GROUNDWATER

1. Groundwater

Groundwater is that portion of the water beneath the surface of the earth that can be collected with wells, tunnels, or any other drainage pipes, or that flows naturally to the Earth's surface via seeps or springs (Bouwer 1978, 1). Groundwater is found within pore spaces of porous and pervious geologic materials, as well as in joints, i.e. fractures in impervious crystalline bedrock. However, as Bouwer (1978) suggests, not all underground water is groundwater. If a hole is dug, moist or even saturated soil may be encountered. As long as this water does not seep freely into the hole, it is not groundwater. True groundwater is reached only when water begins to flow into the hole.

In more technical terms, groundwater is 'water obtained from aquifers'. As Hess (1986, ix) defines, an aquifer is 'an underground formation that contains sufficient saturated permeable material to yield significant volumes of water to wells'. Cech (2003, 95) defines an aquifer as "water-bearing geologic formation that can store and yield usable amounts of water". The word "aquifer" comes from the Latin words *aqua*, meaning water, and *ferre,* meaning "to bear or carry". Aquifer materials include sand, gravel, sandstone, limestone, and fractured rock such as granite, which has sizable fissures.

Groundwater is directly linked to the hydrologic cycle and accounts for a major portion of the world's freshwater resources. Using systems terminology of inflow and outflow, the inflow of the groundwater systems begins with precipitation, which converts into two types of runoff: the surface runoff and the groundwater runoff. The groundwater runoff goes through at least five stages of infiltration through soil, soil moisture storage, groundwater recharge, saturated groundwater storage and baseflow, before it reappears as streamflow. The total time taken by this journey from the moment of input to the time of output – the so-called input-output interval – is called the residence time and may take anywhere between 2 weeks and 10,000 years. Thus, most of the huge amount of groundwater resources of the world is locked beneath the surface in aquifers, because of its long residence time. In contrast, the residence time of atmospheric water (humidity, cloud, precipitation) is only about 10 days and that of river water is about 2 weeks. (See Slide 5, of Table 4.4 (after Freeze and Cherry 1979, 5)

As these data indicate, the residence time of both ice caps, i.e. continental glaciers in Antarctica and the North Pole and groundwater could be very high, as much as 10,000 years, with major implications for management.

2. Nature of aquifer

There are two types of aquifers. *Consolidated rock* includes sandstone, limestone, granite, or other porous rock. Generally, these rock formations yield very little water since the materials are almost impervious allowing only limited movement of water through them. In contrast, *unconsolidated rock* consists of granular material such as sand and gravel and generally yield larger amounts of groundwater. More technical terms for these two types of aquifers are *confined* and *unconfined* aquifers.

Unconfined aquifers are like underground lakes in porous materials. There is no clay or other restricting material at the top of groundwater, so that groundwater levels are free to rise or fall. The top of an unconfined aquifer is the water table, which is the plane where groundwater pressures are equal to atmospheric pressure. The zone between ground surface and the top of the groundwater is called the *vadose zone*.

A *confined aquifer* is a layer of water-bearing material that is sandwiched between two layers of much less pervious material (Figure 1.2, Bouwer 1978, 4). An example is a sandy layer between two clay layers or sandstone between layers of shale or solid limestone. If the confining layers are essentially impermeable, they are called *aquiclude*. Confined aquifers are completely filled with groundwater, and they do not have a free water table. The pressure condition in a confined aquifer is characterized by the *piezometric surface*, which is obtained by connecting equilibrium water levels in tubes, or piezometers, penetrating the confined aquifers. Artesian springs is created from a confined aquifer sandwiched between two *aquicludes*.

3. Geographical studies of groundwater

(a) Distribution of aquifers

The studies of groundwater could be highly technical, involving groundwater geology of aquifers, hydrology of movement of groundwater, engineering of extraction, and modeling by groundwater engineers and computer scientists. Most of the geographical studies of groundwater are conducted at local level with details of location of geologic deposits, bedrock, aquifers, wells and other land use features. Figure 4.16 is an example of such local level study of groundwater.

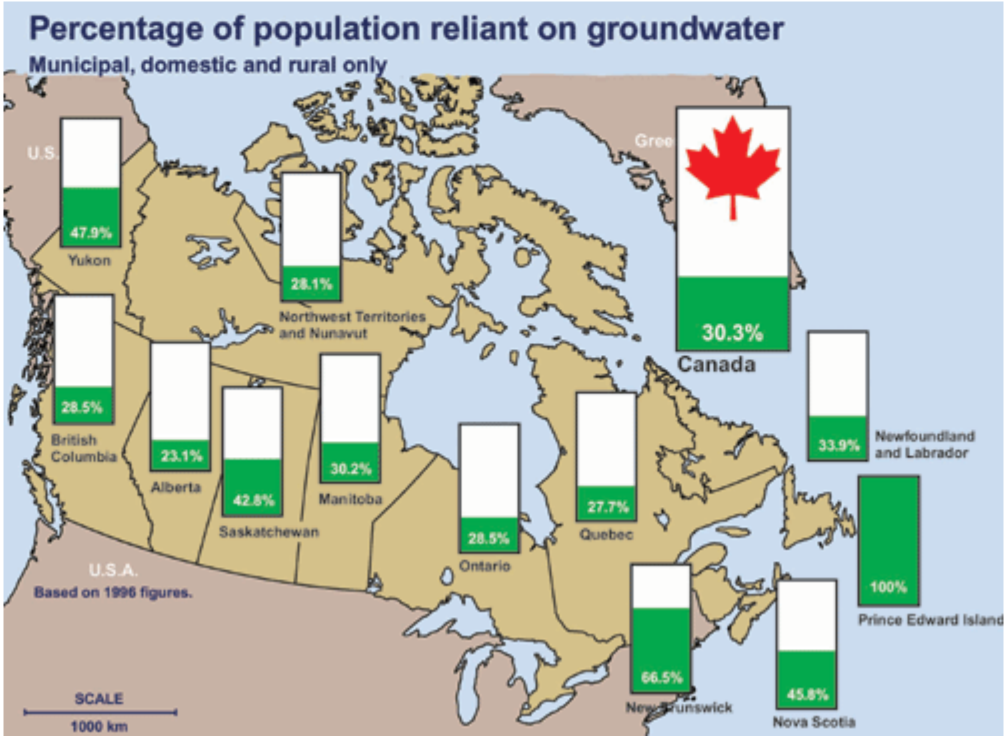
(b) Vertical and horizontal movement of groundwater

Vertical and horizontal movement of groundwater also leads to some of the familiar geographical concepts. The most basic concepts of vertical movement deal with infiltration and recharge. As indicated earlier briefly, following precipitation certain amounts of surface water infiltrate through soil under the influence of gravity, until an impervious layer of material such as clay or shale stops this process. This naturally occurring process of downward movement of water is called groundwater *recharge*. The rates of groundwater recharge depend on climate, terrain, geology, and vegetation cover. The rates tend to be extremely slow in consolidated bedrock, whereas unconsolidated sandy deposits accelerate recharge rates.

Two physical properties of aquifers, which are directly related to the rates of movement and recharge of groundwater are *porosity* and *permeability*. The former refers to pore spaces or openings in geologic material and determine the volume or capacity of the aquifer to hold the maximum amount of water. In more mathematical terms, *porosity* is the percentage of the total volume of pore spaces within a geologic formation that can fill with water.

4. Geography of groundwater uses in Canada

(a) Regional use of groundwater Approximately 1.46 billion m^3 of groundwater was used in Canada in 1981. If we convert this annual total to daily use by dividing the data by 365, we get a value of 4 million m^3/day. Compared to the US, this value is 66 times lower. To put it another way, the US has about 10 times more population than Canada, but 66 times more groundwater use. If the population is prorated at the same level, groundwater use is about 6.6 times higher in the US. The US, being more industrialized than Canada, uses more than 50% of groundwater by industries. The equivalent amount for Canada is only 22%.



Source: Statistics Canada, 1996 (https://www.ec.gc.ca/eau-water/default.asp?lang=En&n=300688DC-1#sub5)

Ontario is the largest groundwater user, but its principal use is for municipal supply, with very low industrial use (implying heavy reliance of the industries on surface water). The Prairies, the second largest user, uses 50% of groundwater for irrigation. BC, the third largest user, on the other hand, uses more than 50% for industries, namely pulp and paper and mining. Quebec, the fourth largest user, uses 38% for municipal supply. In the Atlantic provinces, again, municipal and rural supplies dominate. The most striking contradiction between the level of industrialization and groundwater use is displayed by the North, which is least industrialized but uses 72% of groundwater by the industrial sector, primarily the mining and the energy sector.

(b) Comparison of groundwater use to total water use

Canada relies much less on groundwater than the US. Whereas about 1/5 of the total water use in the US was on groundwater in 1970, the relative proportion for Canada was only 4-8%. If thermal use had been excluded, then the contribution by groundwater would increase to 8% from 4%. This meant that large amount of water use by thermal plants was from surface water sources.

(c) Nature of users

Groundwater users in Canada have been classified into four sectors: (a) municipal, (b) rural, (c) agricultural, and (d) industrial.

From the point of view of groundwater use, a *municipality* is a community of any size, which has a municipal distribution network. Whereas a municipality often is an urban centre with a population of 1000 or more, data in Table 4 included even rural municipalities with population of 100 or less. A municipal user might either be a domestic residence or an industrial, commercial or other type of institution. Approximately 85% of the population served by municipal distribution network received treated water prior to distribution. In 1981, nearly 80% of Canada's 24.3 million population were served by municipal domestic water supply. Of them, the percentage of municipalities reliant entirely or partially on groundwater was 38%.

Rural users comprised the balance of the population who were not classified as municipal domestic users. In 1981, their number was 4.8 million or about 20% of the total Canadian population. Of them, 82% was still reliant on groundwater, i.e. these were the well water users.

Agricultural water was defined as water obtained for livestock and /or irrigation use. According to an estimate of Environment Canada, 90% of the water used for livestock was obtained from groundwater, but livestock consumed only 12% of total water use. The remaining 88% of agricultural use was for irrigation. The leading provinces for irrigation were Alberta and Saskatchewan, but most of the irrigation water in these provinces came from surface water sources, such as Lake Diefenbaker, for example. Therefore, the proportion of irrigation water that came from groundwater was less than 3% for entire Canada.

Industrial water use was defined as water that was self-supplied by industrial plants throughout Canada. The largest proportion of the groundwater use under the industrial sector was for fish enhancement facilities (about 44% of industrial use), followed by manufacturing (28%), and mining (25%).

5. Groundwater protection in Ontario

(a) Nature of the problem

The term groundwater protection implies increasing threat of subsurface contamination, notably by waste disposal systems. In Canada, this problem has assumed significance in high-density areas of southern Ontario. Approximately 30% of the population of Ontario (3.9 million) relied on groundwater as a primary source of drinking water in 1981. This figure increased to 90% of the rural population who were primarily well water users. Historically, groundwater management has been defined in terms of regulating the withdrawal rates as well as enforceable regulations on drinking water quality. Contamination of groundwater is a relatively recent problem. A team of specialists, which include geographers such as Sanderson, Mitchell and Shrubsole (1995), has presented an exhaustive case study of groundwater contamination in the Kitchener-Waterloo area. Another article by Walker et al (1992) describes how the GIS technology can be used as a useful tool for studying local groundwater problems in an Atlantic province case study.

Groundwater that is overlain by sand or gravel and which rises between 2 and 10 m below the surface is most readily contaminated. Contaminants may penetrate into the water table through the relatively large openings in such overburden and then spread both downward and laterally. In addition to these unconfined sand and gravel aquifers, many areas in southern Ontario have relatively thin (<10 m) clay overburden. Fissures in clay due to weathering processes as well as root holes can provide pathways for rapid movement of contaminants to ground.

Groundwater contamination can result from either point sources or non-point sources. Point sources include municipal landfill sites, industrial waste sites, mine tailings, human wastes, livestock wastes, wells for disposal of liquid wastes, Municipal waste disposal system is considered to be the greatest threat to groundwater contamination. Non-point sources include application of fertilizer and pesticide for agriculture and forest.

(b) Management and protection programs

In 1986 the Ontario Ministry of Environment (MOE) issued the *Guidelines for the Restoration of Groundwater Quality Interference Problems.* The mandate of this guideline is to take action to clean up and restore or replace groundwater supply where significant deterioration of groundwater quality has occurred. At least seven types of activities fall under the mandate of the Guidelines.

Water quality objectives. The Ontario Water Resources Act provides for the development of regulations prescribing water quality standards for water supplies and water courses. The province has non-statutory *Ontario Drinking Water Objectives.* Maximum Acceptable Concentration (MAC) related to health has been defined for 14 inorganic substances (e.g. lead, mercury), 16 organic substances, five radionuclides, and turbidity. These regulations apply to groundwater.

Groundwater management programs. These programs normally include publication of data on wells and maps on aquifers. In addition, the MOE has drafted groundwater susceptibility maps for 24 selected areas of the province. However, there is no program to monitor the long-term quality of groundwater in the province. A draft program entails sampling selected municipal water supply wells accross Ontario for a variety of substances. The MOE has also groundwater evaluators who investigate complaints relating to groundwater quality or quantity interference.

Regulation of waste sites. Waste sites or landfills are regulated by the EPA. The 1986 Guidelines outlined the MOE procedures for determining the acceptable level of groundwater quality degradation in waste disposal sites and adjacent properties. For example, wgere the designated reasonable use of the groundwater is for drinking water, its quality is above the provincial Drinking water Objectives, and a reduction in quality by a maximum of 25% of provincial guidelines may be considered as acceptable.

Regulation of underground storage tanks. Under the *Gasoline Handling Act* all gasoline handling equipment, including underground storage tanks in a service station, consumer outlet, marina, etc. must be approved by the Ministry of Consumer and Commercial Relations. The *1987 Act to Amend the Gasoline Handling Act* provided for additional measures to protect the subsurface environment by ascertaining the number and location of underground tanks in private property.

Regulation of winter road maintenance. Road salting and related activities are not regulated under the EPA. However, in 1984 the MOE issued a policy on the *Resolution of Well Water Quality Problems Resulting from Winter Road Maintenance.* It summarizes the cost-sharing arrangement between the Ministry and a road authority to reimburse homeowners whose well water might have been adversely affected by winter road maintenance.

Regulation of Pesticides. The restricted use of a given pesticide in Ontario is generally guided by a federal initiative, such as the recent temporary restriction on the use of Alacher, which has been found to be carcinogenic in laboratory animals and which had been found in rural well water in Ontario.

Land use planning. At present, no provincial policy statements under the Planning Act have been issued on the subject of groundwater protection. In addition, no zoning orders have been made for the purpose of protecting the quality of groundwater in Ontario. The groundwater staff of the MOE's Drinking Water Section do not review official plans routinely.

Concluding “big-picture” features to consider
Many countries include discussion of rights to water and air in their constitutions. International discussion and law includes a universal human right to a “safe, clean, healthy and sustainable environment.” More than 90 countries have included the “right to live in a healthy environment” in their constitutions; the U.S., Canada, Australia and Britain are not among them.

Climate change is often framed as an issue of science, economics, policy and politics, “but more than anything else, it is an issue of ethics and justice,” said Michael E. Mann, a well-known climatologist and director of the Earth System Science Center at Pennsylvania State University.

Slide 5

Estimates of the water balance of the world (after Freeze and Cherry 1979, 5)

System components	***Volume ($km^3 x 10^6$)***	***Volume (%)***	***Residence Time***
Oceans and seas	**1370**	**94**	**4000 y**
Lakes	**0.13**	**<0.01**	**10 y**
Rivers	**<0.01**	**<0.01**	**2 wks**
Soil moisture	**0.07**	**<0.01**	**2 wks - 1 y**
Ice caps /glaciers	**30**	**2**	**10-10 000 y**
Groundwater	**60**	**4**	**2 wks - 10 000 y**
Atmospheric moisture	**0.01**	**<0.01**	**10 days**

Table 2 Estimated groundwater use in Canada, 1981 (from Hess 1986, 17)

Region	***Annual groundwater use (m^3/y x 10^6)****	***Percent of use by sector***			
		Municipal	***Rural***	***Agricultural***	***Industrial***
Ontario	**398**	**51**	**18**	**23**	**8**
Prairies	**342**	**15**	**21**	**50**	**14**

BC	329	18	7	20	55
Quebec	226	38	22	29	11
Atlantic	153	34	41	7	18
North	13	27	1	0	72
CANADA	1461	31	19	28	22

* $(m^3/y \times 10^6)/365$ = daily use

Table 3 Estimated total water use in Canada and the percentages obtained from groundwater 1981 (From Hess 1986, 18)

Region	*Total water use ($m^3/y \times 10^6$)*	*% from groundwater*	*Total water use excluding thermal use ($m^3/y \times 10^6$)*	*% from ground water*
Ontario	21,186	2	6,252	6
Prairies	5,373	6	3,555	10
Quebec	4,239	5	3,931	6
BC	3,844	9	3,485	9
Atlantic	2,874	5	1,076	14
North	35	37	35	37
CANADA	37,552*	4	18,347	8

*($10^3 \times 10^6$ m^3/day)