Answer Key

Answers to Study Questions

1. *Porosity* refers to the proportion (%) of open spaces within a rock. Porosity determines a rock's capacity to hold water. *Permeability*, on the other hand, describes the interconnectedness of pore spaces within a rock; hence, permeability is a measure of a rock's ability to transmit fluid. Clastic sedimentary rocks, particularly those with large grains and clasts such as conglomerates and sandstones, usually have high permeability. Crystalline rocks such as granite (i.e., not jointed) usually have low permeability.

2. The saturated zone of a rock body is the region in which all openings in the rock are filled by water. The water table constitutes the upper surface of the saturated zone.

3. The capillary fringe is the narrow zone at the base of the unsaturated zone, overlying the water table. It contains more moisture than the unsaturated zone. The capillary fringe forms a transition zone between the saturated and unsaturated zones.

4. Most plants draw their water from the upper part of the unsaturated zone. Swamp vegetation and other water-loving plants are different, however. They draw their water from the saturated zone.

5. The hydraulic head of a drop of water is the sum of the drop in height plus the water pressure on the drop involved.

6. Equipotential lines are lines joining all points of equal hydraulic head. Water, which flows from zones of high hydraulic head to low hydraulic head, crosses equipotential lines orthogonally (at right angles).

7. Darcy's Law describes the flow of a fluid through a porous medium. It states that the velocity of groundwater is equal to permeability divided by porosity, multiplied by the hydraulic gradient:

   $$V = \frac{K}{n}\frac{\Delta h}{L}$$

   In this equation, K is the hydraulic conductivity (a parameter determined by the permeability, which varies from aquifer to aquifer); n is the porosity; Δh is the difference in head; and L is the distance.

8. The steepness of the water table is proportional to the velocity of the water: the greater the slope of the water table, the faster the water moves.

9. In most cases, the slope of the water table mirrors the topography above it: where the topography rises, the water table also rises, and where the topography dips, the water table also dips. Hence, the water table essentially runs approximately parallel to the surface of the land (topography).

10. The term *aquifer* refers to a porous geological formation (rock or sediment) that is saturated by water and is permeable to water—water can flow through it easily. Porous clastic rocks such as sandstone, conglomerate, and loose, coarse-grained sediments including gravel and sand usually form good aquifers. At times, fractured crystalline rocks such as limestone and volcanic rocks also form good aquifers.

11. An *unconfined aquifer* is one that can freely be recharged by precipitation and that has a table which falls and rises freely in response to recharging. Its upper boundary is the water table. Groundwater movement through an unconfined aquifer is relatively rapid. Conversely, a *confined aquifer* is one that is found underneath a confining layer, which is a geological unit through which water cannot move easily, such as shale. A confined aquifer is usually completely saturated with water, but the rate of recharge is very slow, since water must be transmitted through the confining layer. The water level in a confined aquifer does not respond to seasonal variations in water availability.

12. A cone of depression is a lowering of the water table in the form of an inverted cone that develops on the water table as water is pumped from an open well. The drawdown or drop in the water table is greatest closest to the well, but tapers off farther away from the well—hence the conical shape.

13. A gaining stream is one that intersects the water table such that the streambed and banks lie below the water table. In such a setting, water flows from the saturated zone into the stream. A losing stream, on the other hand, is characterized by water seepage from the stream into the saturated zone. In a losing stream the water table slopes away from the stream. In dry climates, streams can be disconnected completely from the saturated zone so that water from the stream passes through an unsaturated zone before it reaches the saturated zone.

14. Toxic chemicals such as pesticides and herbicides as well as fertilizers used in crop farming are chief contributors to groundwater pollution. Pesticides such as diazinon, and herbicides that include atrazine, DEA, and 2,4-D are chemical agents that can be washed down from

the topsoil by infiltrating water to reach groundwater. Similarly, downward percolating water can introduce the nitrate from fertilizer to groundwater supplies, where the nitrate forms a toxic contaminant. Nitrate is harmful to human health.

15. Acid mine drainage occurs in mines such as coal mines and metallic mineral mines, where excavations lead to the exposure of sulphide-bearing minerals that oxidize to form strong acids. For example, the oxidation of sulphur in pyrite leads to the formation of sulfuric acid, which is highly toxic to all forms of aquatic life.

16. A contaminant that disperses in water usually forms a plume as it spreads. However, some contaminants do not form plumes. When leaking gasoline reaches the saturated zone, for example, it floats on the water table rather than mixing with the water, because it is less dense than water. Conversely, substances that are denser than water sink to the bottom of the saturated zone, after which their movement is determined by the morphology of the impermeable unit at the base.

17. Human sewage in groundwater can be purified naturally by a range of physical and biological processes that take place below ground. Through filtration, soil or rock particles sift out the particulate materials. Clay minerals and humus in the soil extract contaminants by absorption. Finally, biological organisms decompose degradable materials. Under optimum conditions, human sewage material passing through a geological substrate of ideal composition (e.g., a sandy loam) can be cleansed in about 30-45 m of flow through the medium.

18. In coastal areas, freshwater usually occurs in the ground as a distinct zone floating above a more dense saltwater zone. Saltwater intrusion refers to a process that occurs when wells sunk to tap freshwater close to the coast are over-pumped such that the freshwater lens thins. Saltwater then rises to fill the void left by the diminishing freshwater, and may eventually be discharged by the well if pumping continues.

19. Extraction of groundwater without adequate recharge can result in a negative water balance; that is, the water table drops in elevation. A drop in the water table can result in a number of other problems such as ground subsidence and compaction. To circumvent such problems, artificial recharge can be used to augment natural recharge processes. Water used for artificial recharge includes flood waters and treated industrial or domestic waste waters, which are collected and stored in specially-designed infiltration ponds for percolating into the ground. Alternatively, water can be pumped into the ground as opposed to letting it infiltrate from surface ponds.

20. *Hard water* describes water with a high content of dissolved ions, particularly calcium and magnesium. The calcium usually comes from the weathering of calcium-bearing minerals such as calcite and dolomite. Magnesium is produced by the weathering of minerals that contain magnesium, such as dolomite and ferromagnesium minerals.

21. Speleotherms are deposits of calcite that form from dripping water in subterranean cavities. They essentially belong to two main categories: stalactites and stalagmites. Stalactites are protrusions that hang from the roof of caves that form as calcite precipitates from dripping water. They are often found aligned with cracks in the cave ceiling. Stalagmites, on the other hand, are conical projections that form on the cave floor as water precipitates from dripping water. Thus, stalactites grow downwards, while stalagmites grow upwards.

22. Sinkholes are depressions on the landscape that form when roofs of subterranean cavities collapse. Alternatively, sinkholes can form when downward percolating groundwater enlarges cracks in soluble rocks such as limestone, rock salt (halite), or gypsum.

23. Geodes are rock cavity infills with an exterior that comprises layers of non-crystalline (amorphous) silica, and an interior that is often hollow and contains well-formed crystals projecting inwards. Geodes form when crystal growth fills in the cavities.

24. When hot water discharges from the ground, it often has minerals crystallizing from solution as it exits. Under such circumstances, deposits of calcite form travertine, while precipitating silica forms sinter. The type of precipitate is determined by the geology of the subsurface.

25. As a source of electricity, geothermal energy offers some advantages over fossil fuels because it has no emissions such as those associated with coal, oil, or natural gas. However, steam from the hot water often contains hydrogen sulphide gas, which is toxic, and the hot water itself may contain metal ions in solution such as lead and mercury, which are harmful to biological organisms. The extraction of water for geothermal energy may also lead to ground subsidence, although pumping the cooled water back into the ground may circumvent this. Finally, geothermal fluids are commonly highly corrosive.