GROUNDWATER AS A WATER-SUPPLY SOURCE 3

The rocks that form the earth's crust are divided into three classes:

1. *Igneous.* Rocks that are derived from the hot magma deep in the earth. They include granite and other coarsely crystalline rocks, dense igneous rocks such as occur in dikes and sills, basalt and other lava rocks, cinders, tuff, and other fragmental volcanic material.
2. *Sedimentary.* Rocks that consist of chemical precipitates and rock fragments deposited by water, ice, or wind. These include deposits of gravel, sand, silt, clay, and the hardened derivatives of these—conglomerates, sandstone, siltstone, shale, limestone, and deposits of gypsum and salt.
3. *Metamorphic.* Rocks that are derived from both igneous and sedimentary rocks through considerable alteration by heat and pressure at great depths. These include gneiss, schist, quartzite, slate, and marble.

The pores, joints, and crevices of the rocks in the zone of saturation are generally filled with water. Although the openings in these rocks are usually small, the total amount of water that can be stored in the subsurface reservoirs of the rock formations is large. The most productive aquifers are deposits of clean, coarse sand and gravel; coarse, porous sandstone; cavernous limestone; and broken lava rock. Some limestone, however, is very dense and unproductive. Most of the igneous and metamorphic rocks are hard, dense, and of low permeability, and generally yield small quantities of water. Among the most unproductive formations are the silts and clays. The openings in these materials are too small to yield water, and the formations are structurally too weak to maintain large openings under pressure. Compact materials near the surface, with open joints similar to crevices in rock, may yield small amounts of water.

GROUNDWATER YIELD AND QUALITY

In an undeveloped groundwater basin, water movement to lower basins, seepage from and to surface-water sources, and transpiration depend on water in storage and the rate of recharge. Following abundant rainfall, recharge may exceed discharge. When recharge does exceed discharge, the excess rainfall increases the amount of water stored in the groundwater basin. In most undeveloped basins, the major fluctuations in storage are seasonal, with the mean annual elevation of water levels showing little variation. Thus, the average annual inflow to storage equals the average annual outflow, a quantity of water referred to as the basin yield.

Proper development of a groundwater source requires careful consideration of the hydrological and geological conditions of the area. To take full advantage of a water source, the assistance of a qualified groundwater engineer, groundwater geologist, hydrologist, or contractor familiar with construction of wells in the area should be obtained. Facts and experience should be relied on, not instinct or intuition. Information about the geology and hydrology of an area may be available in publications of the US Geological Survey or from other federal and state agencies. The National Water Well Association also offers assistance.

Sanitary Quality of Groundwater

When water seeps through overlying material to the water table, particles in suspension, including microorganisms, may be removed. The extent of removal depends on the thickness and character of the overlying material. Clay or hardpan provides the most effective natural filtration of groundwater. Silt and sand also provide good filtration if it is fine enough and in thick enough layers. The bacterial quality of the water also improves during storage in the aquifer because storage conditions are usually unfavorable for bacterial survival. It is important to remember, however, that clarity alone does not guarantee that groundwater is safe to drink; this can only be determined by laboratory testing.

Groundwater found in unconsolidated formations (sand, clay, and gravel) and protected by similar materials from pollution sources is more likely to be safer than water coming from consolidated formations (limestone, fractured rock, lava, etc.).

Where limited filtration is provided by overlying earthen materials, water of better sanitary quality can sometimes be obtained by drilling deeper into the ground. It should be realized that there are areas where it is not possible, because of the geology, to find water at greater depths. Much unnecessary drilling has been done in the mistaken belief that more and better quality water can always be obtained by drilling to deeper formations.

In areas without central sewage systems, human feces are usually deposited in septic tanks, cesspools, or pit privies. Bacteria in the liquid effluents from such installations may enter shallow aquifers. Sewage effluents have been known to enter directly into water-bearing formations by way of abandoned wells or soil-absorption systems. In such areas, the threat of contamination may be reduced by proper well construction—locating the well farther from the source of contamination. The direction of groundwater flow usually approximates that of surface flow, and it is always desirable to locate a well so that the normal movement of groundwater flow carries the contaminant away from the well.

Chemical and Physical Quality of Groundwater

The mineral content of groundwater reflects its movement through the minerals that make up the earth's crust. Generally, groundwater in arid regions is harder and more mineralized than water in regions of high annual rainfall. Also, deeper aquifers are more likely to contain higher concentrations of minerals in solution because the water has had more time (perhaps millions of years) to dissolve the mineral rocks. For any groundwater region there is a depth below which salty water, or brine, is almost certain to be found. This depth varies from one region to another.

Some substances found naturally in groundwater, while not necessarily harmful, may impart a disagreeable taste or undesirable property to the water. Magnesium sulfate (Epsom salt), sodium sulfate (Glauber's salt), and sodium chloride (common table salt) are a few of these. Iron and manganese are commonly found in groundwaters. Regular users of water containing relatively high concentrations of these substances commonly become accustomed to the water and consider it good tasting.

Concentrations of chlorides and nitrates that are unusually high for a particular region may indicate sewage pollution. This is another reason why a chemical analysis of the water should be made periodically, and the results interpreted by someone familiar with this type of analysis.

Temperature

The temperature of groundwater remains nearly constant throughout the year. Water from very shallow sources (less than 50 ft [15 m] deep) may vary in temperature from one season to another, but water from deeper zones remains quite constant—its temperatures being close to that for the average annual temperature at the surface. This is why water from a well may seem to be warm in winter and cold in summer.

Colder water is not obtained by drilling deeper. Beyond about 100 ft (30 m), the temperature of groundwater increases steadily at the rate of about 1° F (5/9° C) for each 75–150 ft (23–46 m) of depth. In volcanic regions, this rate of increase may be much greater.

Distances to Sources of Contamination

All groundwater sources should be located a safe distance from sources of contamination. In cases where sources are severely limited, however, a groundwater aquifer that might become contaminated may be considered for a water supply if treatment is provided. After a decision has been made to locate a water source in an area, it is necessary to determine the distance the source should be placed from the origin of contamination and the direction of water movement. A determination of a safe distance is based on specific local factors described in Chapter 1, under "Sanitary Survey." Table 3-1 is a guide for determining safe distances.

Table 3-1
Guide for Determining Location of Water Source From Contamination Source

Formation	Minimum Acceptable Distance From Well to Source of Contamination
Favorable (unconsolidated)	50 ft (15 m). Lesser distances only with health department approval following comprehensive sanitary survey of proposed site and immediate surroundings.
Unknown	50 ft (15 m) only after comprehensive geological survey of the site and its surroundings has established, to the satisfaction of the health agency, that favorable formations do exist.
Poor (consolidated)	Safe distances can be established only following both the comprehensive geological and comprehensive sanitary surveys. These surveys also permit determining the direction in which a well may be located with respect to sources of contamination. In no case should the acceptable distance be less than 50 ft (15 m).

Because many factors affect the determination of safe distances between groundwater supplies and sources of pollution, it is impractical to set fixed distances. Where insufficient information is available to determine the safe distance, the distance should be the maximum that economics, land ownership, geology, and topography will permit. It should be noted that the direction of groundwater flow does not always follow the slope of the land surface. Each installation should be inspected by a person trained and experienced to evaluate all factors involved.

Since safety of a groundwater source depends primarily on considerations of good well construction and geology, these factors should be the guides in determining safe distances for different situations. The following criteria apply only to properly constructed wells as described in this book. There is no safe distance from a poorly constructed well.

When a properly constructed well penetrates an unconsolidated formation with good filtering properties and when the aquifer itself is separated from sources of contamination by similar materials, research and experience have demonstrated that a minimum of 100 ft (30 m) is an adequate distance for separating the well from the contamination source. However, certain geological conditions exist whereby contamination may be carried a much greater distance. Distances less than 100 ft (30 m) should be accepted only after a comprehensive sanitary survey, conducted by qualified state or local health agency officials, has proven that such lesser distances are both necessary and safe.

If it is proposed to install a properly constructed well in formations of unknown character, the State or US Geological Survey and the state or local health agency should be consulted. When wells must be constructed in consolidated formations, extra care should be taken in locating the well and in setting safe distances, since pollutants can travel great distances in such formations.

Evaluating contamination threats to wells. Conditions unfavorable to the control of contamination and that may require the specification of greater distances between a well and sources of contamination include:

- *Nature of the contaminant.* Human and animal feces and toxic chemical wastes are serious health hazards. In addition, salts, detergents, and other substances that dissolve in water can mix with groundwater and travel with it; they are not ordinarily removed by natural filtration.
- *Deeper disposal.* The danger of contamination is increased by cesspools, dry wells, disposal and waste injection wells, and deep leaching pits that reach aquifers or reduce the amount of earthen filtering material between the wastes and the aquifer.
- *Limited filtration.* When earthen materials surrounding a well and overlying the aquifer are too coarse to provide effective filtration—as with limestone, coarse gravel, etc.—or when they form a layer that is too thin, the risk of contamination is increased.
- *The aquifer.* When the materials that make up the aquifer are too coarse to provide good filtration—as is the case with limestone, fractured rock, etc.—contaminants entering the aquifer through outcrops or excavations may travel great distances. It is especially important in such cases to know the direction of groundwater flow and whether there are outcrops of the formation (or excavations reaching it) upstream and close enough to be a threat.
- *Volume of waste discharged.* Since large volumes of wastes discharged and reaching an aquifer can significantly change the slope of the water table and the direction of groundwater flow, it is obvious that heavier discharges can increase the threat of contamination.
- *Contact surface.* When pits and channels are designed and constructed to increase the rate of absorption—as with septic tank leaching systems, cesspools, and

leaching pits—more separation from the water source will be needed than when tight sewer lines or waste pipes are used.

- *Concentration of contamination sources.* The existence of more than one contamination source increases the total pollution load and, consequently, the danger of contamination.

DEVELOPMENT OF GROUNDWATER

The type of groundwater development to be undertaken depends on the geological formations and hydrological characteristics of the water-bearing formation. Development of groundwater falls into two main categories:

1. Development by wells
   a. Nonartesian or water table
   b. Artesian
2. Development from springs
   a. Gravity
   b. Artesian.

Nonartesian wells penetrate formations in which groundwater is found under water-table conditions. Pumping from the well lowers the water table in the vicinity of the well, and water moves toward the well due to the pressure differences that are artificially created.

Artesian wells penetrate aquifers in which the groundwater is found under hydrostatic pressure. Such a condition occurs in an aquifer that is confined beneath an impermeable layer of material at an elevation lower than that of the intake area of the aquifer. The intake areas or recharge areas of confined aquifers are commonly at high-level, surface outcrops of the formations. Groundwater flows from high-level outcrop areas to low-level outcrop areas, which are areas of natural discharge. It also flows toward points where water levels are lowered artificially by pumping from wells. When the water level in the well stands above the top of the aquifer, the well is described as artesian. A well that yields water by artesian pressure at the ground surface is a flowing artesian well.

Gravity springs occur where water percolating laterally through permeable material overlying an impermeable stratum comes to the surface. They also occur where the land surface intersects the water table. This type of spring is particularly sensitive to seasonal fluctuations in groundwater storage and frequently dwindles to a seep or disappears during dry periods. Gravity springs are characteristically low-discharge sources, but when properly developed they make satisfactory small water-supply systems.

Artesian springs discharge from artesian aquifers. They may occur where the confining formation above the artesian aquifer is ruptured by a fault or where the aquifer discharges to a lower topographic area. Flow from these springs depends on the difference in recharge and discharge elevations of the aquifer and on the size of the openings transmitting the water. Artesian springs are usually more dependable than gravity springs, but they are particularly sensitive to the pumping of wells developed in the same aquifer. As a consequence, artesian springs may dry up due to pumping.

Springs may be further classified by the nature of the passages through which water issues from the source.

Seepage springs are those in which the water seeps out of sand, gravel, or other material that contains many small openings. The term, as used here, includes many large springs as well as small ones. Some of the large springs have extensive seepage areas and are usually marked by the presence of abundant vegetation. The water of small seepage springs may be colored or carry an oil scum due to decomposition of organic matter or the presence of iron. Seepage springs may emerge along the top of an impermeable bed, but they occur more commonly where valleys are cut into the zone of saturation of water-bearing deposits. These springs are generally free from harmful bacteria, but they are susceptible to contamination by surface runoff, which collects in valleys or depressions.

Tubular springs issue from relatively large channels, such as the solution channels and caverns of limestone, and soluble rocks and smaller channels that occur in glacial drift. They are sometimes referred to as bold springs because the water issues freely from one or more large openings. When the water reaches the channels by percolation through sand or other fine-grained material, it is usually free from contamination. When the channels receive surface water directly or receive the indirect effluent of cesspools, privies, or septic tanks, the water must be regarded as unsafe.

Fissure springs issue along bedding, joint, cleavage, or fault planes. Their distinguishing feature is a break in the rocks along which the water passes. Some of these springs discharge uncontaminated water of deep-source origin. A large number of thermal springs are of this type. Fissure springs, however, may discharge water that is contaminated by surface drainage from strata close to the surface.

DEVELOPMENT OF WELLS

When a well is pumped, the level of the water table in the vicinity of the well will be lowered (Figure 3-1A). This lowering, or drawdown, causes the water table or artesian pressure surface, depending on the type of aquifer, to take the shape of an inverted cone called a cone of depression. This cone, with the well at the apex, is measured in terms of the difference between the static water level and the pumping level. At increasing distances from the well, drawdown decreases until the slope of the cone merges with the static water table. The distance from this point to the well is called the radius of influence. The radius of influence is not constant but continuously expands with continued pumping. At a given pumping rate, the shape of the cone of depression depends on the characteristics of the water-bearing formation. Shallow and wide cones will form in highly permeable aquifers composed of coarse sand or gravel. Steep and narrow cones will form in less permeable aquifers. As the pumping rate increases, the drawdown increases and consequently the slope of the cone steepens.

The character of the aquifer—artesian or water table—and the physical characteristics of the formation that will affect the shape of the cone include thickness, lateral extent, and size and grading of sand or gravel. In a material of low permeability such as fine sand or sandy clay, the drawdown will be greater and the radius of influence less than for the same pumpage from very coarse gravel (Figure 3-1B). For example, when other conditions are equal for two wells, it may be expected that pumping costs at the same pumping rate will be higher for the well surrounded by material of lower permeability because of the greater drawdown.

When the cones of depression overlap, the local water table will be lowered (Figure 3-1C). An increase in pumping lifts is required to obtain water from the interior portion of the group of wells. In addition, a wider distribution of wells over the groundwater basin will reduce the cost of pumping and allow the development of more water.

Yield of Wells

The amount of water that can be pumped from any well depends on the character of the aquifer and the construction of the well. Contrary to popular belief, doubling the diameter of a well increases its yield only about 10 percent. Or, it could be said that it decreases the drawdown only about 10 percent at the same pumping rate. The casing diameter should be chosen to provide enough room for proper installation of the pump.

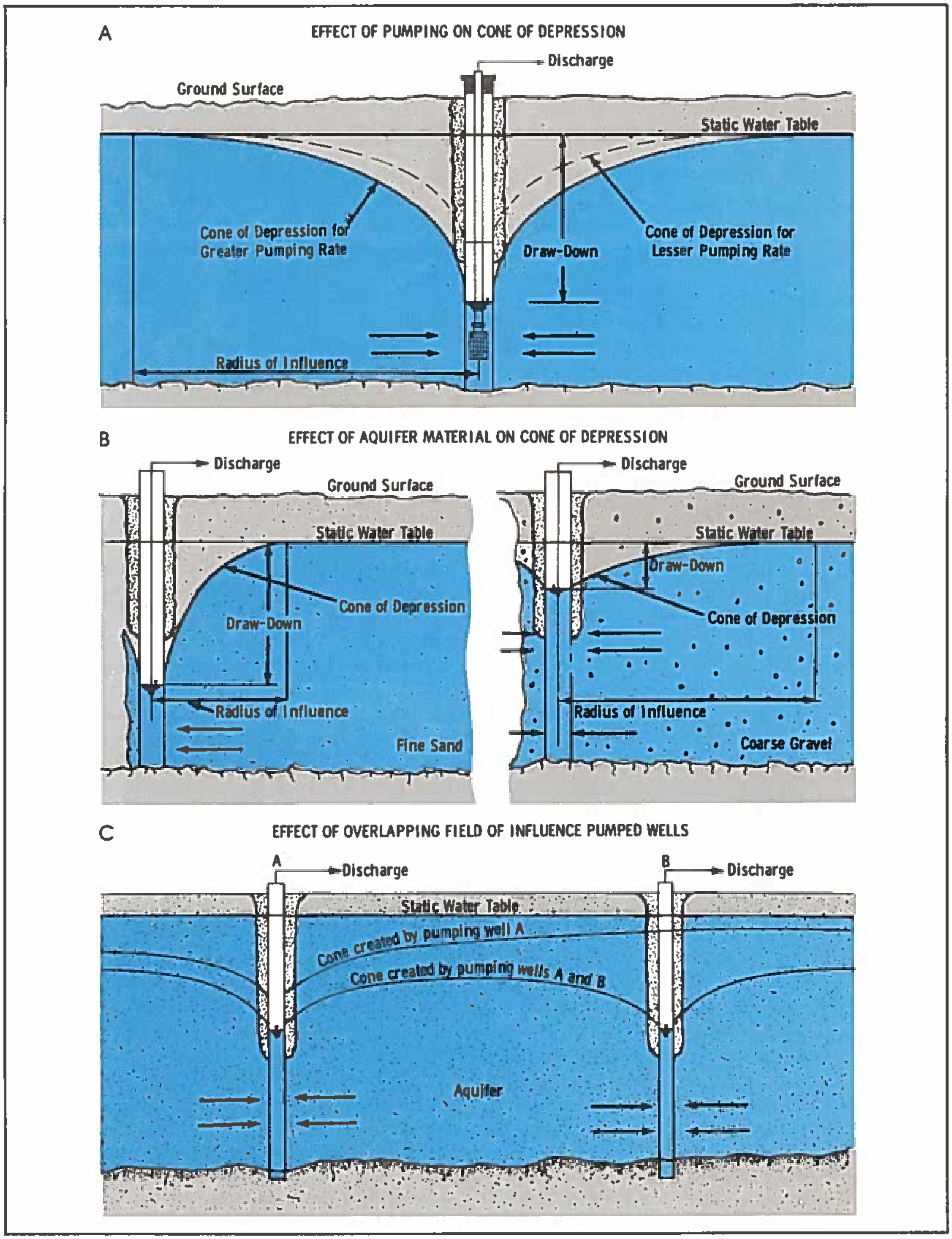

Figure 3-1 Pumping Effects on Aquifers

A more effective way of increasing well capacity is by drilling deeper into the aquifer—assuming that the aquifer has the necessary thickness. Consideration of the inlet portion of the well structure (screen, perforations, slots) is also important in determining the yield of a well in a sand or gravel formation. The amount of open area in the screened or perforated portion exposed to the aquifer is critical. Wells completed in consolidated formations are usually of open-hole construction; that is, there is no casing in the aquifer itself.

It is not always possible to accurately predict the yield of a well before it is completed. Knowledge can be gained, however, from studying the geology of the area and interpreting the results obtained from other wells constructed in the vicinity. This information is helpful in selecting the location and type of well most likely to be successful. The information can also provide an indication of the quantity or yield to expect.

A common way to describe the yield of a well is to express its discharge capacity in relation to its drawdown. This relationship is called the specific capacity of the well and is expressed in gallons per minute per foot (litres per minute per metre) of drawdown. The specific capacity may range from less than 1 gpm/ft (12 L/min/m) of drawdown for a poorly developed well or a well in a tight aquifer to more than 100 gpm/ft (1241 L/min/m) of drawdown for a properly developed well in a highly permeable aquifer.

Types of Wells and Their Construction

The following paragraphs detail common methods of well construction along with advantages and disadvantages. Reliable local contractors and state or local health agencies can give valuable advice specific to a utility's needs. AWWA A100-66, Standard for Deep Wells, contains sample contract language and an extensive appendix discussing areas to be specified in a well-construction contract.

Preparation of ground surface at well site. A properly constructed well should exclude surface water from a groundwater source to the same degree as does the undisturbed overlying geologic formation. The top of the well must be constructed so that no foreign matter or surface water can enter. The well site should be properly drained and adequately protected against erosion, flooding, and damage or contamination from animals. Surface drainage should be diverted away from the well.

Dug wells. The dug well, constructed by hand, is usually shallow. It is difficult to protect from contamination, although if finished properly it may provide a satisfactory water supply. Consideration should first be given to other types of wells because of the advantages they offer. Figure 3-2 shows a dug well that has been grouted and sealed to prevent contamination.

Most dug wells do not penetrate much below the water table because of the difficulties in manual excavation and the positioning of linings. This seriously limits the drawdown that can be imposed during pumping, which in turn limits the yield of the well. The depth of excavation can be increased by using pumps to lower the water level during construction. Because of their shallow penetration into the zone of saturation, many dug wells fail in times of drought when the water level recedes or when large quantities of water are pumped from the wells.

A dug well that taps a highly permeable formation such as gravel may yield 10–30 gpm (38–114 L/min) or even more in some situations with only 2 or 3 ft (0.6 or 0.9 m) of drawdown. If the formation is primarily fine sand, the yield may be on the order of 2–10 gpm (8–38 L/min). These yields apply to dug wells of the sizes commonly used.

Bored wells. Bored wells are commonly dug with earth augers turned either by hand or by power equipment. Such wells are usually regarded as practical at depths of less than 100 ft (30 m) when the water requirement is low and the material overlying the water-bearing formation has noncaving properties and contains few large boulders. In suitable material, holes from 2–30 in. (50–760 mm) in diameter can be bored to about 100 ft (30 m)

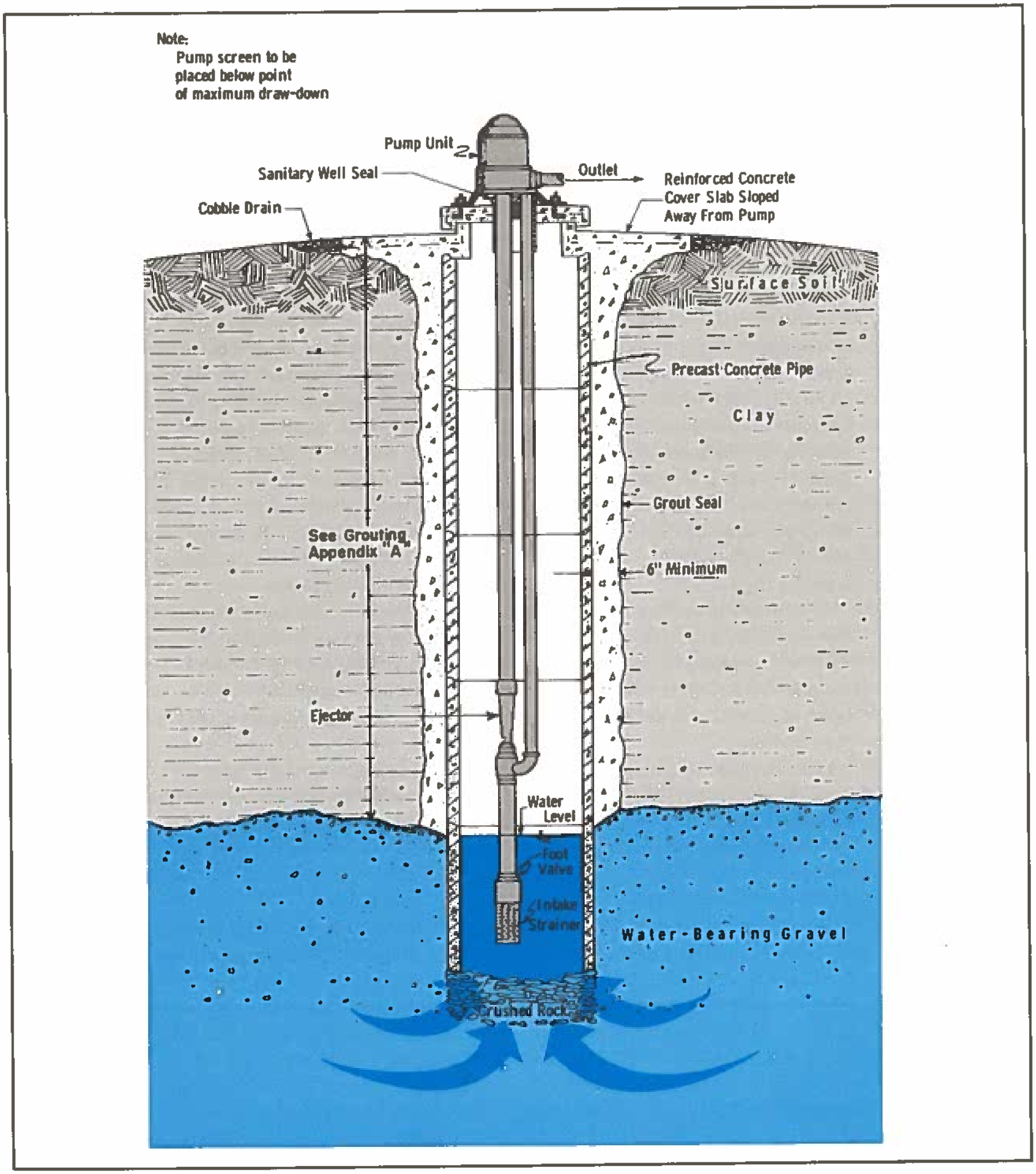

Figure 3-2 Grouted and Sealed Dug Well

without caving in. In general, bored wells have the same characteristics as dug wells, but they may be extended deeper into the water-bearing formation.

Bored wells may be cased with vitrified tile, concrete pipe, standard wrought iron, steel casing, or other suitable material capable of sustaining imposed loads. The well may be completed by installing well screens or perforated casing in the water-bearing sand and gravel. Proper protection from surface drainage should be provided by sealing the casing with cement grout to the depth necessary to protect the well from contamination. See "Sanitary Construction of Wells," this chapter and Appendix C for more information.

Bored wells, like dug wells, can also be sunk only a limited depth below the static water level. Penetration of 5–10 ft (1.5–3 m) into the water-bearing formation can probably be achieved. If the well is nonartesian, the available drawdown will be 2 or 3 ft (0.6 or 0.9 m) less than the depth of water standing in the well. If the well taps an artesian aquifer, however, the static water level will rise to some point above the top of the aquifer. This rise of the static water level increases the water depth. The available drawdown and the yield of the well will therefore be increased. A bored well tapping a highly permeable aquifer and providing several feet of available drawdown may yield 20 gpm (76 L/min) or more. If the aquifer has a low permeability or the depth of water in the well is small, the yield may be much lower.

Driven wells. The simplest and least expensive type of well is the driven well. It is constructed by driving into the ground a drive-well point, which is fitted to the end of a series of pipe sections. The drive point is of forged or cast steel. Drive points are usually 1¼ or 2 in. (30 or 100 mm) in diameter. The well is driven with the aid of a maul, or a special drive weight. For deeper wells, the well points are sometimes driven into water-bearing strata from the bottom of a bored or dug well. The yield of driven wells is generally small to moderate. Where they can be driven an appreciable depth below the water table, they are no more likely to be seriously affected by water-table fluctuations than bored wells. The most suitable locations for driven wells are areas containing alluvial deposits of high permeability. Coarse gravel, cobbles, or boulders interfere with sinking the well point and may damage the wire mesh jacket.

Well-drive points can be obtained in a variety of designs and material. In general, the serviceability and efficiency of each type is related to its basic design. The continuous-slot, wire-wound type is more resistant to corrosion and can usually be treated with chemicals to correct problems of incrustation. It is more efficient because of its greater open area, and is easier to develop because its design permits easy access to the formation for cleanup.

Another type of point has a metal gauze wrapped around a perforated steel pipe base and is covered by a perforated jacket; if it contains dissimilar metals, electrolytic corrosion is likely to shorten its life, especially in corrosive waters.

Wherever maximum capacity is required, well-drive points of good design are a worthwhile investment. The manufacturer should be consulted for his recommendation of the metal alloy best suited to the particular situation.

Good well-drive points are available with different size openings, or slot sizes, for use in sands of different grain sizes. If too large a slot size is used, it may never be possible to develop the well properly, and the well is likely to be a "sand pumper" or to gradually fill in with sand, cutting off the flow of water from the aquifer. On the other hand, if the slot size is too small, it may be difficult to improve the well capacity by development and the yield may be too low. When the nature of aquifer sand is not known, a medium-sized slot—0.015 in. (0.4 mm) or 0.020 in. (0.5 mm)—can be tried. If sand and sediment continue indefinitely to pass through the slots during development, a smaller slot size should be used. If, however, the water cleans up very quickly with very little sand and sediment removed during development—less than one-third of the volume of the drive point—then a larger slot size could have been selected, resulting in more complete development and greater well yield.

When a well is driven, it is desirable to prepare a pilot hole that extends to the maximum practical depth. This can be done with a hand auger slightly larger than the well point. After the pilot hole has been prepared, the assembled point and pipe are lowered into the hole. Depending on the resistance afforded by the formation, driving is accomplished in several ways. The pipe is driven by directly striking the drive cap, which is snugly threaded to the top of the protruding section of pipe. A maul, a sledge, or a special driver may be used to hand-drive the pipe. The special driver may consist of a weight and sleeve arrangement, which slides over the drive cap as the weight is lifted and dropped in the driving process.

Driven wells can be sunk as much as 30 ft (9 m) or more below the static water level. A well at this depth can provide 20 ft (6 m) or more of drawdown when being pumped. The small diameter of the well, however, limits the type of pump that can be used, so that the yield under favorable conditions is limited to about 30 gpm (114 L/min). In fine sand or sandy clay formations of limited thickness, the yield may be less than 5 gpm (19 L/min).

Jetted wells. A rapid and efficient method of sinking well points is that of jetting or washing-in. This method requires a water source and a pressure pump. Water forced under pressure down the riser pipe issues from a special washing point. The well point and pipe are then lowered as material is loosened by jetting.

The riser pipe of a jetted well is often used as the suction pipe for the pump. In such instances, surface water may be drawn into the well if the pipe develops holes by corrosion. An outside protective casing may be installed to the depth necessary to provide protection against the possible entry of contaminated surface water. The annular space between the casings should then be filled with cement grout. The protective casing is best installed in an auger hole and the drive point then driven inside it.

Drilled wells. Construction of a drilled well (Figure 3-3) is ordinarily accomplished by one of two techniques—percussion or rotary hydraulic drilling—or a variation of one of these techniques. The selection of the method depends primarily on the geology of the site and the availability of equipment.

Percussion (cable-tool) method. Drilling by the percussion or cable-tool method is accomplished by raising and dropping a heavy drill bit and stem. The impact of the bit crushes and dislodges pieces of the formation. The reciprocating motion of the drill tools mixes the drill cuttings with water into a slurry at the bottom of the hole. This is periodically brought to the surface with a bailer, a 10- to 20-ft (3- to 6-m) pipe equipped with a valve at the lower end.

Caving is prevented as drilling progresses by driving or sinking into the ground a casing slightly larger in diameter than the bit. When wells are drilled in hard rock, casing is usually necessary only through the overburden of unconsolidated material. A casing may be necessary in hard rock formations to prevent caving of beds of softer material.

When good drilling practices are followed, water-bearing beds are readily detected in cable-tool holes, because the slurry does not tend to seal off the water-bearing formation. A rise or fall in the water level in the hole during drilling or more rapid recovery of the water level during bailing indicates that a permeable bed has been entered. Crevices or soft streaks in hard formations are often water bearing. Sand, gravel, limestone, and sandstone are generally permeable and yield the most water.

Hydraulic rotary drilling method. The hydraulic rotary drilling method may be used in most formations. The essential parts of the drilling assembly include a derrick and hoist, a revolving table through which the drill pipe passes, a series of drill-pipe sections, a cutting bit at the lower end of the drill pipe, a pump for circulation of drilling fluid, and a power source to drive the drill.

During the drilling operation, the bit breaks up the material as it rotates and advances. The drilling fluid (called mud) pumped down the drill pipe picks up the drill cuttings and carries them up the annular space between the rotating pipe and the wall of the hole. The mixture of mud and cuttings is discharged to a settling pit where the cuttings drop to the bottom and mud is recirculated to the drill pipe.

When the hole is completed, the drill pipe is withdrawn and the casing placed. The drilling mud is usually left in place and pumped out after the casing and screen are positioned. The annular space between the hole wall and the casing is generally filled

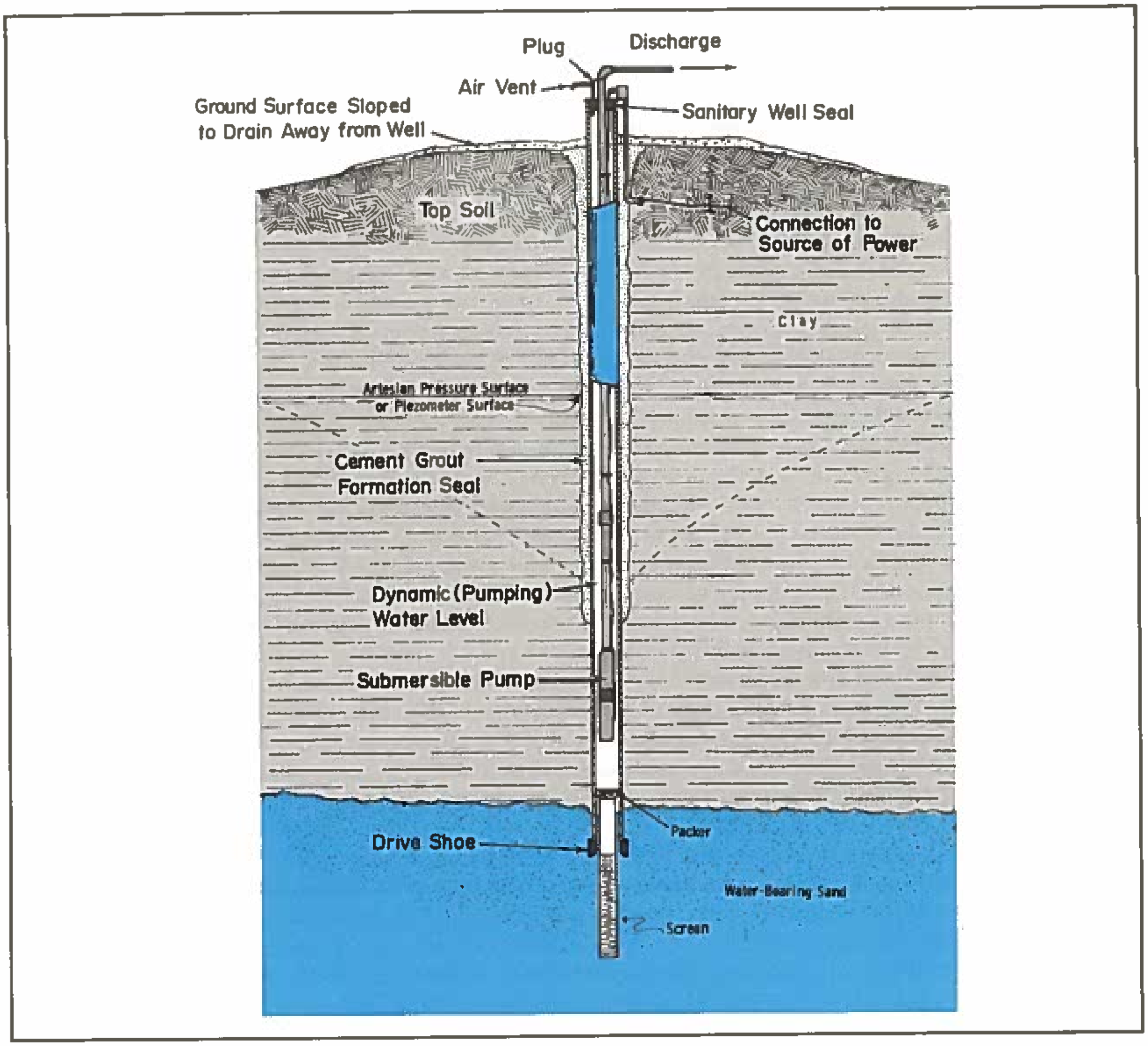

Figure 3-3 Drilled Well

with cement grout in non-water-bearing sections, but may be enlarged and filled with gravel at the level of water-bearing strata.

When little is known about the geology of the area, the search for water-bearing formations must be done carefully and deliberately so that all possible formations are located and tested. Water-bearing formations may be difficult to recognize by the rotary method or may be plugged by the pressure of the mud.

Air rotary drilling method. The air rotary method is similar to the rotary hydraulic method in that the same type of drilling machine and tools may be used. The principal difference is that air rather than mud or water is used as the drilling fluid. In place of the conventional mud pump to circulate the fluids, air compressors are used. Many drillers equip the rig with a mud pump to increase the versatility of the equipment.

The air rotary method is well adapted to rapid penetration of consolidated formations, and is especially popular in regions where limestone is the principal water source. This method is not generally suited to unconsolidated formations where careful sampling of rock materials is required for well-screen installation. Small quantities of water can be readily detected during drilling and the yield estimated. Larger sources of water may impede progress.

The air rotary method requires that air be supplied at pressures from 100–250 psi (690–1720 kPa). To effect removal of the cuttings, rising velocities of at least 3000 fpm (15 m/s) are necessary. Penetration rates of 20–30 fph (6–9 m/h) in very hard rock are common with air rotary methods.

Conventional mud drilling is sometimes used to drill through caving formations that overlie bedrock. Casing may have to be installed through the overburden before continuing with the air rotary method.

Down-the-hole air hammer. The down-hole pneumatic hammer combines the percussion effect of cable-tool drilling and the rotary movement of rotary drilling. The tool bit is equipped with tungsten-carbide inserts at the cutting surfaces. Tungsten-carbide is very resistant to abrasion.

General. Jetted and drilled wells can usually be sunk to such depths that the depth of water standing in the well and consequently the available drawdown will vary from less than 10 feet to hundreds of feet (less than three metres to hundreds of metres). In productive formations of considerable thickness, yields of 300 gpm (1135 L/min) and more are readily obtained. The capacity or yield of a well varies greatly, depending on the permeability and thickness of the formation, the construction of the well, and the available drawdown.

Drilled wells can be constructed in all instances where driven wells are used and in many areas where dug and bored wells are used. The larger diameter of a drilled well as opposed to that of a driven well permits use of larger pumping equipment that can develop the full capacity of the aquifer. Table 3-2 gives general information on the practicality of penetrating various types of geologic formations by the methods indicated.

Well Components

Water well casing and pipe. There are several kinds of steel pipe suitable for casing drilled wells. The following are the most commonly used: standard pipe, line pipe, drive pipe, reamed and drifted (R&D) pipe, and water-well casing.

There are certain differences in size, wall thickness, type of threaded connection available, and method of manufacture between the pipe types. Well casing must meet certain generally accepted specifications for quality of steel and thickness of the wall. Both are important because they determine resistance to corrosion and consequently the useful life of the well. Strength of the casing may also be important in determining whether certain well-construction procedures may be successfully carried out, particulary in cable-tool drilling where hard driving of the casing is sometimes required.

The most commonly accepted specifications for water well casing are those prepared by the American Society for Testing and Materials (ASTM), American Petroleum Institute (API), American Iron and Steel Institute (AISI), and the federal government. Each source lists several specifications that might be used. Refer to Appendix B for the addresses of the above-mentioned associations.

Table 3-3 lists standard weight wall thicknesses for standard pipe and line pipe through the sizes ordinarily used in well construction. Thinner pipe should not be used. If conditions in the area are known to be highly corrosive, the extra strong, heavier weight pipe should be used.

PVC plastic well casing may be considered in cases of corrosive water. For a satisfactory installation, it is important that the manufacturer's recommendations be closely followed during installation. All PVC casings must be made of a material approved for use with potable water by the National Sanitation Foundation (NSF).

Table 3-2
Suitability of Well Construction Methods to Different Geological Conditions*

Characteristics	Dug	Bored	Driven	Drilled			Jetted
					Rotary		
				Percussion	Hydraulic	Air	
Range of practical depths (general order of magnitude)	0-50 ft (0-15 m)	0-100 ft (0-30 m)	0-50 ft (0-15 m)	0-1000 ft (0-305 m)	0-1000 ft (0-305 m)	0-750 ft (0-229 m)	0-100 ft (0-30 m)
Diameter	3-20 ft (1-6 m)	2-30 in. (51-762 mm)	1¼-2 in. (32-51 mm)	4-18 in. (102-457 mm)	4-24 in. (102-610 mm)	4-10 in. (102-254 mm)	2-12 in. (51-305 mm)
Type of geologic formation:							
Clay	Yes	Yes	Yes	Yes	Yes	No	Yes
Silt	Yes	Yes	Yes	Yes	Yes	No	Yes
Sand	Yes	Yes	Yes	Yes	Yes	No	Yes
Gravel	Yes	Yes	Fine	Yes	Yes	No	¼-in. (6-mm) pea gravel
Cemented gravel	Yes	No	No	Yes	Yes	No	No
Boulders	Yes	Yes, if less than well diameter	No	Yes, when in firm bedding	(Difficult)	No	No
Sandstone	Yes, if soft and/or fractured	Yes, if soft and/or fractured	Thin layers only	Yes	Yes	Yes	No
Limestone			No	Yes	Yes	Yes	No
Dense igneous rock	No	No	No	Yes	Yes	Yes	No

*The range of values in this table are based upon general conditions. They may be exceeded for specific areas of conditions.

Table 3-3
Steel Pipe and Casing, Standard and Standard Line Pipe

Nominal Size *in. (mm)*	Diameters *in. (mm)* Outside	Diameters *in. (mm)* Inside	Wall Thickness *in. (mm)*	Approximate Weight *lb/ft (kg/m)* Plain Ends	Approximate Weight *lb/ft (kg/m)* Threaded and Coupled
1¼ (32)	1.660 (42.16)	1.380 (35.05)	.140 (3.55)	2.27 (3.38)	2.30 (3.42)
1½ (40)	1.900 (48.26)	1.610 (65.84)	.145 (3.68)	2.72 (4.05)	2.75 (4.09)
2 (50)	2.375 (60.33)	2.067 (52.50)	.154 (3.91)	3.65 (5.43)	3.75 (5.58)
3 (80)	3.500 (88.90)	3.068 (77.93)	.216 (5.49)	7.58 (11.30)	7.70 (11.50)
4 (100)	4.500 (114.30)	4.026 (102.30)	.237 (6.02)	10.79 (16.06)	11.00 (16.37)
5 (125)	5.563 (141.30)	5.047 (128.20)	.258 (6.55)	14.62 (21.75)	15.00 (22.32)
6 (150)	6.625 (168.30)	6.065 (154.10)	.280 (7.11)	18.97 (28.23)	19.45 (28.94)
8 (200)	8.625 (219.10)	8.071 (205.00)	.277 (7.04)	24.70 (36.75)	25.55 (38.02)
8 (200)	8.625 (219.10)	7.981 (202.70)	.322 (8.18)	28.55 (42.48)	29.35 (43.67)
10 (250)	10.750 (273.05)	10.192 (258.88)	.279 (7.09)	31.20 (46.43)	32.75 (48.73)
10 (250)	10.750 (273.05)	10.136 (257.45)	.307 (7.80)	34.24 (50.95)	35.75 (53.20)
10 (250)	10.750 (273.05)	10.020 (254.51)	.365 (9.27)	40.48 (60.23)	41.85 (62.27)
12 (300)	12.750 (323.85)	12.090 (307.09)	.330 (8.38)	43.77 (65.13)	45.45 (67.63)
12 (300)	12.750 (323.85)	12.000 (304.80)	.375 (9.53)	49.56 (73.75)	51.10 (76.04)

Grouting. After the casing is placed, the space between the outside of the casing and the surrounding earth must be sealed with grout to prevent contamination of the aquifer. Grouting is discussed in detail under "Sanitary Construction of Wells," later in this chapter.

Setting screens or slotted casings in wells. Screens or slotted casings are installed in wells to permit sand-free water to flow into the well and to provide support for unstable formations to prevent caving. In a drilled well, the screens are normally placed after the casing has been installed; however, in a driven well, the screen is a part of the drive assembly and is sunk to its final position as the well is driven.

The size of the slot for the screen or perforated pipe should be based on a sieve analysis of carefully selected samples from the water-bearing formation that is to be developed. The analysis is usually made by the screen manufacturer. If the slot size is too large, the well may yield sand when pumped. If the slot size is too small, the slots may become plugged with fine material, and the well yield will be reduced. Slots or holes burned into the bottom end of the casing should not be substituted for a manufactured well screen.

The relationship between the open area of the screen and the velocity of water through the openings should be considered if maximum hydraulic efficiency is desired. Loss of energy through friction is kept to a minimum by holding velocities to 0.1 fps (0.03 m/s) or less. Since slot size is determined by grain size distribution in the aquifer sand, the required open area must be obtained by varying the diameter or, if aquifer thickness permits, by varying the length of the screen. Manufacturers of well screens provide tables of capacities and other information to facilitate selection of the most economical screen dimensions.

Methods of screen installation in drilled wells include (1) the pullback method, (2) the open-hole method, (3) the baildown method, and (4) the washdown method. The pullback method of installation is one in which the casing is drawn back to expose a well screen placed inside the casing at the bottom of the well. In the open-hole installation, the screen attached to the casing is inserted in the uncased bottom portion of the hole when the aquifer portion of the hole remains open. When the baildown method is used, the screen is placed at the bottom of the cased hole and advanced into the waterbearing formation by bailing the sand out from below the screen. The pullback method is suited to bored or drilled wells, as long as the casing can be moved, while the open-hole method is usually used with rotary drilling. The baildown method may be used in wells drilled by any method where water-bearing formations consist of sand. It is not well adapted to gravel formations. A screen is seldom required in wells tapping bedrock or tightly cemented sediments such as sandstone or limestone.

The fourth method, the washdown method, is adaptable primarily in rotary drilled holes. This procedure entails the circulation of water, by use of the mud pump, through a special self-closing bottom upward around the screen and through the annular space between the washpipe and the permanent casing to the surface. As material is washed by jet action from below, the well screen settles to its desired position.

If the screen is placed after positioning of the casing, it must be firmly sealed to the casing. This is generally done by swaging out a lead packer attached to the top of the screen. When the pullback method is used, a closed bail bottom usually provides the bottom closure; a self-closing bottom is used with the washdown method. A special plug is placed in the bottom when the baildown method is used. A quantity of lead wool or a small bag of dry cement may also be tamped into the bottom of the screen to seal it.

Developing a Well

Before a well is put into use, it is necessary to completely remove silt and fine sand from the formation adjacent to the well screen by one of several processes known as well development. The development procedure unplugs the formation and produces a natural filter of coarser and more uniform particles of high permeability surrounding the well screen. After the development is completed, there will be a well-graded, stabilized layer of coarse material, which will entirely surround the well screen and facilitate the flow of water from the formation into the well.

The simplest method of well development is that of surging. In this process silt and sand are agitated by a series of rapid reversals in the direction of flow of water and are drawn toward the screen through larger openings. A well may be surged by moving a plunger up and down in it. This action moves the water alternately into and out of the formation. When water containing fine granular material moves into the well, the particles tend to settle to the bottom of the screen. They can then be removed by pumping or bailing.

One of the most effective methods of development is the high-velocity hydraulic-jetting method. Water under pressure ejected from orifices passes through the slot openings and violently agitates the aquifer material. Sand grains finer than the slot size move through the screen and either settle to the bottom of the well (from which they are subsequently removed by bailing) or are washed out at the top (if the well overflows). Conventional centrifugal or piston pumps may be used. The mud pump of the rotary hydraulic drill can also be used. Pressures of at least 100 psi (690 kPa) should be used, with pressure greater than 150 psi (1030 kPa) preferred. In addition to the intensity of development that may be applied by this method, the method permits selective concentration of development on those portions of the screen most in need. High-velocity jetting is of most benefit in screens of continuous, horizontal-slot design. It has also proven effective in washing out drilling mud and cuttings from crevices in hard-rock wells. It is less useful in slotted or perforated pipe.

Other methods of development include interrupted pumping and, sometimes in consolidated material, explosives (which should be used only by experts). The method of development must be suited to the aquifer and the type of well construction. Proper development is necessary in many formations and under many conditions for the completion of a successful well. Its importance should not be overlooked.

Testing Well for Yield and Drawdown

In order to select the most suitable pumping equipment, a pumping test should be made after the well has been developed to determine its yield and drawdown. The pumping test for yield and drawdown should include determination of the volume of water pumped per minute or hour, depth to the pumping level as determined over a period of time at one or more constant rates of pumpage, recovery of the water level after pumping is stopped, and length of time the well is pumped at each rate during the test procedure. When the completed well is tested for yield and drawdown, it is essential that it be done accurately using approved measuring devices and accepted methods.

Detailed instructions for testing and evaluating well yield are contained in *Improving Well and Pump Efficiency* by Helweg, Scott, and Scalmanini (AWWA; Denver, Colo; 1983). Additional information regarding the testing of wells for drawdown or yield may be obtained from the US Geological Survey, the state or local health department, and manufacturers of well screens or pumping equipment.

Water-table wells are more affected than artesian wells by seasonal fluctuations in groundwater levels. When testing a water-table well for yield and drawdown, it is desirable, though frequently not practical, to test it near the end of the dry season. If this cannot be done, it is important to determine as nearly as possible, from other wells tapping the same formations, the additional seasonal decline in water level that can be expected. This additional decline should then be added to the drawdown determined by the pumping test in order to arrive at the ultimate pumping water level. Seasonal declines of several feet (metres) in water-table wells are not unusual, and these can seriously reduce the capacity of such wells in the dry season.

Individual wells should be test pumped at a constant pumping rate that is not less than that planned for the final pump installation and preferably 1½ times the proposed pump rate. The well should be pumped at this rate for not less than 24 hours, and the maximum drawdown recorded. Measurements of water levels during recovery can then be made. Failure to recover completely to the original static water level within 24 hours should be reason to question the dependability of the water-bearing formation.

Sanitary Construction of Wells

The penetration of a water-bearing formation by a well provides a direct route for possible contamination of the groundwater. Although there are different types of wells and well construction, there are basic sanitary aspects that must be considered and followed. These include:

- The annular space outside the casing should be filled with a watertight cement grout or puddled clay from a point just below the frost line or deepest level of excavation near the well to as deep as necessary to prevent entry of contaminated water, whether from surface runoff or other aquifers.

- For artesian aquifers, the casing should be sealed into the overlying impermeable formations so as to retain the artesian pressure.

- When a water-bearing formation containing water of poor quality is penetrated, the formation should be sealed off to prevent infiltration of water into the well and aquifer.

- A sanitary well seal with an approved vent should be installed at the top of the well casing to prevent entrance of contaminated water or other objectionable material. The well seal should be installed only in well houses; a pitless adapter and cap assembly should be used in all other situations. Pitless adaptors are covered in greater detail in Chapter 6.

For large-diameter wells such as dug wells, it is difficult to provide a sanitary well seal; consequently, a reinforced concrete slab, overlapping the casing and sealed to it with a flexible sealant or rubber gasket, should be installed. The annular space outside the casing should first be filled with suitable grouting or sealing materials—cement, clay, or fine sand.

Grouting. When wells are drilled, the hole is made much larger than the casing. The space between the casing and the hole, called the annular space, or annulus, provides a direct channel from the surface to the groundwater. This space must be filled with grout to prevent surface contaminants from running down the annulus and into the aquifer. The typical grout seal shown in Figures 6-2 and 6-5 greatly reduces the possibility of contamination.

Sealing the annulus has added advantages: It seals out poor quality from an overlying aquifer; it increases the life of the well by protecting the casing against exterior corrosion; and it stabilizes the soil and rock formation to help prevent caving.

Well covers and seals. Every well should be provided with an overlapping, tight-fitting cover at the top of the casing or pipe sleeve to prevent contaminated water or other material from entering the well.

The sanitary well seal in a well exposed to possible flooding should be either watertight or elevated at least 2 ft (0.6 m) above the highest known flood level. When it is expected that a well seal may become flooded, it should be watertight and equipped with a vent line that has an opening to the atmosphere at least 2 ft (0.6 m) above the highest known flood level.

The seal in a well not exposed to possible flooding should be either watertight (with an approved vent line) or self-draining with an overlapping and downward flange. If the seal is of the self-draining (non-watertight) type, all openings in the cover should be either watertight or flanged upward and provided with overlapping, downward flanged covers. All sanitary well seals, pitless adapter units, and caps must be approved by local or state health departments.

Some pump and power units have closed bases that effectively seal the upper terminal of the well casing. When the unit is the open type or when it is located at the side (some jet- and suction-pump-type installations), it is especially important that a sanitary well seal be used. There are several acceptable designs consisting of an expandable neoprene gasket compressed between two steel plates (Figures 3-4 and 3-5). They are easily installed and removed for well servicing. Pump and water-well suppliers normally stock sanitary well seals.

If the pump is not installed immediately after well drilling and placement of the casing, the top of the casing should be closed with a metal cap screwed or tack-welded into place, or covered with a sanitary well seal.

A well slab alone is not an effective sanitary defense since it can be weakened by burrowing animals and insects, cracked from settlement or frost heave, or broken by vehicles and vibrating machinery. The cement grout formation seal is far more effective. It is recognized, however, that there are situations that call for a concrete slab or floor around the well casing to facilitate cleaning and improve appearance. When such a floor is necessary, it should be placed only after the formation seal and the pitless installation have been inspected.

Well covers and pump platforms should be elevated above the adjacent finished ground level. Pumproom floors should be constructed of reinforced, watertight concrete, and carefully leveled or sloped away from the well so that surface and wastewater cannot stand near the well. The minimum thickness of such a slab or floor should be 4 in. (100 mm). Concrete slabs or floors should be poured separately from the cement formation seal and, when the threat of freezing exists, insulated from freezing and from the well casing by a plastic or mastic coating or sleeve to prevent bonding of the concrete to either.

All water wells should be readily accessible at the top for inspection, servicing, and testing. This requires that any structure over the well be easily removable to provide full, unobstructed access for well-servicing equipment. The so-called buried seal, with the well cover buried under several feet (metres) of earth, is unacceptable for the following reasons: (1) it discourages periodic inspection and preventive maintenance, (2) it makes severe contamination during pump servicing and well repair more likely, (3) any well

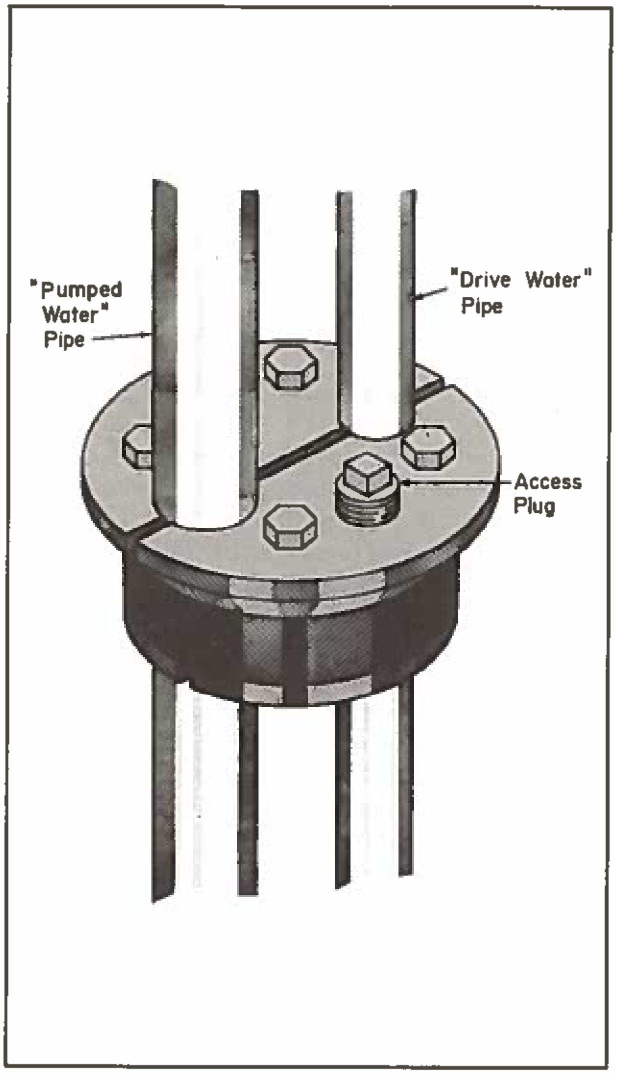

Figure 3-4 Well Seal for Jet Pump Installation

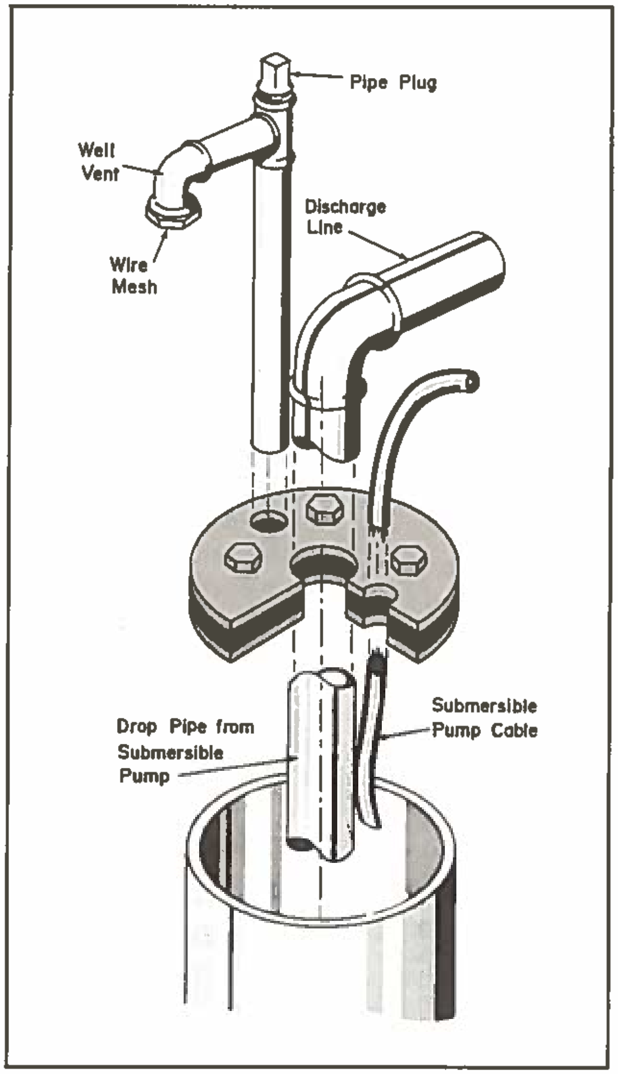

Figure 3-5 Well Seal for Submersible Pump Installation

servicing is more expensive, (4) excavation to expose the top of the well increases the risk of damage to the well, the cover, the vent, and the electrical connections, and (5) the vent pipe may rust off, allowing surface runoff to contaminate the well.

Disinfection of wells. All newly constructed wells should be disinfected to eliminate contamination from equipment, material, or surface drainage introduced during construction. Every well should be disinfected promptly after construction or repair.

An effective and economical method of disinfecting wells and appurtenances is use of calcium hypochlorite containing approximately 70-percent available chlorine. This chemical can be purchased in granular or tablet form at hardware stores, swimming pool-equipment outlets, or chemical supply houses.

When used to disinfect wells, calcium hypochlorite should be added in sufficient amounts to provide a dosage of approximately 100 mg/L of available chlorine in the well water. This concentration is roughly equivalent to a mixture of 2 fl oz (59 mL) of dry chemical per 100 gal (380 L) of water to be disinfected. Disinfection requires the use of a stock solution. The stock solution should be prepared by mixing 2 fl oz (59 mL) of high-test hypochlorite with 2 qt (2 L) of water. Mixing is facilitated if a small amount of the water is first added to the granular calcium hypochlorite and stirred to a smooth, watery paste, free of lumps. It should then be mixed with the remaining quantity of water. The stock solution should be stirred thoroughly for 10 to 15 min prior to allowing the inert ingredients to settle. The clearer liquid containing the chlorine should be used and the inert material discarded. Each 2 qt (2 L) of stock solution will provide a concentration of approximately 100 mg/L when added to 100 gal (380 L) of water. The solution should be prepared in a thoroughly clean container; the use of metal containers should be avoided because they are corroded by strong chlorine solutions. Crockery, glass, or rubber-lined containers are recommended.

If small quantities of disinfectant are required and a scale is not available, the material can be measured with a spoon. A heaping tablespoon of granular calcium hypochlorite weighs approximately ½ fl oz (15 mL).

When calcium hypochlorite is not available, other sources of available chlorine—sodium hypochlorite (12–15 percent of volume)—can be used. Sodium hypochlorite, which is also commonly available as liquid household bleach with 5.25-percent available chlorine, can be diluted with one part of water to produce the stock solution. Two quarts (2 L) of this solution can be used for disinfecting 100 gal (380 L) of water.

Stock solutions of chlorine in any form will deteriorate rapidly unless properly stored. Dark glass or plastic bottles with airtight caps are recommended. Bottles containing solution should be kept in a cool place and protected from direct sunlight. If proper storage facilities are not available, the solution should always be prepared immediately before use.

Table 3-4 shows quantities of disinfectants to be used in treating wells of different diameters and water depths. For sizes or depths not shown, the next larger figure should be used. Table 3-5 shows the volume of water contained in each 1 ft (0.3 mm) of water depth for wells having diameters ranging from 2 in. (50 mm) through 48 in. (1220 mm). See Appendix C for information on emergency disinfection.

Dug wells.

1. Remove all equipment and materials, including tools, forms, platforms, etc., that will not form a permanent part of the completed structure.
2. Using a stiff broom or brush, wash the interior wall of the casing or lining with a strong solution (100 mg/L of chlorine) to ensure thorough cleaning.
3. Place the cover over the well and pour the required amount of chlorine solution into the well through the manhole or pipesleeve opening just before inserting the

Table 3-5
Volume of Water Contained in Wells of Various Casing Diameters*

Diameter of Casing *in. (mm)*	Volume of Water for Every Foot (0.3 m) of Water Depth *gal (L)*
2 (50)	0.16 (0.62)
3 (75)	0.37 (1.39)
4 (100)	0.65 (2.47)
5 (125)	1.0 (3.9)
6 (150)	1.5 (5.6)
8 (200)	2.6 (9.9)
10 (255)	4.1 (15.4)
12 (305)	5.9 (22.2)

*Example: A well with a 6-in. diameter (distance across the well, from one inside wall to the other) has a water depth of 8 ft. From the table, a 6-in. diameter well contains 1.5 gal of water for every foot of depth. Therefore, with 8 ft of water, the well contains 8 times 1.5 gal, which is 12.0 gal.

Table 3-4
Quantities of Calcium Hypochlorite, 65 Percent (Row A) and Liquid Household Bleach, 5.25 Percent (Row B) Required for Water Well Disinfection at 100 mg/L*

Depth of Water in Well *ft (m)*		Well Diameter *in. (mm)*															
		2 (50)	3 (75)	4 (100)	5 (125)	6 (150)	8 (200)	10 (255)	12 (305)	16 (405)	20 (510)	24 (610)	28 (710)	32 (810)	36 (915)	42 (1065)	48 (1220)
5 (2)	A	1T	1T	1T	1T	1T	1T	1T	2T	3T	4T	3 oz	4 oz	5 oz	6 oz	8 oz	10 oz
	B	1C	1C	1C	1C	1C	1C	1C	1C	2C	3C	1Q	1½Q	2Q	2½Q	3Q	1 gal
10 (3)	A	1T	1T	1T	1T	1T	1T	2T	3T	5T	4 oz	5 oz	7 oz	9 oz	11 oz	1 lb	1½ lb
	B	1C	1C	1C	1C	1C	1C	2C	2C	1Q	1½Q	2Q	3Q	3½Q	4½Q	1½ gal	2 gal
15 (5)	A	1T	1T	1T	1T	1T	2T	3T	4T	7T	5 oz	8 oz	10 oz	13 oz	1 lb	1½ lb	2 lb
	B	1C	1C	1C	1C	1C	2C	2C	3C	1½Q	2Q	3Q	1 gal	5Q	7Q	2½ gal	3 gal
20 (6)	A	1T	1T	1T	1T	2T	3T	2 oz	3 oz	5 oz	7 oz						
	B	1C	1C	1C	1C	1C	2C	3C	1Q	2Q	2½Q						
30 (9)	A	1T	1T	1T	2T	2T	4T	5T	4 oz	7 oz	11 oz						
	B	1C	1C	1C	1C	2C	3C	1Q	2Q	3Q	1 gal						
40 (12)	A	1T	1T	1T	2T	3T	5T	7T	5 oz	9 oz	14 oz						
	B	1C	1C	1C	2C	2C	1Q	1½Q	2Q	1 gal	1½ gal						
60 (18)	A	1T	1T	2T	3T	4T	4 oz	5 oz	8 oz								
	B	1C	1C	2C	2C	3C	1½Q	2Q	3Q								
80 (24)	A	1T	2T	3T	4T	5T	5 oz	7 oz	10 oz								
	B	1C	1C	2C	3C	1Q	2Q	3Q	1 gal								
100 (30)	A	1T	2T	3T	5T	3 oz	6 oz	9 oz	1 lb								
	B	1C	2C	2C	1Q	1½Q	2Q	3½Q	1½ gal								
150 (46)	A	1T	3T	4T	7T	5 oz	8 oz	13 oz	1½ lb								
	B	1C	2C	3C	1½Q	2Q	3½Q	1½ gal	2 gal								

*Quantities are indicated as: T = tablespoon = 15 mL, oz = ounces (by weight) = 2T = 30 mL, C = cups = 240 mL, lb = pounds = 0.45 kg, Q = quarts = 0.95 L, gal = gallons = 3.8 L.

NOTE: Quantities in Row A are amounts of solid calcium hypochlorite required; those in Row B are amounts of liquid household bleach. For cases lying in shaded area, add 5 gal of chlorinated water, as final step, to force solution into formation. For those in unshaded area, add 10 gal of chlorinated water. Quantities listed yield a minimum initial concentration of 100 mg/L.

pump cylinder and drop-pipe assembly. The chlorine solution should be distributed over as much of the water surface as possible to obtain proper diffusion of the chemical through the water. Diffusion of the chemical may be facilitated by running the solution into the well through the water hose or pipeline as the line is being alternately raised and lowered. This method should be used whenever possible.

4. Wash the exterior surface of the pump cylinder and drop pipe with the chlorine solution as the assembly is being lowered into the well.
5. After the pump has been set in position, pump water from the well until a strong odor of chlorine is noted.
6. Allow the chlorine solution to remain in the well for not less than 24 hours.
7. After 24 hours or more have elapsed, flush the well to remove all traces of chlorine. The well should then be tested for bacteriological quality to determine the chlorine's effectiveness as described below.

Drilled, driven, and bored wells.

1. When the well is being tested for yield, the test pump should be operated until the well water is as clear and as free from turbidity as possible.
2. After the testing equipment has been removed, slowly pour the required amount of chlorine solution into the well just before installing the permanent pumping equipment. Diffusion of the solution with the well water may be facilitated as previously described ("Dug Wells," Step 3).
3. Add 5 to 10 gal (19 to 38 L) of clean, chlorinated water (Table 3-4) to the well to force the solution into the formation. One-half teaspoon of calcium hypochlorite or ½ cup (240 mL) of laundry bleach in 5 gal (19 L) of water is enough for this purpose.
4. Wash the exterior surface of the pump cylinder and drop pipe as they are lowered into the well.
5. After the pump has been set in position, operate the pump until a distinct odor of chlorine can be detected in the water discharged.
6. Allow the chlorine solution to remain in the well for at least 4 hours, preferably overnight.
7. After disinfection, pump the well until the odor of chlorine can no longer be noticed in the water discharged. The well should then be tested for bacteriological quality to determine the chlorine's effectiveness as described below.

In the case of deep wells having a high water level, it may be necessary to use special methods of introducing the disinfecting agent into the well so as to ensure proper diffusion of chlorine throughout the well. A suggested method is to place the granulated calcium hypochlorite in a short section of pipe capped at both ends. A number of small holes should be drilled through each cap or into the sides of the pipe. One of the caps should be fitted with an eye to facilitate attachment of a suitable cable. The disinfecting agent is then distributed when the pipe section is lowered or raised throughout the depth of the water.

Flowing artesian wells. The water from flowing artesian wells is generally free from contamination as soon as the well is completed or after it is allowed to flow a short time. Therefore, it is not generally necessary to disinfect flowing wells. If, however, analyses show persistent contamination, the well should be thoroughly disinfected, and the source of the contamination determined and eliminated.

To disinfect the well, use a device such as the pipe described in the preceding section or any other appropriate device that allows a surplus supply of disinfectant to be placed at or near the bottom of the well. The cable supporting the device can be passed through a stuffing box at the top of the well. After the disinfectant has been placed at or near the bottom of the well, throttle down the flow sufficiently to obtain an adequate concentration. When water showing an adequate disinfectant concentration appears at the surface, close the valve completely and keep it closed for at least 24 hours. After disinfection, allow the well to flow until the odor of chlorine can no longer be noticed, then test again for bacteriological quality.

Bacteriological tests following disinfection. The water from the system should not be used for domestic and cooking purposes until the results of the tests indicate that the water is safe for such uses. If bacteriological examination of water samples collected after disinfection indicates that the water is not safe for use, disinfection should be repeated until tests show that water samples from that portion of the system being disinfected are satisfactory. Samples collected immediately after disinfection may not be representative of the water used. Hence, if bacteriological samples are collected immediately after disinfection, the sampling must be repeated several days later to check on the delivered water under normal conditions of operation and use. If the water is unsatisfactory after repeated disinfection, the supply must be treated in order to provide water that always meets the bacteriological requirements of the National Interim Primary Drinking Water Regulations. Under these conditions, the supply should not be used for drinking and cooking purposes until adequate treatment has been provided.

Abandoning Wells

Unsealed, abandoned wells constitute a potential hazard to the public health and welfare of the surrounding area. Sealing an abandoned well presents certain problems, and the solution involves consideration of well construction and the geological and hydrological conditions of the area. In the proper sealing of a well, the main factors to be considered are elimination of any physical hazard, prevention of any possible contamination of groundwater, conservation and maintenance of the yield and hydrostatic pressure of the aquifer, and prevention of any possible contact between desirable and undesirable waters.

Proper sealing of any abandoned well primarily involves restoration, as far as feasible, of the controlling geological conditions that existed before the well was drilled or constructed. If this restoration can be properly accomplished, an abandoned well will not create a physical or health hazard.

When a well is to be permanently abandoned, the lower portion of it is best protected when filled with concrete, cement grout, neat cement, or clays with sealing properties similar to those of cement. When dug or bored wells are filled, as much of the lining should be removed as possible so that surface water will not reach the water-bearing strata through a porous lining or one containing cracks or fissures.

When any question arises, follow the regulations and recommendations of the state or local health department. Abandoned wells should never be used for the disposal of sewage or other wastes.

Well Failure

Over a period of time, wells may fail to produce for any of these main reasons:

- Failure or wear of the pump
- Declining water levels
- Plugged or corroded screens
- Accumulation of sand or sediments in the well.

Proper analysis of the cause necessitates measuring the water level before, during, and after pumping. To facilitate measuring the water level, an entrance for a tape or an electrical measuring device into the well in the annular space between the well casing and the pump column should be provided.

An air line with a water-depth indicating gauge, available from pump suppliers, may also be used. Although not as accurate as the tape or electrode method, the air line and gauge are left installed on some larger wells so that periodic readings can be taken and a record of well and pump performance kept.

Unless the well is the pitless-adapter or pitless-unit type, access for water-level measurements can be obtained through a threaded hole in the sanitary well seal. This applies for submersible and jet pump installations, as well as for some others. If it is not possible to gain access through the top of the well, access may be provided by means of a pipe welded to the side of the casing. (See Chapter 5, "Installation of Pumping Equipment" for further discussion.)

If the well is completed as a pitless-adapter installation, it is usually possible to slide the measuring device past the adapter assembly inside the casing and on to the water below. If it is a pitless unit, particularly the spool type (Figure 6-7), it probably will not be possible to reach the water level. In the latter case, the well can only be tested by removing the spool and pump and reinstalling the pump, or another one, without the spool.

Any work performed within the well including insertion of a measuring line is likely to contaminate the water with coliform bacteria and other organisms. The well should be disinfected before returning it to service. (See the "Disinfection of Wells" section in this chapter.) All access holes should be tightly plugged or covered following the work.

Special Considerations in Constructing Artesian Wells

To conserve water and ensure good productivity from an artesian well, it is essential that the well casing be sealed into the confining stratum. Otherwise, water loss may occur by leakage into lower-pressure, permeable strata at higher elevations. A flowing artesian well should be designed so that the movement of water from the aquifer can be controlled. Water can be conserved if such a well is equipped with a valve or shutoff device. When the recharge area and aquifer are large and the number of wells that penetrate the aquifer is small, the flowing artesian well produces a fairly steady flow of water throughout the year.

DEVELOPMENT OF SPRINGS

There are three general requirements necessary in developing a spring used as a source of domestic water: (1) selection of a spring with adequate capacity to provide the required quantity or quality of water for its intended use throughout the year, (2) protection of the sanitary quality of the spring, and (3) a bacteriological sampling and testing program extending at least 6 months in order to determine if satisfactory bacteriological quality exists. The measures taken to develop a spring must be tailored to its geological conditions and sources.

The features of a spring encasement include the following: (1) an open-bottom, watertight basin intercepting the source, which extends to bedrock or a system of collection pipes and a storage tank, (2) a cover that prevents the entrance of surface drainage or debris into the storage tank, (3) provision for the cleanout and emptying of the tank contents, (4) provision for overflow, and (5) a connection to the distribution system or auxiliary supply (Figure 3-6).

A tank is usually constructed in place with reinforced concrete enclosing or intercepting as much of the spring as possible. When a spring is located on a hillside, the downhill wall and sides are extended to bedrock or to a depth that will ensure maintenance of an adequate water level in the tank. Supplementary cutoff walls of concrete or impermeable clay extending laterally from the tank may be used to assist in controlling the water table near the tank. The lower portion of the uphill wall of the tank can be constructed of stone, brick, or other material placed so that water may move freely

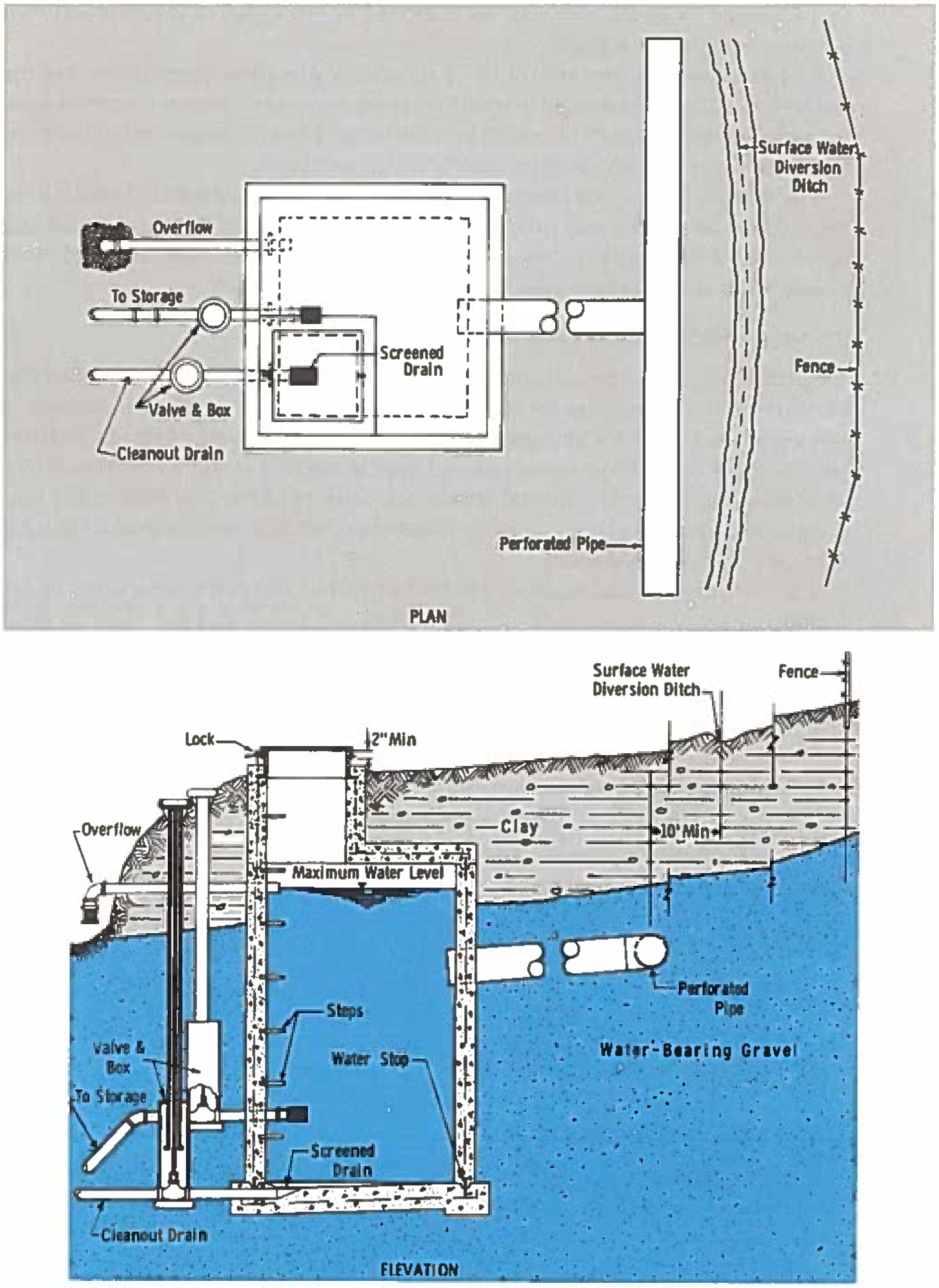

Figure 3-6 Spring Protection

into the tank from the formation. Backfill of graded gravel and sand will aid in restricting movement of fine material from the formation toward the tank.

The tank cover should be cast in place to ensure a good fit. Forms should be designed to allow for shrinkage of concrete and expansion of form lumber. The cover should extend down over the top edge of the tank at least 2 in. (50 mm). The tank cover should be heavy enough so that it cannot easily be dislodged and should be equipped for locking.

The tank overflow is usually placed slightly below the maximum water-level elevation and screened. A drain apron of rock should be provided to prevent soil erosion at the point of overflow discharge.

A drain pipe with an exterior valve should be placed close to the wall of the tank near the bottom. The pipe should extend horizontally so as to clear the normal ground level at the point of discharge by at least 6 in. (150 mm). The discharge end of the pipe should be screened to prevent entrance of rodents and insects.

The supply outlet from the developed spring should be located about 6 in. (150 mm) above the drain outlet and properly screened. Care should be taken in casting pipes into the walls of the tank to ensure good bond with the concrete and freedom from honeycomb around the pipes.

Sanitary Protection of Springs

Springs usually become contaminated when barnyards, sewers, septic tanks, cesspools, or other pollution sources are located on higher adjacent land. In limestone formations, however, contaminated material frequently enters the water-bearing channels through sink holes or other large openings and may be carried along with groundwater for long distances. Similarly, if material from such sources of contamination finds access to the tubular channels in glacial drift, this water may remain contaminated for long periods of time and for long distances.

The following precautions will help to ensure developed spring water of a consistently high quality:

- Provide for the removal of surface drainage from the site. A surface drainage ditch should be located uphill from the source so as to intercept surface-water runoff and carry it away from the source. Location of the ditch and the points at which the water should be discharged are a matter of judgment. Criteria used should include topography, subsurface geology, land ownership, and land use.
- Construct a fence to prevent entry of livestock. Its location should be guided by the considerations mentioned above. The fence should exclude livestock from the surface-water drainage system at all points uphill from the source.
- Provide for access to the tank for maintenance, but prevent unauthorized removal of the cover with a suitable locking device.
- Monitor the quality of the spring water with periodic checks for contamination. A marked increase in turbidity or flow after a rainstorm is a good indication that surface runoff is reaching the spring.

Disinfection of Springs

Spring encasements should be disinfected by using a procedure similar to that used for dug wells. If the water pressure is not sufficient to raise the water to the top of the encasement, it may be possible to shut off the flow and keep the disinfectant in the encasement for 24 hours. If flow cannot be shut off entirely, arrangements should be made to supply disinfectant continuously for as long a period as practical.