
Title 210 – National Engineering Handbook
Part 650 – Engineering Field Handbook
Subpart L – Spring and Well Design
Amended August 2025

650.180 Introduction

A. Purpose

1. This subpart provides NRCS employees with key fundamentals of planning and developing groundwater resources. By policy, NRCS geologists must conduct or provide direct guidance for geologic investigations and technical review of geologic work conducted by other NRCS employees or non-NRCS engineering services when groundwater resource development, quality protection, and control are key elements of the design (Title 210 National Engineering Manual, Part 531 Geology). Geologists must understand the basic groundwater concepts in this subpart.
2. Groundwater is of significant economic importance and has many advantages over surface, atmospheric and frozen water sources. Some advantages of using groundwater are that it is a more reliable source than surface water, is generally cleaner due to natural filtration, stores large amounts of water, and contributes base flows to rivers, wetlands, and ecosystems. Groundwater provides 37 percent of the water for public supply, more than 90 percent for rural populations, and 42 percent is for irrigation.
3. The principal ways of extracting groundwater are through spring and well developments. For a successful long-lasting water supply from springs or wells, consider information in this subpart in addition to information in Title 210 National Engineering Handbook, Part 631 Geology, Chapter 31 “Groundwater Investigations.” This subpart describes different geologic settings that springs and seeps may form in; how to design for spring and seep development; different well types; the basics of well hydraulics and capacity; and well design, development, testing, maintenance, and abandonment (decommissioning).

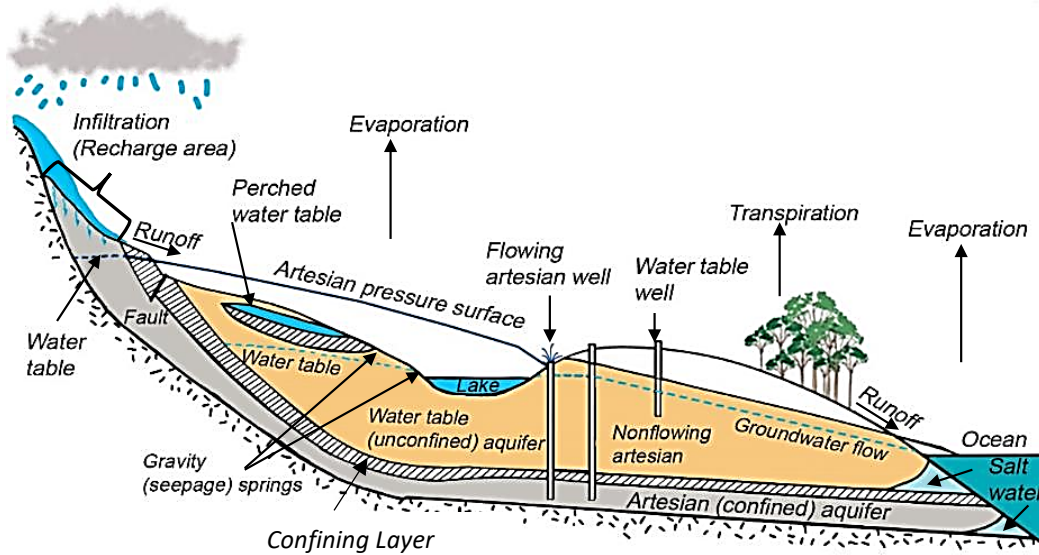
B. Groundwater Definition

1. Groundwater is all the water beneath the Earth’s surface (210 H 631, Chapter 31 “Groundwater Investigations”). The Earth is a closed system, where little matter, such as water, enters or leaves the atmosphere. Earth recharges its water supply through the hydrologic cycle. The hydrologic cycle involves the continuous circulation of water through precipitation, condensation, and evaporation within the Earth’s atmosphere. Figure 650L-1 summarizes the hydrologic cycle and groundwater occurrence and movement. For a detailed discussion of groundwater hydrology, see 210 H 631.3103, “Groundwater Hydrology.”

C. Groundwater Resource Conservation

1. Conserving and protecting groundwater becomes increasingly important as the demand for water rises. It is important to:
 - a. Understand the geology to know how other operations on the farm or in the area may affect groundwater resources with respect to quality and quantity.
 - b. Take measures to prevent cross-contamination when a recovery system passes through an upper aquifer to draw from a lower one.
 - c. Protect groundwater resources around livestock pens and waste confinement facilities.
 - d. Use the most conservative of local, state, and Tribal law, or Conservation Practice Standard (CPS) setback distances between a new well and:
 - (1) Other wells. Locating a new well too close to other operating wells (irrigation, domestic, stockwater, etc.) may lower the water table, and lead to depleting the existing aquifer systems and dry wells. Typically, the recommended minimum distance between new and existing operating wells is 100 feet. However, this minimum distance may vary from state to state.
 - (2) Agricultural waste facilities. Locate the well upgradient from the facility at least the minimum distance required by state law.
 - (3) Surface water and springs.
 - (4) Subsurface drains, drain fields, and soil absorption systems.
 - (5) Property boundaries.
 - (6) Floodplains.
 - (7) Storm water ponds and ditches.
 - (8) Cisterns.
 - (9) Roadcuts and escarpments.
 - (10) Septic systems and sewer lines.
 - e. Recognize that uncontrolled discharge from a free-flowing artesian aquifer may waste substantial amounts of groundwater.
 - f. Analyze the amount of groundwater that is safe and economical to withdraw from the aquifer, the purpose of use, and the expected recharge amount.
2. For more information on groundwater contamination, including common contaminants found on farms, see 210 H 631.3108, "Groundwater Quality."

Figure 650L-1: Hydrologic cycle with a groundwater focus



D. Title 210, National Engineering Handbook References

1. For more detailed information, see 210 H 631, “Geology.”

E. National CPS related to this subpart include:

1. CPS Spring Development (Code 574)
2. CPS Water Well (Code 642)
3. CPS Well Decommissioning (Code 351)
4. CPS Groundwater Testing (Code 355)
5. CPS Pumping Plant (Code 533)

650.181 Groundwater Occurrence and Terms

A. Aquifers

1. An aquifer is a saturated, permeable geologic unit capable of storing and transmitting usable amounts of groundwater to wells or springs. When designing an agricultural component, know the types, depths, and classification of all aquifers present at that location.
2. An aquifer can occur in many situations. The principal types of aquifer materials are identified below. For more information, see 210 H 631.3107, “Groundwater Geology.”
 - a. Unconsolidated sand, gravel
 - b. Sedimentary rocks with both primary and secondary porosity
 - (1) Jointed and permeable sandstone
 - (2) Joints and solution passages in limestone
 - c. Fractured and faulted volcanic and metamorphic rock (dense, hard rock)

- (1) Joints or fracture zones in dense, hard rock may yield small amounts of groundwater up to about 300 feet below land surface
3. Aquifers are divided into four types: unconfined or water table aquifers, confined aquifers, semi-confined aquifers, and perched aquifers. An aquifer may be considered a sole source aquifer, the only drinking water source for a specific area. These terms are briefly described below but are detailed in 210 H 631.3103, “Groundwater Hydrology.”
- a. Unconfined (Water Table) Aquifer. Water table aquifer and unconfined aquifer are synonymous. This is an aquifer where the water level is at atmospheric pressure. Water levels in the well may rise or fall dramatically, depending on recharge and withdrawal rate, drainage, or outflow.
 - b. Confined (Artesian) Aquifer. A confined aquifer, also known as an artesian aquifer, is bound above and below by geologic materials with lower permeabilities known as aquicludes, aquitards, or aquifuges. When a water well penetrates a confined aquifer, water rises above the top of the aquifer. An artesian well that flows to the surface is called a flowing artesian well. Not all artesian wells are flowing wells. For a well to classify as flowing artesian, the top of the well casing must be below the potentiometric surface elevation (figures 650L-1 and 650L-2). See 650.1 B1 and 210 H 631.3105, “Groundwater Movement,” for a discussion of potentiometric surface.
 - c. Semi-confined Aquifer. Semi-confined aquifers, also known as leaky aquifers, are confined between semi-permeable formations, where water slowly passes through to recharge the aquifer. When water is pumped from a well installed in this type of aquifer, it moves both horizontally within the aquifer and vertically through the semi-permeable layer.
 - d. Perched Aquifer. A perched aquifer (figure 650L-1) is a local zone of unconfined groundwater occurring above the regional water table, with unsaturated conditions below it. Perched aquifers form where downward percolating groundwater is blocked by a zone of lesser permeability, allowing water to accumulate above it. This lower confining unit is called a perching bed, and it commonly occurs where clay lenses are present, particularly in glacial outwash and till. These perched aquifers generally have limited lateral extent and may not provide a long-lasting water source. Perched aquifers can cause problems in construction activities and must be identified during a site investigation. Perched aquifers may be significant sources of water on islands.
 - e. Sole Source Aquifer. A sole source aquifer is an aquifer that provides the primary or sole source of drinking water to an area. Under the provisions of the Safe Drinking Water Act (1974), the U.S. Environmental Protection Agency (EPA) has the authority to designate any aquifer as a “sole source aquifer.” The EPA can do this on their own or upon petition by state or local government. The use of federal funds is prohibited for any project that the EPA finds would contaminate a sole source aquifer and cause significant health hazards. For more information on locations of designated sole source aquifers, see the [EPA website](#).

Figure 650L-2: Water well penetrating an artesian aquifer, Missouri



4. General information about groundwater and aquifers in the United States is available from the United States Geological Survey (USGS).
 - a. United States principal aquifers: National Atlas of the United States [USGS 2021 Principal Aquifers of the United States](#).
 - b. United States significant groundwater provinces, based on the areal extent of important water-bearing formations. See the [USGS 1984 Groundwater Regions of the United States](#) document for a detailed description of the provinces.
 - c. United States karst map, based on areas with soluble rock (carbonates and evaporites) and insoluble volcanic rock. Volcanic rocks are included on this map, because these areas have lava tubes, which are hollow and act like voids and caverns. See the [USGS 2020 Karst Map of the Conterminous United States](#).
5. State geological surveys may also have more detailed groundwater maps and other information about groundwater resources.

B. Potentiometric Surface

1. A potentiometric (piezometric) surface is the height that groundwater will rise in a properly cased and constructed well to atmospheric pressure. This is also called the saturation line, seepage line, or phreatic line, and separates saturated soils from the unsaturated soils. The hydrostatic pressure above this line is negative, and the pressure below this line is positive. The potentiometric surface provides important information about the pressure conditions and flow dynamics in a confined aquifer and within and below dams or other structures.
2. In an unconfined aquifer, the potentiometric surface is also known as the water table or phreatic surface. The water level in a well may be above the top of the aquifer, indicating that the water in the aquifer is under greater than local hydrostatic pressure. For more information about potentiometric surface, see 210 H 631.3105, “Groundwater Movement.”

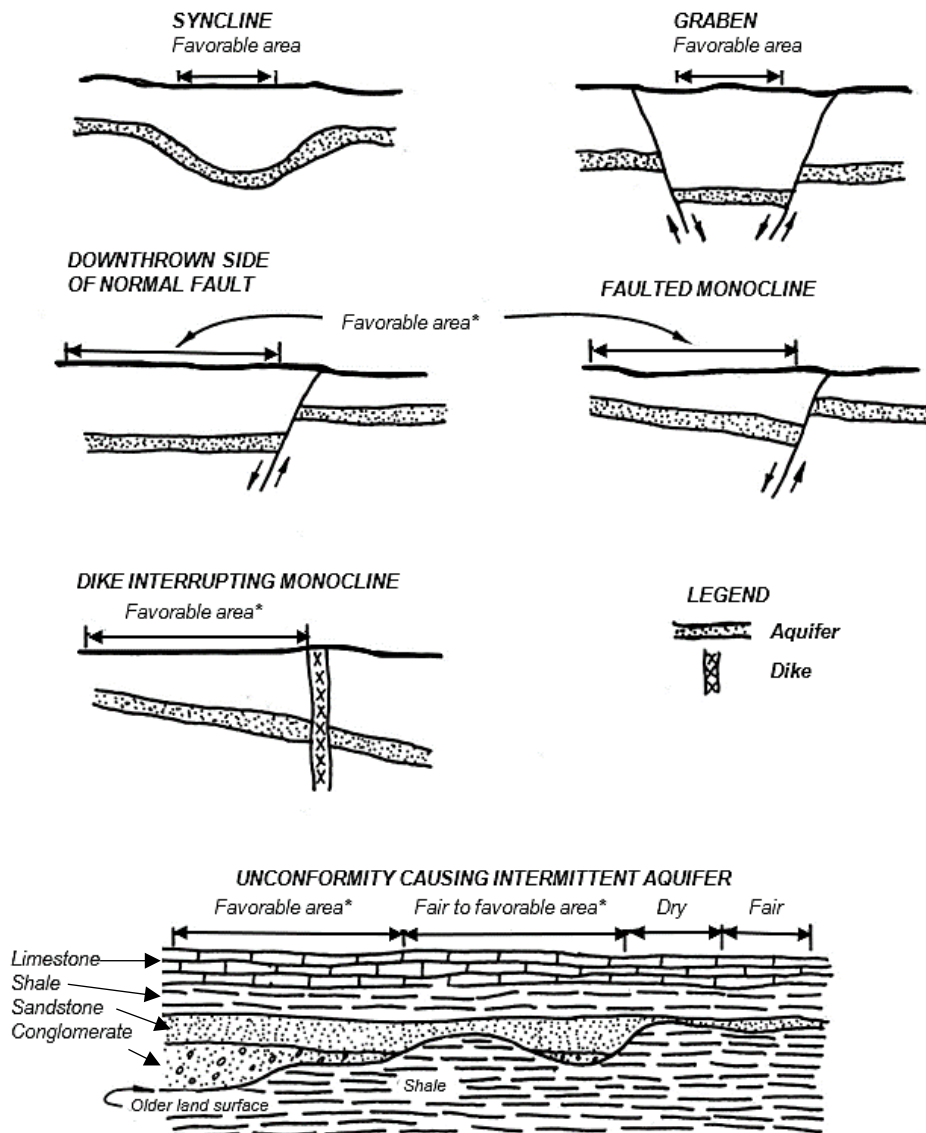
C. Water-Bearing Material Properties

1. The following hydrogeologic terms are important to understand for geology and engineering applications. For more details, see 210 H 631.3104, “Hydraulic Material Properties.”
 - a. Porosity. The ratio of the volume of voids to the total volume of a soil or rock mass, expressed as a percentage. There are two types of porosity: primary and secondary. Primary porosity is the pore space between grains at the time of deposition. Secondary porosity is the voids that develop after the rock forms.
 - b. Permeability (k). The ease at which water flows through a material.
 - c. Specific Yield. The ratio of the volume of water that an unconfined aquifer (soil or rock) drained by gravity to the volume of soil or rock mass.
 - d. Hydraulic Conductivity (K). The volume of water that flows through a unit cross-sectional area in unit time, under unit hydraulic gradient, and at a standard temperature.
 - e. Specific Discharge. The apparent velocity that can be calculated using Darcy’s law (210 H 631.3105, “Groundwater movement”). Specific discharge represents the flow rate at which water would flow in an aquifer if the aquifer were open.
 - f. Transmissivity (T). The rate of water flow through a vertical strip of unit width, which extends through the entire saturated thickness of the aquifer under unit hydraulic gradient and at the prevailing water temperature.
 - g. Storativity (S). Aquifer storativity, also known as storage coefficient, is a unitless measure of the volume of water that the aquifer releases or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface.

D. Geologic Structure Effects

1. Some structural features or conditions favor groundwater accumulation in aquifers; others act as drains. Conditions favorable for retaining groundwater are as necessary for underground storage as dams are for surface reservoirs. Such geologic dams (or traps) can be structural or caused by differences in water-bearing capabilities of strata. Examples of structural traps include folds, faults, unconformities, cleavage, fractures, joints, solution cavities, and combination traps (figure 650L-3). For more discussion, see 210 H 631.3107, “Groundwater Geology.”

Figure 650L-3 Geologic structure effects on groundwater



650.182 Springs and Seeps

A. Spring and Seep Definitions

1. A spring or seep is a place where water from an aquifer discharges naturally into a surface water body or onto the land surface. Flow is controlled by either gravity or hydraulic pressure (artesian). The difference between a spring and a seep is that a spring has a defined surface discharge point, while a seep does not.
2. Spring flows may vary considerably throughout the year, especially when originating from an unconfined aquifer. Spring flow variations are due to the rise and fall of water in a water table aquifer, rate of recharge, or the variation of pressure in an artesian aquifer.

B. Gravity Springs

1. Gravity springs occur where water moves from the water table aquifer through permeable materials to the land surface, or where the land surface intersects the water table. Gravity springs that are not fed by large, interconnected fractures or cave systems are normally low-yielding sources of groundwater. However, they may supply enough water for individual household or livestock needs.
2. Three principal gravity spring types are:
 - a. Depression (Seepage, Filtration) Springs. Formed when the land surface intercepts the water table in permeable material (figure 650L-4). The water supply may be intermittent, depending on seasonal precipitation, and not necessarily as reliable a water supply source as contact, fracture, joint, or tubular springs.
 - b. Contact Springs. Formed when groundwater moves along a contact between a permeable and less permeable rock (sandstone and shale), until it reaches an area where erosion has exposed the formation to the atmosphere, such as a hillside (figure 650L-5).
 - c. Fracture, Joint, or Tubular Springs. Formed when water emerges from fractures, faults, rock joints, solution channels in sandstone, limestone or gypsum, or natural tunnels in volcanic rock (figures 650L-6 through 650L-9). Tubular springs range in size from too small to see without magnification to large enough to walk through. They can have high yields with highly interconnected fractured systems.

Figure 650L-4 – Depression Spring

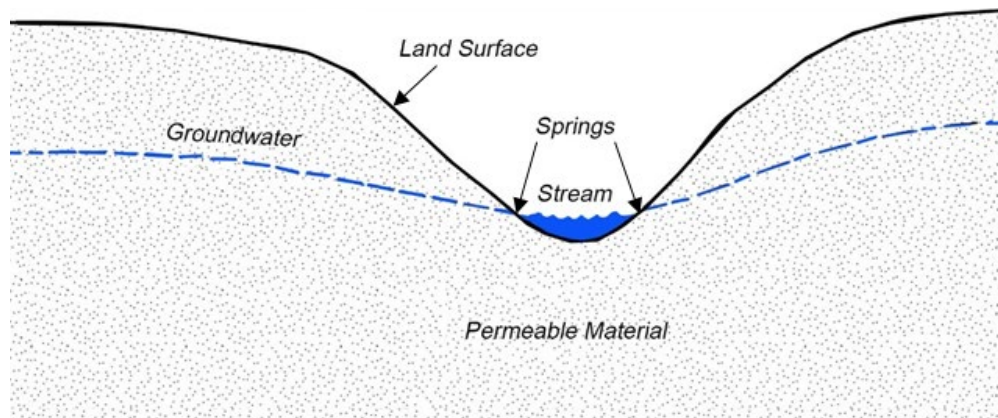


Figure 650L-5: Contact spring

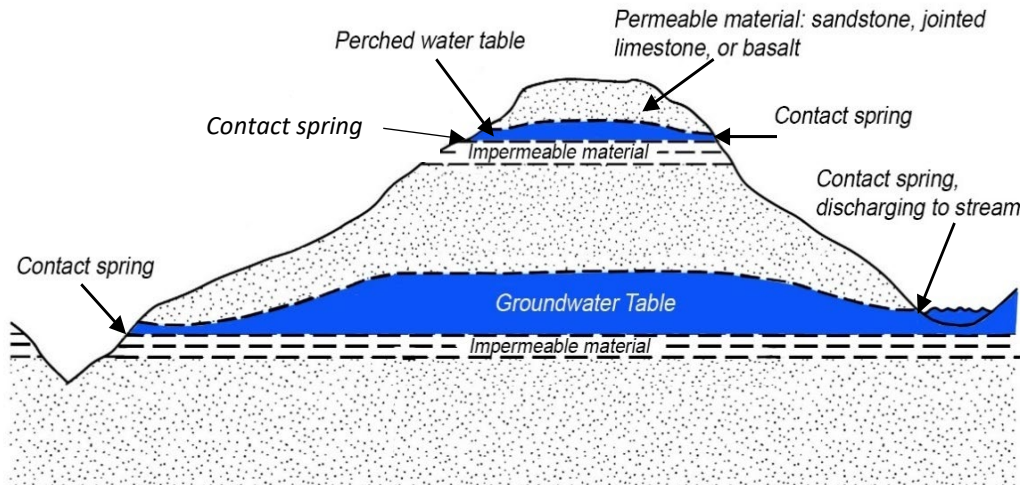


Figure 650L-6: Springs in jointed sandstone

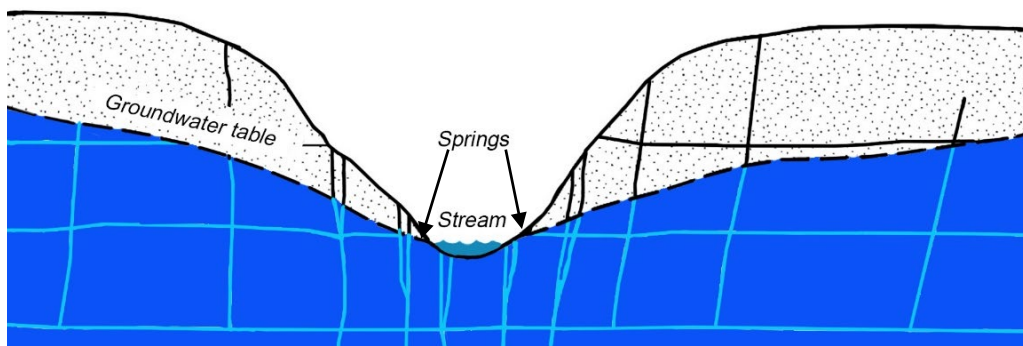


Figure 650L-7: Springs in jointed basalt

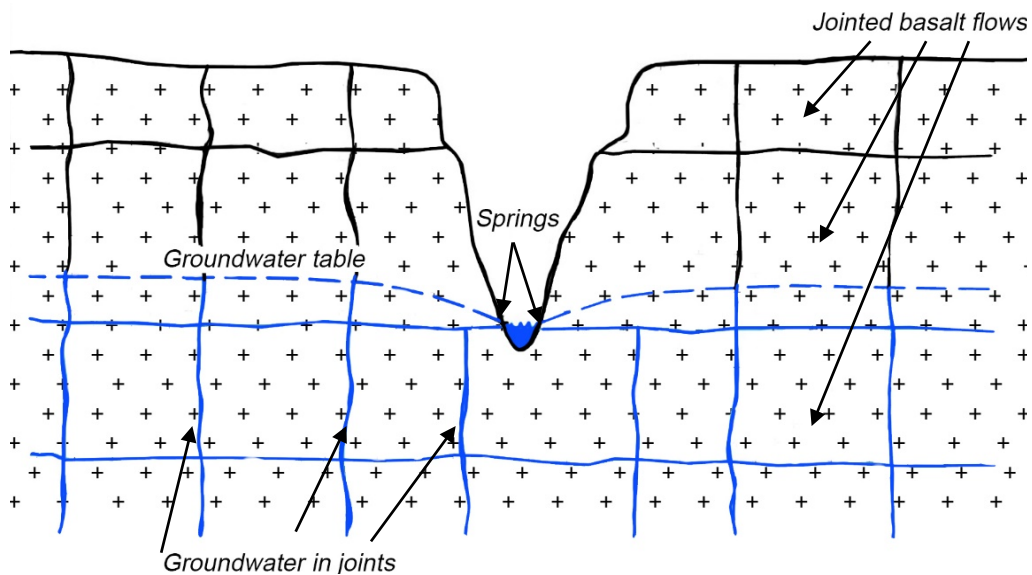
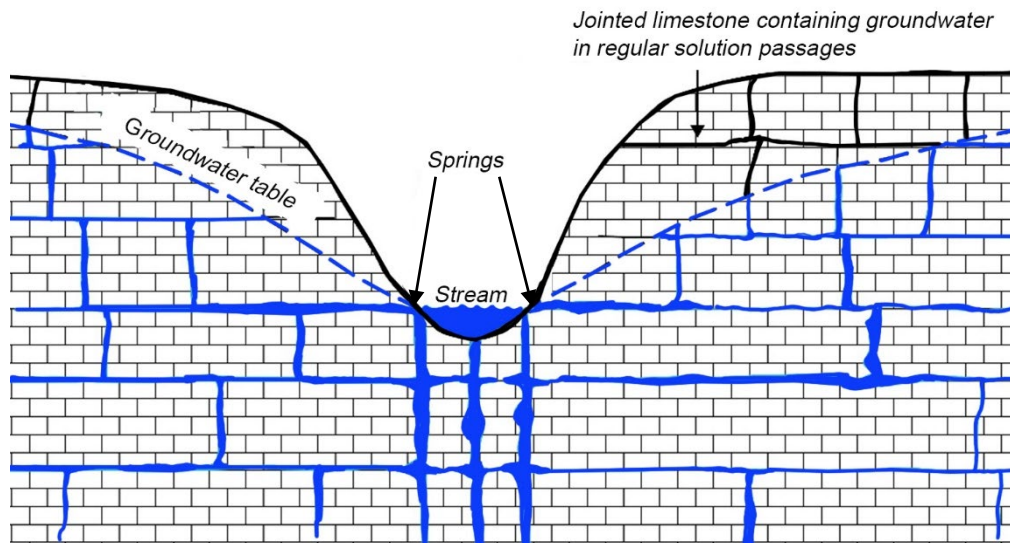


Figure 650L-8: Springs in jointed limestone



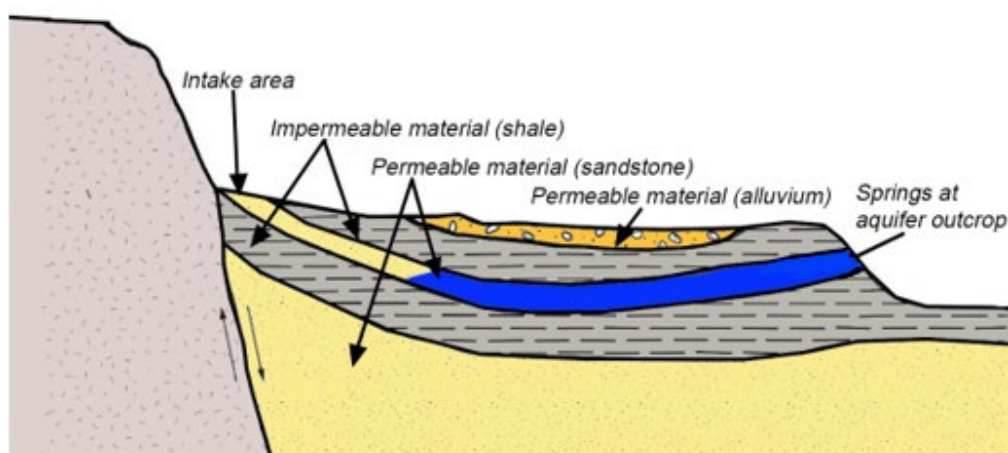
C. Aquifer Outcrop Springs

6. Aquifer outcrop springs may occur in any topographic position along an outcrop (figure 650L-9). The type of opening depends on the nature of the water-bearing material. If the aquifer is sandstone, water may seep from spaces between grains, fractures, or open bedding planes. If the aquifer is limestone, or another type of rock (e.g., jointed basalt), water will emerge from joints or tubular openings. Figures 650L-6 through 650L-9 illustrate springs in different kinds of rock.
7. Flow from these springs may range from a few gallons to several thousand gallons per minute. Drought and water wells drawing from the same aquifer, and aquifer size, may affect the flow.
8. Water temperature will approximate the mean annual atmospheric temperature of the location unless the aquifer is deeply buried. If so, temperature will be a few degrees above the mean annual temperature or about 1 degree above the annual mean for each 100 feet that the aquifer lies beneath the surface. A limestone aquifer with warmer water than the mean annual temperature indicates a hydraulic connection with surface water, which can bring pollutants. Warmer water causes calcium carbonate to rapidly precipitate, forming travertine (CaCO_3), which may obstruct spring flow.

D. Artesian Springs

1. Artesian springs occur when water enters a confined water-bearing layer at a higher elevation than the spring's outflow. Water flows downgradient between two relatively impervious layers and surfaces under pressure (figure 650L-9). Nearby operating water wells can impact artesian springs by reducing the spring's pressure and stopping the flow.
2. These springs typically occur along faults or in areas with high topographic relief, such as cliffs or valleys.

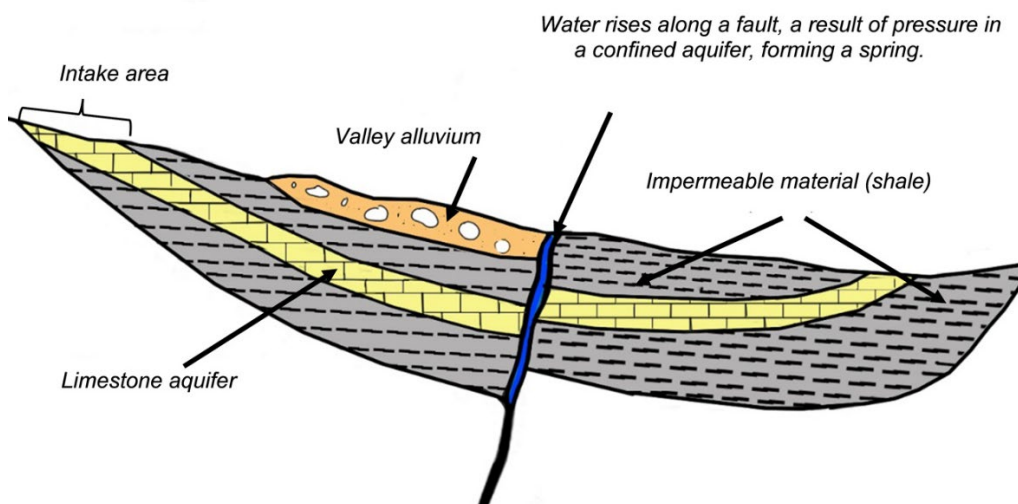
Figure 650L-9: Artesian Spring at aquifer outcrop



E. Fault Springs

1. Fault springs occur at any location along a fault or related fractures (figure 650L-10). The type of opening depends on the material at the land surface. For example, if the surface is alluvium, water comes from spaces between the grains; but if the surface is rock, water emerges from fractures. These springs may come from any rock type, with the volume of flow ranging from a few gallons to several thousand gallons per minute.
2. The flow type is perennial, constant, and only affected by prolonged drought and operating water wells.

Figure 650L-10: Fault Spring



F. Seepage Springs

1. Seepage springs occur when a relatively impervious earthen material redirects groundwater to the surface. They are difficult to develop because they do not have a defined outlet like other springs. Instead, flows are over a wide area and come from zones where seepage emerges.

2. Flows are typically low since these springs are not necessarily originating from a confined aquifer, making them less dependable. They are also difficult to protect from surface water contamination.

650.183 Spring Development and Design

A. Introduction

1. CPS Spring Development (Code 574) is not intended for developing water sources for human consumption. The purpose of this practice standard is to “improve the quantity and/or quality of water for livestock and wildlife.”

B. Spring development involves collecting flowing spring water or seep into a pipe and delivering to the system. Spring development requires planning and investigation, removing obstructions, and collecting flows.

1. Planning and Investigation

- a. If required by local, state, or Tribal law, the landowner must acquire water rights and other necessary permits before spring development.
- b. During the planning, collect information about the spring or seep to determine feasibility and potential for development for water supply, such as:
 - (1) Spring and well locations and yields.
 - (2) Select a spring or seep that can provide the required quantity and quality of water for the intended use, as determined by NRCS requirements.
 - (3) Protect the water source for use without excessive maintenance.
 - (4) Current hydrologic conditions (precipitation and departure from normal).
 - (5) USGS and state geological survey investigative reports.
 - (6) Copies of well logs of nearby wells or in aquifers of interest.
 - (7) Communications with licensed water well drillers who have worked in the area.
 - (8) Web soil survey reports and interpretation data, and general geologic description of site conditions.
 - (9) Map showing groundwater development sites and the geologic situation of each.
 - (10) Groundwater or structural contour maps of known aquifers.
 - (11) Previous geology investigation reports.
- c. Spring flow may vary significantly throughout the year. Determine the range of flows throughout the year, the nature of the water-bearing material, and the hydrogeologic conditions that create the spring. Determine if spring development will affect ecological functions.
- d. Conduct a [wetland determination](#) and [cultural resources assessment](#).
- e. Prepare a plan with the landowner before making design and construction decisions. Identify possible contamination sources from barns, feedlots, septic fields, and other zones of saturation that are upgradient from the spring site.
- f. Plan to remove obstructions to increase the volume of flow to the spring box (see 650.3 B.2, “Removing Obstructions”).
- g. Plan to develop an artesian spring by using any of the gravity spring methods in 650.4 B.3 and lowering the outlet elevation.

- h. Construction Planning
 - (1) One of the most important factors in spring development is previous local experience. Base the construction method on spring characteristics such as topography, nature of the water-bearing material, type of spring opening, volume of flow, and seasonal or yearly variations in flow.
 - (2) Lowering the outlet elevation can improve the spring flow supplied by an extensive system of rock channels, or by a large volume of permeable water-bearing material, as in some artesian springs. Lowering the outlet elevation increases the head of water available to increase flow at the spring. If the available volume is substantial, lowering the outlet elevation may produce a substantial and long-lasting increase in flow. However, the increase in flow may be only temporary if limited volume is present.
 - (3) NRCS does not recommend using explosives for spring development. Rock shattering and dislocation from blasting may cause the existing flow to cease or move elsewhere.
2. Removing Obstructions
- a. Types of obstructions that may indicate pollution has reached the spring may include fine sand and fine-grained materials (silt, or clay) brought to the outlet by groundwater, mineral deposits such as calcium carbonate (travertine), and slope-wash materials that have deposited on the outlet can obstruct spring flow. Consider water quality testing to verify the water quality.
 - a. Use a filter or sump if spring water carries sediment to the opening. Locate the sump below the spring so that the sediment will not build up over the outlet between periodic cleanings. Design the sump to facilitate cleaning by sluicing (washing) when possible.
 - b. Diversions can carry surface drainage away from the spring area to prevent slope-wash material from clogging the outlet. For collecting several small flows, use covered galleries or drains in the design to avoid the need to clean and maintain diversions.
 - c. Woody vegetation, such as trees and shrubs, growing in or around the outlet, can obstruct flow and consume and transpire (through evapotranspiration (ET)) water. Removing obstructions usually increases spring flow. Remove woody plants mechanically or by controlled use of herbicides, exercising care in either method.
 - (1) Woody vegetation, such as trees and shrubs, growing in or around the outlet can obstruct flow and consume and transpire (through evapotranspiration (ET)) water. Removing obstructions usually increases spring flow. Remove woody plants mechanically or by controlled use of herbicides, exercising care in either method. When mechanically removing plants, establish suitable herbaceous vegetation (e.g., grasses, forbs) to prevent exposing large areas of erodible earth and to reduce the impairment at the spring opening or downstream areas by sediment.
 - (2) Herbicides pose a significant contamination risk to springs. Select aquatic herbicide formulations for use near water to prevent spring contamination and use only as directed by the manufacturer.

3. Flow Collection and Development

- a. If the spring flows from rock outcrop fractures, clean the individual openings, and collect water in a perforated pipeline or gravel-filled ditch (French Drain) graded to discharge into a central sump or spring box. If the sediment in the water is very fine, a graded filter with sand may be necessary. For more details about filters, see 650.10, “Well Screen and Filter Pack Design.”
- b. To collect water seeping from permeable material, excavate a ditch or tunnel to the necessary length and thickness of the water-bearing zones. The excavation must extend far enough below the water-bearing zones to ensure gravity collection.
- c. Excavation may increase the flow of depression and contact springs to drain additional portions of the aquifer. Excavation may include ditches or tunnels, depending on the topography at the spring, and characterizing the underlying water-bearing materials.
- d. If the spring outlet is on gently sloping or nearly level terrain, excavating a ditch along the outcrop of the water-bearing material is the most economical collection method. Dig a ditch to intercept as much of the water-bearing zone as practical.

650.184 Structures

- A. Various types of structures and methods, including perforated pipelines laid in gravel-filled ditches and drainage ditches back-filled with gravel or sand, are used in groundwater collection for spring developments.
- B. The best means of collecting and delivering water to the usage point is with a collector, spring box, and pipeline (figures 650L-11 through 650L-14).
 1. Collector
 - a. Use a collector to develop an underground seep by transporting water for an above ground system. Collectors consist of perforated pipe laid in graded small gravel or graded sand (figure 650L-12) or a ditch backfilled with graded small gravel or graded sand. The goal is to design a filter that will keep existing soils in place while allowing the seep to permeate through pipes or a lined ditch to the desired location.
 - b. The collector design depends on the site soil type. Design a graded filter using the appropriate standard that will allow water through while keeping the existing soils and filter in place.
 - (1) For example, install a graded filter in a site with clay soil before placing the perforated pipe, starting with sand and progressively increasing in size to coarse gravel.
 - (2) Depending on the soils and the spring production, the collector may need fewer filter stages, and the perforated pipe may be optional. Conduct a hydraulic analysis to properly size the perforated pipe or gravel ditch.
 - (3) Under some conditions, a sand point (aka “driven point well,” “gravel point,” or “well point”) serves as a collector. A sand point is a 1- to 2-inch diameter well with screen and a conical point attached to the bottom. The sand point is driven or pounded into the ground until the saturated material is reached (see 210 H 631.3111, “Groundwater Monitoring,” for more information).

- c. Collectors with coarse soil filters will need a cutoff wall on the downslope side of the trench. Cutoff walls concentrate the flow into an outlet so that the coarse soil filters do not provide a reservoir and path for water to “escape.”
 - (1) Use 4- to 6-inch-thick concrete, masonry, sheet piling, plastic, or clay for the cutoff wall and wingwalls.
 - (2) Construct the cutoff wall as linear, combination, or a large V with the apex downslope and the wall and/or wingwalls extending into the hill to prevent water from escaping.
 - (3) Extend the cutoff wall to impervious material to intercept water and allow it to flow to the collection point and to prevent underflow.
2. Spring Box
- a. A spring box receives water collected from the spring and serves as a settling basin for sediment removal. Design and locate the spring box to accommodate a large range of water surface elevations (see CPS 574 Spring Development). To prevent ponding, place the spring box top above the highest surface water elevation. See figures 650L-13 through 650L-16 for sketches of typical collector, spring box, and pipe arrangements. The collection systems shown are suitable for developing a seepage (filtration) spring or a contact spring.
 - b. Construct a spring box in the spring location to capture the most productive portions to the left and right of the source. The upper wall should have openings located in a way that allows all the collected water to enter the box. Do not build the upper wall when a spring does not require a collector system. Figure 650L-12 shows an example of collecting from the apex of a V-shaped headwall.
 - c. Construct concrete spring boxes using galvanized metal or concrete pipe sections, High Density Polyethylene (HDPE) pipe, or other prefabricated materials. Construct wooden spring boxes from untreated and rot resistant wood.
 - d. A tight-fitted cover is required to prevent contamination. If the spring box top is above the ground surface, incorporate a grate into the design to keep debris and animals out. Bury the spring box with enough earth to prevent from freezing. Revegetate the disturbed area and protect the spring box from livestock, wildlife, and vehicular traffic.
 - e. Consider including a shutoff valve to the spring box outlet pipe to shut off the flow when not in use (figure 650L-14).
3. Delivery of Spring Water by Gravity Flow
- a. An important part of the spring development is the arrangement of the delivery and overflow pipe layout (figures 650L-13 and 650L-14). Pipelines are constructed out of plastic, steel, copper, or galvanized iron.
 - (1) Size the pipe for the flowrate needed based on the expected production of the spring.
 - b. Place spring box discharge pipe invert at least 6 inches above the floor to include room for deposited sediment. Make a watertight connection where the pipe leaves the spring box or extends through the cutoff wall. Install an appropriately sized filter or trash rack on the inlet pipe within the spring box to reduce plugging by leaves or debris. Ensure the filter surface area is large enough to prevent clogging.

- c. For pipe design and water tank connections, use CPS Livestock Pipeline (Code 516).

Figure 650L-11: Artesian Spring Collection from V-shaped Headwall

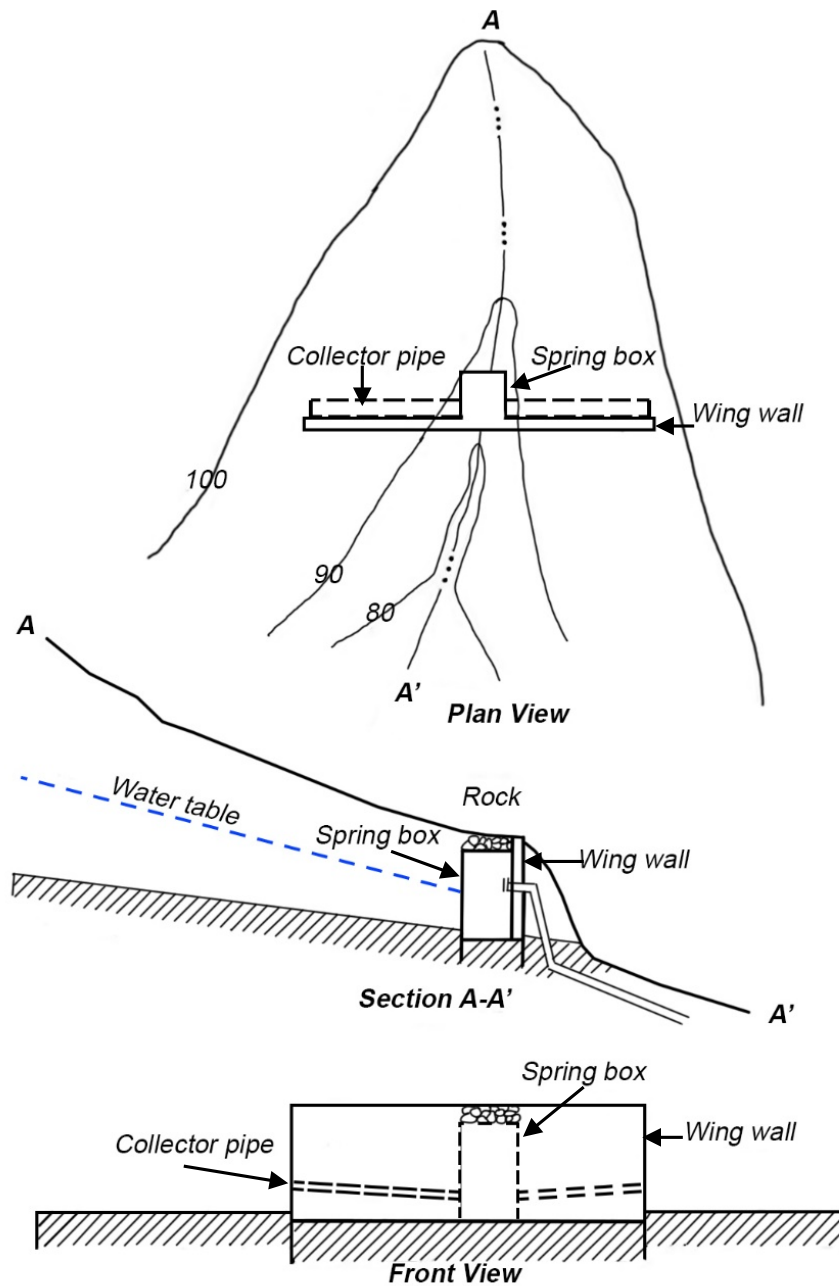


Figure 650L-12: Spring Collection System

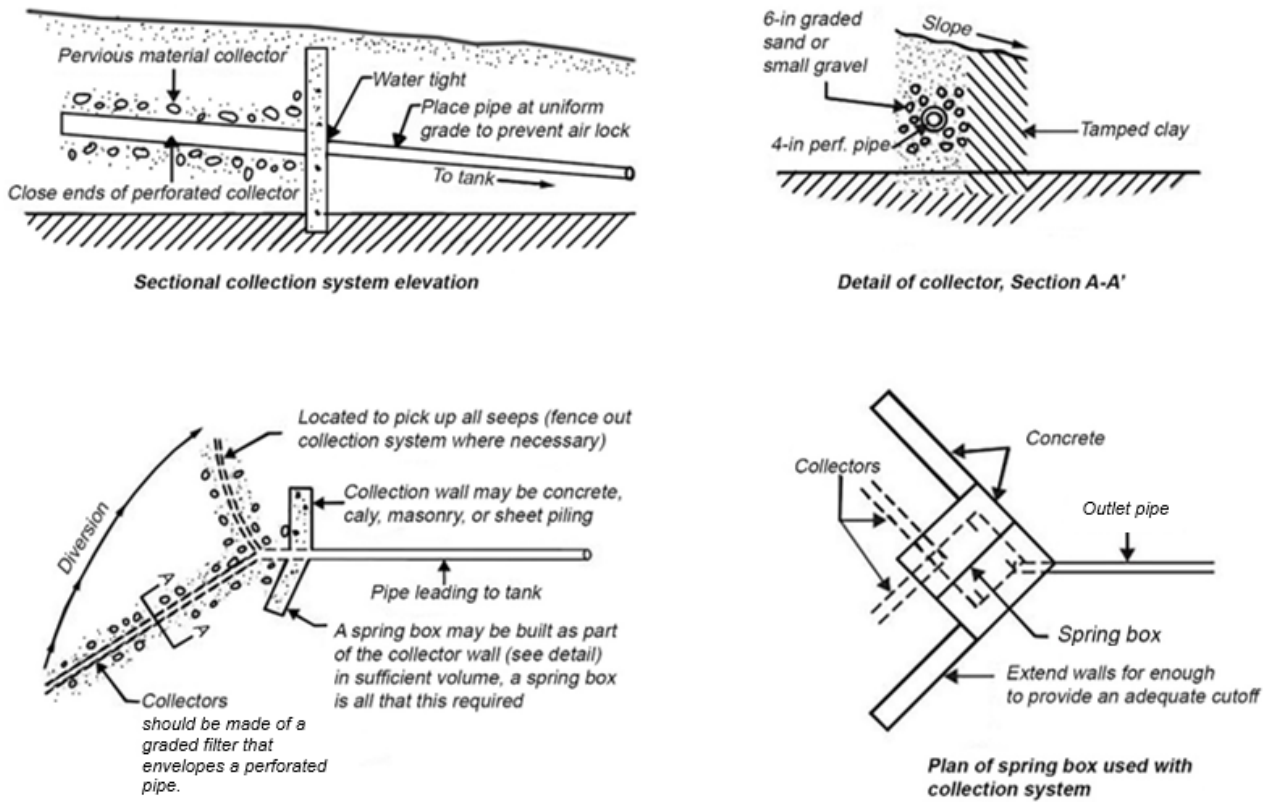


Figure 650L-13: Spring box and pipe arrangement

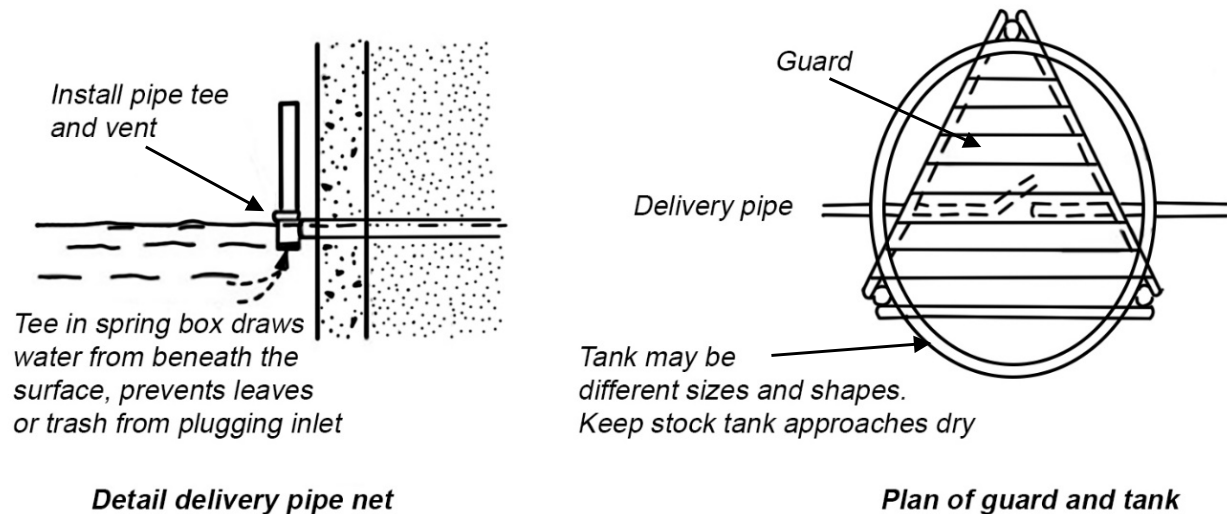
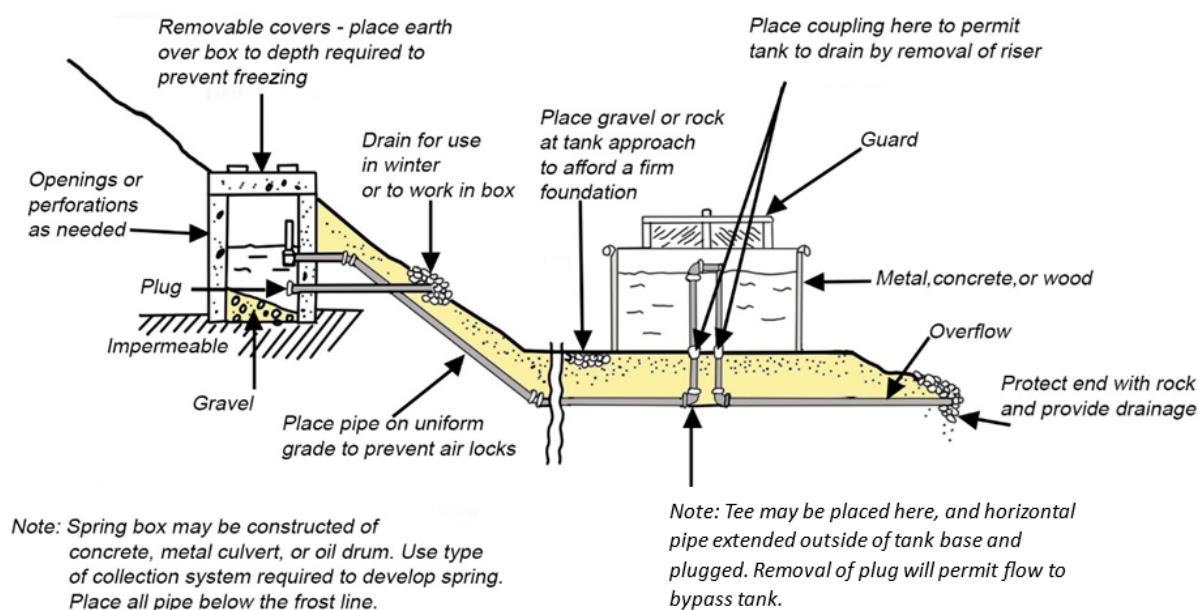


Figure 650L-14: Spring box and pipe arrangement profile



4. Dugouts (Ponds)

- a. Dugouts are excavations below the water table, usually made with dragline equipment, to store groundwater. They are generally developed in stream system valleys and wherever the water table is permanently close to the land surface. Extending the dugouts deep enough into the saturation zone is important to allow for an abnormally low water table during dry periods.
- b. Dugouts are like dug wells, but the main difference is that dugouts are not required to meet CPS Water Well (Code 642) grouting and sealing requirements. A dugout must conform to either CPS Spring Development (Code 574), or CPS Pond (Code 378). This distinction allows creativity in how the dugout structure is screened and cased when the engineer chooses to do so. Installing horizontal screens in dugouts is possible when sand and gravel lenses are near the surface. For more information about dug wells, see 650.5 (C.1), "Dug Wells."
- c. Dugouts are easy to construct, usually require low maintenance, and are economical. However, they also have some downsides.
 - (1) Because foundation materials are so soft, animals can get stuck in the mud and become sanitary hazards. Bacterial contamination is also an issue due to the lack of drainage away from the water supply. Although flood waters may flush bacteria, they also create loose muds that trap animals.
 - (2) Dugouts are not suitable for cold climate winter use because of ice.
 - (3) Dugouts can accumulate sediments from wind and water erosion that greatly reduce holding capacity.
- d. For livestock watering facilities in shallow groundwater areas where dugouts are usually constructed, a shallow well is preferred over dugouts. If an electric service is available, a watering tank with a float switch to activate an electrically operated

pump provides a more desirable and sanitary water supply. See 650.10, “Pumps and Multiple Well Systems,” for pump options. When a float and pump are used, the tank should have an overflow pipe that will dispose of excess water some distance away to prevent a mud hole from developing around the tank.

- e. Install the fencing on three sides and construct a hardened livestock access ramp on the fourth side of the dugout. These can restrict animal access, reduce sedimentation, and improve water quality.

C. Structure Protection

5. Springs frequently occur at locations susceptible to flooding. Protect the spring and appurtenant structures from flooding to allow use without continual maintenance. In many instances, properly located diversions will give protection.
6. Develop the spring so that flood flows passing over the top do not cause damage. A properly constructed and located concrete retaining wall (or wingwall) prevents channel degradation and dewatering of the spring aquifer.
7. A spring box is protected by a steel or concrete lid placed below the top of the concrete wingwall and a rock and gravel debris basin. Additional protection includes extending the pipeline far enough down the valley to avoid flooding the watering tank. This development is illustrated in figures 650L-11 through 650L-14.

D. Pumps

1. Introduction

- a. Use a pump to deliver the water supply if the outlet of the spring is lower than the usage point. See 210 H 634, “Hydraulics,” and 210 H 623, “Irrigation Pumping Plants,” for guidance on selection and design of pumps and energy sources.

2. Hydraulic Rams

- a. A hydraulic ram is a water-powered automatic pump. The hydraulic ram uses the power developed by the surge of a quantity of falling water to force a much lesser amount of water to an elevation above the source of supply. Figure 650L-15 shows a typical hydraulic ram construction in cross section. Figure 650L-16 shows the general configuration of a hydraulic ram used for spring development.
- b. A hydraulic ram works in the following way. Water flows down the drive pipe to the ram, developing power due to the water weight and velocity. Water continues to flow through the outside valve until reaching a specific velocity, then the valve closes. Water continues through the inside or check valve into the air chamber. When the air chamber water pressure equalizes and overcomes the water column driving force, a rebound occurs, closing the inside valve and opening the outside valve. This allows water to start flowing again, and the process is repeated 25 to 100 times per minute, building pressure in the air chamber. The air chamber forces water through the delivery pipe to the usage point.
- c. The amount of water a ram pump can deliver depends on three factors: the vertical drop from the water source to the ram, the height the water needs to raise from the ram to the outlet, and the volume of water available. Figure 650L-17 shows the number of gallons of water lifted by hydraulic ram per gallon received from the water source.

- d. Rams can operate successfully on flows of 1.5 gallons per minute or more with at least 2 feet of head.
- e. When using a hydraulic ram, consider the need for a stable location to accept the wasted water. Wasted water can be a significant volume and potentially induce erosion.

Figure 650L-15: Hydraulic ram cross section

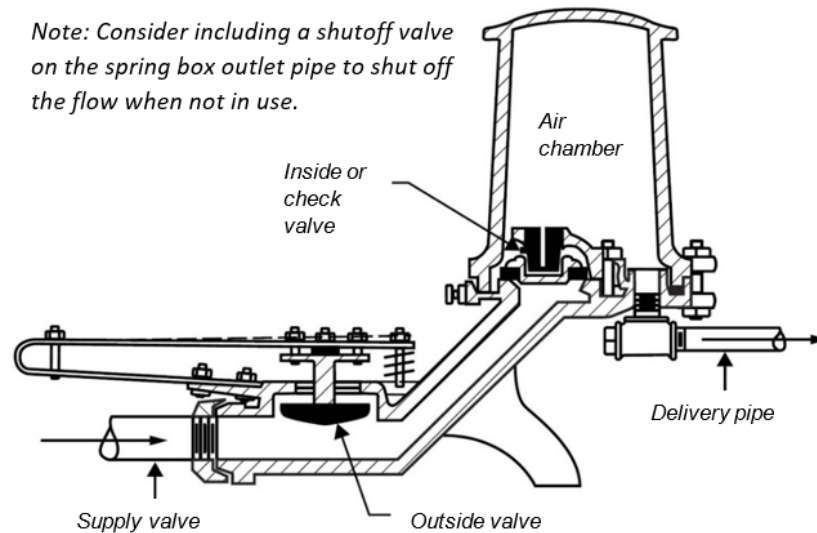


Figure 650L-16: General configuration of a hydraulic ram

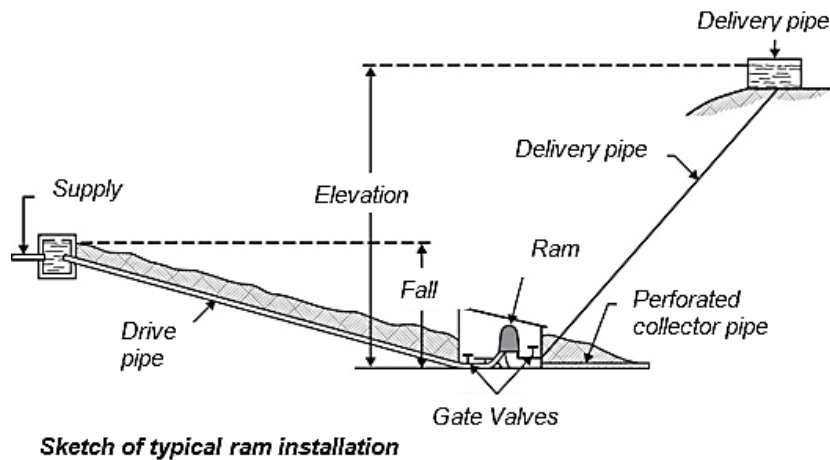


Figure 650L-17: Water vertically lifted by hydraulic ram per gallon received from source

Vertical Lift	12 ft	18 ft	24 ft	30 ft	36 ft	48 ft	60 ft	72 ft
2-foot fall between water supply and ram	0.10	-	-	-	-	-	-	-
4-foot fall between water supply and ram	0.18	0.15	0.10	-	-	-	-	-
6-foot fall between water supply and ram	0.33	0.20	0.17	0.13	0.10	-	-	-
8-foot fall between the water supply and ram	0.42	0.28	0.20	0.17	0.15	0.10	-	-
10-foot fall between water supply and ram	0.54	0.36	0.22	0.22	0.18	0.14	0.10	-
12-foot fall between water supply and ram	0.67	0.44	0.26	0.26	0.22	0.16	0.13	0.10

Source: Farmer's Bulletin No. 1978, Safe Water for the Farm

- f. To determine if a ram is practical, collect the following information:
 - (1) Number of gallons per minute the spring, artesian well, or stream will deliver.
 - (2) Number of gallons per day desired from the ram.
 - (3) Vertical lift (elevation, in feet) to which the water is raised above the ram.
 - (4) Pipeline distance, in feet, from the ram to the point of discharge.
 - (5) Pipeline distance, in feet, from the source of water to the ram.
- g. Estimate the number of gallons of water delivered per minute to a given point with the following formula:

$$D = \frac{VFe}{E} \quad (\text{eq. 650L-1})$$

Where:

D = gallons per minute (gpm) that the ram will deliver

V = water supply available (gpm)

F = fall (feet) between the water supply and the ram

e = ram efficiency (use 0.6 if there is no specific data)

E = lift in vertical elevation (feet) of water above the ram (height delivered)

3. Windmills and Wind Turbines

- a. A windmill is a possible power source for a pump if electricity is not available at the site.
- b. Windmills can power pumps for livestock or domestic water use, either by mechanical lift or generation of electricity for an electric pump. Contact the NRCS state conservation engineer for design criteria of windmills and turbines. Prevailing wind velocities and direction are key criteria, as well as the potential power delivered.

4. Photovoltaic Cells

- a. Solar-powered pumps are another option when grid electricity is not available. The system consists of a solar panel array, solar charge controller, water pump, fuse box/breakers, electrical wiring, and a water storage tank.
 - b. Use solar power to operate water pumps if suitable solar panel arrays are used and provide enough power for the design needs. Photovoltaic powered pumps must have power storage and alternate power sources. Contact the NRCS state conservation engineer for technical guidance on design of solar-powered systems. An example guide is Technical Note No. 28, (Portland Oregon) Design of Small Photovoltaic (PV) Solar-Powered Water Pump Systems.
5. Electric Motors
- a. Where available, use electricity as a power source for pumping water. Electric motors are reliable and efficient, have low maintenance cost, and can easily adapt to automatic control. An electric motor will deliver full power throughout its life.
 - b. The disadvantages of electric motors are the high construction and power costs and power interruptions. Also, the capacity of many single-phase lines limits the power of motors that can be used to about 5.6 kW (7.5 hp), which may not be adequate for high lifts and high-yield developments.

E. Maintenance

1. A developed spring can provide good quality water for many years with periodic maintenance. Springs usually become contaminated when barnyards, sewers, septic tanks, cesspools, or other pollution sources are upstream in the recharge area. In very permeable formations (gravels, limestone, basalt, etc.), water-bearing channels through sinkholes or other large openings may carry contaminated material in the groundwater for long distances. The following precautionary measures help to ensure consistent high quality spring water:
 - a. Test spring water quality before development (CPS Water Quality (Code 355)).
 - b. Install a diversion uphill from the site to intercept surface-water runoff and carry it to a safe outlet.
 - c. Build a fence to exclude livestock from the surface-water drainage system at all points uphill from the spring.
 - d. Provide access to the tank for maintenance.
 - e. Periodically check the spring water for contamination. A marked increase in turbidity or flow after a rainstorm is a good indication that surface runoff is reaching the spring.
 - f. Disinfect spring encasements using a procedure like that used for dug wells (CPS Water Well (Code 642)). If the water pressure is low enough that water does not rise to the top of the encasement, hold disinfectant for 24 hours or according to state or local laws. For continuous flow, introduce disinfectant continuously for as long as practicable or per state or local laws.

- g. Continually check the trough for algae buildup, mudholes, and animal damage. Make necessary repairs or adjustments. Methods to control algae buildup include chemicals (e.g., copper sulfate or chlorine bleach), with quantities depending on the intended water use, or ultrasonic methods.

650.185 Wells

A. Introduction

1. A well is a drilled, driven, or excavated hole in the ground constructed for obtaining water from the material which it penetrates. The purpose of the well (livestock, irrigation, terrestrial wildlife), the geology and hydrogeology, and the required yield determine the optimal well size. The casing, screen type, and installation method are dictated by the potential for corrosion and expected pressure from the formation. Laboratory results of aquifer samples guide the design of filter packs and well screens. The goal in well design and construction is to provide an efficient well to produce the required amount of water at the least cost. An efficient well is designed and constructed using sound geological and engineering principles.
2. NRCS National CPS Water Well (Code 642), USBR (2001), American Society for Testing and Materials (ASTM) D5092, “Standard Practice for Design and Installation of Groundwater Monitoring Wells,” and ASTM D6724, “Standard Guide for Installation and Direct Push Ground Water Monitoring Wells,” provide minimum criteria for water well use, design, and installation.
3. Install all water wells according to local, state, and Tribal laws and NRCS CPS Water Well (Code 642).

B. Drilling Methods

1. Introduction

- a. Drilling a well creates a conduit in the Earth to access and extract groundwater. There are five principal drilling methods: sonic, rotary, cable tool or percussion, jetting, and auger drilling. Each well drilling method has advantages over the other methods under certain conditions.

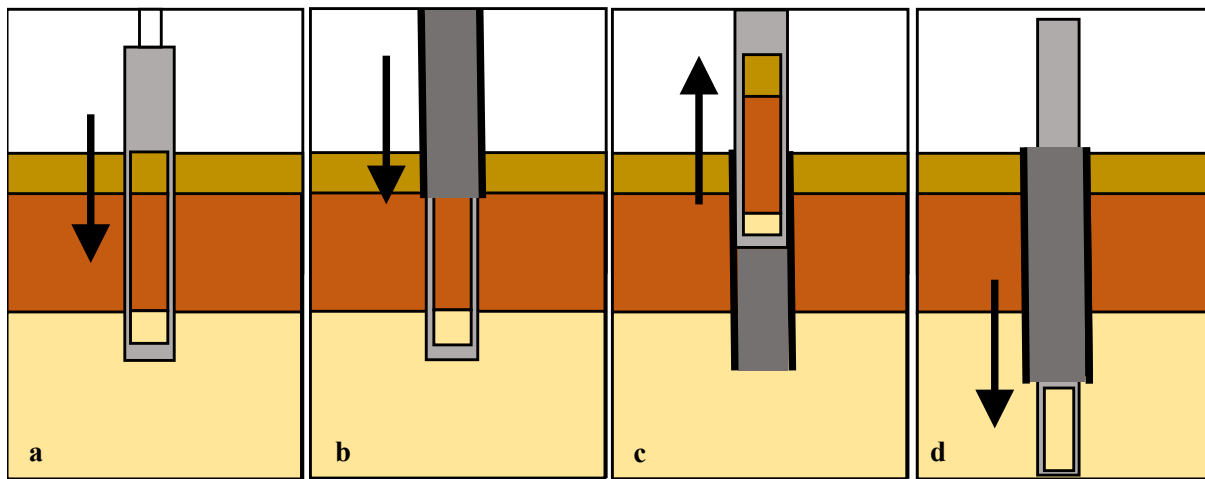
2. Sonic

- a. Sonic drilling, also referred to as rotary vibratory drilling, is ideal for drilling shallow and deep wells and in almost any type of geological setting, including cobbles, boulders, gravels, sand, clay, and glacial tills (figure 650L-18). Sonic drilling is a good choice for any geologic material known as challenging or difficult with other conventional methods. Drilling fluids are not required unless drilling into rock, and samples are relatively undisturbed and continuous.
- b. The sonic sampling barrel can collect unconsolidated material and rock cores. An override core barrel with sonic casing is advanced around the sample barrel to ensure that there is no contamination or mixing within the hole. The licensed water well driller pulls the sample from the ground and extrudes the sample into a sample bag or plastic sleeve. Another drill rod is added to the existing drill string

to advance the sample core barrel beyond or in front of the casing. The process is then repeated until reaching the final bore hole depth.

- c. A disadvantage to sonic drilling is that it has a relatively expensive daily rate and may be more costly than conventional drilling methods. Drilling vibrations can disturb the surrounding formation and create new rock fractures which can affect aquifer testing. Drilling is slow through hard rock.
- d. For additional discussion on sonic drilling, see ASTM D6914, “Standard Practice for Sonic Drilling for Site Characterization and the Installation of Subsurface Monitoring Devices.”

Figure 650L-18: Sonic drilling process



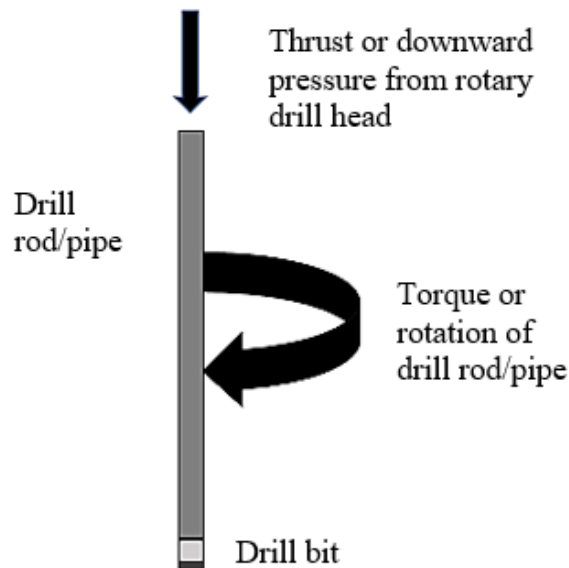
(a) Advancing hole with sampler using high frequency vibration energy, (b) Installing override core barrel with casing around the sample barrel, (c) Extracting sample barrel from bore hole, and (d) Advancing sample core barrel in front of casing and repeating the process until final bore hole depth is reached.

3. Rotary Drilling

- a. Rotary drilling is used to drill and sample most subsurface rock with sharp rotating bits attached to long, hollow steel rods and downward pressures. Drilling fluid such as air, water, polymer, foam, or mud is pumped under pressure and circulated down through the drill rods and out the drill bit to the hole bottom. As the hole is advanced, the drill bit cuts the rock into small pieces, creating drill cuttings. The cuttings are carried upwards by the drilling fluids in the annular space between the drill rods and bore hole wall, and into a mud or drilling pit at the surface. Drill cuttings settle in the pit, and the fluid is recirculated down the hole again. Fluids cool the bit and stabilize bore hole walls to prevent collapsing. Figure 650L-19 is a conceptual drawing showing generalized rotary drilling.
- b. Rotary drilling is the most effective drilling method for collecting representative formation rock samples. The hardest rocks may be drilled with calyx-shot, tungsten carbide-tipped, and diamond bits. Bore hole diameters are between 3- and 18-inches, and typical maximum depths are up to 1,500 feet deep. See ASTM D5783, “Standard Guide for Use of Direct Rotary Drilling with Water-Based Drilling Fluid for Geoenvironmental Exploration and the Installation of Subsurface Water Quality Monitoring Devices.”

- c. There are several different types of rotary drilling methods, including, but not limited to:
 - (1) Open hole drilling
 - (a) Open hole drilling is used when subsurface rock is stable enough to not require casing. Drilling techniques use direct or reverse circulation systems with tricone or drag rock bits and a down-hole hammer. Rock samples are not collected using these methods, which makes this method typically faster than other drilling methods.

Figure 650L-19: Rotary drilling schematic



- (2) Core Drilling
 - (a) Core drilling typically requires a steel cabled wireline, sample barrel, and diamond or tungsten core bits. Samples are collected in either a single steel tube or barrel, an outer steel barrel with an inner split liner, or an outer steel barrel with two inner steel liners. Also known as single, double, or triple tube samplers. The most common sample barrels used are the double or triple tube samplers also known as the Denison or triple tube core barrel Denison. For more information about these sampling techniques, see 210 H 631.0503, “Engineering Geology Logging, Sampling, and Testing.”
 - (b) Before the hole advancement begins, the sample barrel is lowered onto the drill rods using an over-shot tool and steel cable wire line which is attached to the drill rig. An over-shot tool, commonly called a “fishing tool,” is used to retrieve a “fish,” the sample barrel, from the bottom of the bore hole. Depending on the hole depth, the licensed water well driller either lowers the barrel to the bore hole bottom, or the sample barrel is lowered only part way into the bore hole where it releases the barrel from the overshot tool. The tool is retracted to the surface while the barrel drops to the bore hole bottom. The licensed water well driller then pumps and

circulates water into the drill rods until the core barrel locks within the rods.

- (c) As the licensed water well driller begins coring and advancing the bore hole deeper, the core barrel with inner liner(s) slides over the rock core sample. The time required to drill a 10-foot-long sampled interval can vary significantly, ranging from 30 minutes to over 2 hours, depending on the rock hardness. When the sampled interval is completed, the over-shot tool is lowered back into the drill rods and locks on top of the sample barrel. The wire line is retracted, pulling the sample barrel to the surface. The core sample remains inside the sample barrel because a split ring core lifter or basket keeps the core in place. When the barrel is removed from the hole, the licensed water well driller connects one end of the hose to the top of the sample barrel while the other end is attached to the drill rig. Pressurized air and water are used to push the inner liner from the outer steel sample barrel.

(3) Mud Rotary

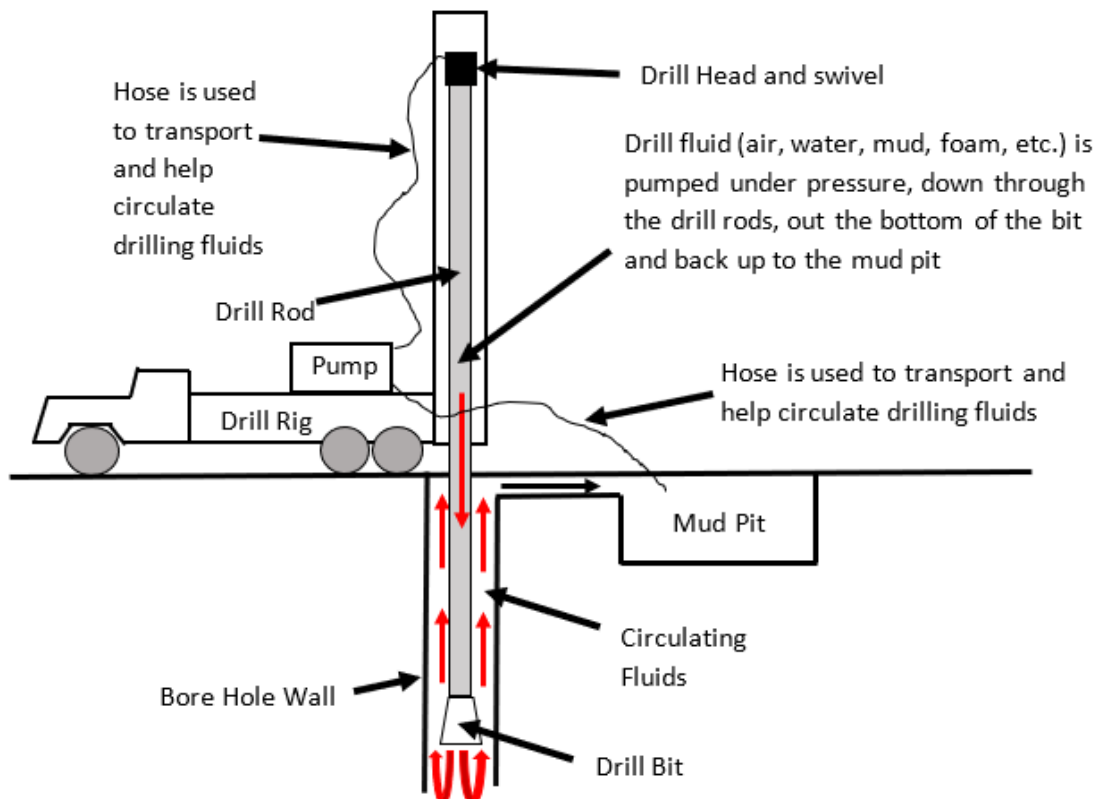
- (a) Mud rotary drilling is an open hole drilling method accomplished by down hole pressure and rapid rotation of the drill bit and rods, while pumping a bentonite or polymer drill mud slurry into the hole (figure 650L-20). Drill mud is circulated down through the drill rods and out the drill bit, where cuttings are picked up and transported upwards in the annulus between the drill stem and bore hole wall, and back into a mud or drilling pit at the surface. Drill cuttings settle in the pit, and mud is then recirculated down the hole. When fluids may be lost to the formation, more mud is added as the bore hole gets deeper. Mud slurry is also used to cool the bit, stabilize the bore hole wall, and reduce cross-contamination between aquifers.
- (b) Mud rotary is best for telescoped casings, where the casing starts at a larger size and successively changes to smaller sizes. Telescoping isolates drilled intervals and protected lower geologic formations from contamination from upper sediments. Mud rotary is a fast and efficient method designed to handle a wide range of geologic conditions. Geologic conditions best suited for mud rotary are rock, consolidated sand, or tight gravel formations where a hollow stem auger is ineffective. Conditions not suited for mud rotary are cavernous limestone formations and poorly stabilized cobble and boulder materials.

(4) Air Rotary (including using drilling foam)

- (a) Air rotary is typically used for deep bore holes in consolidated formations, such as hard granite, sandstone, and shales. Bore holes are advanced by rapidly rotating drill bit, which is attached to the end of a long string of 10-foot-long steel pipes. Like other rotary drilling methods, the drill bit cuts the formation into small pieces. High pressure compressed air is circulated through the hole to capture the cuttings and bring them to the surface. Split-spoon sample barrels and thin-wall samplers are not used for this drilling method. Proper airflow is crucial when using this method. Insufficient airflow can prevent the cuttings from being lifted, causing the pipe to become clogged. Excessive airflow leaves inadequate space for the

cuttings to return to the surface. See ASTM D5782, “Standard Guide for Use of Direct Air-Rotary Drilling for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices.”

Figure 650L-20: Generalized rotary drilling method with drill fluid circulation



(b) Several different variations for air rotary drilling include:

- Direct air rotary casing hammer (aka Top Drive or ARCH) – This method combines direct air rotary drilling with the operation of a casing hammer. This method is best suited for alluvial formations and is not designed to drill through hard rock. When needed, this method is used to initially cut through unconsolidated materials to top of bedrock. This allows the licensed water well driller to switch to a different drilling method, such as rotary or reverse circulation drilling.
- Down hole hammer – Down hole hammer uses a mini jackhammer attached to the bottom of a string of drill pipe (drill stem) to break hard rock into small pieces. Compressed air or fluids are used to expel cuttings and fluids from the bore hole. This method is one of the fastest ways to drill hard rock.
- Under reaming – Under reaming is a variation of the direct air rotary casing drilling that uses a cutting bit in front of the casing to enlarge the boring below an existing casing. This allows for easier casing advancement and cementing casing properly. This method is commonly used in swelling shales or when there is a need to install

larger casing. This method can be used either in existing boreholes or during drilling of new boreholes.

(5) Dual Rotary

- (a) Dual rotary is the most efficient and cost-effective method for drilling in unconsolidated formations, such as sand, gravel, cobbles, and boulders. This drilling method uses both an upper and lower head drive to advance the drill bit and casing, compared to other drill rigs which only use an upper drive. Typically, the drill bit is a carbide-studded shoe that is welded to the first casing.

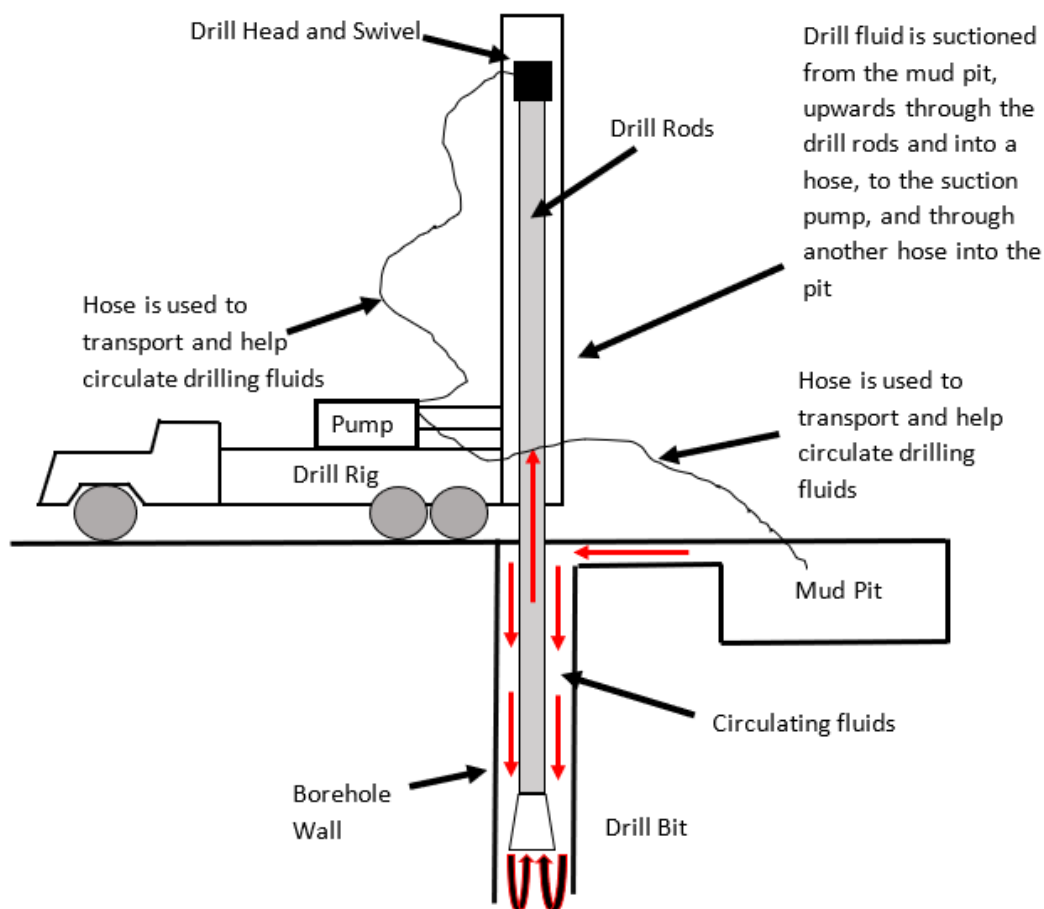
(6) Diamond Core

- (a) Diamond core rotary drilling uses a diamond-impregnated drill bit, secured to the end of hollow drill rods or pipes, to cut hard, consolidated rock core samples. The diamond size and count in the bit vary, depending on the rock hardness. For example, a softer rock might use a bit with a low diamond count, while harder rock may use a bit with more diamonds. This drilling method is much slower than reverse circulation or other drilling methods due to the rock hardness and core retrieval methods. Drilling depths can be up to around 6,000 feet or greater.

(7) Reverse Circulation

- (a) Reverse circulation is like rotary drilling except that drilling fluids and cuttings are returned upward through the drill stem by a suction pump to the mud pit at the surface (figure 650L-21). This method is best suited for larger diameter bore holes, 16 to 50 inches. Smaller diameter holes are not recommended because plugging of the drill pipe becomes a bigger problem, and hole advancement is significantly slower. This method is used on a bore hole that is up to 2,000 feet deep.
- (b) Drilling requires large volumes of water, but this method is effective for drilling in unconsolidated sediments, such as gravel and sand. With reverse circulation drilling, fluids in the bore hole are brought to the surface faster than conventional circulation drilling, bore hole washout is reduced, and sampling is faster and more accurate because drill cuttings are not in contact with or mixed with bore hole wall cave or slough materials.
- (c) Reverse circulation has two methods:
 - Flood reverse – This method adds fluid to the bore hole through a flow ditch or settling pit to keep the bore hole full of water. This method works well in unconsolidated formations that require high hydrostatic head.
 - Air reverse – This method uses a small air line inside the drill pipe to lift cuttings. This works well in limestone or other similar formations that produce groundwater. Instead of hauling water to the site, this method requires removing water from the site as it is discharged from the bore hole. This method typically requires a water disposal plan before being used onsite.

Figure 650L-21: Generalized reverse rotary drilling method with drill fluid circulation



4. Cable Tool or Percussion Drilling

- a. Cable tool or percussion drilling operates by repeatedly lifting and dropping a chisel faced bit or heavy impact tool with either motorized equipment or by manual labor, progressively boring subsurface materials.
- b. The impact tool is secured to a wireline or steel cable attached to either a drill rig or a tripod and pulley system and is fitted with a cutting basket to trap drill cuttings. After several impacts, the tool is raised from the borehole, the cuttings basket is emptied, the hole is bailed of any remaining cuttings, and the tool is lowered back down into the hole. The process is repeated until completion. This drilling method is not effective for consolidated geologic formations and has a slow hole advancement rate, but cable tool drilling is relatively inexpensive and good for collecting soil samples and water level information.

5. Jetting

- a. The jetting drilling method advances the hole based on water circulation and pressure. Water that is pumped down the drill pipe and out the bit erodes the bottom of the hole. Slurry, a combination of water and cuttings, is then

transported under the same pressures upward between the drill pipe and bore hole wall to ground surface. Drilling fluid additives can prevent hole collapse and reduce water movement into the formation.

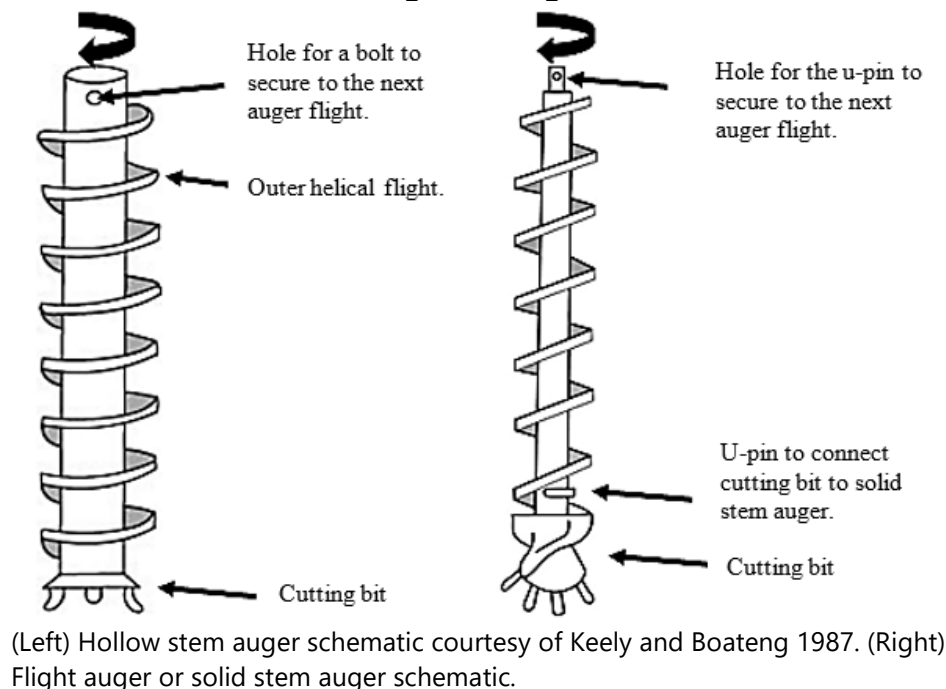
- b. Although this method can be fast, identifying and measuring the water table is not possible during drilling, and the ground surface can quickly become saturated and make accessibility challenging. The maximum drilling depth for this method is 150 feet.

6. Auger Drilling

- a. Auger drilling is the simplest drilling method for investigating and sampling soil and very soft to soft rock. This method has some limitations, including rock hardness, amount and size of cobbles and boulders when compared to the auger diameter, and depth to water table.
- b. For additional discussions about auger drilling, see ASTM D1452, “Standard Practice for Soil Exploration and Sampling by Auger Borings,” and Bureau of Reclamation Earth Manual, Part I.
- c. Two auger drilling methods are commonly used:
 - (1) Hollow Stem
 - (a) Hollow stem auger drilling (figure 650L-22) is a common method used for soil and very soft to soft rock sampling and groundwater monitoring well installation. Hollow stem augers are approximately 5 feet long, manufactured from steel, and have an outer helical flight welded around a hollow shaft. The lead auger is equipped with a cutting head and plug.
 - (b) When the bore hole is advanced, augers are rotated and forced downward by pressure from the drill rig. As each auger is drilled into the ground, another auger with identical helical flight is added. Joining the augers results in a continuous flight from the bottom of the bore hole to above the ground surface.
 - (c) When no samples are collected, a pilot bit, bit plug, or center bit assembly is used with a secondary internal rod string as the bore hole is advanced. Drill cuttings are pushed upward from the bore hole bottom between the annulus of the auger string and the bore hole wall. When the bore hole is drilled to the required depth, the pilot bit is retracted from the augers, and the licensed water well driller reverse drills or rotates the augers in the opposite direction to slowly retract and remove each flight auger.
 - (d) When samples are collected, a split-spoon sample barrel is lowered into the hollow shaft of the augers to the bottom of the hole and is retracted at the end of each sampled run. After the soil and/or soft rock sample is removed and logged, the sample barrel is returned inside of the augers and the process is repeated. For this sampling method, different soil horizons and rock intervals can be measured and logged with a high degree of accuracy.
 - (e) Hollow stem augers accommodate different testing and sampling techniques, including standard penetration testing and vane shear testing, both disturbed and undisturbed sampling, and installation of piezometers or monitoring wells. When sampling is not required, a pilot bit with plug

or center bit assembly is inserted into the augers, instead of a sample barrel, to prevent soil from entering the augers.

Figure 650L-22: Hollow stem and solid stem auger drilling



(2) Continuous Flight or Solid Stem

- (a) Continuous flight augers (figure 650L-22) and corresponding drilling methods are comparable to hollow stem auguring except that the shaft is solid instead of hollow. Bore holes are advanced in a similar manner, using rotation and downward pressure, and each auger section is added to form one continuous flight. To help bring cuttings to the surface and clean out the bore hole, the licensed water well driller typically increases the rotation speed without downhole pressures at the end of each auger section, before adding the next auger.
- (b) As drill cuttings are brought to the surface, augured materials mix with bore hole sidewall material to form a composite sample. Composite sampling is not as accurate as split-spoon sampling and may not accurately represent the subsurface materials. For example, non or low cohesive, low-density material, such as a poorly or well graded sand, will likely mix with a higher density material, such as a lean clay, to form a sandy lean clay. This may be problematic for groundwater investigations where locating more permeable materials is important.

C. Other Methods

1. Dug Wells

- a. Dug wells are shallow and dug to or below the groundwater table using a backhoe or excavator. Dug wells must meet CPS Water Well (Code 642), grouting and

sealing requirements. Otherwise, the structure is considered a dugout, and subject to meeting either CPS Spring Development (Code 574), or CPS Pond (Code 378).

- b. A geologist should confirm that the shallow aquifer is adequate to provide water quantity and water quality for the well purpose.
- c. Construction is sometimes difficult due to caving, and any opportunity to improve yield by development is lost due to the inherent sealing caused by the digging process.
- d. Dug wells are very susceptible to contamination from surface or near-surface run-in (see 650.4 B. 4, “Dugouts,” for more information).

2. Drive Point Wells

- a. Drive point wells, sometimes called sand point wells, are steel pipes with a screen and drive point attached to the end. The drive point is driven into the ground.
- b. The use of drive point wells is limited to areas underlain by unconsolidated clay, silt, and sand that are relatively free of gravel, cobbles, or boulders. Depth to water, including drawdown, must be less than the suction limit at the elevation of the well. The practical limit of suction lift for pumps is 22 feet at sea level, 17 feet at 5,000-foot elevations, and 14 feet at 10,000-foot elevations. Driven wells are constructed by driving pipe fitted with a sand point sufficiently below the water table so that fluctuations and drawdown from pumping will not lower water below the drive point.
- c. A sand point consists of a forged steel point attached to a short length of perforated pipe. The perforated pipe is wrapped with either brass screen or spiral wound brass bands having a trapezoidal cross section. The bands form a relatively non-clogging slot that is narrowest on the outside.
- d. In driving the point through materials containing considerable amounts of clay, the openings often become clogged. It may prove advisable to auger or jet the hole through the clay layers.

3. Hand and Power Auger

- a. Hand augers are manual tools used to drill shallow wells, less than about 20- to 60-feet deep, depending on the soil conditions. They are best used in soft, unconsolidated soils like sand, silt, and clay, but are not as effective in gravelly materials, rock, or compacted soil and rock. Ensure that State, local, and Tribal regulations allow hand augering a water well.
- b. Power augers are generally more efficient and powerful than hand augers but have the same limitations as hand augers. They are best suited for shallow wells, and work well in soft, unconsolidated sand, silt, clay, and rock. They are not as effective in gravelly materials or compacted soil and rock. Similarly, ensure that State, local, and Tribal regulations allow power augering a water well.

D. Water Well Construction and Application

- 1. Figure 650L-23 summarizes various well construction methods and the appropriate application of each.
- 2. Greater drilling depths are reached with heavier equipment. Use care when selecting material and designing casing for wells constructed at greater depths.

E. Site Selection

1. Complete a geologic report to assist in site selection. A geologic report provides the essential elements needed to select a well site. 210 H 631.1110, "Groundwater Data Collection," covers geologic investigations and reports. The essential elements include:
 - a. An adequate (quality and quantity) and dependable water source.
 - b. Geologic maps and published groundwater studies.
 - c. History of potential hydraulic connections and aquifer testing data.
 - d. A structure or conditions that act to retain or obtain and transmit water.

Figure 650L-23: Water well construction methods and applications

Well Construction Method	Best Suited Materials	Best Suited Water Table Depth (ft)	Typical Max. Depth (ft)	Typical Diam. Range (in)	Typical Casing Material	Typical Use	Remarks
Driven Wells Hand, air hammer	Silt, sand, gravel <2 inches	5–15	50	1.25–4	Standard weight pipe	Domestic, drainage	Limited to shallow water tables, no large gravel.
Drives Wells Sonic (vibratory)	Solid to hard consolidated rock	Any depth	~900	12–12.75	None in consolidated rock	All uses	Rapid hole advance in unconsolidated materials but may slow in hard rock.
Jetted Wells Light, portable rig	Silt, sand, gravel < 1 inch	5–15	50	1.5–3	Standard weight pipe	Domestic drainage	Limited to shallow water tables, no large gravel.
Drilled Wells Cable tools	Unconsolidated and consolidated medium hard and hard rock	Any depth	1,500 ¹	3–24	Steel, wrought iron, fiberglass, or plastic pipe ²	All uses	Effective for water exploration. Requires casing in loose materials. Mud-scow and hollow rod bits developed for drilling fine to medium sediments.
Drilled Wells Hydraulic rotary	Silt, sand, gravel, < 1 in.; soft to hard consolidated rock	Any depth	1,500 ¹	3–18	Steel, wrought iron, fiberglass, or plastic pipe ²	All uses	Fastest method for all except hardest rock. Casing is usually not required during drilling. Effective for gravel envelope wells.
Drilled Wells Reverse Hydraulic Rotary	Silt, sand, gravel, cobble	5–100	200	16–48	Steel or wrought iron pipe	All uses	Effective for large-diameter holes in unconsolidated deposits. Requires a large volume of water for drilling. Effective for gravel envelope wells.
Drilled Wells Air Rotary	Silt, sand gravel <2 in.; soft to hard consolidated rock	Any depth	2,000 ¹	12–20	Steel, wrought iron, fiberglass, or plastic pipe ²	All uses	Very fast drilling. Combines rotary and percussion methods, and air drilling. Cuttings are removed by air. Economic for deep water wells.
Augered Wells Hand auger	Clay, silt, sand, gravel < 1 inch	5–30	35	2–8	Sheet metal or plastic	Domestic, drainage	Most effective for penetrating and removing clay. Limited by gravel > 1 inch. Casing is required if material is loose.
Augered Wells Power auger	Clay, silt, sand, gravel < 2 inches	5–50	75	6–36	Concrete, steel, wrought iron, fiberglass, or plastic pipe	Domestic, irrigation drainage	Limited by gravel >2 inches, otherwise same as for hand auger.

¹ Greater depths reached with heavier equipment

² Use care when selecting material and designing casing for greater depths.

F. Design Planning

1. A properly designed and constructed well is a conservation practice. Design and install all water wells according to State, Tribal, and local law, and NRCS CPS Water Well (Code 642). Note that State, local, and Tribal requirements and criteria may differ.
2. Consider the following for each water well:
 - a. Obtain information needed in designing a well from studying logs and sieve analyses of samples from test holes. The samples must be representative of the aquifer materials. If site information is not available, records of nearby wells will be helpful. If area information is not available, a geologic report on the site will provide the best basis for design decisions.
 - b. Use geologic, engineering, and economic considerations, and CPS Water Well (Code 642) requirements to make the following design decisions.
 - (1) Drilling method
 - (2) Earth materials
 - (3) Hole diameter and depth
 - (4) Position, size, and number of casing perforations
 - (5) Need for a well screen
 - (6) Need for a gravel envelope
 - (7) Choice of well development method.
 - (8) Earth materials
 - c. Design a well to fit site conditions and document the information during construction. Consider the:
 - (1) Annual amount of water required
 - (2) Annual pumpage and duration
 - (3) Economic life of the well
 - (4) Type of production system
 - (5) Well type
 - (6) Materials used to construct the well
 - (7) Cost estimates for installation, pump, well materials (screen, casing, etc.), testing and well development
 - d. Water well vertical alignment.
 - (1) Drill the well in such vertical alignment that after well completion and testing, a deep-well pump can readily be installed and operated without undue stress or wear from excessive inclination of the shaft.
 - e. Annular space between the casing and pump.
 - (1) Ensure that the amount of clearance from the well casing to the well pump meets or exceeds manufacturer's requirements.
 - f. Well screen installation.
 - (1) Use the grain-size distribution of aquifer materials to justify the installation of a well screen, an artificial gravel envelope, or both, according to best practice.
 - (2) Install the well screen in the desired water-bearing strata to yield the required quantity and quality of water. Use grain-size distribution of aquifer materials to size perforations according to best practice.
 - g. Contracts and Specifications

- (1) A landowner may want to consider having a written contract when having a well drilled. Although an oral contract is binding on both parties, misunderstandings can develop because it depends on memory. For written contracts, avoid contract specifications that are too rigid because they may lead to excessive costs.
 - (2) Legal contracts can be complicated. The landowner can consult with an attorney before entering a contract. A thorough understanding and agreement on at least the following points are necessary for a satisfactory job:
 - (a) Casing construction and specifications
 - Casing diameter (inches)
 - Casing weight (pounds per foot) or polyvinyl chloride (PVC) class
 - Casing length from the ground surface to termination depth
 - (b) Estimated water well cost
 - Require a unit price per foot of well which will include the cost of moving to and from the well site and setting up the equipment.
 - Require a line item for well and aquifer testing including time for installing and removing the pump in dollars per hour.
 - (c) Well development and Pump test (not to be confused with an aquifer test)
 - After well completion, the licensed water well driller will develop (air test) the well with a surge block, bailer, or other equipment until the water is sand-free.
 - The licensed water well driller or pump installer will test the pump after surging and bailing the well. The pump will have a capacity more than the expected yield and can pump at variable rates. Operate the pump continuously for a specified amount of time (hours). Use an airline or other suitable method to measure the drawdown periodically during pumping.
 - (d) Aquifer Test
 - Understand NRCS aquifer testing requirements, the goal of aquifer testing, and what information is expected from the test.
 - For more information about aquifer testing, see 650.9 G and 210 H 631.3112, “Groundwater Investigations.”
 - (e) Water quality testing
 - Understand what water quality testing may be required for the water well. See 650.5 I., “Water Quality Testing,” for more information.
 - (f) For more information about water well installation requirements, see CPS Water Well (Code 642).
3. Potential consequences for an incorrectly installed well.
 - a. Turbid, sediment laden water, which can lead to health risks.
 - b. Well yields may decrease over time.
 - c. Pump issues due to sediment intake.
 - d. May shorten the well lifespan.
 - e. Groundwater and surface water contamination.

G. Records

1. Maintaining complete records aids efficient and economical groundwater development. Retain copies of the records of test holes, completed well and equipment, development operations, and pumping tests in the field office and other offices as required.
2. A permanent file may contain the following:
 - a. Test hole logs and location map
 - b. Sieve analyses of formation samples
 - c. Water analyses
 - d. All geologic data collected in the exploration stage
 - e. Well design drawing showing accurate finished dimensions and details
 - f. Pump specification sheets, performance curves, parts lists, etc.
 - g. Details of repairs, acid treatments, etc.
3. Document well construction using a well completion diagram such as those in figures 650L-24 and 650L-25.
4. Ensure that all local, State, and Tribal reporting regulations are followed.

H. Construction Tips

1. Have all required construction equipment and materials to finish the well at the site before drilling starts.
2. For cased wells, avoid leaving a hole open for any length of time. Swelling, caving in, and sloughing of formation materials might permanently damage the well and lessen its yield.
3. Construct a hole of constant diameter and alignment.
4. Use extreme care to place the screen and casing according to the manufacturer's recommendations.
5. When placing the filter pack and sealant materials, avoid separation or bridging of material.

I. Water Quality Testing

1. Review existing water quality reports to assess the potential for corrosion or encrustation. Knowing this in advance enables installation of an appropriate screen or casing. Screens of various metals, alloys, plastic, and other materials are available for specific water quality applications.
2. Some licensed water well drillers will water quality test for total dissolved solids (salts) in the field and report it on the well or boring log. The landowner will need to contact a local laboratory for comprehensive water quality testing.
3. See 210 H 631.3108, "Groundwater Quality," for a detailed discussion of groundwater quality, common farm pollutants, and factors affecting groundwater quality.

Figure 650L-24: Non-flowing artesian well design documentation

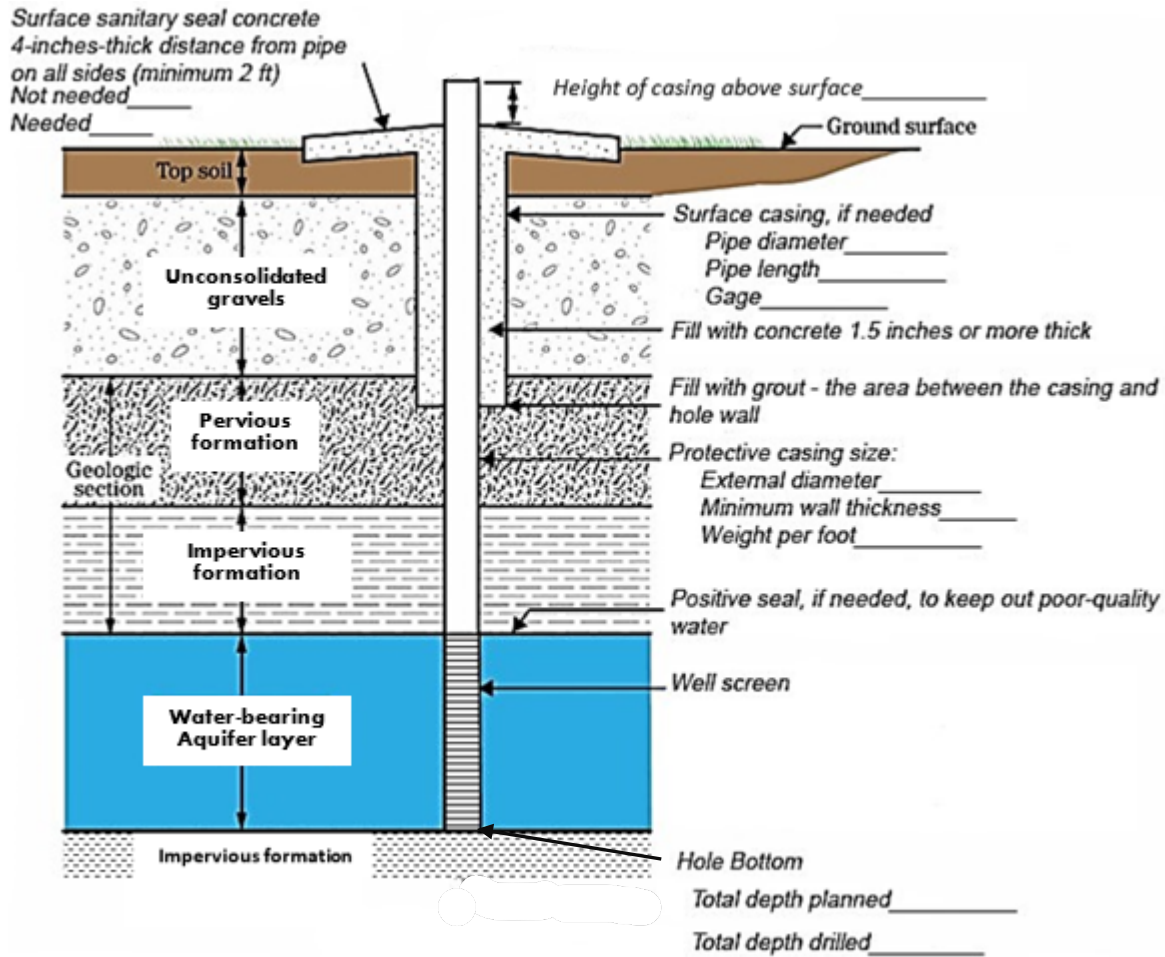
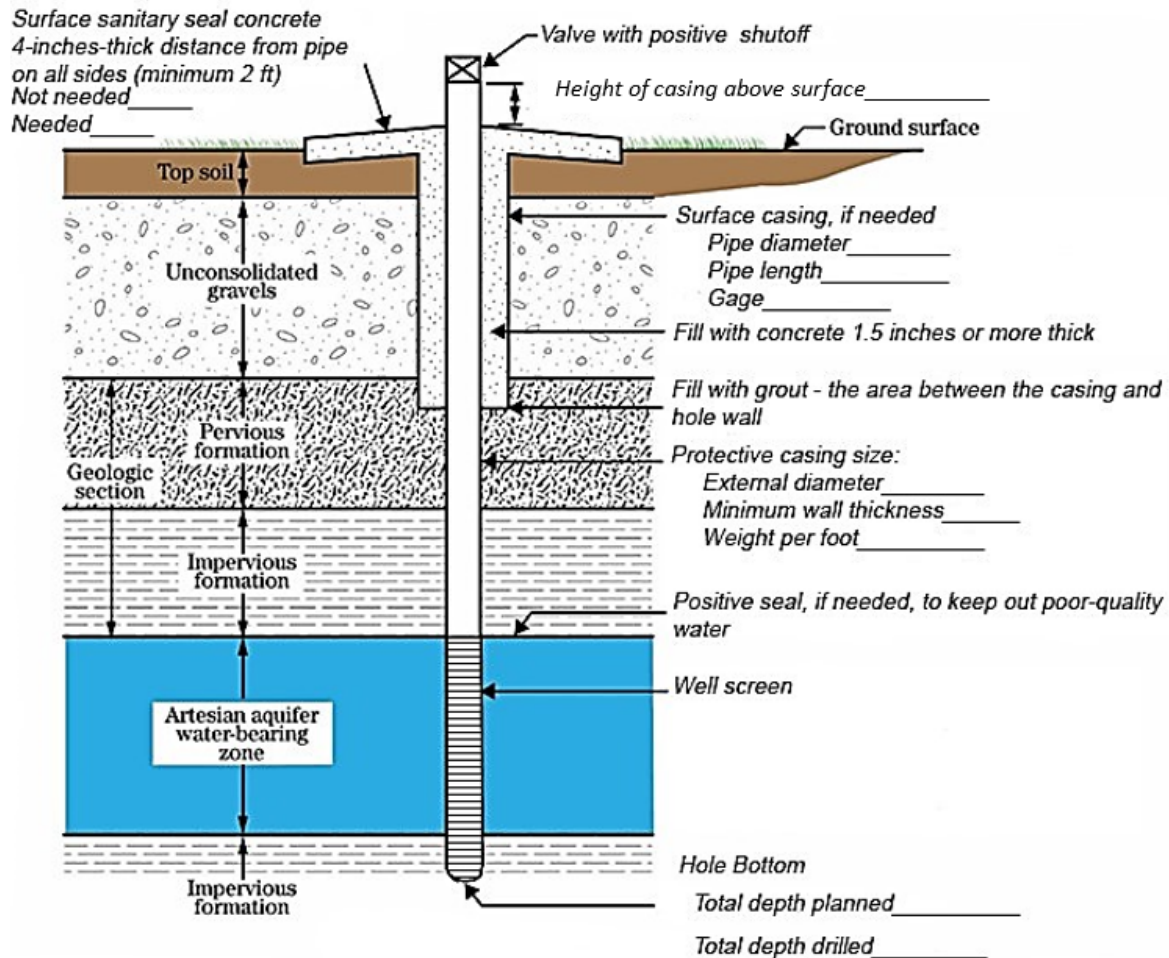


Figure 650L-25: Flowing artesian well design documentation



650.186 Artesian Wells

A. Controlling Flowing Artesian Wells

1. Introduction

- a. Artesian wells occur when the aquifer pressure raises water into the well casing to above the aquifer. Flowing artesian wells occur when the aquifer pressure forces water above the top of the casing and out of the well. Flows can be continuous or intermittent.
- b. Before drilling a water well, the licensed water well driller must investigate the region to see if flowing artesian is possible to ensure that they have the proper equipment and supplies. They must select the appropriate casing material, grout, and wall thickness to account for water pressures, sealants, and possible freezing.
- c. Drilling through a confined aquifer may provide a potential pathway for flowing water outside of the well casing. The licensed water well driller must prevent this from happening by grouting the annular space between the boring and permanent casing. Drilling into a flowing artesian aquifer leads to uncontrolled water flowing

out the top of the casing. To control this, the licensed water well driller often uses drilling mud, also called drilling fluid, to increase the density, control pressures, and to stabilize boring to keep the walls from collapsing before installing the casing.

- d. A tight annular seal is imperative. Otherwise, when the licensed water well driller controls the flows within the casing, pressurized water will likely flow upward along and around the casing, which is typically the path of least resistance, to the ground surface.
 - e. If this breached water flows into an upper unconfined aquifer, such as alluvial sand and gravel, the water may surface above ground and saturate the soils around the well. This may give the appearance of a “spring” and indicate that the confining layer is eroded and breached. Similarly, older flowing artesian wells with surrounding saturated conditions could mean that the confining layer did not breach but that the casing has corroded and failed.
 - f. Like all water wells, a vermin-proof, water-tight well cap is required for protection.
 - g. A control valve is typically installed on the production casing above ground to regulate flows.
 - h. Raising the casing or adding a watertight or welded cap can sometimes stop the flow. However, the water is prone to freezing in the winter, because the static level is above the frost line. The licensed water well driller must select and install casing and caps adapted for colder temperatures and possible freezing. Watertight caps or welded caps are difficult to repair and service.
2. Flowing Artesian Wells Requiring a Pump
- a. Typically, flowing artesian wells do not require a pump to bring water to the surface. However, a pump is occasionally used to boost low yielding flows. When a pump is needed, a minimum 4-inch diameter well casing is likely required. This is because the smallest pump that has enough energy to lift water to the surface is 3-inches in diameter.
 - b. The licensed water well driller will install a spool-type pitless adaptor below the frost line, which is designed to handle high pressures. The spools are made of rubber rings attached to steel plates and are designed to keep the water below the frost line in the well casing. The spool allows for electrical cables to connect to the submersible pump.
 - c. The licensed water well driller may install one or more flowing packers, also known as drawdown seals, below the pitless adaptor. The packer seals the area above the submersible pump and creates a low-pressure vacuum below the seal to lower the static water level in the casing.
 - (1) The packer is made of rubber between two steel plates and is attached to long metal rods. This enables the licensed water well driller to lower it deep into the well. The packer bottom must be equipped with an air vacuum valve and/or a combined air vacuum and air release valve. Air vacuum valves allow air to enter and rapidly vents air from the system. An air release valve allows gas buildup in the water to slowly vent while keeping a watertight seal.
 - (2) When the licensed water well driller lowers the packer to the correct depth in the well, they use a socket wrench to turn the steel rod. Turning the rod

squeezes the plates and expands the packer to seal the inner casing annulus at that location.

(3) The packer top and bottom have wiring to attach to the submersible pump and extend wires out of the well and connect to an electrical service.

(4) When well maintenance or repair is required, the licensed water well driller must use caution because sometimes high-water pressures force the packer from the well.

3. Using a Tank to Control Artesian Well Flow

- a. Another option for controlling an existing flowing well is to install a tank next to the well and direct the flow into the tank until the water level rises and the pressure is equalized thus stopping the flow.

4. Artesian Well Casing Installation

- a. Overburden aquifers typically require a permanent outer casing that is grouted in place.
- b. Bedrock aquifers typically require driving the casing into the rock and seated securely to create a seal.
- c. When drilling through multiple confining layers or through multiple aquifers above the artesian aquifer, the licensed water well driller typically seals the outer casing into the lowest layer prior to advancing the inner casing.
- d. Oversizing the hole is important to ensure adequate sealant is placed to contain flowing water.

650.187 Well Hydraulics

A. Well hydraulics focuses on how groundwater flows and the behavior of the water in the wells.

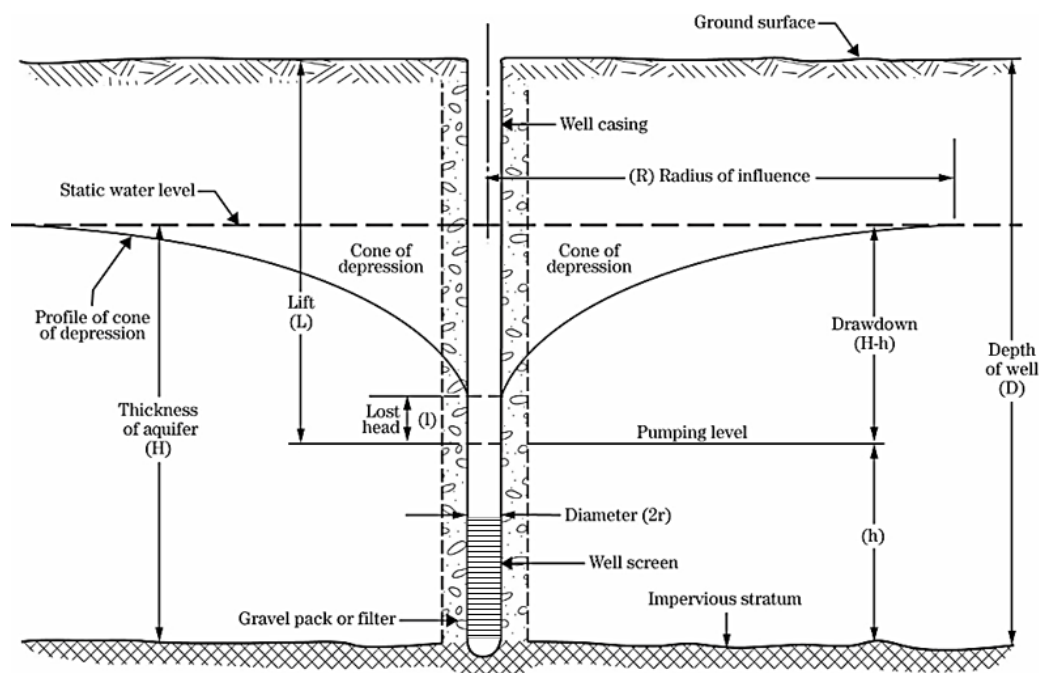
B. Equilibrium Conditions

1. A groundwater reservoir trends toward an equilibrium state, with natural discharge balancing natural recharge. In other words, recharge equals discharge, and the water level reaches a steady-state or has no drawdown. Installing a discharge well disturbs this balance, and a new equilibrium state is reached by the propagation of a cone of depression. As the cone of depression extends outward and deepens, the natural recharge is increased – or natural discharge and well discharge are decreased, until equilibrium is again established. The extent of the cone of depression is called the area of influence or more commonly the radius of influence (ROI) (figure 650L-26).

C. Note, figure 650L-26 uses a lower case “r” to represent the well radius while a capital “R” is used for the radius of influence. Whereas Fetter 1994 illustrations use a lower case “r” for the radius of influence. In other words, publications may use different letters to represent the same dimension. Pay close attention to equation components and their definitions to understand what information is needed.

1. Wells can take a few hours, days, weeks, or months to reach equilibrium, if they do reach it. For wells that do not reach equilibrium, see 650.7 C, “Nonequilibrium Conditions.”

Figure 650L-26: Diagram showing groundwater terminology



2. A multi-well aquifer test is required to calculate transmissivity and storativity under equilibrium conditions. This means that a pumping well and one or more observation wells are needed. The dynamic water level (pumping water level, PWL) is measured in the observation well, and the ROI (r) is measured between the pumping well to the observation well. If more than one observation well is used, measure the distance from the pumping well to each observation well.
3. NRCS will mostly perform single well aquifer tests, where the pumping water level is measured in the pumping well. This is because drilling and installing observation wells, in addition to the pumping water well, is not an economic or common practice for NRCS projects. Also, useable existing wells are generally not available. However, when a producer has multiple, useable wells on their property, NRCS may elect to contract a multi-well aquifer test.
4. When a single well aquifer test is conducted, the time-drawdown data plotted on a semi-log graph is used to calculate transmissivity, but not storativity. Determining storativity, the aquifer's ability to store water, requires performing a multi-well aquifer test.
5. For more information about aquifer testing, see 650.9 G and 210 H 631.3112, "Groundwater Investigations."
6. In an ideal, homogenous, isotropic aquifer of finite thickness and infinite extent, a completely penetrating discharge well is surrounded by a series of imaginary concentric cylinders. At equilibrium, the flow through each cylinder is equal to the well discharge, and the cylindrical section areas become successively smaller as water moves toward the well.
7. For example, cylinder A radius (r_2) is 100 feet from the well center, and cylinder B radius (r_1) is 50 feet from the well center. Cylinder A area is twice cylinder B given that the area of a cylinder equals $2\pi rh$. Since the same amount of water flows

through both cylinders to the well, the velocity at cylinder B (closest to the well) is twice the velocity at cylinder A (furthest from the well). In other words, the closer water gets to the well, it is forced to move faster through the smaller area.

8. Darcy's law describes flow through a permeable material:

$$Q = KIA$$

therefore,

$$K = Q/IA \quad (\text{eq. 650L-2})$$

Where:

K = hydraulic Conductivity (ft³/ft²/d)

Q = discharge (groundwater flow) from pumped well (ft³/d)

I = hydraulic gradient (ft/ft)

A = cross-sectional area through which flow occurs (ft²)

5. Confined Aquifer Equilibrium Conditions

- a. Aquifer permeability is determined if the groundwater hydraulic gradient is known at distance, r, from a well discharging a known volume of water. At this distance, the cylinder area through which flow occurs is $2\pi rb$ for a confined aquifer, "r" is the well radius and "b" is the saturated aquifer thickness (figure 650L-27).
- b. Since the hydraulic gradient is not measured at a point, a mathematical treatment of Darcy's equation substitutes the drawdown in two observation wells for the hydraulic gradient. This is known as the Thiem formula, which is used to calculate transmissivity in confined aquifers (Fetter 1994):

$$T = \frac{Q \ln \left(\frac{r_2}{r_1} \right)}{2\pi (h_2 - h_1)} \quad (\text{eq. 650L-3})$$

Where:

T = transmissivity (ft²/d)

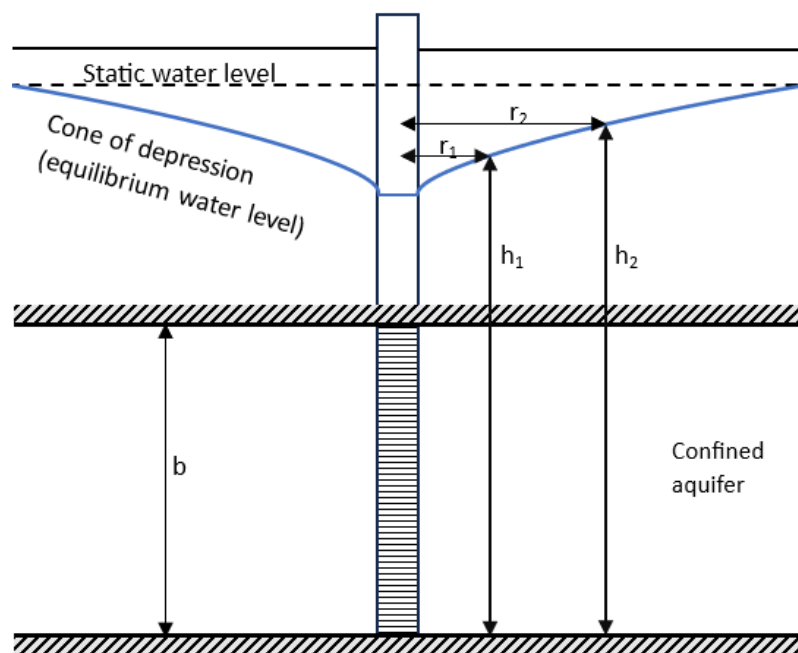
Q = discharge from pumped well (ft³/d)

r₁, r₂ = distances from pumped well to the observation well(s) (ft)

h₁, h₂ = head at r₁ and r₂ from the pumping well (ft)

- c. The Thiem formula assumes the following:
 - (1) The aquifer is confined.
 - (2) The well discharge is constant.
 - (3) Equilibrium is reached.

Figure 650L-27: Equilibrium in a confined aquifer



Modified from Fetter 1994

- d. Alternatively, a simpler equation to determine transmissivity for a confined aquifer is:

$$T = K * b \text{ (eq. 650L-4)}$$

Where:

T = transmissivity (ft²/d)

K = hydraulic conductivity (ft/d)

b = saturated confined aquifer thickness (ft)

6. Unconfined Aquifer Equilibrium Conditions

- For an unconfined aquifer, the area of the cylinder is $2\pi r(b_2 - b_1)$, where “ b ” is the saturated aquifer thickness in an observation during pumping in the discharge well.
- Note, the unconfined saturated aquifer thickness “ b ” (figure 650L-28) is the same as the head “ h ” in the confined aquifer (figure 650L-27). This is because a confining layer is absent in the unconfined aquifer (figure 650L-28).
- The Thiem formula for an unconfined aquifer in an equilibrium condition is (Fetter 1994):

$$K = \frac{Q \ln \left(\frac{r_2}{r_1} \right)}{\pi (b_2^2 - b_1^2)} \text{ (eq. 650L-5)}$$

Where:

K = hydraulic Conductivity ($\text{ft}^3/\text{ft}^2/\text{d}$)

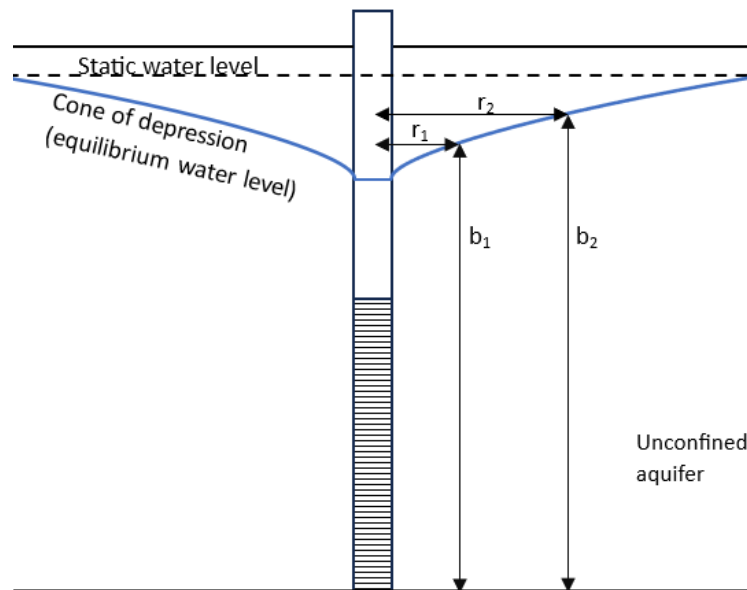
Q = discharge from pumped well (ft^3/d)

r_1, r_2 = distances from pumped well to two observation wells (ft)

b_1, b_2 = saturated thickness at a distance r_1 and r_2 from the pumping well (ft)

- d. The Thiem formula assumes the following:
- (1) The aquifer is homogenous, of infinite areal extent and rests on a horizontal impermeable bed.
 - (2) The discharging well penetrates the entire saturated aquifer thickness.
 - (3) The observation wells are placed in line with the discharging well.
 - (4) Pumping has continued at a constant rate for enough time for the drawdown cone to have reached a steady state.
 - (5) Flow to the well is radial.
 - (6) The non-pumped water table was horizontal.
- e. Observation well drawdown measurements are plotted on a semi log scale with drawdown, s , on the arithmetic scale and distance, r , on the logarithmic scale. When two or more observation wells are used, all values of r and s at a given time, t , should fall on a straight line on the semi log plotting if equilibrium is attained. Convenient values of r_1 and r_2 , and s_1 and s_2 are picked from the curve, and the Thiem formula solved for K .

Figure 650L-28: Equilibrium in an unconfined aquifer



Modified from Fetter 1994

D. Nonequilibrium Conditions

1. When equilibrium is not established, a nonequilibrium, or transient, equation is used to determine the aquifer constants. Many wells during an aquifer test may not reach equilibrium.
2. Several methods are available to analyze nonequilibrium conditions in unconfined aquifers. Some of the analyses include, but are not limited to, the Theis (1935) method, the Cooper-Jacob time-drawdown and distance-drawdown methods, and a leaky (confined) aquifer with no aquitard storage method.
3. The Theis (1935) method is commonly used for confined aquifers in hydrogeology and is relatively easy to use. The Neuman (1972) method is used for unconfined aquifers, but it is involved and complicated. These methods are not discussed in this handbook, because NRCS will mostly use the Cooper-Jacob time-drawdown method. For details about these and other methods, see Driscoll (1989) and Fetter (1994).

E. Equilibrium and Nonequilibrium Conditions

1. The Cooper Jacob time-drawdown equation is the simplest method to evaluate aquifer tests. This method can be used for confined and unconfined aquifers in both equilibrium and nonequilibrium conditions.
2. Plot drawdown versus time on a semi-log graph and use the Cooper Jacob time-drawdown equation to calculate transmissivity (Fetter 1994):

$$T = \frac{2.3Q}{4\pi\Delta(s)} \quad (\text{eq. 650L-6})$$

Where:

T = transmissivity (ft²/d)

Q = discharge from pumped well (ft³/d)

Δs = drawdown per log cycle of time (ft)

3. The drawdown equation for this method is *H-h* per log cycle, and the representative symbol is a lower case “s.” Drawdown per log cycle is determined from the trendline slope on the semi-log graph.
4. When conducting a multi-well test in a confined aquifer, use the Cooper Jacob straight-line time drawdown to calculate storativity (S) as applicable:

$$S = \frac{2.25Tt_0}{r^2} \quad (\text{eq. 650L-7})$$

Where:

T = transmissivity (ft²/d)

t₀ = time where straight intersects the zero-drawdown axis (min)

r = distance from the pumping well to the observation well (ft)

5. To determine time (t₀), extend the straight trendline that crosses through data points on the semi-log graph backward to the zero-drawdown axis. The zero-drawdown axis is like the x-axis but is at the top of the graph. Measure the distance from the pumping well to each observation well to determine the r, the radius of influence.

6. Alternatively, the simplest method for determining transmissivity in an unconfined aquifer is:

$$T = K * h \text{ (eq. 650L-8)}$$

Where:

T = transmissivity (ft²/d)

K = hydraulic conductivity (ft/d)

h = saturated aquifer thickness (ft)

650.188 Design Capacity

A. Potential Well Capacity in Unconsolidated (Unconfined) Material

1. Factors affecting well capacity in unconsolidated sand or gravel formations include:
 - a. Physical characteristics
 - (1) Physical characteristics influencing well capacity include, but are not limited to, casing size and the aquifer particle size, porosity, and uniformity. Generally, sands suitable for irrigation development have a porosity of 20 to 40 percent of the volume of the water-bearing material. A uniform sand size has greater porosity and more water-bearing capacity than a nonuniform sand.
 - b. Water-bearing formation
 - (1) Maximum drawdown in a water well is theoretically the depth from the static water level to the well bottom or the impervious stratum (Driscoll 1989). In most cases, this does not consider the pump elevation. The top of the pump intake will often dictate the amount of drawdown a well can have. Drawdown influences the slope and velocity of the water approaching the well and helps determine well capacity. Other factors being equal, well capacity is in proportion to $H - h$, where H is the depth of water-bearing formation and h is the depth of water remaining in the well while pumping, measured from the top of casing (figures 650L-26 and 650L-28).
 - c. Water-bearing Formation Extent
 - (1) Formation influences limit the total water quantity pumped from a well. A blocked off water supply (aquifer) on one or more sides naturally restricts flow.
 - d. Well Diameter
 - (1) Well diameter is more important for proper pump installation than determining well yield. Increasing the well diameter increases its yield, but not in direct proportion to the increase in diameter. In other words, doubling the well diameter does not double its yield. See 650.7 D., “Well Diameter,” for more information.
 - e. Screen or Casing Effectiveness
 - (1) Consider the open area of casing perforations or well screen needs when determining the well capacity.
2. Most of a well’s yield (90 percent) in an unconfined (water table) aquifer is obtained at about 70 percent of the maximum drawdown (Driscoll 1986). Operating a well at more than 70 percent of the maximum drawdown is not economical (Driscoll 1986).

3. The quantity of available water moving into a well increases rapidly as the aquifer grain size increases. The effective diameter (D_{10}) size for sand is determined by screening samples of the aquifer formation. Estimate the porosity percentage by compacting a sample of the aquifer formation material to its natural state in a quart jar and then measuring the quantity of water needed to fill the voids.

B. Calculating Estimated Well Yield (Well Capacity)

1. Use the following Driscoll (1986) formula to predict the capacity for any desired drawdown or the drawdown for any desired well capacity, if the discharge and pumping water level are known for a given condition (eq. 650L-9). See Appendix A, “Example Problem to Estimate Capacity,” and figure 650L-26.

$$\frac{Q}{Q_1} = \frac{H^2 - h^2}{H^2 - h_1^2} \text{ (eq. 650L-9)}$$

Where:

Q = measured well capacity at known drawdown depth

Q_1 = well capacity at desired drawdown depth

H = aquifer saturated thickness (static head) before pumping; the static water level to the well bottom.

h = aquifer saturated thickness (head) during pumping; the pumping water level to well bottom.

h_1 = aquifer saturated thickness (head) during pumping; the pumping water level to well bottom.

C. Specific Capacity

1. The well’s pumping rate (gpm) divided by the drawdown depth in the well (ft), or gallons per minute per foot, is the specific capacity of a well. The specific capacity integrates all the variables that affect water yield, including aquifer characteristics and well design, construction, and condition. A recorded change in specific capacity over time indicates either changes occurring in the aquifer or (more likely) changes in the condition of the pump, screen, or casing.
2. Space wells far enough apart so that their radii of influence do not intersect. Depending on the aquifer permeability and the drawdown, the radius of influence, R , may range from 100 to 3,000 feet or more, determined from observation wells spaced at regular intervals away from a pumping well. Drilling and installing observation wells in addition to the pumping water well is not economical or common practice for NRCS projects. This is for informational purposes only.

650.189 Well Casing Design

A. Introduction

1. Most wells consist of a cased section and an intake section or screened section. However, some water wells are installed in a stable formation and do not always require casing or a well screen.

2. Well casing stabilizes the formation to keep it from collapsing on the well, seals out contaminated or undesirable waters, and protects the pump and electrical wiring. Casing must be strong enough to resist earth pressure, self-weight; and depending on method of placement, may have to withstand considerable shock and compressive stress. Casing should be sufficiently resistant to corrosion to last at least the design practice life of 20 years.
3. Water well casing selection and design is a function of hydrostatic head, aquifer materials, and desired yields. Permanent casing must be continuous and watertight from top to bottom, except for the well screen section(s).
4. Design and install water wells according to State, local, and Tribal law and NRCS CPS Water Well (Code 642) and CPS Monitoring Well (Code 353). See 650.5, "Wells," and 650.5 F., "Drilling Planning Process."

B. Casing Materials

1. The local geology and water chemistry dictate the casing type used. Water corrosivity is an important factor when selecting the casing type. Alkaline (high pH) and acidic (low pH) environments, or water high in total dissolved solids (TDS) ("salts") may corrode metal casing. The well designer must select the appropriate casing type and size that is best suited for the environmental conditions.
2. Several casing types exist, but the most common are PVC (polyvinyl chloride), steel, and stainless steel. The following is a list of commonly accepted casing types:
 - a. Steel
 - b. Iron
 - c. Stainless steel
 - d. Copper alloys (for mostly marine environments)
 - e. Plastic
 - f. Fiberglass
 - g. Concrete (for dug wells)
3. Steel and iron pipe, while not corrosion resistant, have adequate life for use as well casing under most conditions. The use of heavy pipe is an economical means of obtaining long life, even in corrosive conditions.
4. Plastic pipe must meet or exceed ASTM F-480, "Standard Specification for Thermoplastic Well Casing Pipe and Coupling Made in Standard Dimension Ratios (SDR), SCH 40 and SCH 80." Approved plastic pipe for potable water includes:
 - a. Polyvinyl Chloride (PVC) cell classification PVC-12454 or -14333
 - b. Acrylonitrile-butadiene-styrene (ABS) cell classification ABS-44322 and ABS - 33333 (ASTM D3965, "Standard Classification System and Basis for Specifications for Rigid Acrylonitrile Butadiene-Styrene (ABS) Materials for Pipe and Fittings").
 - c. Styrene Rubber (SR) cell classification SR-4434A (ASTM D4549-15, "Standard Classification System and Basis for Specification for Polystyrene and Rubber-Modified Polystyrene Molding and Extrusion Materials").

5. PVC, stainless steel, brass, and copper alloys containing manganese, nickel, and silicon are commonly used in corrosive conditions.
6. Copper alloys typically have good resistance to corrosion and biofouling and are commonly used in marine environments. Significant corrosion can occur in soils or water high in sulfate, chloride, or nitrate. Considering the environment is important when choosing the right copper alloy casing. Copper-nickel and aluminum-bronze are often preferred in marine environments, but other copper alloys include (Powell and Webster 2012):
 - a. Copper
 - b. Bronze
 - c. Brass
 - d. Copper-beryllium
7. Aluminum and some of its alloys corrode rapidly under most soil conditions and are not commonly recommended for water well casing. Aluminum (or thermoplastic) is often used as a protective well cap.
8. Corrosion can occur when different metals are in contact. Some metals, such as brass, copper, and aluminum are resistant to corrosion but may corrode or cause other metals to corrode when in contact with each other (figure 650L-29). Insulate different metal types from each other in a corrosive environment by using rubber, plastic, or another non-conductor. Carefully select welding material; corrosion often begins at weld connections.
9. For dug wells, use concrete casing or other material of equivalent strength and durability consistent with the intended water use and the maximum anticipated differential head between the inside and outside of the casing, using depth and material tables. Recommendations are to install a graded filter outside of the concrete casing to ensure that fine particles don't migrate.
10. Ensure that well casing is free from pits, breaks, and serious imperfections, such as dents.
11. For recommended well casing thicknesses, see 650.8 (F), "Steel and Plastic Casing Collapse and Pressure Design."

Figure 650L-29: Metals that may corrode when in contact with each other. Corrosion risk (black). Non-corrosion risk (gray).

	Cathodic															
Anodic Metals (Corrodes)	Magnesium & Alloys	Zinc & Alloys	Aluminum & Alloys	Cadmium	Steel (Carbon)	Cast Iron	Stainless Steels	Lead, Tin & Alloys	Nickel	Brasses, Nickel-Silvers	Copper	Bronzes, Cupro-Nickels	Nickel Copper Alloys	Nickel-Chrome Alloys	Titanium	Silver
	Graphite	Gold	Platinum													
Magnesium & Alloys																
Zinc & Alloys																
Aluminum & Alloys																
Cadmium																
Steel (Carbon)																
Cast Iron																
Stainless Steels																
Lead, Tin, & Alloys																
Nickel																
Brasses, Nickel-Silvers																
Copper																
Bronzes, Cupro-Nickels																
Nickel Copper Alloys																
Nickel-Chrome Alloys																
Titanium																
Silver																
Graphite																
Gold																
Platinum																

Source: Modified from Monarch Metal, Inc.

C. Size

1. Steel and iron pipe have standard dimensions, weight, and threads. For more information, see ASTM A589, “Standard Specification for Seamless and Welded Carbon Steel Water-Well Pipe;” ASTM A53, “Standard Specification for Pipe, Steel, Black, and Hot-Dipped, Zinc-Coated, Welded, and Seamless;” and ASTM A139, “Standard Specification for Electric-Fusion (Arc)-Welded Steel Pipe” (Nominal Pipe Size (NPS) 4 and over).

D. Well Diameter

1. Well diameter depends on the nature and thickness of the water-bearing material, the area of openings necessary to allow for water entrance velocity at about 0.10 feet per second, and the required pump size. Increasing the well diameter increases its yield, but not in direct proportion to the increase in diameter. In other words, doubling the well diameter increases the yield only by about ten percent. Figure 650L-30 shows the general relationship between yield and diameter.

Figure 650L-30: General relationship between possible yield percentage increase and well diameter (in inches)

Well diameter (inches)	2	4	6	8	12	18	24	36	48
Percent yield increase	0	10	15	20	25	33	38	48	55
Percent yield increase	-	0	5	10	15	23	28	38	45
Percent yield increase	-	-	0	5	10	18	23	33	40
Percent yield increase	-	-	-	0	5	13	18	28	35
Percent yield increase	-	-	-	-	0	8	13	23	30
Percent yield increase	-	-	-	-	-	0	5	15	22
Percent yield increase	-	-	-	-	-	-	0	10	17
Percent yield increase	-	-	-	--		-	-	0	7
Percent yield increase	-	-	-	-	-	-	-	-	0

Note: For percentage in yield, read across only.

2. If installing a turbine pump, the minimum inner casing diameter recommended is at least 1 to 2 inches larger than the pump bowl diameters. Follow the manufacturer's recommendations if the well diameter is larger. This will allow water to flow past the bowls to the intake with minimum head loss and allow for some deviation of the well from the vertical. Follow recommended state law and manufacturers recommendations for installation procedures.
3. For submersible pumps, follow the manufacturer's recommendations for distance to casing. For low volume pumps, the distance to casing is less than large volume pumps. Follow all local ordinances, State and Tribal laws, and CPS, whichever is most stringent. The minimum inside casing diameter recommended is at least 1 to 2 inches larger than the pump diameter, depending on state law (see CPS Water Well (Code 642) for more information).

E. Casing Installation

1. The water well must be designed and installed according to local, State, and Tribal law and NRCS CPS Water Well (Code 642).
2. Seat the casing on hard rock or stiff clay, when possible, to eliminate or reduce settlement. Grout casing in place, forming a seal between the casing and the disturbed formation, preventing surface water from entering and possibly contaminating the

well. Extend grout deep enough to seal off undesirable water zones between the ground surface and top of the aquifer to prevent co-mingling.

3. In a corrosive environment, grout sealing the entire casing length can protect from corrosion. Minimum grout thickness at any point should be about 1.5 inches. Place grout either through the casing if it is an outer casing, or through the annular space between the casing and the boring. Grouting must occur in one continuous operation. Remove any temporary casing to increase contact between grout and permanent casing. Allow grout to set up, usually about 72 hours, to prevent damage by vibration when drilling is resumed (see 210 H 631.3112, “Groundwater Investigations”).
4. For more information about proper casing installation, see NRCS CPS 642 Water Wells, AWWA (2020) Water Wells; and ASTM D5092, “Standard Practice for Design and Installation of Groundwater Monitoring Wells.”

F. Steel and Plastic Casing Collapse and Pressure Design

1. The maximum allowable well casing pressure is based on collapse resistance of the casing and must exceed the unbalanced hydrostatic pressure from the maximum anticipated differential head. The term “differential head” applies to the difference in water levels between the inside and outside of the casing.
 - a. For unconfined aquifers, the maximum anticipated differential head is the difference between the highest anticipated water table elevation and the water surface elevation during maximum anticipated drawdown.
 - b. For confined aquifers, the maximum anticipated differential head is the difference between the highest anticipated potentiometric surface elevation (highest level water will rise in tightly cased wells or static water level) and the water surface elevation during maximum anticipated drawdown (pumping water level).
2. Steel Well Casing
 - a. Steel casing collapse resistance, also called design collapse pressure, is a function of diameter, wall thickness, and eccentricity (out-of-roundness). Eccentricity or deformation can originate from rough handling in transport or at the job site. The design collapse pressure for a perfect cylinder (no eccentricity) is 3,826 pounds per square inch (lbs/in²) (8,838 head in ft). However, with eccentricity values of 0.5, 1.0, and 1.5 percent, the design collapse pressures are reduced to 1,576 lbs/in² (3,639 head in feet), 1,231 lbs/in² (2,844 head in feet), and 1,024 lbs/in² (2,365 head in feet), respectively. Eccentricity up to 1.5 percent (0.015) is acceptable. Reject casing with obvious eccentricity or other defects.
 - b. Eccentricity is calculated by measuring the casing wall thickness around the casing perimeter at any cross section to establish a maximum and minimum value. Measuring casing eccentricity is not likely possible or practical before installation. This is because NRCS may not always be onsite when the water well is drilled. Therefore, eccentricity is frequently assumed as 0.01 or 1.0 percent.
 - c. The Timoshenko Elastic Formula is a commonly accepted and the most accurate available method for estimating steel pipe collapse strength (eq. 650L-10). Use this equation for any Young’s Modulus of Elasticity (E), Poisson’s ratio (μ), casing eccentricity (e), and yield strength (Y_p).

$$P_d^2 - P_d \left(\frac{2Y_p}{SDR-1} + P_{cr}[1 + 3e(SDR - 1)] \right) + \frac{2Y_p P_{cr}}{SDR-1} = 0 \quad (\text{eq. 650L-10})$$

Where:

P_d = design collapse pressure, lb/in² [alternatively, $2.31(P_d)$ = head, in feet]

Y_p = yield strength, lb/in²

e = casing eccentricity (measured up to 0.015)

SDR = standard dimension ratio, d/t

d = outside diameter of casing, in

t = wall thickness of casing, in

P_{cr} = critical collapse pressure of a perfect cylinder, lb/in² (eq. 650L-12)

- d. Equation 650L-11 is a simplified version of the Timoshenko Formula (eq. 650L-10). Use this abbreviated equation only when $e = 0.01$ (1.0%), $E = 3 \times 10^7$ lb/in², $\mu = 0.30$, and $Y_p = 35,000$ lb/in².

$$P_d = 1.4897 \times 10^7 (SDR)^{-2.5526} \quad (\text{eq. 650L-11})$$

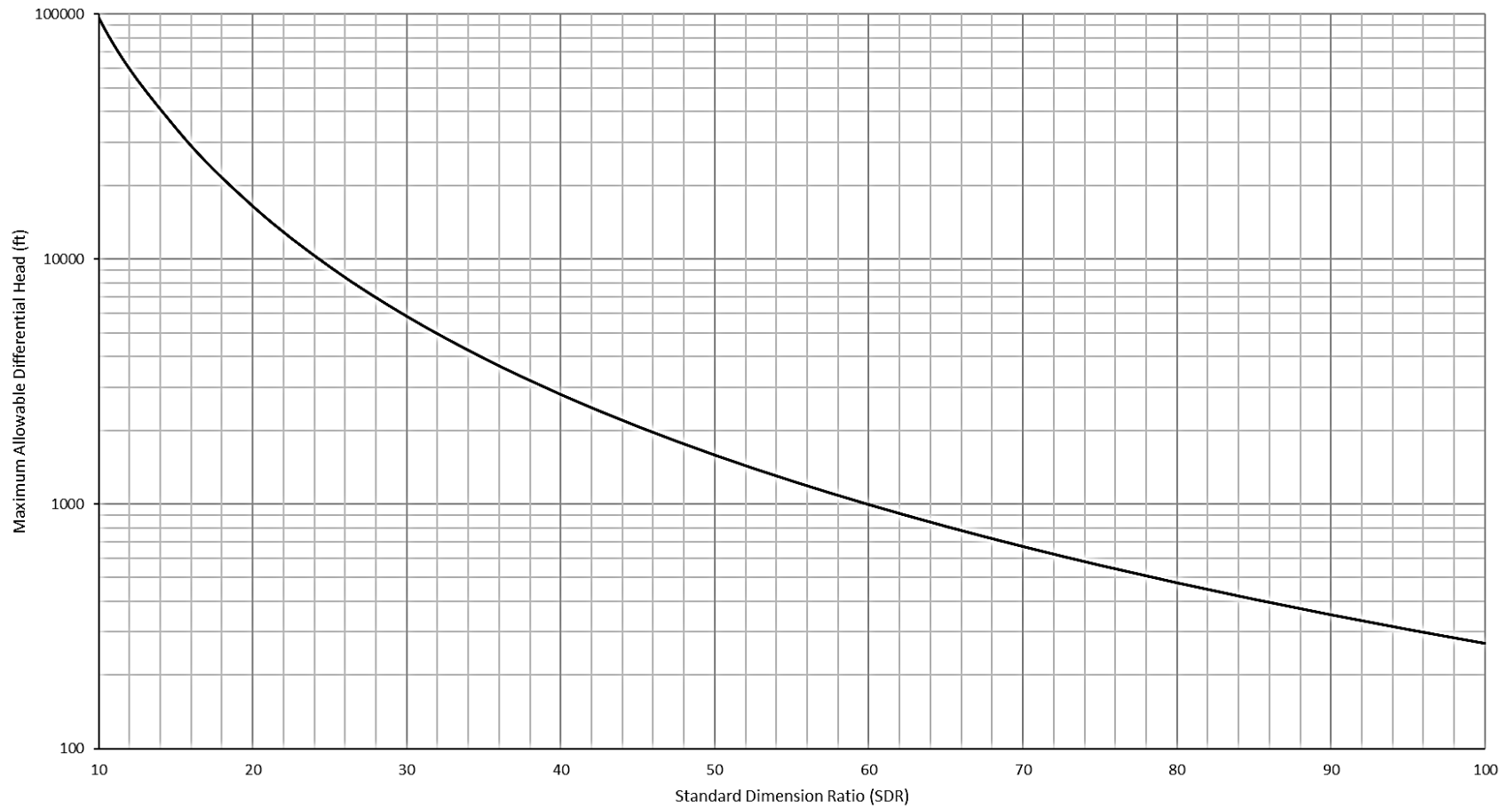
- e. Figure 650L-31 gives maximum allowable differential head calculated for selected sizes of ASTM A139M-22, “Standard Specification for Electric-Fusion (Arc)-Welded Steel Pipe (NPS 4 and Over)” Grade B carbon steel casing, using equation 650L-11.
- f. Figure 650L-32 is a smooth plot of standard dimension ratios (SDR) for ASTM A139 Grade B carbon steel casing versus calculated maximum allowable differential head (in feet), using equation 650L-11. The curve simplifies the determination without having to run the abbreviated calculation.

Figure 650L-31: Maximum allowable differential head for steel casing

Nominal Casing Size (in)	4	5	6	8	10	12	14	16	18	24
Casing Outside Diameter (in)	4.5	5.563	6.625	8.625	10.75	12.75	14	16	18	24
MADH 20 Ga (0.036)	65	40	25	15	5	5	5	5	0	0
MADH 18 Ga (0.048)	140	80	50	25	15	10	10	5	5	0
MADH 16 Ga (0.06)	245	140	90	45	25	15	15	10	5	5
MADH 14 Ga (0.075)	430	250	160	80	45	30	25	15	15	5
MADH 12 Ga (0.105)	1015	590	380	195	110	70	55	40	30	15
MADH 10 Ga (0.135)	1930	1125	720	365	210	135	105	75	55	25
MADH 8 Ga (0.164)	3175	1845	1180	605	345	220	175	125	90	45
MADH 7 Ga (0.179)	3970	2310	1480	755	430	280	220	155	115	55
MADH Sch. 40 Variable thicknesses	8120	5420	4630	3375	2650	2250	2150	2145	2140	1720
MADH Sch. 80 Variable thicknesses	19772	15342	14095	10301	9178	8561				
MADH 3116 Nichrome (0.188)	4495	2615	1675	855	485	315	250	175	130	60
MADH 7132 aluminum (0.219)	6640	3865	2475	1260	720	465	365	260	195	90
MADH 114 aluminum (0.250)		4730	3470	1770	1010	650	515	365	270	130
MADH 9132 alloy steel (0.280)				2360	1350	870	685	490	360	175
MADH 5116 aluminum (0.312)				3115	1775	1150	905	645	475	230
MADH 318 stainless (0.375)						1840	1445	1030	760	365
MADH 7116 aluminum (0.438)								1530	1130	545

Note: MADH = Maximum Allowable Differential Head. Wall thickness (uncoated) is described in terms of Gage (Ga) and (inches), e.g. 18 Ga (0.048).

Figure 650L-32: Steel pipe maximum allowable differential head



4. Plastic Casing

- a. The Clinedinst equation (ASTM F480, “Standard Specification for Thermoplastic Well Casing Pipe and Couplings Made in Standard Dimension Ratios (SDR), SCH40 and SCH 80”) is used to calculate critical collapse resistance for SDR pressure-rated plastic pipe, denoted either Pressure Rating (PR) or Standard Ratio-Pressure Rating (SR-PR), including ABS, PVC, and SR. The Clinedinst equation is:

$$P_{cr} = \frac{2E}{(1-\mu^2)} \times \frac{1}{[SDR(SDR-1)^2]} \text{ (eq. 650L-12)}$$

Where:

P_{cr} = critical collapse pressure, lb/in² [alternatively, 2.31 (P_{cr}) = head in feet]

E = Young’s modulus of elasticity, lb/in²

μ = Poisson’s ratio = 0.38

SDR = standard dimension ratio, d/t

d = outside diameter of casing, in

t = wall thickness of casing, in

- b. Note, the critical collapse pressure is denoted by P_{cr} or P_c in different publications. Both mean “critical” buckling pressure and are interchangeable.
- c. Poisson’s ratio depends on the type of casing material. The designer will need to research the appropriate Poisson’s ratio for a specific casing type.
- d. Figure 650L-33 gives the maximum allowable differential head for selected PVC (12454 and 14333), ABS (44322 and 33333), and SR (4434A) plastic pipe (SDR-PR), based on the Clinedinst Equation (eq. 650L-12), using $\mu = 0.38$.
- e. Figure 650L-34 gives dimension and maximum allowable differential head for PVC-12454 plastic pipe, Schedules 40 and 80, constructed of material with $E = 400,000$ lb/in² and $\mu = 0.38$, based on the Clinedinst Equation (eq. 650L-12). Factors given at the bottom of figure 650L-35 are used in determining limitations for ABS Schedules 40 and 80 plastic pipes.
- f. Figure 650L-35 provides dimension and maximum allowable differential head for representative sizes of reinforced polymer mortar plastic (RPMP) well casings (ASTM D3517, “Standard Specification for Fiber”).
- g. Figure 650L-36 is used to determine maximum allowable differential head for SDR-PR plastic pipe. Four curves are plotted for representative values of $E = 500,000$; 400,000; 300,000; and 200,000 lb/in² and $\mu = 0.38$, according to the Clinedinst Equation (eq. 650L-12). The curves simplify the determination without having to run the Clinedinst calculation (eq. 650L-12).

Figure 650L-33: Maximum allowable differential head (in feet) for selected plastic pipe

Standard Dimension Ratio (SDR)	13.5	17.0	21.0	26.0	32.5
MADH PVC – 12454 (400,000)	1020	495	255	130	65
MADH for ABS (350,000)	920	445	230	120	60
MADH for PVC – 14333 (320,000)	815	395	205	105	50
MADH for ABS (250,000)	665	320	165	85	40
MADH for SR – 4434A (300,000)	768	372	193	100	50

Note: MADH = Maximum allowable differential head. Values are from ASTM F480.

Figure 650L-34: Dimension and maximum allowable differential head for selected PVC-12454 Plastic Pipe, Schedules 40 and 80

Nominal Diameter (in)	2.00	2.50	3.00	3.50	4.00	5.00	6.00	8.00	10.00	12.00
Outside Diameter (in)	2.38	2.88	3.50	4.00	4.50	5.56	6.63	8.63	10.75	12.75
Schedule 40 MWT (in)	0.15	0.20	0.22	0.23	0.24	0.26	0.28	0.32	0.37	0.41
Schedule 40 SDR (in)	15.40	14.20	16.20	17.70	19.00	21.60	23.70	26.80	29.50	31.40
Schedule 40 MADH (ft)	675	879	575	435	350	235	175	120	90	70
Schedule 80 MWT (in)	0.22	0.28	0.30	0.32	0.34	0.38	0.43	0.50	0.59	0.69
Schedule 80 SDR (in)	10.90	10.40	11.70	12.60	13.40	14.80	15.30	17.30	18.10	18.60
Schedule 80 MADH (ft)	2020	2350	1610	1270	1045	765	690	470	405	375

Note: Figure 650L-34 is for PVC schedule pipe having a modulus of elasticity of 400,000 lbs/in². For PVC schedule pipe having a modulus of elasticity of 360,000 lbs/in², multiply the maximum head by a factor of 0.9. For PVC schedule pipe having a modulus of elasticity of 320,000 lbs/in², use a factor of 0.8. For ABS Schedules 40 and 80 pipe having a modulus of elasticity of 250,000 lbs/in², use a factor of 0.625. In all cases, $\mu = 0.38$. MWT = Minimum wall thickness. SDR = standard dimension ratio. MADH = Maximum allowable differential head.

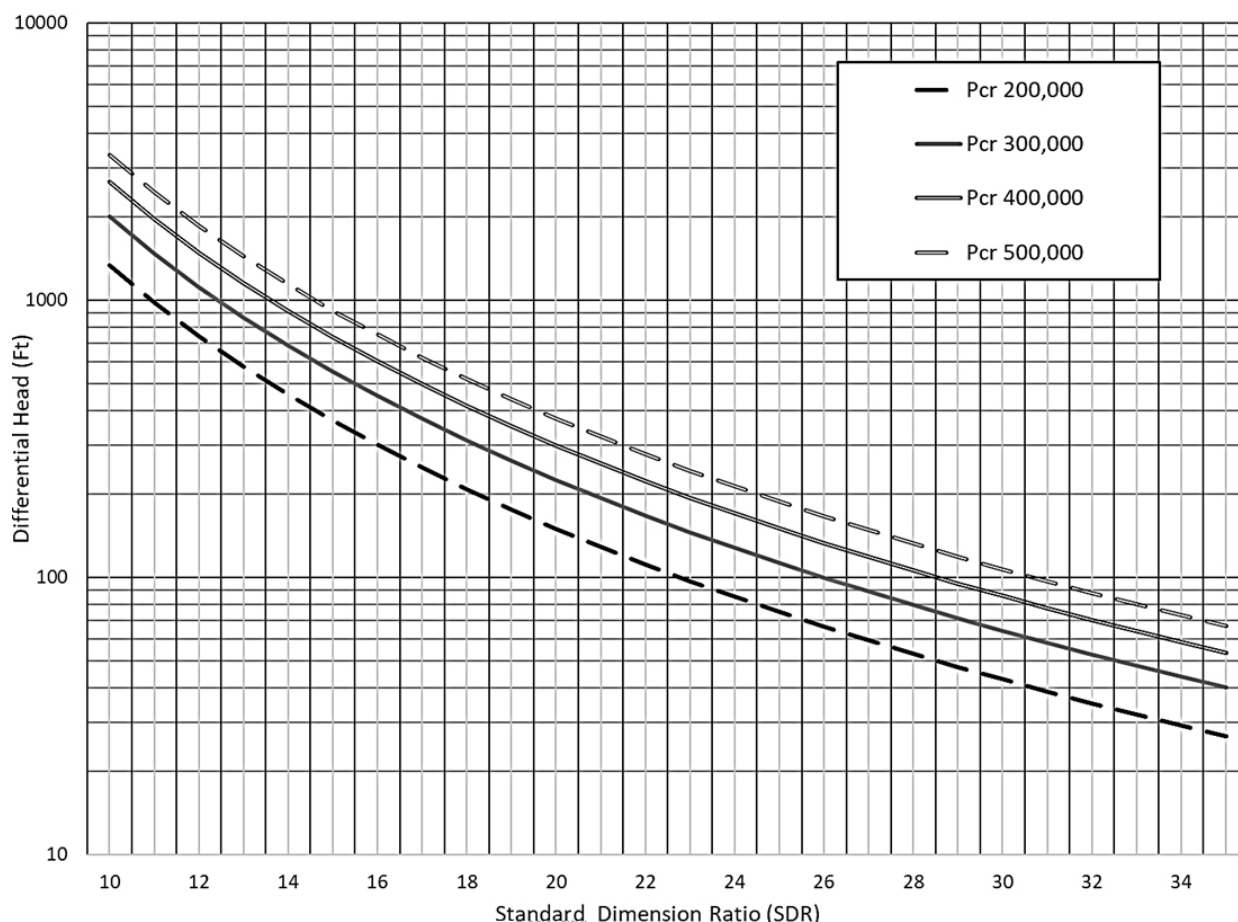
Figure 650L-35: Dimension and maximum allowable differential head for reinforced plastic (RPMP)

MADH (ft)	20	60	100	200	300	400	500	720	1000
MWT for 8-inch casing diameter	0.17	0.17	0.23	0.23	0.23	0.29	0.29	0.33	0.33
MWT for 10-inch casing diameter	0.17	0.17	0.28	0.28	0.28	0.36	0.36	0.41	0.41
MWT for 12-inch casing diameter	0.18	0.19	0.34	0.34	0.34	0.43	0.43	0.46	0.46
MWT for 14-inch casing diameter	0.19	0.22	0.34	0.34	0.40	0.43	0.46	0.46	0.46
MWT for 15-inch casing diameter	0.19	0.24	0.34	0.34	0.46	0.46	0.46	0.46	0.46
MWT for 16-inch casing diameter	0.20	0.25	0.36	0.36	0.46	0.46	0.46	0.46	0.46
MWT for 18-inch casing diameter	0.21	0.28	0.40	0.40	0.46	0.46	0.46	0.52	0.52
MWT for 20-inch casing diameter	0.21	0.31	0.42	0.42	0.46	0.46	0.46	0.54	0.54
MWT for 21-inch casing diameter	0.21	0.33	0.48	0.48	0.48	0.48	0.48	0.57	0.57
MWT for 24-inch casing diameter	0.24	0.38	0.48	0.48	0.48	0.57	0.57	0.57	0.57
MWT for 27-inch casing diameter	0.26	0.40	0.49	0.49	0.49	0.62	0.62	0.62	0.62
MWT for 30-inch casing diameter	0.29	0.44	0.49	0.49	0.49	0.68	0.68	0.68	0.68
MWT for 33-inch casing diameter	0.32	0.44	0.60	0.60	0.60	0.75	0.75	0.75	0.75
MWT for 36-inch casing diameter	0.35	0.48	0.65	0.65	0.65	0.82	0.82	0.82	0.82

Note: MADH = Maximum allowable differential head. MWT = Minimum wall thickness.

RPMP = Reinforced polymer mortar pipe

Figure 650L-36: Maximum allowable differential head for plastic pipe graph



G. Design Considerations

1. Data for maximum allowable differential head in figures 650L-33 through 650L-38 consider only unbalanced hydrostatic pressure. Overburden pressure at depth in a vertical well is the sum of the weight of the overburden material and the contained groundwater. Ordinarily, the weight of the formation is borne by the formation itself. Under some circumstances, part or all the overburden pressure can be transmitted to the interstitial groundwater and may result in casing collapse.
2. Design must also consider conditions that can result in pressures (static or dynamic) that exceed hydrostatic pressure (fluids at rest). Examples of static and dynamic conditions include:
 - a. Deep confined aquifers can generate significant artesian head on the outside of the casing. (Static)
 - b. Heavily pumped, deep, unconsolidated aquifers are subject to compaction and consolidation processes that can result in formation settlement, movement, and subsidence. (Dynamic)
 - c. An improperly installed filter pack (with bridged particles or pockets) can collapse, resulting in rupture of the casing or screen. In a fine sand aquifer,

quicksand conditions can arise from an upward movement of groundwater. The sand goes into suspension and is then unable to support the weight of the formation. Effective pressure is reduced to zero, and under-designed casing and screen could collapse. (Dynamic)

- d. Earthquakes and blasting (dynamite) can generate forces that result in rearrangement, consolidation, and settlement of aquifer materials that could cause an otherwise satisfactory casing and screen to collapse. Sudden ground motions can induce liquefaction of saturated fine sands and silts with similar deleterious effects on casing or screens. (Dynamic)

H. Design Guidance

1. If the well is bailed or pumped dry, such as during development or when pumping a low yield, substitute the well bottom elevation for the maximum drawdown elevation. Also, if the maximum drawdown is not determined with confidence, use the well bottom elevation.
 - a. The maximum differential head will almost always occur during well development. The water level is often drawn down to the well bottom for the typical low yield water well in the semi-arid and arid west.
 - b. The maximum differential head after the well is installed is not as important when the casing is properly supported in the annulus between the casing and borehole. Casing collapse due to differential head will most often occur during installation and well development while the grout or bentonite is still gaining strength to support the casing, or it will occur if voids are in the annulus. When the casing is fully supported, calculations for the critical collapse analyses are no longer valid.
2. If, in addition to unbalanced hydrostatic pressure, conditions at the well site are anticipated to result only in static pressure increases on the casing and screen, use 40 percent of the maximum allowable differential head values provided in the tables and figures. If dynamic increases in pressure are anticipated, the values should be even less. For more information about casing types, installation, sizing, and diameter:
 - a. CPS Water Well (Code 642)
 - b. ASTM A589, "Standard Specification for Seamless and Welded Carbon Steel Water-Well Pipe"
 - c. ASTM F480, "Standard Specification for Thermoplastic Well Casing Pipe and Couplings Made in Standard Dimension Ratios (SDR), SCH40 and SCH80"
 - d. ASTM D3517, "Standard Specification for Fiberglass (Glass-Fiber-Reinforced Thermosetting-Resin) Pressure Pipe"
 - e. ASTM D2996, "Standard Specification for Filament-Wound Fiberglass (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe"
 - f. ASTM D5092, "Standard Practice for Design and Installation of Groundwater Monitoring Wells"
3. Example: Collapse resistance for steel casing.
 - a. Problem

- (1) A rancher is drilling a stockwater well and would like to use new 6-inch (nominal) Grade B steel casing they have on hand. Determine whether this casing meets criteria for maximum allowable head.
- b. Given
 - (1) The aquifer is unconfined, and the greatest anticipated differential head in the well is 925 feet, determined from aquifer testing. The steel casing has the following characteristics:
 - (a) Outside Diameter = 6.625 inches
 - (b) 8-gauge steel = 0.164 inches
- c. Solution
 - (1) Step 1: Calculate the SDR
 - (a) $SDR = \frac{6.625}{0.164} = 40.4$
 - (2) Step 2: Determine maximum differential head limitation for 8-gauge, 6.625-inch (outside diameter) steel casing, from equation 650L-11 or figure 650L-32: Answer = 1182 ft
 - (3) Step 3: Decision.
 - (a) Because the greatest anticipated differential head, 925 ft, is less than the maximum allowable 1182 ft, the rancher can use their casing in this well.

I. Well Sealant

1. The well sealant is material used to fill and seal the annular space between the hole and the casing above the intake section. Bentonite pellets or chips are used to seal 2 or more feet directly above the sand and gravel pack which extends above the screen. The bentonite is hydrated after being carefully placed in position to prevent gaps or bridging. This bentonite keeps the grout from seeping into the sand and gravel pack surrounding the screen. The well sealant must have no gaps or bridges. If separation occurs when placing the materials, the void can cause the casing to collapse. See “Wellhead Protection” below. For more information about sealants, see CPS Water Well (Code 642), and ASTM D5092, “Standard Practice for Design and Installation of Groundwater Monitoring Wells.” ASTM D5092 is applicable for water wells because there is essentially no difference between a monitoring well and water well.

J. Wellhead Protection

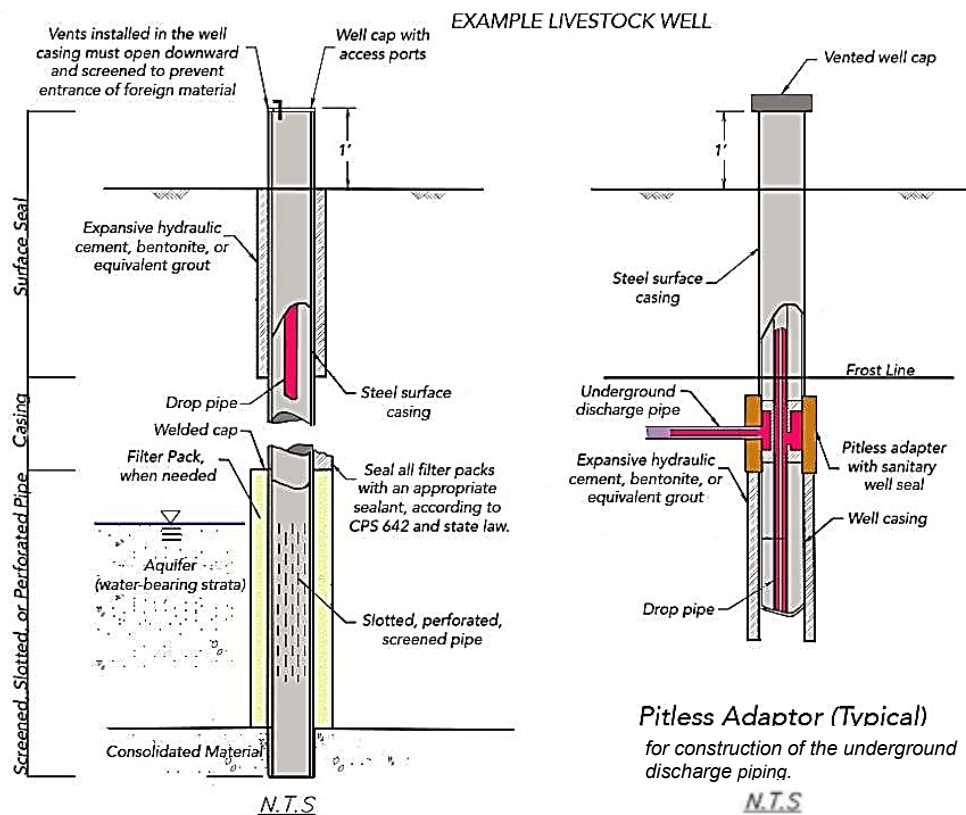
1. All wells must have sanitary protection. Although state laws may vary, NRCS advises terminating the well casing at least 1 foot above the ground surface. Wells must have a watertight cover or seal to prevent contaminated water or other objectionable material from entering the well. Fill the annular space around the casing with cement grout, bentonite clay, or other suitable materials, according to state law. Artesian wells require a positive seal between the casing and the impervious material overlying the aquifer. See CPS Water Well (Code 642) for more information about wellhead protection.

K. Pitless Adapter

1. Pitless adapters provide a water-tight connection between the submersible pump’s drop pipe inside of the well, below the frost line, and the water discharge line to the service location (figure 650L-37). They prevent water in the pipe from freezing.

2. Pitless adapters allow for easier water well maintenance without digging the ground up around the well.

Figure 650L-37: Water well with pitless adapter



650.190 Well Screen and Filter Pack Design

A. Introduction

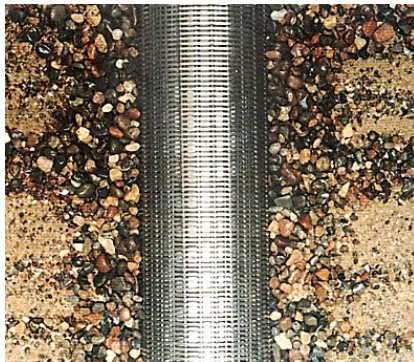
1. The most important part of any well is the area where the water flows from the aquifer into the well or the well screen. Proper construction and development are necessary for the efficient production of the optimum amount of groundwater.
2. In unconsolidated sand and gravel aquifers, a well screen is necessary to stabilize the aquifer materials and allow water from the aquifer to enter the well. Poorly designed well screens typically result in either poor water yields or pumping sand due to incorrect sizing of the screen openings.
3. Consolidated rock aquifers may not require a well screen. If caving or raveling from joints or bedding planes occur or is likely to occur, install a well screen and casing.
4. For more information about water well design, including diameter, screen length, screen types, filter pack, etc., see NRCS CPS Water Well (Code 642); ASTM D5092, "Standard Practice for Design and Installation of Groundwater Monitoring Wells;" ASTM D6725, "Standard Practice for Direct Push Installation of Pre-packed Screen Monitoring Wells in Unconsolidated Aquifers;" and AWWA (2020) Water Well.

B. Screen Types

1. Screens are manufactured according to several designs and from a variety of corrosion-resistant materials. Important considerations are strength, durability, and maintainability. Various screen types include but are not necessarily limited to:
 - a. Pre-pack (Muni-Pak)
 - (1) Pre-pack well screens are typically made with two layers of steel screen with filter media between. Because they come with a filter pre-installed, an external filter pack is not required.
 - (2) Pre-packed well screens can eliminate the need for a larger borehole, shorten the time to drill and develop a well, and eliminates bridging. Additionally, they are easier to maintain.
 - (3) Pre-pack made with glass beads reduces biofouling and encrustation, lowering well maintenance costs. This type offers better hydraulic conductivity than silica beads.
 - (4) They are used as a liner in existing wells to eliminate the need for new well construction.
 - (5) Wide variety of wire sizes and filter options, diameters, and connections for an array of uses.
 - b. Fiberglass
 - (1) Light weight easy-to-install alternative to steel.
 - (2) Resistant to corrosion, heat, and encrustation or scale build-up, requiring less maintenance.
 - (3) Durable and long lasting.
 - (4) High pressure resistance, surpassing iron, carbon, and stainless steel.
 - (5) More costly compared to PVC and carbon steel but costs less than stainless steel.
 - (6) Less availability compared to other screen types.
 - c. PVC
 - (1) Light weight, corrosion resistant, and used in many different environments.
 - (2) Long life, easy to install, and cost effective.
 - (3) Not as strong as steel and is susceptible to further strength reductions from cement curing during annular sealing.
 - (4) Low to moderate collapse strength.
 - (5) Not as chemical resistant and susceptible to chlorine and ammonia damage, making the plastic brittle, swell, and deform.
 - (6) Low heat tolerance.
 - d. Steel includes, but is not limited to, stainless steel, bridge slot, shutter (Louver), and continuous slot wire-wrap (Wire Wrap). Steel is prone to corrosion, can have scale build-up, and is more costly than PVC. Type 304 and 316L are commonly used and can provide corrosion resistance in salty and/or corrosive environments. Steel absorbs many forces, such as from earthquakes or subterranean movements, and can maintain its structural integrity.
 - (1) Wire Wrap
 - (a) Manufactured from 304 stainless steel, galvanized steel, and carbon steel (figure 650L-38).

- (b) Installed without a filter pack.
 - (c) Offers the highest surface opening of any screen and has very small slots (0.005 – 0.035 inches). Thus, has a high area exposed to corrosion.
 - (d) Resistant to clogging.
 - (e) More costly but does not necessarily increase production, efficiency, or durability.
 - (f) Has lower collapse strength.
 - (g) Repair is difficult to impossible, and well development and cleaning are more difficult.
- (2) Bridge Slot
- (a) Has vertical slots and high percentage of open area (POA).
 - (b) Installed with a filter pack.
 - (c) Minimum frictional head losses.
 - (d) Low collapse strength due to the large number of vertically oriented slots.
 - (e) Limited in wall thickness, and 0.250 inches is the maximum available.
- (3) Shutter (Louver)
- (a) Common in southwestern U.S., used in fractured rock and coarse alluvial aquifers.
 - (b) Installed with a filter pack.
 - (c) High tensile and collapse strength than blank (non-slotted) casing of the same wall thickness.
 - (d) Resistant to clogging.
 - (e) Repair, well development, and cleaning are possible without risk.

Figure 650L-38: Developed well cross section showing filter pack and well screen



Source: E.E. Johnson, 1986.

C. Slot Size

1. Slot size is the width or diameter of the openings in the well screen. The optimum slot size is the largest size that will maintain the stability of the aquifer or pack material as determined by analysis of the grain size distribution curve.

D. Filter Pack

1. Introduction

- a. Filter packs act as a filter around the well screen to retain formation material while allowing groundwater to enter the well. The filter pack is often referred to as “gravel pack;” however, this is misleading because packs may consist of different size particles—from fine sand to coarse gravel—depending on the size and gradation of the aquifer materials. Filter packs are also used to help stabilize the well casing and prevent the boring walls from collapsing.
- b. There are two types of filter packs: natural and artificial.

2. Natural Filter Pack or Naturally Developed Wells

- a. Natural filter packs allow the formation to collapse around the well screen when the formation is compatible with the screen slot size. This kind of filter is recommended for permeable, uniform sized, and coarse-grained formation materials.
- b. Gradation or particle-size distribution curves are used to calculate the coefficient of uniformity (C_u), a gradient characteristic guide used to help determine if a natural filter pack is acceptable or if an artificial filter pack is required. Particle size of filter pack or aquifer material is determined from laboratory sieve analysis.
- c. C_u is expressed as a ratio, where 60 percent (by weight) of finer material (D_{60}) passes a sieve to the sieve size that allows 10 percent (by weight) of finer material (D_{10}) to pass the sieve. The Hazen equation for this calculation is:

$$C_u = \frac{D_{60}}{D_{10}} \quad (\text{eq. 650L-13})$$

- d. Low C_u values indicate uniformly graded materials, while large C_u values indicate a large range in sizes or well graded material. If the uniformity coefficient of the aquifer material is 2.0 or less, an artificial filter pack is usually not required. If no coarse particles (between 0.5 and 1.0 mm) are present, an artificial filter pack is usually required, even when C_u is greater than 2.0.
- e. C_u is only a guide and there are no hard and fast rules for when an artificial filter pack is or is not required. Experience with other wells in the same area with similar conditions will help to determine if an artificial filter pack is required. Wells installed in cohesive bedrock may use open bore hole intakes (no filter pack).
- f. For more information about natural filters, see Johnson 1986, USBR 1964, NRCS CPS Water Well (Code 642), and ASTM D5092, “Standard Practice for Design and Installation of Groundwater Monitoring Wells.”

3. Artificial Filter Pack

- a. Artificial packs should be poorly graded, well-rounded, clean, and chemically inert, such as a clean quartz sand. Selection of filter pack is based on the formation particle size. If the filter pack is too small, it is possible to lose the pack to the formation, which can lead to the annular sealant to settle into the screened interval. Conversely, if the filter pack grains are too large, the pack will not effectively filter the finer-grained materials.
- b. Installation involves the direct placement of coarse-grained materials around the screen through the top of the casing, in the annular space between the aquifer and screen. Installation may include tremie pipe, gravity emplacement, reverse circulation, and backwashing. The filter pack increases the well diameter and reduces head loss, which results in a more efficient well. Choosing a properly graded sand or gravel to retain part of the aquifer is important to prevent the well from pumping sand and the filter and/or well screen from gradually becoming plugged with fines.
- c. Use the coefficient of uniformity (C_u) of the aquifer to determine the need for a gravel pack. Determine the C_u by dividing the D_{60} size by the D_{10} size (Hazen formula, eq. 650L-13).
- d. Sands with a $C_u < 2$ do not benefit greatly from development by surging (650.9 F “Well development after installation”). Sands with $C_u > 2$ but < 3 may benefit from development by surging, but water will flow through the aquifer freely enough that surging is not essential.
- e. Meet the following five conditions in selecting the size of gravel or filter material:
 - (1) C_u of the filter material should be < 2 .
 - (2) D_{15} size of the filter material should be $> 4 \times D_{15}$ size of the aquifer material.
 - (3) Include the uniformity of the aquifer in the criterion for a filter. If D_{50} filter/ D_{50} aquifer < 7.5 , the movement of sand into the filter should not be excessive. Assume this same criterion will hold true when aquifers with C_u 's > 2 are gravel packed and determine the maximum D_{50} size of the filter by the following formula.

$$C_u = \frac{D_{60}}{D_{10}}$$

$$D_{50} (filter) = \frac{15 \times D_{50} (aquifer)}{C_u (aquifer)} \quad (\text{eq. 650L-14})$$

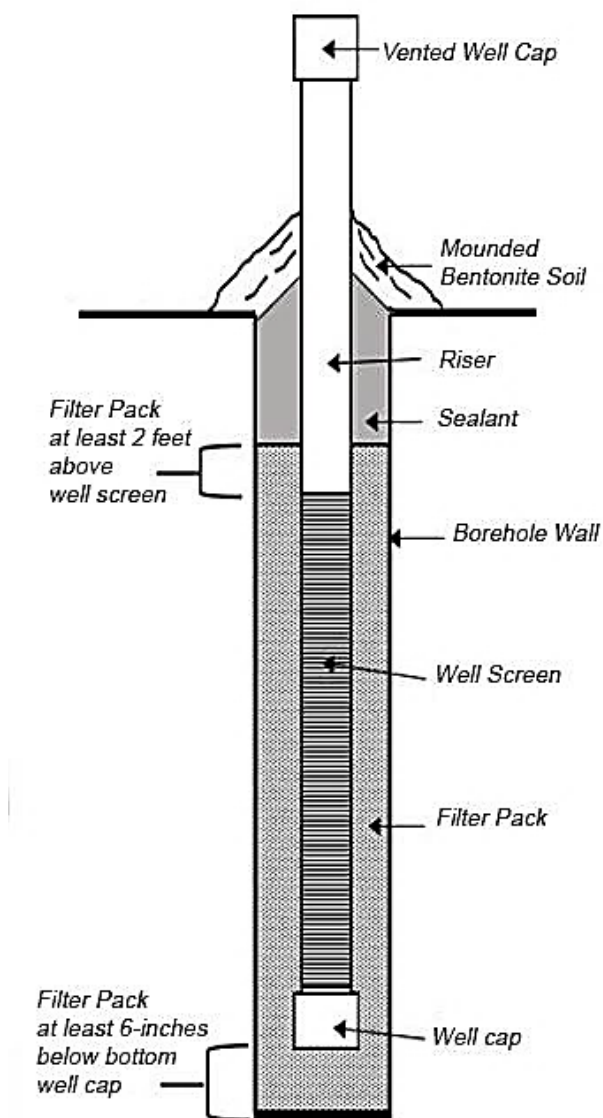
- (4) The D_{85} size of the filter should be $< 2.5 \times D_{10}$, to keep the C_u within 2.
 - (5) The filter gradation curve should be as nearly parallel to the aquifer gradation curve as the above conditions will allow.
- f. Figure 650L-39 provides general guidance for filter packs, based on aquifer characteristics, and figure 650L-40 shows a generalized water well installation.

Figure 650L-39: Guidance for when to use a filter pack

Filter Pack Recommendation for coefficient of uniformity $C_u < 2$	Use filter pack
Filter Pack Recommendation for coefficient of uniformity $2 < C_u < 3$ and aquifer grain size $D_{60} < 0.76$ mm	Use filter pack
Filter Pack Recommendation for coefficient of uniformity $2 < C_u < 3$ and aquifer grain size $0.76 \text{ mm} < D_{60} < 2.54$ mm	Do not use filter pack if well screen has enough openings to allow water to enter well without excessive head loss
Filter Pack Recommendation for coefficient of uniformity $2 < C_u < 3$ and aquifer grain size $D_{60} > 2.54$ mm	Do not use filter pack and use a manufactured well screen
Filter Pack Recommendation for coefficient of uniformity $C_u > 3$	Do not use filter pack because it might hold back fine sand removed from the aquifer by natural development

- g. The procedure to use in applying the above conditions to determine the size of filter material is:
 - (1) Step 1: Perform a sieve analysis of aquifer material to determine the percentage smaller than the screen openings.
 - (2) Step 2: Compute the D_{50} size of the filter using equation 650L-14 and locate and plot on figure 650LA-2 Filter Design Gradation graph.
 - (3) Step 3: Assume that D_{10} , D_{50} , and D_{60} are in a straight line. The C_u should not exceed 2; then D_{10} minimum size would equal D_{50} size multiplied by 0.6. Locate and mark this D_{10} minimum point on the graph.
 - (4) Step 4: Locate and plot the maximum D_{85} size of the filter at $2.5 \times D_{10}$ size of the filter.
 - (5) Step 5: Plot a uniform filter curve through the D_{50} point as nearly parallel to the aquifer curve as the above minimum D_{10} and maximum D_{85} points will permit.
 - (6) Step 6: Check to see that the D_{15} minimum size meets the requirement of being at least 4 times the D_{15} size of aquifer. If not, move the D_{15} point to meet this requirement and replot the filter curve through this point and the D_{50} point with a $C_u < 2$ to fit a new curve.
- h. See Appendix A for a filter design example problem.
- i. Ideally, the uniformity coefficient (C_u) should be as close to 1.0 as possible but not exceed 2.5. For filter pack criteria and installation methods, see CPS Water Well (Code 642) and ASTM D5092, "Standard Practice for Design and Installation of Groundwater Monitoring Wells."

Figure 650L-40: Schematic showing a generalized water well installation



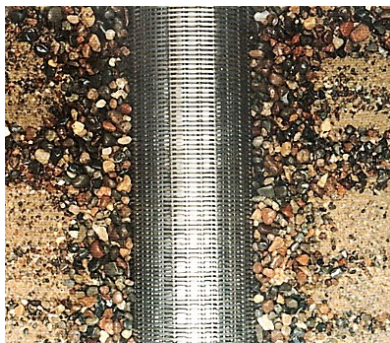
E. Well Development

1. Well development is a required process after drilling is completed and before aquifer testing is done. The purpose of development is to condition the well to produce the maximum amount of sediment-free water with minimum drawdown. Development is the last operation in constructing a well. It is the mechanical removal of fine sand, silt, and clay from the aquifer around the well, forming a natural filter pack. Or, if no coarse particles are present, it removes fines through an artificial filter pack.
2. Development also stabilizes the formation and artificial filter pack, where applicable, and increases the potential well efficiency and hydraulic connectivity between the well and surrounding formation. Poorly developed wells can impact well performance, water quality, increase the potential for damaging the pump, and

shorten the well's lifespan. Figure 650L-41 shows a cross section of a filter pack in a developed aquifer, along with the well screen.

3. Well development methods vary, depending on the physical characteristics of the surrounding geologic materials. Develop wells by surging, backwashing, jetting, pumping, use of compressed air, dry ice, acid, or dispersing agents. Use packers (inflatable or mechanical) to separate or isolate water-bearing strata during well development. Use knowledge of drilling methods and formation reactions to select the proper method. Use information from the record of materials to guide the development process.
4. Bridging of fine sand in the aquifer near the well may result from too violent action at the beginning of development. When pumping the well, sand particles in the formation tend to move toward the well. Because the steady pull of pumping is in one direction, finer sand grains wedge against each other and bridge across openings between coarser grains. To prevent bridging and remove fine grains, keep the water agitated by periodically reversing the direction of flow.
5. If a well is not adequately developed, data from an aquifer test may not accurately reflect aquifer conditions. If the well is suspected of poor development or if nothing is known about the well, conduct a step-drawdown test to evaluate the well. If plugging of the well screen and pump is determined to be a problem, typical remediation is to redevelop the well prior to conducting a step-drawdown test.
6. The type of well development and duration for development is important to record.
7. ASTM D5521/D5521M-18, "Guidance for Development of Groundwater Monitoring Wells in Granular Aquifers," discusses well development in detail.

Figure 650L-41: Developed well cross section showing filter pack and well screen



Source: E.E. Johnson, 2007

F. Aquifer Testing

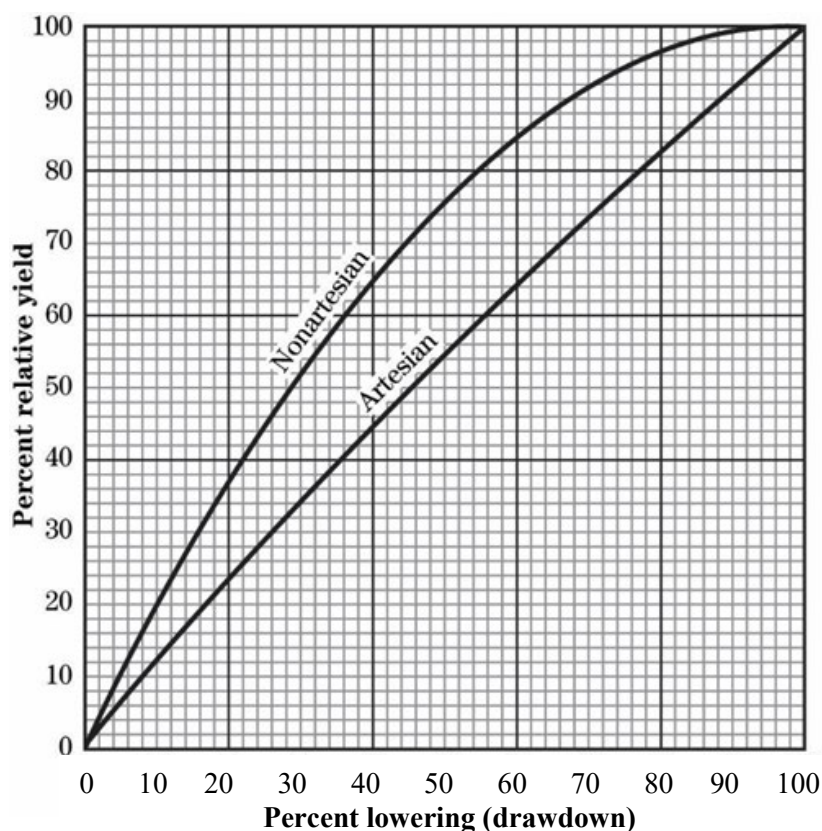
1. Aquifer tests are conducted to obtain information on well performance and efficiency to properly size a pump, evaluate aquifer characteristics and the well's ability to produce and sustain the planned flow rate. The terms "aquifer testing" and "pumping tests" are often used interchangeably. These terms should not be confused with "pump test" which refers to testing the pump itself to test the pump/motor efficiency and energy use. Pump tests have nothing to do with the well or aquifer.

2. Pump a well to determine its capacity and drawdown. A completed well does not yield undesirable sediment when pumped at the required capacity. The contractor should complete development and testing of the well before leaving the job.
3. Aquifer testing takes the guesswork out of pump selection. Allowing a licensed water well driller to “guesstimate” well productivity based on a visual estimate of the amount of mud and water that are purged from a well during well cleanout and development may result in choosing a pump that over-pumps the well, causing the pump to suck air as the water levels reach the pump intake.
4. A non-artesian well usually produces about 75 percent of its capacity when the drawdown is at half the water depth and about 90 percent when the drawdown is at two-thirds the water depth. For economical pumping, design the pump to operate between these two extremes, since increasing the pumping rate to the maximum causes every gallon that is pumped to be lifted the total depth from the surface to the drawdown level. Over-pumping a well may also cause excessive sand pumping and possible well failure. Soon after well completion and well development, install a test pump and perform an aquifer (pumping) test to verify the well development and yield.
5. See Appendix A in this subpart for an example on how to estimate optimum drawdown and yield and the most economical water yield from a specific well.
6. Estimate the optimum yield and required lift by converting drawdown obtained from the tests to percentage of possible drawdown and relating it to yield (figure 650L-42). The curves shown are average drawdown-yield relations for many wells. At 50-percent drawdown, non-artesian wells produce about 77 percent of possible yield and artesian wells produce about 55 percent.
7. For a detailed discussion on how to perform aquifer testing and analyze the tests, see 210 H 631.3112, “Groundwater Aquifer Testing.”

G. Efficiency

1. Well efficiency is the ratio of theoretical drawdown to actual drawdown and is a function of the design. It is not uncommon for a well to be only 60 – 65 percent efficient. However, with good construction and development, up to 90 – 95 percent efficiency is possible. For more information on well efficiency, see 210 H 631.3112 (C)(9), “Well Efficiency.”

Figure 650L-421: Relationship between drawdown and yield



650.191 Pumps and Multiple Well Systems

A. Selecting a Pump

1. When selecting a pump, consider required capacity, total lift, system pressure, well diameter, well location, and type of power available. The common types of pumps are turbine, centrifugal, propeller, gear, plunger, and airlift. Pump construction is based on a specific range of conditions to operate. Do not select a pump without a thorough knowledge of the planned operating conditions and pump characteristics. Figure 650L-43 shows a large capacity irrigation well head, with electric motor powering the pump.

Figure 650L-43: Water well pump image powered by electric motor, Washington



B. Pump Service

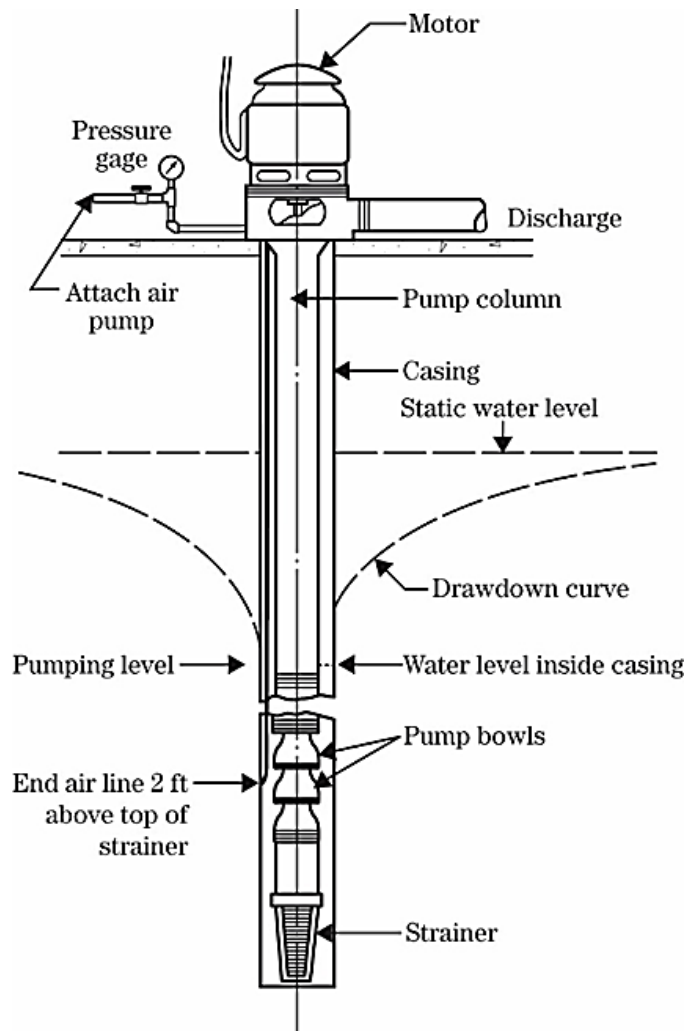
1. Pump manufacturers issue instructions and recommendations for pump operation and maintenance. Precise compliance with manufacturer-specified operational protocols and maintenance recommendations is critical to optimizing the pump's expected service life and functional integrity.

C. Measuring Drawdown

1. Measure drawdown using an airline (air pressure gage) or an electric sounder. Equip deep-well pumps with pressure gages and air lines of known lengths.
2. The airline is usually a copper tube 1/8 to 1/4 inch in diameter but may be a quarter inch galvanized pipe. Connect the surface end to a pressure gage with an air valve just below the gage (figure 650L-44). The lower end of the pipe is open. The pipe must be airtight and should extend 20 feet or more below the lowest pumping level. The exact depth to the lower end of the airline must be known.
3. Provide air pressure by a tank connected to the line or by a hand pump. The gage indicates the pressure necessary to counterbalance the depth of water outside the air line and when it has reached maximum pressure.
4. Depth to water level is the depth to the lower end of the airline minus the gage reading in meters or feet. If the gage reads in psi, multiply the reading by 2.31 to obtain feet.

5. An electric sounder is an accurate method of measuring water level. Electric sounders complete an electric circuit when in contact with water, and a buzzer sounds, and/or a light illuminate. The water depth is then read off the marked cable.

Figure 650L-44: Airline measuring depth to water level



D. Measuring Yield

1. Perform an aquifer test to obtain well yield and determine if the well can sustain pumping at that rate for long duration. See 210 H 631, "Groundwater Investigations," for more detailed information about aquifer testing.

E. Multiple Well Systems

1. If needed, use a multiple-well or manifold system to obtain the amount of water to meet design requirements. Three conditions are necessary for a manifold system to be successful.
 - a. The water table should be close enough to the land surface to permit pumping the wells by suction lift.

- b. The water-bearing sand and gravel should permit good water yield without excessive drawdown, and the stratum should be thick enough to permit prolonged pumping.
 - c. Individual wells must be highly efficient. Investigation, casing, and screen selection are the same for a multiple-well system as for any other well.
- 2. Two types of installations use multiple-well systems: sand points and small individual wells. Figure 650L-45 shows the components for a satellite well unit. Figure 650L-46 shows a typical manifold multiple-well system with four satellite wells. Add additional satellite wells to a system if needed.
- 3. Figure 650L-47 shows several layouts of satellite wells relative to the central well. The general configuration of the aquifer with respect to the overlying property largely dictates which arrangement is best. Drilling test wells may be necessary to locate the aquifer and define its characteristics.
- 4. No exact spacing of the wells can be set. Sometimes the water supply will be adequate on 10-foot spacings. However, it is good practice to space wells at least 40 feet apart so that interference between them will be at a minimum. After the first well is set, the remaining wells can be set by connecting the pump discharge to them and jetting them into place.
- 5. A drop pipe installed in each of the wells is connected to the manifold or header pipe, which is connected to the intake side of the pump.
- 6. All connections on the suction side of the pump must be airtight. The practical suction lift on most suction pumps is 25 feet or less. A common practice with satellite wells is to drill and case to about 35 feet below the normal water table in the aquifer.
- 7. The drop pipe extends to within 2 feet of the bottom of the well, making it about 30 feet below the manifold line. The manifold line may be on the surface of the ground or buried close to normal water level.
- 8. The size of manifold lines depends on the friction loss, the volume of water flowing, and the distance that water flows through the pipe. If more than one well is on a manifold, increase the pipe size as the pipe approaches the central well. Each manifold is an individual design problem.
- 9. Install manifold lines with a slight incline toward the central well. This incline prevents high points that trap air pockets and reduce the flow.
- 10. Drill an observation well at some measured distance from the well and determine the drawdown at that point. If the drawdown at the well (outside the casing) is known, the radius of influence can be determined. For example, when measured, 40 percent of drawdown is at 50 feet from the well, then 20 percent drawdown will be at 100 feet from the well, 10 percent drawdown at 200 feet from the well, and 5 percent drawdown at 400 feet from the well. If possible, space wells at least twice the radius of influence as determined above.
- 11. Closer spacing causes interference between the wells (figure 650L-48). Wells spaced 800 feet in the above example would have radii of influence overlapping each other at the 5-percent drawdown point, causing interference and inefficiency.

Figure 650L-45: A satellite well unit of a multi-well system

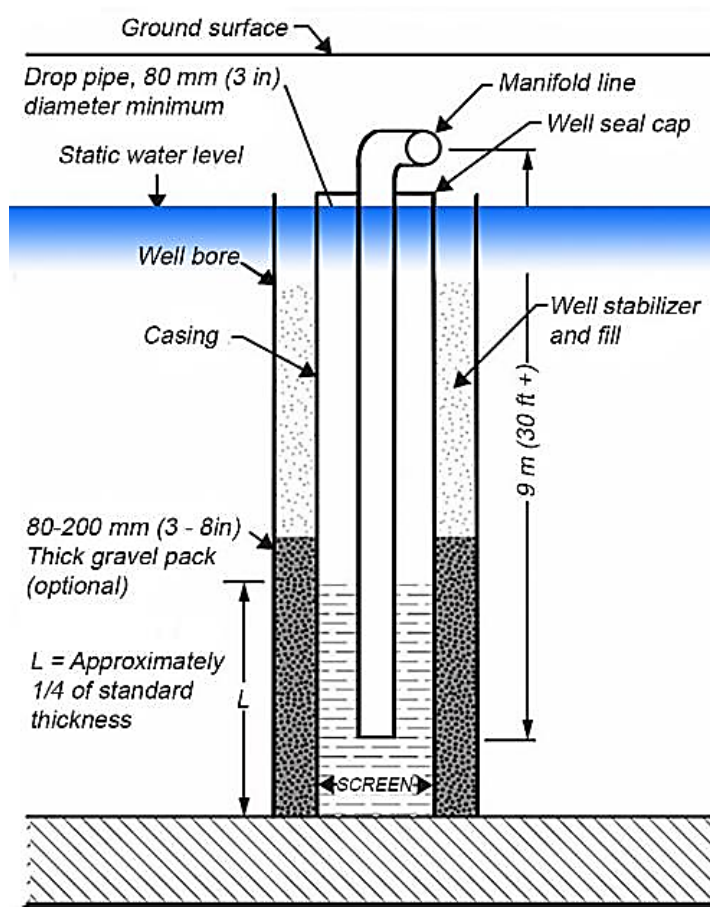


Figure 650L-46: Sample layouts for manifold pumping systems

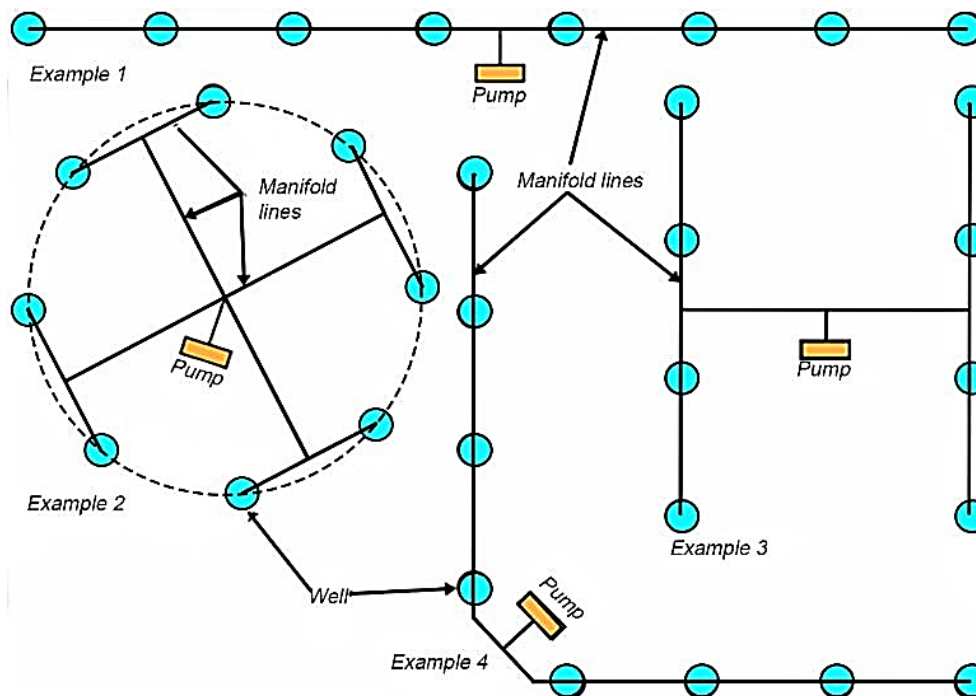


Figure 650L-47: Well interference in an unconfined aquifer

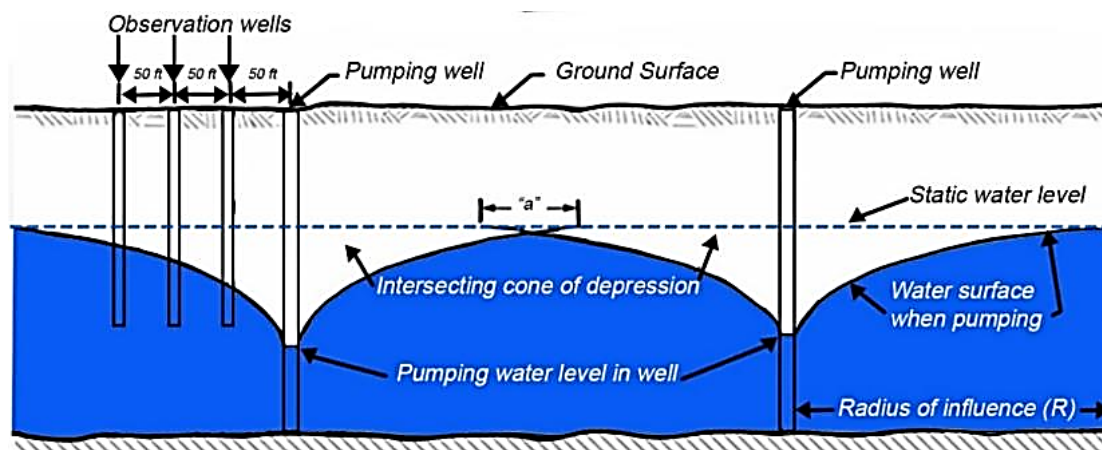
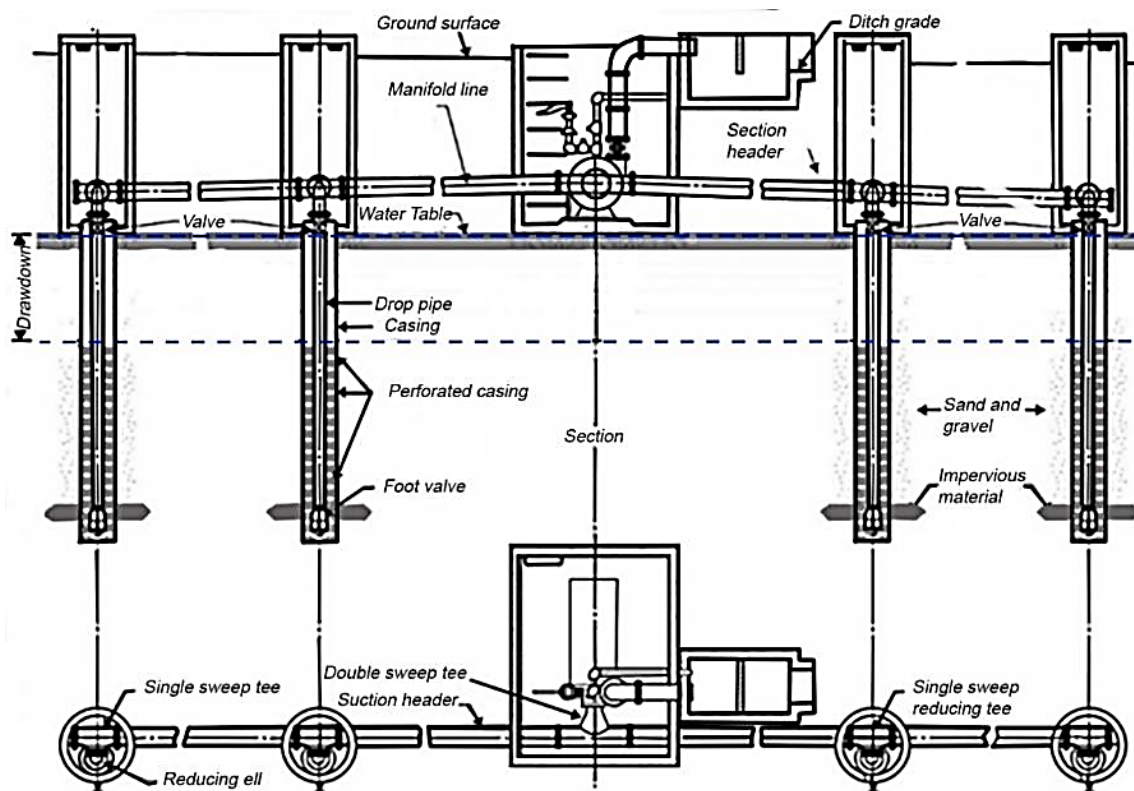


Figure 650L-48: Typical multi-well manifold system (pump may be an engine or electric motor)



650.192 Well Maintenance

A. Introduction

1. Well maintenance or rehabilitation is a cleaning or reconstructive process that restores a water well to the most efficient condition. Regular maintenance can sustain well performance, retain, or restore lost water volume and/or quality, potentially increase a well's lifespan, and decreases the need for reconstruction.
2. Maintenance frequency may occur every 2 to 15 years, depending on the aquifer type and well construction and development. For example, a well installed in alluvium may require more frequent maintenance due to higher percent fines compared to a well installed in metamorphic rock. Or a poorly constructed well may require frequent maintenance compared to a properly constructed well. Consideration for the operating history of other wells may also assist in determining a maintenance schedule. A licensed water well driller can inspect and provide a maintenance schedule, based on the water well needs.
3. Well maintenance includes one or more of the following:
 - a. Using a downhole camera to video the well
 - b. Pulling and cleaning the pump

- c. Mechanical treatment, including cleaning the well with a brush, percussion tool, or another tool
- d. Chemical treatment to break down encrusting materials
- e. Remove finer debris from the well bottom using bailer, air-lift methods
- f. Pumping the well at maximum capacity
- g. Conducting a step drawdown pumping test to evaluate well performance
- h. Winterizing the well system during periods of subfreezing temperatures

B. Reasons for Well Maintenance

1. Corrosion

- a. Corrosion is the removal of metal in water by chemical or electrolytic action. Methods of protecting against corrosion have been discussed previously in this subpart. If corrosion impairs a well, the solution is to remove and replace the corroded well screen and/or casing.

2. Encrustation

- a. Encrustation is deposition of foreign material, such as calcium carbonate, iron, or biofilm, on or around the well screen that can clog the screen, filter pack, pump intake, and pipeline system. Unlike corrosion, encrustation reduces and will, in time, plug screen openings and possibly damage the pump.
- b. Encrustations consist of iron, manganese, calcium, or sulfates and result mostly from precipitation in groundwater, deposition of suspended clay and silt, or bacterial growth. Encrustations are usually hard and cement-like but may have the consistency of paste or jelly until exposed to air.
 - (1) Carbonate encrustation occurs due to pumping, which causes a reduction of pressure in the vicinity of the well and releases carbon dioxide. The water is unable to carry in solution the former amount of calcium, magnesium, and other metal salts, and particles are deposited as carbonates and oxides on the screen and in the adjacent aquifer.
 - (a) Drawdown reduction is the most effective means of slowing carbonate encrustation. Drawdown may be reduced in several ways:
 - Design of the screen to keep entrance losses at a minimum.
 - Well development to increase effective diameter of the well.
 - Pumping at a reduced rate for a longer period.
 - Use of a greater number of smaller wells.
 - (2) Biofilm or biofouling (bacteria) encrustation occur when a water well sits unused for a long duration and/or has poor water quality. Typically, biofilms are red or black, thick, and have a fibrous, gelatinous, or slimy texture. A stagnant well with biofilm encrustations may emit a sulfur odor.
 - c. Where encrustation is a problem, periodic cleaning by a reliable and experienced well servicer may be necessary. Clean the well to reduce the risk of a major reduction in yield. Select chemicals to treat wells based on the type of encrustation, screen, and casing composition.

C. Well Treatments - Acids

1. Chemical treatment dissolves mineral encrusting materials, making removal from the well easier. When encrustation is rapid, periodic acid treatment may be required. Acid treatments are effective but dangerous to handle. Toxic fumes are emitted from the well within minutes of application for most of the acids and these vapors can be highly corrosive. Inhalation can cause death and contact with bare skin can result in serious injury. Any acid used should be food grade and National Sanitation Foundation (NSF)-certified.
2. Common acids used during well maintenance include:
 - a. Hydrochloric (muriatic) Acid
 - (1) Hydrochloric acid is extremely effective in dissolving many minerals, is inexpensive, and is more available compared to other acids. However, this acid and its vapors are highly corrosive to most metals due to the chloride content.
 - b. Phosphoric Acid
 - (1) Phosphoric acid is a mild acid that does not give off harmful vapors compared to other acids, but inhaling or contact with sprays or mists can be dangerous. Phosphoric acid is less corrosive and slower reacting to metal than hydrochloric acid. This acid is less effective at dissolving calcium, iron, and manganese, compared to hydrochloric acid, but it is not effective for dissolving phosphates or removing biological films. Phosphoric acid contains phosphorous which can enhance algae growth.
 - c. Sulfamic Acid
 - (1) This acid is moderately soluble in water and is even less soluble in warmer water. This is a strong acid that reacts quickly with carbonates and should be dissolved in water before addition to the well. This acid is ineffective for gypsum and sulfates and is limited for use within smaller well diameters.
 - d. Acetic Acid
 - (1) Acetic acid is an excellent solvent for phosphates and some sulfates. This acid is extremely corrosive to bare skin and can produce toxic vapors that can cause severe lung damage. However, this acid is less corrosive than hydrochloric acid. In some cases, acetic acid is used with hydrochloric acid and other acid additives.
 - e. Hydroxyacetic Acid
 - (1) Hydroxyacetic acid, also known as glycolic acid, is a weak acid used to remove calcium, magnesium, manganese, salts, iron, and polysaccharide deposits. This acid has low corrosivity, low toxicity and odor, is nonflammable, and produces negligible fumes compared to other acids.
 - f. Citric Acid
 - (1) Citric acid is a weak acid that comes in a crystalline powder and should always be combined with a stronger acid. Citric acid is very soluble when paired with hydrochloric acid, and together, increase phosphate and iron solubility for easy removal from the well. However, any solution with citric acid will enhance and support bacterial growth.

g. Oxalic Acid

- (1) Oxalic acid is a strong acid used for removing iron and manganese scale but is not as effective with high water hardness or significant biological accumulation. This acid is much stronger than acetic acid and is more soluble in warm water.

3. The most common of these acids used in well maintenance and rehabilitation are hydrochloric (muriatic), phosphoric, and sulfamic. For more detailed information about acid treatment and application, see Driscoll 1986.

D. Well Treatments – Polyphosphates and Chlorine

1. Polyphosphates are an effective treatment to break up or disperse silt, clay, iron oxides, and manganese encrustations from a water well. This dispersing agent causes the clay and silt particles to repel each other, increasing their mobility and removal ability. Iron oxides, calcium, magnesium, and manganese bond to finer particles like clay and silt and remain in a soluble state, making it easier to remove these minerals from the well and aquifer. For more information see Driscoll 1986.
2. Chlorine is inexpensive, readily available, and suited for use in potable water supplies. A typical solution is a concentration of at least 50 mg/L for the entire well for both within the water column and cleaning the casing above static water levels. Agitate the solution throughout the entire well and mix it in such a way to ensure that the mixture is uniformly mixed from the bottom to top of the well. Agitation is best achieved by jetting chlorinated water into the formation. Other suitable methods include surging or injecting and releasing compressed air, forcing the chlorine solution through the well screen openings. After agitation, allow the solution to rest in the well for at least 12 hours before flushing or pumping.
 - a. If water quality sampling after treatment shows bacteriological contaminants, a solution of at least 100 mg/L, equal to at least four times the volume of the water well, is required. Agitate the solution and allow the mixture to rest in the well for at least 24 hours before flushing or pumping. Test the water quality of the well and repeat chlorination procedure as needed. For more information, see Driscoll 1986.
 - b. Chlorine is a common and effective method for eliminating bacterial accumulations. Chlorine treatment is effective when combined with a biocides where the cause of screen clogging is bacteria that generate an iron or slime precipitate.

E. Well Testing

1. Consider performing annual well testing. Make the following tests and measurements for comparison with previous data:
 - a. When all wells are not regularly used and have been at rest a long time, run a 2-hour pumping test. Record the static water level, the pumping rate, and frequent drawdown measurements. One of the purposes for well testing is to agitate stagnant wells to prevent bacteria and mineral accumulations which can contaminate the groundwater. Well testing can also track well performance over time.

- b. Measure static water level and drawdown water level while pumping and determine the well's specific capacity (gal/min/ft) as an indicator of overall well performance. Changes in specific performance may indicate that the well may require remediation.
- c. Every 2 months measure and record the static water level when the pump has been off at least four days. Record details.
- d. During the heavy pumping season, measure the yield and drawdown and record them along with the length of time that the pump has been running. Several measurements per summer are advisable.

650.193 Well Abandonment (Decommissioning)

A. Introduction

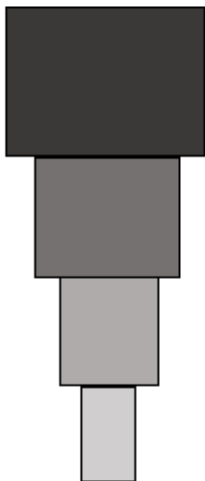
1. Well abandonment, also called decommissioning, is performed when a well that is no longer in use or is in disrepair and can no longer pump useable quantities. Well abandonment does not mean "walking away from" the well without properly sealing the well according to local, State, and Tribal laws.
2. Abandonment is important to prevent groundwater pollution, eliminate physical hazards, in some cases conserve aquifer yield, and prevent aquifer commingling. The main objective for abandonment is to restore the geology, as much as possible, to the original hydrogeologic conditions. Each abandonment is unique and should consider the following:
 - a. Purpose
 - b. Well location
 - c. Well condition
 - d. Hydrogeology and groundwater quality
 - e. Geology
 - f. Well construction
3. Before abandonment and when possible, remove all tubing, screens, casing, filter pack, and sealant from the well. Removal assures an effective seal. Sound or video inspect the well to ensure all obstructions are removed before placing applicable sealant. If some or all equipment and casing resists removal, the casing must be ripped, perforated, and cut off a minimum of 2 feet below the ground surface before placing sealant.
4. The preferred abandonment method is fully grouting a non-flowing or out-of-use well. However, there are accepted alternative abandonment methods, depending on State, Tribal, and local regulations, and the above site conditions (650L-13A (2)).
5. Sealants are used to provide a watertight barrier to prevent water migration into the well or bore hole from fractures within the surrounding formation. Sealants typically consist of concrete, grout, bentonite, or a combination and must conform to ASTM D5299, "Standard Guide for Decommissioning or Groundwater wells, Vadose Zone Monitoring Devices, Boreholes, and Other Devices for Environmental Activities," or state regulatory requirements. Sealant material selection depends on well construction, surrounding geologic formation, and available equipment. Sealant

additives are commonly used to either enhance or delay setting time, shrinkage, or strength. A grout pump and tremie pipe are typically used to place sealant from the well or bore hole bottom to near ground surface.

6. For abandonment procedures, see local, Tribal, and State laws and NRCS CPS Well Decommissioning (Code 351). For sealant placement procedures, follow ASTM D5299, “Standard Guide for Decommissioning of Groundwater Wells, Vadose Zone Monitoring Devices, Boreholes, and Other Devices for Environmental Activities,” and AWWA100-20 “Water Wells.”
7. Generally, four main factors complicate abandonment (decommissioning):
 - a. Flowing artesian
 - (1) Properly sealing the annular space surrounding the well casing is critical to prevent uncontrolled flows from reaching the ground surface. Inadequate surface seals or well casing corrosion can lead to a blowout.
 - (2) Uncontrolled flows can erode and transport formation materials to the surface. This can result in widening the boring, large subsurface voids, and turbid discharge intermingling and contaminating surface water. Groundwater quality and cooler temperatures can also adversely affect warmer surface water and animal habitats.
 - (3) Stopping or reducing flows on older wells is a risk for blowouts, because they may have corroded casing or defective annular seals. When feasible and before abandonment, verify the casing condition with a downhole camera. However, turbid flows may impact the ability to clearly see the casing.
 - (4) Sealing artesian flowing wells poses many challenges. Control water flow before placing sealant materials. When feasible, the following are options to either stop or reduce flows before sealant placement:
 - (a) Install well packers or wooden plugs. Ensure the plug length is several times longer than the well diameter to prevent tilting.
 - (b) Pump high-specific gravity fluids into the well through a tremie pipe (small diameter PVC pipe) or drill rod, such as drilling mud or cement.
 - (c) Extend the well casing high enough above the ground surface to stop the flow.
 - (d) Pump the well or nearby wells in the same flowing artesian aquifer to increase drawdown in the well being abandoned.
 - (e) Ensure that sealants are designed to withstand the maximum anticipated hydraulic head of the flowing artesian aquifer.
 - (f) For additional guidance, see Driscoll 1986 and EPA 1998.
 - (5) The abandonment (decommissioning) method used depends on the well shut-in pressure and depth to which the water level must be lowered.

- b. Multiple aquifers
 - (1) Wells installed in multiple aquifers should be sealed in such a way that commingling of water between aquifers is prevented. If commingling is occurring or likely, over-drilling the existing well may be necessary for proper abandonment.
- c. Carbonate rocks
 - (1) For wells penetrating rocks with large voids or caverns, ensure that aggregates and sealants are properly sized and have the appropriate consistency to prevent removal by any potential water flow into or out of the space. Installing a bridge seal in competent rock above the cavern or large void may be required to isolate the production area. This avoids having to fill a possibly deep and wide expansive hole, which may never have been filled. Adding a bridge provides structural integrity for overlying sealants.
 - (2) There are two types of bridges: temporary and permanent. Temporary bridges provide a base for the permanent bridge. Temporary bridges consist of materials such as expandable wood plugs, neoprene, plastic, rubber, or various packers. Permanent bridges are typically composed of concrete, sand-and-cement grout, and cement grout.
 - (3) For additional bridging guidance, see EPA 1991.
- d. Telescoped casing
 - (1) For wells with telescoped or nested casing, a larger, outer bore hole is drilled and cased through the subsurface, followed by inserting successively smaller inner casings (figure 650L-49). Telescoped casings complicate abandonment. When possible, remove inner casing strings, if removal will not jeopardize well abandonment. When inner strings cannot be removed, vertically split plastic cased wells or cut metal cased wells at enough intervals to ensure that sealant completely fills the annular space.

Figure 650L-49 – Example of telescoped casing



650.194 References

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ASTM D5521, Standard Guide for Development of Groundwater Monitoring Wells in Granular Aquifers.

ASTM D5092, Standard Practice for Design and Installation of Groundwater Monitoring Wells

ASTM D6914, Sonic Drilling for Site Characterizations and the Installation of Subsurface Monitoring Devices.

ASTM D3965, Standard Classification System and Basis for Specifications for Rigid Acrylonitrile-Styrene (ABS) Materials for Pipe and Fittings.

ASTM D3517, Standard Specification for “Fiberglass” (Glass-Fiber Reinforced Thermosetting-Resin) Pressure Pipe.

ASTM D2996, Standard Specification for Filament-Wound “Fiberglass” (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe.

ASTM D1892, Standard Specification for Styrene.

ASTM F480, Standard Specification for Thermoplastic Well Casing Pipe and Couplings Made in Standard Dimension Ratios (SDR), SCH 40 and SCH 80.

ASTM A589, Standard Specification for Seamless and Welded Carbon Steel Water-Well Pipe

ASTM A139, Standard Specification for Electric-Fusion (Arc)-Welded Steel Pipe (NPS 4 and Over).

ASTM A53, Standard Specification for Pipe, Steel, Black, and Hot-Dipped, Zinc-Coated, Welded and Seamless.

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Appendix A – Example Problems

Example Problem to Estimate Capacity

See 650.7 “Design Capacity.” A well has a static water level at a depth of 50 feet and a measured capacity of 850 gallons per minute with a drawdown of 34 feet. The capacity for 25 feet of drawdown is calculated below. Note, H is the depth from the static water level to the well bottom before pumping began, and h , is the depth from the pumping water level to the well bottom during pumping. To calculate h , the drawdown ($H-h$), subtract the pumping water level (h) from the static water level (H). See figure 650L-26 for a diagram showing groundwater terminology.

$$\frac{Q}{Q_1} = \frac{H^2 - h^2}{H^2 - h_1^2}$$

$$Q_1 = \frac{Q(H^2 - h_1^2)}{H^2 - h^2}$$

$$Q_1 = \frac{850 \text{ gal/min}((50\text{ft})^2 - (50\text{ft} - 25\text{ft})^2)}{(50\text{ft})^2 - (50\text{ft} - 34\text{ft})^2}$$

$$Q_1 = \frac{850 (2,500 - (25)^2)}{2,500 - (16)^2}$$

$$Q_1 = \frac{850 \times 1,875}{2,244}$$

$$Q_1 = \frac{1,593,750}{2,244} = 710 \text{ gal/mins}$$

Example Problem for Filter Design Example

Use equation 650L-17. Given aquifer sieve results (figure 650LA-1):

Figure 650LA-1: Aquifer Materials Sieve Results

Sieve no.	% passing
3/8	99
4	97
10	90
20	72
40	19
60	4

Step 1. Determine filter gradation.

Step 2. Plot sieve results on grain-size distribution forms (figure 650LA-2).

Step 3. Read $D_{10} = 0.3 \text{ mm}$, $D_{50} = 0.65 \text{ mm}$, $D_{60} = 0.75 \text{ mm}$, then calculate C_u and $D_{50} \text{ filter}$:

$$C_u = \frac{D_{60}}{D_{10}} = \frac{0.75}{0.30} = 2.5$$

$$D_{50 \text{ filter}} = \frac{15'D_{50 \text{ aquifer}}}{C_u \text{ aquifer}} = \frac{15(0.65)}{2.5} = 3.9 \text{ mm}$$

$$D_{10} \text{ filter} = 0.6 \times D_{50} = 0.6(3.9) = 2.3 \text{ mm, minimum}$$

$$D_{85} \text{ filter} = 0.6 \times D_{10} = 2.5(2.3) = 5.8 \text{ mm, maximum}$$

Step 4. Plot filter on curve (figure 650LA-2).

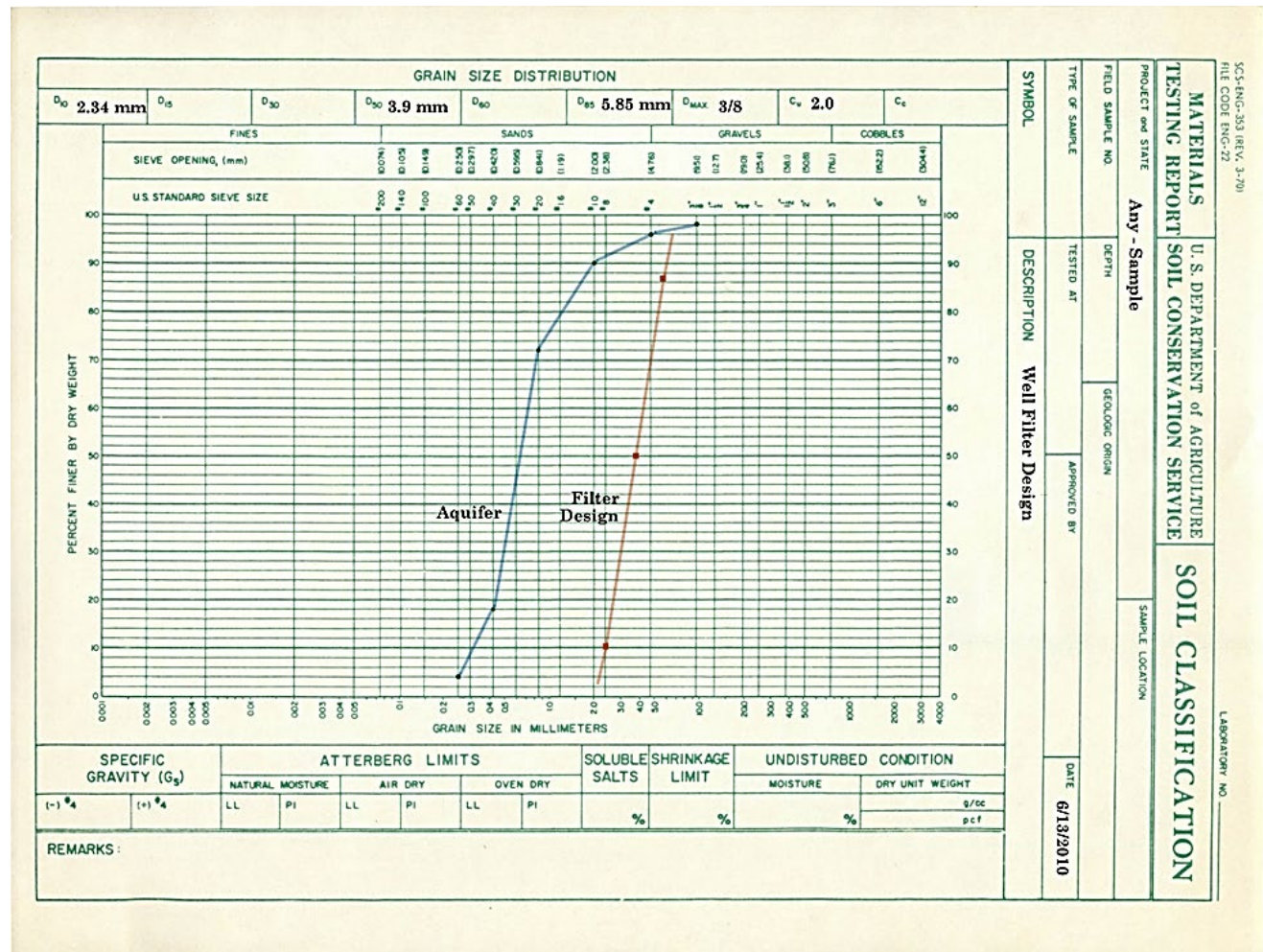
Filter design limits

100% pass 3/8 sieve

64% (± 8) or 56 to 72% pass #4

6% (± 8) or 0 to 14% pass #8

Figure 650LA-2: Filter Design Gradation, based on Aquifer Particle size Distribution



A filter from 4 to 8 inches thick is sufficient for a gravel envelope. Installing a thicker filter enlarges the effective well area and only decreases the velocity of water approaching the well. If difficulty is encountered in keeping the velocity low enough to prevent the water from carrying sand into the well, the effective diameter of the well can be increased by using a thicker filter or by installing a larger casing.

Optimum Drawdown and Yield Estimation Example Problem

See 650.10(G), “Aquifer Testing.” The water is 75-feet-deep in a well and the pumping test yielded 1,470 gallons per minute with a drawdown of 23 feet. This is 31 percent of the total possible draw down. Figure 650L-42 shows that at 31 percent of the maximum drawdown, this non-artesian well will produce 53 percent of the maximum yield, so the maximum yield would be about:

$$\frac{1,470}{0.53} = 2,770 \text{ gal/min}$$

Figure 650L-42 shows that 77 percent of the maximum yield can be obtained with a 51-percent (38 ft) drawdown, for a yield of about 2,130 gallons per minute. Use the following test procedures:

- Measure and record the depth to static water level (measure with a steel tape that has 1 to 2 feet of its lower end chalked).
- Determine whether the well is artesian or non-artesian by referring to the well log for evidence of the presence of a confining layer. If the static water level is above the bottom of the confining layer, the well is artesian.
- Measure the height of the static water column or 100 percent drawdown. For non-artesian wells, 100 percent drawdown is the depth from the static water level to the bottom of the aquifer or to the bottom of the well if the aquifer is not completely penetrated. For artesian wells, 100 percent drawdown is the depth from static water level or piezometric surface to the bottom of the confining layer.
- Pump the well at a near-maximum rate (50 percent drawdown or slightly more) until drawdown and yield are constant at that rate. When three measurements taken 1 hour apart are the same, drawdown is constant. Measure water levels during pumping with an electric sounder or airline. This may take several hours to several days of continuous pumping. Record drawdown and yield.
- Convert measured drawdown to percent drawdown. See the above figure to estimate optimum drawdown and yield and the most economical water yield from a specific well.