Title
Basic Concepts of Groundwater Hydrology

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This Reference Sheet is part of the **Farm Water Quality Planning (FWQP)** series, developed for a short course that provides training for growers of irrigated crops who are interested in implementing water quality protection practices. The short course teaches the basic concepts of watersheds, nonpoint source pollution (NPS), self-assessment techniques, and evaluation techniques. Management goals and practices are presented for a variety of cropping systems.

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Reference:

Basic Concepts of Groundwater Hydrology

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Life depends on water. Our entire living world—plants, animals, and humans—is unthinkable without abundant water. Human cultures and societies have rallied around water resources for tens of thousands of years—for drinking, for food production, for transportation, and for recreation, as well as for inspiration.

Worldwide, more than a third of all water used by humans comes from ground water. In rural areas the percentage is even higher: more than half of all drinking water worldwide is supplied from ground water.

In California, rural areas' dependence on ground water is even greater. California has 8,700 public water supply systems. Of these, 7,800 rely on ground water, drawing from more than 15,000 wells. In addition, there are tens of thousands of privately owned wells used for domestic water supply within the state. Although sufficient aquifers for this sort of use underlie much of California (Figure 1), the large metropolitan areas in Southern California and the San Francisco Bay Area rely primarily on surface water for their drinking water supplies. Overall, ground water supplies one-third of the water used in California in a typical year, in drought years as much as one-half.

WHAT IS GROUND WATER?

Despite our heavy reliance on ground water, its nature remains a mystery to many people. Many find it hard to imagine that water can move underground at rates sufficient to allow California's largest springs to discharge almost 1 million gallons per minute (e.g., Fall River in Shasta County). Likewise, it is hard to understand how a domestic or irrigation well can extract from 500 to 2,000 gallons of water per minute out of a pipe in the ground that is merely 1 foot in diameter. More often than not, people envision that ground water exists somehow in a mysterious, hidden system of underground rivers, reservoirs, and water "veins." Although these terms may be useful when speaking metaphorically about ground water, they are far from accurate.

Ground water is water that fills pores and fractures in the ground, much as milk fills the voids within bits of granola in a breakfast bowl (Figure 2). The top of ground water is called the *water table*. Between the water table and the land surface is the *unsaturated zone* or *vadose zone*. In the unsaturated zone, moisture is moving downward to the water table to recharge the ground water. The water table can be very close to the surface (within a few feet), or very deep (up to several hundred feet). In most California regions, the water table is between 10 and 100 feet below the land surface (in some Southern California desert basins it is as deep as 300 feet).

It is in California's numerous valleys and intermontane basins that ground water exists in the greatest quantity (California and Nevada groundwater basins are shown in Figure 1). The basins are like large bathtubs enclosed by the rocks of surrounding mountains. Over millions of years, these "bathtubs" were filled with hundreds and even thousands of feet of sediment and debris that were carried into the basins by

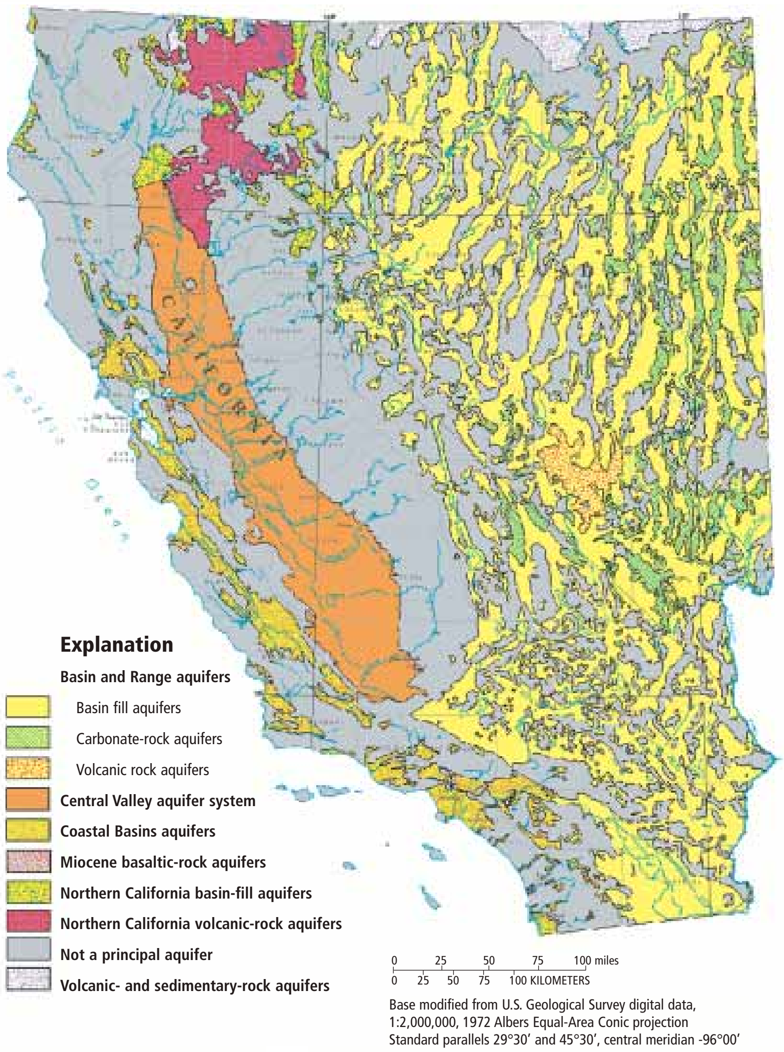

Figure 1. Groundwater basins of California and Nevada (Source: http://capp.water.usgs.gov/gwa/ch_b/index.html, USGS Groundwater Atlas Figure 11 in section HA 730-B).

rivers and floods (Figure 3). In these so-called *alluvial basins,* ground water fills small, often microscopic pores between the grains of gravel, sand, silt, and clay.

In the rocks that make up the hills and mountains of California's uplands, ground water is also quite common, although in most cases not nearly as plentiful. In these rocks ground water occupies practically every fracture and fissure below the water table. However, unless fractures are large and numerous, little water can be extracted.

AQUIFERS, AQUITARDS, AND SPRINGS

A geologic formation from which significant amounts of ground water can be pumped for domestic, municipal, or agricultural uses is known as an *aquifer.* In some cases, aquifers are vertically separated from each other by geologic formations that permit little or no water to flow in or out. A formation that acts as such a water barrier is called *aquitard* if it is much less permeable than a nearby aquifer but still permits flow (e.g., sandy clay). If the water barrier is almost impermeable (e.g., clay) and forms a formidable flow barrier between aquifers, it is known as an *aquiclude.*

Aquifers can be of two major types: *unconfined* or *confined.* An unconfined aquifer has no overlying aquitard or aquiclude (Figure 4). Where there are multiple levels of aquifers, the uppermost aquifer typically is unconfined. Vertical recharge of an unconfined aquifer by rainwater or irrigation water that filters downward through the soil is not restricted. The water table at the top of the unconfined aquifer can migrate freely up and down within the sediment formation, depending on how much water is stored there (Figure 3). The water level in a borehole drilled into an unconfined aquifer will be at the same depth as the water table in the aquifer.

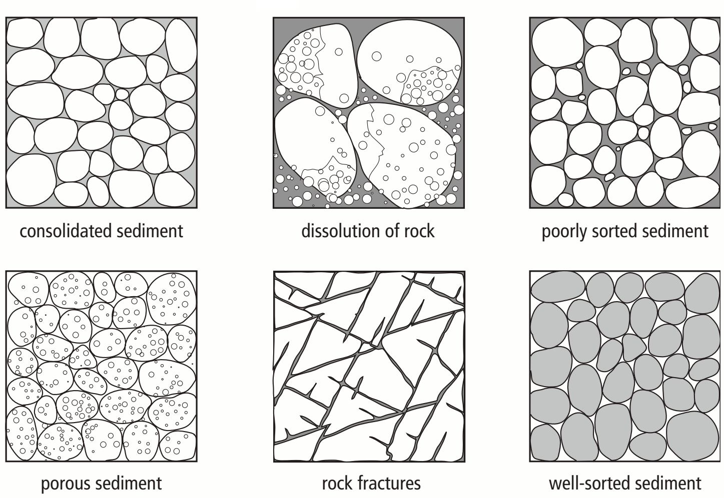

Figure 2. Types of pore space in sediments and rocks.

A confined aquifer, on the other hand, is sandwiched between an aquitard above and an aquiclude or aquitard (e.g., bedrock) below (Figure 4). Because the water table in the recharge area of the confined aquifer is much higher than the top of the confined aquifer itself, water in a confined aquifer is pressurized. This pressurization means that

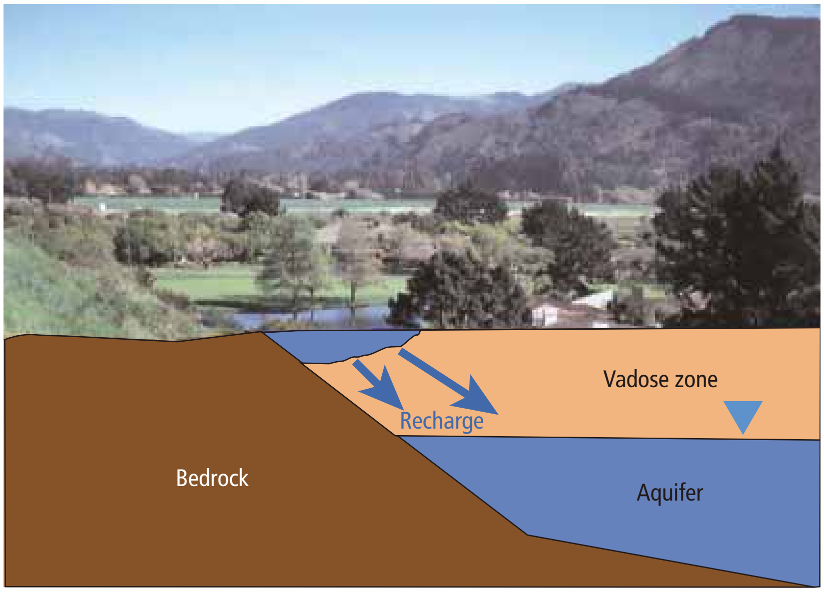

Figure 3. Schematic cross-section of an unconfined aquifer in a California valley filled with alluvial sediments. The bottom point of the inverted triangle indicates the position of the water table.

the water level in a borehole drilled into a confined aquifer will rise significantly above the top of the aquifer. A *flowing artesian well* occurs where the pressure is so high that the water level in a well drilled into the confined aquifer rises above the land surface—in other words, an open well flows freely with no pumping.

Sometimes hydrogeologists use the term *semi-confined aquifer* if an aquifer acts partly like a confined aquifer (particularly if pumping rates are low or if pumping is necessary only over a relatively short period of time) and partly like an unconfined aquifer (for example, after long periods of heavy pumping).

Springs form where the water table intersects with the land surface: for example, in a small depression (common on hillsides). Sometimes ground water is forced into a spring because a low permeable layer of rock or fine sediments (clay) keeps the water from percolating deeper. A spring may also occur where subsurface pressure forces water to the surface through a fracture or fault zone that acts as a conduit for water movement from a confined aquifer.

DIRECTION AND SPEED OF GROUNDWATER MOVEMENT

Ground water moves from higher elevations to lower elevations and from locations of higher pressure to locations of lower pressure. Typically, this movement is quite slow, on the order of less than one foot per day to a few tens of feet per day. In groundwater hydraulics (the science of groundwater movement), water pressure surface and water table elevation are referred to as the *hydraulic head*. Hydraulic head is the driving force behind groundwater movement. Groundwater movement is always in the downward direction of the hydraulic head gradient (Figure 5). If there is no hydraulic head gradient, there is no flow. The hydraulic gradient is often but not always similar to that of the land surface. In most areas of California's valleys and basins the hydraulic gradient is in the range of 0.5 to 10 feet per thousand feet (0.05 to 1.0 percent).

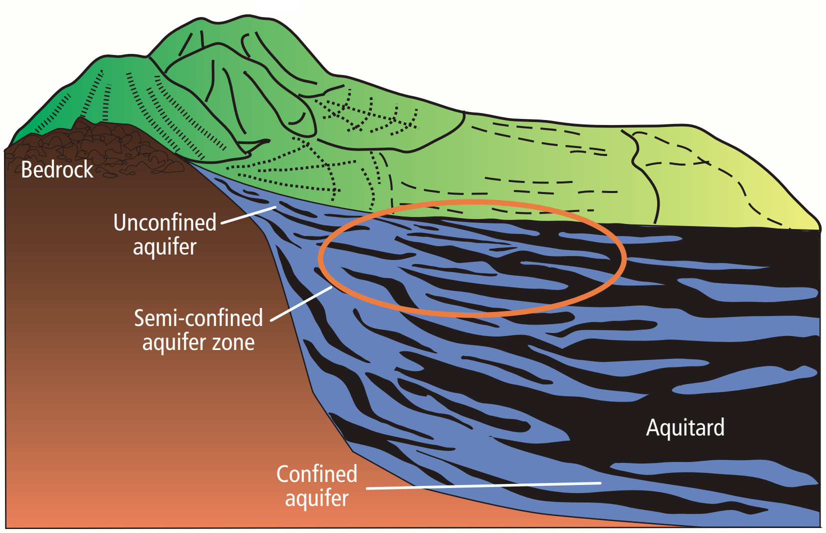

Figure 4. Unconfined, semi-confined, and confined aquifers in a typical California alluvial basin. Dark-colored sediments indicate fine-grained clay or predominantly clay materials *(aquitard)*. Light-colored materials indicate coarser-grained aquifer materials.

Groundwater movement in gravels and sands is relatively rapid, whereas it is exceedingly slow in clay or in tiny rock fractures. The ability of geologic material to move ground water is called *hydraulic conductivity*. It is measured in gallons per day per square foot (gpd/ft^2) or in feet per day (ft/day). The amount

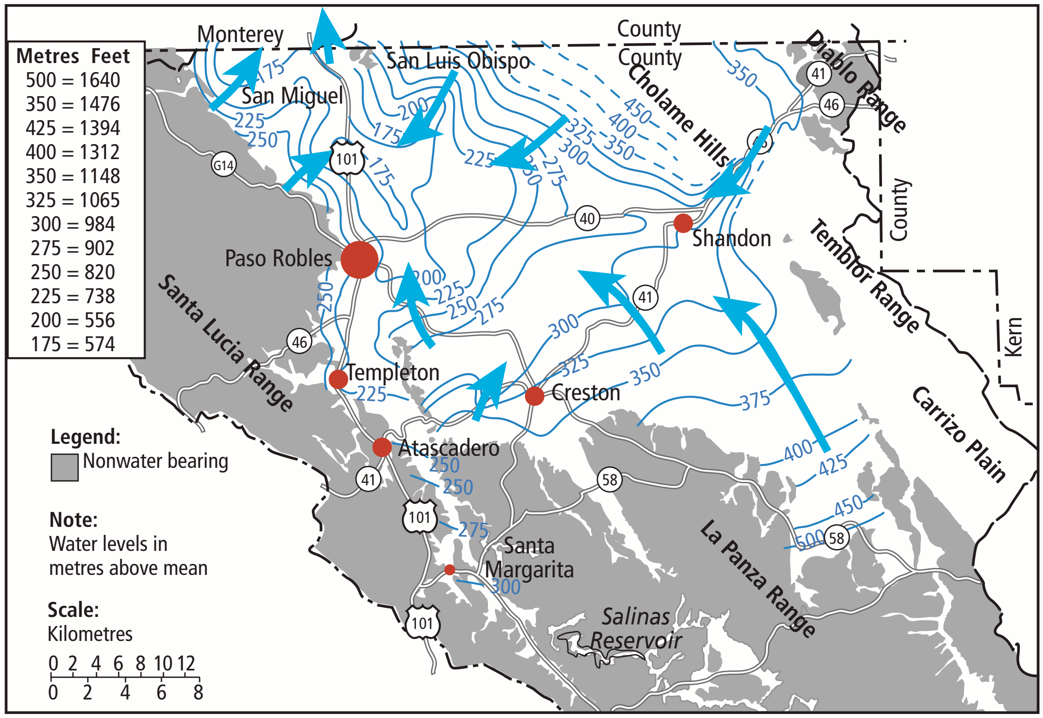

Figure 5. Water level contours and approximate direction of groundwater flow *(arrows)* in the Paso Robles Basin, Monterey and San Luis Obispo Counties, California. *Source:* California Department of Water Resources.

of groundwater flow is greater with higher hydraulic conductivity, even if the hydraulic gradient is the same. The hydraulic conductivity of sandy or gravelly aquifers typically ranges from 100 to 10,000 gallons per day (gpd) per square foot (approximate equivalent: 10 to 1,000 ft/day). On the other hand, the hydraulic conductivity of clays, which consist of tiny particles that stick together and block water movement, is a tiny fraction of the hydraulic conductivity of a sandy aquifer: 0.001 gallon per day per square foot or less. The hydraulic conductivity of fractured rock depends greatly on the degree of fracturing. It may be as high as 10 to 100 gpd per square foot (approximately 1 to 10 ft/day).

The groundwater velocity is the product of hydraulic conductivity and hydraulic gradient, with adjustments for the porosity of the soil material (usually from 5 to 20 percent):

$$\text{groundwater velocity} = \frac{\text{hydraulic conductivity} \times \text{hydraulic gradient}}{\text{porosity}}$$

This is called *Darcy's Law,* named after the French engineer Henry Darcy who first discovered this natural law in the Nineteenth Century. Typical groundwater velocity in a sandy or gravelly aquifer may range from 0.5 to 50 feet per day.

GROUND WATER IN THE CALIFORNIA HYDROLOGIC CYCLE

Ground water is part of the hydrologic cycle (see Reference Sheet 10.1, Watershed Function [ANR Publication 8064]). Aquifers are recharged from precipitation, seepage from rivers, and seepage from irrigated fields. If no one pumps the ground water, aquifers eventually "overflow;" that is, they discharge water to the surface through springs and seepage along river beds and lakes in the lower parts of California's valleys and basins. A century of groundwater pumping has lowered water levels in many areas of California and established a new balance between recharge and groundwater pumping. During a series of wet years less water is pumped from wells, and that allows water levels to rise as a result of surplus recharge. During dry years, however, the amount of recharge water is typically much less than the amount of ground water pumped and groundwater levels drop. If groundwater recharge cannot keep pace with extraction over an extended period of years, despite the absence of a major drought, the groundwater basin is said to be in *overdraft*.

In California the regional pattern of groundwater recharge and pumping and its interaction with rivers is dictated by topography and the availability of surface water for groundwater recharge. Most of California has a semi-arid to arid climate. The largest amount of surface water available for recharge is near the mountain fronts where perennial, intermittent, or ephemeral streams draining California's uplands (e.g., Coast Range, Sierra Nevada, mountain ranges of the desert southeast) flow onto the highly permeable, unconsolidated sediments that fill California's valleys and basins. Thus, most of California's streams provide significant groundwater recharge.

Rainfall also recharges ground water, but in California's large groundwater basins direct recharge from precipitation accounts for only a minor fraction of the total recharge. In the agricultural valleys, deep percolation from summer irrigation is a much more important source of recharge than winter precipitation. Recharge from natural precipitation is only significant in some of the coastal valleys, in inland basins in northern California, and in the small groundwater basins nestled in California's mountain ranges.

FOR MORE INFORMATION

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