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Water Well Design and Construction

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Water Well Design and Construction

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WATER WELL BASICS

A water well is a hole, shaft, or excavation used for the purpose of extracting ground water from the subsurface. Water may flow to the surface naturally after excavation of the hole or shaft. Such a well is known as a *flowing artesian well*. More commonly, water must be pumped out of the well.

Most wells are vertical shafts, but they may also be horizontal or at an inclined angle. Horizontal wells are commonly used in *bank filtration,* where surface water is extracted via recharge through river bed sediments into horizontal wells located underneath or next to a stream. The oldest known wells, *Qanats,* are hand-dug horizontal shafts extending into the mountains of the old Persian empire in present-day Iran.

Some wells are used for purposes other than obtaining ground water. Oil and gas wells are examples of this. Monitoring wells for groundwater levels and groundwater quality are other examples. Still other purposes include the investigation of subsurface conditions, shallow drainage, artificial recharge, and waste disposal.

In this publication we focus on vertical water-production wells commonly used to supply water for domestic, municipal, and agricultural uses in California. Our purpose is to provide readers with some basic information about water wells to help them understand principles of effective well construction when they work with a professional driller, consultant, or well servicing agency for well drilling and maintenance.

DETERMINING A WELL LOCATION

The location of a well is mainly determined by the well's purpose. For drinking and irrigation water-production wells, groundwater quality and long-term groundwater supply are the most important considerations. The hydrogeological assessment to determine whether and where to locate a well should always be done by a knowledgeable driller or professional consultant. The water quality criteria to use for drinking water wells are the applicable local or state drinking water quality standards. For irrigation wells, the primary chemical parameters of concern are salinity and boron and the sodium-adsorption ratio.

Enough ground water must be available to meet the pumping requirements of the wells. For large municipal and agricultural production wells, pumping rate requirements range from about 500 to 4,000 gallons per minute (gpm). Small- and medium-sized community water systems may depend on water wells that produce from 100 to 500 gpm. Individual homes' domestic wells may meet their needs with as few as 1 to 5 gpm, depending on local regulations. To determine whether the desired amount of ground water is available at a particular location and whether it is of appropriate quality, drillers and groundwater consultants rely on their prior knowl-

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A Water Quality and Technical Assistance Program for California Agriculture

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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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Well Design Objectives

- Highest yield with minimum drawdown
- Good quality water with proper protection from contamination
- Sand-free water
- Long lifetime (>50 years)
- Reasonable short-term and long-term costs

edge of the local groundwater system, experience in similar areas, and a diverse array of information such as land surface topography, local vegetation, rock fracturing (where applicable), local geology, groundwater chemistry, information on thickness, depth, and permeability of local aquifers from existing wells, groundwater levels, satellite or aerial photographs, and geophysical measurements.

In most cases, the well location is further limited by property ownership, the need to keep surface transportation of the pumped ground water to a minimum, and access restrictions for the drilling equipment. When locating a well, one should also consider the proximity of potential sources of contamination such as fuel or chemical storage areas, nearby streams, sewer lines, and leach fields or septic tanks. The presence of a significant barrier between such potential sources and the well itself is very important for the protection of the well.

WATER WELL DESIGN AND INSTALLATION

Once the well location has been determined, a preliminary well design is completed. For many large production wells, a test hole will be drilled before well drilling to obtain more detailed information about the depth of water-producing zones, confining beds, well production capabilities, water levels, and groundwater quality. The final design is subject to site-specific observations made in the test hole or during the well drilling.

The overall objective of the design is to create a structurally stable, long-lasting, efficient well that has enough space to house pumps or other extraction devices, allows ground water to move effortlessly and sediment-free from the aquifer into the well at the desired volume and quality, and prevents bacterial growth and material decay in the well (see sidebar, Well Design Objectives).

A well consists of a bottom sump, well screen, and well casing (pipe) surrounded by a gravel pack and appropriate surface and borehole seals (Figure 1). Water enters the well through perforations or openings in the well screen. Wells can be screened continuously along the bore or at specific depth intervals. The latter is necessary when a well taps multiple aquifer zones, to ensure that screened zones match the aquifer zones from which water will be drawn. In alluvial aquifers, which commonly contain alternating sequences of coarse material (sand and gravel) and fine material, the latter construction method is much more likely to provide clean, sediment-free water and is more energy efficient than the installation of a continuous screen. Hardrock wells, on the other hand, are constructed very differently. Often, the borehole of a hardrock well will stand open and will not need to be screened or cased unless the hard rock crumbles easily.

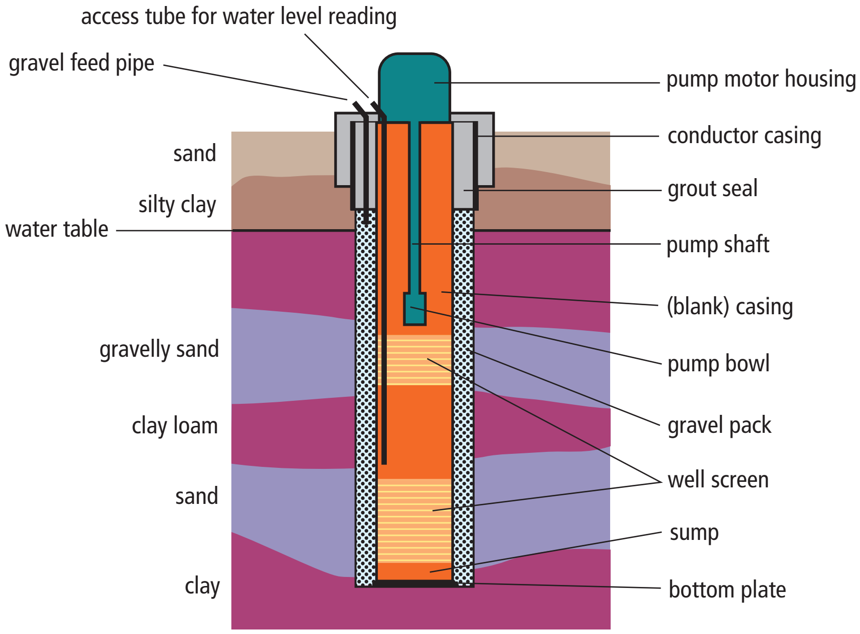

Figure 1. Components of a well.

Drilling a Well: Overview

The process of designing and constructing a water well begins when you make arrangements with a licensed driller or with a professional consultant who designs the well and oversees the work of the licensed driller. We strongly recommended against any reliance on dowsers or well witchers to locate a well site. Research shows no scientific or other reliable basis to substantiate the use of water dowsing as a means to locate a well site.

The driller or consultant finds a suitable location to meet the specified purpose of the well and a preliminary design is established. Once the drilling rig is set up, the drilling process itself may last from a few hours (for a shallow, small-diameter well) to several weeks (for a deep, large-diameter well). Sometimes, particularly for large production wells and where water quality is particularly important, the driller will drill a small-diameter pilot hole before drilling the well bore. From information obtained from the pilot hole, a driller or consultant can determine aquifer formations and groundwater quality at various depths and then optimize the final well design for the specific hydrogeological conditions at the site. Appropriate materials (screen, casing, gravel) can then be ordered in a timely fashion prior to the final drilling.

Once the well bore is drilled, the driller installs well casing and well screens and fills the annulus around the casing with a gravel (filter) pack and the appropriate cement and bentonite seal to prevent water from leaking between uncontaminated and contaminated aquifers or from the land surface into the well (*bentonite* is a special type of clay used to seal against water leaks). Then the driller develops the well (see Well Development), implements an aquifer test, completes the sanitary seal of the well head, and installs a pump and power source. Proper design, construction, development, and completion of the well will result in a long life for the well (as long as half a century or more) and efficient well operation.

The purpose of the screen is to keep sand and gravel from the gravel pack (described below) out of the well while providing ample water flow to enter the casing. The screen should also be designed to allow the well to be properly developed (see Well Development). Slotted, louvered, and bridge-slotted screens and continuous wire wrap screens are the most common types. Slotted screens provide poor open area. They are not well suited for proper well development and maintenance, and are therefore not recommended. Wire wrap screens or pipe-based wire wrap screens give the best performance. The additional cost of wire wrap screens can be offset if you only install screen sections in the most productive formations along the borehole.

The purposes of the blank well casing between and above the well screens are to prevent fine and very fine formation particles from entering the well, to provide an open pathway from the aquifer to the surface, to provide a proper housing for the pump, and to protect the pumped ground water from interaction with shallower ground water that may be of lower quality.

The annular space between the well screen, well casing, and borehole wall is filled with gravel or coarse sand (called the *gravel pack* or *filter pack*). The gravel pack prevents sand and fine sand particles from moving from the aquifer formation into the well. The gravel pack does not exclude fine silt and clay particles; where those occur in a formation it is best to use blank casing sections. The uppermost section of the annulus is normally sealed with a bentonite clay and cement grout to ensure that no water or contamination can enter the annulus from the surface. The depth to which grout must be placed varies by county. Minimum requirements are defined in the *California Well Standards* (Bulletin 74–90, California Department of Water Resources [http://www.water.ca.gov]): 50 feet for community water supply wells and industrial wells and 20 feet for all other wells. Local county ordinances may have more stringent requirements depending on local groundwater conditions.

At the surface of the well, a surface casing is commonly installed to facilitate the installation of the well seal. The surface casing and well seal protect the well against contamination of the gravel pack and keep shallow materials from caving into the well. Surface casing and well seals are particularly important in hardrock wells to protect the otherwise open, uncased borehole serving as a well.

WELL DRILLING

Wells can be constructed in a number of ways. The most common drilling techniques in California are rotary, reverse rotary, air rotary, and cable tool. Auger drilling is often employed for shallow wells that are not used as supply

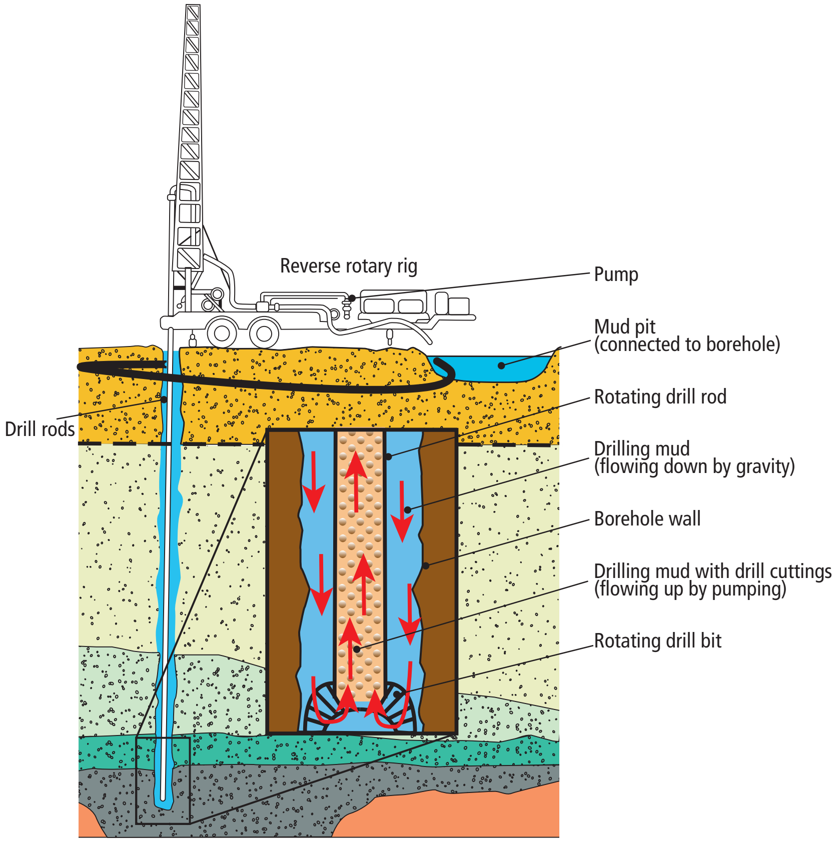

Figure 2. Principles of reverse rotary drilling. (adapted from Driscoll, 1996. Johnson Screens/A Wetherford Company is publisher and copyright holder.)

wells. In unconsolidated and semi-consolidated materials, (reverse) rotary (Figure 2) and cable tool methods are most commonly employed. Hardrock wells generally are drilled with air rotary drilling equipment.

Properly implemented, all of these drilling methods will produce equally efficient and productive wells where ground water is available. Cable tool drilling generally is less labor-intensive but takes more time than (reverse) rotary drilling. Reverse rotary and rotary drilling require large amounts of circulation water and the construction of a mud pit, something to be considered if the well is to be drilled in a remote location with no access to water.

During drilling, drillers must keep a detailed log of the drill cuttings obtained from the advancing borehole. In addition, after the drilling has been completed but before the well is installed, it is often desirable to obtain more detailed data on the subsurface geology by taking geophysical measurements in the borehole. Specialized equipment is used to measure the *electrical resistance* and the *self-potential* or *spontaneous potential* of the geological material along the open borehole wall. The two most important factors that influence these specialized logs are the texture of the formation and the salinity of the ground water. Sand has a higher resistance than clay, while high salinity reduces the electrical resistance of the geological formation. Careful, professional interpretation of the resistance and spontaneous potential log and the drill cuttings' description provides important information about water salinity and the location and thickness of the aquifer layers. The information obtained is extremely useful when finalizing the well design, which includes a determination of the depth of the well screens, the size of the screen openings, and the size of the gravel pack material.

Because of timing issues, it is better—especially in remote areas—to drill a pilot hole a good deal ahead of the well construction date and obtain all pertinent log information early on from the pilot hole. The well design can then be completed and the proper screen, casing, and gravel materials can be ordered for timely delivery prior to the drilling of the well.

Note that a copy of all well log information should be given to the person who pays for the drilling job. The Department of Water Resources keeps copies of all well logs and has a large collection of past well logs. These can be requested by a well owner if the original records are unavailable. The well log contains important information about construction details and aquifer characteristics that can be used later for troubleshooting well problems.

WELL DEVELOPMENT

After the well screen, well casing, and gravel pack have been installed, the well is *developed* to clean the borehole and casing of drilling fluid and to properly settle the gravel pack around the well screen. A typical method for well development is to surge or jet water or air in and out of the well screen openings. This procedure may take several days or perhaps longer, depending on the size and depth of the well. A properly developed gravel pack keeps fine sediments out of the well and provides a clean and unrestricted flow path for ground water.

Proper well design and good well development will result in lower pumping costs, a longer pump life, and fewer biological problems such as iron-bacteria and slime build-up. Poorly designed and underdeveloped wells are subject to more frequent pump failures because sand and fines enter the well and cause significantly more wear and tear on pump turbines.

Poorly designed and underdeveloped wells also exhibit greater water level drawdown than do properly constructed wells, an effect referred to as *poor well efficiency.* Poor well efficiency occurs when ground water cannot easily enter the well screen because of a lack of open area in the screen, a clogged gravel pack, bacterial slime build-up, or a borehole wall that is clogged from incomplete removal of drilling mud deposits. The result is a significant increase in pumping costs. Note that well efficiency should not be confused with pump efficiency. The latter is related to selection of a properly sized pump, given the site-specific pump lift requirements and the desired pumping rate.

Once the well is completed and developed, it is a good practice to conduct an *aquifer test* (or *pump test*). For an aquifer test, the well is pumped at a constant rate or with stepwise increased rates, typically for 12 hours to 7 days, while the water levels in the well are checked and recorded frequently as they decline from their standing water level to their pumping water level. Aquifer tests are used to determine the efficiency and capacity of the well and to provide information about the permeability of the aquifer. The information about the pumping rate and resulting pumping water levels is also critical if you are to order a properly sized pump.

Once the well development and aquifer test pumping equipment is removed, it may be useful to use a specialized video camera to check the inside of the well for damage, to verify construction details, and to make sure that all the screen perforations are open.

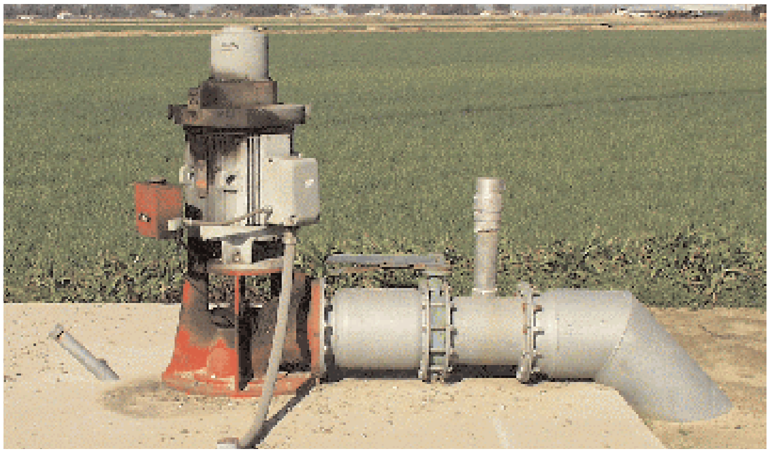

Figure 3. Properly completed well with elevated concrete seal (but with leaking lubricant).

WELLHEAD PROTECTION

The construction of the final well seal is intended to provide protection from leakage and to keep runoff from entering the wellhead (Figure 3). Minimum standards for surface seals have been set by the California Department of Water Resources (DWR Bulletin 74–90). It is also important to install backflow prevention devices, especially if the well water is mixed with chemicals such as fertilizer and pesticides near the well. A backflow prevention device is intended to keep contaminated water from flowing back from the distribution system into the well when the pump is shut off.

FOR MORE INFORMATION

For more online information on groundwater-related topics, visit http://waterquality.ucanr.org and http://groundwater.ucdavis.edu.

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