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Groundwater– Wisconsin's buried treasure

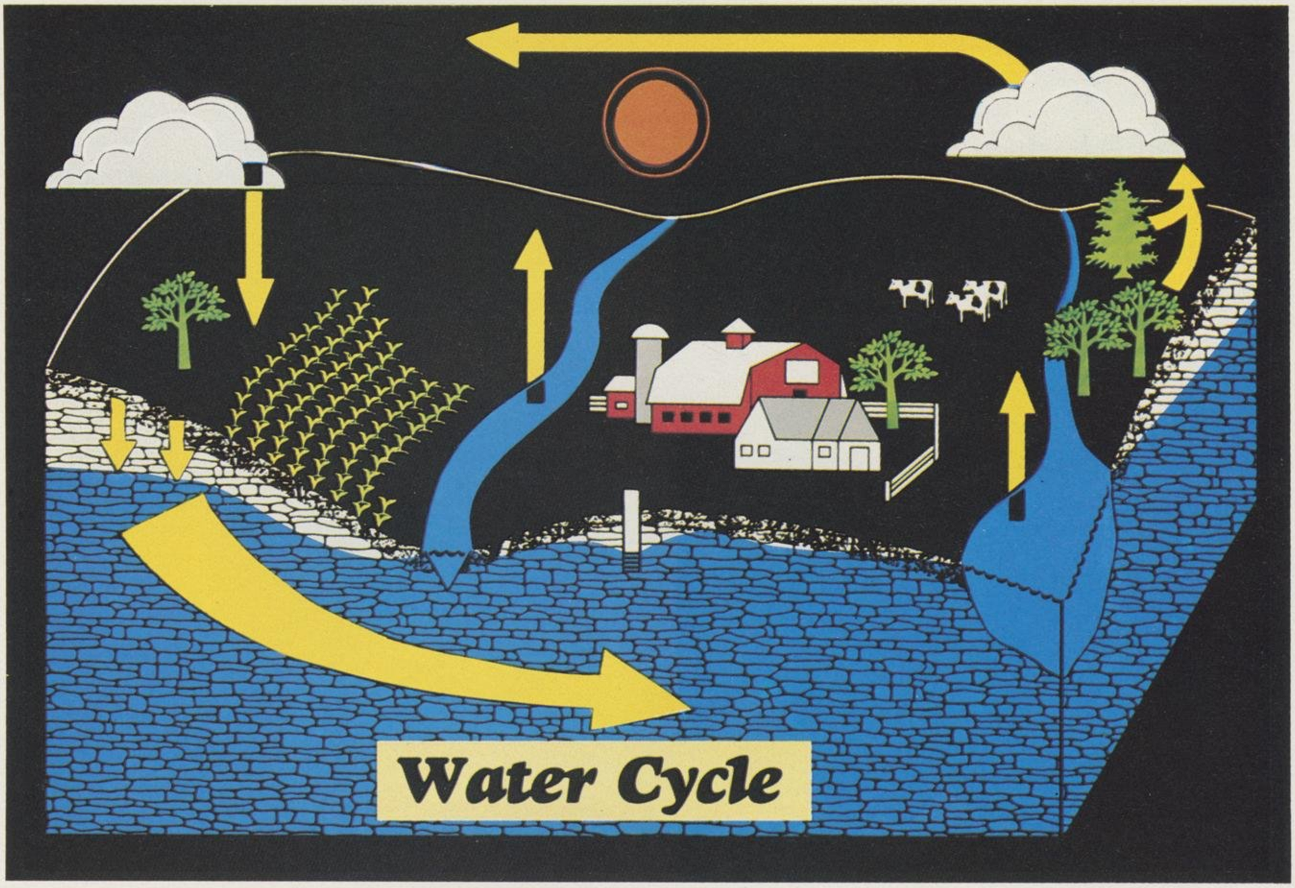
Supplement to

Wisconsin
NATURAL RESOURCES
MAGAZINE

Groundwater—
Wisconsin's buried treasure

Drill a hole just about anywhere in Wisconsin, and you'll find a dependable water supply. Draw enough to fill 100 glasses and you'll pay just one cent.

Groundwater — many of us call it well water — is plentiful and cheap in Wisconsin. But it is still a treasure for the simple reason that without it, life as we know it here would change radically. Two-thirds of us use groundwater for daily drinking. Agriculture is a major portion of Wisconsin's economic base, and nearly every drop of water used to irrigate crops, plus a



Contents

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Front Cover: Water from a flowing artesian well in Door County picks up the sun.
Photo by Ken Bradbury

Back Cover: A windmill pumps groundwater for farm use.
Photo by Paul Peeters

great deal used in milk and beef production, comes from groundwater reserves. Tourism, manufacturing, beer-making — all are groundwater-dependent.

Groundwater in Wisconsin is indeed a treasure. But like all our natural bounties, it is a treasure whose high value must be sustained not by accident but by purpose. By accident, groundwater falls victim to leaking gasoline tanks, chemicals misapplied on farm fields, poorly designed landfills or mismanaged animal wastes. By purpose, groundwater should be consciously protected from these and other dangers.

"Wisconsin's buried treasure" has been prepared to communicate a sound understanding of the resource and the ways our actions affect this resource. By understanding groundwater and our relationship with it, we take the first step toward insuring its value in Wisconsin's future.

Described herein are the groundwater, the layers of rock and soil that hold our groundwater, the water cycle that replenishes it, the human activities that endanger it and those that preserve it.

Each of us in Wisconsin is a beneficiary of this groundwater treasure; we must each learn to be its guardian.

GROUNDWATER
Wisconsin's buried treasure

USING THE GROUNDWATER RESOURCE

Wisconsin is water rich

From tap to turnip to tannery, we all use groundwater. The farm, the home and the factory all depend on it. There's plenty in Wisconsin. But don't take it for granted.

We often do take it for granted though, because our lifestyle and technology make resources accessible. Clean drinking water in seemingly endless quantity is readily, effortlessly available. Even a two-year-old tot can flip a faucet and get water. The vastness of Wisconsin's supply and the demand for it are hard to grasp. But even though it's plentiful, it remains a buried treasure.

Wisconsin is water-rich. Each year about 29 trillion gallons of water fall as rain or snow on Wisconsin's 36 million acres. The numbers are big! An estimated two million-billion (two quadrillion) gallons of groundwater are stored underground in this state.

A US Geological Survey study of 1979 data estimates that daily groundwater use in homes, businesses, industries, farms and other places totals about 600 million gallons. Even that large amount, though, is only 4% of what is recharged into the ground.

Water isn't everywhere in the same amounts

Precipitation doesn't fall evenly in the state and groundwater is not uniformly available. North central and southwestern Wisconsin get heavier precipitation than other parts of the state. Like the variation in rain and snow, there's a difference in groundwater abundance from west to east and areas in between. Cities and towns running north and south along the eastern quarter of Wisconsin are underlain by dolomite rock and clay which have a variable, fluctuating water table. Wells of comparable depth only a short distance apart may produce five gallons or a few hundred gallons of water per minute.

In most wells, a water level drop of a few feet doesn't mean much, but in cases where wells are shallow, it might be necessary to go deeper to find water.

Wells that dry up during a drought are usually shallow. On the other hand, deeper wells usually tap aquifers where the supply is less affected by seasonal changes in the amount of rainfall and is, therefore, more dependable. Considering that Wisconsin citizens have constructed approximately 500,000 wells, it's remarkable that fewer than half of one percent have ever required deepening or replacement due to lack of water. That's not to say we should not conserve water, avoiding wasteful practices.

The amount of irrigated cropland in Wisconsin has increased dramatically over the past two decades.

Municipal household use

About 94% of Wisconsin's cities and villages get their drinking water from the ground. Households use about 165 million gallons per day — around 52 gallons per person. Almost 50% goes down the toilet, another 30% down the bathtub and about 20% drains out of laundry tubs and kitchen sinks. Relatively, only a drop flows from the cup to the lip as drinking water. Overall, domestic use of groundwater is low; it amounts to only 27% of total groundwater use.

But it's important to conserve water at home because of hidden costs. Drilling community wells, installing water pipes, pumping water and treating wastewater and sewage are expensive. The less water used, the fewer facilities needed and the less cost.

Industrial use

Wisconsin industries use substantial quantities of groundwater (133 million gallons per day) to help produce machinery and electrical parts to fabricate metal, cars, leather and a host of other goods. Most of these companies are concentrated in southeastern Wisconsin where surface water from Lake Michigan is abundant. However, groundwater still provides more than 25% of our manufacturers' water needs.

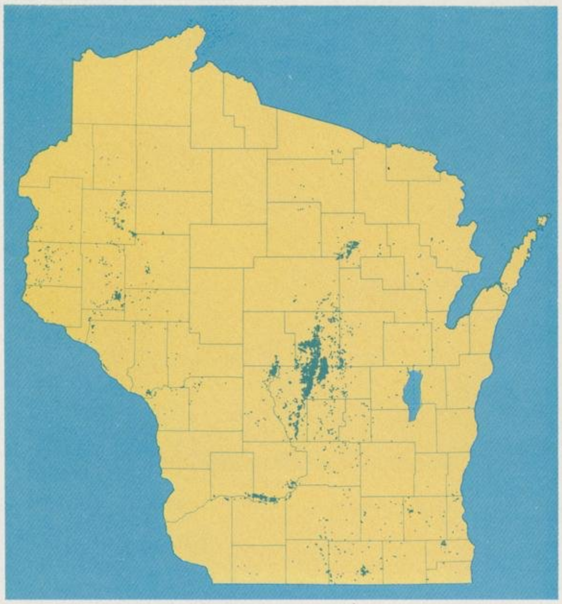
Six industries, in particular, use tremendous amounts. They are: pulp and paper, fruit and vegetable processing, cheesemaking, electroplating, meat processing and brewing. These industries don't just need water, they need clean water. Groundwater is a hefty part of the canned fruit, vegetable, meat and beverage industries vital to the state's economy. Wisconsin ranks number one nationally in processed foods.

Groundwater is a precious economic commodity in itself because many industries need clean, abundant water to survive.

Agriculture

Although Wisconsin has fewer farms today than 30 years ago, productivity has increased over the recent past. But changing agricultural methods have brought a growing thirst for groundwater.

Irrigation is almost essential for growing crops on the permeable soils of the state's Central Sands. But repeated, excessive watering can leach nutrients, fertilizers and pesticides into the groundwater.



Most of Wisconsin's 3,000 high-capacity irrigation wells cluster in the ten-county Central Sands area and other areas having permeable sand and gravel aquifers.

Dairy and cattle operations use more water than ever in production, maintenance and cleaning. The Wisconsin dairy marketing system places a premium on the purity of water used on the farm. A Grade A dairy operation needs Grade A water to bring a high quality product to market. Beef and dairy farms use clean groundwater — about 27 billion gallons a year.

The increasing popularity of irrigation has placed significant added demands on Wisconsin groundwater. Beginning in 1958, and spurred by new, less expensive techniques, irrigation well drilling approvals jumped dramatically from about 14 per year to more than 500 in the year following the 1976 drought.

Several factors made large portions of Wisconsin farmland ideal for irrigated crops. Level lands can accommodate the long, spreading arms of sprinkling equipment without straining motors. Sandy, permeable soils let water seep in and drain quickly while helping plant roots breathe and grow healthy. Irrigation is almost essential to coax a crop from these lands. Sandy soils are easy to prepare for planting, need less plowing and provide easy harvest in rainy weather. Low-cost piping, new mechanical vegetable harvesters, relatively inexpensive land and the University of Wisconsin research station to test new technology and plants combined to make formerly marginal land show a profit. Wisconsin farmers have become a national force in food production — potatoes, peppers, snap beans, peas, mint and corn.

Irrigation equipment withdrew almost 30 billion gallons of groundwater in Wisconsin in 1981. Demand for irrigated water is expected to rise dramatically in the next 20 years.

However, Wisconsin's environment, particularly its groundwater, may be paying a price for the glowing success of irrigation farming. Increased irrigation can speed soil erosion as windbreaks come down to accommodate the wide-swinging irrigation arms. Irrigation encourages cropping on the same piece of land year after year instead of using a cover crop and letting the land rest periodically. Repeated watering may leach materials from the soil, driving nutrients, fertilizers and pesticides into the groundwater.

Economics

As stories of water shortages and contamination multiply from elsewhere in the nation, more and more business and political leaders are talking about the relationship between water and economic development.

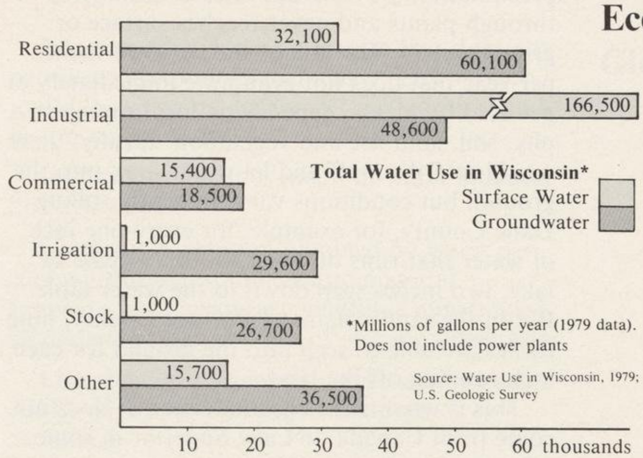
Analysts say that water shortages and accelerating costs of delivering water to users represent the darkest cloud on the horizon of the Sun Belt, the southwest portion of the United States that has experienced a recent economic boom. Indeed, if the 70s were characterized as an era when industry got energy-conscious and fled the snow for the Sun Belt, then the 80s could be the era when industry comes home for a drink.

Surface water supplies are already over-assigned in some areas. And now there is a study that suggests the Ogallala Aquifer that supplies water to much of the high plains is drying up. The federal study suggests that the plains — enjoying an irrigation-sustained agricultural prosperity never before experienced — may have to return to dryland farming. If that's the case, Wisconsin and the Upper Midwest — which have surface and groundwater abundance — may be more attractive to agricultural investors.

Also, some feel that investors looking to the economic future of urban areas and communities should take water supplies into account before financing developments or siting plants.

Harry G. Powell, senior vice-president and investment officer for Merrill Lynch Asset Management, Inc. of New York, says water shortages should have a substantial impact on future economic and investment decisions.

In a Wisconsin speech, he said many observers believe water will become "even a more critical problem for the world than energy." He reflected on the recent shift of jobs and people to the Sun Belt and said:



"During the 1970s, the migration from the northern part of the country to the south and west was very significant. Two-thirds of new employment in fact, was a direct result of this movement.

"Already, some of the most notable beneficiaries such as Phoenix, Tucson and Houston are experiencing problems with water and some observers claim that water will prompt a reverse migration [back to the North]."

That's the feeling of former Michigan Governor William G. Milliken, who has been active in efforts to emphasize the value of water, especially Great Lakes water, to the region's future.

"Water will be for the Midwest almost like oil is to the OPEC countries," he said. "It is vital to life and agriculture and attracts industry and tourism."

Within the Upper Midwest, Wisconsin not only has access to the Great Lakes, it has groundwater supplies that are relatively clean and abundant. Supplies that — if properly managed — will be able to sustain business, industry and agriculture for centuries to come.

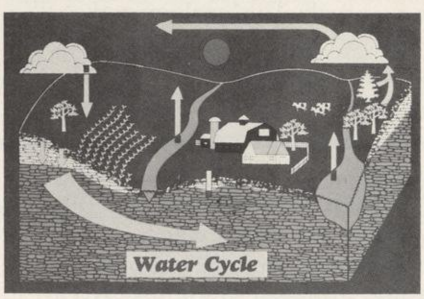
GROUNDWATER Wisconsin's buried treasure

UNDERSTANDING THE RESOURCE

Water might be called our most recycled resource. Consider, for example, that the water you bathed in this morning may have contained the same water molecules that washed over a South Pacific coral reef millions of years ago. The distribution of the earth's total supply of water changes in time and space, but the amount has remained basically constant.

Distribution of water changes according to a phenomenon known as the hydrologic cycle, kept in motion by solar energy and gravity.

Pick a bursting cloud as the start of the cycle. Its rain falls to earth. Some flows downhill as runoff (to a stream, lake, eventually the ocean); some evaporates; some is taken up by plants. The rest trickles down through unsaturated subsurface soil and rock formations, traveling through pore spaces and open cracks. This water eventually reaches the top of the saturated layer which is called the water table. The



When rain falls, some evaporates, some waters plants, some runs off into lakes or streams and some trickles through the soil to become groundwater.

water contained in the saturated layer below the water table is called groundwater.

Groundwater seeps from upland to lowland areas, eventually discharging in low places where the water table intersects the land surface — in streams, lakes, wetlands. Solar energy will cause evaporation from these surface waters, and as clouds accumulate, the cycle begins again.

In Wisconsin, an average of 30 to 32 inches of precipitation per year falls on the state. Most precipitation (75%) evaporates or transpires through plants and never reaches surface or groundwaters. The fate of the six to 10 inches per year that does not evaporate immediately or get used by plants, depends on local topography, soil, land use and vegetation. Ideally, these would retard runoff and let water soak into the ground, but conditions vary. In gently rolling Dane County, for example, for every one inch of water that runs off the land to a stream or lake, two inches seep down to the water table. But in the sandy plains of Portage County, nine inches are able to seep into the ground for each inch running off the land.

This is what makes groundwater. It does not come from Canada or Lake Superior in some mysterious underground stream.

All groundwater moves continually toward an area of discharge. But rates of movement vary greatly.

The reason for this variability is a matter of geology. The size of the cracks in rocks, the size of the pores between soil and rock particles and whether the pores are connected, all contribute to the rate of movement to, through and out of the saturated zone.

For example, water generally moves more quickly into, through, and out of coarse sand as compared with other materials, sometimes as much as several feet per day. Openings between the grains are large and interconnected, resulting in high permeability. Very fine-grained material like clay has many pores where water can be stored, but the pores are small so moving water through or out is difficult. Such formations are relatively impermeable; movement here may be only a few inches a year. Permeability in limestone rock, on the other hand, depends not on pore spaces but on the size, frequency and distribution of fractures and cracks.

Groundwater flow systems

Groundwater moves through the water cycle as part of a dynamic flow system, from recharge areas where infiltration occurs to discharge areas (streams, lakes, springs and many wetlands). It may move downgradient following the configuration of the water table, or in deeper confined layers of rock or soil under artesian pressure. In Wisconsin, the natural movement is always from upland recharge areas to lowland discharge areas. Because groundwater naturally moves to and discharges into lowland areas, it is a significant factor in the development of our lakes, streams and wetlands.

Did you ever wonder why some streams continue to flow during dry periods, or during the winter even though there is no rainfall? The answer is that winter stream flow is largely groundwater discharge (called baseflow), which is relatively warm (about 50°F). Streams, and most lakes and wetlands, are constantly replenished during the winter by groundwater in the uplands surrounding that stream, wetland or lake. The water table steadily lowers during the winter discharge period, and it is not until the following spring thaw that water can once again infiltrate the soil to recharge the groundwater and thus cause the water table to rise.

Groundwater in Wisconsin does not move hundreds of miles. Most precipitation which recharges groundwater moves only a few miles from the point of recharge to the point of discharge. In the vast majority of cases, it stays within the same surface runoff watershed.

Aquifers of Wisconsin

An underground rock or soil formation that can store and transmit water efficiently is called an aquifer. In a few areas of northern Wisconsin, clay soils overlay granite or some similar hard nonporous rock. This geology makes it unsuitable for storing and transmitting water efficiently or economically and as a result, substantial well water supplies are not available.

Wisconsin is favored with thick sequences of permeable deposits across most of the state. These layers of soil and rock formations comprise the four principal aquifers of the state; the sand and gravel aquifer, the eastern dolomite aquifer, the sandstone and dolomite aquifer and the crystalline bedrock aquifer.

Sand and gravel aquifer

The sand and gravel aquifer is the surface material that covers most of the state, except for parts of southwest Wisconsin which were not glaciated. It is made up mostly of sand and gravel deposited from glacial ice or in river floodplains. The deposits are unconsolidated so they are often called soil, even though they are different from agricultural soil and are more than 300-feet thick in some places. The groundwater occurs and moves in the void spaces (pores) among the grains of sand and gravel.

The glaciers themselves were formed by the continuous accumulation of snow and played an interesting role in Wisconsin's groundwater geology. The snow turned into ice which reached a maximum thickness of almost two miles. The ice sheet spread over Canada, and part of it flowed in a general southerly direction toward Wisconsin and neighboring states.

The ice sheet transported a great amount of rock debris called "drift."

As the ice melted, the drift was reworked by the running water. Large amounts of sand and gravel were deposited to form "outwash plains;" pits were formed in the outwash where buried blocks of ice melted and many of these are now occupied by lakes. The sand and gravel aquifer was deposited within the past million years.

The sand and gravel outwash plains now

form some of our best aquifers in Wisconsin. Many of the irrigated agricultural lands in central, southern and northwestern Wisconsin use the glacial outwash aquifer. Many other glacial deposits are also useful aquifers, but in some places, large glacial lakes were formed which accumulated thick deposits of clay. These old lake beds of clay do not yield or transmit water.

Because the top of the sand and gravel aquifer is also the land surface for most of Wisconsin, it is highly susceptible to human-induced and some natural pollutants.

Eastern dolomite (limestone) aquifer

The eastern dolomite aquifer occurs in eastern Wisconsin from Door County to the Wisconsin-Illinois border. It consists of the Niagara dolomite formation underlain by the Maquoketa shale formation. These formations were deposited 400 to 425 million years ago. Dolomite is a brittle rock that is similar to limestone and contains groundwater in interconnected cracks. As a result, the yield of water from a well depends upon the number of fractures the well intercepts. Closely spaced wells, therefore, can vary greatly in the amount of water that can be pumped.

Where this fractured dolomite bedrock occurs at or near the land surface, the groundwater in shallow portions of the eastern dolomite aquifer can easily become contaminated. In those areas (such as parts of Door, Dodge and Waukesha counties), there is little soil to filter pollutants carried or leached by precipitation. Little or no filtration takes place once the water reaches large fractures in the dolomite. This has resulted in some special groundwater quality problems and should prompt special care to prevent pollution.

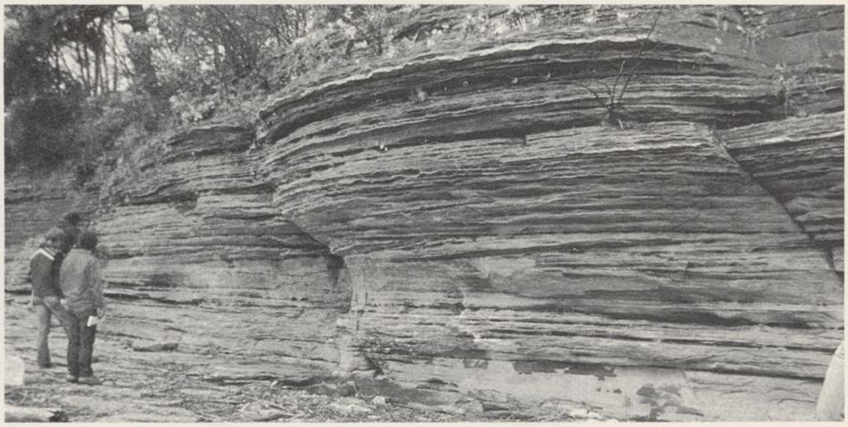
The Maquoketa shale layer beneath the dolomite is a rock formation formed from clay that doesn't transmit water easily. Therefore, it is important not as a major water source, but as a barrier between the eastern dolomite aquifer and the sandstone and dolomite aquifer below.

Sandstone and dolomite aquifer

The sandstone and dolomite aquifer consists of layers of sandstone and dolomite bedrock units that vary greatly in their water yielding properties. In these types of rock, groundwater occurs in fractures. In sandstone it also occurs in pore spaces between loosely cemented sand grains. These units occur over the entire state, except in the north central portion where these formations are not present. In eastern Wisconsin, this aquifer lies below the eastern dolomite aquifer. In other areas it lies beneath the sand and gravel aquifer. These rock units gently dip to the east, south and west away from the north central portion of the state, becoming much thicker and extending to greater depths below the lands surface.

The rock units that make up the sandstone and dolomite aquifer were deposited between 425 and 600 million years ago. The sandstone and dolomite aquifer is the principal bedrock aquifer for the southern and western portions of the state. In addition, in eastern Wisconsin, most users of substantial quantities of groundwater, such as cities and industries, tap this deep aquifer to obtain a sufficient amount of water.

Left: Cracks in dolomite and limestone readily transmit water . . . and pollutants.



Right: In sandstone, groundwater flows not only between layers, but between loosely cemented sand grains as well.

Crystalline bedrock aquifer

The crystalline bedrock aquifer consists of a variety of rock types formed during a geologic time called the Precambrian Era. The Precambrian Era lasted from the time the earth cooled, more than 4,000 million years ago, until about 600 million years ago, when the rocks that comprise the sandstone and dolomite aquifer began to be formed. During this vast period of 3,400 million years, sediments, some of which were rich in iron and which now form iron ores, were deposited in ancient oceans; volcanoes spewed forth ash and lava; mountains were built and destroyed, and the rocks of the upper crust were intruded by molten rocks of deep-seated origin. The rocks that remain today have a granite-type crystalline structure. These are the "basement" rocks which underlie the entire state. In the north central region, they are the only rocks which occur beneath the sand and gravel aquifer.

The cracks and fractures that store and transmit water in these very dense rocks are spaced many feet apart. The amount of water available to a well can vary within a single homesite. To obtain water a well must intersect some of these cracks.

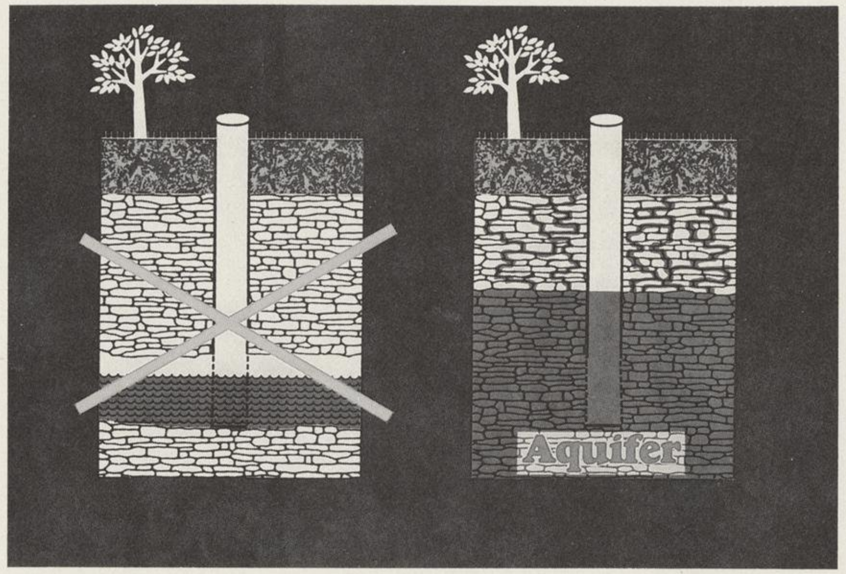
Many wells in the crystalline bedrock aquifer have provided good quality water. However, most of these wells do not penetrate deeply into the rock. Water samples from mineral exploration holes near Crandon and deep iron mines near Hurley have yielded brackish water near or exceeding mineral concentrations in sea water.

Common myths about groundwater

There's a lot we don't know about groundwater. It's one of our most mysterious natural resources. So it should be no surprise that there are many myths and misconceptions about groundwater, and that many of us still hold those myths and misconceptions, even in this modern age. Some of them:

- Groundwater comes all the way from Canada.
- There are vast underground lakes and rivers.
- We can't pollute groundwater because it's so deep underground.
- If polluted or contaminated, groundwater is easily cleaned.
- Water rushes so rapidly underground that its presence can be detected by listening.
- Groundwater migrates thousands of miles through the earth.
- There is no relationship between groundwater and surface water.
- Groundwater is an insignificant source of water supply. It is unimportant.

All of the above statements are false and by better understanding the properties and behavior of groundwater, we will not only learn about a most valuable natural resource, we will be able to better protect it. While all of the above statements are false, the truths — those that we know — about groundwater are more complicated than a one-word response. By discarding the myths about groundwater you may have already come a long way toward understanding the resource.



Groundwater occurs not as a subterranean stream, but more like an immense, saturated underground sponge with water seeping from upland areas to streams, lakes and wetlands.

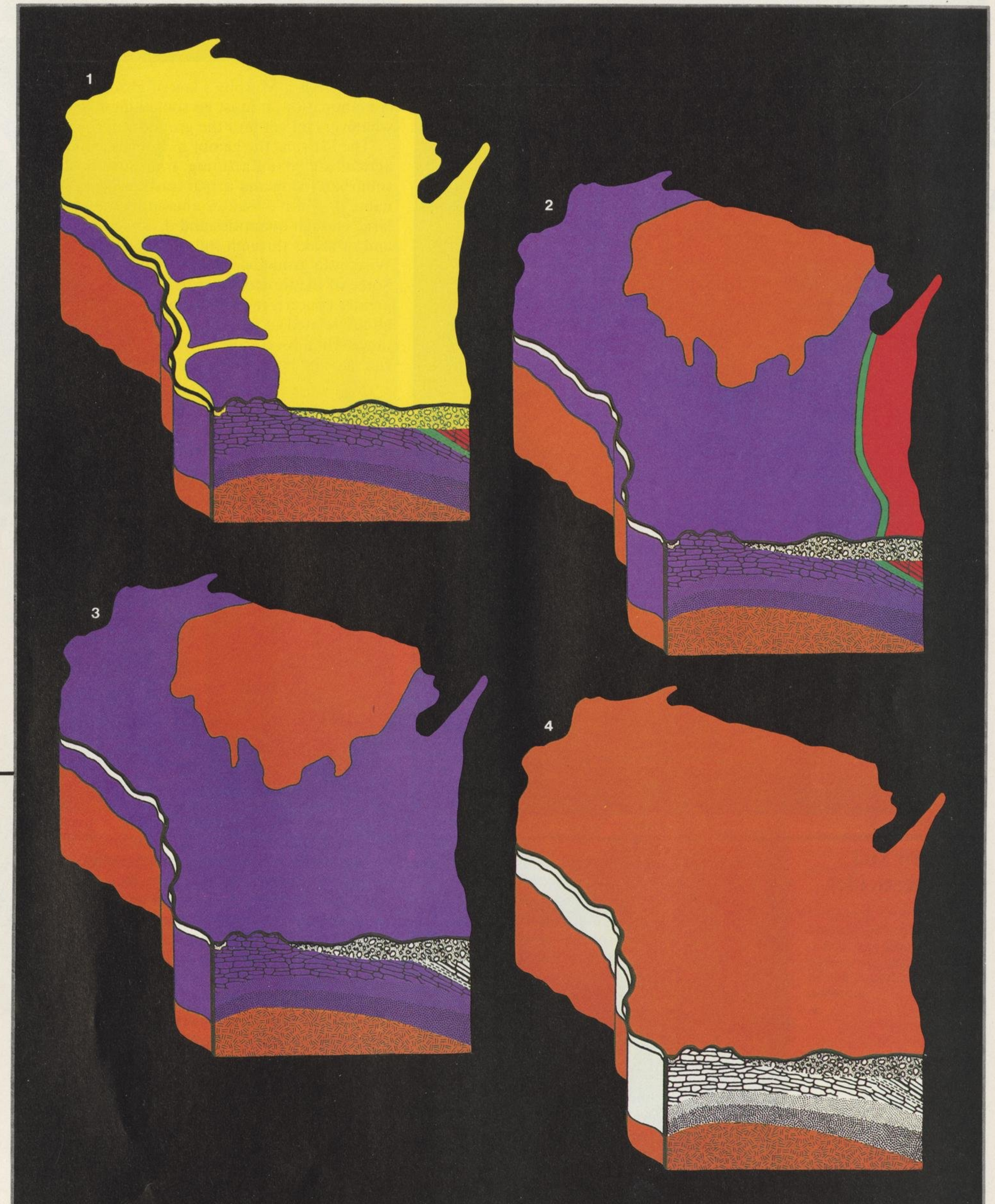
Wisconsin's Aquifers

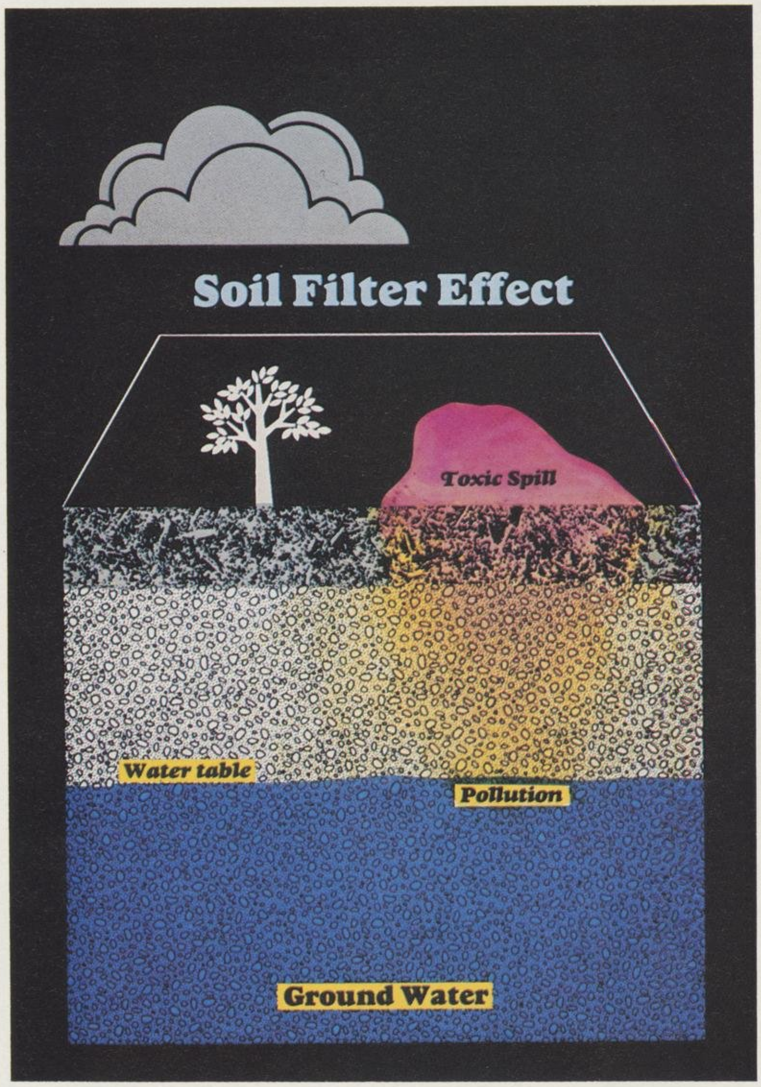
1. This shows the aquifer nearest the land surface. It is *sand and gravel* (yellow) and covers the entire state except unglaciated southwestern Wisconsin. This aquifer was deposited 10,000 to one million years ago.

2. If the sand and gravel aquifer were stripped away from the top of the first illustration, this would be the result. It is called the *eastern dolomite aquifer* and occurs in eastern Wisconsin. Deposited 400 to 425 million years ago, it consists of Niagara dolomite (red) underlain by Maquoketa shale (green). The Maquoketa shale formation is relatively impermeable and prevents water from moving readily between the Niagara dolomite and the sandstone and dolomite aquifer (purple) below.

3. When the eastern dolomite aquifer is stripped from the second illustration, the *sandstone and dolomite aquifer* (purple) is revealed. It lies beneath the Maquoketa shale in eastern Wisconsin and beneath the sand and gravel aquifer in most of the rest of the state except in the north-central region. The sandstone and dolomite formations were deposited 425 to 600 million years ago.

4. Finally, when the sandstone and dolomite aquifer is stripped away the *crystalline bedrock aquifer* (orange) is uncovered. These granite-type rocks underlie the entire state and were formed more than 600 million years ago. They contain few fractures and, therefore, usually yield limited quantities of water although some high capacity wells have been developed in this aquifer.





If there is a Murphy's law of groundwater contamination, it must go something like this: whatever can get into the groundwater, will.

The list runs the gamut of human activity — agriculture, manufacturing, transportation, even suburban living and urban trash disposal. You name it — if it's used or abused by humans in large enough quantities and dissolves in water and/or soaks through soil, it may show up in Wisconsin groundwater at some place or time. Some of the threats described here are of greater concern to Wisconsin than others, but all are related to problems of statewide importance. On a local scale, any one of these threats can become paramount at a given time.

Not all harmful materials spilled on land end up in groundwater. Soils such as clay can attract and hold surprising amounts of pollutants. But porous sands allow contaminants a nearly direct channel to groundwater. ◄

This dye poured on the surface demonstrates how contaminants can move through soil to groundwater. ▼

Aldicarb and other pesticides

Pesticides (including insecticides, herbicides and fungicides) are vital to Wisconsin agriculture and to our methods of producing crops. We are just beginning to understand, though, that some highly water-soluble pesticides may be of concern because of their potential for leaching into groundwater. Aldicarb is a case where the presence of the pesticide in Wisconsin groundwater has been well-documented and where, as a result, special restrictions have been placed on its use.

In the six-county Central Sands region around Stevens Point and Wisconsin Rapids, aldicarb (Temik) has been the potato growers' preferred pesticide for controlling nematodes and Colorado potato beetles, their two most serious enemies. It's cheap, effective and convenient to apply.

But, unfortunately, with aldicarb's advantages also comes a serious disadvantage when it is used in the Central Sands area: It sometimes contaminates groundwater there. Aldicarb is applied to the soil in granular form where it dissolves readily and is taken up by the growing plant. An insect eating any part of the plant gets a dose of the insecticide and dies.

But because of this high solubility, rain and irrigation water can wash any aldicarb not taken up by plants through the sand and into groundwater.

Scientists say that in the warm, moist, well-aerated upper soil levels, bacteria breaks down aldicarb relatively rapidly. But they disagree on just how long it will remain in groundwater. Industry experts have predicted that aldicarb will have a 2 1/2 year half-life in Wisconsin groundwater, meaning that at least traces will remain in Wisconsin groundwater for a long time.

There's plenty of reason for worry about aldicarb in drinking water. In large enough doses, aldicarb can cause serious illness. It's not believed anyone has gotten sick drinking water contaminated with aldicarb in Wisconsin, and there are no known long-term health effects of low level exposure to the chemical.

Between 1980 and 1982 researchers discovered aldicarb in several Wisconsin wells. Some contained more than 10 parts per billion (ppb); recommended as the maximum level of safety by the federal government. Not surprisingly, the highest aldicarb levels and greatest number of contaminated wells showed up in Portage and Marathon Counties, which also have many acres of sandy-soil potato fields.

Since 1982, special restrictions have been placed on use of aldicarb. The allowable amount and frequency of use has been reduced. The timing of application has been delayed, from planting until emergence of plants. In places where the chemical has been detected in wells above the 10 ppb guideline, use is not allowed at all. The State Pesticide Review Board has stated its intent to closely monitor aldicarb to assure that present restrictions are adequate.

Testing in 1982 revealed concerns about other pesticides in groundwater beneath agricultural fields in Portage, Waushara, Marathon and Langlade counties. These tests have been very preliminary, and the presence of these compounds or their concentration must be confirmed by subsequent testing. A limitation has been that no state-owned laboratory is currently set up to conduct the required types of tests in water.

Application of pesticides and herbicides is essential in modern farming but in some locations can threaten groundwater.

Landfills

More and more, materials that society once thought of as wastes are seen as resources, to be used and reused time and time again. Industries are practicing waste reduction and recovery. Communities and households are recycling and reusing.

But still there remains material to dispose of — solid waste that is sometimes toxic or hazardous. These are materials left over after resource recovery and treatment are no longer economic or feasible. These leftovers are typically destined for a landfill. To protect groundwater from them, requirements and regulations have been imposed governing landfill planning, design, operation, and finally, abandonment.

In general, today's landfills in Wisconsin consist of an excavation either dug into or lined with a heavy layer of impermeable clay. Atop this clay base a network of perforated pipes is installed to collect leachate, a foul, sewage-like substance that forms when water percolates through solid waste. These pipes funnel liquid landfill leachate into one or more collection tanks for treatment and disposal.

As separate areas fill with incoming garbage, they are topped with yet another layer of clay to encase the refuse in a tight "cell" sloped to shed precipitation. The less water percolating through the site, the less leachate to cause problems.

But such modern landfills are the ideal. And many that don't meet modern standards still exist, "grandfathered" into existence when today's landfill regulations were developed during the last decade.

There is also a problem with landfills abandoned before regulation began. Locations are often unknown but they may leak contaminants that get into the groundwater. Properly designed modern sites should not cause problems, but even the best-engineered landfill can sometimes leak leachate into the groundwater.

Landfills: An example of past problems

In the 1950s, before the days of landfill regulations, a trucking company began filling in a gravel pit near Delafield, piling refuse directly on top of fractured bedrock. In the early 70s, the pit was "grandfathered" as a registered landfill. Because of its proximity to metropolitan Milwaukee, the landfill was a precious commodity. The facility grew to be among the largest landfills in the state.

In 1974, the owner was ordered to update the site, put in a leachate collection system, install monitoring wells, reduce runoff and windblown litter and otherwise operate according to modern standards.

As the landfill grew, so did the suburbs around it. By 1977, wells in the area began showing signs of leachate contamination. Water from at least seven wells became undrinkable. From 1978 to 1980, the owner of the landfill voluntarily supplied nearby residents with bottled water, then drilled two deep-aquifer wells to supply all the affected homes in the neighborhood.

In late 1982, the site was permanently closed and capped with two feet of compacted clay to limit infiltration of rain and melting snow into the site and thus minimize leachate generation. Samples from up to 15 monitoring wells on the site and at least 30 private wells in the area will be analyzed quarterly for perhaps years into the future to track possible spread of the contaminants.

Ponds, lagoons and land disposal of wastewater

Municipal, industrial and private concerns use ponds, lagoons and other onsite methods to store, treat and dispose of wastewater. One familiar example is the common small community sewage plant, many of which use a lagoon as final treatment before releasing purified wastes to rivers or streams. These lagoons are sealed with compacted clay-type soils or a plastic liner. Nevertheless, some old or malfunctioning lagoons leak anyway, some so much that treated sewage wastewater flows in, but not out — it all leaks away first. As inspections turn up these imperfect systems, they are repaired or replaced.

Even if there is nothing wrong with the lagoon itself, human mismanagement of it can be responsible for polluted groundwater. Some sewage systems use treatment lagoons for oxidation and settling, followed by seepage cells for filtering away treated wastewater through the soil like a septic system drainfield. If treatment in the lagoons is not complete or if they are not maintained properly, poorly treated wastewater in the seepage cells can wind up in the groundwater. Needless-to-say, the seepage cells also need good maintenance.

Industrial wastewater is often treated in the same kind of lagoon, and subject to the same drawbacks. The water is also oftentimes disposed of through wastewater irrigation, a process where wastewater is sprayed on crops in the vicinity of the plant. A similar alternative is

ORPHANED LANDFILLS

An introduction

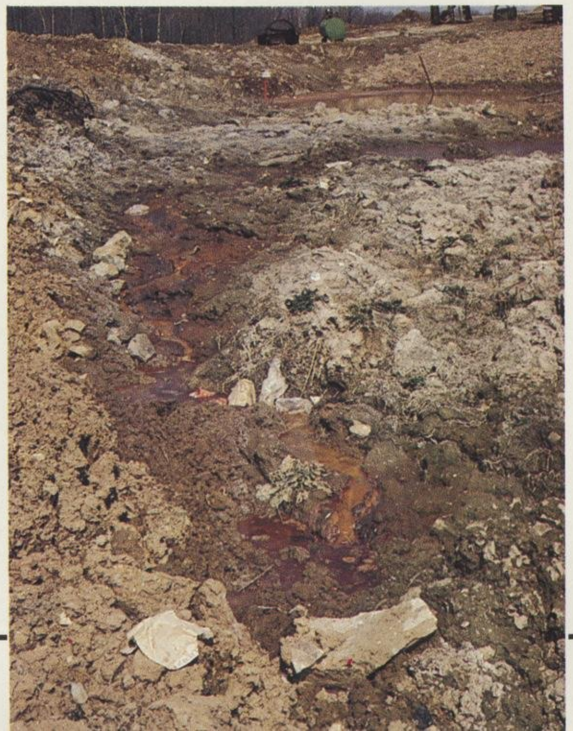
In years past, few appreciated the need for properly disposing of household refuse and industrial wastes. Even fewer realized that some were especially toxic or hazardous. We are suffering today from that lack of foresight. Orphaned dumps and landfills, many long abandoned and forgotten, contain the discards of decades past. Some threaten Wisconsin's high quality environment and the health of our citizens. Most were closed before we learned how to care for old sites. Only a handful of these abandoned sites have any groundwater monitoring wells in place to check for pollution.

▲ Leachate and rainwater form surface ponds on the Mid-State landfill near Wausau. In 1979 DNR fined the owners more than $800,000. The company declared bankruptcy shortly thereafter, leaving behind a leaking, orphaned landfill.

A solid waste specialist ▶ tests for conductivity in a rivulet of leachate draining toward nearby Rock Creek and hence to the Big Eau Pleine River less than a mile away. Checking conductivity gives a rough measure of the amount of dissolved solids in the leachate load.

Unfortunately, when problems arise — like the discovery of contaminated drinking water near old sites — there are numerous obstacles to correcting the situation. Most tragically, families, farms and businesses affected by orphaned landfills have few places to turn to for help. Their property values may slip, and they may fear adverse health effects from drinking water that may be contaminated. Governments, courts and state agencies lack laws and funds to provide compensation or relief — even immediate relief like a replacement water supply.

Rusty-brown leachate drains off the 158-acre orphaned landfill. Since the owners have no assets, responsibility falls by default to state and local taxpayers. ▼



There generally are no records of what went into dump sites. The land may now belong to a new owner; businesses that dumped wastes may have moved. It's tough to pinpoint legal responsibility in cases like this. The wastes may even have been legally disposed of at the time. State landfill laws only date back to 1967.

These problems create complex public policy issues. Who should pay for cleaning up the environment and helping people?

One possible outcome is a state program that is able to answer a series of pertinent questions, such as:

- Identification. Where are the sites?
- Assessment. What do old records and files reveal?
- Inspection. Are there any visible problems?
- Investigation. Is there hidden contamination?
- Remedial Action. How should a cleanup be handled?
- Final Determination. How should the site be cared for and monitored?

This will be costly work. There may be as many as 2,000 abandoned dumps and all will have to be examined.

The public role: What citizens can do

Here are a few suggestions on how to help out and keep safe:

- Support local and state initiatives to solve problems caused by abandoned, orphaned landfills.
- Avoid potential dangers by leaving site investigations to the experts. Don't play Sherlock Holmes! Never open abandoned barrels.
- Alert your neighbors of your suspicions so they can keep children and pets away from danger.
- If you notice peculiar odors or tastes in your water, consider getting it tested and finding an alternate supply.
- Get in touch with your DNR district office to report problems and complaints.

If you call DNR, describe the circumstances thoroughly. Mention whether wastes are exposed to view, and any odd colors or odors in drinking water and surface water. Recall what you know about the site's history. This will help insure that the right investigator is assigned to the case. Remember to avoid any physical contact with potentially dangerous substances.

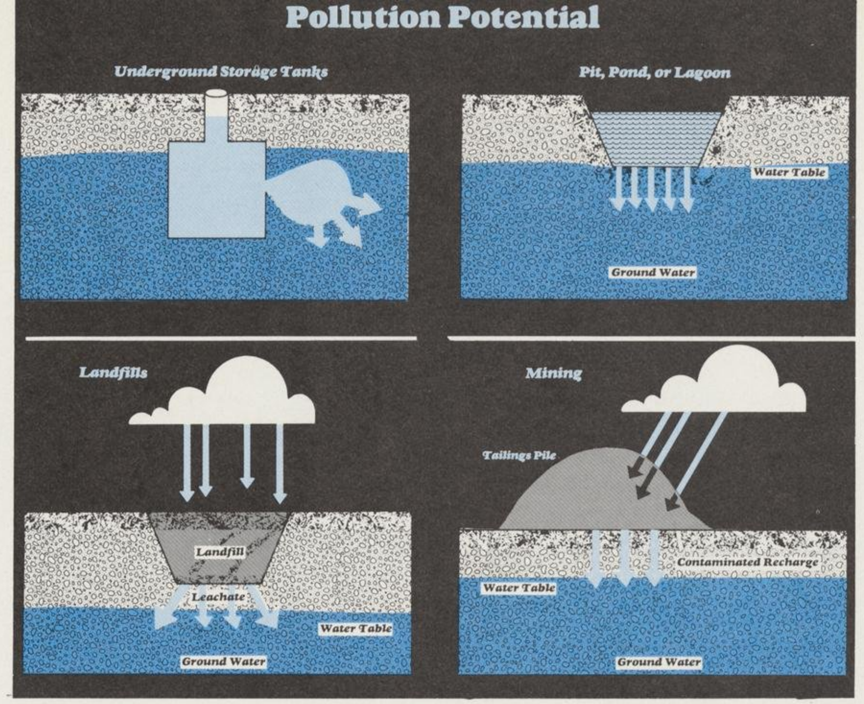
DNR's role: What we're doing now

DNR staff throughout the state are trained to follow a series of logical steps to address citizen complaints. They investigate, inform affected parties and follow through with the case. More specifically, they will:

- Obtain information about the problem through interviews, site inspections and file searches.
- Determine the seriousness of the case in the quickest possible time.
- Take actions to keep harmful wastes away from people and the environment.
- Develop a long-term solution,

This will be done by: 1-Searching for the responsible parties including waste producers, landowners and disposal site operators. 2-Defining and assessing environmental impacts through sampling and laboratory tests. 3-Working with responsible parties to clean up the situation and avoid future trouble.

Professional investigation of citizen complaints is an important way to resolve particular concerns about the effects of orphaned landfills. There are appropriate actions for everyone in identifying problems and promoting timely solutions. DNR can help when notified that environmental quality or public health are threatened. When responsible parties are known, they can sometimes be convinced to pay for site investigation and remedial action. However, tougher state laws and more public funds are needed for examining all orphaned sites and assuring money for any cleanups needed. Widespread cooperation and communication will be the keys to success.



The causes of groundwater contamination are as many and varied as human activities.

called a "ridge and furrow" system which directs wastewater down a one-foot wide, one-foot deep trench. Some water is taken up by plants on ridges between the furrows and some evaporates, but most is filtered through the soil. In either method, if the system is poorly managed or if more is applied than the land can filter, groundwater can be polluted.

Across the state, 2,500 to 3,000 farms have installed manure storage pits. By most estimates, only a third are constructed with some kind of liner, usually packed earth, according to US Soil Conservation Service standards. Improperly constructed, earthen pits can leak directly into the ground. Polluted groundwater under the farmstead obviously is something farmers want to avoid, not only because it could affect their health, but because well replacement is costly.

In rare instances, even silage has been known to pollute groundwater if stored where leaching "silo liquor" can seep into porous soils or fractured bedrock.

Mining

Mining, particularly metallic mineral mining, may pose a threat to groundwater quality in two ways: 1) from the waste material that must be disposed of; and 2) from the processes used in removal of ore from the subsurface, which is often below the water table.

The amount of waste rock removed from any mine far outweighs the quantity of metal or ore recovered, often by a factor of 8 to 1 or more. The process of separating the metal-containing minerals from the waste rock produces a large quantity of finely ground waste called "tailings." In some mines, these "tailings" are no more hazardous than common roadside gravel, and in fact are often used for road construction and fill.

In other places, however — and northern Wisconsin is one such area — a sulfur-containing mineral called pyrite would be present in tailings of proposed mines. Percolation of rainwater through such tailings has the potential of producing sulfuric acid. This acid in turn could dissolve traces of toxic heavy metals remaining in the rock. DNR's new metallic mining waste regulations minimize the possibility of the development and leakage of such acidic leachate by requiring proper design, construction, operation and closure of mine waste disposal facilities.

Most deep mines extend below the water table to get at the metal concentrations and so must be continually pumped to control the flow of water into the mine. This pumping effectively lowers the water table and exposes once saturated rocks and minerals to oxygen, thereby promoting the oxidation of these minerals into other compounds, some of which may pose a threat to the groundwater.

Example: In the Shullsburg area of southwestern Wisconsin, underground mines were developed to extract zinc and lead sulfide minerals from the limestone-dolomite rock, which also happens to be the area's main aquifer. The pumping necessary to control the flow of groundwater into the mine permitted some sulfide materials to be oxidized into sulfates. Saddled with low zinc prices, a firm that operated a mine near Shullsburg closed in October of 1979, after more than 30 years of continuous operation.

With the pumps shut down, groundwater levels rose, allowing the groundwater to come into contact with the oxidized compounds that had developed in the dewatered areas. Nearby residents began to experience water quality problems in their wells. Eventually, their water became undrinkable. In some cases, cattle reportedly refused to drink and milk production suffered.

Subsequent testing revealed high levels of three contaminants — sulfates, iron and zinc — in 11 wells near the mine.

Eventually, most of the affected area residents had to construct new deeper wells to obtain uncontaminated groundwater. The State Mining and Local Impact Fund paid most of the cost of construction of the new wells. Reportedly, 11 of the well owners are in the process of reaching a settlement with the mining company for other losses associated with the incident. Wisconsin's Long Term Liability Act, which did not apply to this situation because of the pre-existence of the mine, would provide for compensation to property owners if a similar situation arose for one of the proposed new mines. Such a situation is unlikely because none of the proposed mines would be developed in aquifers and new laws to regulate metallic mineral mining are now in place.

Abandoned and drainage wells

Well workers mix a cement grout to pour down and seal an abandoned drainage well.

Not so very long ago, a well was something that a landowner laboriously dug with pick and shovel, shoring up the earthen walls as he went deeper and later lining the sides with bricks, boards or stone. More recently, people dug a "well pit" six to 10 feet deep and then drilled a well or drove a "sand point" from there. Temperature in the underground pit remained nearly constant and kept the pump and pipes from freezing in the winter.

Wells of this type are no longer constructed. Many dug in the past have been abandoned, although thousands are still in use. Abandoned wells, if not properly filled, give surface water a direct channel to groundwater. Old dug wells also offer a tempting place to throw all manner of unwanted refuse which can leak and pollute nearby wells. Likewise, well pits — used or unused — tend to fill with water in the spring. If the seal in an abandoned well leaks, bacteria and other contaminants can get directly into a nearby water supply.

In some areas, there are drainage wells that pierce an impermeable soil layer — usually clay — and let surface water drain away directly into the groundwater. These are illegal in Wisconsin.

Example: In early March, 1982, a landowner north of Manitowoc complained he had well water quality problems at certain times of the year. Testing confirmed that his well water was high in both bacteria and nitrates. He first tried chlorinating the water, then drilled a new well down to uncrevassed limestone, but nothing helped. His water remained bad.

The landowner then remembered that a neighbor about a half-mile uphill had installed a drainage well during the 1950s to drain a spot of wet ground (a practice that has been prohibited in Wisconsin since at least 1936). The resident and DNR investigators looked for the well in late March but it was hidden under standing water. When they returned a month later, however, they found that where there had been three or four feet of water, it was now almost completely dry. Following their ears, they discovered a cased drainage well. Water from the area was flowing into it with a sound much like a bathtub draining.

The owner of the land was requested to properly seal the 51-foot deep well. It turned out that the limestone underground was so fissured that the well driller hired to seal it had to first pour in sand to close large cracks before he could pump the casing full of concrete.

1 When rain or snow falls on a corn field, water collects on the surface and flows into rivers or lakes. Some soaks into the ground to become groundwater. And groundwater, in turn, may evantually end up in a stream, well, or lake.

2 The force behind groundwater flow is gravity. Gravity pulls the rain to the earth, then down through fractures and between soil particles.

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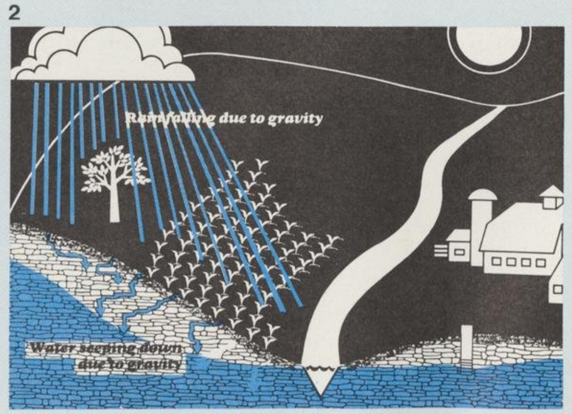

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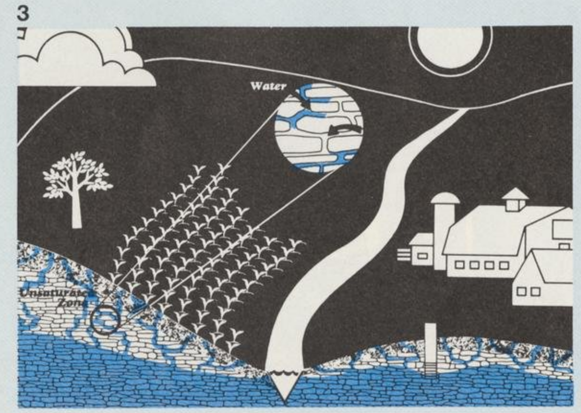

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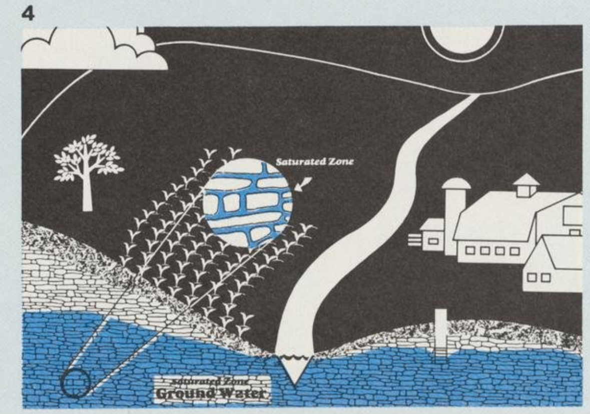


3 The soil nearest the surface contains both water and air in the spaces between soil particles. This is called the "un-saturated zone."

4 When water completely soaks soil or rock and fills all the cracks and spaces, it is called the "saturated zone." The top of the saturated zone is known as the "water table."

Spills and illegal dumping

More than 400 accidental spills of toxic or hazardous materials are reported in Wisconsin every year --- more than one per day. Besides those, an undetermined number of additional spills and illegal dumpings go unreported. Half of the ones reported occur on the ground surface and run the danger of polluting groundwater.

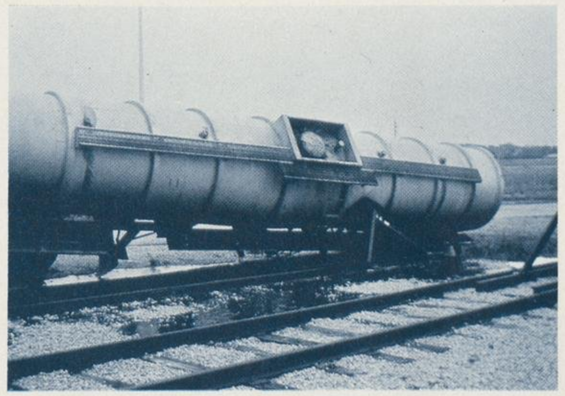
Luckily, many of those spills are small and thus can be cleaned up quickly before much of an unwanted substance penetrates groundwater. But unfortunately, the first people on the scene of a toxic or hazardous spill many times are not trained to deal with it. Too often, their first response is to flush the area with firehoses and dissipate the offending chemical, washing it into the ground and perhaps ultimately into the groundwater.

Sometimes even those who are specially trained to handle spills are hampered. Department of Natural Resources spill coordinators have containment and cleanup equipment, but it's mostly meant to deal with oil spills on surface waters, not toxic chemicals in the ground. Private companies with equipment and expertise that specialize in toxic spills are often precious hours and miles away.

Example: Several Soo Line railroad cars derailed at Beulah Station in Walworth County in July, 1974, one of which contained some 9,000 gallons of liquid phenol (carbonic acid). Some of the chemical was recovered from the tanker, but much leaked into the ground. Within two weeks, seven or eight shallow wells in the area became contaminated.

Ultimately, more than 800 water samples were tested and several railroad cars of contaminated soil scooped up and hauled away. The testing and cleanup involved the combined efforts of no less than six state and federal agencies.

State and federal grants eventually funded a new, $600,000 community water system, including a well drilled into a deep aquifer below the contaminated area. After living on bottled water for 2 1/2 years, 21 families were finally hooked into this water supply system. A jury awarded the town and the individual families $500,000 in settlement for expenses and hardships suffered as a result of the spill, one of the largest legal awards ever in Wisconsin for a groundwater contamination incident.



Contaminants from accidental spills by tank cars or trucks can get into the groundwater unless prompt cleanup action is taken. If the material is toxic people may be harmed and wells rendered useless.

Synthetic chemicals

Scattered across Wisconsin and around the nation, a six-syllable synthetic chemical solvent and several of its kin are turning up in public drinking water supplies.

The chemical, trichloroethylene or TCE, is a common household and industrial solvent used in such everyday products as paint thinners, engine degreasers, dry cleaning fluids, septic tank cleaners and for removing oil and grease from metals before welding.

TCE and similar solvents belong to the family of volatile organic compounds, or VOC's, which means only that they are carbon-based and evaporate readily. For the most part, they mix best with other hydrocarbons like alcohol, oil, grease and fats and so don't dissolve well in water.

But enough manages to mix with groundwater to create the low levels now being found there. In almost all known cases, the quantities are exceedingly minute, often just several parts per billion. TCE is the most commonly found of these VOC's. Although TCE is considered a possible carcinogen, the quantities turning up in Wisconsin wells are thought mostly too small to affect health.

Perhaps most discouraging is the fact that the solvents have turned up in city public water supplies, several with deep wells in deep aquifers previously thought to be completely safe. The discovery is particularly troubling because many new synthetic chemicals, far more than can be assessed for health affects and certified as safe, are introduced each year.

Example: In 1982, DNR sampling of 208 community water wells found that 51 contained detectable amounts of TCE and/or other synthetic chemical compounds. Most are well within safe limits, but water from four communities — Hartland, Delevan, Wausau and Grafton — contained amounts sufficient to warrant closing down the affected wells.

One Hartland well contained the largest amounts, more than double the 45 ppb health advisory level of TCE, plus lesser amounts of similar chemicals. The affected well is one of three comprising the village water system but accounts for two-thirds of the community's total pumping capacity. Only seven years old at the time, it had been constructed in 1974 at a cost of more than $400,000 to village taxpayers. It was expected to last as long as 50 years. Replacing the well today would cost Hartland at least $625,000.

Experiments show that TCE and other synthetic chemicals might be removed from the four communities' water either by filtering it through activated charcoal or aerating it to evaporate the chemical. But both processes are expensive---in excess of $100,000 to $150,000, according to one estimate.

Leaking gasoline and oil tanks

Throughout Wisconsin, underground gasoline or oil-storage tanks installed during the booming road construction era of the 50s and early 60s have now reached, or exceeded, their expected 20 to 30 year lifespan. Some have begun to leak into the soil and contaminate the groundwater. Although many such tanks are checked daily, the disappearing inventory may be so minute that weeks, months or even years may pass without discovery...until finally it shows up in someone's well water.

Fortunately, petroleum products are somewhat cooperative. They tend to attach themselves to soil particles and then stay attached. As long as there is enough oxygen in the soil, certain types of bacteria at shallower depths can work to break down gas and oil. If the leak proves too large for the soil to absorb, whatever reaches the groundwater will concentrate near the top of the water table. Unfortunately, small amounts of gasoline also dissolve in the water and it takes very little to make water totally undrinkable. Larger amounts seeping into wells or basements can become an explosion hazard.

Example: In late January, 1979, 1,200 gallons of gasoline leaked from a 20-year-old underground storage tank at a high school in Door County. The gasoline sank into the area's fractured dolomite aquifer and quickly polluted seven nearby wells. Attempts to pump and purge the wells to rid them of petroleum were unsuccessful.

The school district resolved the incident by removing the ruptured tank and installing new wells for the affected residents.

Then, in April of 1981, a supplier delivering gasoline overfilled the tanks and spilled an unknown quantity on the ground. The area was immediately flushed with water to eliminate any fire hazard. Flushing diluted the gasoline and speeded its migration through the thin Door County soil and into the groundwater. Within a day, three of the new wells just constructed at school district expense were again contaminated with gasoline. A thorough flushing and purging was again tried, but residents were still forced to carry their drinking water for roughly a year and a half before the wells cleared of gasoline. A lawsuit by the three landowners against the school district was ultimately settled out of court.

5 Groundwater moves in around and through sand grains, rock fractures and other obstacles. The flow is very slow.

6 Most often, groundwater follows not a straight-line flow but a tortuous, twisting, complex path. This can make tracking and monitoring the route of pollutants a tricky business.

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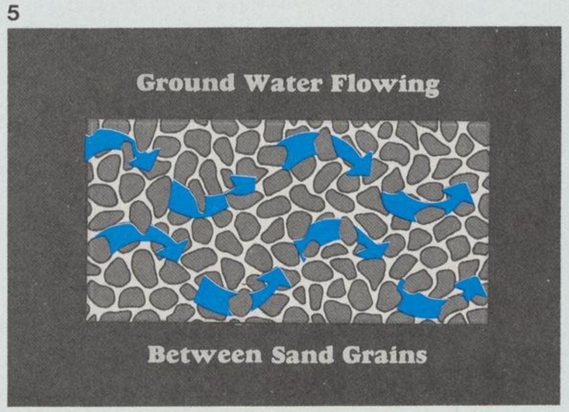

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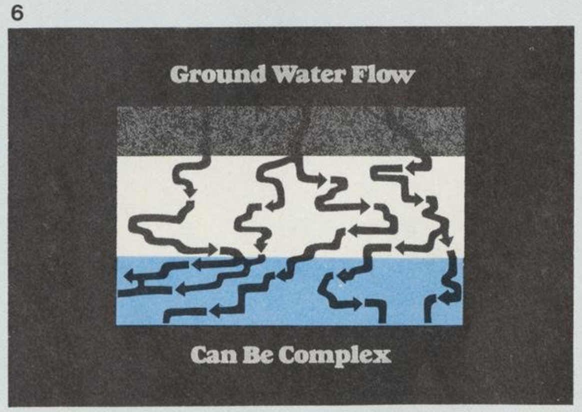

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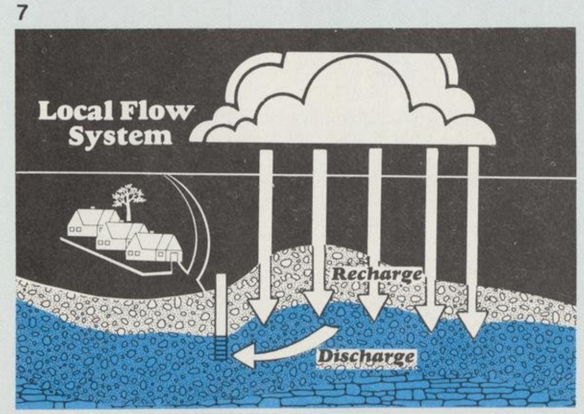

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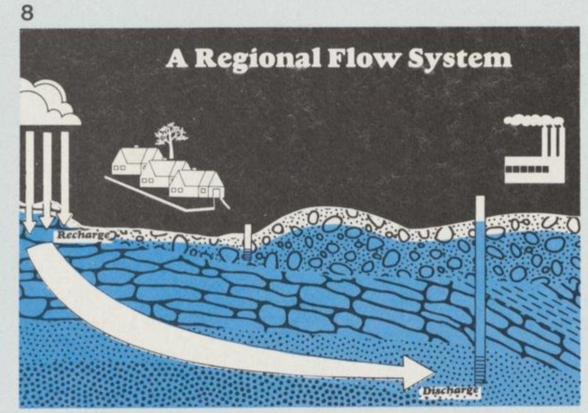

7 Most private, relatively shallow wells are served by a "local flow system," where precipitation falling nearby supplies the aquifer.

8 Many high-output industrial and municipal wells tap deeper aquifers supplied by a "regional flow system." Water may take years to move from the point where it enters the aquifer to where it's pumped out.

Stockpiles and bulk storage

Dump enough of almost anything soluble where rain and snow can wash through it and contaminated groundwater may result unless precautions are taken. In Wisconsin, the stockpiles of salt used to keep winter roads free of ice and snow are the most common example.

If salt is stored in the open or spilled outside, concentrated quantities can pollute nearby wells. Once there, it can make drinking water taste undrinkably salty. It can also pose a health concern to anyone restricted to a low-sodium diet.

Problem is, there are almost no laws or regulations governing how road salt is stored. The Department of Transportation (DOT) contracts with each county for snowplowing and road-salting on state highways. DOT requires and pays for proper storage of what salt the counties use on state roads. But cities, villages and towns can store their own salt however they see fit. Some small, often financially strapped municipalities still dump their salt in a handy vacant lot or parking area — sometimes covered with tarps, sometimes not. Under current laws, the Department of Natural Resources can order correction of these polluting salt piles, but only after local groundwater begins to turn up salty.

Existing regulations cover only wastes generated at the end of a manufacturing process. Few rules govern bulk storage of substances considered either raw materials or finished products, before they've been used for their intended purpose.

Other contaminants

The most routine tests of well water are for bacteria and nitrates. Tests for organic pollutants require special equipment and are very expensive.

Nitrates

A 1979-80 DNR study of 11,396 small public water systems (private wells serving schools, churches, motels, service stations, campgrounds and the like) found that 311 — almost 1 in 40 — contained more than the allowable 10 parts per million (ppm) of nitrate-nitrogen. More than one in three (43%) had detectable levels. Many of the contaminated wells were located in the highly permeable soils of the state's Central Sands region. Problems also exist in the south and west.

Nitrates are not usually harmful to adults or older children. In fact, we consume a great deal every day in our food. But stomach acid is not yet strong enough in some infant's stomachs to prevent growth of certain types of bacteria. In some susceptible babies under six-months old, nitrates can be converted by these bacteria to harmful nitrites. These nitrites can then bind with hemoglobin in the blood to prevent oxygen from getting to the rest of the body. The result is methemoglobinemia which can cause "blue baby symptoms." Although it can be fatal, it is easily treated and there has never been an infant death in Wisconsin related to nitrates in drinking water.

Nitrates get into groundwater from many human-made causes and some natural ones. In areas with permeable, sandy soils or where fractured bedrock is close to the surface, septic tanks are sometimes a source. On the farm there can be problems with animal wastes from feed lots, with improperly constructed or leaking manure storage tanks and pits, and with heavy application of nitrogen fertilizers, especially when excess irrigation water is used.

Even rotting vegetation in soil can add nitrates to groundwater. While any one septic tank or barnyard may add only small amounts, accumulated contributions from many sources can result in high levels.

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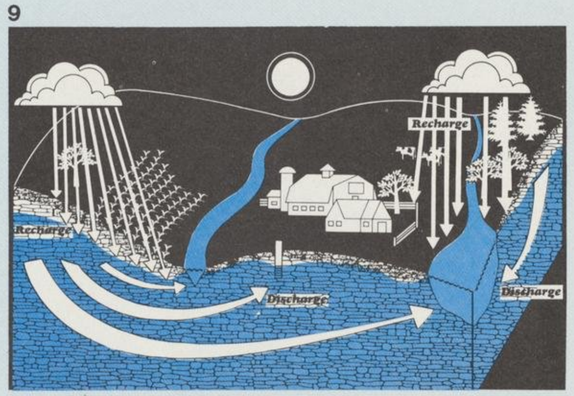

9 Groundwater is "recharged" by precipitation which falls on the earth and moves through the soil to the saturated zone. When this water leaves the ground through a lake, stream or someone's well, it is called "discharge."

10

10 Improperly designed or located septic systems can be a pollution source. Seepage from this septic system recharges the same sand and gravel aquifer that supplies drinking water.

Bacteria

Septic tanks, leaking sewer pipes, feed lots and manure piles or pits, and even the soil are all sources of bacteria that can seep through fractures or channels in rock and get into groundwater. When analysts test water, they look for what are called "coliform" bacteria. Although these microorganisms don't typically cause illness themselves, they indicate that more serious typhoid, hepatitis or other waterborne disease-causing bacteria from human or animal wastes could also be present.

Coliform bacteria are found almost everywhere on the surface of the earth. When they show up in a well or public water system, the fault is often the well, rather than the groundwater itself. The cause is also usually always the same — contaminated surface water getting into what should be a completely closed system.

All wells have a cap or seal at the top of the casing. To be safe, the casing must extend well above the ground surface and be capped there. Wisconsin has a progressive well construction code aimed at minimizing problems.

Example: In 1974, private wells on the public water system in the Village of Rewey began to show high bacteria counts. Although the public well in this southwest Iowa County community served most of the town's 232 residents, some people still drew some water from their own private wells, a few of which were poorly constructed. Some houses were hooked to both wells and the public water system allowing private water from both sources to intermingle within the home's plumbing. These "cross-connections" gave bacteria-laden water from the private wells a direct line into the village system.

Further inspection revealed that one party was running raw sewage from a failing septic system directly into his own well, polluting his own water supply and ultimately the whole town's.

In 1977, the village abandoned all private wells, filled them with concrete and hooked all homes into the public water system. The village's water soon returned to normal, testing bacteria-free.

Natural contaminants

Minerals that exist quite naturally in soils and rocks can and do contaminate groundwater. Nitrate is one of the most widespread natural contaminants but high levels that cause problems are usually human-made. Other natural contaminants such as radium, barium, fluoride, lead, zinc, iron, manganese and sulfur also turn up. Of these, radium has been of concern recently because of its discovery in eastern Wisconsin. It is radioactive and thus poses a risk of cancer, but only an extremely slight one in the amounts present — about the same odds as being struck by lightning.

The problem with many natural contaminants such as iron, sulfate or manganese is not safety, but aesthetics. High levels of iron can stain plumbing fixtures and laundry and give drinking water an unpleasant taste and odor. High levels of iron in drinking water are found in hundreds of places statewide. Occasional excess levels of fluorides, manganese, sulfur and lead are less common and more localized.

Sometimes such off-tastes confuse the issue, making a natural pollutant seem like a human made one. Bacteria that digest iron, for instance, give off as a waste product a harmless slime that can look like a petroleum sheen on well water. It may not only look like gasoline, it can even smell like it.

Example: Excess levels of natural radium have turned up in 11 deep sandstone wells in a narrow 40-mile-wide band of counties extending from Door County south to the Illinois border. All but one contained less than 10 picocuries (a measure of radiation) per liter of water. The federal standard for the radioactive element is five picocuries per liter, a limit based on the amount thought to cause no more than one excess death per year per million people drinking a half-gallon of water each day during a lifetime. It is also roughly equal to the amount of background radiation received daily by Wiscon-

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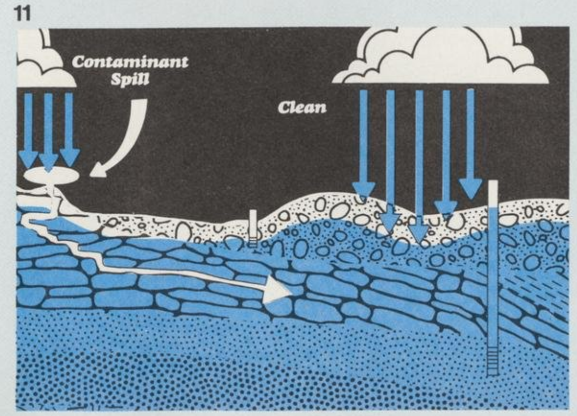

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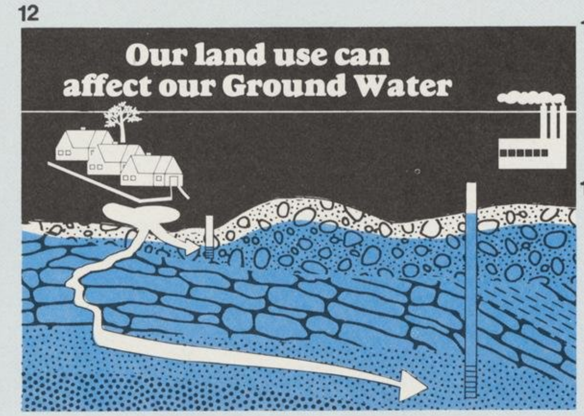


11 Contaminants that are improperly stored, disposed of or accidently spilled, can filter into groundwater as polluted recharge.

12 Because surface activities affect groundwater, we must plan land use practices carefully. An aquifer is even more difficult to clean than a lake or river and must be managed differently.

sin residents.

Barium is another naturally occurring contaminant. It is known to be present in some deep wells along the Wisconsin-Illinois border. In 1979, one community water system in Walworth County found levels slightly higher than the one part per million drinking water standard in a new well. Continued pumping resulted in a drop to acceptable levels, however. Elevated levels of barium are linked to high blood pressure and heart attacks.

Both radium and barium are chemically similar to calcium and can thus be easily removed with conventional water-softening equipment. Disposal of the waste, though, can be a problem.

When a threat becomes a reality

Dealing with contaminants once they get into the groundwater is no small feat. First, you have to know what they are.

Even if you already know what's there, sometimes it's nearly impossible to figure out where the contamination is coming from. In 1982, 28 Wisconsin communities found detectable amounts of trichloroethylene (TCE) and/or other organic solvents in their community water supplies. In some cases, the sources of the contaminants may never be found.

Even when the number of potential sources is limited, it can take a tremendous effort to pinpoint the single source. When gasoline is discovered in well water, for instance, it may take days or weeks for investigators to figure out which of perhaps a half-dozen or more buried gas tanks in the area is the culprit. Isolating the source of a groundwater contaminant is a complicated process that involves a combination of chemistry, hydrogeology and good old-fashioned trial-and-error sleuthing to eliminate sources that aren't contaminating, then zeroing in on the ones that might be.

Even then, it may be impossible to prove in a court of law that the suspected source really is responsible and should pay for the clean up. The process of elimination is not legal proof. And the stakes are high, because while it's sometimes possible to remove contaminants from groundwater, it's always expensive to try.

A case in point will illustrate.

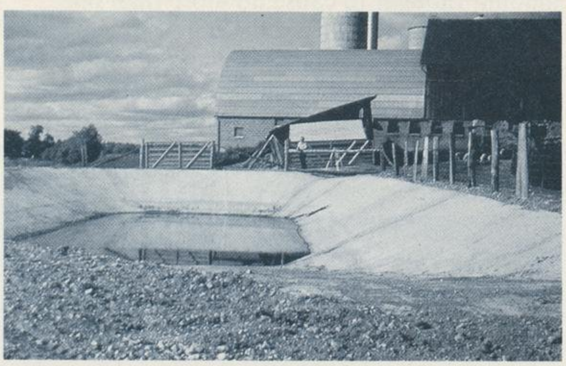
When a tank truck overturned east of Madison, it dumped more than 7,000 gallons of gasoline onto the ground. A professional fuel recovery team moved in quickly, got to work and eventually retrieved perhaps as much as 95% of the gas. The dealer was lucky — the soils at the site were clayey and the gasoline spread out over only a half-acre. Despite such "nearly ideal" conditions, the response team found it necessary to construct more than 180 recovery and monitoring wells. Costs to the gasoline dealer exceeded $40,000.

In cases where no responsible party can be found, such bills might fall to state and local taxpayers. But worse, in many cases costs are incurred by individuals who must dig into their own pockets to pay for alternate water supplies. Often when a landowner's well gets polluted the contamination is confined to upper layers of a shallow aquifer. To restore a supply of clean water it is often possible to drill an existing well deeper to get below the pollutant into an uncontaminated water supply. But it's a costly process. Well drilling costs can run $15 per foot or more and reaching an uncontaminated aquifer can mean drilling hundreds of feet deeper.

Prevention

GROUNDWATER
Wisconsin's
buried treasure

PROTECTING THE RESOURCE



When manure pits are installed in permeable soils, cement lining can prevent the leakage of pollutants to groundwater.

Nearly everyone agrees that it is more economical and efficient to prevent groundwater deterioration than to try to clean it up. The technology for cleanup is expensive and unproven. The potential costs of damaged health, degraded property values and limited economic development that can result from contaminated water are incalculably high.

What can be done to prevent groundwater pollution? The answers are as variable as the pollution sources.

Wisconsin already has many regulations that protect groundwater. DNR and other agencies make rules that affect at least a dozen groundwater related activities. For example, no one may dispose of wastes by pumping them down a well (injection). Septic systems may only be put in by licensed installers. The soil must be tested first to make sure the system will work and a permit must be granted by the county inspector. Many other rules exist that protect the health of water users. Existing regulations are continually reviewed, expanded, and strengthened to include new technologies.

Some potential pollution sources like mines and landfills are easy to pinpoint. Others, like fertilizers and pesticides, animal wastes and road salt are everywhere. This "non-point source" pollution is a problem with groundwater just as it is with surface water. Both are difficult to control.

New sites for disposal of mining wastes and solid and hazardous wastes must meet strict standards. Their design must keep water from leaching toxic and harmful elements into the groundwater. The groundwater must be monitored through wells to determine if leachate is escaping.

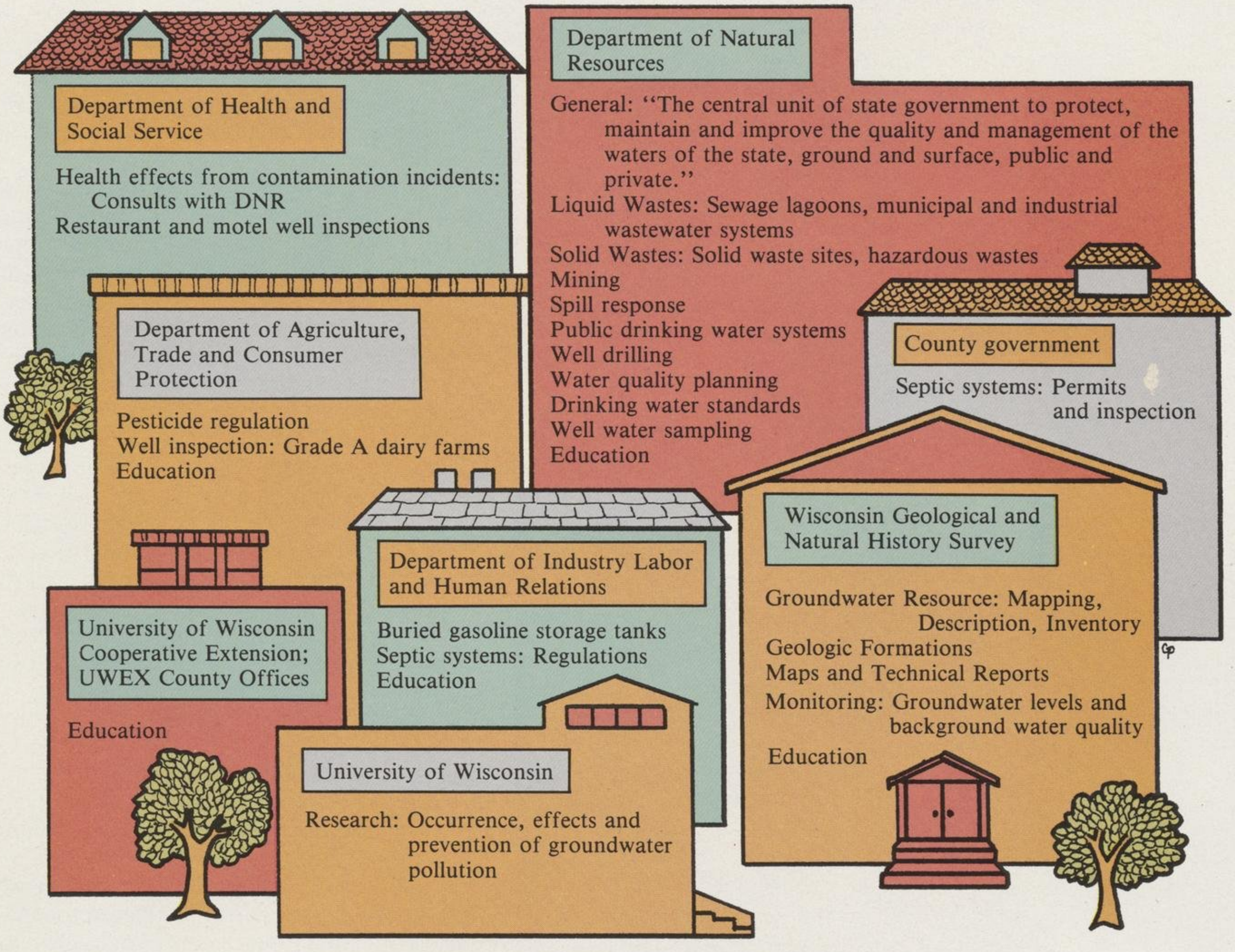
But the widespread nonpoint pollution sources pose hard problems. Fertilizers and pesticides, animal wastes and road salt are handled by many thousands of people over hundreds of thousands of acres of land. They offer many chances for pollution.

Technology can provide some answers. Agrichemical companies can test products to identify drinking water hazards. They can establish the most efficient rates and times of application and even indicate soil and bedrock types where the chemicals should not be used.

Animal waste holding tanks can be engineered to minimize leaks or overflow. Salt truck sprayers can be calibrated and new mixtures formulated to reduce amounts needed to make the roads safe. Some research indicates that calibration can save significant amounts of money by eliminating waste. Or, sand can be substituted, as some Wisconsin communities are doing.

Preventing pollution through technology is easier and cheaper than trying to clean up groundwater after it has been contaminated. But technology is expensive, and it won't work if people don't use it. Getting companies and individuals to invest in prevention requires regulations, standard setting, enforcement, economic incentives, disincentives and a variety of other techniques that influence the way people use the resource. Actually doing it means weighing the benefits of protecting the resource against the costs of restricted freedom and required expenses.

Who's in charge of groundwater protection?



Source. Groundwater Management in Wisconsin: A Background Report Staff Brief 82-4, Wisconsin Legislative Council Staff, April 20, 1982

Groundwater law

Most state laws to protect the environment developed historically as the need arose. Case histories of battles for surface water rights are voluminous in Wisconsin and the laws are more or less concrete. But Wisconsin has largely been spared the wars that established strict rights for underground water. These battles, some involving violence, took place in the western states. Legal fights for groundwater in Wisconsin have so far been relatively infrequent and peaceful. The Legislature has passed few laws directly governing Wisconsin's groundwater. In addition, while the courts have settled a number of local disputes over groundwater rights, there is limited case law on the issue.

The law requires DNR to specify methods of obtaining public and private water supplies to protect public health and welfare. In some instances, DNR may be able to prosecute those who pollute groundwater. Where DNR is unable to act, individuals may sue polluters for creating a nuisance and may obtain an injunction and monetary damages as compensation. If several people are affected, the state may institute a public nuisance action against an alleged polluter.

When a well is constructed, the state well code sets standards for location, depth, pump installation and other details.

Wisconsin laws governing the right to use groundwater are not specific. A landowner is guaranteed the right to use groundwater under his or her land to meet personal needs, unless the withdrawal causes unreasonable harm to another through lowering the water table or reducing artesian pressure.

But what about extra groundwater? Who has the right to draw groundwater under your land that you don't need? There are no specific statutes in Wisconsin law stating who has groundwater rights, how groundwater should be divided among users or who has the first right to water under a particular parcel of land. The major exception is that DNR must guarantee adequate public drinking water supplies in considering applications for high-capacity wells (those capable of pumping in excess of 70 gallons per minute).

Rules on installation of septic systems are stringent to prevent effluent from contaminating groundwater.

One might reasonably think that it doesn't really matter. No one can remove your groundwater if they don't sink a well on your property. Right? Not exactly! The level of groundwater in the water table changes as groundwater is pumped to the surface. When a well is pumped the surrounding water is drawn towards the well. As more and more water is removed by pumping, the water table drops to form a funnel-shaped cone around the well.

This cone not only gets deep but it fans out laterally drawing water toward the well from a wider and wider area. Water specialists call this phenomenon a "cone of depression." It varies in size depending on the well capacity and the nature of the aquifer. In theory, the cone of depression will get bigger and bigger until the amount of water entering the funnel matches the amount drawn out at the pump.

In rural Wisconsin, wells are usually spaced far enough apart so the cone of depression from one well doesn't affect another and doesn't lower the regional water table significantly.

But high-capacity wells for city water supplies, irrigation or industry can form wide or deep cones of depression. If high-capacity wells in less productive aquifers are placed too close together, their combined cones could drop the water table locally, even drying up some shallower wells.

State law requires DNR to review applications for all high-capacity wells and decide whether a new one will cause a cone of depression that will "adversely affect" a nearby public water supply.

A private well owner who feels that a high-capacity well is decreasing his or her water supply must bring the high-capacity well owner to court. Then a judge decides who's liable among competing water users.

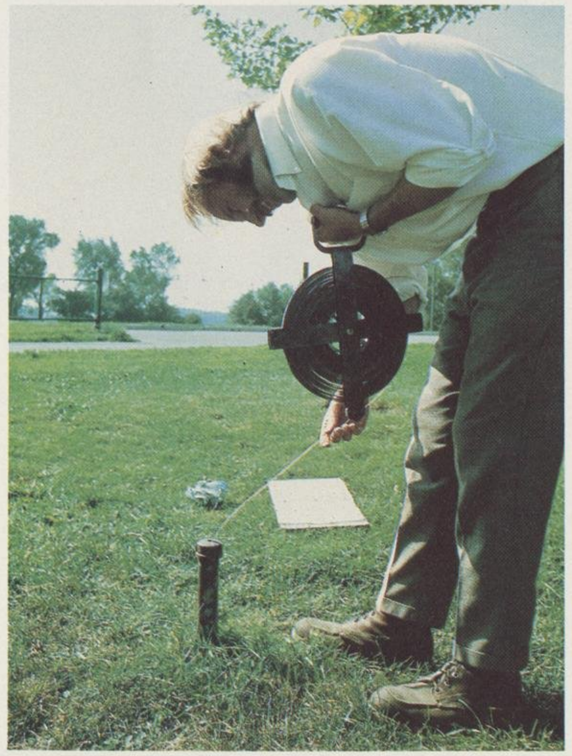
Under a 1974 Wisconsin Supreme Court ruling (State v. Michels Pipeline Construction, Inc.), if a property owner constructs a well that significantly reduces a neighbor's water supply, the neighbor may seek relief in court.

Such cases in Wisconsin are unusual because the state is blessed with such vast groundwater reserves. Problems, however, have arisen in the Milwaukee and Green Bay areas where heavy municipal and industrial use caused cones of depression that affected neighboring wells.

But even a 100% increase in Wisconsin water use by the year 2000 wouldn't seriously deplete the overall supply. The principal difficulties with substantial groundwater use hit the wallet harder than the well. It's expensive to keep drilling deeper, pumping harder and piping further to meet needs.

Groundwater that is both clean and convenient is important to Wisconsin homeowners, industry and agriculture. With reasonable care it does not appear that the well will ever run dry. Protecting groundwater's purity, however, is another matter. It will require constant vigilance.

▲ Early groundwater law was based on a limited understanding of groundwater. Many believed that springs came from underground streams.



Measuring water levels can be used to determine the direction of groundwater flow—a key step in determining the source of pollution. ◀

Managing the resource

It is relatively easy to agree in theory that groundwater is a precious resource that must be protected from significant degradation. But in practice, many questions and conflicts arise. How much degradation is "significant?" How contaminated must the groundwater be before enforcement restrictions take affect? Is it "fair" if the state or local government prohibits a farmer from spreading pesticides, or a developer from installing septic systems to protect the groundwater? How much of a safety factor should there be in setting public health standards? Where and how intensively should sampling occur to monitor problems?

When it rains, contaminants introduced at the land surface—from excess lawn fertilizer to road salt—can be carried through the soil to groundwater.

Setting standards

Setting numerical standards for contaminants means first selecting the most important substances for review and testing them for effects on humans and animals.

We have known for many years for example, that coliform bacteria in drinking water are cause for concern, so standards have been set to protect people. Likewise, the federal Environmental Protection Agency has established limits for 16 organic and inorganic toxic chemicals. At this writing, this is a very small number, considering that we use more than 37,000 chemicals currently in our homes, businesses and agriculture.

Setting standards means making some judgment about how much of each substance is too much. Such judgments weigh the best available evidence about risks against the benefits of using the substance and the costs of not using it. The chemical industries and users, environmental organizations and the public all contribute their perspectives to the standard setting process.

People are the key

Individual people make decisions, take actions and spend time and money on the activities that cause groundwater contamination. One way to protect groundwater is to tell people about the problems they themselves might cause, and rely on their volunteer efforts to do things right. This approach gives maximum respect to individual rights and freedoms, but may protect the resource in only a limited way. Another approach is to offer financial rewards like grants or tax deductions to people who upgrade manure pits, improve junk yards and take other action to help protect groundwater.

The opposite is to collect extra taxes, fees or penalties from those who own or oversee pollution sources. Passing laws and regulations is relatively effective in protecting the resource. But this path causes the most controversy because it involves balancing the personal and property rights of the individual against the public welfare.

Local land use zoning is already used in some other states to protect groundwater recharge areas for municipal wells. Should city, town or county governments prohibit some potentially harmful activities in order to protect groundwater? If so, has government unjustly taken away someone's property rights and lowered property values? This approach poses difficult questions but it is one being tested in some Wisconsin counties that fear groundwater contamination.

Wisconsin has a well-developed process of public hearings, citizen involvement and political review for making judgments like the ones involved in groundwater management. We are also a state whose citizens and government work hard to give the environment equal weight and power against private and corporate interests. Developing management programs for groundwater will require many months or years of negotiation and compromise.

We have a responsibility to make pure drinking water a heritage for the future.

Cleanup

Groundwater contamination is often detected by water testing or by foul odor and taste. To counteract it, we try to track down and stop the source of contamination and establish a new drinking water source if necessary. State agencies have authority in some cases to investigate, order repairs, supervise cleanup and sometimes to send the bill to those responsible. These solutions cost money but they deal with the problem. Such incidents also demonstrate the need for a comprehensive groundwater policy and management plan.

"Cleanup," however, may be too optimistic a term for groundwater contamination. Since groundwater moves very slowly and in the tiny spaces between soil particles and rock crevices, groundwater contamination is virtually impossible to correct. Even when it can be corrected, it is very difficult and costly.

One technique is to drill a "recovery" well. The contaminant seeps in with the groundwater and is pumped out and treated. Another approach is to restrict use of the aquifer until natural dilution and organic processes purify the water. These processes are usually slow, expensive and dependent on a knowledge of site hydrogeology that may not exist.

Who pays the bill for cleaning up the groundwater? Who pays for the cost of repairing the facilities, drilling and casing deeper wells, extending municipal water lines and pumping out a recovery well? Who is responsible for medical bills and livestock replacement resulting from contaminated groundwater?

The logical one to pay the bill is the owner or operator of the contaminant source. When a gasoline truck overturns, spill cleanup costs are sent to the owner. In the case of orphaned or abandoned dump sites, however, the original owners may be bankrupt, out of business, disappeared or dead. Specific individual sources of some groundwater contaminants, like sewage, may be impossible to isolate. Locating the farmer or landowner who is misapplying fertilizers or pesticides is also nearly impossible.

Lawsuits and court decisions will help determine responsibility for compensation and cleanup costs. But these will take years to settle. One alternative is a state "superfund" modeled after the federal fund that resulted from New York state's Love Canal chemical dump. Investigation, cleanup and compensation costs can be paid more quickly from a public fund. Money sources, equitable pay-out procedures and recovering funds from liable parties are problems faced by a public fund approach.

Continued on page 30.

Top: These wells were installed at a spill site near Madison for recovery of gasoline in the groundwater. In many cases, though, restoration of groundwater quality isn't technically or economically feasible.

Bottom: An air stripping tower bubbles well water over a series of baffles, aerating it to evaporate off TCE and other volatile organic chemicals.

Glossary

Aquifer: A rock or soil strata capable of storing, transmitting and yielding water to wells.

Artesian: A condition referring to groundwater under sufficient pressure to rise above the aquifer containing it. Sometimes it produces flow at the surface.

Coliform Bacteria: A group of bacteria whose presence in well water may be evidence of contamination by surface water. Presence of coliform bacteria is an indication that the water should not be consumed.

Dolomite: A rock (calcium magnesium carbonate); a common rock-forming mineral. Many rocks in Wisconsin generally referred to as limestone are actually dolomite.

Esthetic Contaminant: A substance that gives water an objectionable appearance, taste or odor, but which does not by itself present a threat to health.

Evaporation: The process by which water is changed from a liquid or solid into vapor. In hydrology, evaporation is vaporization that takes place at a temperature below the boiling point.

Evapotranspiration: Water returned to the atmosphere by evaporation from water and land surfaces, and by the activity of living plants.

Geology: Science dealing with the origin, history, materials and structure of the earth, together with the forces and processes operating to produce changes on the earth's surface and within it.

Glacial Drift: Sediment transported or deposited by glaciers or the water melting from a glacier.

Groundwater: Water beneath the surface of the ground in a saturated zone.

Hardness: Dissolved calcium and magnesium salts in water; compounds of these two elements are responsible for most scaling in pipes and water heaters. Hardness is usually reported as milligrams per liter (mg/l), zero to 60 mg/l is soft, 61 to 120 mg/l is moderately hard, 121 to 180 mg/l is hard and more than 180 mg/l is very hard water. For household water softening, it is usually expressed as grains per gallon.

Hydrogeology: The study of groundwater and its relationship to the geologic environment.

Hydrologic Cycle: The complete cycle of phenomena through which water passes from the atmosphere to the earth and back to the atmosphere.

Hydrology: The science encompassing the behavior of water as it occurs in the atmosphere, on the land surface and underground.

Impermeable: Having a texture that does not permit water to move through it perceptibly under the pressure differences ordinarily found in subsurface water.

Infiltration: The movement of water into and through a soil.

Leachate: A solution obtained by water percolating through soluble waste material. Leachate from a sanitary landfill is mineralized liquid with a high content of organic substances.

Limestone: A sedimentary rock consisting chiefly of the mineral calcite (calcium carbonate).

Mg/l: Milligrams per liter, approximately equal to parts per million (ppm).

Parts Per Million (ppm): A common basis of reporting water analysis. One part per million (ppm) equals one pound per million pounds of water.

Permeability: The capacity of rock or unconsolidated material to transmit a fluid, usually water.

pH Value: A measure of alkalinity or acidity. Numbers below 7.0 indicate acidity, which increases as the number becomes smaller. Numbers above 7.0 indicate alkalinity, which increases as the number becomes larger. The pH scale runs from 0 to 14, 7.0 being the neutral point.

Pollution: The process of contaminating air, water and land with impurities to a level that is usually undesirable and results in a decrease in usefulness of the environment for beneficial purposes.

Saturated Zone: That part of a water-bearing material in which all voids, large and small, are filled with water.

Septic Tank: A sewage settling tank in which organic solids are separated from wastewater flowing through the tank. The solids in the settled sludge on the bottom of the tank are decomposed by bacterial action and the overflowing wastewater is dispersed into the soil through a lateral, subsurface drainage field.

Spring: Natural discharge of groundwater at the surface.

Water Table: The level below which the soil or rock is saturated with water, sometimes referred to as the upper surface of the saturated zone.

Well: A vertical excavation that taps an underground formation; in Wisconsin, usually to obtain a source of water, to monitor the quality of the groundwater or to determine the position of the water table.

Your Well

"Do's and Don'ts." What to do to avoid problems. What to do if problems arise.

Where to put your well

The Wisconsin well code was established in 1936 and is administered by the Department of Natural Resources. If a well is properly located and constructed and if pumping equipment is properly installed, the well should provide safe water continuously and protect users from contamination. You should adhere to the code and follow pertinent local zoning ordinances.

Wells can no longer be constructed in a crawl space under a building or in a basement unless the basement is of the walk-out type.

Always locate wells up the groundwater gradient and as far from potential sources of contamination as possible. Potential sources of contamination include septic tanks, sewage drainfields or dry wells, sewer lines, farm feed lots, animal yards, manure stacks, silos, buried fuel tanks, liquid fertilizer and pesticide storage sites, sludge disposal sites, lakes or streams, in-ground swimming pools, cemetery grave sites, wastewater lagoons, treatment ponds, or waste disposal sites and proposed or existing landfills. Check DNR's well code for the separating distances required between these and other sources of contamination.

Who can construct wells?

Wells may be drilled only by persons registered with DNR and holding current well driller permits, commonly called licenses. No license is required to construct a driven point well.

Pumps may be installed only by persons holding DNR pump installer permits (licenses). No license is required if you construct your own well or install your own pump. However, state law requires that this work be done according to the state well code.

The well driller's responsibility is to 1) flush the well, 2) test pump it, 3) disinfect it, 4) collect a water sample for bacteriological tests, and 5) send a well constructor's report to DNR and provide the owner with a copy. A pump installer, if different from the driller, must disinfect the well and collect a water sample to check for bacteria.

What if my well is contaminated?

If bacterial contamination occurs, check the system over for sources such as flooded well pits, broken seals, improperly abandoned wells in the area, especially old dug wells, quarries, and any physical changes to the surrounding lands, or potential spills or dumping of wastes.

Wells can be disinfected by 1) displacing all the water in the well with a mixture of bleach (containing at least 5% chlorine) and water or, 2) dropping chlorine tablets or powder down the well. Constant chlorination is prohibited; the well must be replaced or reconstructed instead.

In an emergency, you may purchase bottled water or haul it from a known safe source, like a nearby municipality.

If high nitrates are the problem, well construction and location should be checked. Find a source of low nitrate water for infants under six months old.

Wells can sometimes be deepened to bypass the contamination

An inadequate well installation can sometimes be upgraded. For example, wells located in pits can be extended above ground and the pit filled in.

Who can test my well water?

Write the:
State Laboratory of Hygiene
456 Henry Mall
Madison, WI 53706

Ask for a drinking water test kit. Accompany your request with a check or money order made out to the State Laboratory of Hygiene.

The 1983 cost is $4.00 per item checked. The lab can test for bacteria, nitrate or fluoride. All three tests can be made from the same bottle of water. Tests for other types of contamination can only be performed for a homeowner at a private lab.

For more information contact the DNR Private Water Supply Specialist at any of the six District Headquarters.

DNR North Central District
Box 818, Schiek Plaza
Rhinelander, WI 54501
(715)362-7616

DNR Northwest District
Box 309, Hwy. 70
Spooner, WI 54801
(715)635-2101

DNR Southeast District
2300 N. 3rd Street
Milwaukee, WI 53212
(414)257-6543

DNR West Central District
1300 W. Clairemont Avenue
Eau Claire, WI 54701
(715)836-2821

Regulations on well construction are designed to prevent contamination and assure a safe water supply.

DNR Lake Michigan District
Box 3600, 1125 N. Military Avenue
Green Bay, WI 54303
(414)497-4040

DNR Southern District
3911 Fish Hatchery Road
Madison, WI 53711
(608)266-2628

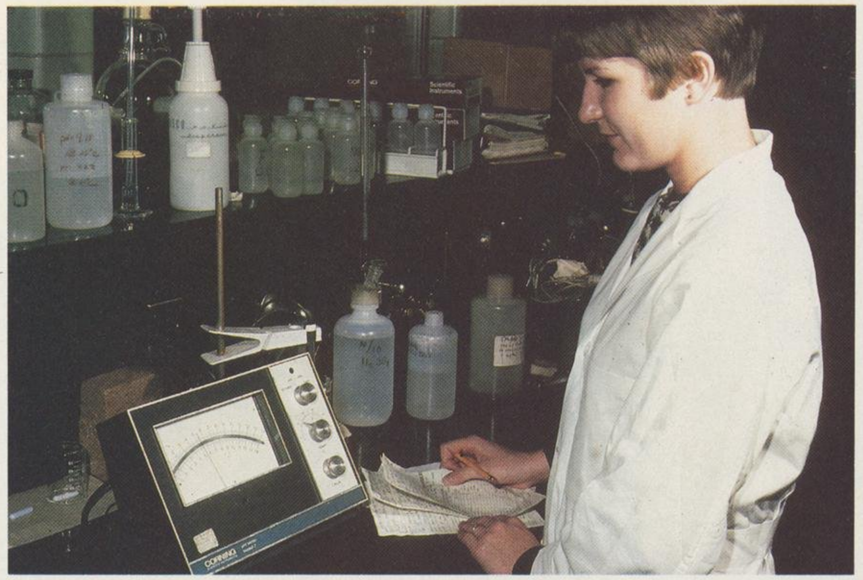
For further information on groundwater, contact:

1. The Wisconsin Department of Natural Resources, (District office addresses are listed opposite.)
2. The Wisconsin Geological and Natural History Survey, 1815 University Avenue, Madison, WI 53706
3. Your county University of Wisconsin Extension Office.

Protecting the resource *continued from page 26.*

Developing an information base

New testing technology will continually improve our understanding of groundwater quality.



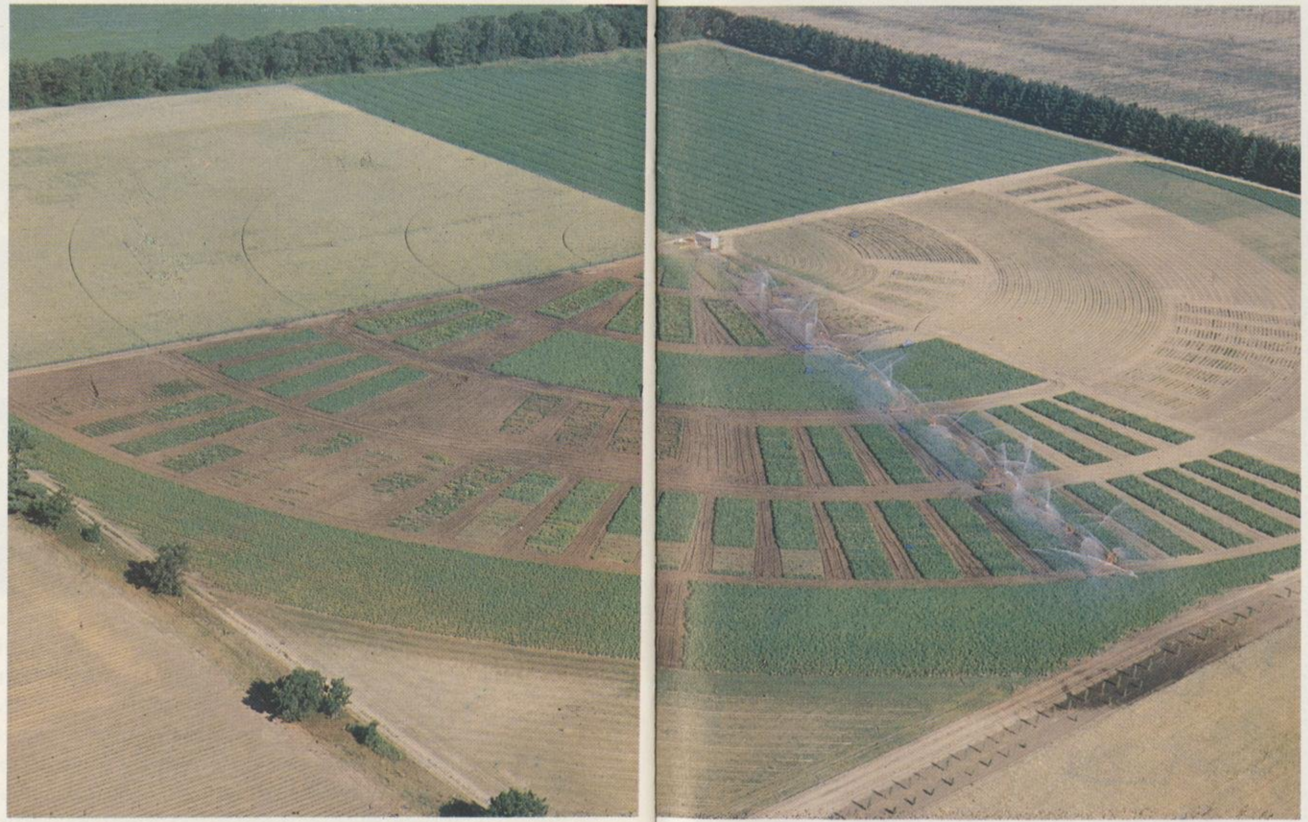
When you manage a family budget, you can do a better job if you know what your income and what your bills will be. The same is true in managing and protecting the groundwater. DNR, the Wisconsin Geological and Natural History Survey, the US Geological Survey and other agencies have collected information from well drillers and samplers for many years. When merged with new groundwater data and properly organized and computerized, this existing information could provide a better picture of the resource. In the Central Sands area, the data is being used to map groundwater systems, identify basins and chart flow directions. Studies there are also detailing the fate of various potential pollutants once they hit the ground. Both projects need to be expanded statewide. Also needed are maps showing locations in Wisconsin that are most susceptible to groundwater pollution. The places where groundwater is threatened vary, and since well drilling, sampling and monitoring are very expensive, agencies have set priorities on where and when the various studies will take place.

Wisconsin must identify and list potential sources of pollution like old dumps, abandoned underground storage tanks and closed mines.

Research

Recent advances in testing equipment made possible the detection of contaminants at levels of only a few parts per billion. More work is needed on these testing technologies. Research is needed on health effects, contamination potential and breakdown rates of fertilizers and pesticides, as well as rates and timing of application.

Irrigation studies will identify how much water is needed for best plant growth and how to keep water use to a minimum. These will not only help groundwater but also save the farmer money. Our understanding of groundwater quality, protection techniques and contaminant transport through soils is still primitive and fragmentary. Safer and more economical design and construction of waste handling facilities also take study. Limited money for research must be allocated very carefully to the most serious problems and research will have to directly deal with solving those problems.



Irrigation studies identify how much water is needed for best plant growth and to keep water use at a minimum.

Information and education

Decisions which can result in groundwater pollution or protection are made by individual human beings. They decide to install the septic tank, drill the well, turn on the irrigation sprayers, start a feed lot, build a gasoline station, change or upgrade an industrial process and dozens of other activities.

People can make better decisions if they understand the impact of various actions and know where to go for help. A worker who installs and builds groundwater-related equipment, can do the job better with training in the latest techniques. People can watch out for illegal waste dumping and chemical spraying, spills and well contamination. All the state agencies involved in groundwater management are responsible for providing information to the public on their own programs as well as technical training to workers like well drillers, pesticide applicators and soil testers. A broad education program which addresses general questions and assists the public in becoming involved in decision-making is essential.

Prevention, management cleanup, knowledge base, research and education are some of the tools of groundwater protection. Many state and local interests and agencies need to cooperate. People getting involved — as citizens, agency staff, political leaders and industry representatives — will supply the energy to make the tools and set them to work. A start has been made. But where do we go from here?

Left: Researchers test aldicarb levels in an irrigated plot.

Right: Education on groundwater flow and quality will allow better management and prevent contamination.