Box 4 How groundwater occurs

Groundwater is part of the Earth's water or *hydrological* cycle. When rain falls, a part infiltrates the soil and the remainder evaporates or runs off into rivers. The roots of plants will take up a proportion of this moisture and then lose it through transpiration to the atmosphere, but some will infiltrate more deeply, eventually accumulating above an impermeable bed, saturating available pore space and forming an underground reservoir. Underground strata that can both store and transmit accumulated groundwater to outlets in rivers, springs and the sea are termed *aquifers.*

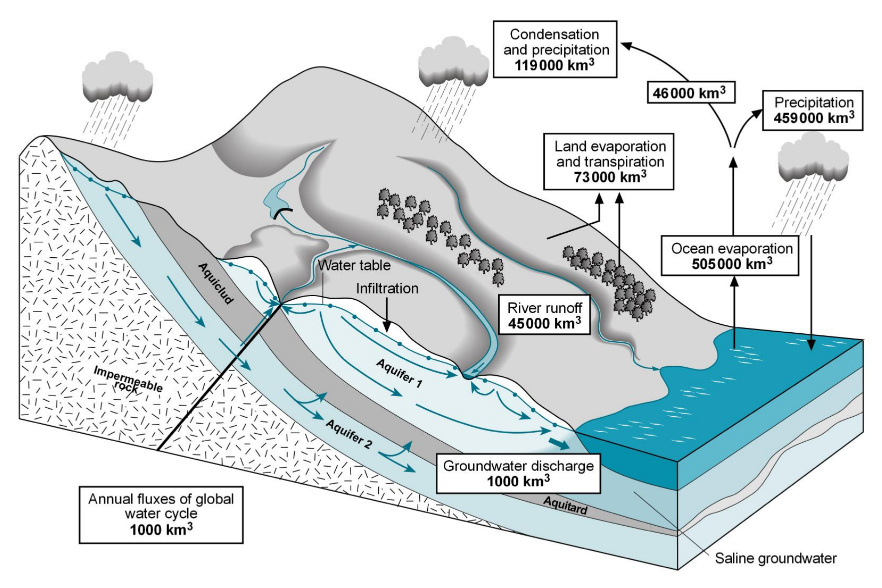

Figure A Groundwater in the hydrological cycle

The *water table* marks the level to which the ground is fully saturated (*saturated zone*) and reaches the surface at most rivers and all groundwater-fed lakes. Above the water table the ground is known as the *unsaturated zone.*

The productivity of an aquifer depends on its ability to store and transmit water, and these qualities may vary (see Figure A). Unconsolidated granular sediments (Figure Ba below), such as sand or gravel contain pore space between the grains and thus the water content can exceed 30 per cent of the volume. This is reduced progressively as the proportion of finer materials such as silt or clay increases and as consolidation occurs, typically accompanied by cementation of the grains (Bb below). In highly consolidated rocks (Bc below) groundwater is found only in fractures and rarely exceeds 1 per cent of the volume of the rock mass. However, in the case of limestones (Bd below), these fractures may become enlarged, by solution and preferential flow to form fissures and caverns. Even then, the total storage is relatively small compared with unconsolidated aquifers; one result is that there is less water available to dilute contaminated water that finds its way into the system.

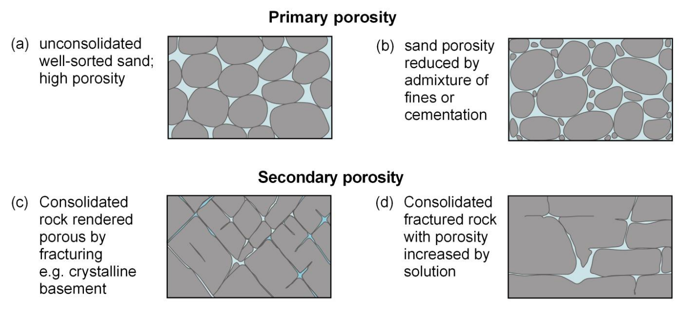

Figure B Rock texture and porosity of typical aquifer materials (modified from Meinzer, 1923)

In the major aquifers, the rock matrix provides a certain proportion of the total storage capacity of the system, while the fractures provide the dominant flow-path.

The most widespread aquifers combine these features and are known as *dual permeability aquifers*, where some regional flow can occur through the matrix and some through structural features such as joints or fault planes. This situation is common in many sandstones. The effect can be enhanced during aquifer development where individual boreholes/well fields may become extra productive after prolonged pumping through preferential near-well development of local fracture systems. This effect has been observed in some Permo-Triassic sandstone aquifers of north-west Europe.

Another combination is the *dual porosity aquifer*, such as the important Chalk aquifer of north-west Europe, where the microporous nature of the limestone provides very large but relatively immobile storage, and practically all lateral flow is through fractures. This arrangement greatly modifies pollutant movement, as the water in the matrix is relatively immobile compared with that in the fissures.

Box 5 How groundwater moves

All freshwater found underground must have had a source of *recharge*. This is normally precipitation (rainfall/snow-melt), but can also sometimes be seepage from rivers, lakes or canals. The recharge typically travels downwards through the unsaturated zone and the aquifer fills up until water reaches the land surface, where it flows from the ground as springs or seepages, providing the dry-weather flow (or *baseflow*) of lowland rivers. Thus the aquifer becomes saturated to a level where the outflow matches recharge.

Shallow aquifers in recharge areas are generally *unconfined,* but elsewhere, and at greater depths, groundwater is often *partially confined* by low permeability strata (an *aquitard*) or fully *confined* by overlying impermeable strata (an *aquiclude*). In confined conditions water may be encountered under pressure, and when wells are drilled, rises above the top of the aquifer, even as far as ground surface, to a level called the *potentiometric surface* (see Figure A).

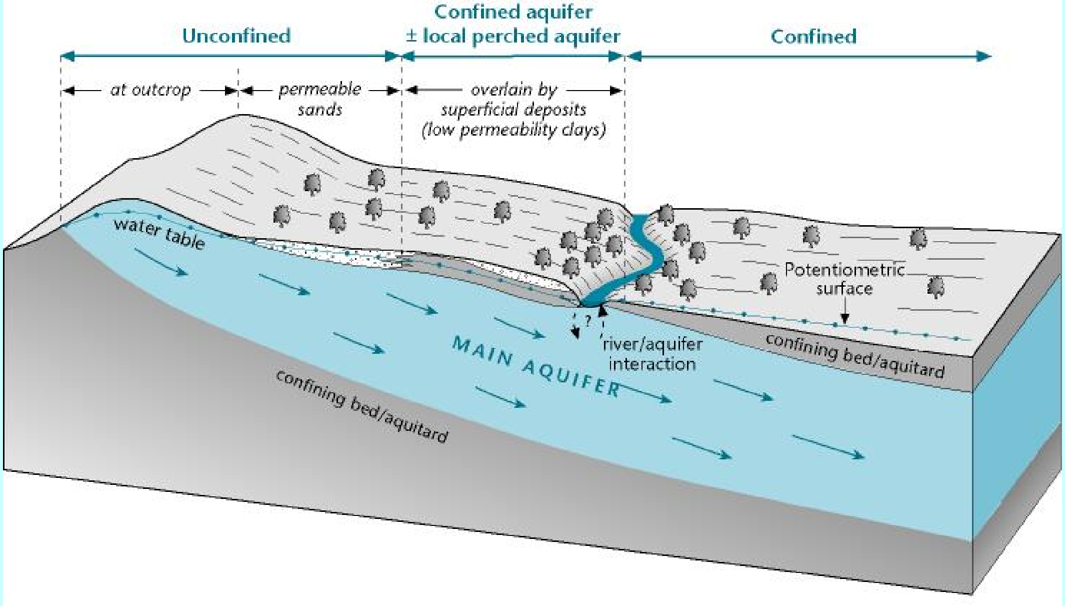

Figure A Schematic of a common aquifer situation

Groundwater systems are dynamic and water is continuously in slow motion down gradient from areas of recharge to areas of discharge. In large aquifer systems, tens or even hundreds of years may elapse in the passage of water through this subterranean part of the hydrological cycle (Figure B). Such flow rates do not normally exceed a few metres per day and compare with rates of up to 1 metre per second for riverflow. Velocities can be much higher where flow is through fracture systems, dependent on factors like aperture or fracture network density. In limestones with well-developed solution or *karst* or in some volcanic aquifers with extensive lava tubes or cooling cracks, velocities can be measured in km/day. Thus supplies located in different aquifers, or in different parts of the same aquifer, can tap water of widely different residence time. This is an important factor for contaminants that degrade over time and in the control of disease-causing micro-organisms such as some bacteria, viruses and protozoa.

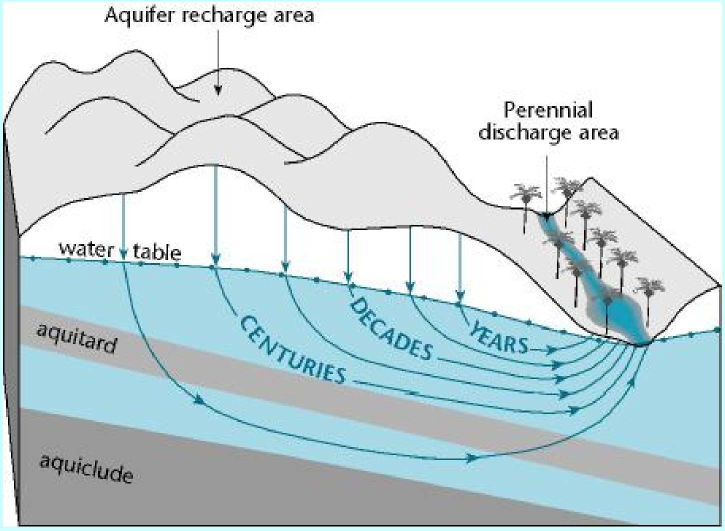

Figure B Groundwater flow system in large aquifer

Reproduced from: Morris, B L, Lawrence, A R L, Chilton, P J C, Adams, B, Calow R C and Klinck, B A. (2003) Groundwater and its Susceptibility to Degradation: A Global Assessment of the Problem and Options for Management. Early Warning and Assessment Report Series, RS.03-3 United Nations Environment Programme, Nairobi, Kenya.