WATER WELL DESIGN, CONSTRUCTION, AND DEVELOPMENT: IMPORTANT CONSIDERATIONS BEFORE MAKING THE INVESTMENT

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INTRODUCTION

Water wells are expensive. A domestic well can cost between $5,000 and $10,000. An irrigation well can cost in excess of $40,000 and as much as $150,000 or more. The actual cost will depend upon the depth to groundwater, the desired well capacity, and choices among a variety of well drilling, well design, well construction, and well development considerations. Given this magnitude of investment, it is easy to understand the motivation to save on costs at every possible opportunity. This issue of this informational series on groundwater and water wells discusses these important considerations. Choosing the most appropriate approach when investing in a well is site specific and largely dependent upon how extensively the well will be used. Sometimes a simple, less expensive well will suffice and other times added investment in drilling, design, construction, and development will pay back substantially.

WELL EFFICIENCY – WHAT IS IT? WHY IS IT IMPORTANT?

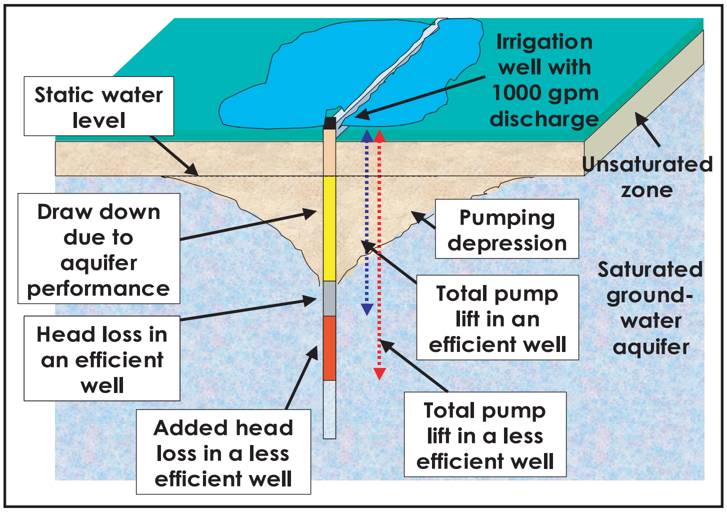

Figure 1. Schematic showing concept of well efficiency.

Well design and construction choices affect how efficiently the water in the aquifer enters into the well. The less efficiently water enters into the well, the greater the pumping lift and yearly energy bill, regardless of the pumping plant design and level of pumping plant efficiency.

The concept of well efficiency is shown in Figure 1. A pumping depression is shown and the extent of the depression is determined by the geologic material in the aquifer and its capacity to transmit water. A corresponding level of drawdown is shown in the well column and is unrelated to the well design. A reasonable amount of head loss in the well column associated with the design of an efficient well is also shown. Every well will have some head loss, some more than others depending on the well design. However, if the well is poorly designed and inefficient, the potential for added head loss exists as illustrated in Figure 1. The two vertical dashed lines denote the potential for well design to affect the total pump lift and annual cost of pumping during the life of the well.

Efficient wells result in less total pumping lift and higher specific well capacity (gpm/ft drawdown). This translates to reduced horsepower needed to lift the water and to decreased hours of pump operation to irrigate a given acreage of crops. Various case studies have conservatively suggested a range from about $300 to $1500 per year in savings on electricity or fuel costs when improved well design reduces the pumping lift on the order of 10 to 50 feet. Over the expected life of a well (30 to 50 years), the cumulative savings in energy costs and reduced repairs may be on the order of $10,000 to over $75,000 depending upon the extent that the pumping lift is reduced and the extent that the well capacity is increased. Life of the pump bowls is extended because improved well design reduces sand and other abrasives from entering the well. Improved well design can extend the life of the well by protecting against encrustation of the well screens. Improved well designs can also minimize impact to other groundwater users by targeting specific aquifers and avoiding others.

FACTORS AFFECTING WELL EFFICIENCY

Well Location

If possible, a new well should be at least 1000 feet away from the nearest well to minimize overlap of the pumping depressions once the new well is in operation. The well site should be easily accessible by drilling rigs and, if rotary methods of drilling are to be used, the well site may need to be large enough to excavate a large pit to handle drilling fluid. In the Sacramento Valley there is a growing base of well drilling experience, so reliable first hand knowledge of a reasonable well site can be provided by a local, experienced well driller.

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Drilling Methods

The three common methods of well drilling used in the Sacramento Valley are percussion, direct rotary, and reverse rotary. Auger drilling and drivers are not typically used in the Sacramento Valley. Air drilling is used primarily in hard rock aquifer systems typically found in intermountain and coastal areas.

Percussion drilling is the oldest method historically used in the Sacramento Valley. Figures 2 shows a cable tool drill rig consisting of a large, metal ram, referred to as "jars", with a hardened bit on the end. The jars and bit, connected to a cable, are raised and dropped and upon impact pulverize the geologic formation. The cuttings, called "sludge", are gathered into a bailer and are pulled to the surface leaving a hole. The well casing is installed as drilling progresses by pushing, pounding, and jacking it into place.

Figures 2. Cable tool drill rig. Note, small rig and no drilling fluid or pit needed.

The primary advantage of percussion drilling is that it is simple and least expensive. A small drill rig operated by one or two people reduces operating costs. Drilling can be done in small areas because no drilling fluid or circulation pit is needed. Percussion drilling is slow and causes compaction and smearing along the sides of the borehole which decreases well efficiency. There is no opportunity to perform an electric log on the borehole and there is little flexibility to engineer the well design because the casing is installed as the well is drilled.

Direct rotary drilling uses a rotating bit and a viscous drilling fluid to excavate a borehole. Typically a combination of water and bentonite clay is circulated in the borehole to provide pressure against the formation as it is penetrated by the drill bit. This keeps the borehole open during the drilling process and the fluid rises to the surface in the space between the drill pipe and the borehole, carrying the drilling cuttings away into a settling pit. Direct rotary drilling is faster than percussion drilling and it allows evaluation of the aquifer formations and engineering of the well design after the hole has been drilled. Direct rotary drilling is more expensive than percussion drilling and it requires more space for a larger drill rig and settling pit. Well development is required to remove the bentonite drilling fluid from the formation after well construction is completed. Direct rotary drilling is limited to wells smaller than about 22 inches in diameter because it is difficult to circulate the drilling fluid and remove the cuttings from larger diameter boreholes.

Figure 3. Reverse rotary drill rig re-circulating drilling fluid into pit.

Reverse rotary drilling is similar to direct rotary because a rotating bit is used to drill the hole. Also, the hole is drilled before installing the well casing. This allows the aquifer formations to be evaluated using an electric log and provides an opportunity to design the well. However, clean water is used as the drilling fluid rather than a bentonite mixture and the fluid is raised up the center of the drill pipe to carry away the drilling cuttings into a settling pit. By using clean water and directing the drilling fluid up the drilling pipe, clogging of the formation is reduced and less well development is needed once the well has been constructed. Reverse rotary drilling is more expensive, though, because the drill rig is larger and more involved to transport, set up, and operate. A reverse rotary drill rig also requires more space to operate, more space for a larger settling pond, and access to a large supply of clean water but it can drill wells larger than 22 inches in diameter. Figure 3 depicts a reverse rotary drill rig.

Tools for Well Design Engineering

A well log provides information to make well design decisions. It is a written record describing the gravel, sand, silt, and clay in the aquifer formations found during the drilling process. The well log helps identify the depth and thickness of strata that will be the most productive and most effectively transmit water into the well. Sample cuttings are analyzed to determine proper screen openings and gravel pack design. Figure 4 displays a sample collection taken while developing a well log.

Figure 4. Sample drill cuttings collected and separated by depth. Note the change in color and gravel content among the samples.

An **electrical resistivity log (e-log)** is recommended for each borehole. This costs about $1000 to $1500 per borehole and provides helpful information to help identify where productive strata are located and how much well screen is needed. A probe consisting of paired electrodes is lowered into a borehole and an electrical current of a known voltage is sent from one electrode through the geologic formation surrounding the borehole. The second electrode detects the drop in electrical current after it has traveled through the formation. Formations with coarse gravel and sand have greater resistance to electrical current while fine grain formations such as clay have less resistance. Formations that contain saline water have even less resistance. Figure 5 shows an e-log being conducted at a well site and an example e-log.

Well Design Engineering Considerations

Choosing to include some type of **well screen** in the well design is among the first considerations in designing a well. Historically, hundreds of **open bottom** wells have been constructed in the Sacramento Valley. The well column is constructed of solid steel casing and the only entry point for water into the well is an open cavity at the bottom of the well column. These wells are the least expensive because they do not require well screens or gravel packs. However, they can lead to more wear on pumps due to sand and other abrasives and often require more well development.

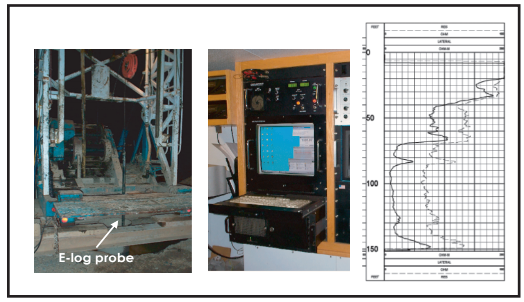


Figure 5. Left photo, electrical resistivity probe is lowered down into borehole. Center photo, data is relayed from probe inside borehole to computer inside van. Right photo, results from e-log show strata with high resistivity and coarse geologic materials from 0 to 40 feet and strata with low resistivity and fine grain geologic materials from 70 to 140 feet Constructing a well with expensive well screens from 70 to 140 feet may increase well construction costs but not necessarily improve well yield.

Well screens, placed adjacent to the most productive water bearing strata will allow water to enter the well while stabilizing the aquifer formation and limiting the amount of sediment entering the well. Three general types of well screens are available for well construction: **slotted, louvered, and continuous wire wrap**. They are displayed in Figure 6. Slotted casing is the least expensive. Mill sawed is most common but torch-cut casing is available. Solid steel casing is sometimes installed in the borehole and then perforated in-place. Slotted casing provides less open area for water to enter the well, results in more head loss, lower well efficiency, and lower well capacity than louvered and wire wrap well screens. Louvered screen is more expensive than slotted but not as expensive as continuous wire wrap. The open area provided with louvered screen is higher than slotted but usually less than continuous wire wrap. Continuous wire wrap screen is more expensive but it provides larger open areas to optimize well yield and efficiency. Triangular shape wires are specifically designed and spaced to prevent sand and other formational materials from entering the well. Compression of the wire screen is sometimes a concern particularly during construction of deep wells.

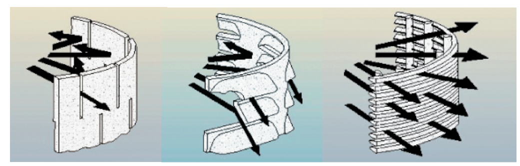


Figure 6. Three types of well screen. Mill slot (left - 2 to 3 % open area), Louver screen (center – 8 to 50 % open area), and Wire Wrap screen (right – 30 to 50 % open area).

A **gravel pack** around the well column increases the effective radius of the well and filters out formational materials such as sand and silt from entering the well through the screens. The typical thickness of the gravel pack is 4 to 6 inches. Well-rounded, graded gravel high in silica should be used in the gravel pack. Gravel size is determined based upon the grain size distribution in the strata targeted for screening. The gradation of the gravel pack will also influence the size of the slot openings in the well screen. Figure 7 provides a photo of a gravel pack.

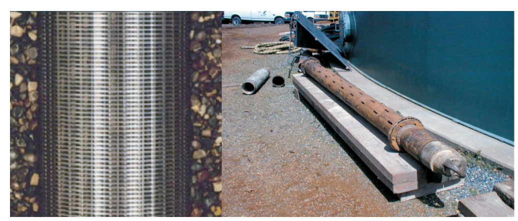


Figure 7. Example of gravel pack around a wire wrap screen (left) and picture of swab/air lift tool used to develop a well (right).

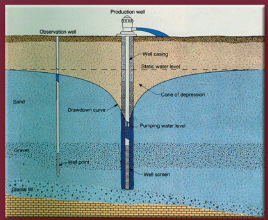
Well development restores the formation around the borehole to near its original porosity and permeability prior to drilling. It repairs damage by removing drilling fluid that may have penetrated the formation. It also sorts and settles the gravel pack or natural formation around the well column enabling it to more effectively transmit water and to filter abrasive sands and other formational materials. Ultimately, well development increases well capacity, well efficiency, and well life.

There are two general forms of well development: mechanical and pumping. Figure 7 shows a swab tool, one method of mechanical well development. During mechanical well development, the swab is raised up and down the well column along the well screen to draw the drilling fluids from the formation through the gravel pack into the well. An airlift raises the drilling fluids to the surface and they are removed. Mechanical development also begins the sorting and settling process that is necessary to develop an effective gravel pack. Pumping development is performed using variable pumping rates beginning with low rates and increasing to the full well capacity. The goal of pumping development is to remove sand from the well. Well development is expensive, adding about $20 per foot to the cost of drilling and constructing a well.

ADDITIONAL INFORMATION

- Water Well Design and Construction. Thomas Harter. 2003. ANR Publication 8086. Available on the web at http://groundwater.ucdavis.edu.
- Water Wells and Pumps: Their Design, Construction, Operation, and Maintenance. V.H. Scott, J.C. Scalmanini. Reprinted 1994. University of California. ANR Bulletin 1889.

NEXT ISSUE – The sixth and final issue of this information series on groundwater and water wells will discuss aspects of energy efficient and cost effective irrigation pumping plants.



This newsletter is the fifth in a series of six discussing topics related to groundwater, water wells and pumping plants.

Water Well Design, Construction, and Development: Important Considerations Before Making the Investment

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This Outreach is funded by the Renewable Resources Extension Act

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