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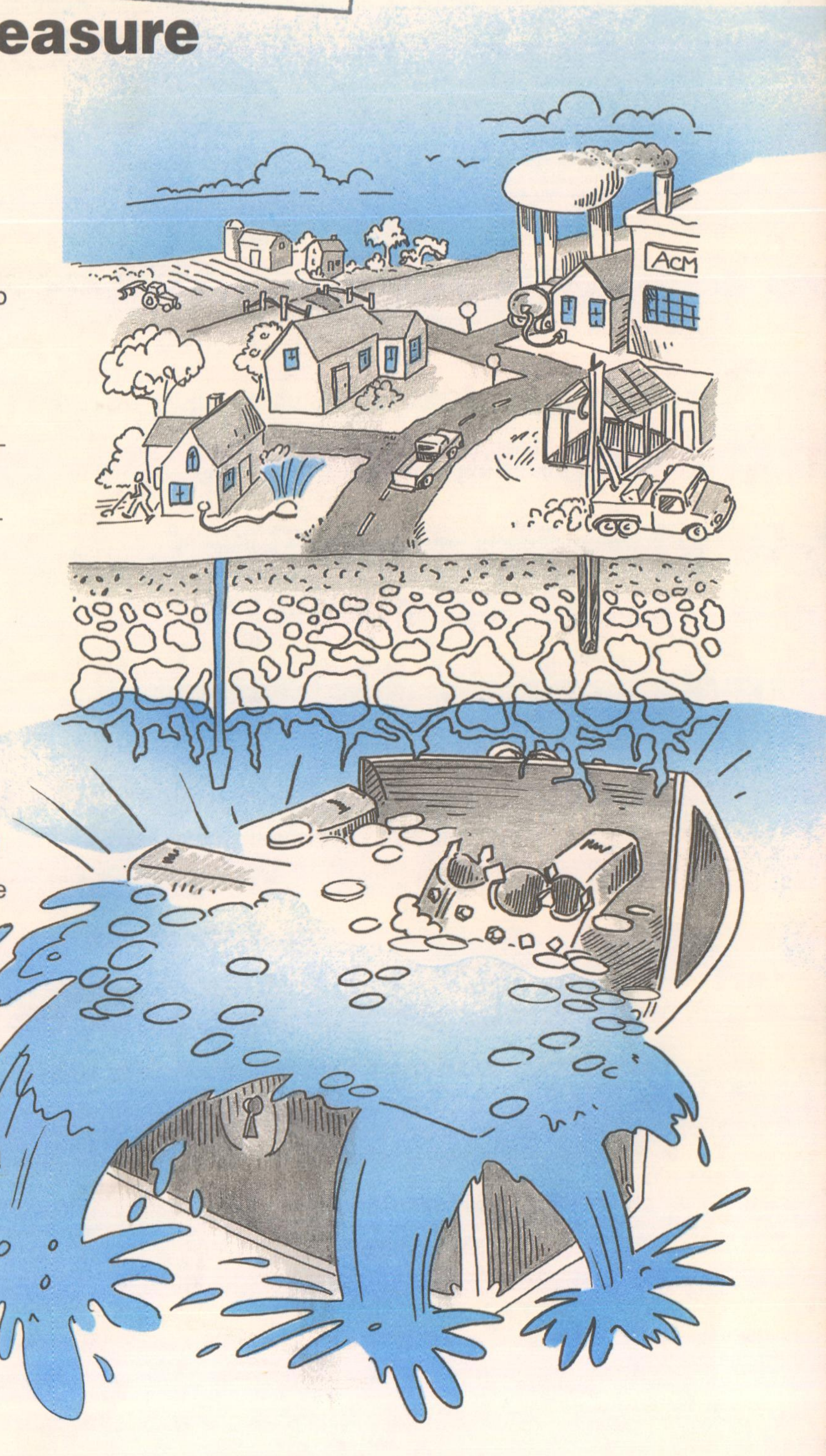
5
Water

Fact Sheet

Groundwater – Nature's Hidden Treasure



What goes down, must come up

Groundwater is an essential and vital resource for about a quarter of all Canadians. It is their sole source of water for drinking and washing, for farming and manufacturing, indeed, for all their daily water needs. Yet for the majority of Canadians – those who do not depend on it – groundwater is a hidden resource whose value is not well understood or appreciated.

Our image of Canada is of a land of sparkling lakes, rivers and glaciers. Groundwater, which exists everywhere under the surface of the land, is not part of this picture. Not surprisingly, therefore, concerns of Canadians about water quality focus primarily on surface waters – our lakes and rivers. The less visible, but equally important, groundwater resources have received less public attention, except in regions of Canada where people depend on them.

Groundwater needs protection

In recent years, however, a number of events affecting groundwater quality have contributed to a heightened public awareness and concern about the importance and vulnerability of the resource. Media reports about the contamination of wells from leaking gasoline storage tanks or dry cleaning solvents, and about the effects on groundwater of chemical leakage from landfill or industrial waste disposal sites have raised public concerns about groundwater quality. Early in 1990, chemical seepage, caused by the tire fire at Hagersville, Ontario, threatened to pollute groundwater supplies in that region. Newspaper reports alerted area residents and helped focus attention on the problem of groundwater pollution.

Even where we might not use it directly as a drinking water supply we must still protect groundwater, since it will carry contaminants and pollutants from the land into the lakes and rivers from which other people get a large percentage of their freshwater supply.

Canada

Groundwater and geology

Groundwater is also important quite apart from its value as a resource or its close connection with surface water supplies. Engineers must consider groundwater when planning almost any kind of structure, either above or below the ground. Ignoring the effect of groundwater on slope stability can be both costly and dangerous. Geologists see groundwater as a major force in geological change. The fluid pressures exerted by groundwater, for example, play an important role in the occurrence of earthquakes. Geologists also know that the movement of water through underground geologic formations controls the migration and the accumulation of petroleum and the formation of some ore deposits.

What is groundwater?

It is sometimes thought that water flows through underground rivers or that it collects in underground lakes. Groundwater is not confined to only a few channels or depressions in the same way that surface water is concentrated in streams and lakes. Rather, it exists almost everywhere underground. It is found underground in the spaces between particles of rock and soil, or in crevices and cracks in rock (Figure 1). The water filling these openings is usually within 100 metres of the surface. Much of the earth's fresh water is found in these spaces. At greater depths, because of the weight of overlying rock, these openings are much smaller, and therefore hold considerably smaller quantities of water.

Groundwater flows slowly through water-bearing formations (aquifers) at different rates. In some places, where groundwater has dissolved limestone to form caverns and large openings, its rate of flow can be relatively fast but this is exceptional.

Many terms are used to describe the nature and extent of the groundwater resource (Figure 2). The level below which all the spaces are filled with water is called the *water table*. Above the water table lies the *unsaturated zone*. Here the spaces in the rock and soil contain both air and water. Water in this zone is called *soil moisture*. The entire region below the water table is called the *saturated zone*, and water in this saturated zone is called *groundwater*.

What is an aquifer?

Although groundwater exists everywhere under the ground, some parts of the saturated zone contain more water than others. An *aquifer* is an underground formation of permeable rock or loose material which can produce useful quantities of water when tapped by a well. Aquifers come in all sizes. They may be small, only a few hectares in area, or very large, underlying thousands of square kilometres of the earth's surface. They may be only a few metres thick, or they may measure hundreds of metres from top to bottom.

Groundwater – Always on the move

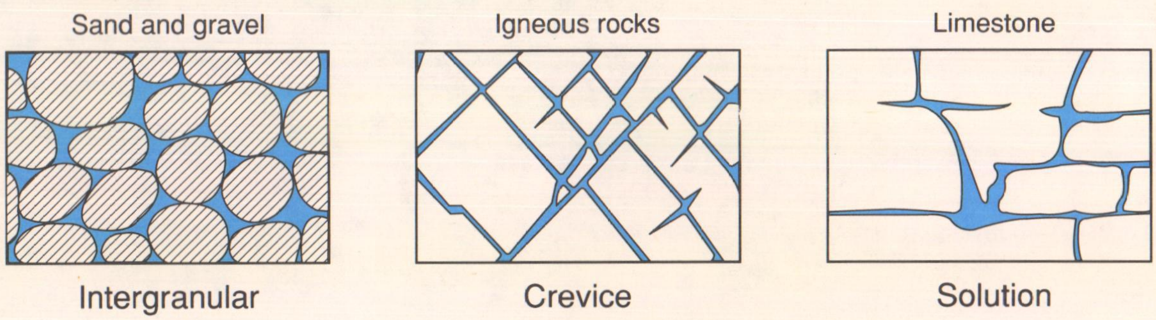
Permeable material contains interconnected cracks or spaces that are both numerous enough and large enough to allow water to move freely. In some permeable materials groundwater may move several metres in a day; in other places, it moves only a few centimetres in a century. Groundwater moves very slowly through relatively *impermeable* materials such as clay and shale.

Groundwater scientists generally distinguish between two types of aquifers in terms of the physical attributes of the aquifer: porous media and fractured aquifers.

Porous media are those aquifers consisting of aggregates of individual particles such as sand or gravel. The groundwater occurs in and moves through the openings between the individual grains. Porous media where the grains are not connected to each

Figure 1

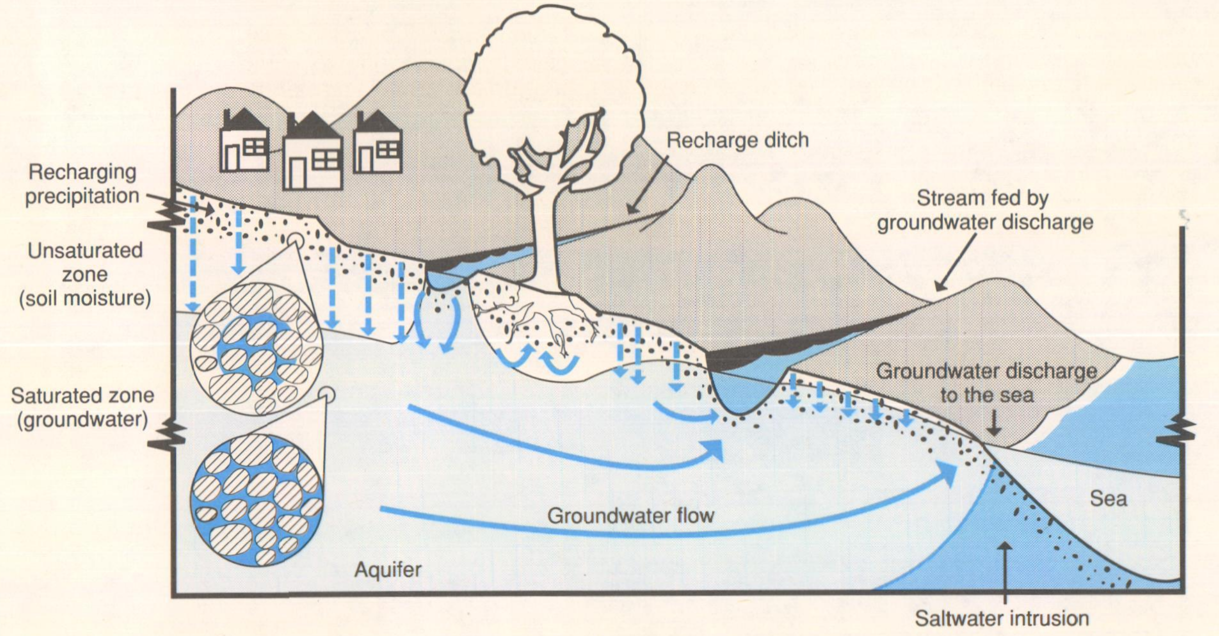
Main types of porosity



Where groundwater can be found. It fills the spaces between sand grains, in rock crevices, and in solution openings.

Figure 2

Groundwater flow



other are considered *unconsolidated.* If the grains are cemented together, such aquifers are called *consolidated.* Sandstones are examples of consolidated porous media.

Fractured aquifers are rocks in which the groundwater moves through cracks, joints or fractures in otherwise solid rock. Examples of fractured aquifers include granite and basalt. Limestones are often fractured aquifers, but here the cracks and fractures may be enlarged by solution, forming large channels or even caverns. Limestone terrain where solution has been very active is termed *karst.* Porous media such as sandstone may become so highly cemented or recrystallized that all of the original space is filled. In this case, the rock is no longer a porous medium. However, if it contains cracks it can still act as a fractured aquifer.

Most of the aquifers of importance to us are unconsolidated porous media such as sand and gravel. Some very porous materials are not permeable. Clay, for instance, has many spaces between its grains, but the spaces are not large enough to permit free movement of water.

Groundwater usually flows downhill with the slope of the water table. Like surface water, groundwater flows toward, and eventually drains into streams, rivers, lakes and the oceans. Groundwater flow in the aquifers underlying surface drainage basins, however, does not always mirror the flow of water on the surface. Therefore, groundwater may move in different directions below ground than it does above.

Unconfined aquifers (Figure 3) are those that are bounded by the water table. Some aquifers, however, lie beneath layers of impermeable materials. These are called *confined aquifers,* or sometimes *artesian aquifers.* A well in such an aquifer is called an *artesian well.* The water in these wells rises higher than the top of the aquifer. If the water level rises above the ground surface a *flowing artesian well* occurs. The *piezometric surface* is the level to which the water in an artesian aquifer will rise.

Groundwater as a source of energy

Groundwater may be used as a source of heat. Ground source heat pumps are receiving increased attention as energy efficient commercial and residential heating/cooling systems. Although initial costs are higher than air source systems – due to the additional costs of the underground installations – the much greater energy efficiency of ground source systems makes them increasingly attractive.

Research into the use of geothermal water has been carried out in a number of institutions across Canada. In Saskatchewan, the University of Regina has drilled geothermal wells as part of a research program, and the City of Moose Jaw is developing a geothermal heating system for a public swimming pool and recreational facility. Carleton University in Ottawa already uses groundwater to heat and cool its buildings. At Springhill, Nova Scotia, a demonstration geothermal heating system is being evaluated.

Figure 3

Aquifers and wells

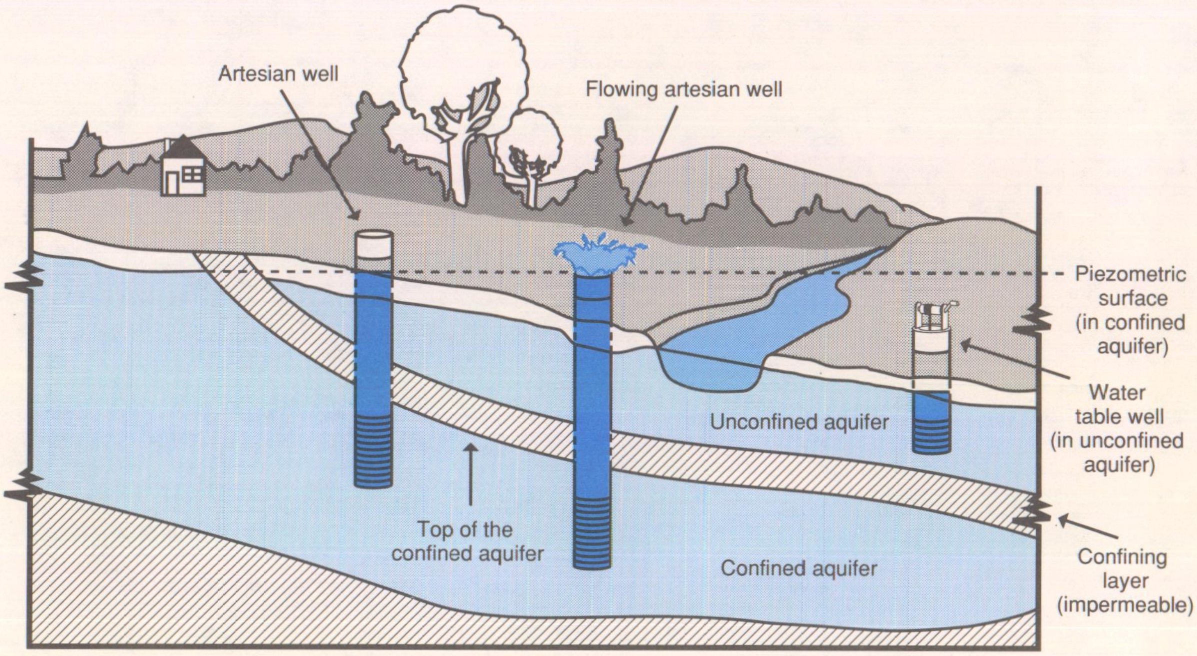
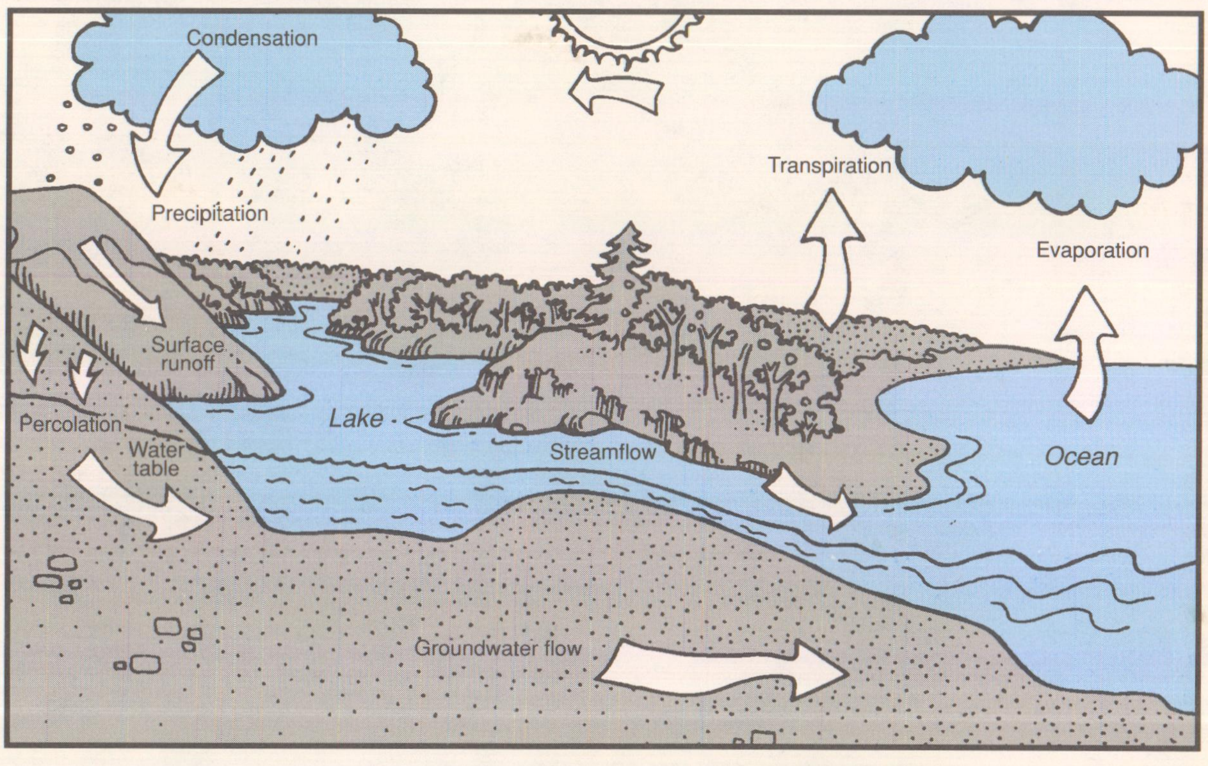
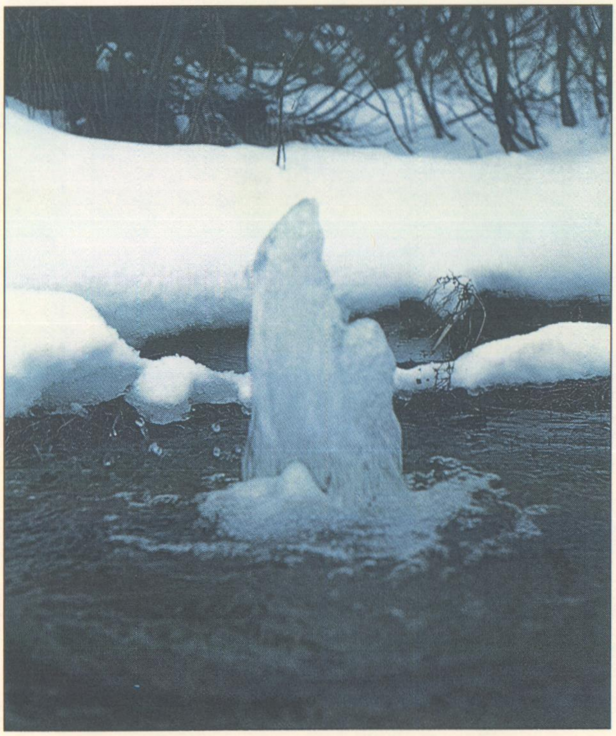


Figure 4

The hydrologic cycle





(Courtesy of A.D. Kindervater)
Pisquid, Prince Edward Island. Artesian spring.

Groundwater – A major link in the hydrologic cycle

Groundwater circulates as part of the hydrologic cycle. As precipitation and other surface water sources recharge the groundwater it drains steadily, and sometimes very slowly, towards its discharge point.

Groundwater does not stay underground forever, and it does not lie still waiting for us to draw it from a well. The *hydrologic cycle* is the series of transformations that occur in the circulation of water from the atmosphere onto the surface and into the subsurface regions of the earth, and then back from the surface to the atmosphere. Precipitation becomes surface water, soil moisture, and groundwater. Groundwater circulates back to the surface, and from the surface all water returns to the atmosphere through evaporation and transpiration (Figure 4).

When precipitation falls on the land surface, part of the water runs off into the lakes and rivers. Some of the water from melting snow and from rainfall seeps into the soil and percolates into the saturated zone. This process is called *recharge* (Figure 2). Places where recharge occurs are referred to as *recharge areas*.

Eventually, this water reappears above the ground. This is called *discharge*. Groundwater may flow into streams, rivers, marshes, lakes and oceans, or it may discharge in the form of *springs* and flowing wells.

Groundwater discharge can contribute significantly to surface water flow. In dry periods, the flow of some streams may be supplied entirely by groundwater. At all times of the year, in fact, the nature of underground formations has a profound effect on the volume of surface runoff. While the rate of discharge determines the volume of water moving from the saturated zone into streams, the rate of recharge determines the volume of water running over the surface. When it rains, for instance, the volume of water running into streams and rivers depends on how much rainfall the underground materials can absorb. When there is more water on the surface than can be absorbed into the groundwater zone, it runs off into streams and lakes.

Figure 5

Estimated depth and residence time of world's water supply

Parameter	Equivalent depth (m)*	Residence time
Oceans and seas	2500	~ 4000 years
Lakes and reservoirs	0.25	~ 10 years
Swamps	0.007	1 – 10 years
River channels	0.003	~ 2 weeks
Soil moisture	0.13	2 weeks – 1 year
Groundwater	120	2 weeks – 10 000 years
Ice caps and glaciers	60	10 – 1000 years
Atmospheric water	0.025	~ 10 days
Biospheric water	0.001	~ 1 week

*Computed as though storage were uniformly distributed over the entire surface of the earth.

Source: Adapted from Freeze and Cherry, p. 5.

Figure 6

Percentage of population reliant on groundwater, 1981

Municipal, domestic and rural use only

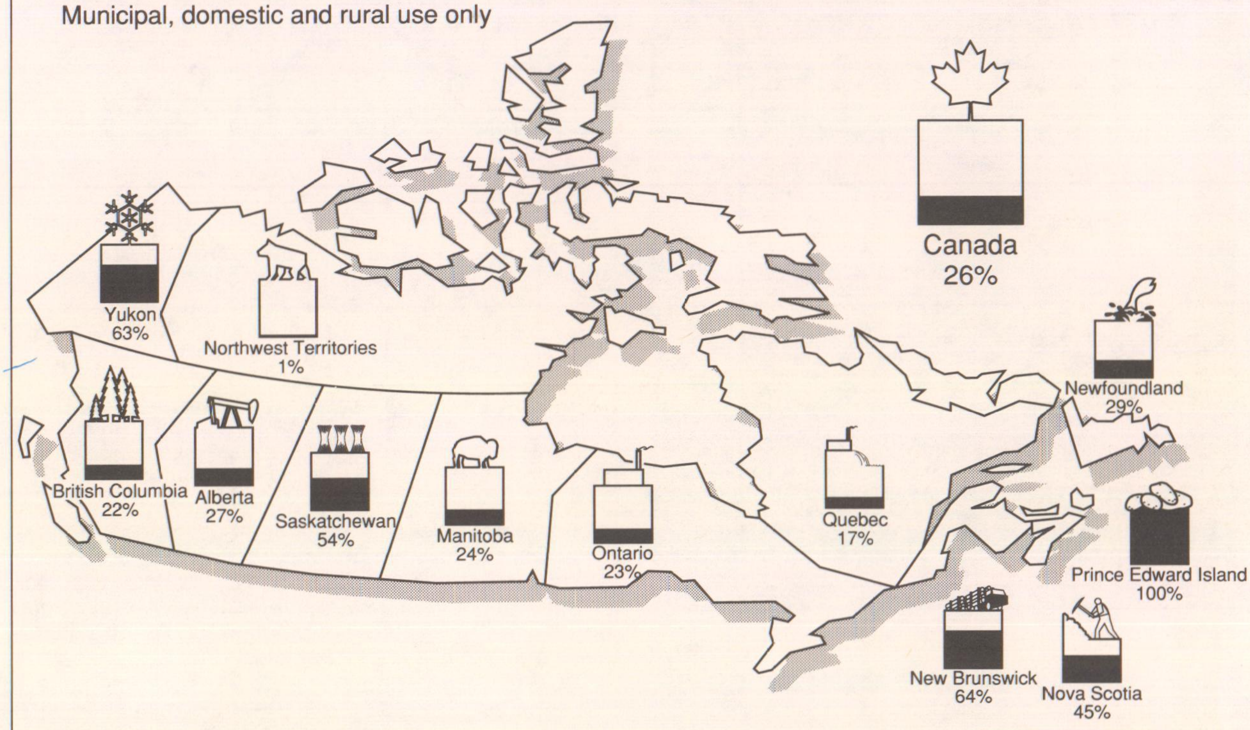
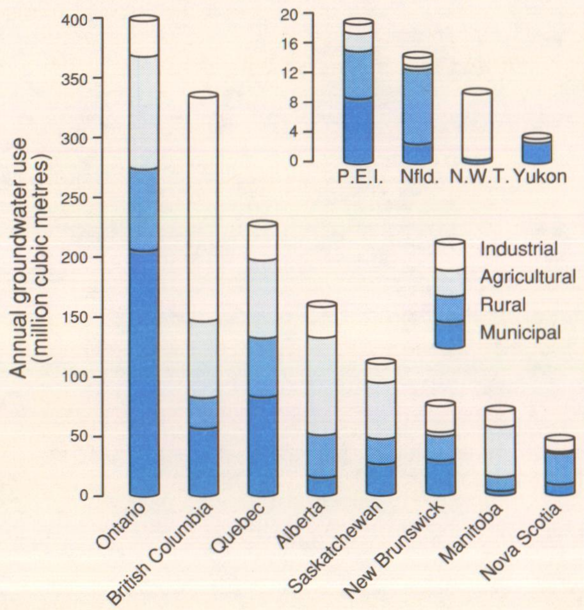


Figure 7

Estimated groundwater use by province and sector, 1981

(Some values derived from previous years)



The *residence time* of groundwater, i.e., the length of time water spends in the groundwater portion of the hydrologic cycle, varies enormously. Water may spend as little as days or weeks underground, or as much as 10 000 or more years (Figure 5). Residence times of tens, hundreds, or even thousands of years are not unusual. By comparison, the average turnover time of river water, or the time it takes the water in rivers to completely replace itself, is about two weeks.

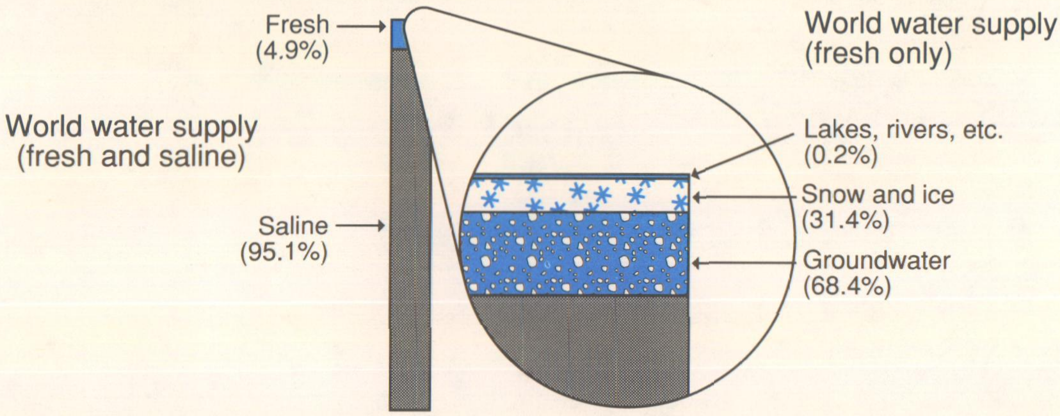
Six million Canadians depend on groundwater

In Canada, over six million people, or 26% of the population, rely on groundwater for domestic use (Figure 6). Approximately two thirds, or four million, of these users live in rural areas. In many areas, wells produce more reliable and less expensive water supplies than those obtained from nearby lakes, rivers and streams. The remaining two million users are located primarily in smaller municipalities where groundwater provides the primary source for their water supply systems. For instance, 100% of Prince Edward Island's population and over 60% of the population of New Brunswick and the Yukon Territory rely on groundwater to meet their domestic needs.

Furthermore, the predominant use of groundwater varies by province (Figure 7). In Ontario, Quebec, Prince Edward Island, New Brunswick, and the Yukon, the largest users of groundwater are municipalities; in Alberta, Saskatchewan, and Manitoba, the

Figure 8

Groundwater and the world's freshwater supply



Source: Adapted from Figure 2, Fact Sheet No 2, "Water – Here, There and Everywhere".

agricultural industry for livestock watering; in British Columbia and the Northwest Territories, industry; and in Newfoundland and Nova Scotia, rural domestic use. Prince Edward Island is almost totally dependent on groundwater for all its uses.

According to some estimates, the quantity of groundwater in the earth would cover the entire surface of the globe to a depth of 120 metres (Figure 5). By contrast, the volume of surface water in lakes, rivers, reservoirs and swamps could be contained in a depth of about one quarter of a metre.

It is extremely difficult to estimate the volume of groundwater on the entire planet. For example, a recent review of the literature revealed estimated figures ranging from 7 000 000 to 330 000 000 cubic kilometres. However, all the estimates imply that if we do not include the water frozen in ice caps, glaciers and permanent snow, groundwater makes up almost the entire volume of the earth's usable *fresh* water (Figure 8). Yet this supply is often not easily accessible, and it may be difficult and expensive to develop these water supplies in some regions. The quality of the groundwater source is also a significant determining factor when identifying its use.

Groundwater quality

We often think of water quality as a matter of taste, clarity and odour, and in terms of other properties which determine whether water is fit for drinking. For other uses different properties may be important. Most of these properties depend on the kinds of substances that are dissolved or suspended in the water. Water for most industrial uses, for instance, must not be corrosive and must not contain dissolved solids that might precipitate on the surfaces of machinery and equipment.

Pure water is tasteless and odourless. A molecule of water contains only hydrogen and oxygen atoms. Water is never found in a pure state in nature. Both groundwater and surface water may contain many constituents, including microorganisms, gases, inorganic and organic materials.

The chemical nature of water continually evolves as it moves through the hydrologic cycle. The kinds of chemical constituents found in groundwater depend, in part, on the chemistry of the precipitation and recharge water. Near coastlines, precipitation contains higher concentrations of sodium chloride, and downwind of industrial areas, airborne sulphur and nitrogen compounds make precipitation acidic.

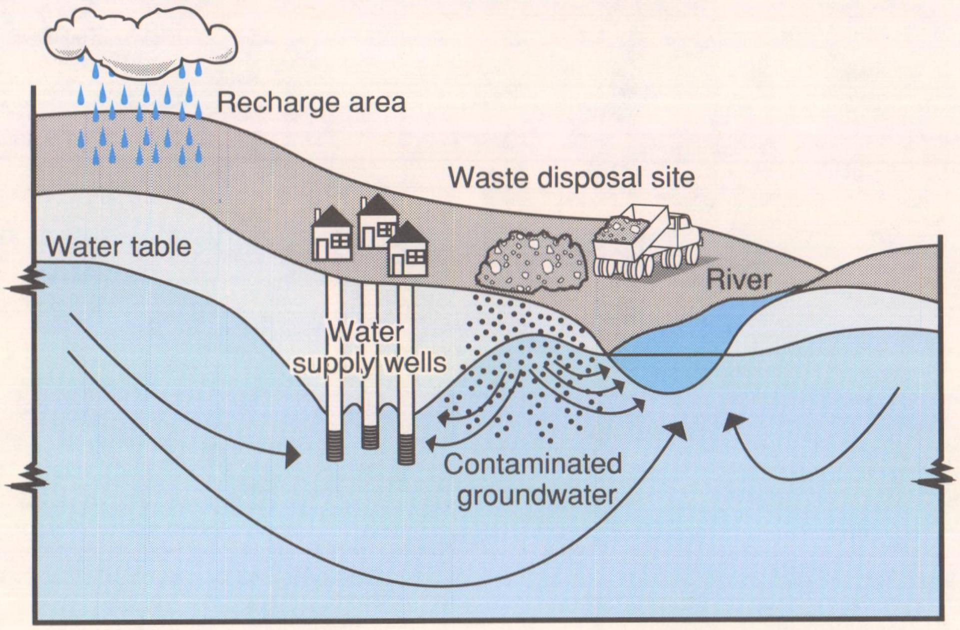
One of the most important natural changes in groundwater chemistry occurs in the soil. Soils contain high concentrations of carbon dioxide which dissolves in the groundwater, creating a weak acid capable of dissolving many silicate minerals. In its passage from recharge to discharge area, groundwater may dis-

Saltwater intrusion

Saltwater intrusion can be a problem in coastal areas where rates of groundwater pumping are high enough to cause seawater to invade freshwater aquifers (Figure 2). The problem can be avoided by appropriate well field design and by drilling relief wells to keep the salt water away from the fresh groundwater source. Some wells pumping salt water in Prince Edward Island, are used as convenient water supplies for shellfish farms.

Figure 9

Groundwater contamination from a waste disposal site



solve substances it encounters or it may deposit some of its constituents along the way. The eventual quality of the groundwater depends on temperature and pressure conditions, on the kinds of rock and soil formations through which the groundwater flows, and on how fast it flows. In general, faster flowing water dissolves less material. Groundwater, of course, carries with it any soluble contaminants which it encounters.

Scientists assess *water quality* by measuring the amounts of the various constituents contained in the water. These amounts are often expressed as milligrams per litre (mg/L), which is equivalent to the number of grams of a substance per million grams of water.

The suitability of water for a given use depends on many factors such as hardness, salinity and pH. Acceptable values for each of these parameters for any given use depend on the use, not on the source of the water, so that the considerations important for surface water (as mentioned in Fact Sheet 3 of this series entitled "Clean Water – Life Depends on It!") are equally applicable to groundwater.

The natural quality of groundwater differs from surface water in that

(a) for any given source, its quality, temperature and other parameters are less variable over the course of time and

(b) in nature, the range of groundwater parameters encountered is much larger than for surface water e.g., total dissolved solids can range from 25 mg/L in some places in the Canadian Shield to 300 000 mg/L in some deep saline waters in the Interior Plains.

At any given location, groundwater tends to be harder and more saline than surface water, but this is by no means a universal rule. It is also generally the case that groundwater becomes more saline with increasing depth, but again, there are many exceptions.

Leaking underground storage tanks

Leaks of petroleum products have been increasing over the last two decades because underground steel tanks installed in large numbers in the 1950s and 1960s have become corroded. Before 1980, all underground tanks were made of steel. Because of corrosion, up to half of them leak by the time they are 15 years old.

Groundwater dissolves many different compounds from petroleum products, and most of these substances have the potential to contaminate large quantities of water. This problem is particularly severe in the Atlantic provinces where hundreds of wells must be abandoned every year. In many cases, the problem is noticed long after the aquifer is contaminated, for example, when consumers start tasting or smelling gasoline.

Figure 10

Sources of contamination that can cause groundwater contamination

Point sources

- On-site septic systems
- Leaky tanks or pipelines containing petroleum products
- Leaks or spills of industrial chemicals at manufacturing facilities
- Underground injection wells (industrial waste)
- Municipal landfills
- Livestock wastes
- Leaky sewer lines
- Chemicals used at wood preservation facilities
- Mill tailings in mining areas
- Fly ash from coal-fired power plants
- Sludge disposal areas at petroleum refineries
- Land spreading of sewage or sewage sludge
- Graveyards
- Road salt storage areas
- Wells for disposal of liquid wastes
- Runoff of salt and other chemicals from roads and highways
- Spills related to highway or railway accidents
- Coal tar at old coal gasification sites
- Asphalt production and equipment cleaning sites

Non-point (distributed) sources

- Fertilizers on agricultural land
- Pesticides on agricultural land and forests
- Contaminants in rain, snow, and dry atmospheric fallout

Source: Adapted from Cherry, p. 395.

As groundwater flows through an aquifer it is naturally filtered. This filtering, combined with the long residence time underground, means that groundwater is usually free from disease-causing microorganisms. A source of contamination close to a well, however, can defeat these natural safeguards. Natural filtering also means that groundwater usually contains less suspended material and undissolved solids than surface water.

DNAPLs

A type of contaminant that is especially troublesome is the group of chemicals known as *dense nonaqueous phase liquids,* or *DNAPLs.* These include chemicals used in dry cleaning, wood preservation, asphalt operations, machining, and in the production and repair of automobiles, aviation equipment, munitions, and electrical equipment. They can also be generated and released in accidents, e.g., the Hagersville " tire fire." These substances are heavier than water and they sink quickly into the ground. This makes spills of DNAPLs more difficult to handle than spills of petroleum products. As with petroleum products, the problems are caused by groundwater dissolving some of the compounds in these substances. These compounds can then move with the groundwater flow. Except in large cities, drinking water is rarely tested for these contaminants.

How we contaminate groundwater

Any addition of undesirable substances to groundwater caused by human activities is considered to be *contamination.* It has often been assumed that contaminants left on or under the ground will stay there. This has been shown to be wishful thinking. Groundwater often spreads the effects of dumps and spills far beyond the site of the original contamination (Figure 9). Groundwater contamination is extremely difficult, and sometimes impossible, to clean up.

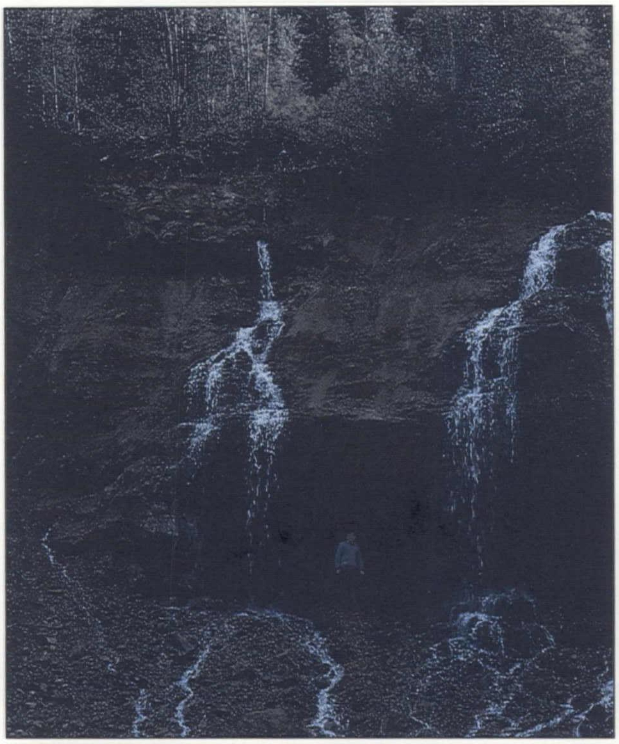
Groundwater contaminants come from two categories of sources: *point sources* and distributed, or *non-point sources* (Figure 10). Landfills, leaking gasoline storage tanks, leaking septic tanks, and accidental spills are examples of point sources. Infiltration from farm land treated with pesticides and fertilizers is an example of a non-point source.

Among the more significant point sources are municipal landfills and industrial waste disposal sites. When either of these occur in or near sand and gravel aquifers, the potential for widespread contamination is the greatest.

In Ville Mercier, Quebec, for example, the disposal of industrial wastes into lagoons in an old gravel pit over many years rendered the water supplies of thousands of residents in the region unusable. Water had to be pumped from a well 10 kilometres away to replace the area's supply.

Other point sources are individually less significant, but they occur in large numbers all across the country. Some of these dangerous and widespread sources of contamination are septic tanks, leaks and spills of petroleum products and of dense industrial organic liquids.

Septic systems are designed so that some of the sewage is degraded in the tank and some is degraded and absorbed by the surrounding sand and subsoil.



(Courtesy of Joachim Moenig)

Revelstoke, British Columbia. Springs along the road side.

Contaminants that may enter groundwater from septic systems include bacteria, viruses, detergents, and household cleaners. These can create serious contamination problems. Despite the fact that septic tanks and cesspools are known sources of contaminants, they are poorly monitored and very little studied.

Contamination can render groundwater unsuitable for use. Although the overall extent of the problem across Canada is unknown, many individual cases of contamination have been investigated such as Ville Mercier in Quebec; the aldicarb (pesticide) problem in Prince Edward Island; industrial effluents in Elmira, Ontario; various pesticides in the Prairie provinces; industrial contamination in Vancouver, British Columbia; and so on. In many cases, contamination is recognized only after groundwater users have been exposed to potential health risks. The cost of cleaning up contaminated water supplies is usually extremely high.

Contamination problems are increasing in Canada primarily because of the large and growing number of toxic compounds used in industry and agriculture. In rural Canada, scientists suspect that many household wells are contaminated by substances from such common sources as septic systems, underground tanks, used motor oil, road salt, fertilizer, pesticides, and livestock wastes. Scientists also predict that in the next few decades more contaminated aquifers will be discovered, new contaminants will be identified, and more contaminated groundwater will be discharged into wetlands, streams and lakes.

Groundwater contamination is extremely difficult and costly to clean up. This means that once an aquifer is contaminated, it may be unusable for decades. The residence time, as noted earlier, can be anywhere from two weeks or 10 000 years.

Furthermore, the effects of groundwater contamination do not end with the loss of well-water supplies. Many studies have documented the migration of contaminants from disposal or spill sites to nearby lakes and rivers as this groundwater passes through the hydrologic cycle. In Canada, pollution of surface water by groundwater is probably at least as serious as the contamination of groundwater supplies. Preventing contamination in the first place is by far the most practical solution to the problem. This can be accomplished by the adoption of effective groundwater management practices by governments, industries and all Canadians. Although progress is being made in this direction, efforts are hampered by a serious shortage of groundwater experts and a general lack of knowledge about how groundwater behaves.

Groundwater and engineering

Groundwater can also have dramatic implications for engineering and geotechnical studies. The study of groundwater is essential for engineers who construct dams, tunnels, water conveyance channels, mines, and other structures. Groundwater must be considered whenever the stability of slopes is important, whether the slope is natural or constructed. Groundwater must also be taken into account when devising measures to control flooding. In all of these situations, groundwater flow and fluid pressure can create serious *geotechnical problems*.

Groundwater, for example, may create structural weaknesses in dams, or it may flow underground right around the structure as it did at the Jerome Dam in Idaho. Water flowed so efficiently through the rock formations surrounding the reservoir that the dam would hold no water, even though it was structurally sound.

In another case, when geological exploration was being carried out in preparation for the construction of the Revelstoke Dam in British Columbia, geologists and engineers were concerned about an old landslide on the bank of the proposed reservoir. They suspected that the water held in the reservoir could increase groundwater pressures enough to make the slide unstable. In 1963, these same conditions at the Vaiont reservoir in Italy had caused a slide which killed 2500 people. The solution to the problem at Revelstoke was to increase drainage around the slide to ensure that groundwater pressures did not increase and that the old slide remained stable.

(Courtesy of J.A. Gilliland)
Blackstrap Lake, Saskatchewan. Vegetation in gullies is fed by groundwater discharge.

Over six million Canadians rely on groundwater for their daily water supply.

Other problems result from the excessive use of groundwater. *Overdrafting* occurs when people draw water out of an aquifer faster than nature can replenish it. The most obvious problem created is a shortage of water. Overdrafting, however, can also create significant geotechnical problems. Although not a major issue in Canada, at many locations around the world overdrafting has caused *land subsidence*. This can produce severe engineering difficulties. Parts of Mexico City, for instance, have subsided as much as 10 metres in the past 70 years, resulting in a host of problems in its water supply and sewerage system. Land subsidence may also occur when the water table is lowered by drainage. In the early 1970s, for example, an entire residential subdivision in Ottawa subsided when a collector sewer was constructed nearby. The subsidence seriously damaged the residents' property.

Safeguarding our groundwater supply

Groundwater is an essential resource. It exists everywhere under the Canadian landscape and is vitally connected to our rich surface water resources.

Contamination of groundwater is a serious problem in Canada. Industrial and agricultural activities are major sources of contaminants, but Canadian households are equally important sources.

Groundwater moves so slowly that problems take a long time to appear. Because of this, and because it is so expensive to clean up a contaminated aquifer (if it can be done at all), it is preferable by far to prevent contamination from happening in the first place. For example, leaking underground storage tanks can be replaced by tanks that will not corrode; landfills can be sited in locations where leachates will not contaminate underlying groundwater; and the impacts of spills of hazardous materials reduced by restricting access to recharge areas.

All levels of government in Canada are starting to take some of the actions necessary to protect our groundwater supplies, but there is a long way to go before these measures are fully effective. At the same time, universities and government research institutes are investigating what happens to water underground and what can be done to preserve it and even improve its availability to us. Both as a society and as individuals, we must keep in mind groundwater's susceptibility to contamination.

Groundwater is just as important as the sparkling lakes and rivers of our postcard image of Canada. This national treasure may be "hidden," but it must not be forgotten.

Groundwater and wetlands

Wetlands, which provide a summer home to nearly all of North America's 45 million ducks and other waterfowl, often have very close connections with the groundwater system. Some wetlands, e.g., potholes in higher ground, may serve as important groundwater recharge areas. Others, especially those in low-lying areas, may be the receptors for significant amounts of groundwater discharge. Therefore, if the underlying groundwater is contaminated, detrimental consequences will be felt by the wildlife and all other resources dependent on that wetland.

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Diving beneath the surface

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