Hazardous Substance Research Center · South & Southwest

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Understanding the Principles of Groundwater

This document has been prepared by the South/Southwest (S/SW) Technical Outreach Services to Communities (TOSC) program to increase understanding of groundwater principles. Many of the environmental problems faced by communities involve the seepage of contaminants into groundwater. If you have any questions regarding the following please do not hesitate to contact program staff at 888-683-5963.

Aquifer

An aquifer is an underground rock or sediment layer composed of materials such as sand, soil, or gravel. These layers are either filled (saturated) with water, can store groundwater, or are sufficiently porous (permeable) to allow water to flow into wells and springs. Aquifers become useful sources of drinking water when production wells are drilled into their water-bearing layers. A well pump draws the water from the subsurface to the surface and feeds it into a water-distribution system. Each aquifer has areas (or zones) that influence the movement of contaminants in groundwater. Recognition of these locations promotes understanding of the possible location of contaminants and the technology needed for treatment.

Unsaturated zone: It is located between the land surface and the water table and sometimes called the vadose zone.

Saturated zone. This is the saturated portion of soil or rock within the water table. It is the zone in which voids in rock or soil are filled with water.

Groundwater table. The groundwater table is the boundary between the saturated and unsaturated zones beneath the earth's surface. The groundwater table is typically the level to which water will rise in a well. The level of the water table may change based on rainfall levels and seasonal variations.

Capillary fringe. This is the zone immediately above the water table, serving as the the "line" between the unsaturated and saturated portions of the aquifer. Capillary force is the tendency of water to be drawn upward towards "drier" areas.

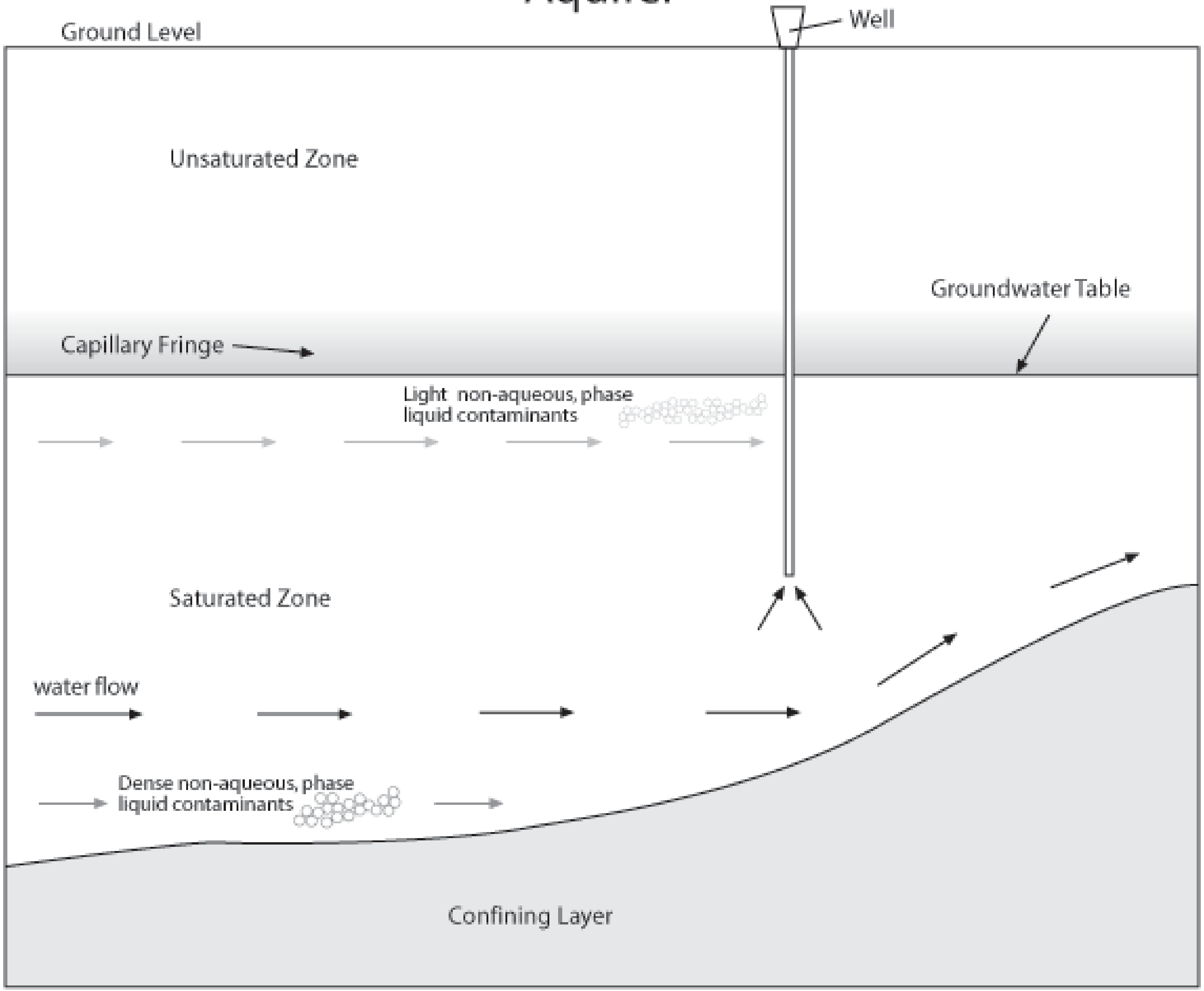
Confining layer. A confining layer is a body of material next to an aquifer with little room between particles for liquid to flow through. For example, dense clays often act as confining layer. Material that *slows down* the flow is called a semi-confining layer, while material that *stops* any flow from passing through is a confining layer.

Permeability and Porosity

An aquifer's porosity and permeability determine how good a source of water it is and the direction and speed of water flow.

Porosity is the ratio between the volume of soil or rock particles and the volume of the area or medium they occupy. For example, sand is considered very porous because it does not restrict the flow of water. Clay is not considered porous because these particles are so close together that they restrict water flow.

Aquifer



Permeability is the relative ease that a liquid flows through a a porous medium. Permeability is determined by the size of the pore opening of the porous medium and not by the nature of the liquid.

Groundwater

Groundwater is the water contained in interconnected pores below the water table. The depth of the water table or groundwater depends on the make-up of the aquifer. In some areas of Florida, it is as shallow as three feet below ground surface. In dry areas such as Arizona, the groundwater may be 200 feet below ground level. Groundwater speed and flow characteristics determine how dissolved contaminants flow through them.

Flow. When rain falls, water soaks into the ground and drains down through the subsurface soil until it reaches the water table. Gravity causes water to flow horizontally from areas of higher elevation to areas of lower elevation. For example, rain falling on a mountain side naturally flows to lower elevation levels. Groundwater follows a similar pattern, flowing horizontally toward sea level. The groundwater table has the same general shape as the surface of the earth above it. Water also flows along the path of least resistance, typically downward. However, if the water encounters a semi-confining or confining layer and cannot flow through it ssmall pore spaces, it normally will begin to flow parallel to the ground on top of the confining layer. This is important to remember when assessing how contaminants spread in groundwater.

Speed. The speed that water travels through permeable soil or rock is due to characteristics of the fluid and the media it flows through. The thicker (or more viscous) the fluid is, the slower it moves. For example, oil has a higher viscosity than water and therefore flows more slowly through a medium. The porosity and permeability of the media also affects water speed. The more permeable the medium, the faster water will flow through it. In such cases, engineers say that water has high hydraulic conductivity.

Contaminant Movement

A water-borne contaminant is a substance that renders water unfit for human consumption. The solubility and specific gravity of the contaminant affect its ability to move through an aquifer.

Solubility. A contaminant's solubility is its ability to dissolve in water. Solubilities of contaminants can range from completely dissolvable to nearly insoluble (not dissolvable at all). The more soluble a contaminant is, the easier it can spread through the environment.

Specific gravity. The specific gravity of a substance is the ratio of its weight at a given volume compared to the weight of the same volume of water. The specific gravity of water is one. If the specific gravity of a contaminant is less than one, then that substance will float on water. If the specific gravity of a contaminant is greater than one, the substance will sink in water. Solubility and specific gravity are two of the factors that determine how freely a contaminant can move between phases—that is, from air to soil to water. Phases of contaminants include the gas phase (in the air), sorbed phase (attached onto or absorbed into soil), dissolved phase (in the water), and free phase (in soil or water).

Gas Phase. Contaminants in the gas phase are either airborne contaminants or trapped in the air space between soil particles.

Sorbed Phase. This phase describes soil that is contaminated with a constituent.

Dissolved Phase. This term typically refers to contaminants that have permeated into water. When a contaminant is dissolved, it is not easy to distinguish it from the water. Dissolved phase contamination is difficult to treat unless the contaminant is separated from the water.

Free Phase. When free phase contamination is present, two distinct layers are visible in groundwater. The generic technical term for a free phase contaminant is non-aqueous phase liquid (NAPL). NAPLs do not mix or dissolve into water. Free phase contamination occurs when the volume of contaminant available to be dissolved into water exceeds its solubility limit. The additional contaminant forms a separate layer either above or below the water table.

Where the NAPL forms, its layer or pool depends on its weight in relation to water (specific gravity). Dense non-aqueous phase liquids, or DNAPLs, sink in water because their specific gravity exceeds that of watr. Light non-aqueous phase liquids, or LNAPLs, float on water because their specific gravity is less than that of water. Both light and dense NAPLs may be partially dissolvable (soluble) in water so that a dissolved portion as well as non-dissolved portion exist.

In the unsaturated zone, LNAPLs move downward like water because of gravity and capillary forces. If areas are already wet with water, LNAPLs may displace some of the capillary water. Once the LNAPL reaches an area close to 100% saturation adjacent to the water table, it begins to accumulate in this location. Residual LNAPL may remain trapped near the top of the water table.

The flow of LNAPLs is complicated by seasonal variations in water table levels. While the floating contaminant will move with the surface of the water table, pockets of LNAPL may be submerged if the water table moves faster than the oil can move through the soil. These pockets form “pools” of LNAPL that are difficult to identify and clean up. In additon, the amount of soil impacted by residual LNAPL may increase based upon water table fluctuations.

When spilled on land, DNAPLs move by gravity through the unsaturated zone once their residual saturation levels are exceeded. Initially, the DNAPLs move through larger pores with less resistance to fluids. DNAPLs coat soil grains and eventually trap water by replacing any air in the soil particle. DNAPLs continue downward through the saturated zone until they reach a semi-confining layer.

The DNAPL moves laterally when it dissolves slowly into the groundwater or the groundwater itself is moving laterally. Depending on their relative proportions, only the water or the NAPL may be mobile.

Source:

Fetter, C.W., “Applied Hydrogeology, Second Edition.” Macmillan, New York, 1988.