1.10: Wells

Student Learning Outcomes

After reading this chapter, you should be able to:

- Explain the different groundwater systems
- Identify the above ground and below ground components of a well
- Describe the different methods of drilling wells

Groundwater Sources of Supply

Groundwater is one of the most important sources of supply of fresh drinking water throughout the United States. Beneath the earth’s surface, there are soil formations where water can be extracted in large volumes. These underground soil formations are referred to as aquifers. An aquifer is an underground layer of water-bearing permeable rock formations or unconsolidated materials such as sand and gravel.

Aquifers

There are two main types of underground systems (called aquifers) where water is stored and can be extracted. These are called:

- **Unconfined Aquifer** – A natural underground layer of porous, water-bearing (strata) materials (sand, gravel) usually capable of yielding a large amount of supply of water
- **Confined Aquifer** – A natural underground layer of porous, water-bearing materials (sand, gravel) separated by
impermeable layers of materials (clay)

The spaces and fractures in the geologic materials underground store water which can be extracted. This material can be classified as consolidated or unconsolidated. Consolidated aquifer systems are less common and consist of materials such as sandstone, shale, granite, and basalt. The more common underground geologic material contains unconsolidated sediment containing granular material such as sand, gravel, silt, and clay. Alluvium aquifers (sand, gravel, and silt deposits by rivers are some of the more common unconfined aquifers. Since these aquifer systems generally lie within river beds, they have a direct connection to the ground surface and therefore are more susceptible to contamination. Any contamination deposited on the ground surface has the potential to percolate (“trickle through”) the sediments into the aquifer.

Wells

In order to extract water out of the ground, a well must be drilled. A groundwater well is a structure constructed in the ground through various methods in order to extract or pump water from underground aquifers. They can be as simple as a deep hole with supports to keep the hole from collapsing and the water is withdrawn using a bucket. Or, they can be thousands of feet deep and constructed with steel reinforcement columns and use pumps to extract the water. Regardless of the type of well, this source is an important resource for communities throughout the world. In this section, we will focus on water utility groundwater wells.
There are three (3) main types of groundwater wells. These can be described as:

- **Bored or shallow wells**: These are usually bored into an unconfined water source, generally found at depths of one hundred (100) feet or less.
- **Consolidated or rock wells**: These are drilled into a formation consisting entirely of a natural rock formation that contains no soil and does not collapse. These are typically around two hundred (250) feet.
- **Unconsolidated or sand wells**: These are the most common type of drinking water wells and are drilled into a formation of soil, sand, gravel, and clay material. If not supported, these wells will collapse upon themselves.

**Well Components**

There are both underground and above ground components to a well. These components channel the water into a pipe, lift the water up from below the ground, and allow the water to flow above ground and into a distribution system. First, we will look at the above-ground surface features of a well, these are:
• Well casing vent
• Gravel tube
• Sounding tube
• Pump pedestal
• Pump motor base
• Sampling taps
• Air release vacuum breaker valve
• Drain line (Discharge to waste)

Well Casing Vent

When a well is in operation, the water in the well starts to rise in the column pipe of the well. However, there is an air space between the water and where the water is being pumped. This “air” needs to be released from the column pipe. The well casing vent provides this release. It prevents vacuum conditions inside a well by admitting air during the drawdown period when the well pump is first started and it prevents pressure buildup inside a well casing during by allowing excess air to escape during the well recovery period after the well pump shuts off.

Gravel Tube

When a well is drilled, a pipe is lowered into the ground. Water enters into this pipe from the surrounding soil. We want water to enter the well, but we do not want the surrounding soil (sand) to enter the well. Gravel is used as a barrier between the surrounding soil outside of the casing and the water entering the casing. A gravel tube is installed to monitor the level of gravel within the well and to add additional gravel as necessary.

Sounding Tube

A sounding tube is a tube (pipe) that is installed into the well casing to allow for the measurement of groundwater levels within a well. There are several methods of measuring the depth to groundwater, which include automatic measuring devices and manual methods. The simplest means of measuring the level of groundwater below ground surface (bgs) is with a cable lowered into a sounding tube, which has markings identifying distances in various increments (inches.) The cable is connected to a light or signal and when the bottom of the cable touches the water a sound or light signal will occur. Other means of measuring the depth to groundwater include electronic transducers and airline water level measuring. Airline tube measuring is accomplished by lowering a tube into the well, supplying air pressure to the tube and measuring the pressure with a gauge. Each pound per square inch of pressure equates to 2.31 feet. In addition to measuring groundwater levels, sounding tubes can be used to add chlorine or other disinfecting or treatment chemical agents into a well.

Pump Pedestal

The well casing vent, gravel tube, and sounding tube are encased within a concrete pump pedestal. A pump pedestal is
designed to support the entire weight of the pumping unit. The concrete should be continuously poured with steel reinforcement in order to minimize cracks and breaches in the concrete. Fractures in the concrete could expose the inside of the well to surface water and other potential contaminants. A pump pedestal must also be a minimum of 18 inches above the finished elevations of the well pad.

### Pump Motor Base

At the point where the motor rests on the pedestal, it must have a watertight seal. This seal is commonly provided by a neoprene rubber gasket. This establishes a barrier seal between the motor base and the concrete pump pedestal.

### Sampling Taps

### Drain Line (Discharge to waste)

These are only some of the more common above-ground components of a well. There are other features, but they will not be covered in this text. The following items are a list of some below-ground features of a well.

### Casing

A casing is an impervious durable pipe placed in a well to prevent the walls of the surrounding soil from caving in on the well. A casing is also designed to seal off water from draining into a well from specific depths.

### Conductor casing

When a well is drilled the upper portions of the surrounding soil tends to be loose and a conductor casing is used to support the drilling operations. It is a tubular structure between the drilled hole and the inner casing completed in the upper portion of a well.

### Annular seal

Another means to prevent surface water from entering a well is the annular seal. An annular or sanitary seal is a cement grout installed between the well casing and the conductor casing, the space between the conductor casing and the borehole, or the space between the well casing and the borehole depending on the well. This seal also protects the well casing or conductor casing against exterior corrosion. Three (3) types of grout are used; neat cement grout, sand-cement grout, and bentonite clay.

### Intake section

Water enters a well through an intake section. This portion of a well is designed to allow water to enter the well casing.
and prevent the surrounding soil from entering. The following items are general characteristics of a properly designed intake section:

- Non clogging slots/screen
- Resistant to corrosion
- Sufficient collapse strength
- Resistant to encrusting
- Low head loss
- Prevent sand from entering

There are five (5) common types of intake sections of a well. These include:

- Well screens
- Mill-cut slots
- Formed louvers
- Torch-cut/chisel-cut slots
- Mechanical slots

Well screens are generally constructed of stainless steel, monel metal, special nickel alloy, silicon red brass, red brass, special alloy steel, and plastic. They are broken into three (3) main categories which include continuous slots, bar, and wire-wound screens.

Mill-cut slots are commonly made of the same type and diameter as the casing. The openings are machine milled (cut) into the wall of the casing pipe parallel to the axis of the casing and uniformly spaced around the casing pipe.

Formed louvers are machined horizontal to the axis of the casing with the openings facing downward. They are shaped to create an upward flow as the water enters a well and they are placed together in vertical rows.

Torch-cut slots are not very common. They are relatively simple to create, but very difficult to control the size of the openings. This has a tendency to produce excessive quantities of sand.

Mechanical slots are usually slotted after the well has been drilled. The openings are made opposite the water-bearing formations by means of a casing perforator tool lowered into the well and activated from the drill rig. One main downside of this process is the openings cannot be closely spaced.
Well Drilling

In order for water to be extracted from an aquifer, a well must be constructed (drilled). There are several methods of well drilling. The more common methods include:

- Cable Tool
- California Stovepipe
- Direct Rotary
- Reverse Circulation Rotary
- Air Rotary

Cable Tool Method

The cable tool method of drilling wells is also referred to as the “percussion” method. This method involves the lifting and dropping of a heavy string of drilling tools into the borehole. The cable tools can weigh in excess of one (1) ton and the drill bit breaks or crushes consolidated rock into smaller and smaller fragments. In unconsolidated rock the bit loosens and breaks apart the material. The reciprocating action of the tools mixes the crushed and loosened materials with water to form a slurry at the bottom of the borehole. The slurry needs to be removed and is done so with the use of a sand pump or bailer. The cable tool drilling equipment consists of five (5) components; drill bit, drill stem, drilling jars, swivel socket, and cable.

California Stovepipe

This method is similar to the cable tool method. The difference is a heavy bailer is used as both a drill bit and bailer. This heavy bailer is referred to as a mud scow. The stovepipe casing is what also distinguishes this method from others. It uses laminated steel in short lengths providing added strength, as opposed to using standard steel. Hydraulics jacks are used to force the casing downward as opposed to driving the casing with impact tools. Once the casing is at the desired depth, a perforator is used to puncture holes in the pipe opposite the water-bearing formation.

Direct Rotary

As drilling technologies progressed, the desire for faster drilling speeds and greater drilling depths increased. The direct rotary method uses a rotating drill bit. The cuttings are removed by the continuous circulation motion of a drilling fluid as the bit penetrates the formation. The bit is attached to a lower end of a string drill pipe, which transmits the rotating action from the rig to the bit. The drilling fluid is pumped down through the drill pipe and out through the ports or jets in the bit. The fluid flows upward in the annular space between the hole and the drill pipe, carrying the cuttings in suspension to the surface.
Reverse Circulation Rotary

The reverse circulation rotary drilling method was designed to overcome limitations in borehole diameter and drilling depths. In this method, both water and air are used as the drilling fluid and the direction of the drilling rotation is reversed. As a result of this direction, the drilling fluid and the load of cuttings move upward inside the drill pipe and are discharged by the pump into a settling pit.

Air Rotary

In solid consolidated materials, standard drilling practices are more difficult. Therefore, an air rotary method is often employed. This process uses compressed air as the drilling fluid as opposed to drilling mud. Air is circulated through the center of the drill pipe out through ports in the drill bit. In order to break through consolidated material, pressures from 100 to 250 pounds per square inch (psi) are needed. The process of removing the cuttings requires ascending air velocities of at least 3,000 feet per minute are necessary.

Shallow Wells

In some areas, groundwater levels are very shallow. These are usually in areas adjacent to running riverbeds and lakes. In these areas, the surface river and lake water could be used as drinking supplies. However, surface waters require a significant amount of treatment in order to remove turbidity (sediment). This can be quite costly. One of the benefits of groundwater is the natural filtration the geological formations provide. In these areas, shallow collector wells are often used. Trenches are dug around ten (10) to twenty (20) feet deep and screened pipe is laid horizontally to the river or lake bank. Depending on the type of surrounding soil, these pipes are often radially driven. Caissons (watertight retaining structures) are used to gain access to the bottom of a stream or other water body. A common shallow collector type is a Ranney.

Well Pumps

A few terms should be defined before discussing the classification and types of pumps used for wells. These terms are general terms relating to the inlet and outlet side of all pumps. Pressure is the concept of a continuous force being exerted on or against an object, while “head” is commonly used because it evaluates a pump’s capacity to do a job. For this discussion, both pressure and head will be considered interchangeable. Pressure is expressed as pounds per square inch (psi) and head expressed in feet.

Suction Head, Suction Lift, and Discharge Head

The inlet side of a pump is referred to as suction head or suction lift. Suction, referring to the “sucking” or pulling aspect of a fluid entering a pump. If the fluid is above the inlet side of a pump it is referred to as suction head. This is because the fluid is providing pressure to the inlet or suction side of a pump. In essence, it is helping the pump push water
through the pump and to the discharge side of the pump. If the fluid being pumped is below the suction side, then the pump has to “suck” or lift the water up to the pump. This is referred to as suction lift. Discharge head refers to the outlet side of a pump, which is “pushing” the fluid out.

There are two major pump classifications for wells: positive displacement and variable displacement. The common types of each include:

- Piston (positive displacement)
- Rotary (positive displacement)
- Centrifugal (variable displacement)
- Turbine (variable displacement)
- Jet (variable displacement)

Positive displacement well pumps deliver the same volume or flow of water against any head pressure within the operating capacity. Typical types are piston (reciprocating) pumps and screw or squeeze displacement (diaphragm) pumps.

Variable displacement well pumps deliver water with the volume or flow varying inversely with the head (the greater the head, the less the volume or flow) against which they are operating. The major types are centrifugal, jet, and airlift pumps.

There are various uses for each type of pump throughout the water utility industry. However, turbine pumps are predominately used for groundwater wells. Since groundwater is found at different depths below the ground, it only stands to reason there might be different types of “turbine” pumps to lift this water out of the ground.

- Shallow Well Pumps – When a well is constructed in shallow aquifer systems. Shallow can be a relative term, but in this context let’s assume it is within fifty (50) feet below ground surface. Under these circumstances, a shallow well pump would be installed above a well. It would take water from the well by suction lift. The critical issue is the water level must be within the “lift” capacity of the pump
- Deep Well Pumps – Since many wells are drilled deeper than fifty (50) feet, most pumps cannot “lift” the water above these depths when they are installed above a well. Therefore, deep well pumps are used. These types of turbine pumps have a series of pump bowls installed in a well with the inlet (suction) section of the pump submerged below the pumping level in a well.

Since pressures can be expressed in both units of psi and feet, there needs to be a way to convert between the two. One pound per square inch equates to just over two feet. See the example below.

- 1 psi = 2.31 feet (head)

If a pump has a discharge head of 100 psi, how many feet does this equal?

- 100 psi x 2.31 feet/psi = 231 feet

While this text discusses aspects of water-related mathematical computations, it is advised to take specific coursework in waterworks mathematics.
Measuring Groundwater Levels

An important set of data associated with groundwater wells is the measurement of water below the ground surface. There are two common measurements in a groundwater well: static and pumping. The static water level within a well is the depth of water below the ground surface when a well is not running. In contrast, the pumping level is the measure below the ground surface when a well is running. The diagram below illustrates these two terms.

![Diagram of groundwater levels and related terms](Image by COC OER is licensed under CC BY 4.0)

In this diagram, there are several other important terms. Drawdown is the difference between the pumping and static water levels. This level identifies the distance the water level drops when a well is off and when it is running. Also depicted in the diagram is something referred to as the cone of depression. The water level in an aquifer is only affected by a well running within a certain area around the well. This area of "depression" pulls the water down deeper closer to the well and the further away from the well the effect is less. Hence, a "cone" shaped effect occurs. The distance from the center of a well to the farthest area where the depression effect occurs is referred to as the radius of influence. These measurements help in the analysis of the health of the underlying aquifer and the efficiency of a well.

Sample Questions

1. If an airline measuring device is used to measure the depth to groundwater displays a pressure of 125 psi, what is the depth in feet?
   1. 125 feet
   2. 289 feet
   3. 54 feet
   4. None of the above
2. An unconfined aquifer is ___________.
   1. More susceptible to contamination than a confined aquifer
   2. Less susceptible to contamination than a confined aquifer
   3. Typically deep within the earth’s crust
   4. Not a common source of water for a water utility

3. A sounding tube is used ___________.
   1. To hear if a motor is running correctly
   2. To test the flow of a well
   3. To measure the depth to groundwater within a well
   4. To see if a well works properly

4. Which of the following materials is not a common well screen?
   1. Stainless steel
   2. Iron
   3. Monel metal
   4. Special nickel alloy

5. The annular seal is commonly made of ___________.
   1. Plastic
   2. Steel
   3. Bentonite clay
   4. All of the above