Groundwater Resources:
Springs and Wells

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United States Department of Agriculture
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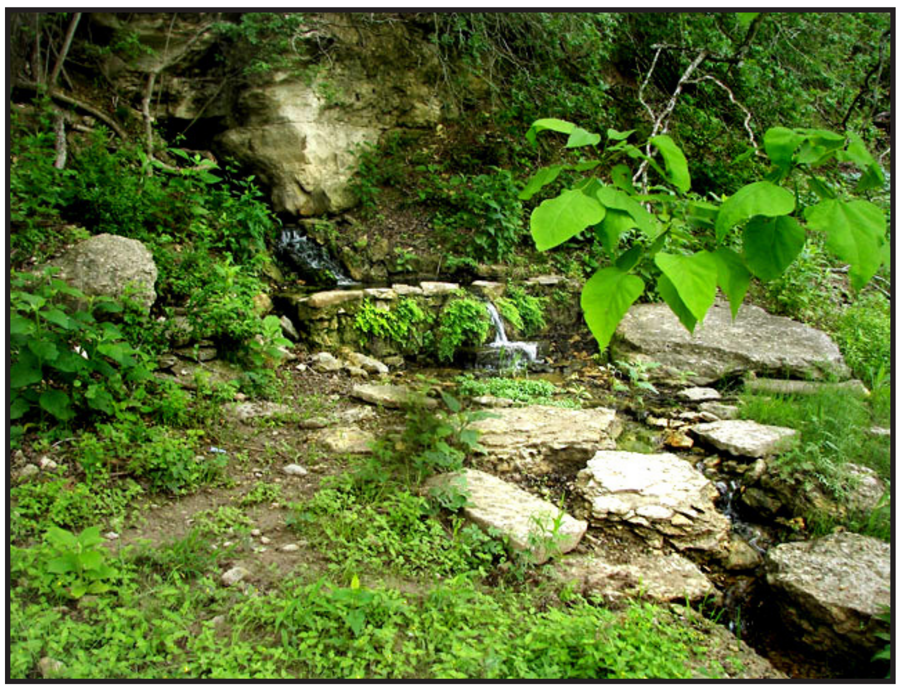
Part 650 Engineering Field Handbook
National Engineering Handbook

Chapter 12 Springs and Wells



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Cover: The spring flows into Onion Creek in Hayes County, Texas

Chapter 12 Springs and Wells

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Chapter 12 Springs and Wells

650.1200 Introduction

The purpose of this chapter is to provide conservationists and engineers with some of the fundamentals of planning and developing groundwater resources. The chapter contains information that must be considered and analyzed if a successful and long-lasting water supply is to be obtained from wells or springs. The nature of groundwater, methods of obtaining it from springs or wells, and the development and maintenance of groundwater recovery systems are described. Groundwater has many advantages over water from other sources, and its economic importance cannot be overemphasized.

The term “groundwater” is a simplistic term that encompasses water in the saturated zone beneath the Earth’s surface, water that is under pressure, and the complex movement of groundwater as an integral part of the Earth’s hydrologic cycle, as depicted in figure 12–1.

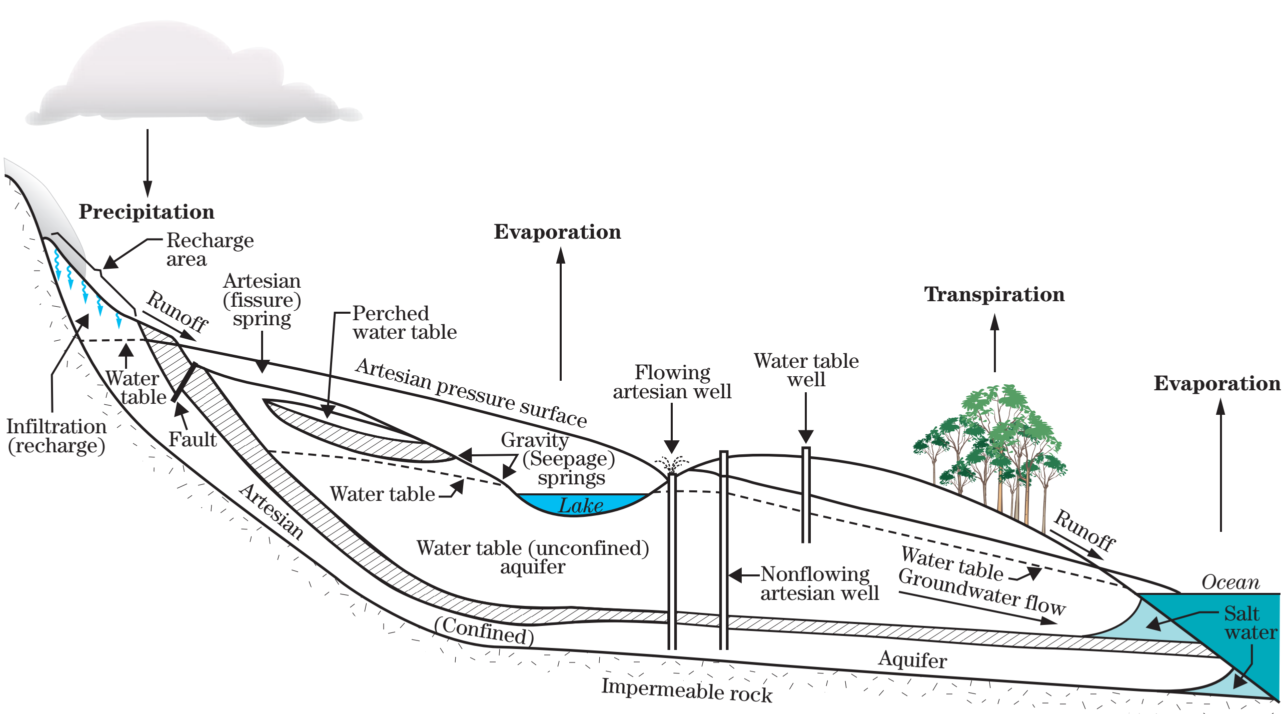
The principal ways of using groundwater are through spring and well developments. A spring is a natural outflow of water from an underground supply to the ground surface. A seep differs from a spring, in having no definite opening. A well (vertical or horizontal) is a hole drilled, dug, or driven into the earth to obtain groundwater.

For more detailed information, refer to the following chapters in the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) National Engineering Handbook (NEH), Part 631:

- Chapter 30, Groundwater Hydrology and Geology
- Chapter 31, Groundwater Investigations
- Chapter 32, Well Design and Spring Development
- Chapter 33, Groundwater Recharge

For springs, see the NRCS National Conservation Practice Standard (CPS), Code 574, Spring Development. For wells, see the CPS Code 642, Water Well.

Figure 12–1 The hydrologic cycle, with a focus on groundwater resources



Groundwater is located in the area of the Earth's crust known as the zone of saturation and is contained in aquifers: water table aquifers, confined aquifers, or perched aquifers.

In a water table aquifer, the water is not confined, is at atmospheric pressure, and may rise or fall in the upper zone of saturation, depending on rate of recharge and rate of withdrawal, drainage, or outflow. In a confined aquifer, the water is confined in the zone of saturation by an overlying relatively impermeable layer and may be at a pressure greater than atmospheric. If the water in a confined aquifer rises above the containing layer when penetrated, the aquifer is said to be artesian, even though water may not freely flow from the well. Many artesian wells do not flow freely at the ground surface (fig. 12–2), but the added pressure reduces pumping requirements.

The elevation to which water will rise up in a tube or well that penetrates an aquifer (confined or unconfined) is the potentiometric surface. The water table is more properly termed the "potentiometric" surface in an unconfined aquifer, also called a water table aquifer.

Perched aquifers occur in the vadose zone above and not connected to the regional water table. They occur because of an aquiclude or lower barrier of less permeable strata. Perched aquifers may be important local but limited sources of fresh water. Many volcanic islands have perched aquifers, which are important freshwater sources, for example.

Figure 12–2 Artesian well flowing at surface, Missouri

650.1201 Source of water supply

(a) Water-bearing materials

Although underground streams may flow in cavernous limestone or lava tubes, the main source of groundwater in rock formations is the pores and cracks.

Unconsolidated sands or gravels generally are the most important aquifers, with high porosity and permeability. Porosity is an expression of void spaces, while permeability is an expression of the ability of the earth material to transmit water. Jointed and permeable sandstone and jointed limestone containing solution passages are next in importance as aquifers. The movement of water in sandstone is controlled by its permeability, or the uniformity, compaction, amount of interconnected voids (pores) in the sand, and by the frequency of joints, fractures, and bedding plane openings.

Groundwater is found in joints and solution passages in limestone. Groundwater is found in joints and fractures in volcanic rock, lava tubes, interflow zones, voids in cinder beds, or alluvial deposits (deposited by running water) between lava flows.

Small amounts of groundwater may be obtained from jointed or fractured zones of dense, hard rock. Joints, fractures, and lineaments stand open in such rock at depths of less than 300 feet. Lineaments can be extensive surface features or a linear topographic feature of regional extent that may reflect crustal structure (e.g., fault lines, aligned volcanoes, and straight stream reaches).

Fine-grained (primarily silts and clays) sedimentary formations and sands or gravels with clay fines are relatively impermeable. These do not yield appreciable amounts of water to wells; although, occasionally water is obtained through open fractures, joints, or lineaments. These materials frequently form confining layers over more permeable materials.

(b) Aquifers in the continental United States

General information about groundwater and aquifers in the United States is available from the U.S. Geological Survey's (USGS) National Atlas of the United States (USGS 2011) (fig. 12–3) *(http://www.nationalatlas.gov/index.html).*

The USGS has delineated significant groundwater provinces of the United States (fig. 12–4) (USGS 1984) *(http://pubs.usgs.gov/wsp/2242/report.pdf)*, based on the areal extent of important water-bearing formations. The provinces are described in detail therein.

State geological surveys may also have more detailed groundwater maps and other information about groundwater resources.

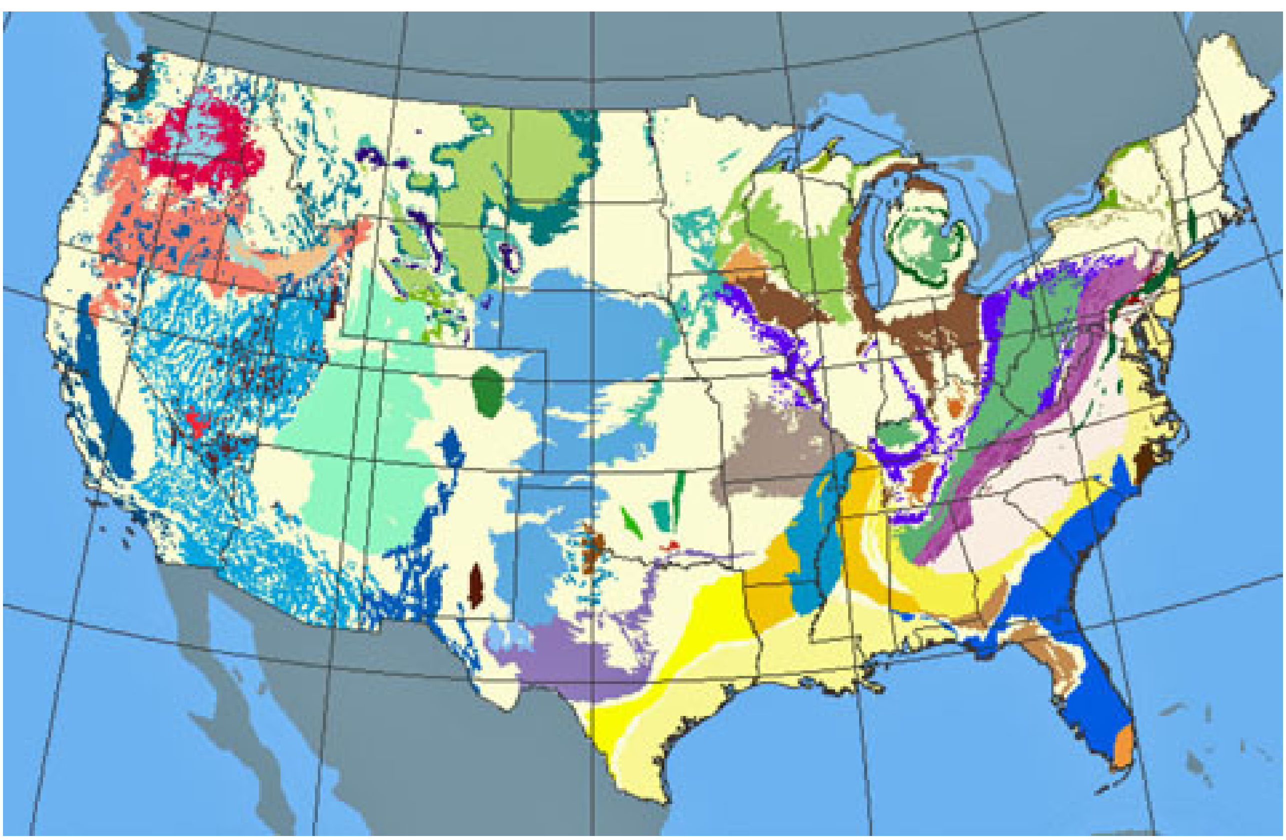
(c) Effects of geologic structure

Some structural features or conditions favor the accumulation of groundwater 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 can be caused by differences in water-bearing capability among strata.

Major geologic structures favoring accumulation and retention of groundwater are synclines, grabens, faults, and dikes (fig. 12–5). Minor structural features such as joints, fractures, and lineaments also influence the accumulation and movement of groundwater in

Figure 12–3 Principal aquifers of the United States



rocks. Joints often occur in a predictable pattern and often determine the best depth and location of wells.

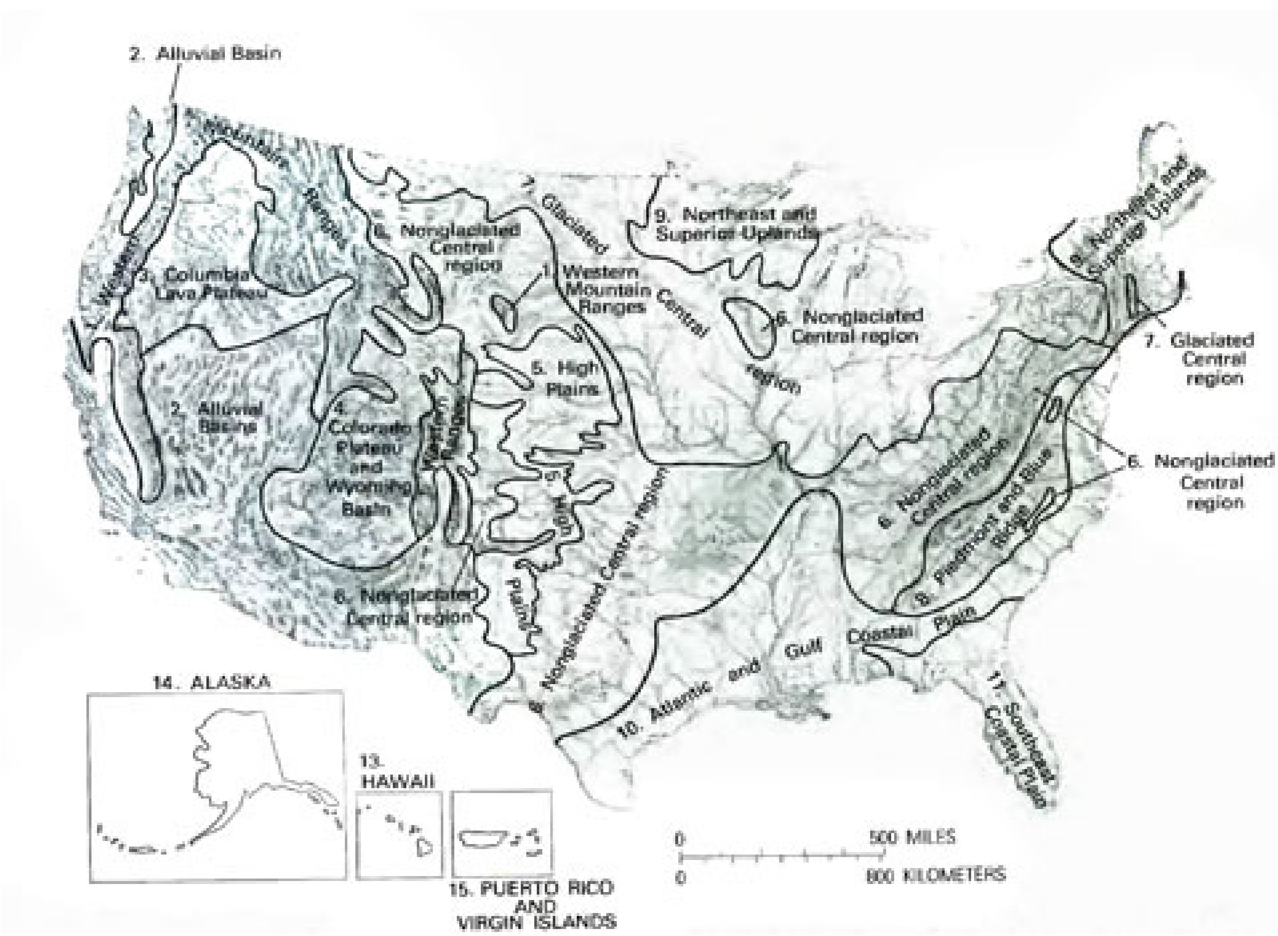
Traps are caused by rock layers, reducing the permeability of an aquifer or completely blocking it. Traps also can result from a change to finer grained deposits, an increase in cementation, or an unconformity. Unconformities, or breaks in the continuity of sedimentary deposition, are common and extensive. They can result in the formation of intermittent aquifers (fig. 12–5) and also introduce doubt in predicting the occurrence of groundwater at specific locations.

(d) Conservation of groundwater resources

With the expanding use of groundwater resources, planners, developers, and users should recognize the need for conservation. A groundwater conservation plan should consider the following:

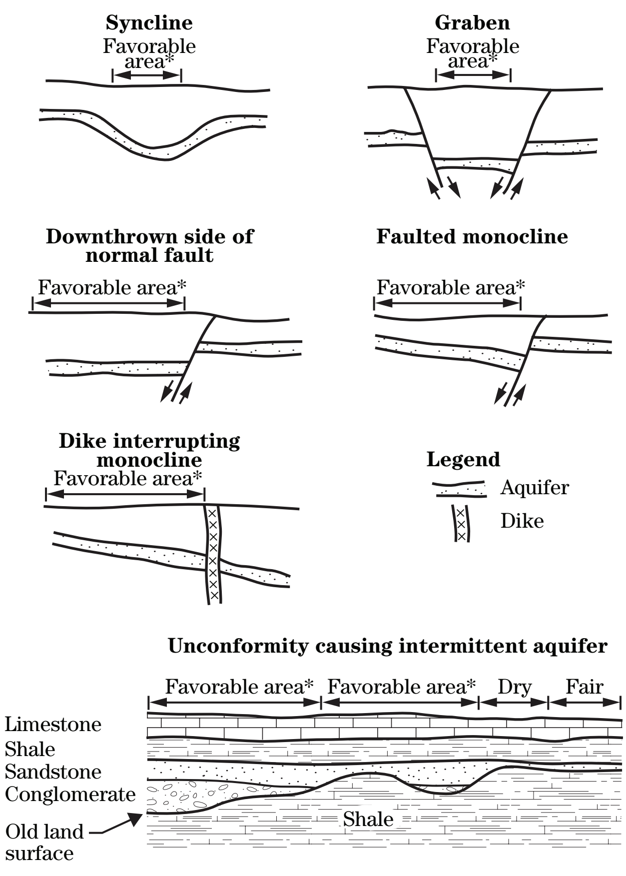
- With two or more aquifers in one recovery system, measures should be designed to prevent cross-contamination.
- Groundwater resources must be protected around livestock waste confinement facilities.

Figure 12–4 Groundwater provinces of the United States



- Uncontrolled discharge from a free-flowing artesian aquifer may waste large amounts of groundwater.
- The conservation program for groundwater development should analyze the amount that is economical to withdraw from the aquifer, the purpose of use, and the expected amount of recharge.
- Locating a new well too close to other operating systems may lower the water table and destroy the existing systems.

Figure 12–5 Effect of geologic structure on groundwater



* Favorable to the accumulation and retention of groundwater

650.1202 Springs and seeps

A spring or seep is a place where water from an aquifer discharges naturally into a surface water body or onto the land surface. Such flow is controlled by either gravity or hydraulic pressure (artesian).

(a) Springs

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.

(1) Gravity springs

Gravity springs result 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 are normally low-yielding sources of groundwater. However, they may supply enough water for individual household or livestock needs.

Gravity springs are of three principal types: depression springs, contact springs, and fracture or tabular springs. Figures 12–6 to 12–10 show the geologic structures for various types of gravity springs.

- A depression spring is formed when the land surface intercepts the water table in permeable material.
- A contact spring is formed when downward movement of water is restricted and deflected laterally to the land surface by a layer of impervious material; for example, the outcrop of a perched water table forms a contact spring.
- Fracture or tabular springs are formed when water emerges from fractures or joints in rock, from solution channels in limestone or gypsum, or from natural tunnels in volcanic rock.

Figure 12–6 Depression spring, seepage or filtration type

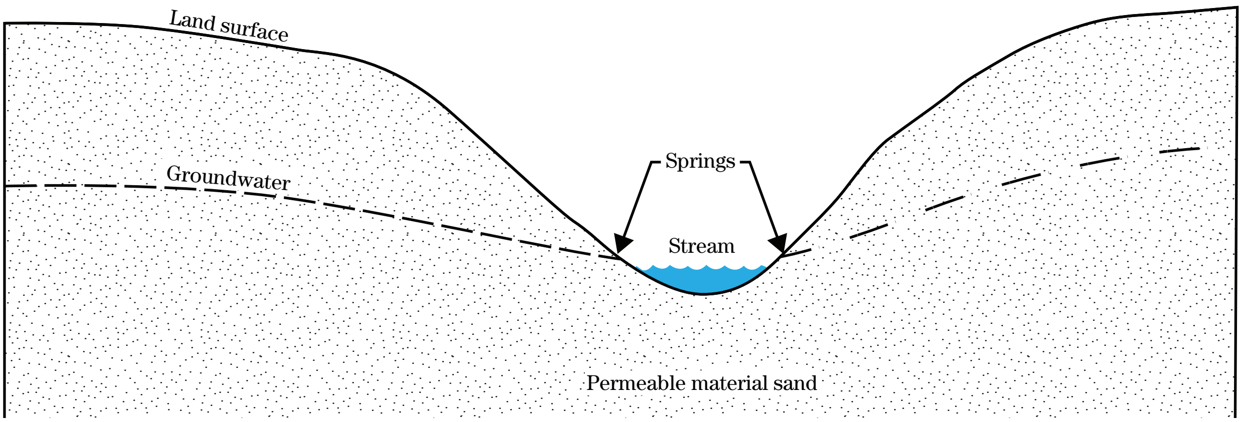


Figure 12–7 Typical contact spring

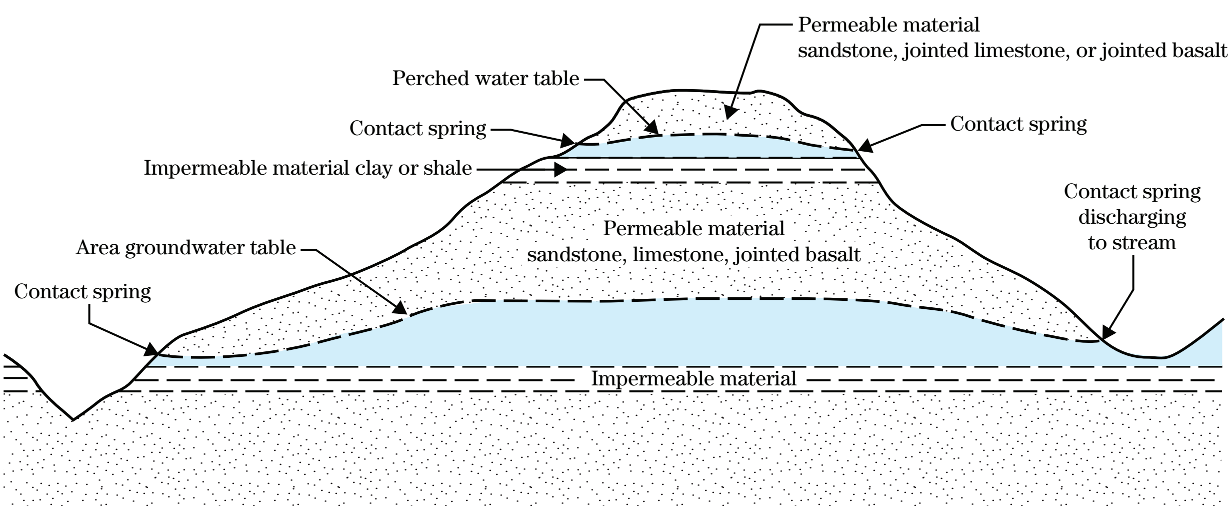
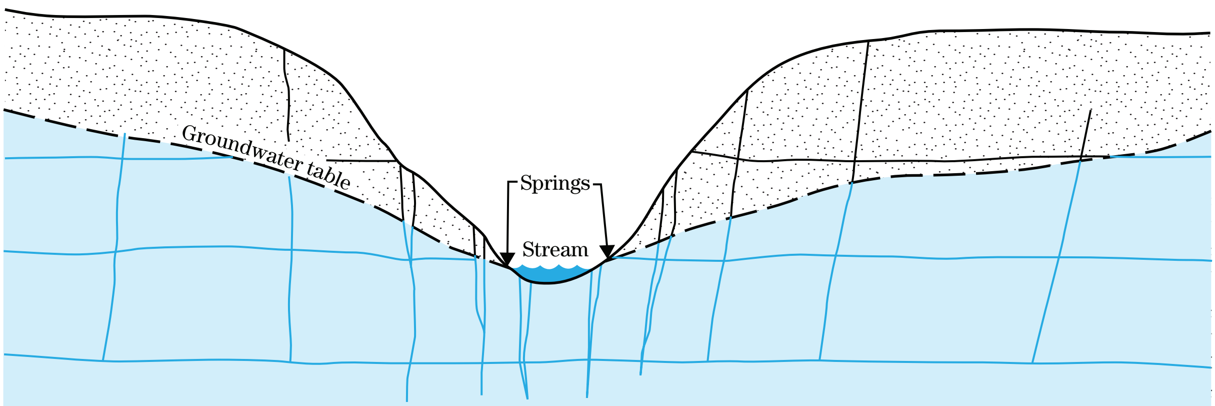
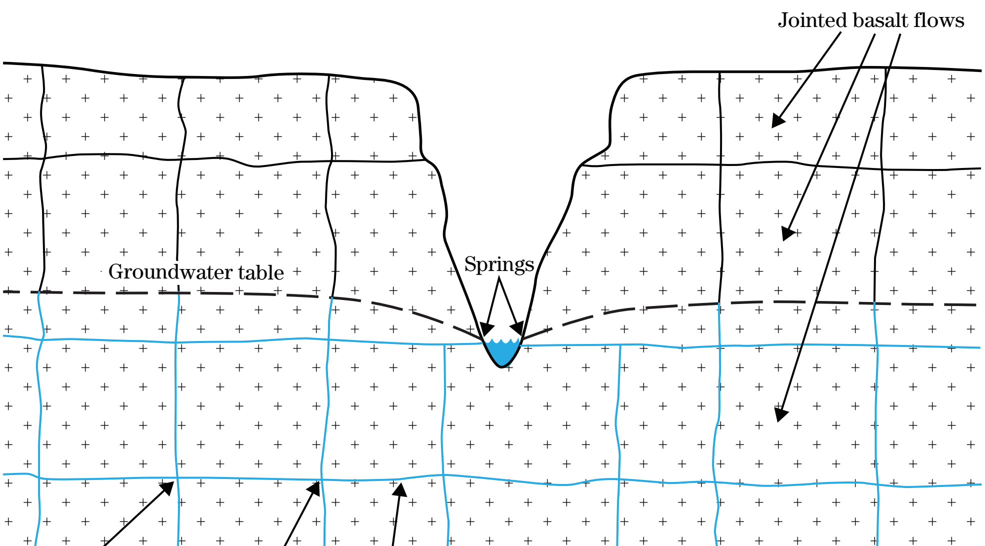


Figure 12–8 Springs in jointed sandstone



Groundwater mainly in joints, fractures, and along bedding planes in sandstone

Figure 12–9 Springs in jointed basalt



(2) Artesian springs

When a water-bearing bed is confined between relatively impervious strata and water is introduced from a higher elevation, the confined water is said to be under artesian pressure. Artesian springs occur where these confined permeable strata are exposed near the surface (fig. 12–11). Springs may also occur where the confining formation over the artesian aquifer is ruptured by a fault or where the aquifer discharges to a lower topographic area. The flow from these springs depends on the difference in the recharge and discharge elevations of the aquifer and the size of the openings transmitting the water. Artesian springs can be sensitive to the pumping of wells located nearby.

(b) Seeps

A seep does not have a defined outlet but zones where seepage emerges, which can be developed like a spring, capturing and funneling the water to a point of use.

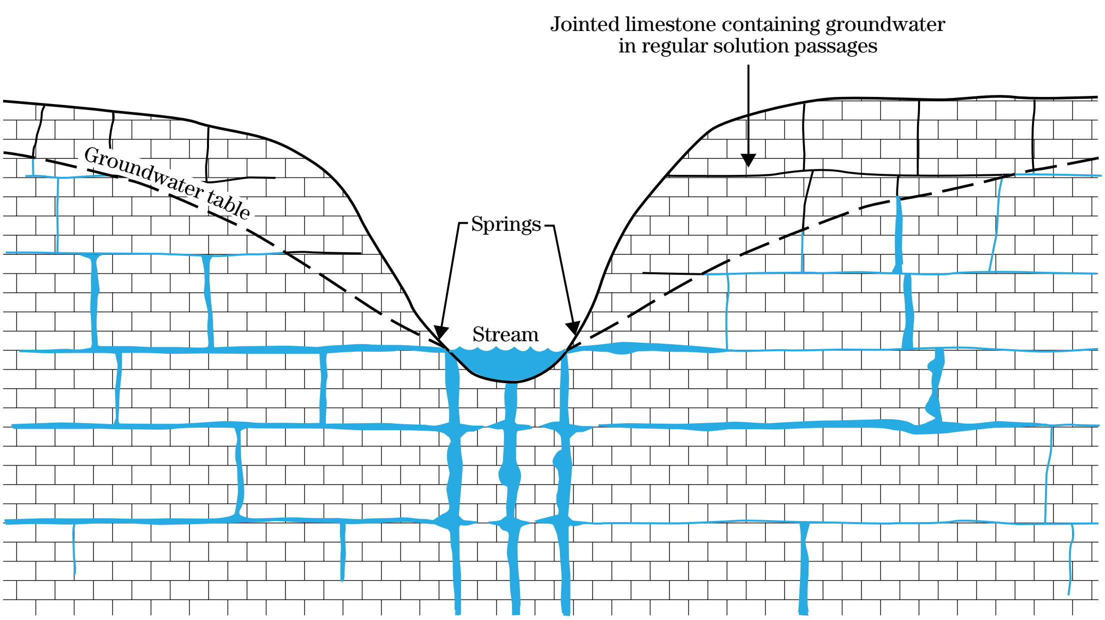
(c) Spring design

Existing information should be collected to determine feasibility and potential for development for water supply, such as:

- existing spring and well locations and yields
- current hydrologic conditions (precipitation and departure from normal)
- USGS and State geological survey investigative reports
- copies of well drillers' logs for wells in the vicinity or in aquifers of interest
- interviews with well drillers who have done work in the area
- county soil survey report and interpretation data, and general description of geologic conditions
- map showing groundwater development sites and including the geologic situation of each site
- groundwater contour maps or structural contour maps of known aquifers
- geology reports from previous investigations

In developing springs or seeps, it is necessary to select a spring that can provide the required quantity and/or quality of water for the intended use, protect it so that it can be used without excessive maintenance, and determine that it will meet all NRCS requirements.

Figure 12–10 Springs in jointed limestone



(1) Planning and investigation

Spring flow may vary significantly throughout the year. The investigation should determine the range of flows and the nature of the water-bearing material and the hydrogeologic conditions that create the spring. The assessment should determine if the spring development will affect ecological functions. Water rights and other necessary permits should be acquired before spring development. Also, conduct a wetland determination and cultural resources assessment.

If the investigation shows that a spring site could be developed, a plan for use should be prepared with the user before making design and construction details. Possible sources of contamination from barns, feedlots, septic fields, and other zones of saturation should be identified in relation to the direction of groundwater flow.

Methods of developing gravity springs normally involve removal of obstructions, collection of flow, and drainage of more of the water-bearing formation if more volume is required.

Artesian springs can be developed by any of the methods for gravity springs, as well as by lowering the outlet elevation.

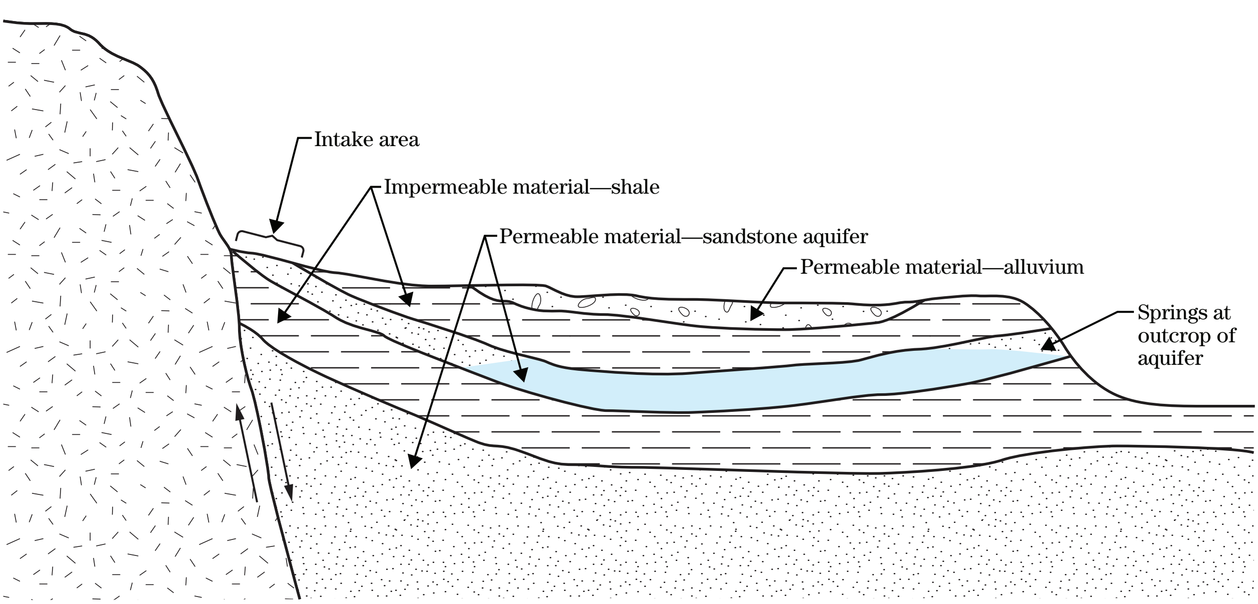
(2) Removing obstructions

Deposits of fine-grained materials (sand, silt, or clay) brought to the outlet by groundwater can obstruct spring flow, as can slope-wash materials deposited on the outlet. Vegetation growing in or around the outlet can obstruct flow and consume water. Removing obstructions usually adds appreciably to the spring flow.

If spring water carries sediment to the opening, a filter or sump may be needed. A sump should be located below the spring so that the sediment will not build up over the outlet between periodic cleanings and should be designed to facilitate cleaning by sluicing if possible. Diversions may be used to carry harmful surface drainage away from the spring area. If the collection of several small flows is planned, use covered galleries or drains to avoid the need to clean and maintain diversions.

The flow of small springs can be reduced substantially by the transpiration of plants. Plants can be removed mechanically or controlled with herbicides. Care must be exercised with either method. The herbicides could contaminate the spring. Mechanical removal may expose large areas of bare, erodible earth, and the resulting sediment may impair the spring opening or downstream areas unless suitable vegetation is established.

Figure 12–11 Artesian springs at outcrop of aquifer



(3) Collecting flow

Collecting the flow from several openings or seepage areas from an outcrop of water-bearing material may be the only practical method for development. If water flows from fractures, the individual openings should be cleaned and the water collected in a perforated pipeline or gravel-filled ditch (French drain) graded to a central sump or spring box.

In collecting water seeping from permeable material, the ditch or tunnel should expose 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.

The flow of depression and contact springs may be increased by excavation to drain additional portions of the aquifer. Such excavation can be either by ditches or tunnels, depending on the topography at the spring, and the characteristics of the water-bearing and underlying materials.

If the spring is on gently sloping or nearly level terrain, a ditch along the outcrop of the water-bearing material is usually the most economical method. The ditch should be dug to intercept as much of the water-bearing zone as practical.

(4) Lowering outlet elevation

This method can improve the flow of springs supplied by an extensive system of channels in rock 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 great, lowering the outlet elevation may produce a substantial and long-lasting increase in flow. If the volume of water is limited, the increase in flow may be only temporary. The supply source should be characterized before the outlet is lowered.

(5) Construction techniques

Previous local experience may be the single most important factor in developing a spring. The method of development chosen should be based on characteristics of the spring, such as topography, nature of the water-bearing material, type of spring opening, volume of flow, and seasonal or yearly variations in flow.

The use of explosives in spring development is not recommended. The shattering and dislocation of rock from blasting may cause the existing flow to cease or to move to another location.

A spring box and pipeline are the most satisfactory means of delivering water to the point of use. The spring box, or collecting basin, should be designed and located so that water does not pond over the spring openings. Ponding above the spring openings reduces spring flow and may cause seeps to change their path of flow. Sketches of a typical spring collection system, spring box, and pipe arrangement are shown in figures 12–12 through 12–14. The collection system shown is suitable for developing a seepage or filtration spring (fig. 12–6) or a contact spring (fig. 12–7).

Spring box—A spring box may be constructed in the apex of the V-shaped headwall as shown in figure 12–12. A spring box provides a settling basin for sediment removal and facilitates maintenance of the spring. If a spring box is used with a collector system as shown, the upper wall should have openings located so that all the water collected can enter the box.

Satisfactory spring boxes can be constructed of concrete, sections of galvanized metal or concrete pipe, HDPE pipe, or other prefabricated materials. Wooden spring boxes should be made of redwood or treated lumber, if permitted for the intended use. For springs not requiring a collector system, the upper wall of the box can sometimes be omitted. The spring box should have a tight-fitting cover. The entire development should be covered with earth to a depth that prevents freezing, and the disturbed area should be revegetated and protected from livestock, wildlife, or vehicular traffic (figs. 12–13 and 12–14).

Collector—The collector can consist of perforated pipe laid in graded small gravel or graded sand (fig. 12–13), or it can be a ditch backfilled with graded, small gravel or graded sand. A hydraulic analysis should be done to properly size pipes. When installing a collector in permeable material, construct a cutoff wall of clay, concrete, sheet piling, or other impervious material in the downhill side of the trench. The cutoff should extend down to impervious material to intercept the water and cause it to flow to the point of collection. Under some conditions, sand points can be driven into saturated material to serve as collectors.

Figure 12–12 Spring development in stream channel

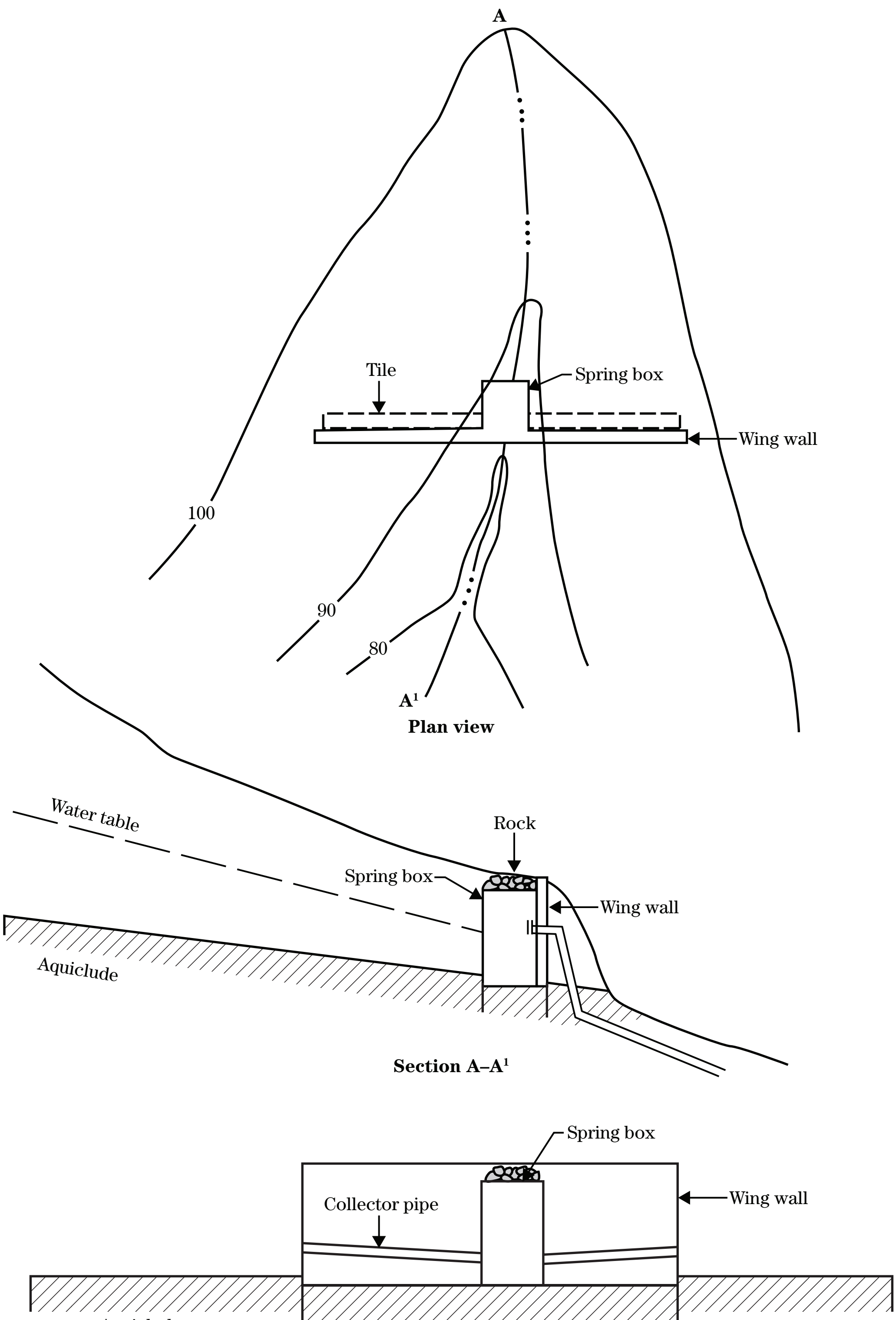
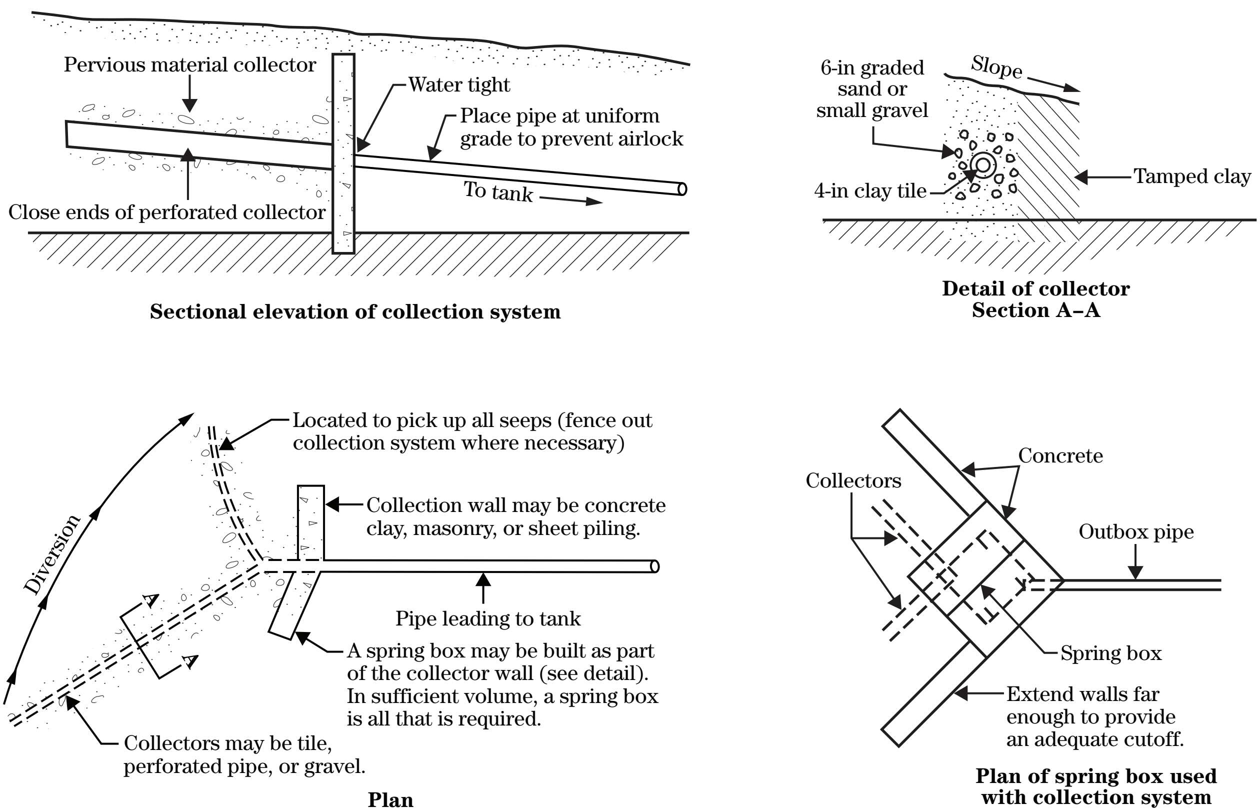


Figure 12–13 Spring collection system



Sectional elevation of collection system

Detail of collector Section A–A

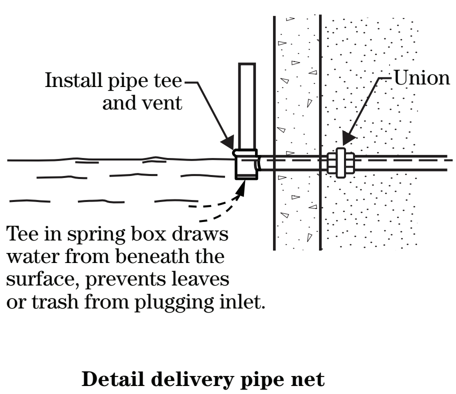
Plan

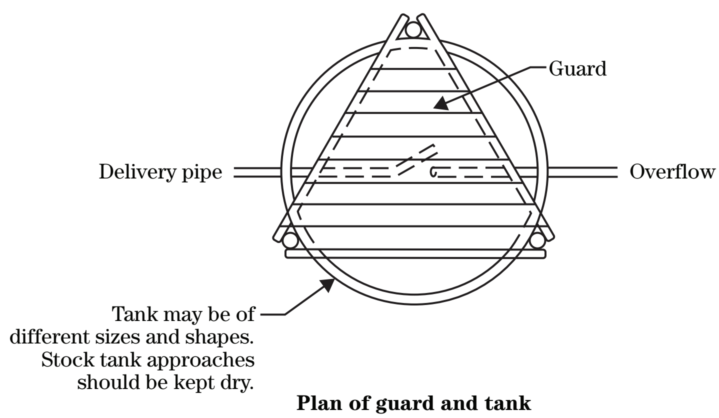
Plan of spring box used with collection system

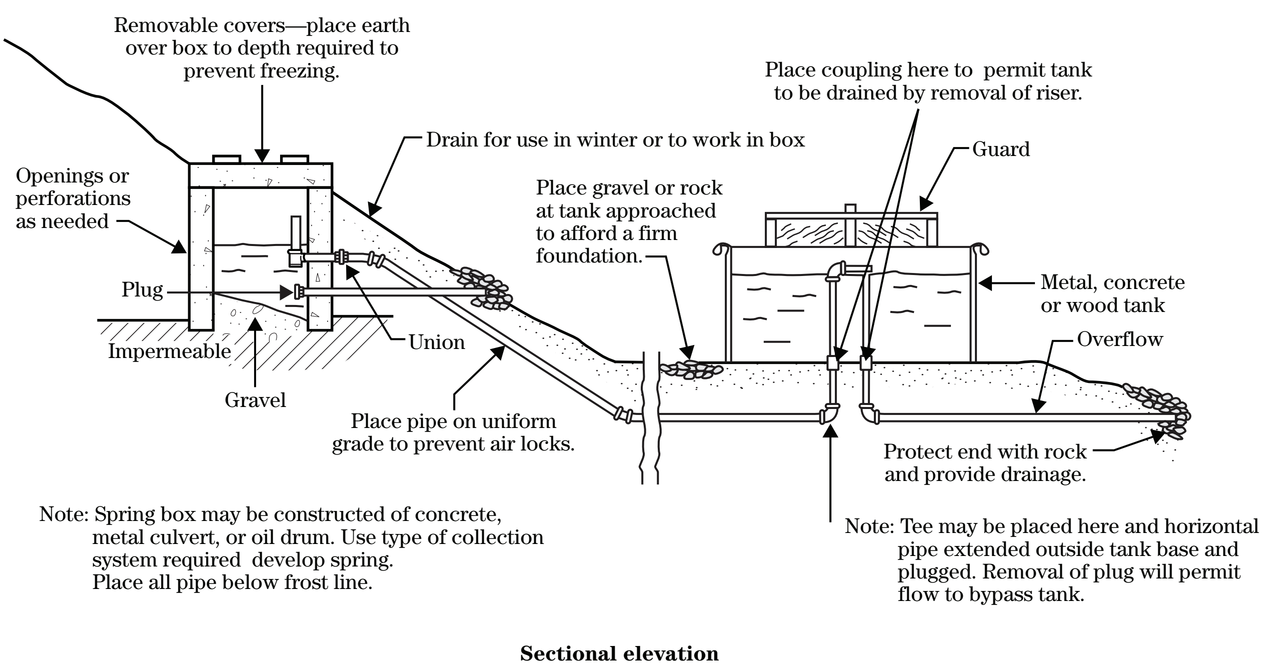
In plan view, the headwall or cutoff is usually constructed as a large V with the apex downhill and the wingwalls extending into the hill to prevent water from escaping. If concrete is used, the wall should be 4 to 6 inches thick. Masonry, sheet piling, plastic, or clay may also be used for the headwall, which should extend deep enough to prevent underflow.

Protection—Springs are frequently at locations susceptible to flooding. The spring and its appurtenant structures should be protected to permit use without continual maintenance. Diversions may be needed. The spring itself can be developed so that flood flows passing over the top do not cause damage. A concrete retaining wall, or wing-wall, properly constructed and located prevents channel degradation and dewatering of the spring aquifer. A spring box with a steel or concrete lid placed below the top of the concrete wingwall and protected by a debris basin of rock and gravel is adequate flood protection. The pipeline should be extended far enough down the valley to avoid flooding of the watering tank. This type of development is illustrated in figure 12–12.

Figure 12–14 Spring box and pipe arrangement







(6) Delivering spring water by gravity flow

An important part of the spring development is the arrangement of the delivery and overflow pipe layout (fig. 12–14). Pipelines can be of plastic, copper, or galvanized iron. When water is to be used for human consumption, the State health department requirements for materials and installation must be met. Pipe with a minimum diameter of 1.25 inches (inside diameter (ID)) should be used where the grade is over 1 percent.

Where the grade is between 0.5 percent and 1.0 percent, a 1.50-inch (ID)-minimum-diameter pipe is recommended. Grades under 0.5 percent require a 2.0-inch-minimum-diameter pipe. Grades less than 0.2 percent are not recommended. If pipe of the recommended size cannot handle the flow, the size should be increased or an overflow provided. See NEH650.03, Hydraulics, for additional information on waterline sizes and capacities. Cleaning may be made easier by placing “Ts” or “Ys” with plugs at strategic points in the pipelines. See CPS Code 516, Pipeline.

The pipe should be laid on a straight, uniform grade, since high spots create air locks that may stop the flow or reduce its velocity. See also “Understanding Gravity-Flow Pipelines: Water Flow, Air Locks, and Siphons,” British Columbia, Ministry of Agriculture and Lands, (*http://www.agf.gov.bc.ca/resmgmt/publist/500Series/590304-5.pdf*). Vents should be installed to improve flow in long delivery lines or at major changes in grade. Pipes should be laid below the frost line and covered to prevent freezing.

The inlet to the pipe leaving the spring box should be placed at least 6 inches above the floor to provide a sediment trap. A watertight connection should be made where the pipe leaves the spring box or goes through the cutoff wall. A tee and vent pipe should be installed on the pipe within the spring box to reduce plugging by leaves or trash, or the entrance to the pipe should be screened.

The pipe can be connected to the water tank in a number of ways. Bringing the pipe under the tank and vertically through the bottom is the most desirable way if the tank is to be used during freezing weather. The inlet and outlet pipes should be fairly close together near the center of the tank. Water may freeze around the edge of the tank, but it will tend to stay open at the center. Figure 12–14 shows a good method of bringing the delivery pipe into the tank and bypassing the flow.

(7) Pumps

If the outlet of the spring is lower than the point of use, a pump will be needed to deliver the water supply. Refer to the NRCS Energy Self Assessment Web site for guidance on selection and design of pumps and energy sources (*http://www.ruralenergy.wisc.edu/default.aspx*).

Hydraulic rams—A hydraulic ram is an automatic pump operated by water power. It 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 12–15a shows a typical hydraulic ram in cross section, and figure 12–15b shows the general configuration of a hydraulic ram used for a stream development.

The volume of water that a ram can pump depends on the fall between the supply and the ram, the height the water is to be raised from the ram to the reservoir, and the quantity of water available. If the water supply is limited, a ram must be selected that will operate with the minimum quantity of water available. If the water supply is ample, the ram size is governed by the quantity of water needed daily.

Manufacturers build rams that operate successfully on flows of 1.5 gallons per minute or more with at least 2 feet of head.

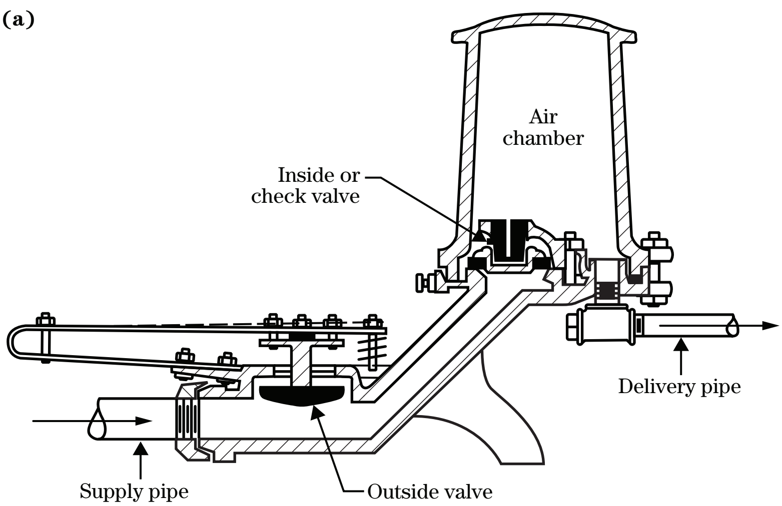
The number of gallons of water delivered per minute to a given point can be estimated with the following formula:

$$D = \frac{VFe}{E}$$

where
- D = volume in gallons per minute that the ram will deliver
- V = water supply available in gallons per minute
- F = fall in feet between the water supply and the ram
- E = vertical elevation in feet that water is to be lifted above the ram
- e = ram efficiency (use 0.6 in the absence of specific data)

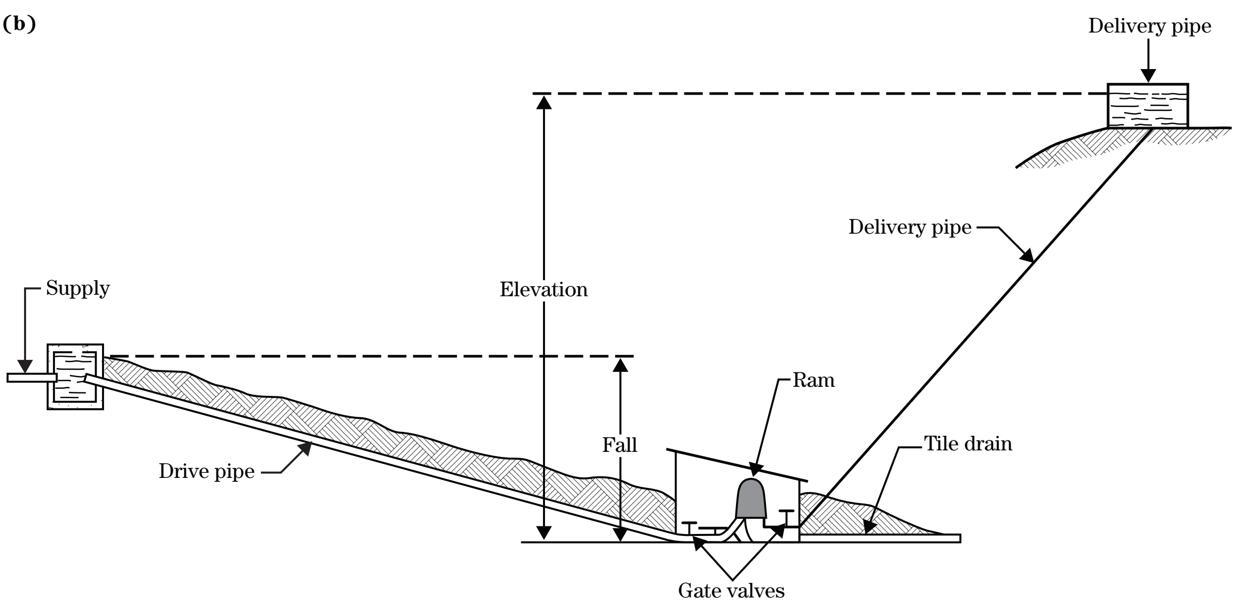
Figure 12–15 Hydraulic ram cross section

(a)



Diagrammatic sketch of ram

(b)



Sketch of typical ram installation

To determine if a ram is practical, collect the following information:

- number of gallons per minute that the spring, artesian well, or stream, will deliver
- number of gallons per day desired from the ram
- available fall, in feet, from the water supply to the ram
- elevation, in feet, to which water is to be raised above the ram
- pipeline distance, in feet, from the ram to the point of discharge
- pipeline distance, in feet. from the source of water to the ram

Windmills and wind turbines—Windmills can power pumps for water for livestock or domestic use, either by mechanic lift or by generation of electricity to power an electric pump. Contact the NRCS State conservation engineer for current design criteria for windmills and turbines. Prevailing wind velocities and direction are key criteria, as well as the potential power delivered.

Electric motors—Where available, electricity can be used as a power source for pumping water. Advantages of electric motors are their reliability, efficiency, low maintenance cost, and easy adaptation to automatic control. An electric motor will deliver full power throughout its life. Disadvantages are cost of construction, cost of power, 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.

Photovoltaic cells—Solar power can be used to power water pumps if suitable arrays can be deployed and provide enough power for the design needs. Power storage and alternate power sources are additional criteria that must be met if photovoltaic arrays are employed. Technical guidance for design of solar-powered systems can be obtained from the NRCS State conservation engineer. An example guide is the NRCS Technical Note No. 28, Design of Small Photovoltaic (PV) Solar-Powered Water Pump Systems (*http://www.or.nrcs.usda.gov/technical/engineering/environmental_engineering/data/SolarTechNote100929.pdf*).

Internal combustion engines—The rated power of internal combustion engines greatly exceeds the power that they can be expected to produce on a sustained basis. The kind of fuel, accessories, and cooling system used, as well as air temperature and altitude, must be considered in selecting internal combustion engines. The fuel may be gasoline, kerosene, diesel oil, propane, butane, or natural gas. The cooling system may use water or air.

Because altitude and air temperature affect power output, and engine ratings are based on performance at sea level and a temperature of 60 degrees Fahrenheit, corrections must be made for most irrigation pumping installations. General rules for correcting for elevation and temperature are: reduce the continuous load rating 3 percent for every 1,000 feet above sea level, and reduce the continuous load rating 1 percent for every 10 degrees above 60 degrees Farenheit.

In addition to the reductions, the rated power should be further reduced by 5 to 10 percent for consumption by accessories (fan, generator, water pump) and 15 to 20 percent for continuous service.

Air quality and energy considerations—Where possible, use renewable energy or electrical power to run pumps in lieu of internal combustion engines to reduce pollution and operating costs.

(d) Maintenance

With periodic maintenance, a developed spring will provide good quality water for many years. Springs usually become contaminated when barnyards, sewers, septic tanks, cesspools, or other sources of pollution are located upstream in the recharge area. In very permeable formations (gravels, limestone, basalt, etc.), however, contaminated material frequently enters the water-bearing channels through sinkholes or other large openings and may be carried in the groundwater for long distances. These precautionary measures help to ensure consistent high quality spring water:

- Test the water quality before a spring is developed. Install a diversion uphill from the site to intercept surface-water runoff and carry it to a safe outlet.

- Build a fence to exclude livestock from the surface-water drainage system at all points uphill from the spring.
- Provide access to the tank for maintenance.
- 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.
- Disinfect spring encasements by a procedure similar to that used for dug wells. If the water pressure is low enough that water does not rise to the top of the encasement, disinfectant may be held for 24 hours. If the flow cannot be shut off entirely, disinfectant should be introduced continuously for as long as practicable or per State or local requirements.
- Continually check the trough for algae buildup, mudholes, and animal damage. Make necessary repairs or adjustments. Methods to control algae include the use of chemicals (e.g., copper sulfate or chlorine bleach), the use and quantity of which depends on the intended water use. Ultrasonic methods can also be used to prevent algae buildup.

650.1203 Wells

A well to extract groundwater consists of a hole, with or without a supporting casing, extending from the ground surface to or into water-bearing earth materials. When properly constructed and developed, it will permit extraction of groundwater. If the aquifer is artesian, pumping requirements are less or precluded if sufficient flow is at the ground surface.

(a) Types

Wells are dug, driven, or drilled, depending on their intended depth, the nature of the earth materials, the rate at which water will be removed, and the depth to the groundwater table or the elevation of the piezometric surface for artesian conditions. Figure 12–16 shows a well being used to supply a traveling center-pivot irrigation system.

(1) Dug or open pit

This type of well is usually excavated by hand into a shallow water-bearing stratum. Such wells are prone to surface water contamination.

Figure 12–16 Water well supplying center-pivot sprinkler irrigation system, Idaho

(2) Driven well

A driven well is constructed by forcing a pipe into the ground until it penetrates the water-bearing stratum. This type of construction is limited to shallow depths, usually less than 50 feet.

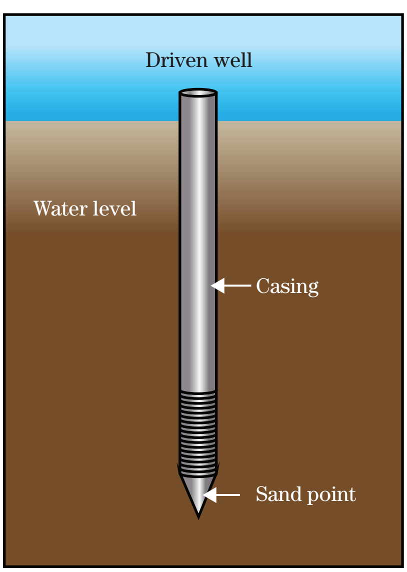
Several methods are used to construct driven wells. The pipe may be fitted with a sand point, which is driven into the water-bearing formation (fig. 12–17). The earth material may be removed from the pipe by a sand bucket or pump, or a hydraulic jet may be used to remove material from the end of the pipe. This type of construction is often used where a battery of wells can be connected to a single pumping unit or where artesian pressure occurs.

“Direct push” techniques may also be employed for shallow wells, using the hydraulic capabilities of drill rigs.

(3) Jetted well

High pressure water delivered through piping may be used to establish a water well. The rods are literally driven through the hydraulic erosion of the earth material and flushing it up to the surface. A drive bit can be combined with the jetting action to break up hard soils or rock formations.

Figure 12–17 Sand point used for small diameter driven well



(4) Drilled well

A drilled well may be constructed through any material and to great depths. Many types of drilling rigs are, in general, used:

- Rotary auger rig uses a cutting bit and receptacle (bucket cylinder or spiral) attached to a drill stem. This equipment is used primarily for exploration wells of shallow depth and small diameter.
- Cable tool rig or “spudder” uses a weighted bit attached to a flexible cable for breaking the material loose and a bailing bucket for removing the loose material from the well. This equipment is generally used for drilling wells 3 to 24 inches in diameter and less than 1,500 feet deep.
- Hydraulic rotary rig uses a bit attached to a hollow drill stem. Water is forced through the drill stem to float the loosened material out of the well. When unstable strata must be drilled through, this equipment relies on the drilling fluid to stabilize these sections until the drilling can be completed and the casing installed.
- Reverse hydraulic rotary rig is similar to the hydraulic rotary rig, but the water is introduced at the top of the well and pumped out through the drill stem, relying on the weight of the water column to hold unstable strata open.
- Air rotary rig has uniform diameter channels rather than water jets, and the mud pump is replaced by an air compressor. Air rotary drills are suitable for drilling through hard rock.
- Sonic (vibratory) drill rig is a large hydraulic rotary rig that cuts through rock with a combination of cutting and high frequency resonant vibrations. This technology also works well in unconsolidated materials and reduces drill cuttings, drilling time, and often minimizes the disruption of bedding, lamina, and material structure. It also reduces sampling time and enables rapid continuous sampling where needed.

Table 12–1 lists various methods of constructing a well and their appropriate application.

Table 12–1 Water-well construction methods and applications

Well construction method	Materials for which best suited	Water table depth for which best suited	Usual maximum depth	Usual diameter range	Usual casing material	Customary use	Yield[1]	Remarks
		ft	ft	in			gal/min	
Driven wells								
Hand, air hammer	Silt, sand, gravel less than 2 inches	5–15	50	1.25–4	Standard-weight pipe	Domestic, drainage	3–40	Limited to shallow water table, no large gravel
Jetted wells								
Light, portable rig	Silt, sand, gravel less than 1 inch	5–15	50	1.5–3	Standard-weight pipe	Domestic, drainage	3–30	Limited to shallow water table, no large gravel.
Drilled wells								
Cable tools	Unconsolidated and consolidated medium hard and hard rock	Any depth	1,500 [2]	3–24	Steel, wrought iron, fiberglass, or plastic pipe[3]	All uses	3–3,000	Effective for water exploration. Requires casing in loose materials. Mud-scow and hollow rod bits developed for drilling unconsolidated fine to medium sediments.
Hydraulic rotary	Silt, sand, gravel less than 1 inch; soft to hard consolidated rock	Any depth	1,500 [2]	3–18	Steel, wrought iron, fiberglass, or plastic pipe[3]	All uses	3–3,000	Fastest method for all except hardest rock. Casing usually not required during drilling. Effective for gravel envelope wells.
Reverse hydraulic rotary	Silt, sand, gravel, cobble	5—100	200	16–48	Steel or wrought iron pipe	All uses	500–4,000	Effective for large-diameter holes in unconsolidated and partially consolidated deposits. Requires large volume of water for drilling. Effective for gravel envelope wells.
Air rotary	Silt, sand, gravel less than 2 inches, soft to hard consolidated rock	Any depth	2,000 [2]	12–20	Steel, wrought iron, fiberglass, or plastic pipe[3]	All uses	500–3,000	Very fast drilling. Combines rotary and percussion methods air drilling, cuttings removed by air. Would be economical for deep water wells.

Table 12–1 Water-well construction methods and applications—continued.

Well construction method	Materials for which best suited	Water table depth for which best suited	Usual maximum depth	Usual diameter range	Usual casing material	Customary use	Yield[1]	Remarks
		ft	ft	in			gal/min	
Driven wells								
Sonic (vibratory)	Soft to hard consolidated rock	Any depth	2,000 [2]	12–20	None in consol. rock	All uses	500–4,000	Rapid hole advance in rock and unconsolidated materials.
Augering								
Hand auger	Clay, silt, sand, gravel less than 1 inch	5–30	35	2–8	Sheet metal or plastic	Domestic, drainage	3–50	Most effective for penetrating and removing clay. Limited by gravel over 1 inch. Casing required if material is loose.
Power auger	Clay, silt, sand, gravel less than 2 inches	5—50	75	6—36	Concrete, steel, wrought iron, fiberglass, or plastic pipe	Domestic, irrigation, drainage	3—100	Limited by gravel over 2 inches, otherwise same as for hand auger.

1 Yield influenced primarily by geology and availability of groundwater.
2 Greater depths reached with heavier equipment.
3 Care must be used in selecting material and designing casings for greater depths. See NEH631.32.

(b) Site selection

The following elements are essential to maximize the potential yield of a site and to document the well's planned use and expected yield requirements:

- a study of the water well successes and failures in the area, including location maps, history, and records of wells
- geologic maps and groundwater availability studies
- history of known contaminants and spills and their locations and potential hydraulic connections relative to the proposed well location
- a study of the geology and groundwater availability is important in obtaining successful wells. These elements are essential:
- an adequate and dependable water source
- sufficient underground reservoir space
- a structure or conditions that act to retain water

It is best to determine whether these elements are present before deciding to drill a well.

The geologic investigation should always include a review of existing information on groundwater. After acquiring the information, the following steps should be taken:

Step 1 Prepare a base map or obtain aerial photographs of the area. The map or photograph should be to a scale of at least 4 inches = one mile (1:15,840).

Step 2 Interview owners of wells in the area.

Step 3 Interview drillers who have worked in the area.

Step 4 Study well logs and notes of other agencies or water specialists knowledgeable about the area.

Step 5 Plot the information acquired on a base map or aerial photograph.

Step 6 Evaluate the chances for obtaining the desired yield and water quality.

If additional information must be obtained, prepare an investigation plan, including:

- the location, depth, and number of test holes
- type of drilling rig
- type of sampling and logs to be kept
- remote sensing tests, using electrical resistivity, conductivity, and seismic methods
- geologic characteristics to be identified

The following should be obtained during the test drilling:

- General information
  - start and completion date
  - name of individual recording drilling data
  - location of hole (georeferenced, include map)
  - drilling method with type of bit, sampling method, mud or fluid type
  - total depth
- name, title, and address of person responsible for the water well
- description of rock characteristics of each stratum
- thickness and depth of each stratum
- drilling characteristics—drilling hard, smooth, fast; bit bounce; mud loss; and bit drop
- time used in drilling each interval
- types of downhole logging
- selected drill cutting and water samples

Aquifer performance testing normally consists of:

- measured static water level depth, date and time recorded, and method of measurement
- the construction of a test well and sometimes observation wells
  - depth of water well
  - length of casing and screening
  - length of stick-up above ground surface
  - inside diameter of well bore or casing

- type of casing material or ASTM material schedule and joint type (e.g., standard weight steel, PVC Schedule-80)
- screen slot size
- type and length of filter material
- sealing material and grout (e.g., bentonite, cement, or admixtures) and quantities used

- a pumping test to show the time, drawdown (distance from the static water table before pumping to the water level in the casing during pumping), and distance-drawdown information
- a pumping test to determine step-drawdown depths
- determining the time required for water level recovery after pumping

Test results are used for:

- determining dependability of storage volume and recharge characteristics
- defining the yield-drawdown relationship, or the well's specific capacity
- analyzing formation samples
- analyzing the water quality for corrosion and encrustation potential, and overall chemical quality for the intended use
- identifying aquifer characteristics

(c) Hydraulics

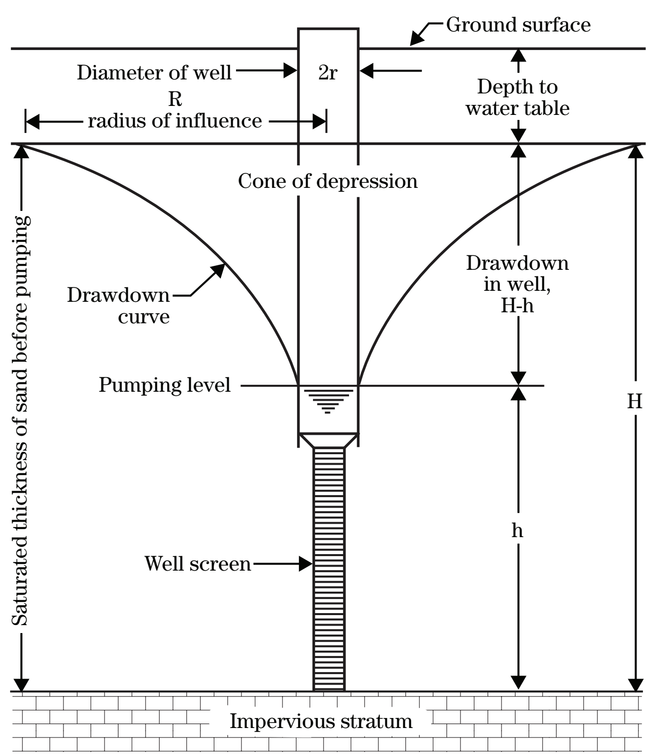
For a well to yield a high rate of flow, the water must move in large volumes through the aquifer into the well. Entrance velocities should be as low as possible. See section 650.1203(d)(5)(i) for information on well screen design. See CPS Code 642, Water Well, for current criteria. Figure 12–18 shows a typical well in two dimensions. Realize, though, that groundwater movement into a well is radial, as well as three-dimensional.

The flow from an aquifer into a well requires a change in water level and in energy measured from that of the static water level. The slope of this change is steepest near the well and determines the cone of depression (figs. 12–18 and 12–19). The dimensions that the cone develops depend on the pumping rate, the time since pumping started, the transmissibility, and the storage coefficient. The cone of depression will continue to expand until the recharge of the aquifer equals the pumping rate. Recharge occurs and stabilizes when the cone enlarges to intercept enough of the aquifer's natural recharge or a body of surface water, or until there is enough precipitation on the area above the cone of depression or leakage through overlying or underlying formations.

When the recharge rate does not equal the pumping rate, the cone of depression grows in depth and width, and yields for the pumping depths may become uneconomical. Another factor is that the cone of depression may expand and intercept the cone of another pumping well, resulting in well interference and loss of efficiency. Whether a favorable recharge is occurring can be determined by measuring the drawdown level in a producing well and an observation well and by studying the changes of the drawdown depths over time.

Figure 12–19 shows the position of the static water level and the shape of the cone of depression that

Figure 12–18 Diagram showing terms used in the water-table aquifer formula



develops around a pumping well. It also illustrates features and terms commonly used in well design and construction.

(d) Design

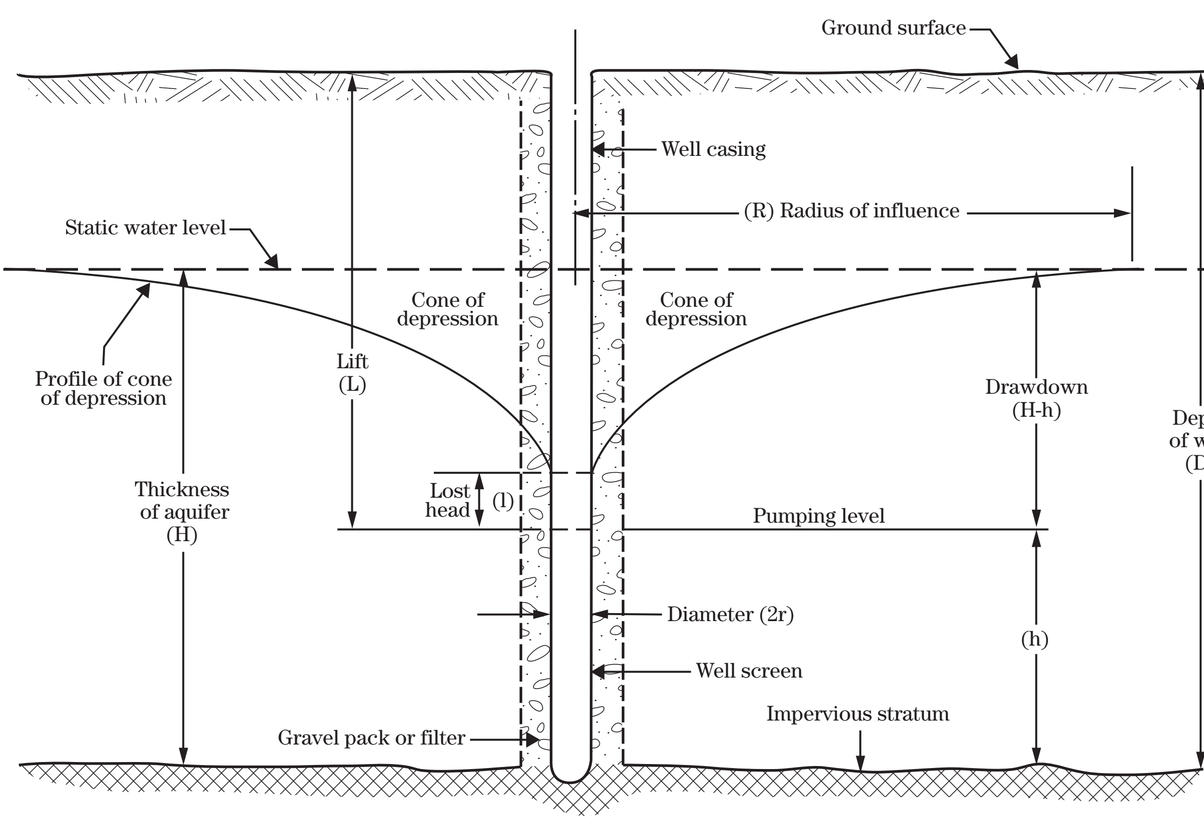
Information needed in designing a well may best be obtained from study of logs and sieve analyses of samples from test holes. The samples must be representative of the aquifer materials. See section 650.1203(b), Site Selection, for items to be observed. If no test holes have been drilled, records of nearby wells will be helpful. If no wells have been drilled in the area, a geologic report on the site will provide the best basis for design decisions.

The following design decisions are influenced by geologic, engineering, and economic considerations, as well as by standards' requirements:

- drilling method
- earth materials
- diameter and depth of hole
- position, size, and number of casing perforations
- need for a well screen
- need for a gravel envelope
- choice of well development method

A well must be designed to fit site conditions. A properly designed and constructed well is a conservation practice. The design information for a well should be

Figure 12–19 Typical irrigation well in unconsolidated materials (see App. A, Glossary) for definition of terms



documented. Figures 12–20 and 12–21 show the minimum information that should be recorded. Note that State and local requirements and criteria may differ. See CPS Code 642, Water Well.

Sometimes final decisions must be made as the well drilling proceeds. Methods of analyzing essential information to design the most efficient well are given in the NEH631.32.

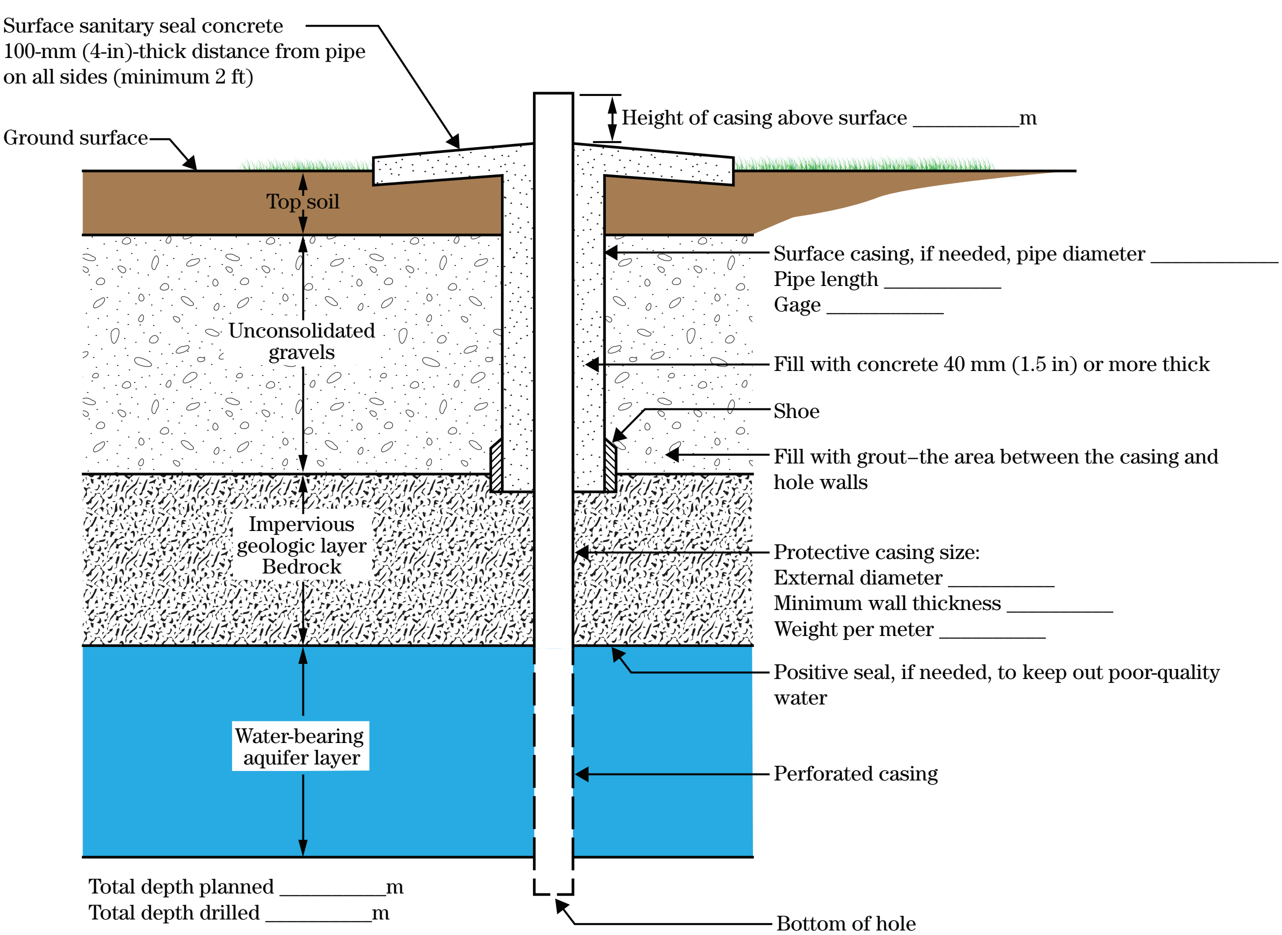
For design purposes, a well is analyzed in two parts: the cased section and the intake section. Before the actual design is started, prepare a design outline that includes the amount of water required, annual pumpage and duration, economic life of the well, type of production system, type of well, materials to be used in the well, and cost estimates for installation, pump, well materials (screen, casing, etc.), testing, and well development.

(1) Capacity

Before selecting a casing diameter, pump size, screen or slot size, the potential well capacity or yield must be known.

These factors affect the capacity of a well in unconsolidated sand or gravel formations.

Figure 12–20 Documentation of water-table well design



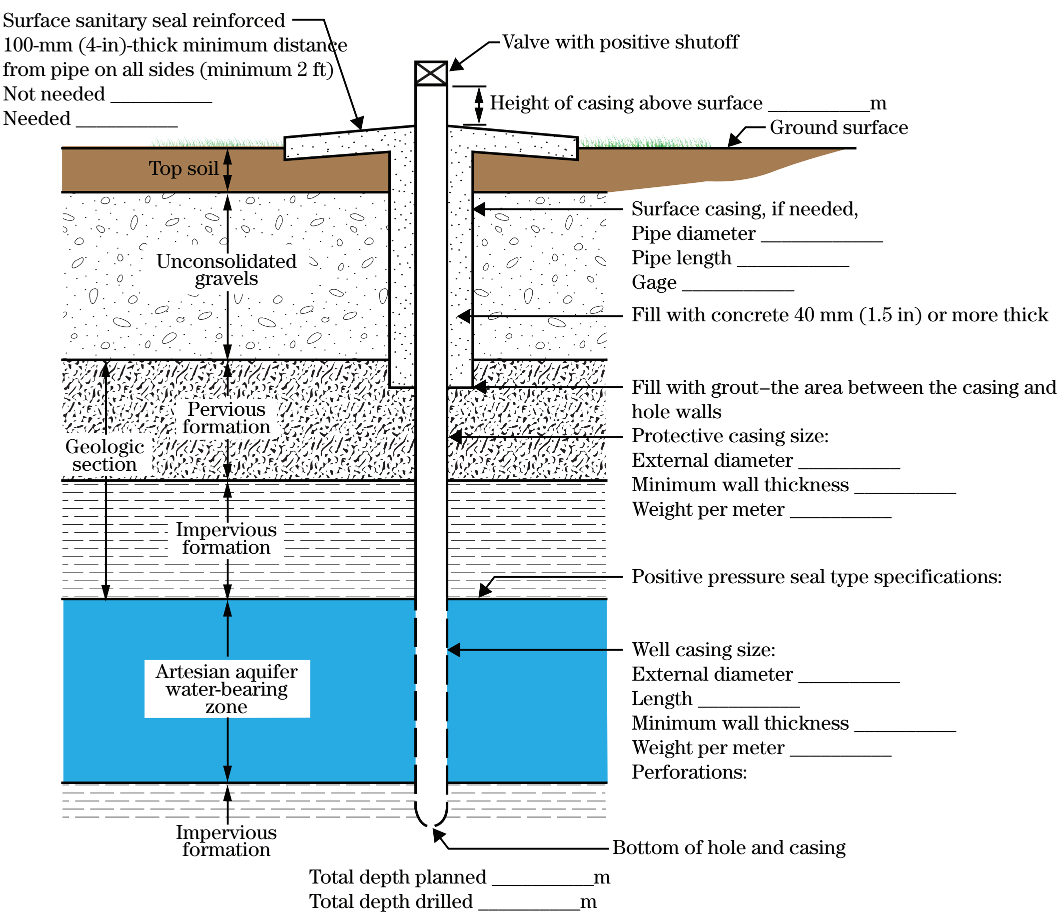
Physical characteristics—Physical characteristics that influence well capacity are size, porosity, and uniformity of the water-bearing materials. Generally, sands suitable for irrigation development have a porosity of 20 to 40 percent of the volume of the water-bearing material. A uniform sand has greater porosity and more water-bearing capacity than a nonuniform sand.

Depth of water-bearing formation—The depth from the static water level to the bottom of the well or the impervious stratum determines the amount of drawdown that a well can have. Drawdown influences the slope and velocity of the water approaching the well and helps determine the 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 on the outside of the casing. See figures 12–18 or 12–19.

The following formula may be used to predict the capacity for any desired drawdown or the drawdown for any desired capacity of a well, if the discharge and drawdown are known for a given condition:

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

Figure 12–21 Documentation of artesian well design



where:
Q = measured well capacity at known drawdown depth
Q_1 = well capacity at desired drawdown depth
H = saturated thickness (static head) of water table aquifer
h = depth to static drawdown level in well during pumping
h1 = desired static drawdown level in well during pumping

For example: 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 would be:

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

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

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

$$Q_1 = \frac{850\left(2{,}500 - (25)^2\right)}{2500 - (16)^2}$$

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

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

Extent of water-bearing formation—The extent of the formation influences the total quantity that may be pumped. If the water supply is blocked off on one or more sides, the quantity pumped is naturally less than unrestricted flow.

Diameter of well—The diameter of the well is more important in allowing proper pump installation than in determining the well yield. Doubling the diameter of a well increases the capacity by only about 13 percent.

Effectiveness of screen or casing—The open area of casing perforations or well screen needs to be considered in determining well capacity.

Computing probable capacity—Discharge formulas for equilibrium conditions have been derived for water table aquifers and artesian aquifers. Each formula is based on the assumption that recharge is at the periphery of the cone of depression (fig. 12–19).

The formula for capacity of a water table aquifer is:

$$Q = \frac{K\left(H^2 - h^2\right)}{1{,}055 \log R/r}$$

where
Q = well capacity or pumping rate, gal/min
K = permeability of aquifer, gal/d/ft^2
H = saturated thickness of the aquifer before pumping, ft
h = depth of water in the well while pumping, ft
R = radius of the cone of depression, ft
r = radius of the well, ft

A properly constructed well in a water table aquifer should yield about 90 percent of its capacity when the drawdown is about two-thirds of the depth of the static water level. The radius of influence for an average well of 12 to 18 inches in diameter is between 200 and 1,000 feet.

The quantity of available water moving into a well increases rapidly as the aquifer grain size increases. The effective diameter of sand, the D_{10} size, can be determined by screening samples of the aquifer formation. The porosity percentage can be estimated 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.

The formula for capacity of an artesian aquifer (fig. 12–22) is:

$$Q = \frac{Pm\left(H_2 - h_1\right)}{528 \log R/r}$$

where:
Q = gal/min
P = permeability of the water-bearing sand, gal/d/ft^2

m = saturated thickness of artesian aquifer, ft
H = static head (or depth) of water in well measured from bottom of aquifer, ft
h = depth of water in the well while pumping, ft
R = radius of the cone of depression, ft
r = radius of the well, ft

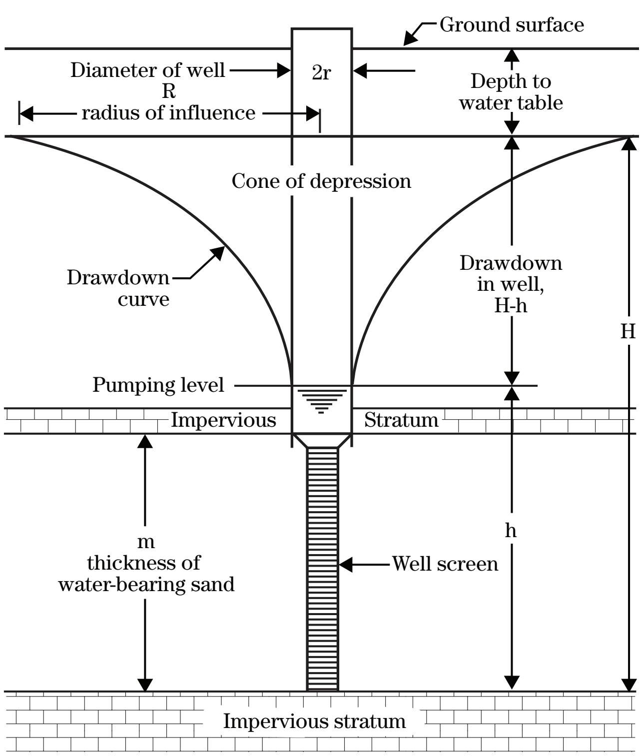
Permeability of an artesian or water table aquifer must be determined from laboratory or field tests.

The cavernous-formation aquifer supports an ideal well if the underground supply is adequate and recharge is rapid. Water enters the well at the bottom of the casing and is pumped. The yield is limited only by the supply and recharge of the underground reservoir. No well screen is required.

A sandstone-formation aquifer is usually a low producer per unit of depth; it may produce only about 1 gallon per foot per minute. However, if cracks or crevices are frequent, wells in this formation may produce up to 5 gallons per foot per minute.

Specific capacity—A water well's overall performance can be expressed in terms of specific capacity, which is simply the well's pumping rate (gpm) divided by the drawdown depth in the well (ft) or gallons per minute per foot. The specific capacity integrates all of the variables that affect water yield, including the aquifer characteristics and the 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.

Figure 12–22 Diagram showing terms used in the artesian aquifer formula



(2) Diameter

In determining the diameter of a well to be installed, the following items should be considered:

- the diameter necessary for installing a pump able to lift the maximum amount of water to the projected elevation with the best pumping efficiency
- the yield capacity of the aquifer
- aquifer characteristics

The relationship between well diameter and yield is not proportional and depends on numerous factors. For unconfined aquifers, table 12–2 shows the approximate increase in yield by changing the diameter of the casing. For artesian aquifers, the increased yield is about half that shown in the table.

Factors such as depth, pump characteristics, layout, and method of developing the well are more important than capacity in determining well diameter. Generally, developing two medium-sized wells, such as a 10-inch or 12–inch well, costs less than developing one large well, such as a 24-inch or 36-inch well. The combined yield of the smaller wells is almost always much greater than the yield of the larger well.

(3) Efficiency

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 percent efficient. However, with good construction and development, up to 90 percent efficiency can be attained.

(4) Cased section

The cased section is the upper part of the well. It includes the hole, the casing, the gravel pack, and sanitary protection. Following are casing considerations.

- The *hole* must be large enough to permit the insertion of casing, gravel pack, and the well stabilizer material. It must be large enough to accommodate the required flow and the necessary parts of the pump to be used. A vertical well should be deep enough to extend to the bottom of the water-bearing strata and should be straight and plumb, which may require the use of centering guides. A well less than 12 inches in diameter generally cannot accommodate a pump large enough to supply sufficient irrigation water. Shallow wells with centrifugal-type pumps are often drilled as a battery of wells connected with a manifold. In this case, the wells are generally drilled 6 to 8 inches in diameter or driven 2 to 4 inches in diameter.
- The *well stabilizer* is material used to fill the annular space between the well hole and the casing and above the intake section. The well stabilizer must have no gaps or bridges. If separation occurs in placing the column of materials, the void could cause the casing to collapse.

Table 12–2 Changes in yield with increase in well diameter

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

- The *casing* is the inner lining of the well that holds the hole open. It also provides a conduit for installing the pump, pump column, or drop pipe. A casing should be used wherever unstable material might cave in or where water from contaminated strata is to be kept out of the well. In a dug well, the casing is usually brick, stone, or concrete. In all other types of wells, the casing material may be plastic (PVC or ABS), styrene-rubber, steel, fiberglass, reinforced plastic mortar, or concrete. The type of casing selected depends on the corrosion and encrustation potential of the water and the strength required for the well site. In installing the casing, precautions should be taken to ensure that joints are watertight.
- All wells should have *sanitary protection*. State laws may vary. However, the well casing should terminate not less than 1 foot above the ground surface and have a watertight cover or seal to prevent contaminated water or other objectionable material from entering the well. The *annular space* around the casing should be filled with cement grout, bentonite clay, or other suitable materials. A positive seal is required between the casing and the impervious material overlying the aquifer of artesian wells.

A concrete slab with watertight connections outside the casing and extending at least 2 feet beyond the well hole is usually adequate. It may be extended to serve as a base for pumping equipment. Internal combustion engines should have a separate base to prevent damage by vibration. If pumping equipment does not cover and seal the top of the casing, an additional cover should be provided. Provision should be made to allow water-level monitoring.

(5) Intake section

The most important part of the well is the intake section. This consists of the screen or slot section and the gravel pack or filter. The design and installation of the intake section affect the well's efficiency.

Well screens—A *well screen* is installed at the lower end of the casing to permit water to flow into the well from the desired or targeted aquifer interval, while retaining the coarser aquifer materials around the well. The screen also permits removal of finer materials during the well development process. Screens must have an open area of at least 15 to 20 percent of their surface to keep entrance *head losses* to a minimum.

Screens are manufactured according to several designs and from a variety of corrosion-resistant materials. Nonmetallic materials are also used for screens.

The screen or perforated length is the first selection in the design of the intake section. The length is controlled by the formation thickness, the aquifer type, stratification, and design efficiency.

Screen length is generally governed by the type of aquifer present. The four types are homogeneous artesian and water-table aquifers and nonhomogeneous artesian and water-table aquifers. Screen design principles include the following:

- From 70 to 80 percent of the thickness of the water-bearing sand in homogeneous artesian aquifers should be screened.
- The screen length for nonhomogeneous artesian aquifers must be determined from sieve analyses of the formation.
- Theory and experience have shown that screening the bottom third of homogeneous water-table aquifers is adequate.
- Screens for nonhomogeneous water-table aquifers are designed the same as those for nonhomogeneous artesian aquifers.

Generally, from a third to half of the water-bearing stratum is cased with a screen or perforated casing, except in formations where no casing is needed. The amount of the water-bearing stratum screened depends on the aquifer materials, but generally most of the water is obtained from the lower third of the water-bearing stratum.

When the pump is operating, the cone of depression lowers the water around the casing so that no water enters along the upper portion of the water-bearing formation. A perforated casing or screen in this area is an added expense with no benefit derived from its use and is often a source of trouble.

When a section is alternately above and below water, corrosion weakens it and may cause it to cave-in. Water entering the casing above the water level inside the casing can entrain air and cause problems in pipeline operation where the pump connects directly to the pipeline. The length of the perforated section needed to keep the head loss through the screen less than 2 feet can be computed by the following formula:

$$L = 6\frac{D}{C}$$

where:
L = length of screen or perforated section
D = diameter of screen or casing
C = Screen coefficient, or 11.31 C_c Ap
where:
C_c = orifice coefficient of contraction for the screen opening (it may be assumed to be about 0.62)
Ap = ratio of total area of screen openings to total area of screen

The size of slots in screen or casing should be $<D_{85}$ and $>D_{60}$ size of the filter. For naturally developed wells, the slots should be small enough to exclude about a third of the aquifer formation. Usually, a screen or casing with 15 to 20 percent open area will cause a small enough head loss for efficient operation of the well. Size gradations of aquifer material or filter material are determined through sieving of samples with standard wire-mesh sieves.

The screen length and slot size are dictated by the characteristics of the water-bearing formation, so the well screen diameter can be varied to meet hydraulic conditions. The main factor that governs screen diameter is limiting the water entrance velocity to reduce clogging, corrosion, or encrustation. The entrance velocity is calculated by dividing the expected or desired yield of the well by the total area of the openings in the screen.

$$V_e = \frac{Q}{A_s}$$

where:
V_e = screen entrance velocity, ft/s
Q = well yield, ft^3/s
A_s = Open area of screen (ft^2)

A conservative water well design has a well screen entrance velocity of about 0.1 foot per second, which has been the common industry standard for many years. The American Water Works Association (AWWA) Standard A–100–06, however, no longer stipulates a maximum screen entrance velocity and cites recent research and testing that indicate that allowable well screen velocities are a function of the aquifer characteristics, the overall well design and intended performance, and the quality of the groundwater being pumped. The maximum recommended entrance velocity should be less than 0.7 foot per second.

Generally, either a manufactured well screen or a factory-perforated casing should have a sharp outer edge, and the perforations should be larger on the inside than the outside to permit the passage of sand grains entering the perforations. Torch-cut perforations are generally unsatisfactory because they cannot be cut uniformly and are larger on the outside than on the inside. They tend to become clogged with sand or gravel grains. Manufacturers of well screens or perforated casing will supply information on the area of perforations for any given diameter, opening size, and capacity per foot of length per foot of head loss.

Filter pack—A sand or gravel *filter pack* should be used in wells developed in strata composed of fine material of relatively uniform size so that aquifer materials cannot pass through the well screen or perforated casing.

The filter must exclude sand and finer materials from the well and permit maximum flow of water from the water-bearing formation to the well screen or perforated section. When a gravel filter pack is to be installed, the well screen should be equipped with centering guides. These guides will assure the uniform placement of the gravel pack.

The design criteria for the filter are based on a *sieve analysis* of the dried aquifer material.

The coefficient of uniformity (C_u) of the aquifer can be used to determine the need for a gravel pack. The C_u is determined by dividing the D_{60} size by the D_{10} size (Hazen formula):

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

where
C_u = coefficient of uniformity

Sands with a C_u<2 do not benefit greatly from development by surging (section 650.12(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.

The following five conditions should be met in selecting the size of gravel or filter material:

- C_u of the filter material should be <2.
- D_{15} size of the filter material should be >4 × D_{15} size of the aquifer material.
- The uniformity of the aquifer should be included 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. This conclusion is based on experiments with aquifer C_u's of less than 2, so the D_{50} size of the filter can be at a maximum of 7.5 × D_{50} size of the aquifer. Assuming that this same criterion will hold true when aquifers with C_u's higher than 2 are gravel packed, the maximum D_{50} size of the filter would be determined by the formula:

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

$$D_{50}\left(\text{filter}\right) = \frac{15 \times D_{50}\ (\text{aquifer})}{C_u\ (\text{aquifer})}$$

- The D_{85} size of the filter should be < 2.5 × D_{10}, to keep the C_u within 2.
- The filter gradation curve should be as nearly parallel to the aquifer gradation curve as the above conditions will allow.

Table 12–3 provides general guidance for filter packs, based on aquifer characteristics.

The procedure to use in applying the above conditions to determine the size of filter material is:

Step 1 Make a sieve analysis of aquifer material to determine the percentage smaller than the screen openings.

Step 2 Compute and locate on graph the D_{50} size of the filter as determined in item (3) above.

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 be D_{50} size × 0.6. Locate this D_{10} minimum point on graph.

Step 4 Locate the maximum D_{85} size of the filter at 2.5 × D_{10} size.

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.

Table 12–3 Guidance on when to use a gravel pack

Coefficient of uniformity (C_u)	Aquifer grain size (D_{60})	Decision whether to use gravel pack
C_u<2	—	Use gravel pack.
2<C<3	D_{60}<0.76 mm	Use gravel pack.
	0.76 mm<D_{60}<2.54 mm	Gravel pack may be omitted if a well screen is used that has enough openings to allow water to enter well without excessive head loss.
	D_{60}>2.54 mm	Do not use gravel pack, but use a manufactured well screen or perforated casing.
C_u>3	—	Omit gravel pack because it might hold back fine sand that should be removed from the aquifer by natural development.

Step 6 Check to see that the D_{15} minimum size meets the requirement of being >4 × 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 less than 2 to fit a new curve.

Filter design example—A sample well-filter design problem follows.

Given aquifer 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 (fig. 12–23).

Step 3 Read D_{10} = 0.3 mm, D_{50} = 0.65 mm, D_{60} = 0.75 mm

$$C_u = \frac{D_{60}}{D_{10}} = \frac{0.75}{0.3} = 2.5$$

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

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

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

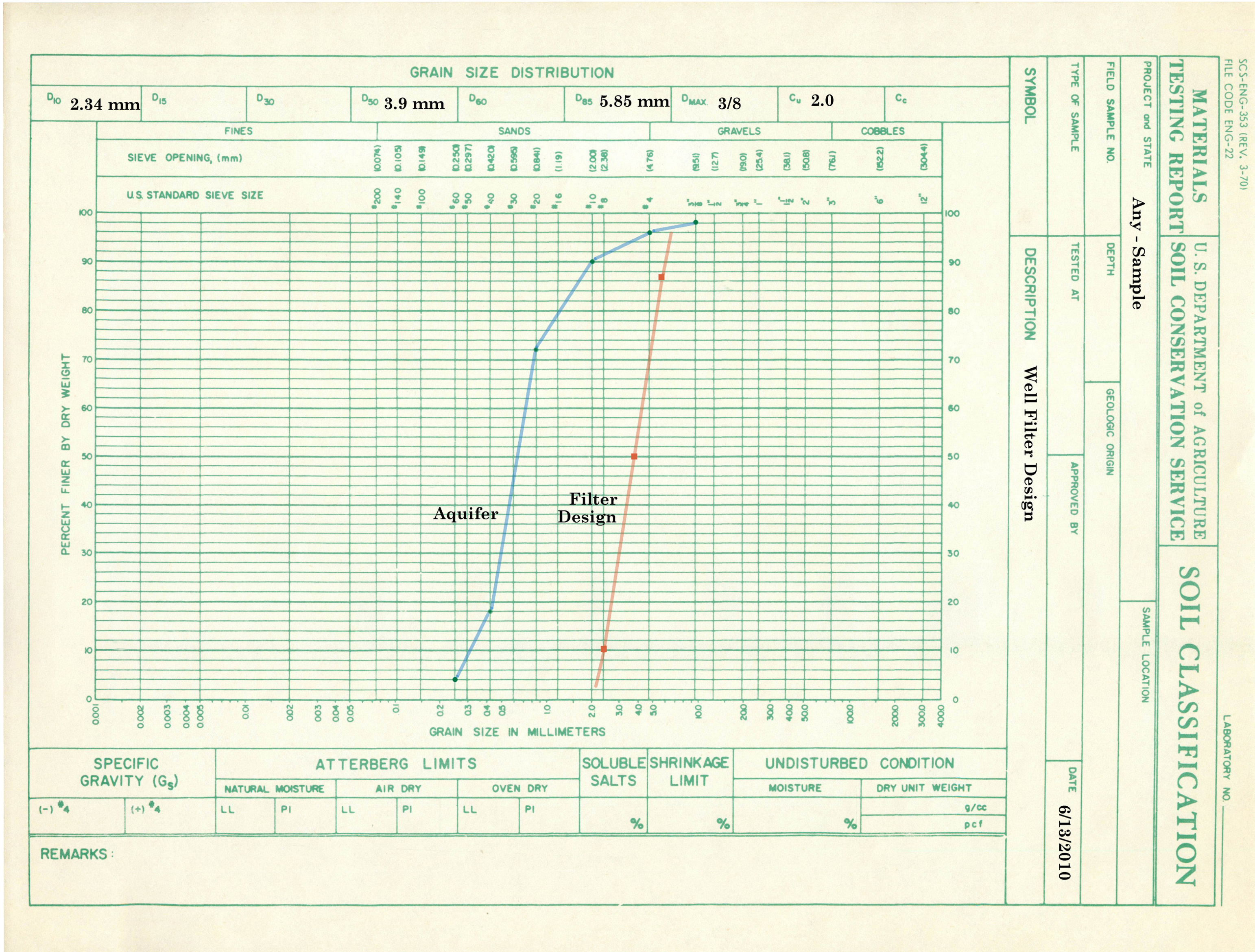
Step 4 Plot filter on curve.

Filter design limits

- 100% pass 3/8 sieve
- 64% (±8) or 56 to 72% pass #4
- 6% (±8) or 0 to 14% pass #8

A filter from 4 to 8 inches thick is sufficient for a gravel envelope. Installing a thicker filter enlarges the effec-

Figure 12–23 Filter design gradation, based on aquifer particle size distribution



tive 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.

(6) Multiple well systems

A multiple-well or manifold system may be required to obtain the needed amount of water. Three conditions are necessary for a manifold system to be successful.

- The water table should be close enough to the land surface to permit pumping the wells by suction lift.
- 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.
- The individual wells must be highly efficient. Investigation, casing, and screen selection are the same for a multiple-well system as for any other well.

Two types of installations are used in multiple-well systems: sand points and small individual wells. Figure 12–24 shows the components for a satellite well unit. Figure 12–25 shows a typical manifold multiple-well system. Only four satellite wells are shown. Additional satellite wells may be added to a system.

Figure 12–26 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.

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 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.

A drop pipe is installed in each satellite well and is connected to the manifold or header pipe, which in turn is connected to the intake side of the pump.

All connections on the suction side of the pump must be airtight. The practical suction lift on most pumps is limited to 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.

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.

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.

Manifold lines should be installed with a slight incline toward the central well. This incline prevents high points where air pockets can be trapped and reduce the flow.

Figure 12–24 A completed satellite well unit as part of a multiwell system

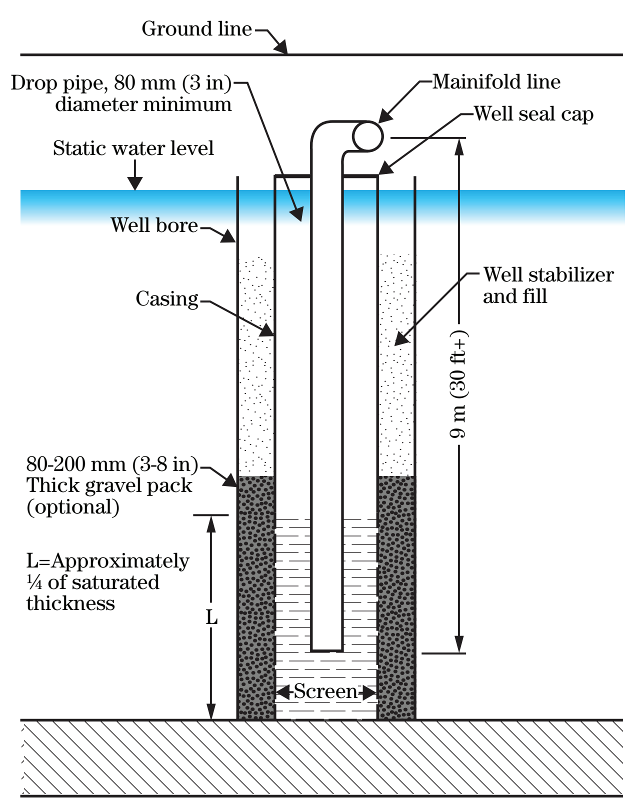


Figure 12–25 Typical manifold multiple-well system. Note that the pump may be an engine or electric motor

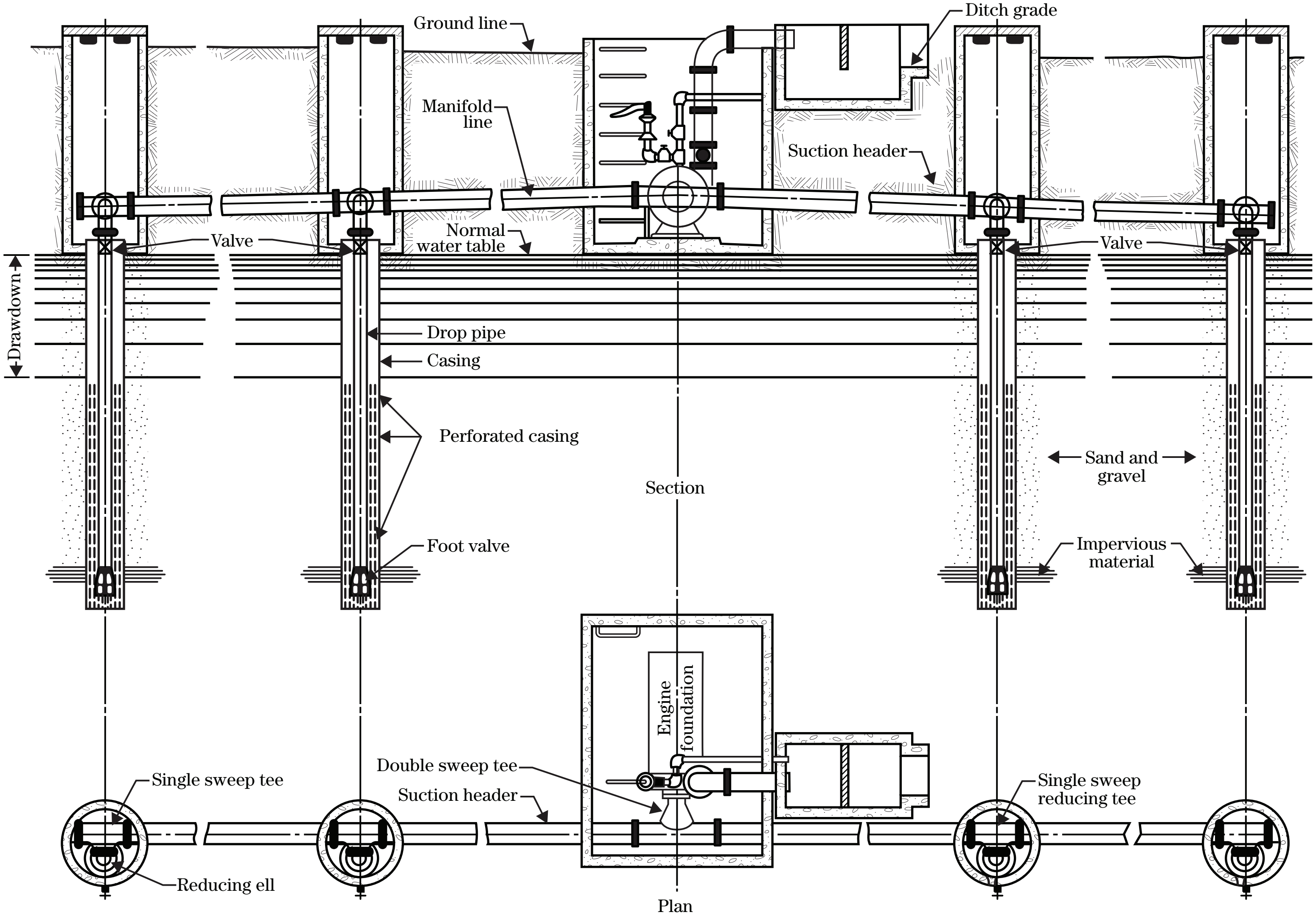


Figure 12–26 Sample layouts for manifolds pumping systems

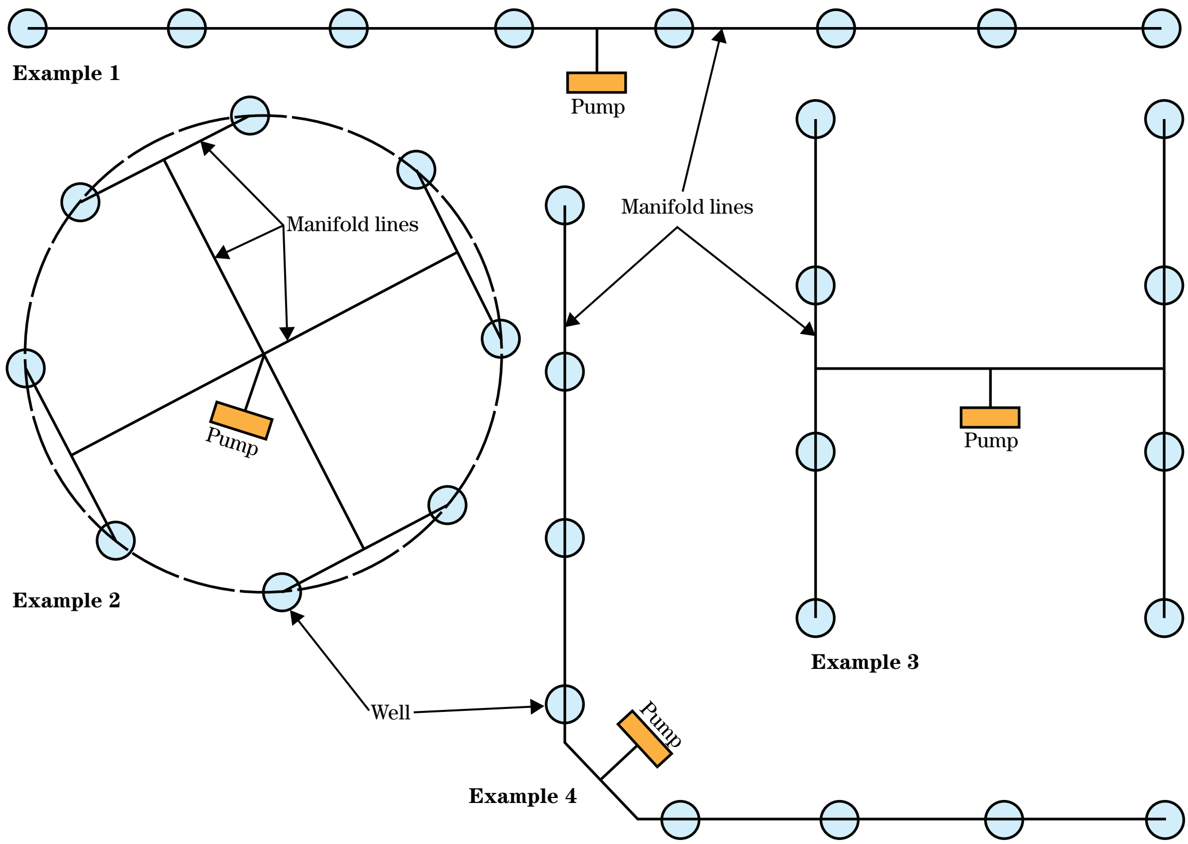
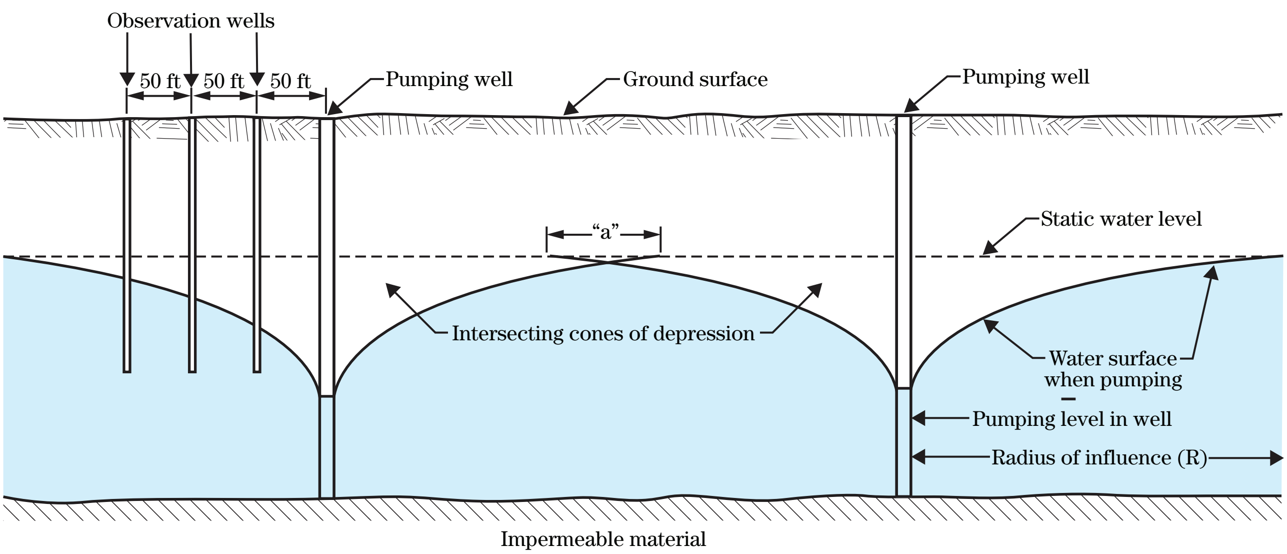


Figure 12–27 Well interference in an unconfined aquifer



An observation well can be drilled at some measured distance from the well and the drawdown determined at that point. If the drawdown at the well (outside the casing) is known, the radius of influence can be determined. For example, if 40 percent drawdown is measured 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, wells should be spaced at least twice the radius of influence as determined above.

Closer spacing causes interference between the wells (fig. 12–27). 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.

(e) Construction

Have all required construction equipment and materials to finish the well at the site before drilling starts.

- 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. Construct a hole of constant diameter and alignment.
- Use extreme care to place the screen and casing according to the manufacturer's recommendations.
- In placing the formation gravel stabilizer and gravel or filter pack, avoid the separation or bridging of material.

Wells should be spaced far enough apart that their radii of influence do not intersect as at “a.” Depending on the permeability of the aquifer and the drawdown, the radius of influence, R, may range from 100 to 3,000 feet or more, determined with observation wells spaced at regular intervals away from a pumping well.

Some checking can be done after the well is ready for testing, but the various parts of the well can be checked only before and during construction, such as the:

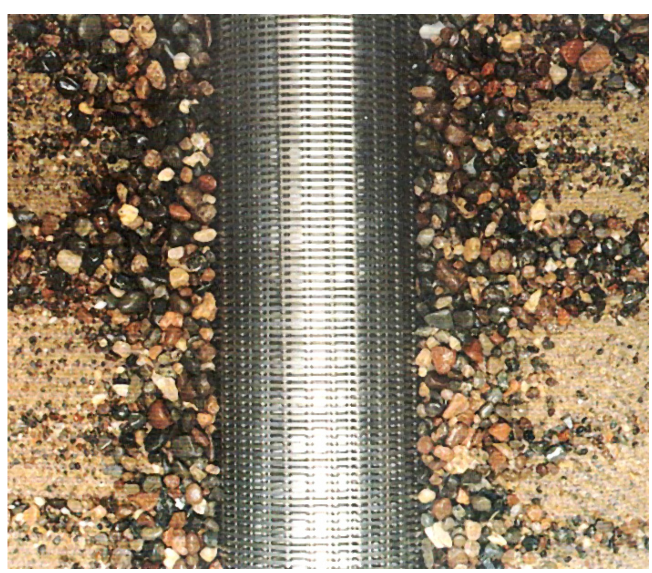
- diameter of the hole
- quality and placement of the gravel pack
- quality, size, and placement of the screen
- quality and dimensions of the casing

(f) Well development after installation

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 gravel envelope. Or, if no coarse particles are present, it removes fines through an artificial gravel envelope. Development is essential to completing wells satisfactorily in unconsolidated materials. Figure 12–28 shows a cross section of a filter pack in a developed aquifer, along with the well screen.

Wells may be developed by surging, backwashing, jetting, pumping, and use of compressed air, dry ice, acid, or dispersing agents. Packers (inflatable or mechanical) may be used to separate or isolate water-bearing strata during well development. Knowledge of drilling methods and the reaction of particular formations to development is required to select the proper method. Information from the record of materials penetrated is used to guide the development process.

Figure 12–28 Cross section of developed well showing filter pack and well screen



Bridging of fine sand in the aquifer near the well may result from too violent action at the beginning of work. When water is pumped from a 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 reversing the direction of flow.

(g) Testing

A well is not completed until it has been pumped to determine its capacity and drawdown and does not yield undesirable sediment when pumped at the required capacity. The contractor should complete developing and testing the well before leaving the job.

A 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, the pump should be designed 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. Overpumping a well may also cause excessive sand pumping and possible well failure. As soon as a well is completed and developed, a test pump should be installed to verify the well development and yield.

The optimum yield and required lift may be estimated by converting drawdown obtained from the tests to percentage of possible drawdown and relating it to yield (fig. 12–29). The curves shown are average drawdown-yield relations for a large number of wells. At 50-percent drawdown, nonartesian wells produce about 77 percent of possible yield and artesian wells produce about 55 percent.

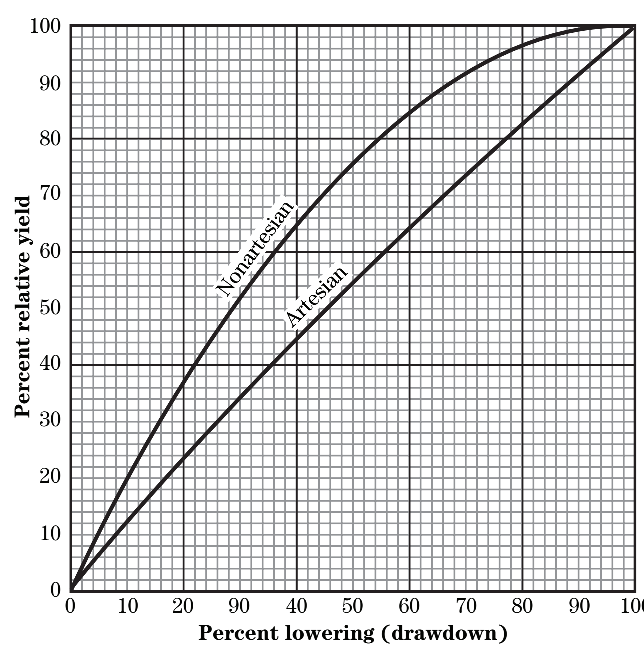
Example—The water stands 75 feet in a well and the pumping test yielded 1,470 gallons per minute with a drawdown of 23 feet. This is 31 percent of the total possible draw down. The curve shows that at 31 percent of the maximum drawdown, this nonartesian well will produce 53 percent of the maximum yield, so the maximum yield would be about

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

The curve 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. The following test procedures are recommended:

1. Measure and record the depth to static water level (may be measured with steel tape that has 1 to 2 feet. of its lower end chalked).
2. Determine whether the well is artesian or nonartesian 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.
3. Measure the height of the static water column or 100 percent drawdown. For nonartesian 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.
4. Pump the well at a near-maximum rate (50% drawdown or slightly more) until drawdown and

Figure 12–29 Relationship between drawdown and yield



yield are constant at that rate. Drawdown may be considered constant when three measurements taken 1 hour apart are the same. Water levels during pumping should be measured with an electric sounder or air line. Several hours to several days of continuous pumping may be required. Record drawdown and yield.

5. Convert measured drawdown to percent drawdown. Refer to figure 12–29 to estimate optimum drawdown and yield and the most economical water yield from a specific well.

(1) Measuring drawdowns

Drawdown can be measured using an air pressure gage or an electric sounder. Many deep-well pumps are equipped with pressure gages and air lines of known lengths.

Air line—The air line is usually a copper tube an eighth to a quarter inch in diameter, but may be a quarter-inch-galvanized pipe. Its surface end is connected to a pressure gage with an air valve just below the gage (fig 12–30). 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 air line must be known. Air pressure can be furnished 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. This is the maximum pressure that can be attained.

Depth to water level is the depth to the lower end of the air line less the gage reading in meters or feet. If the gage reads in pounds per square inch, multiply the reading by 2.31 to obtain feet.

Figure 12–30 Air line for measuring depth to water level

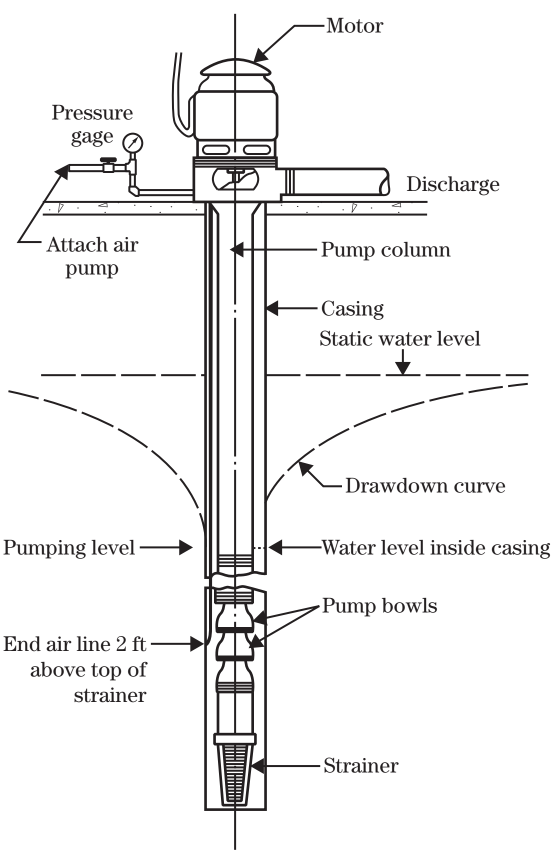


Figure 12–31 Water well pump powered by electric motor, Washington

Electric sounder—Another satisfactory and accurate method of measuring water level is by means of an electric sounder. The electric circuit is completed with water contact.

(2) Measuring yield

An accurate well test requires careful measurement of yield. Pipe orifices are commonly used to measure discharges within a range of 50 to 2,000 gallons per minute. Parshall flumes or sharp-crested weirs are used to measure larger flows. Smaller yields can be measured using a container of known volume and recording time required to fill it (V/t). In-pipe flow meters may also be used to measure water yield, including mechanical impeller-type meters and electronic nonobtrusive meters.

(h) Selecting a pump

In selecting a pump, consider required capacity, total lift, diameter of the well, location of the well, and type of power available. The common types of pumps are turbine, centrifugal, propeller, gear, plunger, and airlift. Each type of pump is constructed to operate under a specific range of conditions. A pump should not be selected without a thorough knowledge of the planned operating conditions and pump characteristics. Figure 12–31 shows a large capacity irrigation well head, with electric motor powering the pump. Refer also to NEH630.1202 for information on pumps and energy sources.

Maintenance—Proper well maintenance will extend the life of the well. Without proper maintenance, a well may fail.

(1) Pump service

The owners may service the pump and treat the well. Pump manufacturers issue instructions and recommendations for pump operation and maintenance. If the owner follows the recommendations, the expected life should be reached.

(2) Water testing

Water samples should be analyzed before a well is constructed to determine if corrosion or encrustation will be problems. Knowing this in advance enables installation of an appropriate screen or casing. Screens of various metals, alloys, and other materials are available for specific water quality applications.

(3) Clogging of intake section

Screen encrustation is caused primarily by deposits of carbonates of calcium or magnesium, deposits of clays or silts, and the presence of iron, bacteria, or slime-forming organisms in the water.

Where encrustation is a problem, periodic cleaning by a reliable and experienced well servicer may be necessary. The well should be cleaned before the yield is reduced seriously. Various chemicals are used to treat wells, depending on the type of encrustation, screen, and casing composition.

Where screen clogging is caused by bacteria that generate an iron or slime precipitate, chlorine treatment is effective when combined with a biodispersant.

(4) Well testing

Each year, make the following tests and measurements for comparison with previous data, so trouble can be detected early, when it is still possible to rectify the problem:

- Each winter, when all wells 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 as described under testing.
- 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 well may require remediation.
- Every 2 months, all year, measure and record the static water level when the pump has been off at least 4 days. Record details.
- 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.

(5) Well failures

Well failure is generally a result of continued sand pumping until the well caves in, the collapse of the well casing, or pumping the aquifer dry. A decrease in the well discharge is usually due to one or more of the following:

- a lowering of the water level or hydrostatic head in the aquifer
- pump or motor wear or failure
- poor installation
- filter or casing failure due to settlement of fine aquifer materials in the gravel pack
- biological growth, iron bacteria, or chemical encrustation on the well screen or perforations

A producing well may fail completely or its output may decrease to a level that it is uneconomical to continue its use. If the specific capacity declines by 30 percent or more, then the well may have a serious problem, requiring additional testing and trouble-shooting. There is no treatment for a falling water table except to use a pumping rate or cycle that allows the water table to be recharged as rapidly as water is withdrawn.

(j) Applicable State laws and groundwater rights

State laws regarding the use of groundwater must be followed. Three principal sets of rules or "doctrines" form the basis for these laws:

- Absolute ownership, or the common-law rule, which states that the owner of the land is the absolute owner of all underground waters under their property. The owner may develop and use their groundwater without regard to effects on groundwater supplies of adjacent landowners, subject to qualifications in some States. This doctrine does not recognize flow¬ing groundwater or the effect that its misuse may have on other landowners using the same source.
- Ownership with reasonable use is similar to the common-law ownership, but limits the owner to a reasonable use related to the needs of other owners of lands overlying a common groundwater source.
- The appropriation doctrine follows the rule that, where groundwater limits or boundaries can be reasonably established, the subsurface waters are public waters and subject to appropriation. Priority rights are issued from a designated State agency after an examination of the intent of use. The appropriation system emphasizes beneficial use and conservation, security of investment, and responsibility for administrative guidance.

Most States regulate the development and administration of groundwater resources in the public interest. Common State regulations include the following:

- All persons drilling wells for others must be licensed.
- Drilling permits, logs, and any work performed on wells must be reported to the State on prescribed forms.
- Wells furnishing domestic or municipal water must be properly constructed and finished to prevent contamination.
- Flowing wells must be suitably capped and regulated to avoid waste.
- Abandoned wells must be sealed.
- Air-conditioning and cooling waters must be returned to the ground through recharge wells.
- Disposal of any contaminants, such as brines or industrial wastes, which affect the quality of public water supplies, can be restricted.

Administering these regulations is usually the responsibility of a designated State agency. Administration and control of groundwater in overdraft areas pose many complex technical problems.

(k) Contracts and specifications

Few individuals take the trouble to draw up a contract when having a well drilled. Although an oral contract is binding on both parties, it can be a source of misunderstanding because it depends on memory. On the other hand, contract specifications that are too rigid lead to excessive costs and should be avoided.

When a legal contract is required, the landowner should be encouraged to consult an attorney. A thorough understanding and agreement on at least the following points are necessary for a satisfactory job:

1. The well will be started at the surface with ____-inch pipe with a weight of _____pounds per foot or _____class polyvinyl chloride and carried to a depth of about _____feet. If two or more lines of

casing are run, an ample overlap will be allowed and an effective seal will be set.

2. The well will be drilled in such vertical alignment that after perforating and testing, a deep-well pump having a clearance of 1 inch on each side can readily be installed and operated without undue stress or wear from excessive inclination of the shaft.
3. As construction progresses, the contractor shall keep, and furnish to the owner on completion of the well, an accurate record of materials passed through; water-bearing strata; progress in sinking the casing; depth, size, and number of perforations, or screen opening and dimensions; static water level; development work; drawdown; and record of testing.
4. The casing will be perforated in all water-bearing strata (except quicksand) likely to yield a satisfactory supply of good-quality water. The sizes of perforations will be determined on the basis of the grain-size distribution of aquifer materials according to best practice.
5. The advisability of installing a well screen, an artificial gravel envelope, or both will be determined on the basis of the grain-size distribution of aquifer materials according to best practice.
6. After completion, the well will be surged thoroughly with a surge block, bailer, or other equipment until sand-free water is obtained. The work of surging or other development will be paid for at the rate of $_____per hour.
7. After the well has been surged and bailed, it will be tested with a pump furnished by the driller. The pump will have a capacity in excess of expected yield and will be able to pump at variable rates. The pump will be operated continuously for _____hours. An air line or other suitable method will be used to measure the drawdown periodically during pumping.
8. The unit price per foot of well will be $______ ($_____per ft), which includes the cost of moving to and from the well site and setting up the equipment. The cost of perforating will be included in the unit price unless otherwise stated. Test pumping will be paid for at the rate of $________ per hour and will include time for installing and removing the pump.

In case a dispute might arise, the procedure to be followed in settling the dispute should be set forth in the contract. Large well-drilling companies have their own contract forms. If company contract forms are used, the landowner should be encouraged to read their provisions carefully and understand the agreement before signing.

(l) Records

Maintaining complete records aids efficient and economical groundwater development. Therefore, copies of the records of test holes, completed well and equipment, development operations, and pumping tests should be retained in the field office and other offices as required.

Prepare a permanent file containing:

- test hole logs and location map
- sieve analysis of formation samples
- water analysis
- all geologic data collected in the exploration stage
- well design drawing showing accurate finished dimensions and details
- pump specification sheets, performance curves, parts lists, etc.
- details of repairs, acid treatments, etc.

(m) Abandonment

Test holes and abandoned wells should be sealed in accordance with the CPS Code 351, Water Well Decommissioning, when they no longer serve their original purpose.

650.1204 References

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Appendix A Glossary

Alluvial materials Recent materials deposited by running water. The unconsolidated sand and gravel commonly found underlying floodplains of major streams or rivers form alluvial aquifers. These sand and gravel deposits are often intermingled with silt and clay.

Annular space The space between two cylindrical objects, one of which surrounds the other, such as the space between the walls of a drilled hole and a casing or between a permanent casing and a temporary surface casing.

Aquifer A geologic formation that will yield enough water to a well for practical use.

Artesian water Any water that is confined in an aquifer under pressure so that it will rise in the well casing or drilled hole above the bottom of the confining layer overlying the aquifer. This term includes water of flowing wells, and water under artesian pressure in wells that do not flow.

Backwashing Forcing the water back out of the well through the screen or slotted casing and into the water-bearing formation. Backwashing is used to develop a well, i.e., to remove undesirable fines.

Bedrock The consolidated or cemented rock, which may underlie the alluvium or soil, or may outcrop at the land surface.

Blotter or sand blotter A layer of fine sand (usually about 2 feet thick) installed between the top of the gravel filter pack and the surface seal (bentonite or concrete), usually at or above the static water level. It helps maintain separation of the seal and filter so that the seal is not pulled into the gravel filter pack

Casing A rigid pipe installed in the well to prevent the walls from sloughing into the well.

Cement grout A mixture of water and cement in the ratio of not more than 5 to 6 gallons of water to 94 pounds of Portland cement. For a better flowing mixture, 3 to 5 pounds of bentonite clay may be added to the cement and the water increased to not more than 6.5 gallons.

Cone of depression As groundwater flows to a pumping well, the slope of the water surface increases. As distance from the well increases, the slope becomes flatter until it merges with the potentiometric surface beyond the influence of the well. The water surface within the influence of a pumped well is an inverted cone with its apex in the well and its base in the static water table.

Consolidated formation A naturally occurring geologic formation that has been lithified (turned to stone). The term is sometimes used interchangeably with the word bedrock. It includes rocks such as basalt, rhyolite, sandstone, limestone, and shale. Commonly, this type of formation will stand at the edges of a bore hole without caving in.

Contamination Introduction of any chemical, organic material, live organism, or radioactive material that will lower the quality of the natural groundwater. Also included is the introduction of heated or cooled water into the groundwater if the changing of the water temperature renders the water less usable.

Drawdown (H–h) The distance from the position of the static water table before pumping to the level of the water in the well during pumping.

Filter or gravel pack A gravel envelope surrounding the well screen, designed to prevent sand from entering the well. Gravel or other permeable filter material is placed in the annular space around the well screen. A gravel pack is frequently used to prevent the movement of finer material into the well and to increase the ability of the well to yield water without pumping sand or sediment.

Head loss (l) The difference in elevation between water level inside the well (during pumping) and outside at the point where the drawdown curve intersects the casing.

Lift (L) The vertical distance from the water level in the well during pumping to the ground surface or some other specified point such as the center of the discharge pipe.

Mineralized water Any naturally occurring groundwater that has a high chemical content.

Permeability The ability of a geologic material (sand, for example) to transmit water.

Porosity The degree to which earth material contains spaces not occupied by solid particles. The amount of water that can be contained in a volume of a formation is the porosity times the volume, usually expressed as a percentage.

Potentiometric surface The elevation to which water will rise up in a tube or well that penetrates a confined aquifer. The water table is more properly termed the potentiometric surface in an unconfined aquifer, also called a water table aquifer.

Pumping level (h) Static head or depth of water in well while pumping.

Radius of influence The area affected by the discharge from a well, also known as the circle of influence, in plan view. The radius of the circle is the radius of influence (R).

Sand pumping The pumping action yields sand that is eroding from the gravel pack or the aquifer.

Screen A perforated or slotted section of pipe or screen used to separate the well water from the surrounding aquifer. Its proper design allows water to flow into the well without eroding the filter pack or aquifer material.

Sieve analysis A procedure for measuring the percentage of various particle sizes, by weight, by shaking grain sizes in an earth material sample by shaking the sample through a series of different-sized sieves, weighing and plotting the results on a grain size distribution chart.

Specific capacity The well's performance expressed as the pumping rate (yield) in gallons per minute divided by the drawdown in feet during the pumping, or gallons per minute per foot of drawdown.

Surging A means of developing a well by forcing water back and forth through the screen or slot area of the well casing.

Unconsolidated materials Naturally occurring earth deposits that have not been lithified. Alluvium, soil, gravel, clay, and overburden are some of the terms used to describe this type of deposit.

Water table The surface level of the groundwater at the top of the saturated zone in a water-bearing formation. More properly termed the potentiometric surface.

Well stabilizer Material placed in the annual space between the hole and the casing to hold the casing in place.