wells; the quantity of water which a unit volume of aquifer, after being saturated, will yield by gravity.
- Synthetic organic compound:** Manufactured compounds of carbon chains or rings, also containing hydrogen and with or without oxygen, nitrogen, and other elements. SOCs that have been found in groundwater include chlorobenzene, di-, tri-, and tetrachloroethylene, chloroform, polychlorinated biphenyls (PCBs), and pentachlorophenol.
- Transpiration:** The release of water to the atmosphere through evaporation from the surface of plant leaves.
- Ultraviolet radiation:** Radiation having a wavelength shorter than that of visible light; used in disinfection processes.
- Unconfined aquifer:** A water-bearing formation under the earth's surface not confined by an overlying impermeable layer. The height of the water in unconfined aquifers is referred to as the *water table*.
- Unconsolidated:** Not formed into a compact mass; loosely associated or soil-like.
- Unsaturated zone:** Layer of rock or soil (or both) not fully saturated with water but instead containing both air and water in its pores; also called *zone of aeration*.
- Volatile:** Easily changed from a solid or liquid to a gas at relatively low temperatures.
- Water table:** The level below which the soil or rock is saturated with water; the upper boundary of the saturated zone.
- Water table well:** A vertical excavation that taps an underground source of water in an unconfined aquifer; the level of water in the well reflects the water table of the aquifer.
- Zone of aeration:** Layer of rock or soil (or both) not fully saturated with water but instead containing both air and water in its pores; also called *unsaturated zone*.

Telephone Numbers for Groundwater Information

Emergency Telephone Numbers

Animal Poison Control Center (24-hour hotline for information and advice) (217) 333-3611
 Chemical Transportation Emergency Center (CHEMTREC) for industry assistance in cleanup of spills and other emergencies (800) 424-8802
 Environmental Protection Agency (24-hour emergency spill hotline) (214) 655-2222
 National Pesticide Telecommunications Network (24-hour medical advisories on pesticide poisoning and general EPA information on pesticides) (800) 858-7378
 National Response Center hotline (for reporting spills of hazardous chemicals and oils) (800) 424-8802
 Virginia Emergency Response Council (804) 786-5999
 (804) 225-2667
 Virginia Office of Emergency Services (for spills) (804) 323-2300
 Virginia Water Control Board (24-hour pollution response program) (804) 257-0080

General Information Telephone Numbers

Appropriate Technology Transfer for Rural Areas (ATTRA) for information and advice on farming (800) 346-9140
 Chemical, Drug, and Pesticide Unit, Virginia Tech (information on pesticides) (703) 961-6543
 Chemical Emergency Preparedness Program (provides information on emergency planning and community right-to-know, SARA Title III) (800) 535-0202
 Environmental Protection Agency Public Information Center (202) 382-2080
 Environmental Protection Agency (Region III) hotline to report hazardous waste dumping in Virginia (800) 438-2474
 Environmental Protection Agency Small Business Hotline (800) 368-5888
 Governmental Refuse Collection and Disposal Association Clearinghouse (800) 458-5886
 Resource Conservation and Recovery Act (RCRA) and Superfund

(CERCLA) (interpretation and assistance with compliance) (800) 424-9346
 Safe Drinking Water Act information hotline (800) 426-4791
 Southern Waste Information Exchange (for information on available or requested industrial wastes) (904) 644-5516
 U.S. Department of Agriculture Information (202) 447-2791
 Economic Research Service (202) 786-1515
 Agricultural Research Service (202) 344-2264
 U.S. Geological Survey (703) 648-7470
 USGS Publications (703) 648-6892
 Virginia Bureau of Radiological Health radon hotline (800) 468-0138
 Virginia Department of Agriculture and Consumer Services (general consumer information and complaints) (800) 552-9963
 Virginia Department of Agriculture and Consumer Services, Office of Pesticide Regulation (pesticide regulatory information) (804) 786-3798
 Virginia Department of Health, Bureau of Toxic Substances Information (804) 786-1763
 Virginia Department of Health, Division of Water Programs (804) 786-1760
 Virginia Department of Waste Management, Hazardous Waste hotline (800) 552-2075
 Virginia Division of Litter Control (800) KEEP-ITT
 Virginia's Used Oil Recycling Program (for information on used oil collection centers) (800) 552-3831
 Virginia Water Control Board (804) 367-0056
 Northern Regional Office, Alexandria (703) 750-9111
 Piedmont Regional Office, Richmond (804) 367-1006
 Southwest Regional Office, Abingdon (703) 628-5183
 Tidewater Regional Office, Virginia Beach: (804) 499-8742
 West Central Regional Office, Roanoke (703) 982-7432
 Valley Regional Office, Bridgewater (703) 828-2595
 For copies of the draft
A Groundwater Protection Strategy for Virginia
 Terry Wagner at the Virginia Water Control Board (804) 367-6304



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