Chapter 12 Springs and Wells

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Springs and Wells

Introduction

Our dependence on the use of ground water for sustaining human and animal life, for producing crops, and for recreation continues to increase. To meet present and future demands, conservation practices must be used to preserve this vital resource. Ground water has many advantages over water from other sources, and its economic importance can hardly be overemphasized.

The purpose of this chapter is to acquaint conservationists, engineers, and technicians with the fundamentals of planning and developing ground-water recovery systems. 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 ground water, methods of obtaining it from springs or wells, and the development and maintenance of ground-water recovery systems are discussed.

The principal ways of using ground water are through spring and well developments. A spring is a natural outflow of water from some underground supply to the ground surface, usually through a definite opening. A seep differs from a spring in having no definite opening. A well is a vertical or horizontal hole drilled or dug into the earth to obtain water from openings in the rocks or voids in the geologic section penetrated.

Source of Water Supply

Subsurface Water

Precipitation that soaks into the ground is called subsurface water. Subsurface water that moves down to the underground reservoir in the saturated zone is called ground water. This water can be found in perched zones, static water-table zones, and artesian zones. Figure 12-1 shows water movement in relation to the hydrologic cycle.

Ground Water

Ground water is located in the area of the earth's crust known as the zone of saturation and is contained in either water table aquifers or confined 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. In a confined aquifer, the water is confined in the zone of saturation by an overlying impermeable formation and may be at a pressure greater than atmospheric. If the water in a confined aquifer rises above the containing zone when penetrated, the aquifer is said to be artesian.

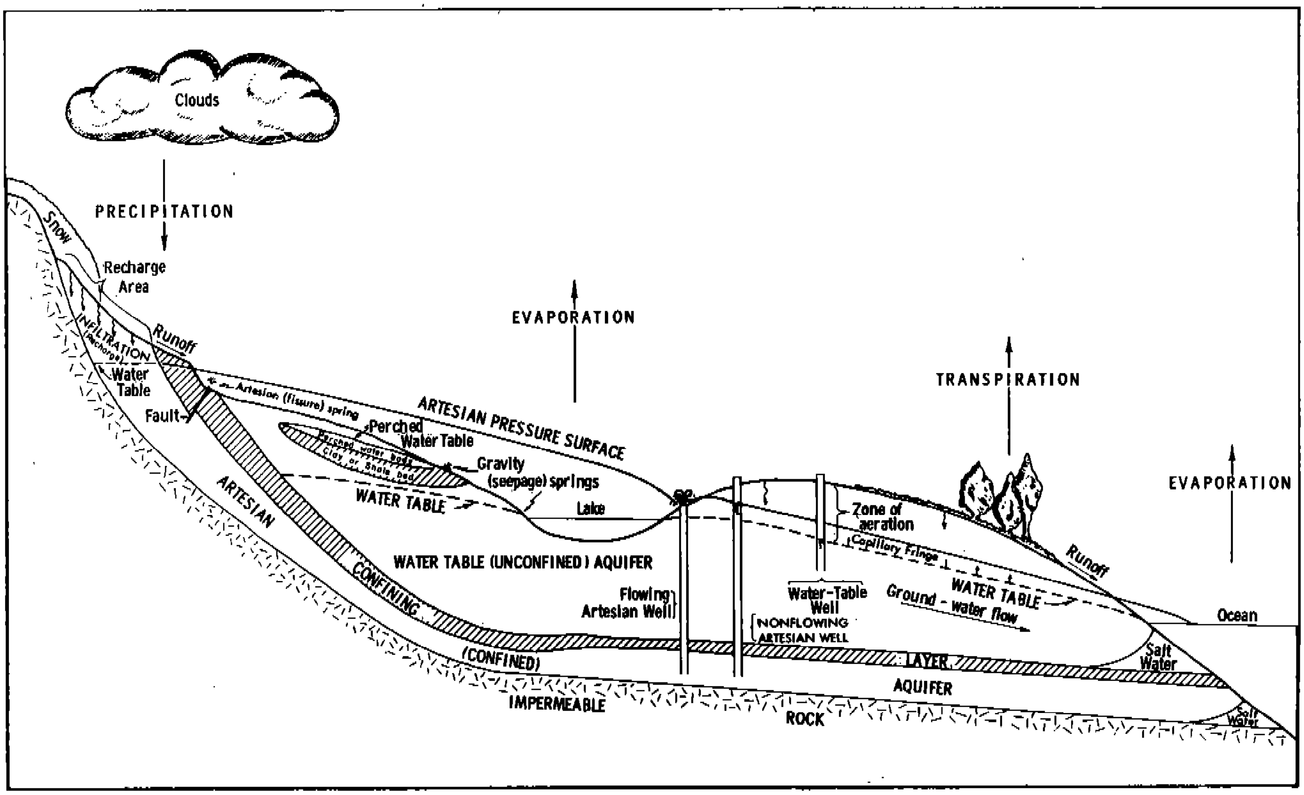


Figure 12-1.—The hydrologic cycle.

Water-Bearing Materials

There is some water under most of the earth's surface; however, its recovery may not be economically feasible. Ground water usually is more plentiful under valleys than under hills. Although underground streams may flow in cavernous limestone or lava rock, the main source of ground water in rock formations is the pores and cracks.

Unconsolidated sands or gravels generally are the most important aquifers. Usually, they have high porosity and permeability. 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 the uniformity, compaction, amount of interconnected voids (pores) in the sand and by the frequency of joints, fractures, and bedding plane openings. In limestone, ground water is found in joints and solution passages.

The presence of ground water in volcanic rock depends on the presence of joints and fractures, permeable lava tubes, interflow zones, voids in cinderbeds, or alluvial deposits between lava flows.

Small amounts of ground water may be obtained from jointed or fractured zones of dense, hard rock. The depth to which joints and fractures stand open in such rock usually is not more than 90 m (300 ft) and may average about 30 m (100 ft). Little if any water can be obtained from unbroken areas of such rocks.

Sedimentary formations and sands or gravels with clay fines are practically impermeable. They do not yield appreciable amounts of water to wells, although occasionally water is obtained through open fractures. These materials frequently form confining layers over more permeable materials.

Ground Water Provinces

The U.S. Geological Survey has delineated, and designated alphabetically, significant ground-water provinces of the United States (fig. 12-2), based on the areal extent of the important superficial water-bearing and bedrock formations. The provinces are discussed briefly here; users of this handbook should seek elsewhere detailed information on a particular province.

A. *Atlantic and Gulf Coastal Plain Province.* Water is derived in rather large quantities from sands and gravels interbedded with clay. Large supplies are obtained from alluvial gravels in the Mississippi Valley and adjacent areas. The province includes extensive areas of artesian flow. In mineral content the ground water ranges from low to high.

B. *Northeastern Drift Province.* Ground water comes principally from glacial drift. The till yields small supplies to many springs and shallow wells (less than 60 m [200 ft]); the outwash gravels yield large supplies, notably on Long Island in New York. Many drilled rock wells receive small supplies, chiefly from joints in crystalline rocks or in Triassic sandstone. Ground water is generally soft and low in mineral content.

C. *Piedmont Province.* Water generally low in mineral content is supplied in small quantities by the crystalline rocks and locally by Triassic sandstone. Many shallow dug wells are supplied from surface deposits or from the upper decomposed part of the bedrock. Many moderately deep (60-300 m [200-1,000 ft]) drilled wells are supplied from joints in the crystalline rocks. Some wells in Triassic sandstone yield large supplies.

D. *Blue Ridge-Appalachian Valley Province.* This is a region of rugged topography with numerous springs that generally yield good-quality water from Paleozoic strata, pre-Cambrian crystalline rocks, or post-Cambrian intrusive rocks. The water is derived chiefly from springs, spring-fed streams, and shallow wells.

E. *Southcentral Paleozoic Province.* The principal water sources are the Paleozoic sandstones and limestones. In many of the valleys, large supplies are obtained from alluvial sands and gravels.

F. *Northcentral Drift-Paleozoic Province.* Most water is derived from glacial drift, where it is generally hard but otherwise good. Numerous drilled wells produce large supplies from glacial outwash or from gravel interbedded with till. Many drilled wells end in Paleozoic sandstone or limestone and receive ample water.

G. *Wisconsin Paleozoic Province.* Most of the water is from wells of moderate depth drilled into Cambrian or Ordovician sandstone or limestone. These wells as a rule yield ample supplies of hard but

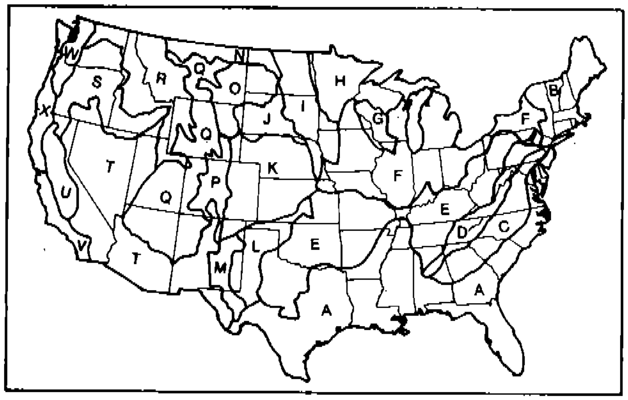


Figure 12-2.—Ground water provinces of the United States.

otherwise good water. In many of the valleys, artesian flows are obtained from the Paleozoic aquifers. The region has no water-bearing drift except in the valleys, where there are water-bearing outwash gravels.

H. *Superior Drift-Crystalline Province.* In most parts of this province satisfactory water supplies are obtained from glacial drift. Where the drift is thin, water is generally scarce, because the pre-Cambrian crystalline rocks in most places yield only meager supplies, and as a rule there are no intervening Paleozoic, Mesozoic, or Tertiary formations thick enough to yield much water. The drift and rock waters range from soft waters in Wisconsin to highly mineralized waters in the western and northwestern parts of the province.

I. *Dakota Drift-Cretaceous Province.* The two important sources of ground water are the glacial drift and the Dakota sandstone. The drift supplies numerous wells with hard but otherwise good water. The Dakota sandstone has extensive areas of artesian flow that supply many strong-flowing wells, a considerable number of which are more than 300 m (1,000 ft) deep. The Dakota sandstone waters are highly mineralized but are used for domestic supplies.

J. *Black Hills Cretaceous Province.* The conditions in this province are, on the whole, unfavorable for shallow water supplies, because most of the province is underlain by the Pierre shale or by shales of the White River group (Oligocene). The principal aquifer is the Dakota sandstone, which underlies the entire region except the Black Hills. This sandstone will probably yield water wherever it occurs, and over considerable parts of the province it will give rise to flowing wells; however, throughout much of the province it is far below the surface. In the Black Hills water is obtained from a variety of sources, ranging from pre-Cambrian crystalline rocks to Cretaceous or Tertiary sedimentary rocks.

K. *Great Plains Pliocene-Cretaceous Province.* The principal aquifers of this province are the late Tertiary sands and gravels (Ogallala formation and related deposits) and the Dakota sandstone. The Tertiary deposits underlying the extensive smooth and uneroded plains supply large quantities of water to shallow wells. The Dakota sandstone underlies nearly the entire province and gives rise to various areas of artesian flow. Throughout much of the province, however, it lies too far below the surface to be a practical source of water. Where the Tertiary beds are absent or badly eroded and the Dakota sandstone is buried beneath thick beds of shale, as in parts of eastern Colorado, developing even small water supplies may be difficult. Many of the valleys contain Quaternary gravels, however, which supply large quantities of good water. Considerable Tertiary and Quaternary sections can yield a supply suitable for irrigation.

L. *Great Plains Pliocene-Paleozoic Province.* The principal aquifers of this province are the late Tertiary and Quaternary sands and gravels, which give the same favorable conditions as those in province K. The Tertiary deposits are underlain practically throughout the province by Permian or Triassic deposits, which in most places yield little or only highly mineralized water. Where the Tertiary deposits are thin or absent, or where they have been eroded, the ground water conditions are generally unfavorable.

M. *Trans-Pecos Paleozoic Province.* The bedrock consists of Carboniferous, Permian, and Triassic strata including limestone, gypsum, red beds of shale and shaly sandstone, and some less shaly sandstone. In most of the province these rocks yield only meager supplies of highly mineralized waters to deep wells. In the Pecos Valley, however, Carboniferous limestones and sandstones yield large supplies to numerous flowing wells; the water is very hard but good enough for irrigation, domestic, and livestock purposes. Locally the bedrock is overlain by Quarternary water-bearing gravels.

N. *Northwestern Drift-Eocene-Cretaceous Province.* Ground water is obtained from glacial drift and from underlying Eocene and Upper Cretaceous formations. Where the drift is absent or not water bearing, wells are sunk into the underlying formations, with variable sucess. The Eocene and latest Cretaceous, which underlie most of the eastern part of the province, generally include water-yielding strata or lenses of sand, gravel, or coal. The Cretaceous formations in the western part consist chiefly of alternating beds of shale and sandstone. The sandstones generally yield water, but the shales are unproductive, and where a thick shale formation immediately underlies the drift or is at the surface, successful wells may be difficult to obtain. In certain localities, upland gravels yield water to shallow wells.

O. *Montana Eocene-Cretaceous Province.* Enough fairly good water for domestic and livestock supplies and even for small municipal supplies is obtained from strata and lenses of sand, gravel, and coal in the Fort Union (Eocene) and Lance (late Cretaceous or Eocene) formations that underlie most of the province. These formations usually rest on the Pierre shale, a thick, dense Upper Cretaceous shale that yields only meager amounts of generally poor-quality water or none at all. Hence, locally, where the Fort Union and Lance are absent or do not yield enough, satisfactory water supplies are very difficult to obtain. The northern part of the province has a little water-bearing glacial drift.

P. *Southern Rocky Mountain Province.* In this mountain province, underlain mostly by crystalline rocks, water is obtained chiefly from springs, from streams fed by springs and melted snow, or from very shallow wells near streams.

Q. *Montana-Arizona Plateau Province.* This large area is mostly an arid to semiarid plateau underlain by sedimentary formations ranging in age from Paleozoic to Tertiary. The formations are not violently deformed, but they are warped and broken enough that the presence of ground water is closely related to rock structure, and conditions vary over short distances. On the whole, water is neither plentiful nor of very satisfactory quality. Where thick formations of nearly impervious material are at the surface, or where the plateau is greatly dissected, as in the Grand Canyon region, water is scarce. Locally, however, sandstone aquifers such as those of the Dakota sandstone and the Ellis, Sundance, Kootenai, Eagle, Mesaverde, and Judith River formations can be developed and may yield very satisfactory supplies—in some places giving rise to flowing wells. There are also local deposits of water-bearing Quaternary gravels.

R. *Northern Rocky Mountain Province.* This is a relatively cold region, chiefly mountainous but with extensive intermontane valleys and plains. It is underlain by a wide variety of rocks with complicated and diverse structure. As in other mountain regions, water is obtained largely from mountain springs and streams. Considerable water is available in places from valley fill made up of ordinary alluvial sand and gravel and from outwash fill made up of ordinary alluvial sand and gravel and the outwash deposits of mountain glaciers. Water is also obtained from wells drilled into various pre-Cambrian and Tertiary rock formations.

S. *Columbia Plateau Lava Province.* The principal aquifers of this province are the widespread Tertiary and Quaternary lava beds and interbedded or associated Tertiary sand and gravel, such as those of the Ellensburg formation. In general, the lava yields abundant supplies of good water. It gives rise to many large springs, especially along the Snake River in Idaho. Locally, the lava or the interbedded sand and gravel give rise to flowing wells. However, much of the lava is so permeable and the relief of the region is so great that in many places the water table can be reached only by deep wells. In certain parts of the province, glacial outwash and ordinary valley fill are also important water sources.

T. *Southwestern Bolson Province.* The principal source of water in this arid province is the alluvial sand and gravel of the valley fill underlying the numerous intermountain valleys. In the elevated marginal parts of the valleys, the water table may be far below the surface or ground water may be absent; in the lowest parts, underlain by clayey and alkaline beds, ground water may be scarce and of poor quality; at intermediate levels, however, large supplies of good-quality water are generally found. Most of the water in the valleys of this province is recovered by means of pumping wells, but there are many springs and areas of artesian flow. In mountain areas of the province many springs, small streams, and shallow wells furnish valuable supplies.

U. *Central Valley of California Province.* Good-quality ground water is found chiefly in alluvial cones formed by streams emerging from the Sierra Nevada, although water can be obtained throughout the valley. The yield of cones flanking the Coast Range is small. Poor-quality water generally comes from the south and central sections, and somewhat better quality from the north. Underlying piedmont deposits consist of marine, lacustrine, and alluvial formations. Highly mineralized water is found in deep strata throughout the valley and near the ground surface in the center of the valley. Extensive irrigation in the valley depends on ground water pumped from wells.

V. *Coastal Ranges of Central and Southern California Province.* The principal ground-water bodies are in the mountain valley and piedmont plains draining to the Pacific Ocean. Aquifers consist of valley fill and alluvial sand and gravel deposits. Locally, good water supplies are developed from underlying younger Tertiary sandstones. Heavy development of ground water along the coast for municipal and irrigation needs has caused the sea water to enter and contaminate aquifers in several valley mouths.

W. *Willamette Valley-Puget Sound Province.* A large body of alluvium fills the structural trough forming this province. Abundant supplies of surface water have delayed investigation and exploitation of the extensive ground-water resources of the area.

X. *Northern Coast Range Province.* Ground water is found in the alluvial fill of the valleys draining to the Pacific Ocean. A small area in the southern part of the province contains heated ground water, hot springs, and geysers. Because surface water is abundant and the province is relatively undeveloped, little detailed information on ground water conditions is available.

Effect of Geologic Structure

Certain structural features or conditions favor the accumulation of ground water in aquifers; others act as drains. Conditions favorable for retaining ground water 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 ground water are synclines, grabens, faults, and dikes (fig. 12-3).

Minor structural features such as joints and fractures also influence the accumulation and movement of ground water in rocks. Joints often occur in a definite pattern and dictate the 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 exten-

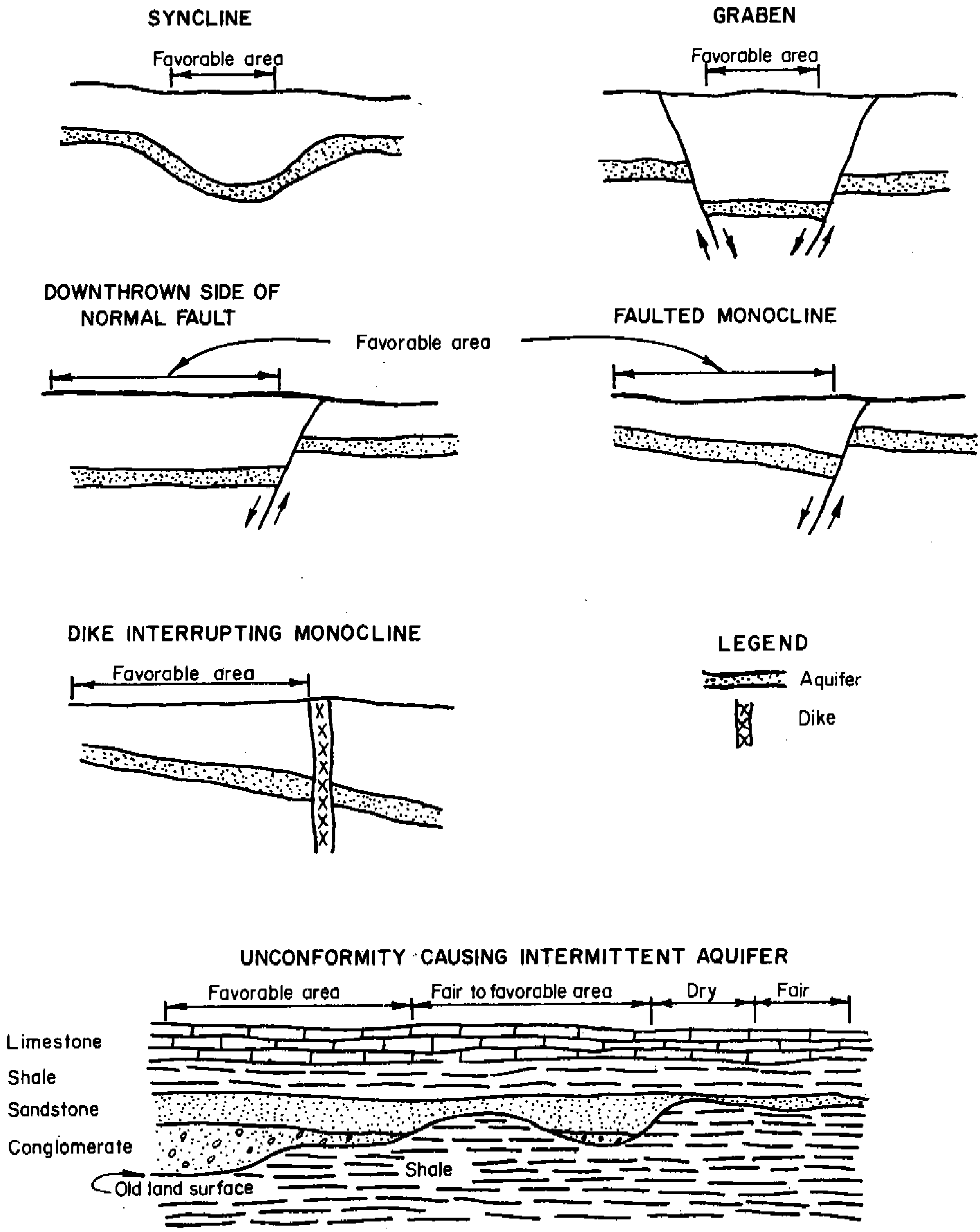


Figure 12-3.—Effect of geologic structure on ground water.

sive. They can result in the formation of intermittent aquifers (fig. 12-3) and also introduce doubt in predicting the occurrence of ground water at specific locations. Unconformities usually are marked by conglomerate (consolidated or cemented gravel) at the bottom of the younger formation. The upper part of the older formation may be weathered and fractured and contain water. A conglomerate, if fractured or not thoroughly cemented, may also yield ground water.

Conservation of Ground Water Resources

With the expanding use of the ground water resource, planners, developers, and users should recognize the need for conservation. Present conservation considerations are normally limited to controlling bacterial contamination. However, the conservation phase of planning, developing, and using the ground water resource must cover many other areas. Some considerations that are often overlooked are:

1. With two or more aquifers in one recovery system, measures should be designed to prevent cross-contamination.
2. Uncontrolled discharge from a free-flowing artesian aquifer may waste large amounts of ground water.
3. The conservation program for ground water development should analyze the amount that is economical to withdraw from the aquifer, the purpose of use, and the expected amount of recharge.
4. Locating a new recovery system too close to other operating systems may lower the water table and destroy the existing systems.

It is essential that the needed conservation program be included in the technical assistance for development of ground water resources.

Springs and Seeps

A spring or seep is a place where water from an aquifer discharges naturally onto the land surface. There are two classes of springs—gravity and artesian. Water may flow by gravity from a water table aquifer or by pressure from an artesian aquifer. Spring flows may vary considerably throughout the year, depending on the rise and fall of water in a water table aquifer or the variation of pressure in an artesian aquifer.

Gravity Springs

Gravity springs result where water moves from the water table aquifer through a permeable formation to the land surface or where the land surface intersects the water table. Gravity springs are normally low-yielding sources of ground water. However, they may supply enough water for individual household or livestock needs. There are three principal types of gravity springs: depression springs, contact springs, and fracture or tabular 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 basaltic lava. Figures 12-4 to 12-8 show the geologic structures for various types of gravity springs.

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 rise where these confined permeable strata are exposed near the surface. They also may rise 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 close by (see figures 12-9 and 12-10).

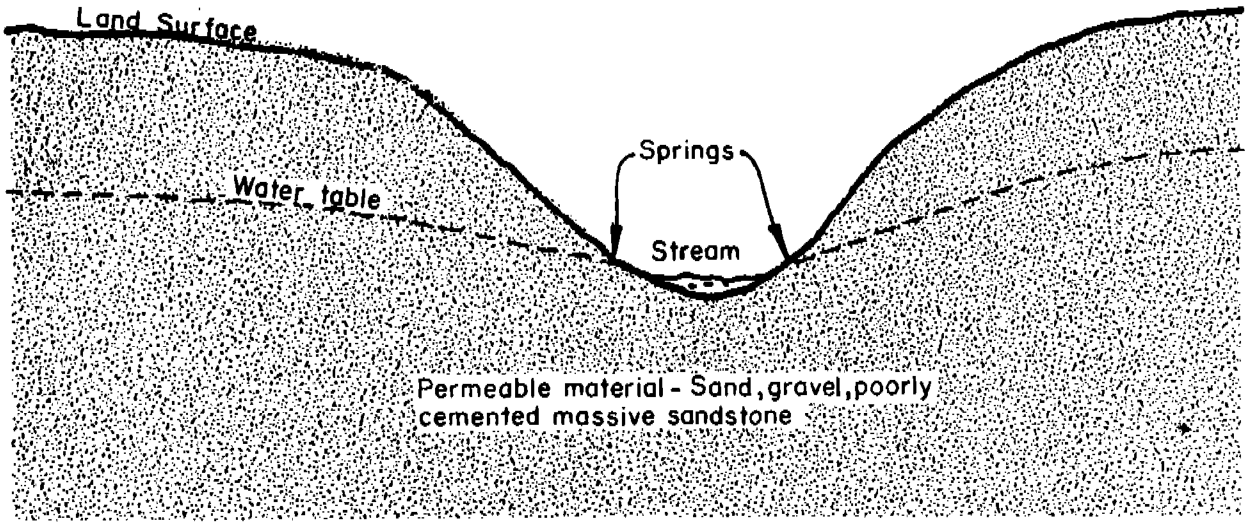


Figure 12-4.—Depression spring, seepage or filtration type.

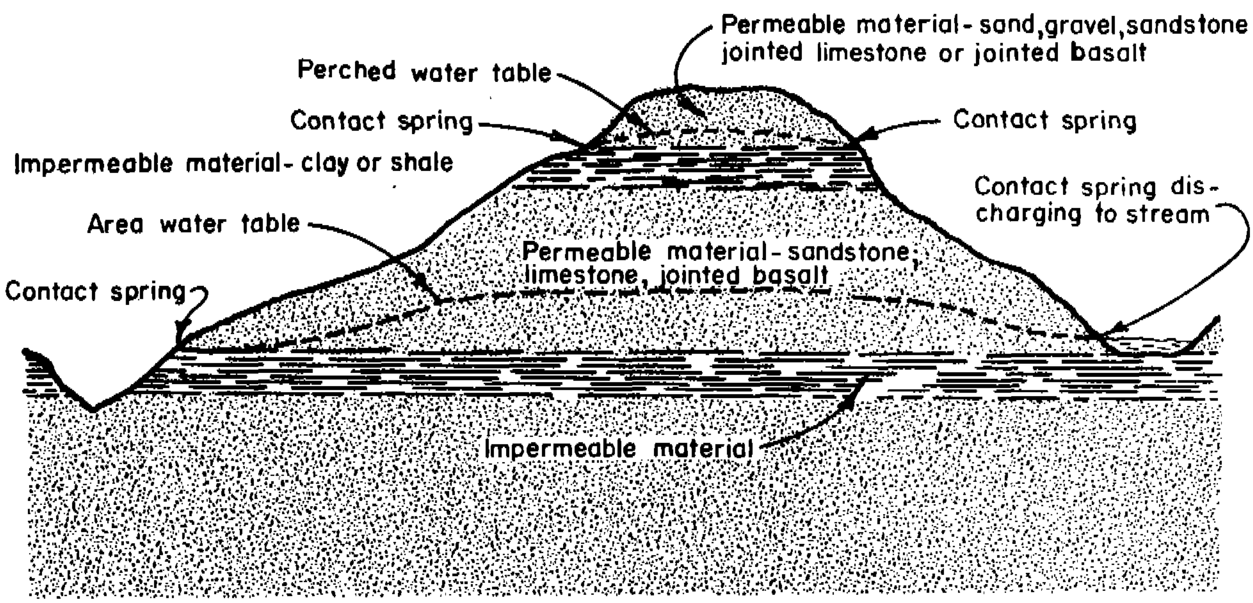


Figure 12-5.—Typical contact spring.

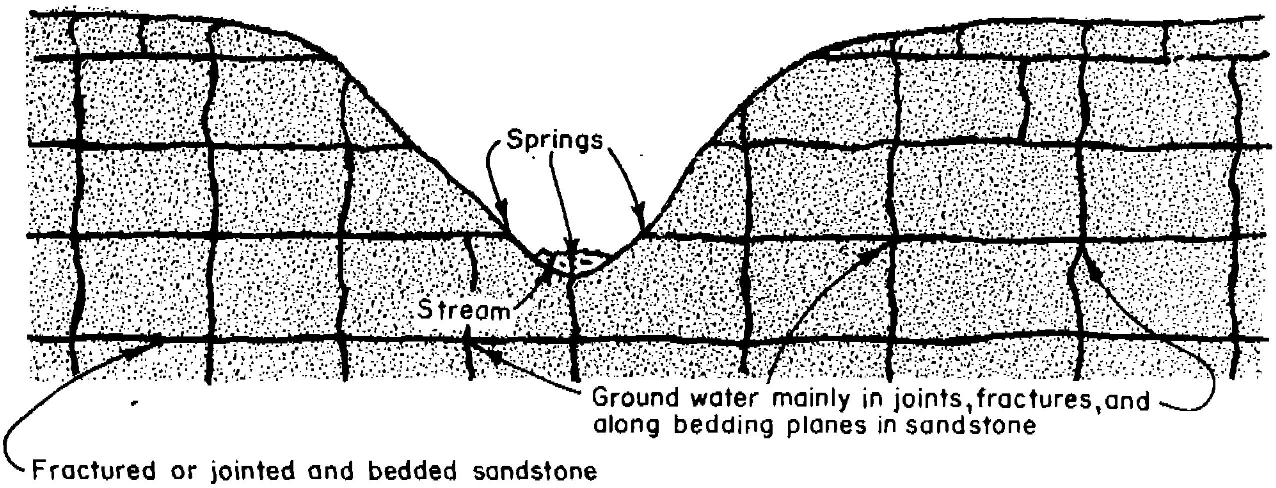


Figure 12-6.—Springs in jointed sandstone.

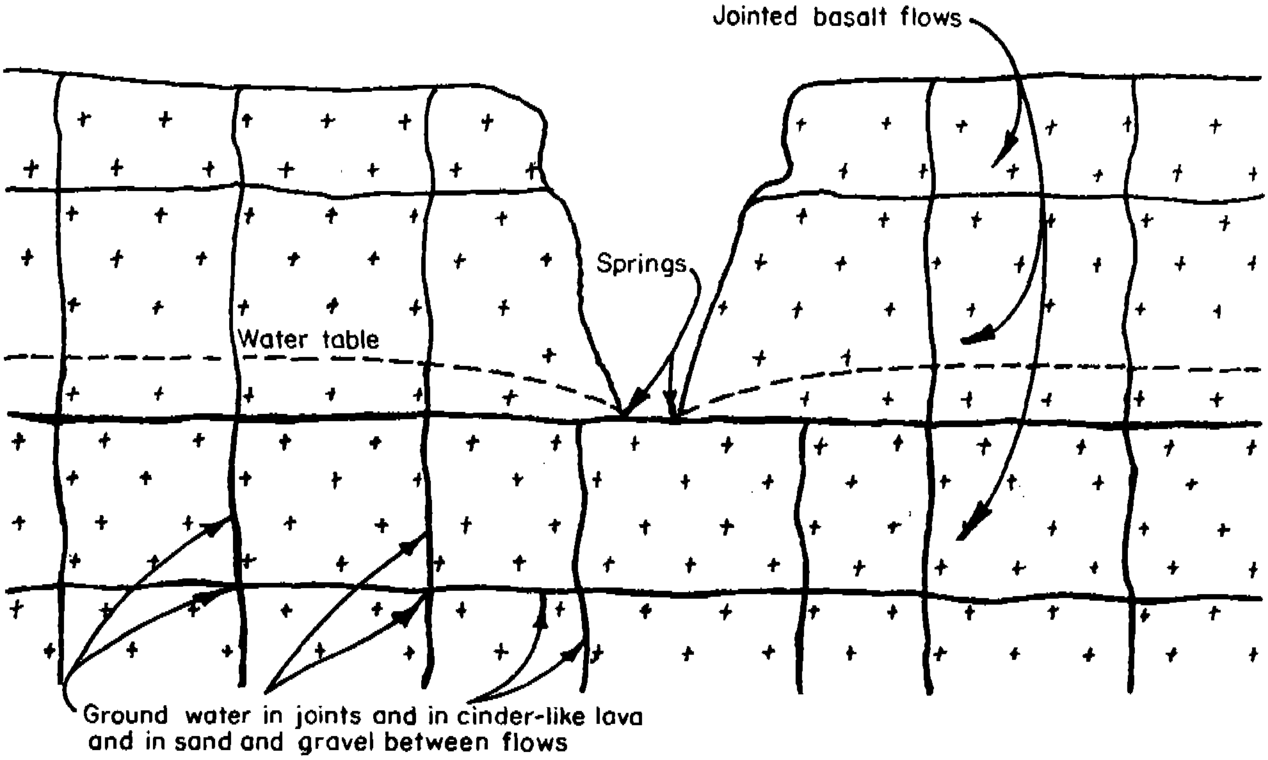


Figure 12-7.—Springs in jointed basalt.

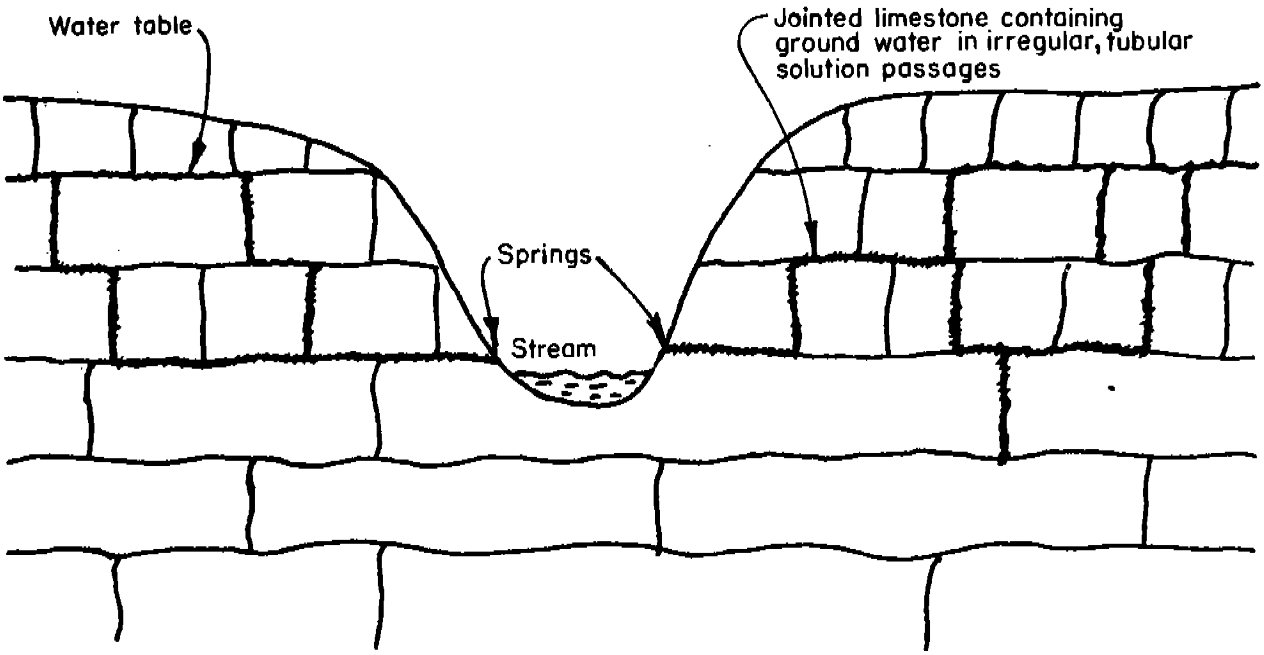


Figure 12-8.—Springs in jointed limestone.

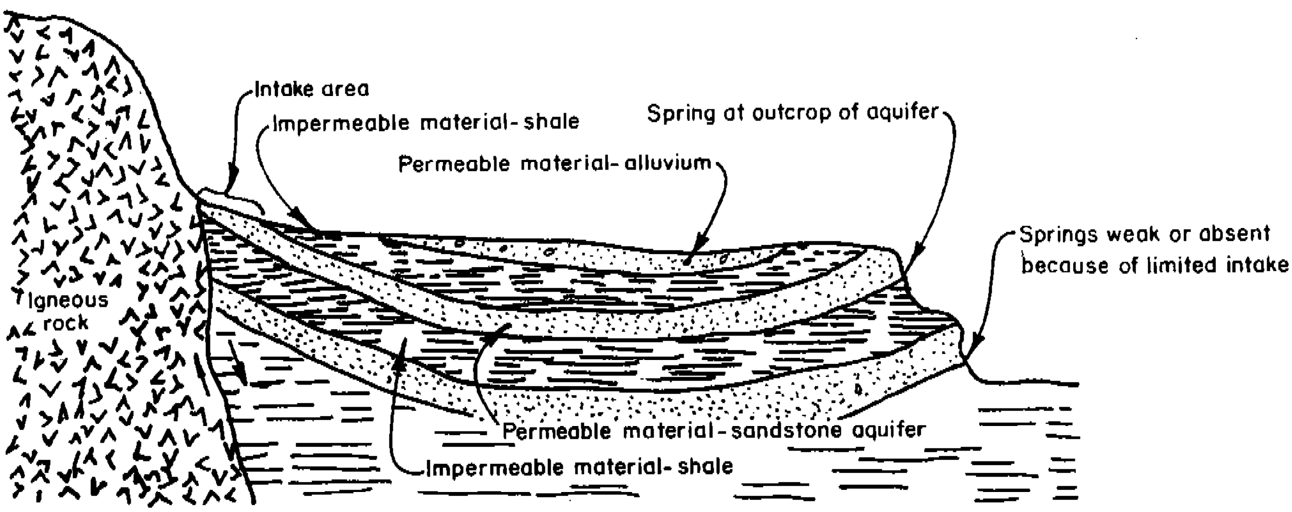


Figure 12-9.—Artesian springs at outcrop of aquifer.

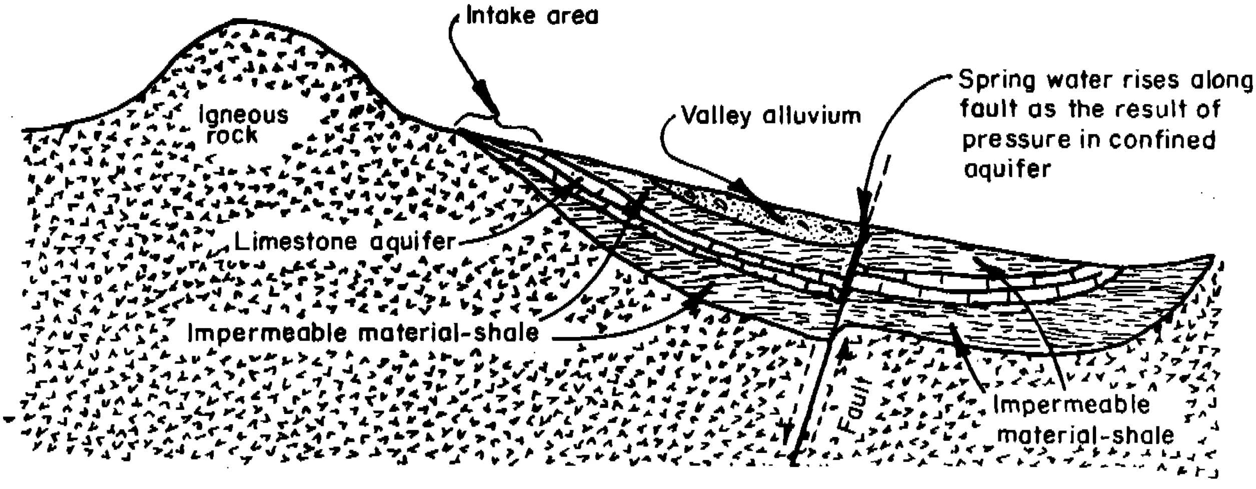


Figure 12-10.—Artesian spring along a fault.

Development

To be able to give useful information on ground water development, SCS personnel should assemble basic facts for the county or work area. Good information already exists that can be assembled for reference. Useful items include:

1. Copies of U.S. and State Geological Survey papers.
2. Copies of State computer printouts of well drillers' logs.
3. County Soil Survey Report and general description of geologic conditions.
4. A map showing ground-water development sites and including the geologic situation of each site.
5. Ground-water contour maps or structural contour maps of known aquifers.
6. A digest of geology reports from previous investigations.
7. Reports prepared for field office use, including county geology reports.

In developing springs or seeps it is necessary to (1) select a spring that can provide the required quantity or quality of water for the intended use and (2) protect it so that it can be used without continual maintenance.

Planning and Investigation

Ordinarily, the user has already identified potential spring sites for development; however, the potential volume is not usually known. The site should be studied during a dry season or the season of intended use and the flow reliability determined by visual observation or field measurements. The investigation should determine the nature of the water-bearing material and the hydrogeologic conditions that cause the spring.

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 ground water flow. After required use-associated practices have been determined, the plan should list them and state the agreement reached on the installation.

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.

Removing Obstructions

Deposits of fine-grained materials (sand, silt, or clay) brought to the outlet by ground water can obstruct spring flow, as can slope-wash materials de--posited on the outlet by surface waters. Vegetation growing in or about the outlet can obstruct flow and certainly consumes water that would otherwise issue as spring flow. Usually, removing obstructions adds appreciably to the spring flow.

If the spring water carries sediment to the opening, some means of desilting the water, such as a filter or sump, is desirable. 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 phreatophytes. These phreatophytes can be removed mechanically or killed 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.

Collecting Flow

At some locations collecting the flow issuing from several openings or seeping from an outcrop of water-bearing material is the only means of development. If water issues from fractures, the individual openings should be cleaned and the water collected in a tile or 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 and outletting.

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 so as to intercept as much of the water-bearing zone as practical.

A tunnel or infiltration gallery may be the most practical method of developing depression or contact springs in steep, hilly terrain. See table 12-1 for tunnel locations in consolidated and unconsolidated material. Tunneling in unconsolidated and in many consolidated deposits requires support of the roof and lining to prevent cave-ins. Miners or others experienced in and equipped for such work should be employed for extensive tunneling. The guiding principle in excavating tunnels for water development should be "follow the water."

Table 12-1—Tunnel location

Aquifer material	Material underlying the aquifer	Location of tunnel
Consolidated	Consolidated	In underlying material with top of tunnel exposing bottom of aquifer
Unconsolidated	Consolidated or unconsolidated	In aquifer at contact with underlying material

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 volume of ground water tributary to the outlet is great, lowering the outlet elevation may produce a substantial and long-lasting increase in flow. If the volume of water tributary to the spring is limited, the increase in flow may be temporary. The supply source should be studied before the outlet is lowered.

Construction Techniques

Previous experience by a contractor or farmer may be the single most important factor in developing a spring. Each site has its own characteristics, and the method of development to use may not be evident until construction starts. The method of development chosen should be based on characteristics of the spring, such as topography, nature of the water-bearing material, type of opening from which water issues, and volume of 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 issue at some other 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 12-11 and 12-12. The collection system shown is suitable for developing a seepage or filtration spring (fig. 12-4) or a contact spring (fig. 12-5). Experience has shown the following to be good construction practices.

Collector.—The collector can consist of tile or perforated pipe laid in graded small gravel or graded sand (fig. 12-11), or it can be a ditch backfilled with graded small gravel or graded sand. When installing a collector in permeable material, it is good practice to construct a cutoff wall of clay, concrete, 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.

In plan, 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 100-150 mm (4-6 in) thick. Masonry, sheet piling, plastic, or clay may also be used for the headwall, which should extend deep enough to prevent underflow.

Spring box.—A spring box may be constructed in the apex of the V-shaped headwall as shown in figure 12-11. 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, or other prefabricated materials. Wooden spring

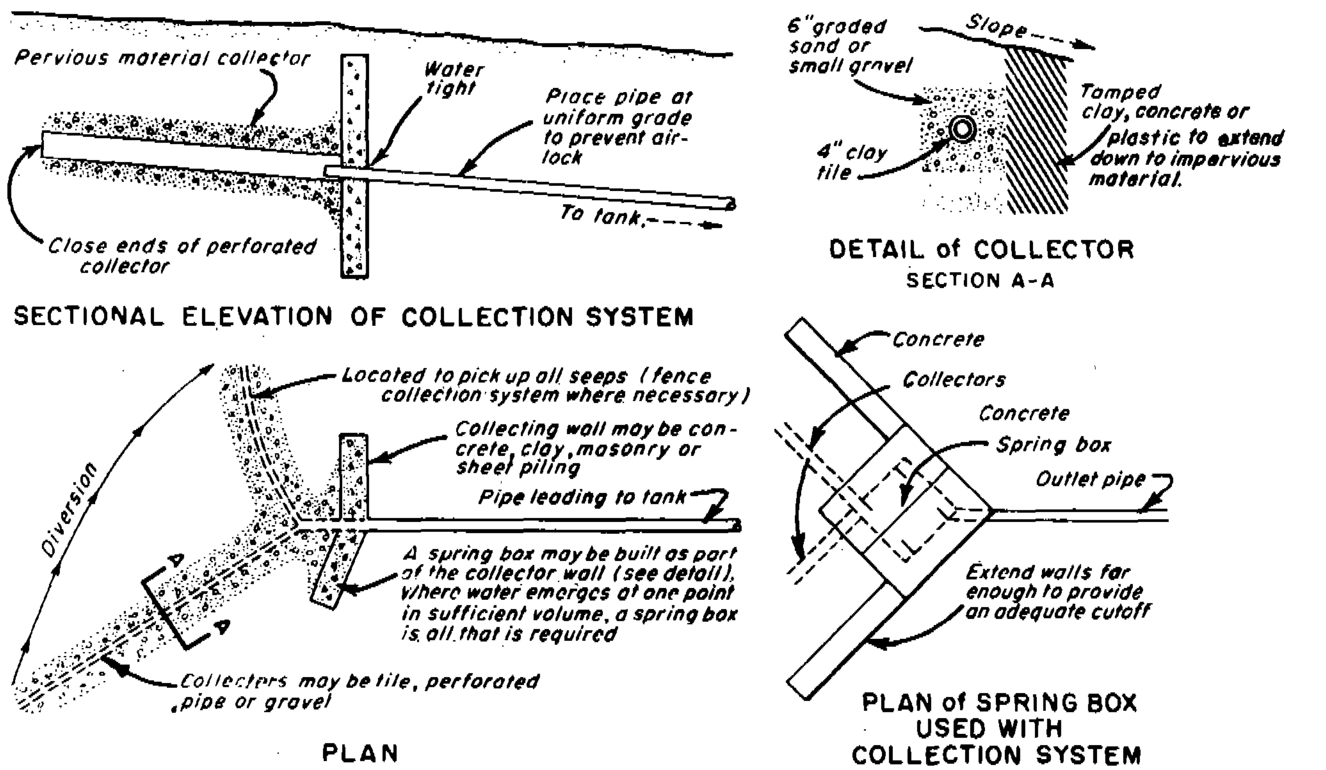


Figure 12-11.—Spring collection system.

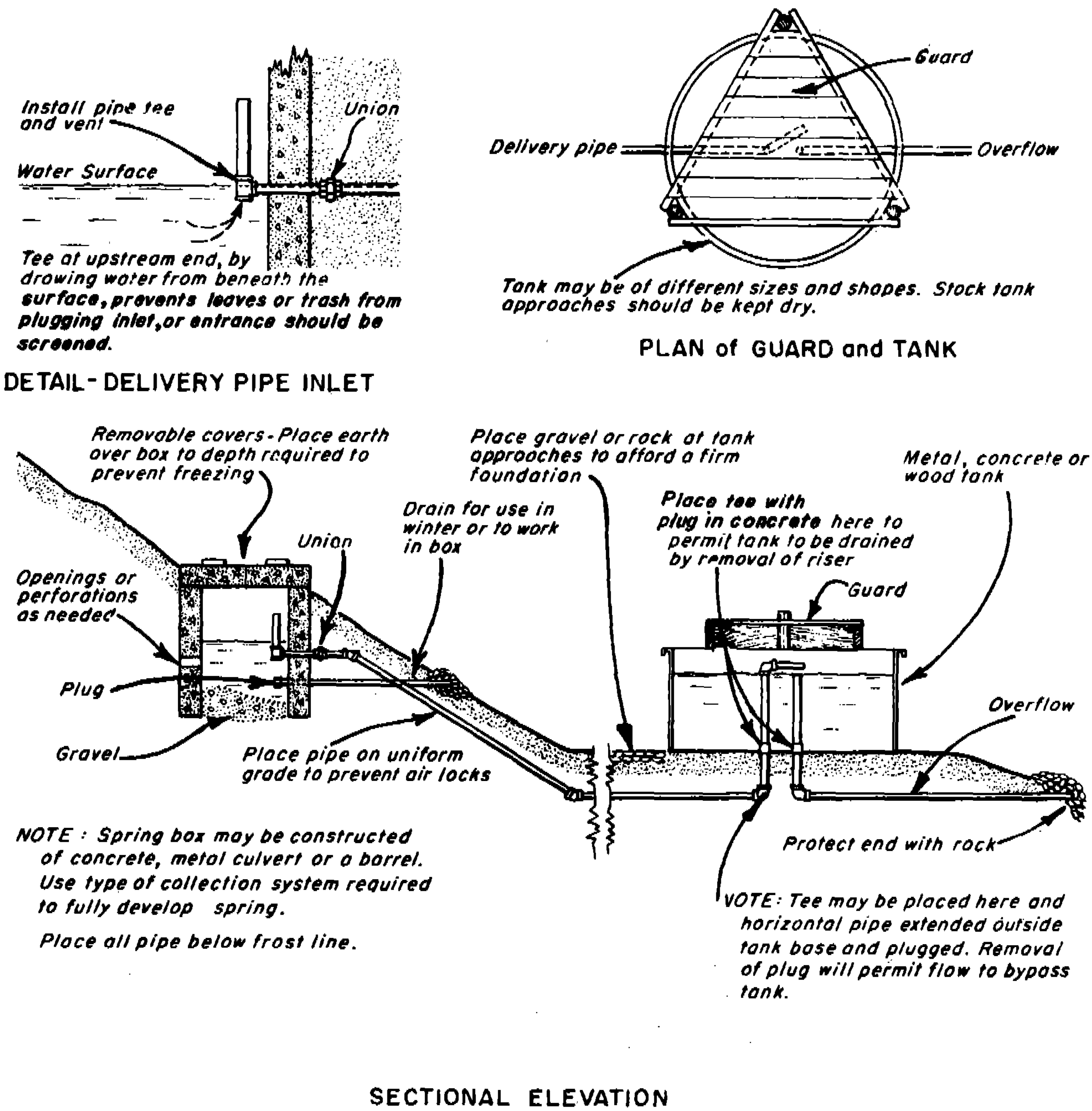


Figure 12-12.—Spring box and pipe arrangement.

boxes should be made of redwood or treated lumber. 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 planted to vegetation (fig. 12-12).

Protection.—Springs are frequently at locations susceptible to flooding. The spring and its appurtenant structures should be protected to permit use without continual maintenance. Properly located diversions can often afford protection. The spring itself can be developed so that floodflows passing over the top do not cause damage. A concrete retaining or wingwall 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 place the watering tank above flood crests. This type of development is illustrated in figure 12-13.

Delivering Spring Water by Gravity Flow

An important part of the spring development is the arrangement of the delivery and overflow pipe layout (fig. 12-12). Pipelines can be of plastic, copper, galvanized iron, or asbestos cement. 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 32 mm (1¼ in) should be used where the grade is over 1 percent. Where the grade is between 0.5 percent and 1.0 percent, a 40-mm (1½-in) minimum is recommended. Grades under 0.5 percent require a 50-mm (2-in) minimum 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 Chapter 3, Hydraulics, of this manual for additional information on waterline sizes and capacities. Cleaning may be made easier by placing "T's" or "Y's" with plugs at strategic points in the pipelines.

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. Vents should be installed to improve flow in long delivery lines or at major changes in grade. Pipes should be laid below the frostline and covered to prevent freezing.

The inlet to the pipe leaving the spring box should be placed at least 150 mm (6 in) 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 union should be placed on the pipe outside of the wall to permit removal for maintenance. A tee and vent pipe should be installed on the pipe within the spring box to reduce plugging from 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 because, even though the water may freeze around the edge of the tank, it will tend to stay open at the center. Figure 12-12 shows a good method of bringing the delivery pipe into the tank and bypassing the flow.

Pumps

If the outlet of the spring is lower than the point of use, a pump powered by an electric motor, internal combustion engine, hydraulic ram, or windmill can be used.

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 to an elevation above the source of supply. Figure 12-14 shows a typical ram installation and a diagram of a ram.

Briefly, a hydraulic ram works as follows: Water from the supply flows down the drive pipe to the ram, thus developing a certain power because of its weight and movement. It flows through the outside valve of the ram until it reaches a certain velocity, whereupon the valve closes. The column of water continues on through the inside valve into the air chamber. When the pressure in the air chamber equalizes and overcomes the power in the column of water, a rebound takes place that closes the inside valve and opens the outside valve. This allows the water to start flowing again, and the entire process is repeated. The cycle is repeated from 25 to 100 times per minute, building up pressure in the air chamber, which in turn forces water through the delivery pipe to the reservoir.

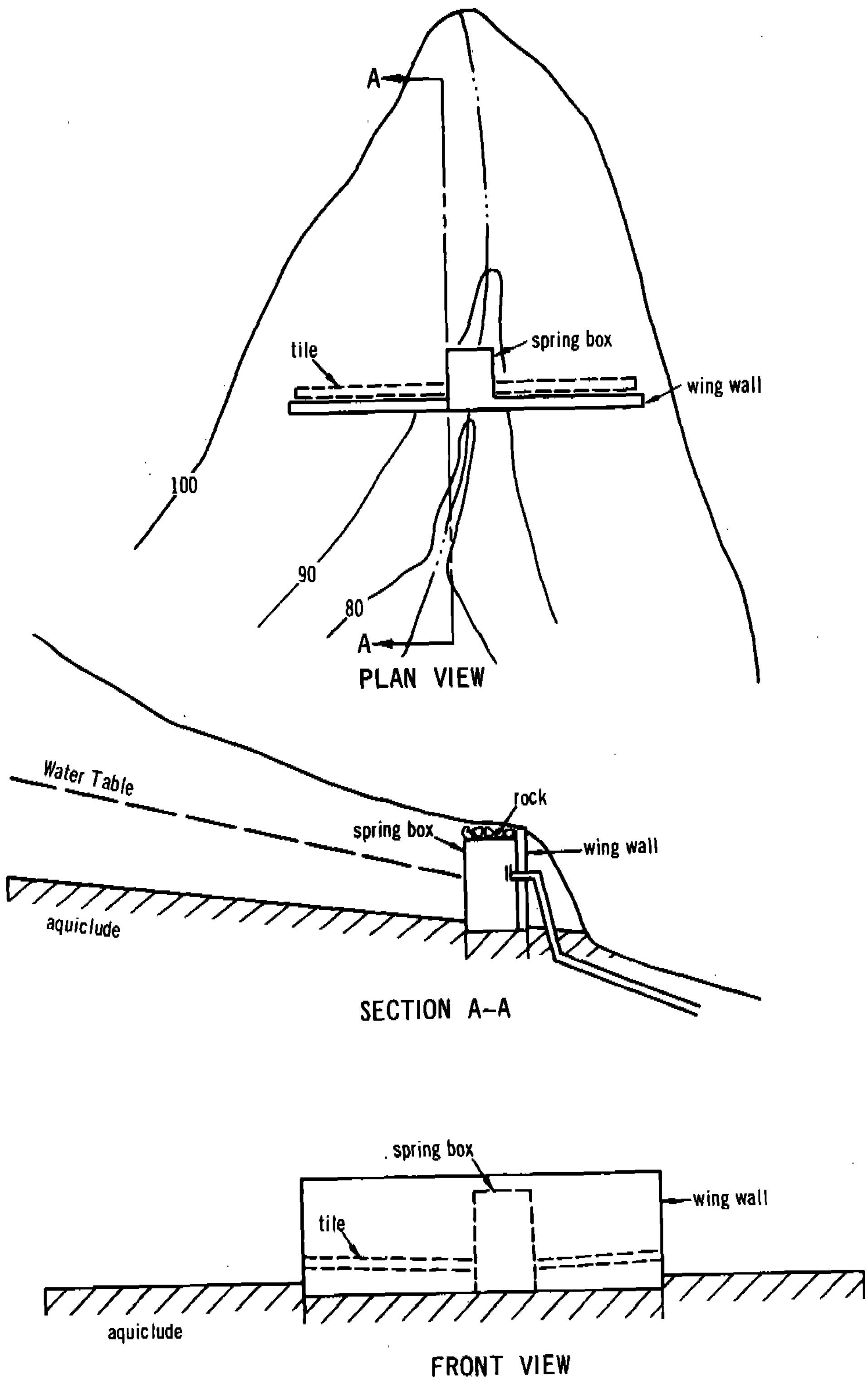


Figure 12-13.—Spring development in stream channel.

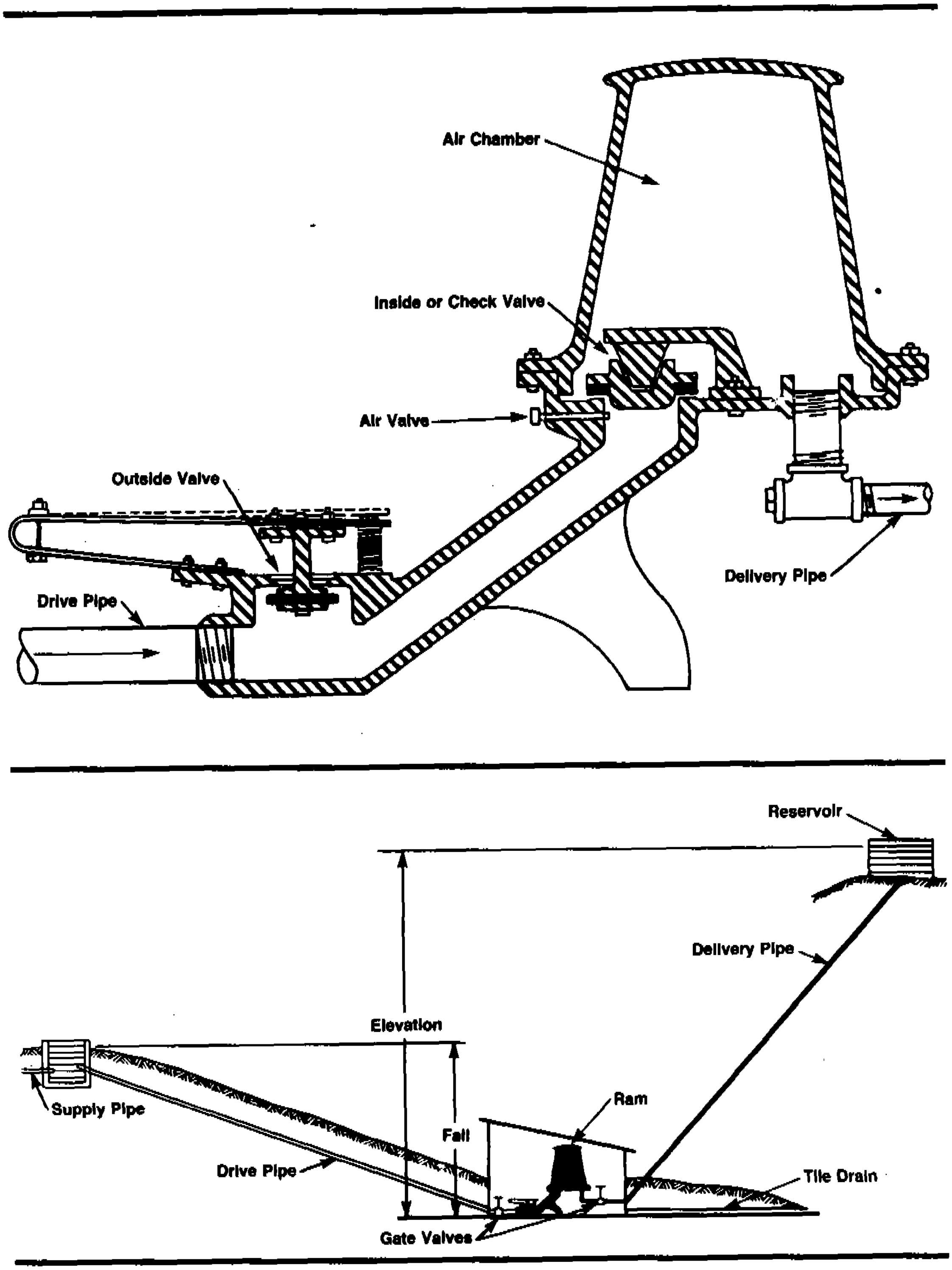


Figure 12-14.—Hydraulic ram.

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 0.1 L/s (1½ gal/min) or more under a head of not less than 0.6 m (2 ft).

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

$$D = \frac{V \times F \times e}{E}$$

where

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

To ascertain the practicability of installing a ram under any particular set of conditions, collect the following information:

1. Number of liters per second (gallons per minute) that the spring, artesian well, or stream will deliver.
2. Number of liters (gallons) per day desired from the ram.
3. Available fall in meters (feet) from the water supply to the ram.
4. Elevation in meters (feet) to which water is to be raised above the ram.
5. Pipeline distance in meters (feet) from the ram to the point of discharge.
6. Pipeline distance in meters (feet) from the source of water to the ram.

This information will enable a ram manufacturer to recommend a specific installation. Because of the variations encountered in ram installations and the differences in rams built by various manufacturers, no attempt is made to discuss the details of selection and installation.

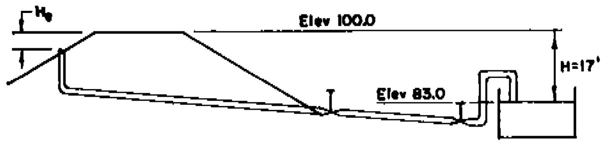
The following is a sample problem for determining delivery pipe size:

Find:

Required size of pipe for delivering water from a pond or spring development to watering trough.

References:

Chapter 3, Hydraulics, and figures 12-15A, B, and C.



Given:

Water surface in pond or spring box—elev. 100.0 ft
Water surface in tank—elev. 83.0 ft
Length of pipe—490 ft
Four 90° elbows
Two gate valves
Minimum discharge required—7 gpm
Use galvanized iron pipe (n = 0.017)

Determine:

Required pipe diameter
Minimum entrance head required (H_e) = entrance loss + velocity head

Procedure:

1. Find available head per foot of pipe (approx).

$$H/L = \frac{100 - 83}{490} = 0.035 \text{ ft/ft}$$

2. From figure 12-15B, flow of 7 gpm versus head loss of 0.035 ft/ft gives a pipe diameter between 1¼ in. and 1½ in. Use 1½-in. diameter pipe; then Q = 9 gpm and velocity = 1.63 fps.
3. Interpolate from chart I the minimum head required over the entrance when velocity = 1.63 fps: H_e = 0.08 ft.
4. Determine exact head available (ft/ft).

$$\frac{\text{Total head} - (\text{entrance loss} + \text{velocity head})}{\text{Length of pipe} + \text{equivalent length of fittings (chart II)}}$$

DISCHARGE THRU PIPE "FLOWING FULL" GALLONS PER MINUTE VS. HEAD IN FEET REQUIRED TO OVERCOME FRICTION LOSS PER FOOT OF PIPE	GALV. IRON PIPE, NEW TO FAIR COND. n = 0.014 (MANNING'S) c = 110 (HAZEN-WILLIAMS)

CHART I

VELOCITIES	1	2	3	4	5	6	7	8
MIN. HEAD (FT.) REQ. OVER ENTRANCE (He)	0.03	0.11	0.25	0.45	0.69	1.0	1.35	1.76

CHART II

EQUIVALENT LENGTHS OF PIPE

n = 0.014	DIAMETER						
	1/2	3/4	1	1 1/4	1 1/2	2	3
90° ELBOW (STANDARD)	0.2	0.4	0.6	0.8	1.0	1.5	2.6
45° ELBOW (STANDARD)	0.2	0.3	0.4	0.6	0.7	1.1	1.9
GATE VALVE (OPEN)	0.1	0.2	0.3	0.3	0.4	0.6	1.1
CONTRACTION ($\frac{d_1}{d_2} = 1.5$)	0.1	0.2	0.2	0.3	0.4	0.5	1.0

Mannings Formula: $Q = \frac{0.276}{n} d^{8/3} s^{1/2}$

Q = Quantity of Flow in Gal./Min.

d = Diameter of Pipe in Inches

n = Coefficient of Roughness of Pipe

s = Hydraulic Gradient in Ft./Ft. = h_f/L

h_f = Friction Head Loss in Feet

L = Length of Pipe in Feet

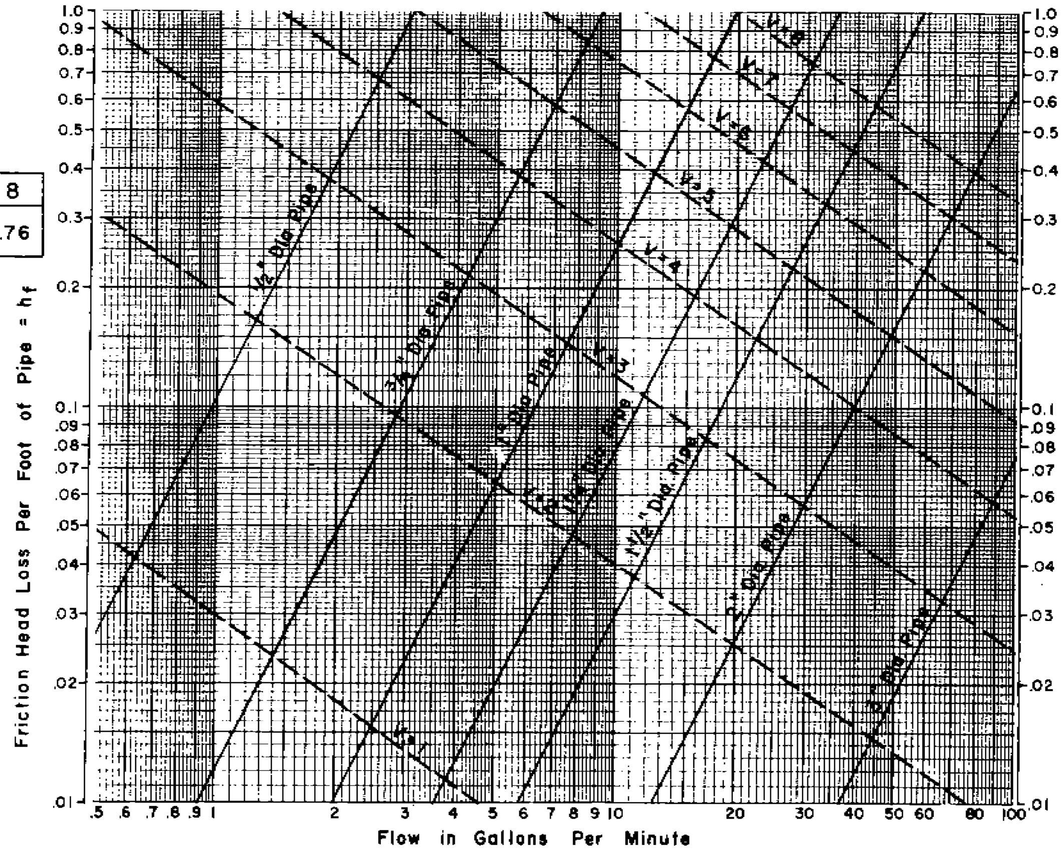


Figure 12-15A.—Discharge through pipe flowing full.

DISCHARGE THRU PIPE "FLOWING FULL"
GALLONS PER MINUTE VS. HEAD IN FEET REQUIRED TO OVERCOME
FRICTION LOSS PER FOOT OF PIPE

GALV. IRON PIPE, OLD TO POOR COND.
n = 0.017 (MANNING'S)
c = 95 (HAZEN - WILLIAMS)

CHART I

VELOCITIES	1	2	3	4	5	6	7	8
MIN. HEAD (FT) REQ. OVER ENTRANCE (He)	0.03	0.11	0.25	0.45	0.69	1.0	1.35	1.76

CHART II

EQUIVALENT LENGTHS OF PIPE

n = 0.017	DIAMETER						
	1/2	3/4	1	1 1/4	1 1/2	2	3
90° ELBOW (STANDARD)	0.2	0.3	0.4	0.6	0.7	1.0	1.8
45° ELBOW (STANDARD)	0.1	0.2	0.3	0.4	0.5	0.7	1.2
GATE VALVE (OPEN)	0.1	0.1	0.2	0.2	0.3	0.4	0.7
CONTRACTION ($\frac{d_1}{d_2}$ = 1.5)	0.1	0.1	0.1	0.2	0.2	0.4	0.6

Mannings Formula: $Q = \frac{0.276}{n} d^{8/3} s^{1/2}$

Q = Quantity of Flow in Gal./Min.

d = Diameter of Pipe in Inches

n = Coefficient of Roughness of Pipe

s = Hydraulic Gradient in Ft./Ft. = h_f/L

h_f = Friction Head Loss in Feet

L = Length of Pipe in Feet

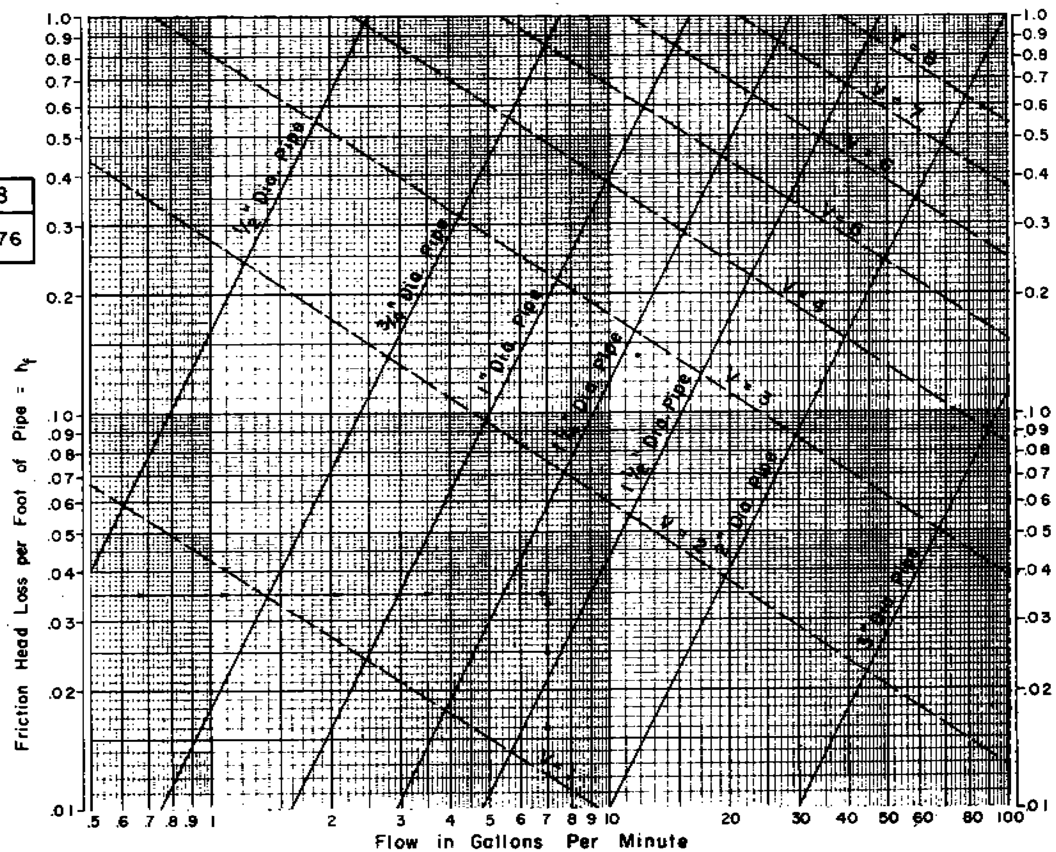


Figure 12-15B.—Discharge through pipe flowing full.

DISCHARGE THRU PIPE "FLOWING FULL"
GALLONS PER MINUTE VS. HEAD IN FEET REQUIRED TO OVERCOME
FRICTION LOSS PER FOOT OF PIPE

PLASTIC OR COPPER PIPE
n = 0.009 (MANNING'S)
c = 140 (HAZEN - WILLIAMS)

CHART I

VELOCITIES	1	2	3	4	5	6	7	8
MIN. HEAD (FT.) REQ. OVER ENTRANCE (He)	0.03	0.11	0.25	0.45	0.69	1.0	1.35	1.76

CHART II

EQUIVALENT LENGTHS OF PIPE

n = 0.009	DIAMETER						
	1/2	3/4	1	1 1/4	1 1/2	2	3
90° ELBOW (STANDARD)	0.6	1.0	1.4	2.0	2.5	3.7	6.3
45° ELBOW (STANDARD)	0.4	0.6	1.0	1.3	1.7	2.4	4.2
GATE VALVE (OPEN)	0.2	0.4	0.6	0.8	1.0	1.5	2.6
CONTRACTION ($\frac{d_1}{d_2} = 1.5$)	0.2	0.3	0.5	0.7	0.9	1.3	2.2

Mannings Formula: $Q = \frac{0.276}{n} d^{8/3} s^{1/2}$

Q = Quantity of Flow in Gal./Min.

d = Diameter of Pipe in Inches

n = Coefficient of Roughness of Pipe

s = Hydraulic Gradient in Ft./Ft. = h_f/L

h_f = Friction Head Loss in Feet

L = Length of Pipe in Feet

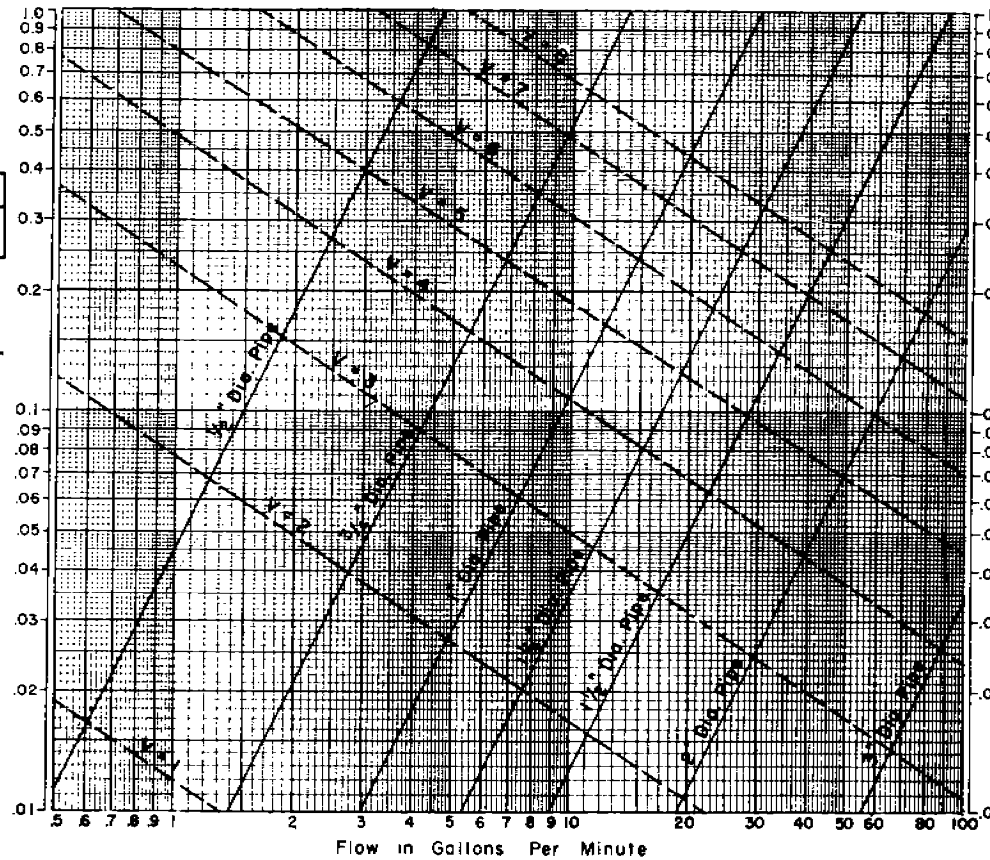


Figure 12-15C.—Discharge through pipe flowing full.

$$\frac{17.0 - 0.08}{490 + (4 \times 0.7) + (2 \times 0.3)} = \frac{16.92}{493.4} = 0.034 \text{ ft/ft}$$

5. Find actual Q when head available = 0.034 ft/ft. Figure 12-15B, Q = 8.86 (meets requirements)

Windmills.—Windmills can power pumps for water for livestock or domestic use. A windmill can be expected to produce from 0.15 kW (0.2 hp) for a 1.8-m-diameter (6-ft) mill to 1.5 kW (2.0 hp) for a 4.9-m-diameter (16-ft) mill during periods of adequate wind movement. Windmills are best adapted for use with a piston-type pump. For best results, the windmill and pump cylinder must be appropriate for the prevailing wind velocity.

The mill should have enough power to pump the quantity of water specified. Table 12-2 gives the approximate delivery capacity for pumps powered by windmills of various sizes operating in a wind strong enough to run them at their maximum number of strokes. Where the prevailing winds are light or variable, where the wind usually blows only a few hours each day, or where the exposure is poor, an oversized mill should be selected. A large tank storage capacity is also desirable. Pumps and cylinders used with the mills of various sizes should be able to give a clear piston stroke equal to 1/12 the diameter of the windmill; for example, 200 mm (8 in) for the 2.4-m (8-ft) mill and 250 mm (10 in) for the 3-m (10-ft) mill. The capacities shown in table 12-2 are based on the long stroke of the mills. When the short stroke is used, the capacity is usually reduced about 25 percent. Use of the short stroke is not recommended except as necessary to fit an existing pump installation.

Towers may be built of either wood or steel. Wood towers are more stable during high winds and do not attract lightning as much as steel. The tower should be tall enough that the wheel is above all wind obstructions.

Electric motors.—Where available electricity can be used as a power source for pumping water, an electric motor properly selected and protected should operate trouble free for many years. The 60-cycle, 220- or 440-V, three-phase squirrel-cage induction motor is the type generally used.

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 (7½ hp), which may not be adequate for high lifts and high-yield developments.

Internal combustion engines.—The rated kilowattage (horsepower) of internal combustion engines greatly exceeds the kilowattage (horsepower) 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 kilowatt (horsepower) output, and engine ratings are based on performance at sea level and a temperature of 15.5° C (60° F), corrections must be made for most irrigation pumping installations. General rules for correcting for elevation and temperature are: (1) reduce the continuous load rating 3 percent for every 300 m (1,000 ft) above sea level, and (2) reduce the continuous load rating 1 percent for every 5.5 Celsius (10 Fahrenheit) degrees above 15.5° C (60° F).

In addition to the above reductions, the rated kilowattage (horsepower) should be further reduced 5 to 10 percent for consumption by accessories (fan, generator, water pump) and 15 to 20 percent for continuous service. See National Engineering Handbook, Section 15, Chapter 8, to determine how to calculate these reductions.

Water Trough

The water trough should be located where it is easily accessible to the livestock and well away from the spring box and collection system. It may be located to serve more than one field. The trough should be placed at a well-drained location, or the site should be drained. Overflow water should be piped away, or the area adjacent to the trough should be paved, graveled, or otherwise treated as necessary to provide firm footing. The size of the trough depends on the number of livestock served and the volume of inflow. For a given number of livestock, a larger trough is needed for a smaller flow. Troughs usually are rectangular or circular and should be constructed of reinforced concrete, galvanized steel, fiberglass, or other equally permanent materials. Uniformity permits standard installation procedures, including the use of portable forms, the assembly of standard pipe kits, and the issuance of job sheets to farmers. Concrete watering troughs of the two sizes and shapes

Table 12-2.—Delivery capacity of water pumps powered by windmills

Diameter of pump cylinder	Delivery capacity							
	Rate with windmill of indicated diameter		Lift elevation with windmill of indicated diameter					
	6 ft	8-16 ft[1]	6 ft	8 ft	10 ft	12 ft	14 ft	16 ft
Inches	*Gal/hr*		*Feet*					
1¾	105	150	130	185	280	420	600	1,000
1⅞	125	180	120	175	260	390	560	920
2	130	190	95	140	215	320	460	750
2¼	180	260	77	112	170	250	360	590
2½	225	325	65	94	140	210	300	490
2¾	265	385	56	80	120	180	260	125
3	320	470	47	68	100	155	220	360
3¼		550			88	130	185	305
3½	440	640	35	50	76	115	160	265
3¾		730			65	98	143	230
4	570	830	27	39	58	86	125	200
4¼		940			51	76	110	180
4½	725	1,050	21	30	46	68	98	160
4¾		1,170				61	88	140

[1]The amount of water pumped by mills ranging in diameter from 2.4 to 5 m (8 to 16 ft) is the same with cylinders of a given diameter.
Note: Conversion factors to metric are 1 in. = 25.4 mm, 1 ft = 0.3048 m, 1 gal/hr = 0.3785 L/hr.

shown in figures 12-16 and 12-17 will meet the needs under most conditions. Numerous kinds of prefabricated troughs are available commercially.

Stockwater Dugouts

Dugouts are excavations below the water table, usually made with dragline equipment. They need to extend deep enough into the zone of saturation to ensure a water supply during dry periods. They are generally located in valleys of stream systems but may be developed wherever the water table is permanently close to the land surface. In areas of shallow ground water, where dugouts are usually constructed, a shallow drilled or dug well may be a more satisfactory livestock watering facility. If electricity is available, a watering tank with a float switch to activate an electric pump can provide a more desirable and sanitary water supply.

Dugouts are favored water developments because they are easy to construct, are automatic waterholes, usually require very little attention, are economical, and usually contain good-quality water because it is moving ground water. The unfavorable aspects of dugouts are that they may have poor sanitation, be potential death traps where foundation materials are so soft that animals get stuck in the mud, are unsuitable for winter use in cold climates because of ice, and are subject to overflow, debris, and sediment deposition. The sanitary hazards pertain to bacterial contamination and lack of drainage away from the water supply. Floodwaters may flush some bacteria, but they also introduce loose mud that increases the hazard of trapping animals.

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 ground water for long distances. Similarly, if material from such sources of contamination finds access to the tubular channels in glacial drift, this water may retain the contaminants for long periods and long distances. The following precautionary measures help to ensure a consistently high quality of developed spring water:

1. Test the water quality before a spring is developed.
2. Install a diversion uphill from the site to intercept surface-water runoff and carry it to a safe outlet.
3. Build a fence to exclude livestock from the

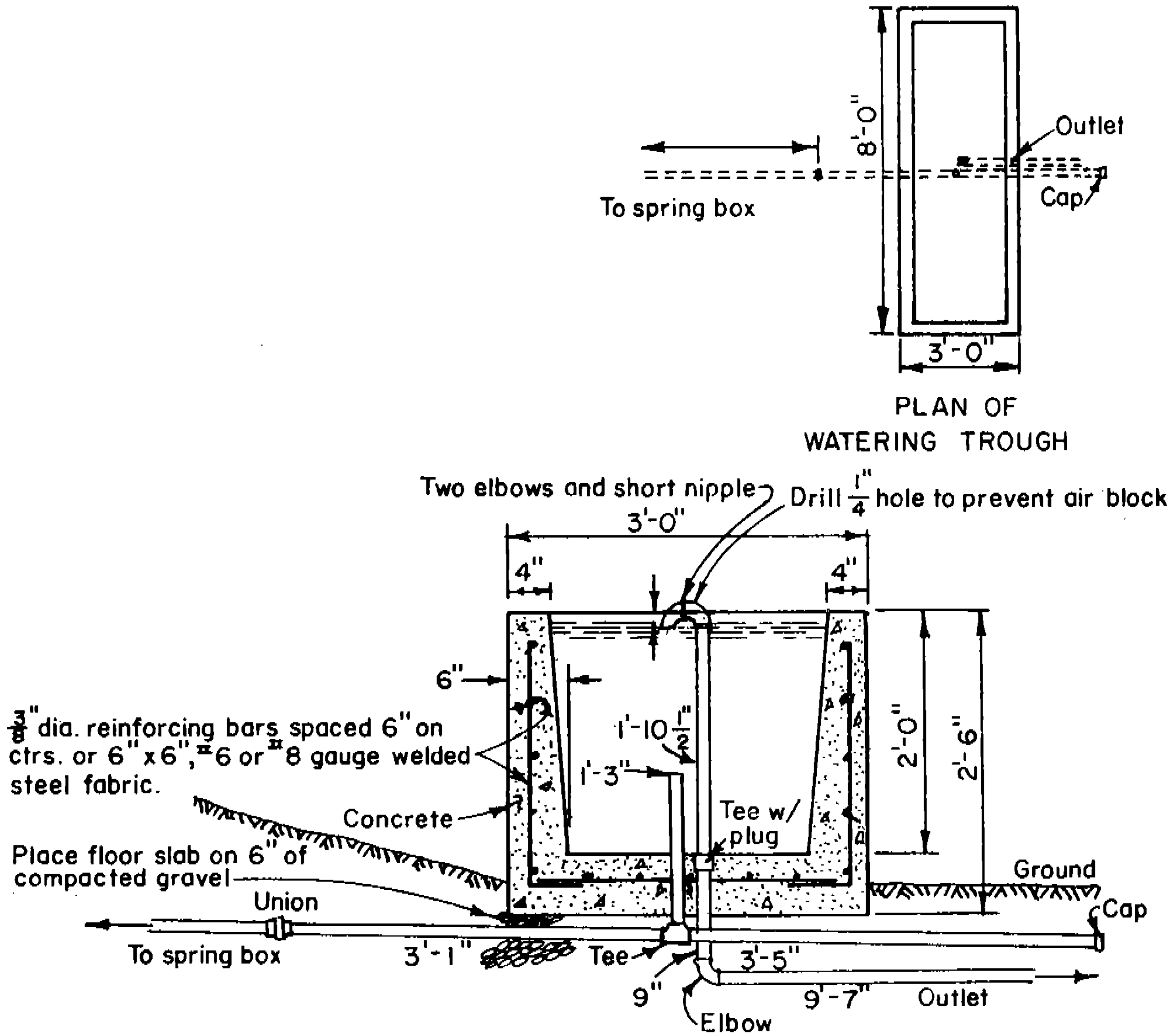


Figure 12-16.—Details of rectangular trough.

surface-water drainage system at all points uphill from the source.

4. Provide access to the tank for maintenance.

5. 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.

6. 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, you may be able to shut off the flow and thus keep the disinfectant in the encasement for 24 hours. If the flow cannot be shut off entirely, supply disinfectant continuously for as long as practicable.

7. Continually check the trough for algae buildup, mudholes, and animal damage.

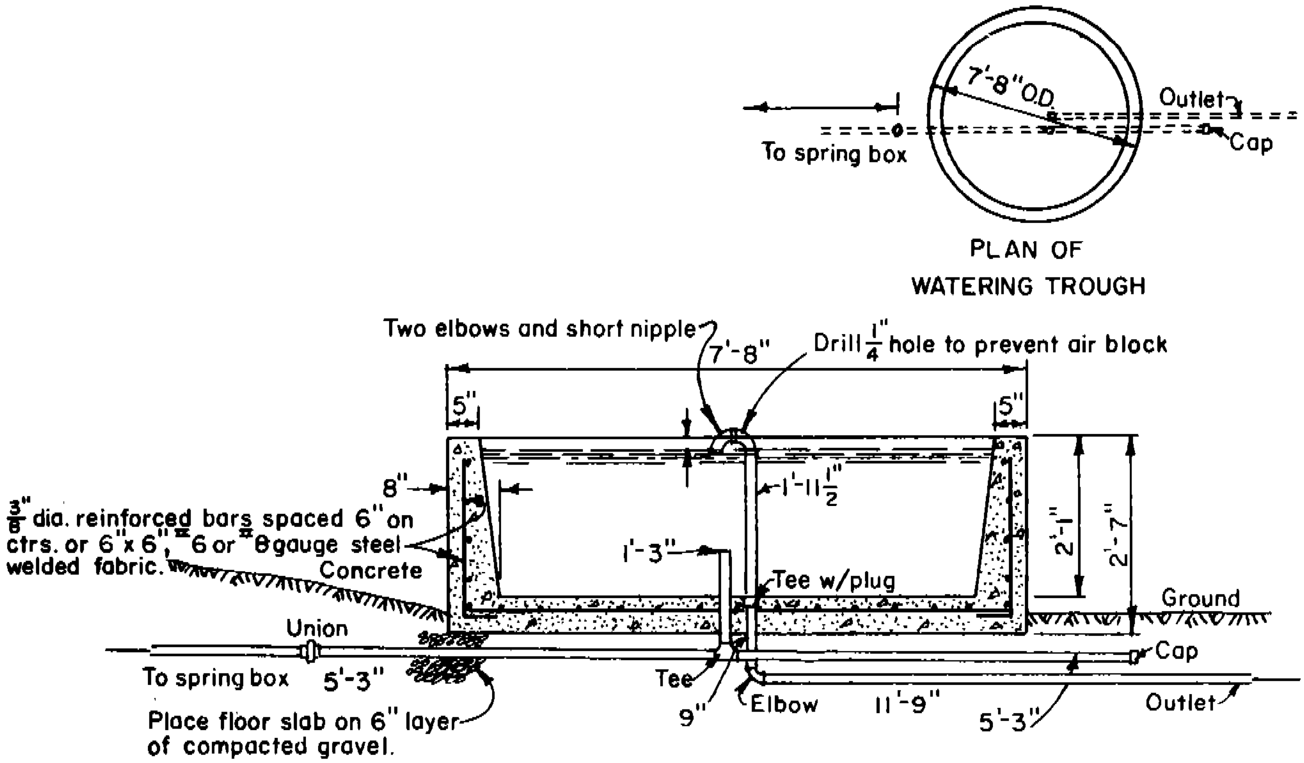


Figure 12-17.—Details of circular trough.

Wells

A well to extract water from ground water aquifers consists of a hole, with or without a supporting casing, extending from the ground surface to or into a water-bearing formation. If properly constructed and developed, it will permit pumping or artesian pressure delivery of the maximum quantity of water that a ground water aquifer(s) can supply.

Types

Wells are dug, driven, or drilled, depending on the depth to which they must go, the nature of the materials through which they must pass, the rate at which water will be removed, and the elevation of the ground water table.

Dug or Open Pit

This type of well is usually excavated by hand down into a shallow water-bearing stratum. The dug well was used widely before modern well-drilling equipment became available. Today the most practical uses of the dug well are to develop shallow, low-yielding aquifers, where large-diameter wells are required, and to permit the installation of a pumping unit nearer to the ground water table.

Driven

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 15 m (50 ft).

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; the earth material may be removed from the pipe by a sand bucket or a pump; or a hydraulic jet may be used to dislodge and 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 flow can be obtained.

Drilled

A drilled well may be constructed through any material and to great depths. The drilling equipment consists of a derrick, a power plant, and special tools. Many types of drilling rigs are in general use:

1. The rotary auger 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.
2. The cable tool 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 80-600 mm (3-24 in) in diameter. Drill depths normally do not exceed 450 m (1,500 ft) unless heavy-duty, nonstandard machines are used.
3. The hydraulic rotary 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.
4. The reverse hydraulic rotary 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.
5. The air rotary 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 of hard rock in arid areas.

Table 12-3 lists various methods of constructing a well and their appropriate application.

Site Selection

A study of the geology and ground water availability is important in obtaining successful wells. These elements are essential: an adequate and dependable water source, sufficient underground reservoir space, and a structure or conditions that act to retain water. It is best to determine whether these elements are present before deciding to drill.

The geologic investigation should always include a review of existing information on ground water for the particular area. After acquiring the information, the following steps should be taken:

1. Prepare a base map or obtain aerial photographs of the area. The map or photograph should be to a scale of at least 100 mm to the kilometer (4 in. to the mile).
2. Interview owners of wells in the area.
3. Interview drillers who have worked in the area.
4. Study well logs and notes of other agencies or

Table 12-3.—Water-well construction methods and applications

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
		m (ft)	*m (ft)*	*mm (in.)*			*L/min (gal/min)*	
Driven wells								
Hand, air hammer	Silt, sand, gravel less than 50 mm (2 in)	2-5 (5-15)	15 (50)	32-100 (1¼-4)	Standard-weight pipe	Domestic, drainage	10-150 (3-40)	Limited to shallow water table, no large gravel.
Jetted wells								
Light, portable rig	Silt, sand, gravel less than 25 mm (1 in)	2-5 (5-15)	15 (50)	40-80 (1½-3)	Standard-weight pipe	Domestic, drainage	10-110 (3-30)	Limited to shallow water table, no large gravel.
Drilled wells								
Cable tools	Unconsolidated and consolidated medium hard and hard rock	Any depth	[2] 450 (1,500)	80-600 (3-24)	Steel, wrought iron, fiberglass, or plastic pipe[3]	All uses	10-11,500 (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 25 mm (1 in); soft to hard consolidated rock	Any depth	[2] 450 (1,500)	80-450 (3-18)	Steel, wrought iron, fiberglass, or plastic pipe[3]	All uses	10-11,500 (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	2-30 (5-100)	60 (200)	400-1,200 (16-48)	Steel or wrought iron pipe	All uses	1,900-15,000 (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 50 mm (2 in), soft to hard consolidated rock	Any depth	[2] 600 (2,000)	300-500 (12-20)	Steel, wrought iron, fiberglass, or plastic pipe[3]	All uses	1,900-11,500 (500-3,000)	Very fast drilling. Combines rotary and percussion methods (air drilling), cuttings removed by air. Would be economical for deep water wells.
Augering								
Hand auger	Clay, silt, sand, gravel less than 25 mm (1 in)	2-10 (5-30)	10 (35)	50-200 (2-8)	Sheet metal or plastic	Domestic, drainage	10-200 (3-50)	Most effective for penetrating and removing clay. Limited by gravel over 25 mm (1 in). Casing required if material is loose.
Power auger	Clay, silt, sand, gravel less than 50 mm (2 in)	2-15 (5-50)	25 (75)	150-900 (6-36)	Concrete, steel, wrought iron, fiberglass, or plastic pipe	Domestic, irrigation, drainage	10-400 (3-100)	Limited by gravel over 50 mm (2 in), otherwise same as for hand auger.

[1] Yield influenced primarily by geology and availability of ground water.
[2] Greater depths reached with heavier equipment.
[3] Care must be used in selecting material and designing casings for greater depths.

water specialists knowledgeable about the area.

5. Plot the above information on a base map or aerial photograph.
6. Evaluate the chances for obtaining the desired yield and water quality.

If additional information must be obtained by test drilling, outline a program that includes determining the location, depth, and number of test holes; type of drilling rig; type of sampling and logs to be kept; and geologic characteristics to be identified. The following should be obtained during the test drilling:

1. General information—location of hole, data on type of mud or fluid, type of bit, and sampling procedure.
2. Description of rock characteristics of each stratum.
3. Thickness and depth of each stratum.
4. Drilling characteristics—drilling hard, smooth, fast; bit bounce; mud loss; and bit drop.
5. Time used in drilling each interval.
6. Types of downhole logging.
7. Selected drill cutting and water samples.

Aquifer performance testing normally consists of:

1. The construction of a test well and sometimes observation wells.
2. A pumping test to show the time, drawdown, and distance-drawdown information.
3. A pumping test to determine step-drawdown depths.
4. Determining the time required for water level recovery after pumping.

Test results are used for:

1. Determining dependability of storage volume and recharge characteristics.
2. Defining the yield-drawndown relationship (specific capacity).
3. Analyzing formation samples.
4. Analyzing the water for corrosion, encrustation, and chemical quality.
5. Identifying aquifer characteristics.

Because many factors are involved in determining the actual data and number of test holes needed, a geologic appraisal of the well site is desirable to help determine the information to be collected. Also, surface features may influence choice of the site within limits permitted by geologic conditions.

Hydraulics

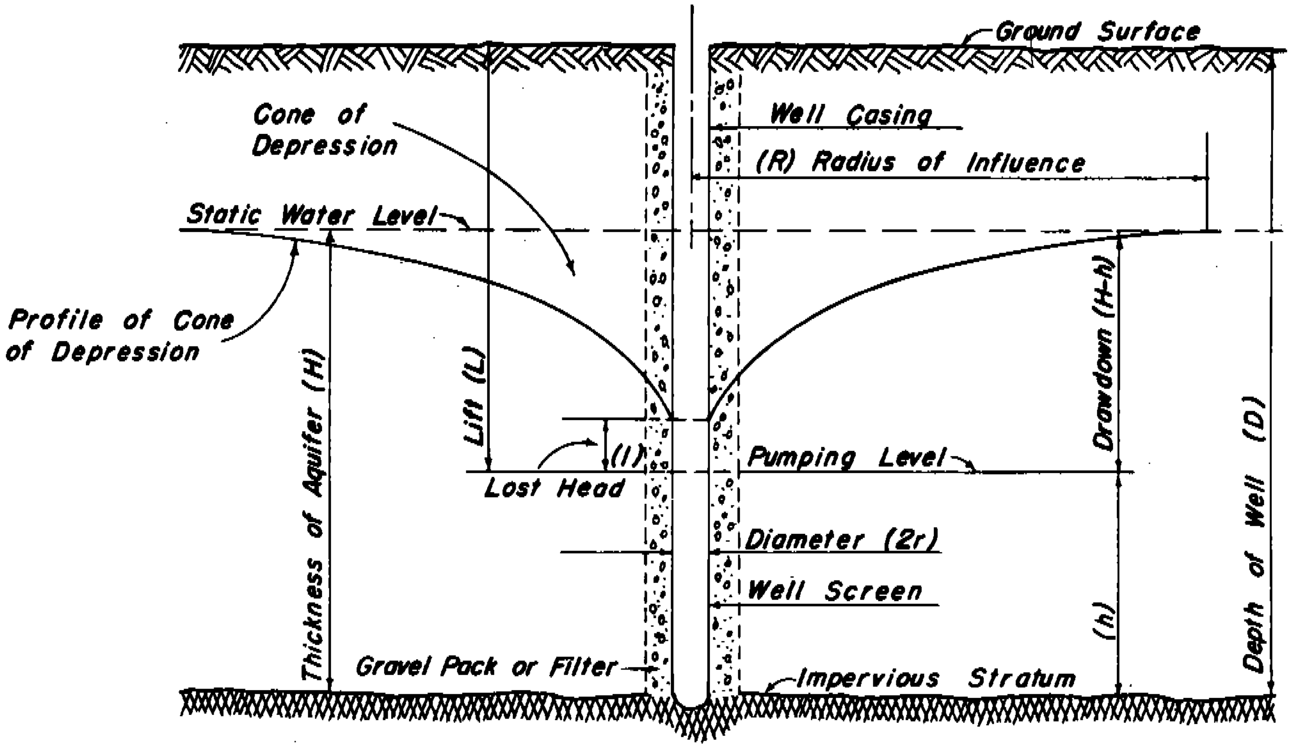
The basic hydraulic function that causes flow of water through porous materials into a well results from the force "available" because of differences in energy content, i.e., differences in hydraulic head. For a well to yield a high rate of flow, the water must move in large volumes through the aquifer into the well. Entrance velocities should be as low as possible. Figure 12-18 shows a typical well in two dimensions; but water movement into a well is radial.

The rate at which water moves from an aquifer into a well is a measurable characteristic called transmissibility. Values of the coefficient of transmissibility may range from less than 4,500 m^3/m-year (1,000 gal/ft-d) to more than 4,500,000 m^3/m-year (1 million gal/ft-d).

The volume of water that may be released from an aquifer is measured in terms of a coefficient of storage, a dimensionless term that has values of 0.01-0.40 (normally 0.10-0.30) for water table aquifers and values of 0.00001-0.001 for artesian aquifers.

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 (fig. 12-18). 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. 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.



Definition of Terms

1. Static Water Table. The surface level of the groundwater at the top of the saturated zone in a water-bearing formation is known as the water table.

2. Cone of Depression. As water approaches a well which is being pumped, the slope of the water table increases. As distance from the well increases, the slope becomes flatter until it merges with the water-table level beyond the influence of the well. The water surface in the influence of a pumped well is an inverted cone with its apex in the well and its base in the static water table. This is known as the cone of depression.

3. Area of Influence and Circle of Influence. The area affected by the discharge from a well is known as the area of influence. The boundary of the area of influence is known as the circle of influence. The radius of the circle is the radius of influence (R).

4. Profile of Cone of Depression (Drawdown Curve). If a cross section is made through a pumped well, as shown in the sketch, the water table appears in profile and is known as the profile of cone of depression.

5. Thickness of Aquifer (H). Saturated thickness before pumping.

6. Pumping Level (h). Depth of water in well while pumping.

7. Drawdown (H-h). Drawdown is defined as the distance from the position of the static water table before pumping to the level of the water in the well during pumping.

8. Lift (L). The term lift or head as applied to a pumped well is defined as the vertical distance from the water level in the well during pumping to the ground surface or some other specified point as the center of the discharge pipe.

9. Lost Head (l). Lost head is defined as the difference in elevation between water level inside the well (during pumping) and outside at the point where the drawdown curve intersects the casing.

10. Gravel Pack or Filter. A gravel envelope surrounding the casing and designed to prevent surrounding sand from entering the well.

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

12. Well Screen. A perforated or slotted section of pipe used to separate the water from the surrounding aquifer.

Figure 12-18.—Typical irrigation well in unconsolidated materials.

Design

Information needed in designing a well may best be obtained from study of logs and sieve analyses of samples from test holes. Refer to 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 well may be designed most effectively by the joint efforts of an engineer and a geologist. Decisions regarding drilling method; diameter and depth of hole; position, size, and number of casing perforations; need for a well screen; need for a gravel envelope; and choice of development method will be influenced by geologic, engineering, and economic considerations. Sometimes final decisions must be made as the drilling proceeds. Methods of putting essential information together to design the most efficient well are given in the National Engineering Handbook, Section 18, Chapter 6.

Figure 12-18 shows the position of the static water level and the shape of the cone of depression that develops around a pumping well. It also illustrates features and terms commonly used in well design and construction.

For design purposes, a well is analyzed in two parts—the cased section, which serves for the installation of pumping equipment, and the intake section, where the water from the aquifer enters the well. Before the actual design is started, it is a good practice to make 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, and materials to be used in the well.

Capacity

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

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

Physical characteristics.—Physical characteristics that influence well capacity are size, porosity, and uniformity of the water-bearing sand. Generally, sands suitable for irrigation development have a porosity of 20-40 percent of the volume of the water-bearing material. A uniform sand has greater porosity and therefore 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. This drawdown then influences the slope and velocity of the water approaching the well and thus helps determine the well capacity. Other factors being equal, well capacity is in proportion to $H^2 - h^2$, where H is depth of water formation and h is depth of water remaining while pumping, measured on the outside of the casing.

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.

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

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 = static head (or depth) of water in well, and
h_1 = desired static head (or depth) of water in well.

For example (metric units):
A well has a static water level at the depth of 20 m and a measured capacity of 3,000 L/min with a drawdown of 15 m. The capacity for 10 m of drawdown would be:

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

Solve for Q_1.

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

$$Q_1 = \frac{3{,}000\ \text{L/min}\ ((20\ \text{m})^2 - (20\ \text{m} - 10\ \text{m})^2)}{(20\ \text{m})^2 - (20\ \text{m} - 15\ \text{m})^2}$$

$$Q_1 = \frac{3{,}000\ (400\ -\ 10^2)}{400\ -\ 5^2}$$

$$Q_1 = \frac{3{,}000\ (400\ -\ 100)}{400\ -\ 25}$$

$$Q_1 = \frac{3{,}000\ (300)}{375} = 2{,}400 \text{ L/min}$$

For example (U.S. units):

A well has a static water level at the depth of 50 ft and a measured capatity of 850 gal/min with a drawdown of 34 ft. The capacity for 25 ft of drawdown would be:

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

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

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

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

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

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

Extent of water-bearing formation.—The extent of the formation influences the total quantity that may be pumped and the rapidity with which water can flow from the supply source into the immediate well area. If the water supply is blocked off on one or more sides, the quantity pumped is naturally less than when the flow is unrestricted.

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 only about 13 percent.

Effectiveness of screen or casing.—The casing perforations or screen openings need 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 equations are based on the following assumptions:

1. The water-bearing materials are of uniform permeability within the radius of influence of the well.
2. The aquifer is not stratified.
3. The saturated thickness is constant before pumping starts; for an artesian aquifer, the aquifer thickness is constant.
4. The pumping well is 100 percent efficient.
5. The pumping well penetrates to the bottom of the aquifer.
6. Neither the water table nor the piezometric surface has any slope; both are horizontal surfaces.

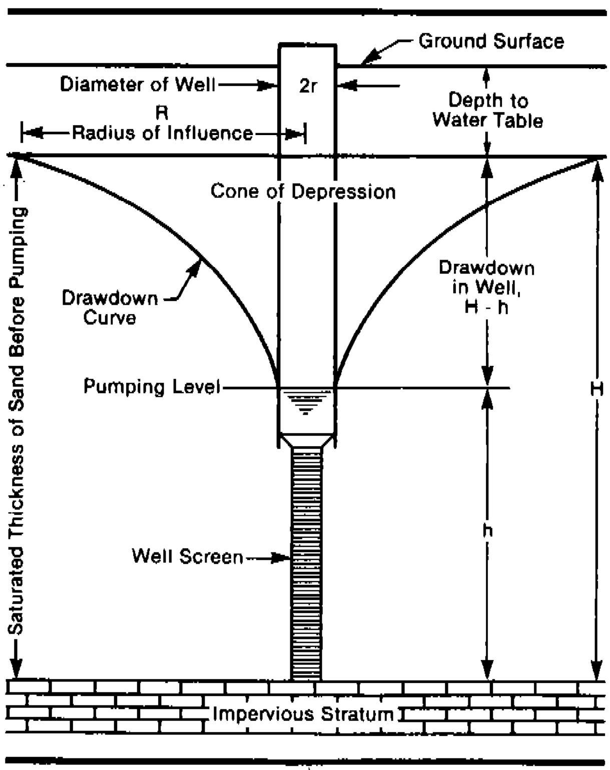


Figure 12-19.—Diagram showing terms used in the water-table aquifer formula.

7. Laminar flow exists throughout the aquifer and within the well's radius of influence.

8. The cone of depression has reached equilibrium, so that both drawdown and radius of influence remain constant with continued pumping at a given rate.

The formula for capacity of a water table aquifer is:

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

where

Q = well capacity or pumping rate, in liters per minute (gallons per minute);
K = a value that depends on the effective size and porosity of the water-table aquifer formation (table 12-4);
H = saturated thickness of the aquifer before pumping, in meters (feet);
h = depth of water in the well while pumping, in meters (feet);
R = radius of the cone of depression, in meters (feet); and
r = radius of the well, in meters (feet).

Table 12-4—K values for various porosities and grain sizes

Porosity	Grain size (mm)						
	0.15	0.20	0.30	0.40	0.50	0.80	1.00
Pct	m^3/m^2s						
25	820	1,320	3,000	5,400	8,500	21,600	33,400
30	1,360	2,450	5,500	9,900	15,500	39,000	61,000
35	2,450	4,000	9,400	16,500	25,400	65,800	103,000
40	3,600	6,100	14,100	23,500	37,600	98,700	155,000

To convert m^3/m^2s to gal/ft-day, multiply by 0.212.
Source: Turneaure and Russell, 1901, *Public Water Supplies*, John Wiley and Sons, Inc.

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 300-450 mm (12-18 in) is between 60 and 300 m (200 and 1,000 ft).

The quantity of available water moving into a well increases rapidly as the aquifer grain size increases. The effective diameter of sand is the D_{10} size. The effective D_{10} size can be determined by screening 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. 12-20) is:

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

where

P = permeability of the water-bearing sand, in gallons per day per square foot;
m = saturated thickness of artesian aquifer, in feet;
H = static head (or depth) of water in well measured from bottom of aquifer, in feet.

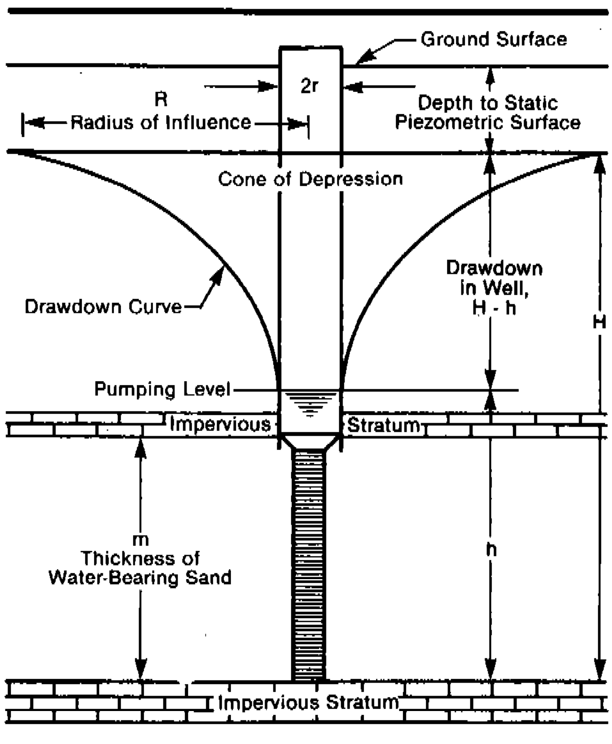


Figure 12-20.—Diagram showing terms used in the artesian aquifer formula.

All other terms are as defined for the equation for water table aquifer (fig. 12-19).

Permeability of an artesian or water table aquifer must be determined from laboratory or field tests. Permeability tests and equations are given in the National Engineering Handbook, Section 18, Chapter 1. This handbook should be referred to for formulas to determine well capacities for nonequilibrium conditions.

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 without changing directions. The yield is limited only by the supply in 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 6,500 m^3/m-year (1 gal/ft-min). However, if cracks or crevices are frequent, wells in this formation may produce up to 32,600 m^3/m-year (5 gal/ft-min).

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 formation; and the nature and extent of the water-bearing area.

The question of the relationship between well diameter and yield often comes up. The relationship is not proportional. It may be asked, how much more water can be expected from doubling the diameter of a well? How much more from a 150-mm (6-in)-diameter well than from an 80-mm (3-in) one? From a 300-mm (12-in) than from a 150-mm (6-in)? From a 600-mm (24-in) than from a 300-mm (12-in), etc.? The answer is not four times or even twice as much, as might be expected; in fact, usually only 11-20 percent more, depending on numerous factors.

Factors such as depth, pump characteristics, layout, and method of finishing are more important than capacity in determining well diameter. Generally, developing two medium-sized wells, such as 250 mm (10 in) or 300 mm (12 in), costs less than developing one large well, such as 600 mm (24 in) or 900 mm (36 in). The combined yield of the smaller wells is almost always much greater than the yield of the larger well.

See table 12-5 for typical well casing diameters required for various well discharge capacities.

Table 12-5.—Typical well casing capacity

Well diameter	Low	Average	Upper
mm		*L/min*	
150	—	—	400
250	400	1,500	2,500
400	3,000	6,500	10,000
600	8,500	14,000	22,000

To convert millimeters to inches multiply by 0.03937; to convert liters per minute to gallons per minute, multiply by 0.2642.

Efficiency

Well efficiency is the ratio of theoretical drawdown to actual drawdown. Historically, efficiency has not been considered a factor in constructing wells. Usually, whatever a well pumps is considered all that is available. Unless the well is known to be 100 percent efficient, this assumption is erroneous. Well efficiency is a function of the design. It is not uncommon for a well to be 60 percent efficient. However, with good construction and development, a well 90 percent efficient can be obtained at the same location and at the same drawdown level. Rarely is it practical to design a well for 100 percent efficiency.

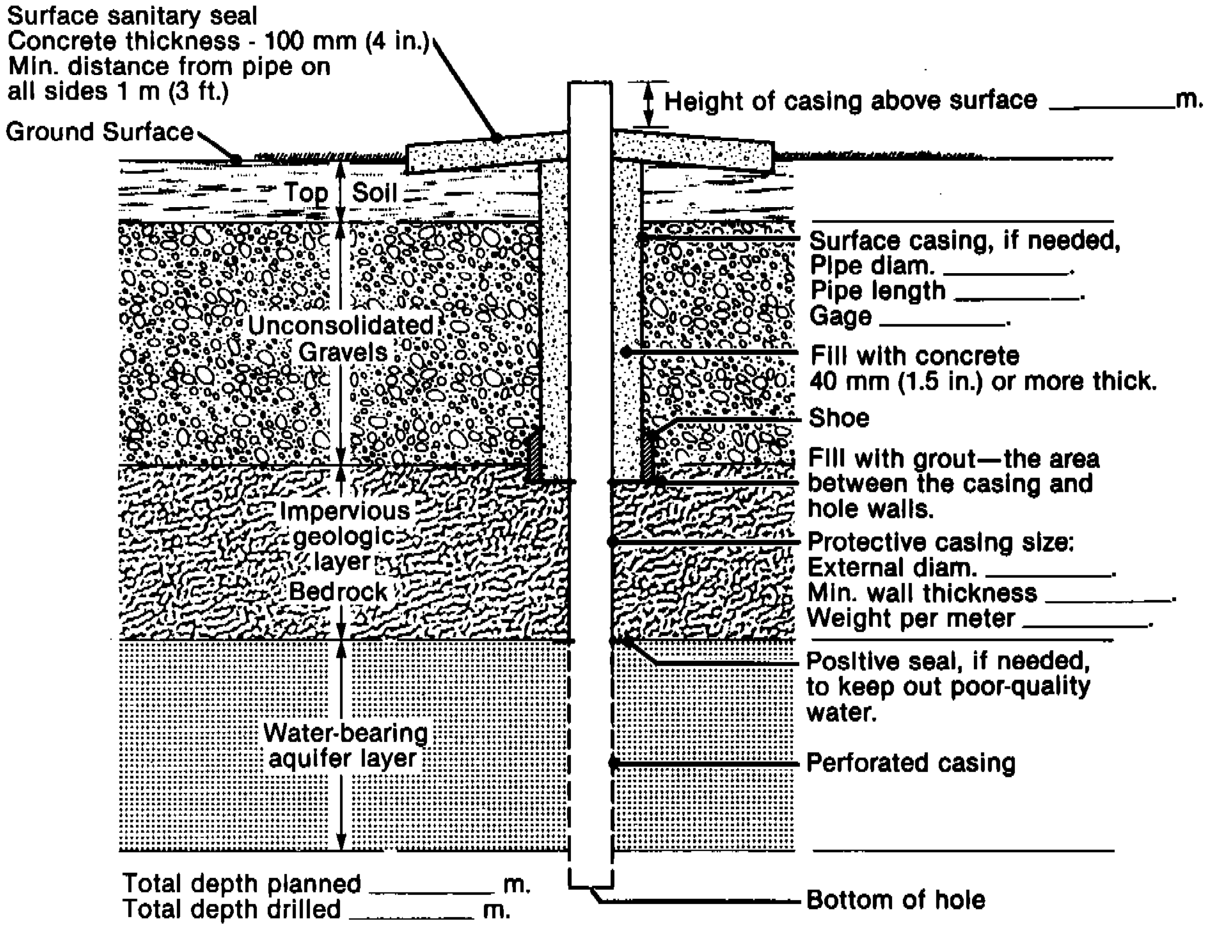
System Design

A well must be designed to fit site conditions. A properly designed and constructed well is a conservation structure. The design information for a well should be documented. Figures 12-21 and 12-22 show the minimum information that should be recorded.

Cased section.—The cased section is the upper part of the well. It includes the hole, the casing, the well stabilizer (the formation above the intake section), and sanitary protection.

1. The hole must be large enough to permit the insertion of casing and gravel pack for the well stabilizer. It must be large enough to accommodate the required flow and the necessary parts of the pump to be used. It should be deep enough to extend to the bottom of the water-bearing strata, and it should be straight and plumb.

The diameter of any well requiring use of a turbine pump should be large enough to allow free working space for the pump bowls to be installed. Many wells are not exactly plumb, and a turbine pump must hang plumb in a well to avoid excessive wear on the bearings. For this reason, the well should generally be



Special Drilling Instructions:

Reviewed with Driller—Date: ____________________ Driller's Confirmation ____________________

Well-Drilling Plan:

Location ____________________ Cooperator ____________________ Field No. ____________________

Costs:

Drilling ____________ Well Casing ____________ Gravel Pack ____________ Perforations and Screens ____________

Type of Well: ______________________________ Minimum Diameter ______________________________

Casing Specifications: ____

____

Screens, perforations, and gravel pack specifications: ____

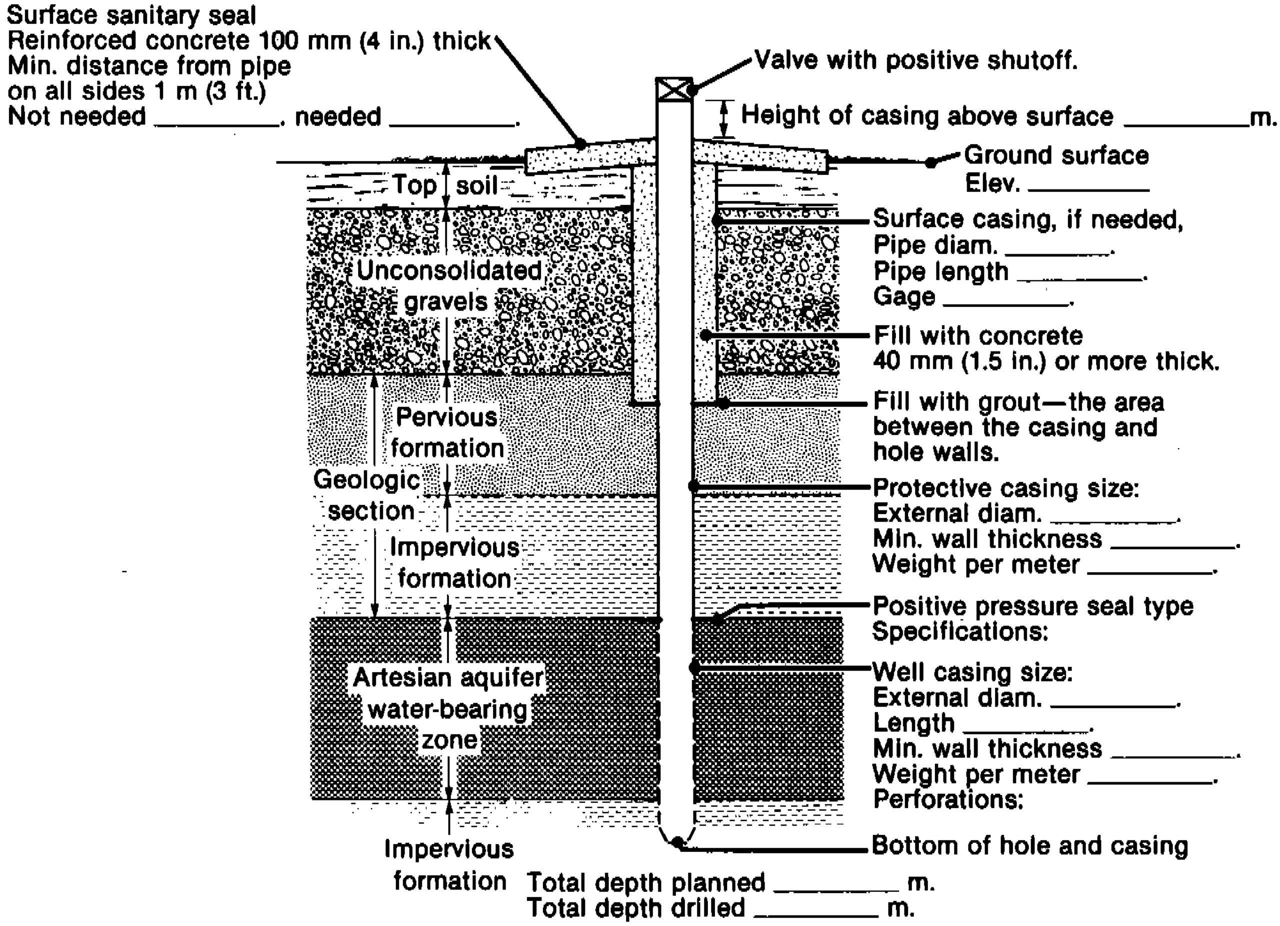
____

____

Reinforcement in sanitary seal: ____

____

Figure 12-21.—Documentation of water-table well design.



Special Drilling Instructions:

Reviewed with Driller—Date: ____________________ Driller's Confirmation ____________________

Well-Drilling Plan:

Location ________________ Cooperator ________________ Field No. ________________

Costs:

Drilling ____________ Well Casing ____________ Gravel Pack ____________ Perforations and Screens ____________

Type of Well: ____________________ Minimum Diameter ____________________

Casing Specifications: ____

____

The positive shutoff valve will be placed below the frost line, where applicable.

Screens, perforations, and gravel pack specifications: ____

____

____

Reinforcement in sanitary seal: ____

____

Figure 12-22.—Documentation of artesian well design.

drilled somewhat larger than would be necessary to fit the pump bowls. A well less than 300 mm (12 in) 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 150-200 mm (6-8 in) in diameter or driven 50-100 mm (2-4 in) in diameter.

2. The well stabilizer is used to fill the space between the well hole and the casing. Ground water specialists recommend that well stabilizer material be placed no lower than about 9 m (30 ft) above the top of the screen or slot section. The only precaution needed in installing the well stabilizer is to have continuous placement. If separation occurs in placing the column of materials, the void could cause the casing to collapse.

3. The casing is the inner lining of the well. 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, polyvinyl chloride (PVC) or acrylonitrile-butadiene-styrene (ABS), styrene-rubber (SR), steel, fiberglass, reinforced plastic mortar, asbestos cement, or concrete.

The type of casing selected depends on the corrosion and encrustation characteristics of the water and the strength required for the well site. The SCS standard for wells (642; U.S. Dep. Agric. 1977) gives information on casing limits and methods for computing strength requirements. In installing the casing, precautions should be taken to ensure that joints are watertight.

4. All wells should have sanitary protection. State laws may vary. However, the well casing should terminate not less than 300 mm (1 ft) 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 at least 80 mm (3 in) and 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 0.7 m (2 ft) 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 seal the top of the casing an additional cover should be provided. If a gravel pack is used, the concrete slab cover must have an opening so that gravel can be added in case of slumping. Provision should be made to allow water-level monitoring.

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 may be the factors that determine whether a well is efficient and high yielding.

1. 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 the sand from the well and permit maximum flow of water from the water-bearing formation to the well screen or perforated section. When a gravel envelope is to be installed, the well screen should be equipped with centering guides to ensure that the screen in the well is centered and to prevent the gravel from shoving the screen to one side. These guides will assist in uniform placement of the gravel pack.

2. Well screens are installed at the lower end of the casing to retain the coarser aquifer materials about the well and permit removal of finer materials by development. They must have an open area of at least 15-20 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. One popular type features a continuous horizontal slot formed by wrapping and welding trapezoidal wire about a cylindrical frame of rods. The slot opening is determined by the spacing between the trapezoidal wire wraps and is varied according to specifications. The wire is placed with the wide side out, forming an opening that widens toward the inside of the screen. This inward-flaring slot reduces clogging of the screen to a minimum. A screen with sectioned horizontal slots is made by wrapping trapezoidal wire over metal strips on perforated steel tubing. The trapezoidal wire is formed with lateral lugs at intervals to maintain the slot width. Another perforated pipe design is like a sand point but much larger. It consists of woven screen of various gages wrapped on casing perforated with 16-mm (⅝-in) holes. The screen is protected by 15-mm (½-in) mesh galvanized iron hardware cloth. Other screens are galvanized iron casing with punched openings in lattice, crow-foot, shutter, or louvered slit design. Louvered horizontal openings reportedly are more effective in controlling unconsolidated materials than vertical slots.

Nonmetallic materials also are being used for screens. Various configurations of such screens are available.

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:

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

Generally, from one-third to one-half of the water-bearing stratum is cased with a screen or perforated casing, except in formations where no casing is used. The amount of the water-bearing stratum cased depends on the formation and the quality of the sand, but generally most of the water is obtained from the lower one-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; in fact, it 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 0.6 m (2 ft) can be computed by the following formula, derived from studies at Colorado State University.

$$L = 6\ D/C$$

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) and Ap = ratio of total area of screen openings to total area of screen.

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}. (Hazen formula:

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

where C_u = coefficient of uniformity.)

Generally, aquifer materials with a C_u of less than 2 should have a gravel pack.

If C_u is greater than 2 but less than 3, a gravel pack should be used if the D_{60} size is less than 0.76 mm (0.03 in). If the D_{60} size is greater than 0.76 mm (0.03 in) but less than 2.54 mm (0.10 in), the gravel pack may be omitted if a well screen is used that has enough openings to allow the water to enter the well without excessive head loss. If the D_{60} size is larger than 2.54 mm (0.10 in), the gravel pack generally should be omitted and either a manufactured well screen or perforated casing used.

If the C_u is greater than 3, the gravel pack should be omitted, because it might tend to hold back the fine sand that should be removed from the aquifer by natural development.

Sands with a C_u less than 2 do not benefit greatly from development by surging. Sands with C_u greater than 2 but less than 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:

1. The C_u of the filter material should not be more than 2.
2. The D_{15} size of the filter material should not be smaller than 4 times the D_{15} size of the aquifer material.
3. The uniformity of the aquifer should be in-

cluded in the criterion for a filter. As long as the ratio D_{50} filter to D_{50} aquifer is less than 7.5, the movement of sand into the filter is not 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 figured at a maximum of 7.5 times the 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:

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

This criterion is based on research done at Colorado State University.

4. The D_{85} size of the filter should not be greater than 2.5 times the D_{10}, to keep the C_u within 2.

5. The filter gradation curve should be as nearly parallel to the aquifer gradation curve as the above conditions will allow.

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

1. Make a sieve analysis of aquifer material to determine the percentage smaller than the screen openings, and plot on Graph for Sand and Gravel Analysis for Well Development.
2. Compute and locate on graph the D_{50} size of the filter as determined in (3) above.
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 $\times$ 0.6. Locate this D_{10} minimum point on graph.
4. Locate the maximum D_{85} size of the filter at $2.5 \times D_{10}$ size.
5. Plot a uniform filter curve through the D_{50} point as nearly parallel to the aquifer curve as the above minimum D_{10} and maximum D_{85} points will permit.
6. Check to see that the D_{15} minimum size meets the requirement of being at least 4 times the D_{15} size of aquifer. If not, move the D_{15} point to meet this requirement and replot the filter curve through this point and the D_{50} point with a C_u less than 2 to fit a new curve.

A sample well-filter design problem follows (see fig. 12-23).

Given aquifer sieve results:

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

Determine filter gradation.

Plot sieve results on grain-size distribution forms.

Read $D_{10} = 0.3$ mm

$D_{50} = 0.65$ mm

$D_{60} = 0.75$ mm

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

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

D_{10} filter $= 0.6 \times D_{50} = 0.6(3.9) = 2.34$ mm minimum

D_{85} filter $= 2.5 \times D_{10} = 2.5(2.34) = 5.85$ mm maximum

Plot filter on curve.

Filter Design: Limits—100% pass 3/8 sieve
64(±8)% or 56-72% pass #4
6(±8)% or 0-14% pass #8

A filter from 100 to 200 mm (4 to 8 in) thick is sufficient for a gravel envelope. Nothing is gained in installing a thicker filter except to enlarge the effective well area to decrease 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.

In some cases, a thick filter reduces velocity enough that sand is carried into and deposited in the filter material. This sand deposit decreases the void spaces and the capacity of the well. It is more important to place the filter uniformly around the casing than to have extra thickness.

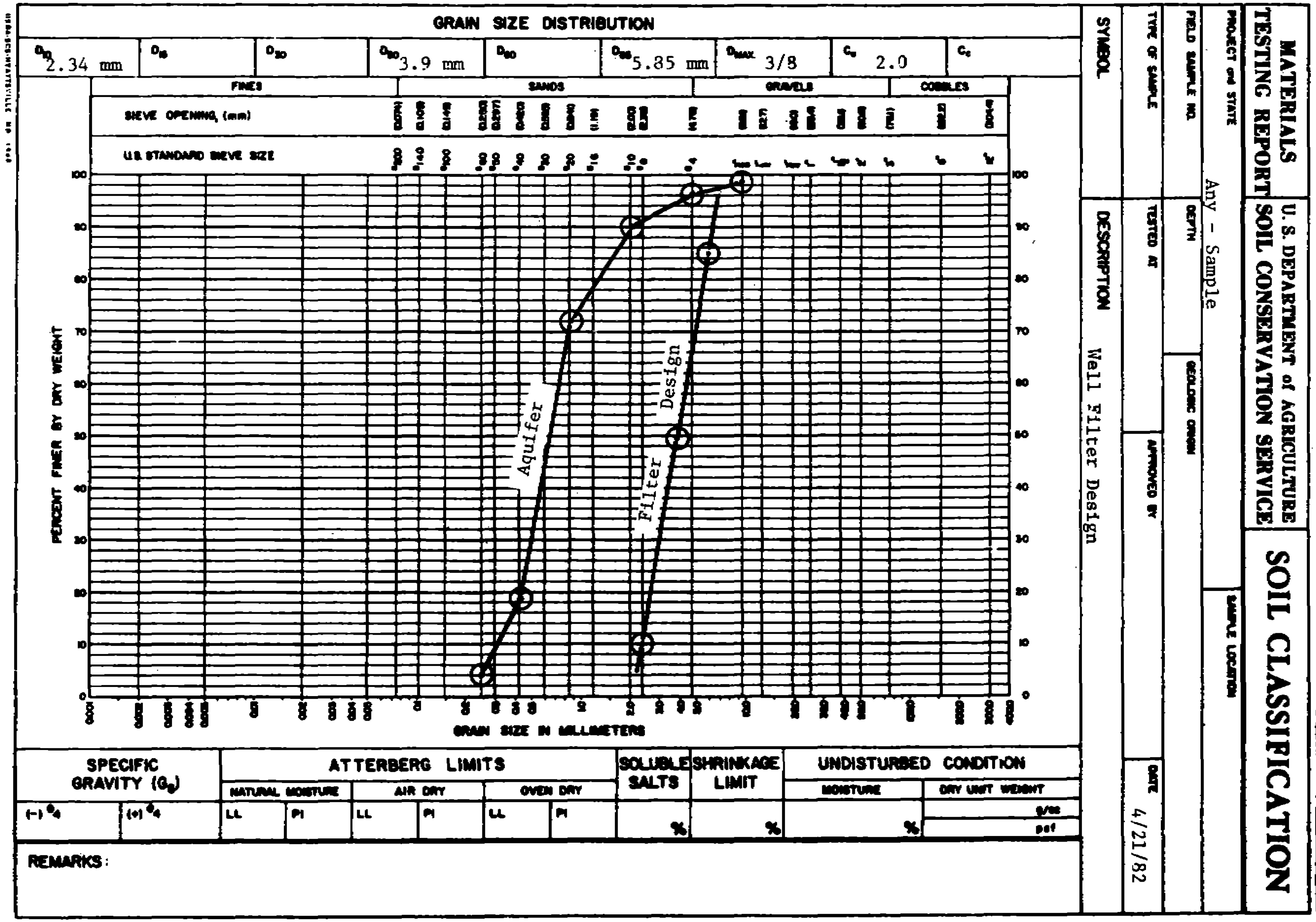


Figure 12-23.—Well-filter design problem.

The size of slots in screen or casing should be less than the D_{85} size of the filter and larger than the D_{60} size of the filter. For naturally developed wells, the slot should be small enough to exclude about one-third of the aquifer formation. Usually, a screen or casing with 15-20 percent open area will cause a small enough head loss for efficient operation of the well.

In nonhomogeneous formations, slot sizes differ for sections in different strata. For selecting multiple-slot screens, the Johnson Well Screen Company[1] recommends that if fine material overlies coarse material, the screen with the slot size designed for the fine material should not extend less than 0.6 m (2 ft) down into the coarse stratum; and the slot size for the coarse stratum should not be more than double the slot size for the overlying finer material.

The screen length and slot size are dictated by the characteristics of the water-bearing formation. Thus, 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 0.03 m/s (0.1 ft/s) or less. 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. 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 meter (foot) of length for 1 m (ft) of head loss.

Multiple Systems

A multiple-well system may be required to obtain the needed amount of water. Three conditions are necessary for a manifold system to be successful. First, the water table should be close enough to the land surface to permit pumping the wells by suction lift. Second, 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. Third, 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, sand point and small individual wells, are used in multiple-well systems. Figure 12-24 shows a typical manifold multiple-well system. Only four satellite wells are shown. Additional satellite wells may be added to a system.

Figure 12-25 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.

If the ground water is flowing along a buried stream channel, wells should be spaced in a line at right angles to the direction of flow. If the water-bearing material contains fine sand and releases water slowly, wells should be located on the circumference of a circle, giving the effect of one large well.

No exact spacing of the sand points can be set. Sometimes the water supply will be adequate on 3-m (10-ft) spacings. However, it is good practice to space wells at least 12 m (40 ft) apart so interference between them will be at a minimum. After the first point is set, the remaining points 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. Figure 12-26 shows the components for a satellite well unit.

The practical suction lift on most pumps is limited to 8 m (25 ft) or less. A common practice with satellite wells is to drill and case to about 10 m (35 ft) below the normal water table in the aquifer.

The "drop pipe" extends to within 0.6 m (2 ft) of the bottom of the well, making it about 9 m (30 ft) 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

[1] *Trade names are used solely to provide specific information. Mention of a trade name does not constitute a guarantee of the product by the U.S. Department of Agriculture nor does it imply an endorsement by the Department over comparable products that are not named.*

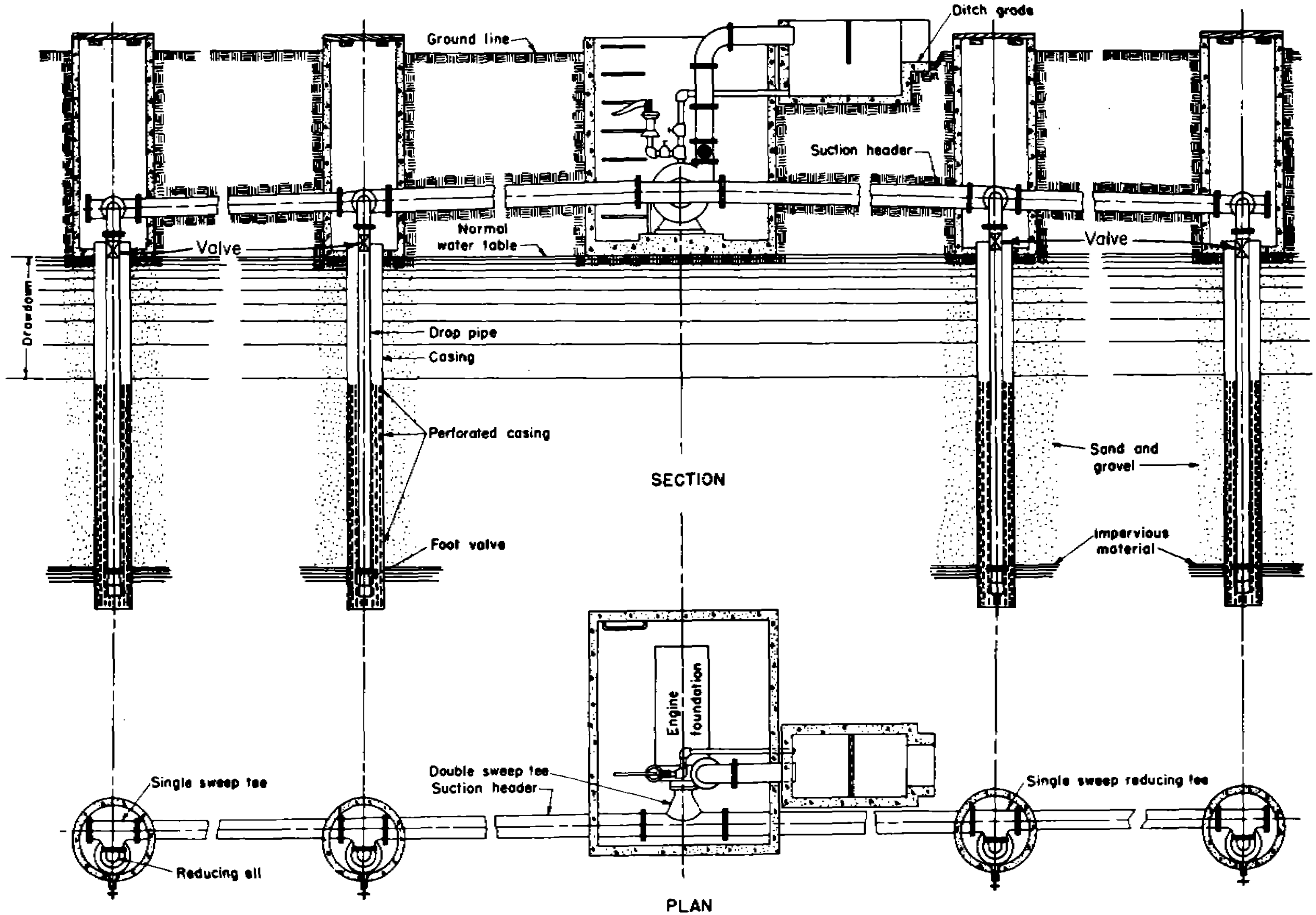


Figure 12-24.—Typical manifold multiple-well system.

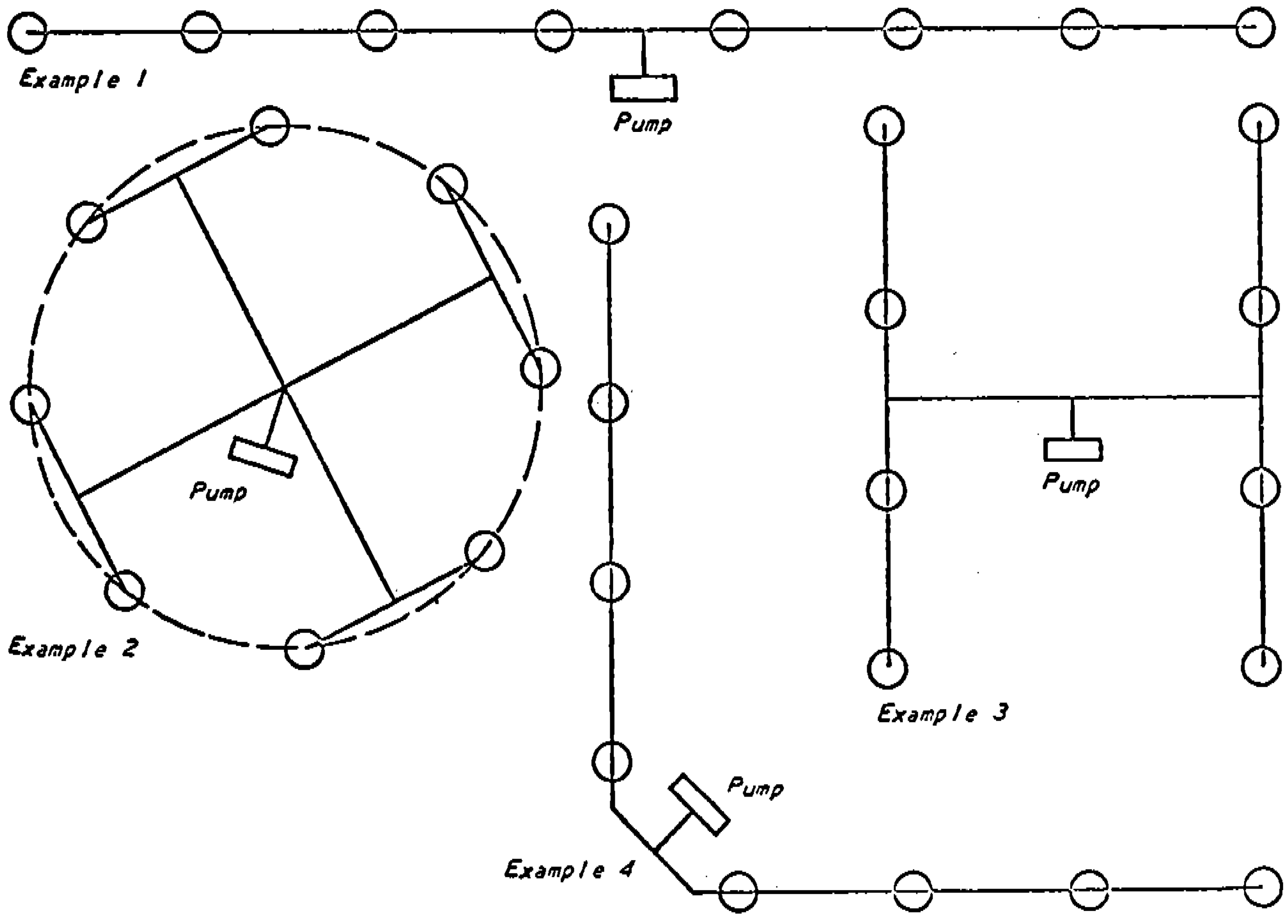


Figure 12-25.—Layouts for manifold pumping systems.

well is on a manifold, pipe size may have to increase 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.

It is fairly common practice to use the engine intake manifold to initially "prime" manifold systems. An engine in good condition can develop a vacuum of about 500 mm (20 in) of mercury (Hg) at sea level and at normal operating speed; 450 mm (18 in) Hg at 610 m (2,000 ft) elevation; and 400 mm (16 in) Hg at 1,220 m (4,000 ft) elevation. A vacuum equal to 450 mm (18 in) Hg lifts water about 6 m (20 ft). Well engineers generally agree that operating wells under vacuum may increase yield 10 percent. This is a help but not a solution. An adequate number of satellite wells, together with proper design and construction, makes up an adequate water system. Vacuum pumps generally are more beneficial where the saturated thickness in the aquifer exceeds 9 m (30 ft), because this is too deep for normal pump-suction lift.

After one well has been completed, it may be desirable to determine the minimum spacing for subsequent wells. Darcy's law of flow of water through porous material states that the rate of water movement through pores in saturated soil is directly proportional to the slope of the water table. Thus the drawdown at any point is inversely proportional to

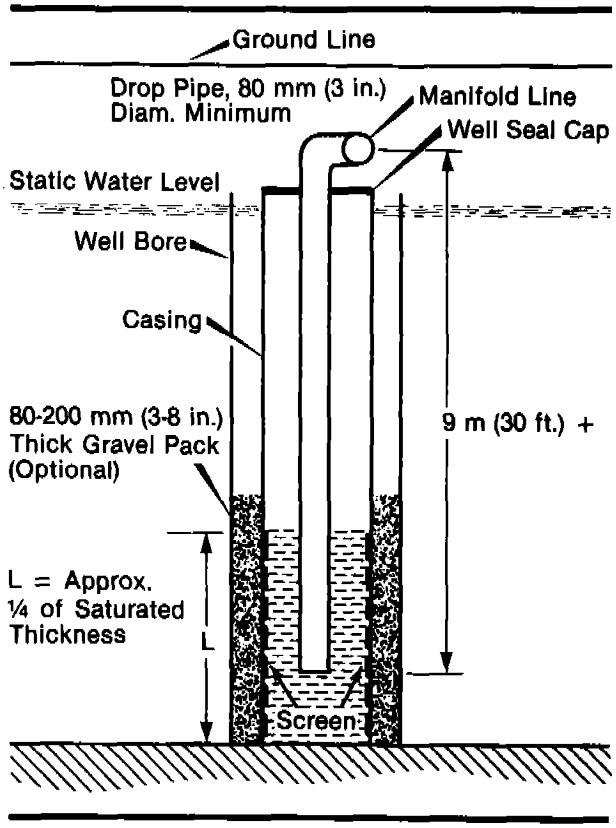


Figure 12-26.—A completed satellite-well unit.

the distance from the well, as long as the porosity and size of the material remain constant. An observation well can be drilled at some measured distance from the well and the drawdown determined at that point; then 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 15 m (50 ft) from the well, then 20-percent drawdown will be at 30 m (100 ft) from the well, 10-percent drawdown at 60 m (200 ft) from the well, and 5-percent drawdown at 120 m (400 ft) from the well.

If possible, wells should be spaced at least twice the radius of influence as determined above. Any lesser spacing causes interference between the wells (fig. 12-27). (Wells spaced 250 m [800 ft] in the above example would have radii of influence overlapping each other at the 5-percent drawdown point, which would lower the drawdown to some extent.) No attempt is made to set a definite drawdown percentage at which interference between wells becomes too great; the intent is merely to show the danger of having wells spaced too closely.

Construction

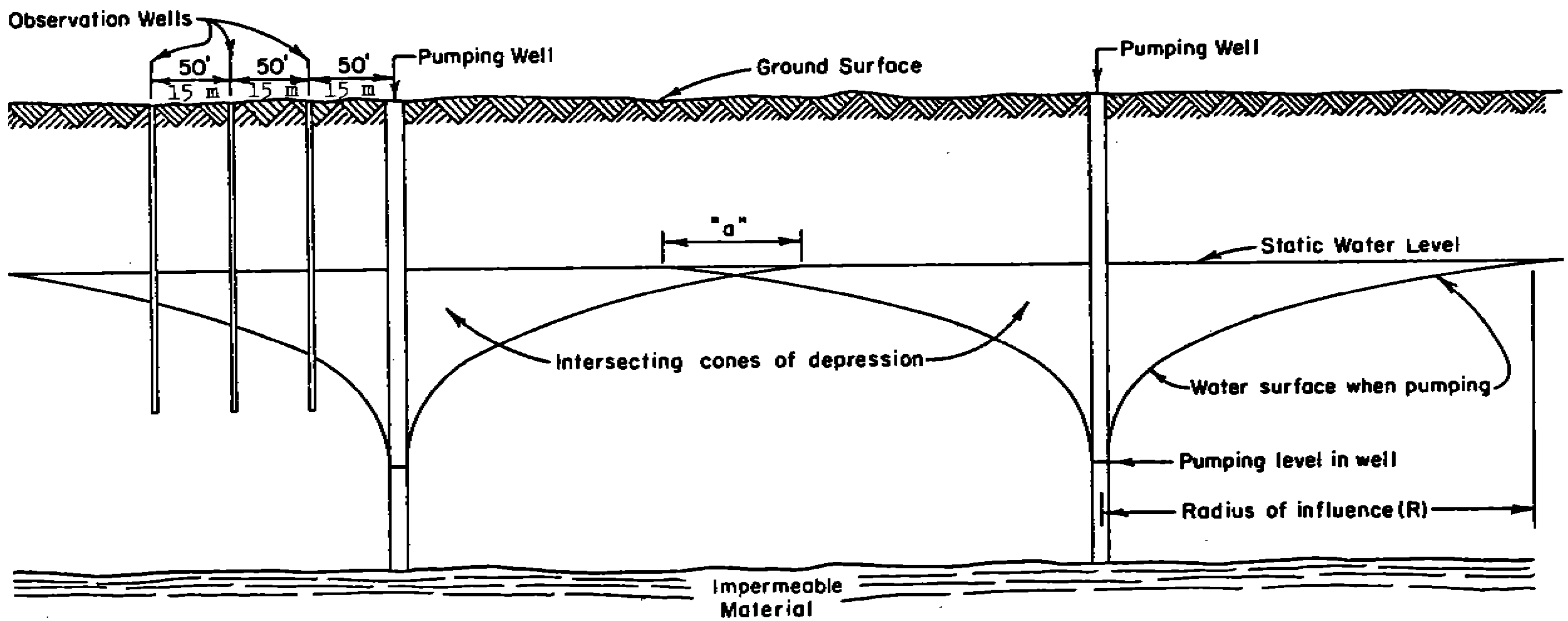
The types of drilling equipment available and their limitations have been discussed. The availability of drillers and their type of equipment ordinarily is the governing factor. However, certain rules for well construction must be adhered to. Have all required construction equipment and materials to 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. Regardless of which drilling techniques are used, construct a hole of constant diameter and alinement. 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 of material.

Some checking can be done after the well is ready for testing, but the various parts of the well, such as the diameter of the hole; the quality and placement of the gravel pack; the quality, size, and placement of the screen; and the quality and dimensions of the casing can be checked only before and during construction. Placement usually depends on the skill of the contractor.

Development

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 about the well, thereby 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 and in some instances has proved beneficial in consolidated deposits. The following discussion relates to development in unconsolidated deposits.

Wells may be developed by one or a combination of methods, including surging, backwashing, jetting,



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 30 to 900 m (100 to 3,000 ft) or more. It may be determined by measuring the depth to water in observation wells spaced at regular intervals away from a pumping well.

Figure 12-27.—Well interference in an unconfined aquifer.

pumping, and use of compressed air, dry ice, acid, or dispersing agents. Some methods are more effective under certain conditions than others. Knowledge of drilling methods and the reaction of particular formations to development is required to select the proper method.

Care must be taken in developing wells. Information from the record of materials penetrated is used to guide development. Operations such as pumping, surging, jetting, and backwashing should start slowly.

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. The only way to prevent bridging and remove fine grains is to keep the water agitated by reversing the direction of flow.

Results should be carefully observed and the tempo of operations increased only if the method is operating as expected. If the aquifer is overlain by fine sand or silt, these materials may be washed down into the aquifer by surging and spoil the well or prolong development.

Testing

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

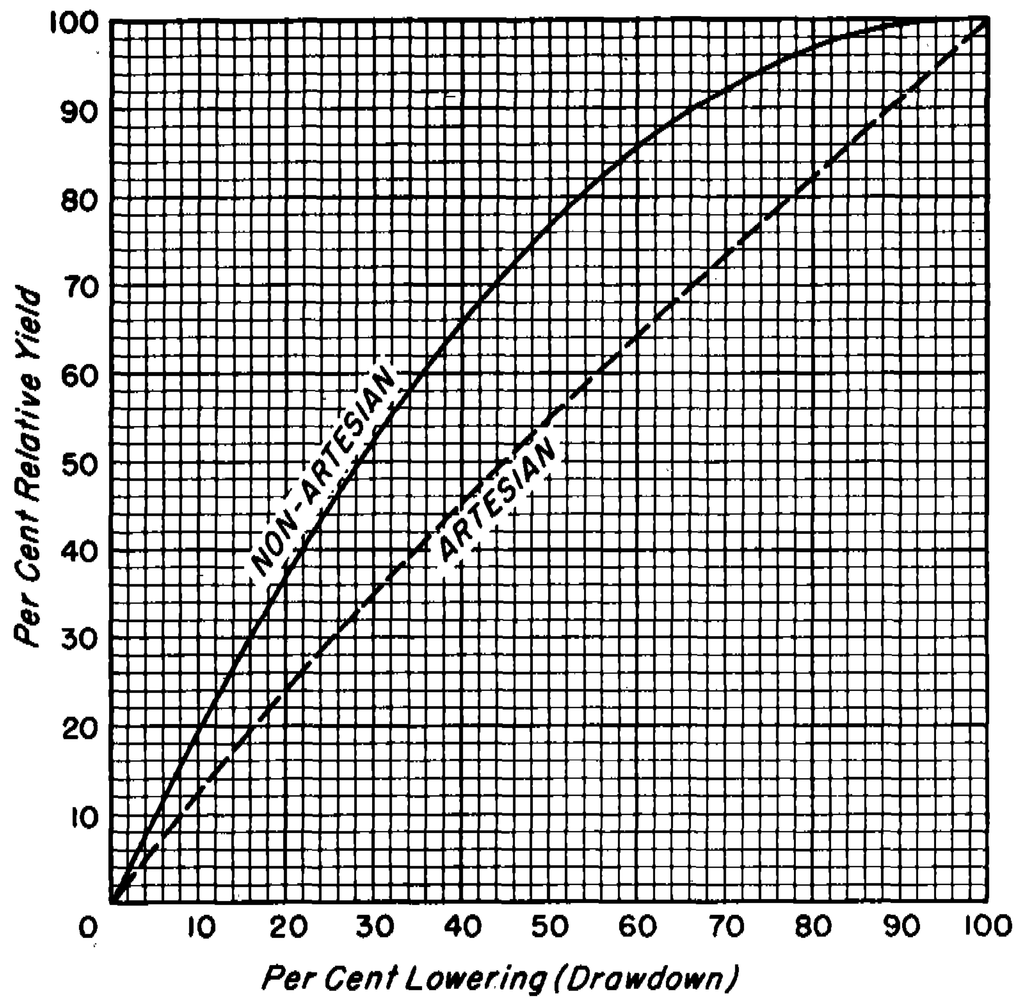
A well usually produces about 75 percent of its capacity when the drawdown is at one-half the water depth and about 90 percent when the drawdown is at two-thirds the water depth. For economical pumping, the pump should be designed to operate between these two extremes, since increasing the pumping rate 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 as much sand is withdrawn by surging and bailing as can be made to flow into the well, a test pump should be installed to complete developing the well. The test pump should be operated for 24-36 hr.

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. 12-28). 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 25 m in a well and the pumping test yielded 5,000 L/min with a drawdown of 7.5 m. This is 30 percent of the total possible drawdown. The curve shows that at 30 percent of the maximum drawdown, this nonartesian well will produce 52 percent of the maximum yield, so the maximum yield would be $\frac{5,000}{0.52}$ = 9,615 L/min. The curve shows that 77 percent of the maximum yield can be obtained with a 50-percent (12.5-m) drawdown, for a yield of 7,403 L/min.

The following test procedures are recommended:

1. Measure and record the depth to static water level. (May be measured with steel tape that has 0.3-0.6 m (1-2 ft) 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. Figure 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-percent drawdown or slightly more) until drawdown and yield are constant at that rate. Drawdown may be considered constant when three measurements taken 1 hr apart are the same. Water levels during pumping should be measured with an electric sounder or air line. Several hours to several days of continous pumping may be required. Record drawdown and yield.
5. Convert measured drawdown to percent drawdown. Refer to figure 12-28 to estimate optimum



Example: The water stands 75 feet in a well and the pumping test yielded 1470 g.p.m with a drawdown of 23 feet. This is 30% of the total possible drawdown. The curve shows that at 30% of the maximum drawdown, the well will produce 52% of the maximum yield. 1470 g.p.m. is 52% so the maximum yield or 100% would be $\frac{1470}{.52}$ = 2827 g.p.m. The curve shows that 77% of the maximum capacity can be obtained with a 50% (38 feet) drawdown. 2827 x .77 = 2253 g.p.m. yield with a 38-foot drawdown.

From Bulletin 1238, Edward E. Johnson Inc. Revised 1955

Figure 12-28.—Relation of drawdown to yield.

drawdown and yield and the most economical water yield from a specific well.

Measuring Drawdowns

There are two satisfactory methods of measuring drawdown in wells—an air pressure gage and an electric sounder. Many deep-well pumps are equipped with pressure gages and air lines of known lengths. The air line is simple to install and operates automatically. Air lines should be a part of each pump installation so that water level can be measured frequently.

The air line is usually a copper tube 4-8 mm (1/8-1/4 in) in diameter but may be 8-mm (1/4-in) galvanized pipe. Its surface end is connected to a pressure gage with an air valve just below the gage (fig. 12-29). The lower end of the pipe is open. The pipe must be airtight and should extend 6 m (20 ft) 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 an ordinary tire 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.

Practically all gages are now calibrated in meters or feet, so that the water level above the end of the air line can be read directly. 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.

Another satisfactory and accurate method of measuring water level is by means of an electric sounder. There are several types of sounders, but the basic principle is the same for all. An electric sounder can be made from two-strand insulated electrical wire with one end shielded to form an electrode. At the surface the wires are connected to flashlight batteries in series with a sensitive ammeter. The electric circuit is completed when the electrode is lowered into the well and the ends of the wires touch water. Contact is registered on the ammeter. Even careful measurements of drawdown vary for the same yield, because the water level in a pumping well is constantly moving. Usually it is going down, slowly but steadily.

Measuring Yield

An accurate well test requires careful measurement of yield. Pipe orifices are commonly used to measure discharges within a range of 3-125 L/s (50-2,000 gal/

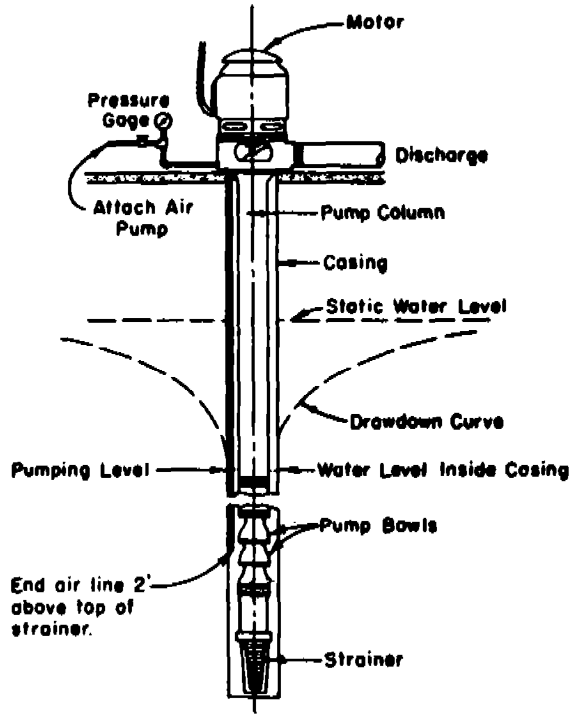


Figure 12-29.—Air line for measuring depth to water level.

min). Parshall flumes or sharp-crested weirs are used to measure larger flows.

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 range of conditions. A pump should not be selected without a thorough knowledge of the operating conditions and pump characteristics.

Maintenance

Many things can reduce the output of a producing well. The owner can do some things to maintain an effective well, but some things are beyond his control. The maintenance program must be looked at from two viewpoints.

First, a producing well may fail completely or its output may so decrease that it is uneconomical to continue its use. Well failure is generally a result of continued sand pumping until the well caves in, the collapse of the well casing from corrosion, or pumping the aquifer dry. A decrease in the well discharge is usually due to a lowering of the water table; encrustation on the well screen or perforations; settlement of fine aquifer materials in the gravel pack; or wearing of the pump, motor, or both, so that the pumping efficiency is decreased. 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.

Second, 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 obtained.

When possible, water samples should be analyzed before a well is constructed, to determine whether the water will corrode certain metals or cause troublesome encrustation. Knowing this in advance enables installation of a corrosion-resistant screen or perforated casing or a screen that can be treated for encrustation. Screens of various metals and metal alloys are available for certain waters and are often well worth the higher cost.

Encrustation of screen stoppage is caused primarily by deposit of chemicals such as carbonates of calcium or magnesium, deposit of soil materials such as clays or silts, and the presence of iron, bacteria, or slime-forming organisms in the water.

There is no foolproof prevention for most chemical encrustation. Pumping at less than maximum drawdown, however, reduces it. The chemistry of well corrosion and encrustation is complex. Detailed information on treating wells is available through commercial well-screen companies and chemical supply houses.

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 acids are used to treat wells, depending on the type of encrustation, but any well so treated must have an acid-resistant screen.

Where the stoppage is caused by bacteria, chlorine treatment is effective. A 25-mm (1-in) pipe can be used to pour the liquid chlorine into the well. A large well (over 400 mm [16 in]) would require 13-18 kg (30-40 lb) of chlorine. The pump can be used to surge the well periodically during the treatment.

Irrigation Age, Inc., Dallas, Tex., recommends that owners maintain their wells in the following manner. Prepare a permanent file containing:

1. Test hole logs and location map.
2. Sieve analysis of formation samples.
3. Water analysis.
4. All geologic data collected in the exploration stage.
5. Well design drawing showing accurate finished dimensions and details.
6. Pump specification sheets, performance curves, parts lists, etc.
7. Details of repairs, acid treatments, etc.

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:

1. Each winter, when all wells have been at rest a long time, run a 2-hr pumping test. Record the static water level, the pumping rate, and frequent drawdown measurements as discussed under Testing.
2. Every 2 months, all year, measure and record the static water level when the pump has been off at least 4 days. Record details.
3. 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.

Applicable State Laws

State laws regarding the use of ground water must be followed. These laws are based on three principal sets of rules or doctrines:

1. Absolute ownership, or the common-law rule, makes the landowner the absolute owner of all underground waters under his or her property. The landowner may develop and use the ground water without regard to the effect on the ground water supplies of adjacent landowners. However, in many States where this rule is followed, it is subject to some qualifications. This doctrine does not recognize flowing ground water or the effect that its misuse may have on other landowners using the same source.
2. Ownership with reasonable use is similar to common-law ownership but limits the owner to use that is reasonable in light of the needs of other landowners whose properties overlie a common source of

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.

Records

Maintaining complete records aids efficient and economical ground-water 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.

Abandonment

Test holes and abandoned wells should be sealed as soon as they have served their purpose. Sealing should be done with materials that prevent transmission of water or reduce it to lower rates than prevail in the material surrounding the well. If more than one aquifer is involved, a positive seal will be provided between the different water-bearing formations.

Glossary

Alluvial Materials. Recent materials deposited by running water. The unconsolidated sand and gravel commonly found underlying flood plains 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 to make practical the production of water for beneficial use.

Area of Influence. The area affected by the discharge from a well.

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.

Artificial Gravel Pack. Gravel or other permeable filter material 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 sand or sediment.

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.

Bailer. A long, narrow bucket made of pipe with a check valve at the bottom, used to remove cuttings from the bottom of the hole.

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

Cement Grout. A mixture of water and cement in the ratio of not more than 19-23 L (5-6 gal) of water to 43 kg (94 lb) of Portland cement. For a better flowing mixture, 1.4-2.3 kg (3-5 lb) of bentonite clay may be added to the cement and the water increased to not more than 25 L (6.5 gal).

Circle of Influence. The boundary of the area of influence. The radius of the circle is the radius of influence (R).

Completed Well. Any well from which the drill rig has been removed, unless the well driller has given the land user written or oral notice that he or she intends to return and do additional work on the well.

ground water. Export of ground water outside of the basin or area is prohibited when owners within the basin or area need these waters. New Hampshire was the first State to adopt this rule, in 1862. Since then it has been adopted by California, Nebraska, Oklahoma, and Hawaii. A recent Supreme Court decision ruled this prohibition invalid.

3. The appropriation doctrine is the concept that, where ground water limits or boundaries can reasonably be established, the subsurface waters are public waters and are subject to appropriation. A designated State agency examines the intent of use and then issues priority rights. The appropriation system emphasizes beneficial use and conservation, security of investment, and responsibility. Statutes based on this doctrine are best known in New Mexico, Oregon, Washington, Kansas, Nevada, Utah, and Arizona. Modified versions of this rule apply in parts of New York and New Jersey.

Most States regulate the development and administration of ground water resources in the public interest.

The more common State regulations are: (1) all persons drilling wells for others must be licensed; (2) drilling permits, logs, and any work performed on wells must be reported to the State on prescribed forms; (3) wells furnishing domestic or municipal water must be properly constructed and finished to prevent contamination; (4) flowing wells must be suitably capped and regulated to avoid waste; (5) abandoned wells must be sealed; (6) air-conditioning and cooling waters must be returned to the ground through recharge wells; and (7) disposal of any contaminants, such as brines or industrial wastes, that 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 ground water in overdraft areas pose many complex technical problems.

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, a contract and 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 ________-mm (____________-in) pipe with a weight of ________________ kg/m (________________ lb/ft) or ____________ class polyvinyl chloride and carried to a depth of about ____________ m (________ ft). 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 alinement that after perforating and testing, a deep-well pump having a clearance of 25 mm (1 in) 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 meter of well will be______ (________________ per foot), 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

Cone of Depression. As water approaches a well that is being pumped, the slope of the water table increases. As distance from the well increases, the slope becomes flatter until it merges with the water table level 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. This is known as the cone of depression.

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 ground water. Also included is the introduction of heated or cooled water into the ground water 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.

Exploratory Holes. Holes or excavations drilled to obtain engineering or geologic data (sometimes referred to as test holes).

Gravel Pack or Filter. A gravel envelope surrounding the well screen, designed to prevent sand from entering the well.

License. A certification, required by the State government, of a person or firm engaged in well drilling.

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.

Lost Head (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.

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

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

Porosity. The degree to which a soil formation 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.

Puddling Clay. A mixture of bentonite, other expansive clays, fine-grained material, and water in a ratio of not less than 3 kg (7 lb) of bentonite or expansive clay per 4 L (1 gal) of water. It must be composed of not less than 50 percent expansive clay, with the maximum size of the remaining portion not exceeding that of coarse sand. Bentonite, cement, or other expansive clays may not be installed dry unless in granulated form.

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

Rawhiding. A way of backwashing that consists of starting and stopping the pump intermittently to produce relatively rapid changes in the pressure heads in the well.

Sand Pumping. The production by a well of sand with the water.

Sieve Analysis. A procedure for measuring grain sizes in a soil sample by shaking the sample through a series of different-sized sieves.

Static Water Table. The surface level of the ground water at the top of the saturated zone in a water-bearing formation.

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

Thickness of Aquifer (H). Saturated thickness of water table aquifer before pumping.

Thickness of Aquifer (M). Saturated thickness of artesian aquifer.

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.

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

Well Driller. Any person who excavates, develops, or opens a well.

Well Drilling. The act of constructing a new well or deepening or modifying an existing well.

Well Drilling Report. A written report concerning the log of the well.

Well Rig. Any power-driven percussion, rotary, boring, digging, jetting, or augering machine used in the construction and development of a well.

Well Screen. A perforated or slotted section of pipe or screen used to separate the well water from the surrounding aquifer.

Well Stabilizer. Material placed around the outside of the well casing to hold it in place.

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