APPENDIX

Chapter 3. WELLS

3.12 WELL SITE SELECTION

This section is intended to be used as a guideline only. Local county health departments or state health agencies should have sanitary setback requirements and regulations pertaining to the location of wells in relation to sanitary hazards. Please contact your local authorities for their requirements and regulations before you select a site and drill.

3.120 Factors to Be Considered

Perhaps the most important consideration in developing a groundwater source is the selection of the well site. In many cases, wells located too close to sources of contamination must be abandoned and destroyed long before their useful life is spent.

Safety of a groundwater source depends primarily on three factors: (1) the proper selection of the well site, (2) good well design and construction, and (3) geology. These factors should be the guides used in determining safe distances for different situations. The guidelines in this appendix apply only to properly constructed wells. A poorly constructed well is potentially unsafe regardless of the distance from a source of contamination.

Geologic and hydrologic (hydrogeologic) data need to be considered when siting a well to maximize the chances of getting a firm yielding well with acceptable water quality, keep costs to a minimum (both for construction and operation), for well site protection, and for wellhead protection. If the location and type of aquifer are known, the quality and quantity of the aquifer should be considered when choosing a well site. Nothing is more frustrating than drilling dry holes or finding water of poor quality requiring extensive treatment. Contact and use the services of a competent hydrogeologist, or geologist, familiar with the local area. But even in the absence of such a consultant there are some simple guidelines to follow that will increase your chances of obtaining a firm potable yield.

1. Drill where aquifers are known to exist. Numerous agencies have some information regarding existing aquifers, their yield, and water quality:
   - Water Agencies
   - Health Departments
   - US Natural Resources Conservation Service
   - US Geological Survey
   - Local Public Works Department
   - Bureau of Reclamation
   - US Army Corps of Engineers

   This is not a complete list and these agencies are not guaranteed to know all about the local groundwater conditions, but they certainly are a good start.
2. Look for areas where you believe groundwater might exist. Water tends to gravitate downward toward lower points. When rain occurs on a watershed, some water percolates downward through aquifers to water tables. As the water table rises, water is deposited in lakes or streams as shown in Figure 3.1, page 64. If groundwater can seep into lakes and streams, then aquifers probably exist close to lakes and streams. When the water table in the aquifer is high, water is fed into lakes and streams. Conversely aquifers can be charged from high water levels in lakes and streams.

   If reliable sources of surface water exist in streams and lakes, there should be groundwater nearby. Hence, it is probable that you will be able to develop a usable well near these sources.
3. Check with area well drillers. Wells are their business and they may be your very best sources to determine a good well location.

Regardless of where you drill your wells, you should do your research. Hydrology and geology are the keys to selecting productive, unpolluted sites.

If you know you have a firm yield of usable water, you should carefully examine several other elements before proceeding to drill. Some of the factors can be evaluated from a cost standpoint, while others must be subjectively weighed.

1. Access is important for ease of maintenance and construction. Can you get to the well on a daily basis to make repairs or monitor your supply? Being able to drive to the site has definite advantages. Can the drill equipment get to the site and will the driller be able to set up and easily operate the equipment? Easy access means efficient installation, operation, and repair.
2. Power sources should be readily available. Utility companies must be able to provide the necessary power at affordable prices. In a remote area, the cost of getting power is sometimes prohibitive. Alternative sources of power, such as gas generators, are always a possibility, but they are expensive, both initially and on a long-term basis.
3. Relationship to storage and treatment facilities has to do with the cost of pumping, transmission lines, and deliverability. This may not be as important as some other considerations, but installation of wells close to your other facilities could simplify maintenance and reduce long-term delivery costs. Longer transmission lines (and initial costs for same) tend to be secondary to some of the other location factors, but distance is definitely a cost factor and a serious look at detailed costs for all materials must be considered.
4. Pollution potential is a serious consideration. The adequate separation of a domestic water supply well away from sources of contamination or pollution is a primary factor in ensuring the continued safety of the water produced by the well. Facilities using or transporting hazardous chemicals near a well are objectionable because leakage of contaminants is possible. Such contaminants may gain entry to the well through unprotected openings, poor well design or construction, failure of the well casing from corrosion or age, or leakage directly into the zone of influence of the well. Well installation upstream (higher portion of the basin) of industrial manufacturing facilities and urban areas with a large number of septic tanks is more desirable than downstream of these facilities. Groundwater tends to gravitate downward and a well located downstream of potential pollutants has a higher probability of contamination. All cases are not the same and you will not necessarily have to avoid downstream installations because pollution may not be a problem. You need to make sure you address pollution potential when considering a new well location.
5. Drainage should definitely move away from the proposed well site. Any runoff from urban areas will be carrying pollutants of some kind. Keep away from areas where drainage might affect the groundwater.
6. Aesthetics is sometimes more of a factor than cost. (Nothing is of greater importance than protection against pollution.) Wells are unsightly to some people and they can be noisy. Having maintenance people around a well at frequent intervals may be undesirable to some neighbors. Aesthetics may seem like a feeble complaint to you, but to more and more people it is becoming a major factor. And, you live in a world where human factors must be dealt with—"Out of sight, out of mind" may be a suitable approach when locating new facilities.
7. Security of some kind needs to be considered. Vandalism is a fact of life. You do not need to install razor tape around the facilities, but a good chain-link fence or pump house is often warranted. Can the site be inspected easily without actually visiting the site? Is the well near residents who can see people coming and going from the site, for example, only one road into and out of the site?
8. Easements and land acquisitions are expensive items and clearly need to be factored into site selection.

These guidelines are for the location of new wells, evaluation of existing wells, and maintenance of sanitary control of future construction in the vicinity of wells. The design and location of a new well should be reviewed with the local health officer or other regulatory authority for approval before construction begins.

3.121 Safe Horizontal Distance

The safe distance of a well from sources of contamination depends upon numerous local factors. To determine the safe distance, evaluate the following factors: (1) character and location of sources of possible contamination, (2) type of well construction, (3) natural *HYDRAULIC GRADIENT*[49] of the water table, (4) permeability of the soil overlying the water-bearing formation, (5) extent of the *CONE OF DEPRESSION*[50] formed in the water table due to pumping the well, and (6) the nature of the soil or rock structure.

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[49] *Hydraulic Gradient.* The slope of the hydraulic grade line. This is the slope of the water surface in an open channel, the slope of the water surface of the groundwater table, or the slope of the water pressure for pipes under pressure.

[50] *Cone of Depression.* The depression, roughly conical in shape, produced in the water table by the pumping of water from a well. Also called the CONE OF INFLUENCE. Also see CIRCLE OF INFLUENCE.

3.122 Minimum Horizontal Distance

The minimum safe horizontal distance between a well and potential sources of contamination should be maintained in accordance with Table 3.10 and as shown in Figure 3.42. No lesser distances should be considered unless approved by the local health officer and unless the special protection requirements described in Section 3.125, "Special Construction of Sanitary or Storm Sewers Under Gravity Flow," are met.

TABLE 3.10 MINIMUM HORIZONTAL DISTANCE TO WELL[a]

Wastewater Facilities	Feet	Meters
Septic Tank (Watertight)	50	15
Horizontal Leach Lines	100	30
Seepage Pit or Cesspool	150[b]	45
Pit Privy	50	15
Vault Privy (Pumpout)	50	15
Sanitary Sewers and House Laterals	100[c]	30
Storm Sewers	100[c]	30
Wastewater Pumping Station	100	30
Effluent Discharge Channel	200	60
Drainage Channel	50	15
Wastewater Treatment Plant	*	*
Wastewater Lagoon	*	*
Wastewater Irrigation Area	*	*
Industrial Facilities		
Barnyard, Feedlot, Grazing Area	*	*
Waste Sewers	100[c]	30
Waste Holding (Watertight)	50	15
Petroleum Storage	*	*
Petroleum Transmission	500[d]	150
Solid Waste Disposal Site		
Class 1	*	*
Class 2	2,000	600
Class 3	1,000	300
Other		
Dwellings	50	15
Pond, Lake, Stream	100	30
Abandoned Conduit	50	15
Cathodic Protection Well		
Cased	50	15
No Casing	200	60
Abandoned and Destroyed Wells	*	*
Wells Destroyed in Accordance with State or Local Health Department Guidelines	None required	

NOTES:

* Case-by-case evaluation.

[a] *STANDARDS REGARDING LOCATION OF PUBLIC WATER SUPPLY WELLS WITH RESPECT TO SOURCES OF CONTAMINATION OR POLLUTION*, California Department of Health Services, Sanitary Engineering Branch, Berkeley, CA.

[b] Bottom of pit should be more than 10 feet above groundwater, preferably separated by an impervious stratum.

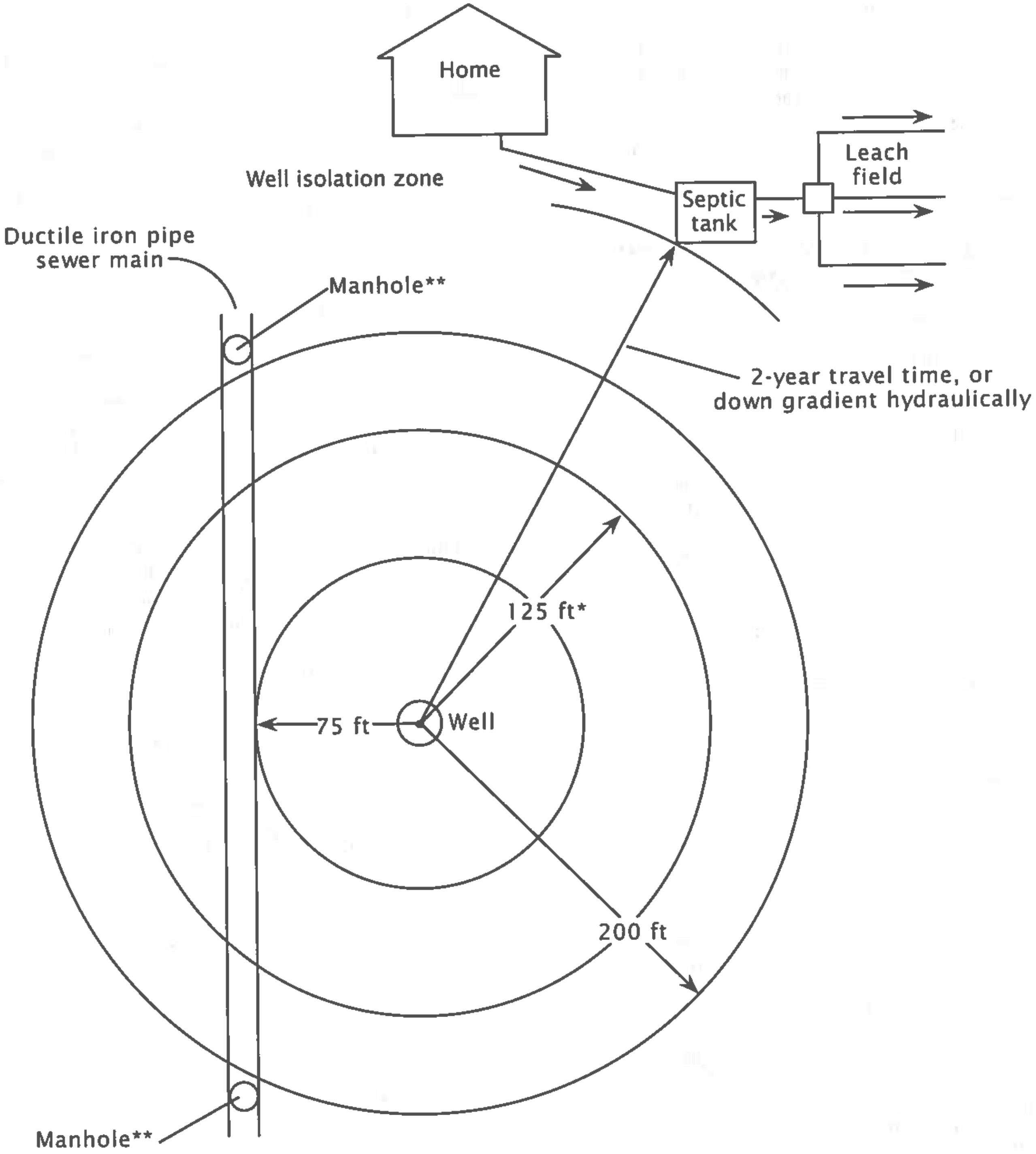
[c] See Section 3.125, "Special Construction of Sanitary or Storm Sewers Under Gravity Flow."

[d] Underground storage and transmission facilities should be pressure tested annually.

Different states have different acceptable minimum safe horizontal distances between a well and potential sources of contamination. For example, the State of Vermont has the following requirements:

1. The minimum radius, in feet, of the area that must be owned by the water purveyor should be at least 200 feet. Acceptable land uses within this 2.88-acre plot would be skiing, organized sports, forest or conservation land, or similar non-threatening uses.
2. Any subsurface wastewater treatment systems should be well away from this protective zone. They must be at a distance that provides at least a two-year residence flow time to permit die-off of viruses that may be pathogenic.
3. Occasionally, the 200-foot radius (protective zone) can be reduced to 125 feet, but only after an extensive study has been conducted by a hydrogeologist that shows no hydraulic connection between the upper soils and the water-bearing strata for the well.
4. Only water supply grade ductile iron pipe (leak-tested) is permitted for sewers within the well isolation zone up to within 75 feet of the well. Manholes are not permitted within the 200-foot protection zone and must be leak tested.
5. Permitted and non-permitted land uses in the well isolation zone within a radius of 200 feet are as follows:
   a. Land uses permitted within the well isolation zones include:
      (1) playground, ballfields, tennis courts
      (2) seasonal light-duty roads
   b. Land uses not permitted within the well isolation zone include:
      (1) application of pesticides and herbicides
      (2) buildings other than those required for the water system
      (3) parking of motor vehicles
      (4) chemical storage other than that required by the water system
      (5) swimming pools
      (6) salted or paved roads passing through the area
      (7) leach fields, septic tanks, and sewer lines
      (8) any other activity that may contaminate the water supply

These standards apply only to wells serving more than 10 living units. This is because public wells are apt to be stressed far more than individual home wells, and thus warrant the extra protective actions and zones because of the tendency to pull water toward them.



NOTE: Check with your state water supply agency for required distances.

- * The 200-foot isolation zone may be reduced to 125 feet on approval by reviewing authority if a hydrogeologist's report shows no hydraulic connection between the upper soil layers and the aquifer.
- ** Manholes and sewers must be tested to show zero leakage prior to use.

Fig. 3.42 Recommended safe distances from a well

3.123 Design of Well Fields

Sometimes, when developing water supplies, especially when large supplies are needed, it becomes necessary to design a system of wells or a well field. In addition to the siting considerations already discussed, planning for the development of a well field must take into account well spacing and location for economics and best use of the aquifer. Other design considerations include the quantity of water needed, size of well, depths of pumps, drawdown effects, and nearby pollution sources. Important information needed to design well fields includes groundwater hydraulic characteristics, such as aquifer transmissivity, storativity, and confining-unit leakage, all of which can be derived from the comprehensive aquifer tests described in Section 3.160, "Well Performance Testing." It will also be necessary to conduct a thorough evaluation of the potential environmental effects of the well field, for example, overdraft and possible subsidence, and the effects of the well field on existing wells nearby.

According to Ralph C. Heath, author of the USGS Paper 2220, some of the basic hydrologic considerations relative to well spacing are:

1. The minimum distance between pumping wells should be at least twice the aquifer thickness if the wells are open to less than about half the aquifer thickness.
2. Wells near recharging boundaries should be located along a line parallel to the boundary and as close to the boundary as possible.
3. Wells near impermeable boundaries should be located along a line perpendicular to the boundary and as far from the boundary as possible.

Beyond these basic rules, a qualified hydrologist or geologist should be consulted for assistance in the design and spacing of well fields.

3.124 Adverse Conditions

In areas where adverse conditions exist, such as coarse gravel formation, lava, fractured or limestone rock, high groundwater, or unusual well construction or topography, the local health officer should approve the well site and the design of the well before construction.

3.125 Special Construction of Sanitary or Storm Sewers Under Gravity Flow

Where 100 feet (30 meters) of separation of the well from a sanitary or storm sewer is not feasible, the sewer should be constructed or reconstructed as specified below.

However, in no case should sewers be permitted within 50 feet (15 meters) of any well.

1. The sewer should be constructed of ductile iron pipe—Class 150—with either rubber ring bell-and-spigot ends or *MECHANICAL JOINTS.*[51] This type of construction should be adequate under most conditions.
2. Under certain conditions, extra-heavy-wall plastic pipe with rubber ring joints could be used.
3. Special construction methods may be considered case by case. For existing sewers, it may be possible to use a ¼-inch (6-mm) thick continuous steel casing to enclose the sewer pipe. All voids between the sewer pipe and casing must then be pressure grouted with sand-cement grout.
4. The sewer should be of adequate strength to withstand the weight of both backfill and any live load (load from a moving vehicle) that may be imposed on the pipe. The trench should be excavated only to the depth required. This will provide uniform, continuous support for the pipe on solid and undisturbed ground at every point. Any part of the bottom of the trench excavated below the specific grade (such as at the joints) should be corrected with suitable material and thoroughly compacted before the pipe is laid. Backfilling should be accomplished by hand from the bottom of the trench to the centerline of the pipe, using suitable material, placed in layers of three inches (75 mm), and compacted by tamping. The pipe should be pressure tested after installation.

3.126 Sanitary Control of Future Construction

Unless future construction in the vicinity of a well is controlled, the continued use of a well for domestic water supplies may be threatened. The best way to prevent the encroachment of hazardous facilities is by owning enough land around the well to guarantee the required separation whenever possible. Where the utility or water company has limited ownership, it should request notification from the building department, public works, and local wastewater utility agencies of any proposed construction near the well. The water agency will then be assured of an opportunity to suggest modification of any proposed facilities.

3.13 TYPES OF WELLS

There are numerous well construction methods ranging from low-yield, hand-dug wells to high-yield, gravel-envelope wells. Let us briefly review the distinguishing characteristics of wells you are likely to encounter.

3.130 Dug Wells

Dug wells are commonly excavated with hand tools. The excavator descends into the well as the excavation progresses. To prevent the native material from caving in, one must place a crib or lining in the excavation and move it downward as the pit is deepened. The space between the lining and the undisturbed embankment should be filled with cement grout down to the water-bearing strata to prevent entrance of surface water along the well lining (see Figure 3.43). Dug wells usually have a very limited yield and tend to fail in times of drought. Also, dug

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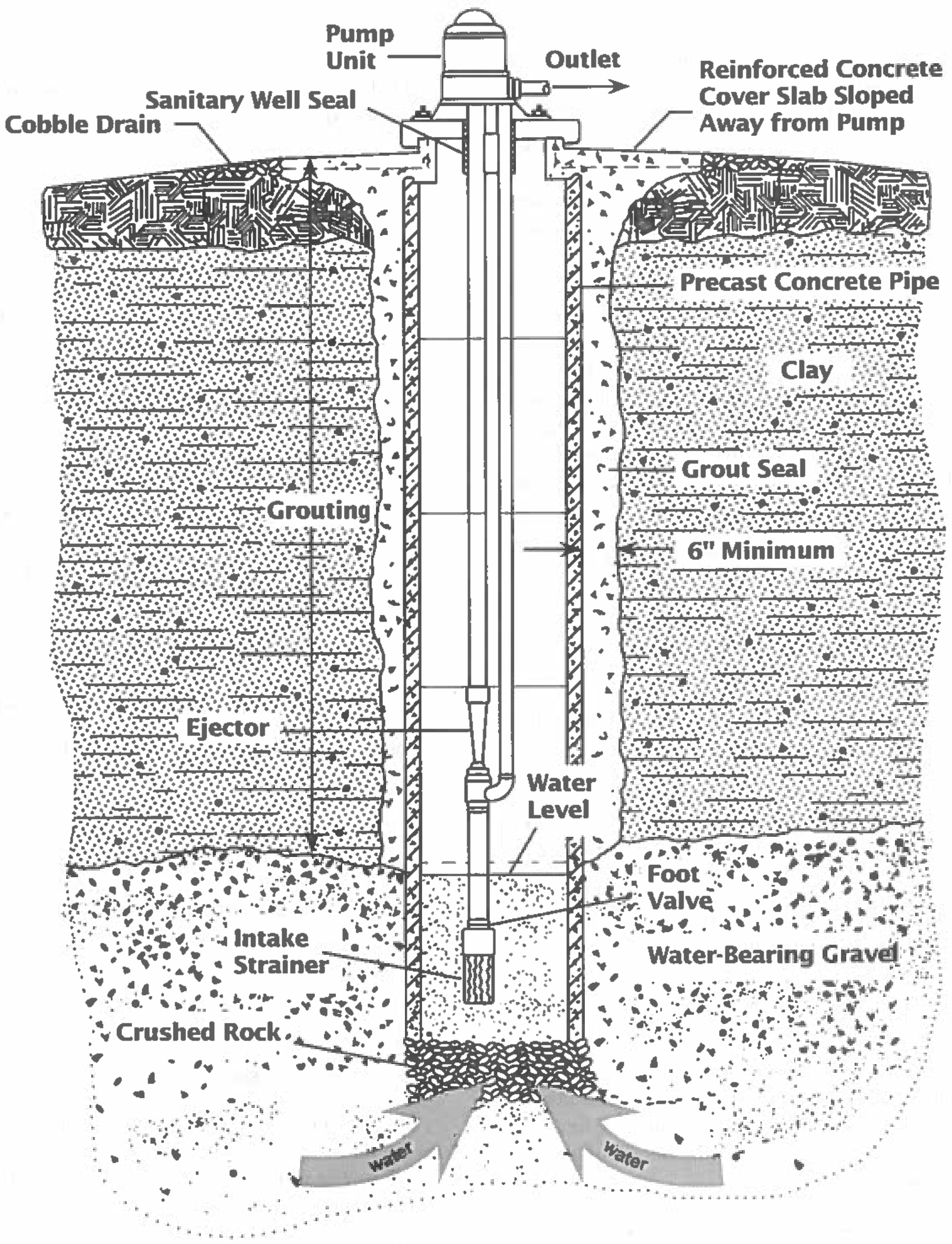
[51] *Mechanical Joint.* A flexible device that joins pipes or fittings together by the use of lugs and bolts.



NOTES:

1. Pump screen is placed below point of maximum drawdown.
2. The grouting should be at least six inches thick, form a seal, and extend from the surface cover slab down to the water-bearing gravel.

Fig. 3.43 Dug well with two-pipe jet pump installation
(Source: *MANUAL OF INDIVIDUAL WATER SUPPLY SYSTEMS,*
US Environmental Protection Agency,
Office of Water Programs, Washington, DC)

wells are more subject to contamination hazards due to their shallow construction.

3.131 Bored Wells

Bored wells are commonly constructed with earth augers (similar to an oversized drill bit) turned either by hand or by power equipment. Such wells are usually regarded as practical at depths of fewer than 100 feet (30 meters) 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 to 30 inches (50 to 750 mm) in diameter can be bored to about 100 feet (30 m) without caving.

In general, bored wells have the same characteristics as dug wells, but they may be extended deeper into the water-bearing formation due to the fact they are less apt to cave in.

Bored wells may be cased with vitrified clay 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 Figure 3.44).

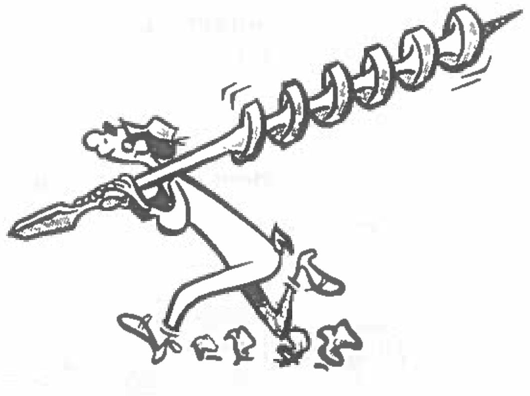
3.132 Driven Wells

The simplest and least expensive of all well types is the driven well. This type of well is constructed by driving into the ground a well drive point, which is fitted to the end of a series of pipe sections (see Figure 3.44). The drive point is of forged or cast steel. Drive points are usually 1¼ or 2 inches (30 or 50 mm) in diameter. The well is driven with the aid of a maul, or a special shafting or falling weight (see Figure 3.45). For deeper wells, the well points are sometimes driven into water-bearing strata at 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 than bored wells to be seriously affected by water table fluctuations. The most suitable locations for driven wells are areas containing *ALLUVIAL*[52] deposits of high *PERMEABILITY.*[53] The presence of coarse gravels, cobbles, or boulders interferes with sinking the well point and may damage the sand screen (Figure 3.45) or wire mesh jacket.

3.133 Drilled Wells

Construction of a drilled well is ordinarily accomplished by one of two techniques—percussion or rotary hydraulic drilling. The selection of the method depends primarily on the geology of the site and the preference of the well owner or driller.



3.1330 Percussion (Cable-Tool) Method

Drilling by the cable-tool or percussion method (Figure 3.46) 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*[54] at the bottom of the hole. This is periodically brought to the surface with a bailer, a 10- to 20-foot-long (3- to 6-m-long) 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, a casing is usually necessary only through the overburden or upper layer of uncompacted 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 formations are generally permeable and yield the most water.

3.1331 Hydraulic Rotary Drilling Method

The direct 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 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.

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[52] *Alluvial* (uh-LOO-vee-ul). Relating to mud or sand deposited by flowing water. Alluvial deposits may occur after a heavy rainstorm.

[53] *Permeability* (PURR-me-uh-BILL-uh-tee). The property of a material or soil that permits considerable movement of water through it when it is saturated.

[54] *Slurry.* A watery mixture or suspension of insoluble (not dissolved) matter; a thin, watery mud or any substance resembling it (such as a grit slurry or a lime slurry).

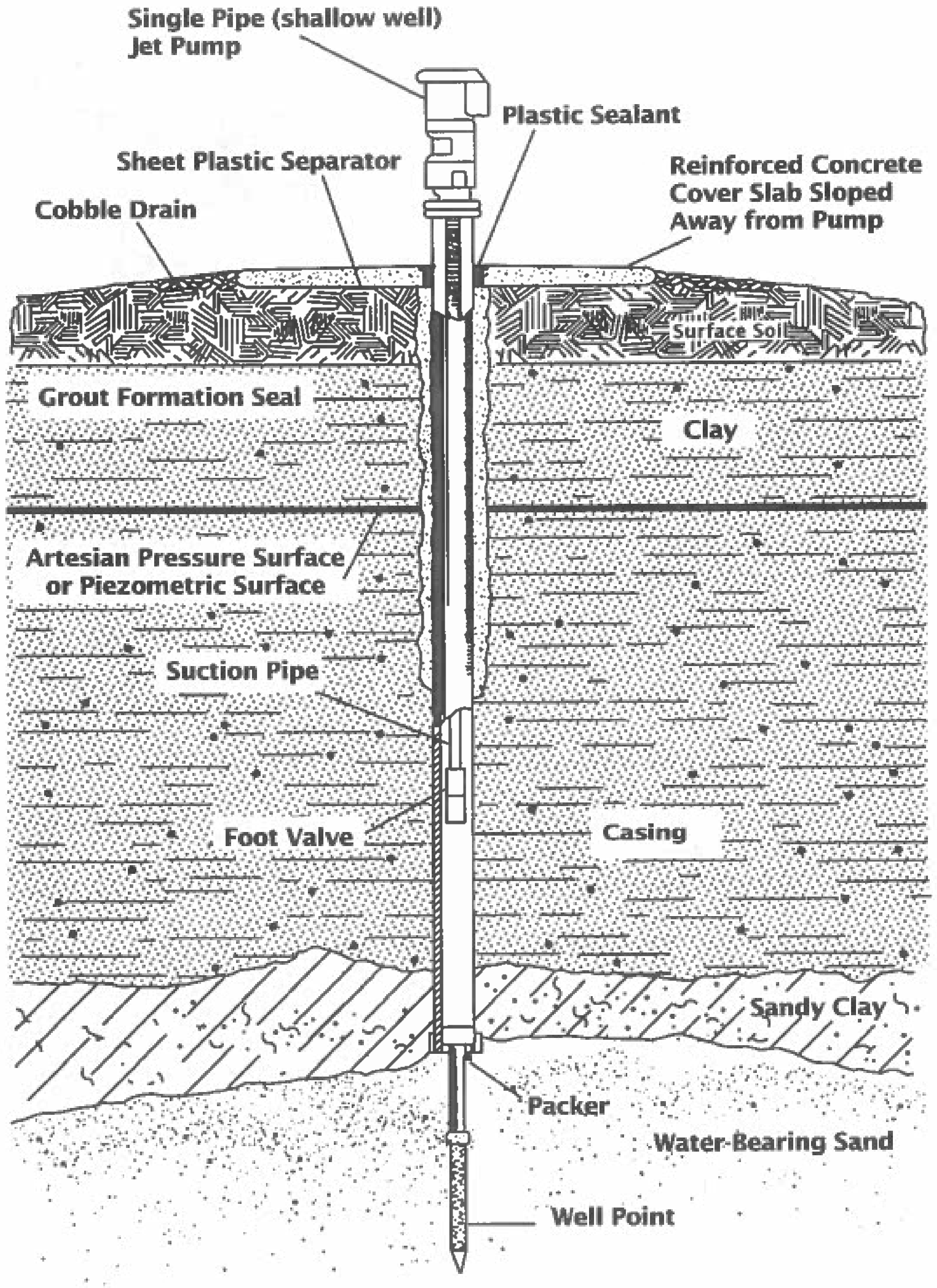


Fig. 3.44 Hand-bored well with driven well point and shallow well pump

(Source: *MANUAL OF INDIVIDUAL WATER SUPPLY SYSTEMS*, US Environmental Protection Agency, Office of Water Programs, Washington, DC)

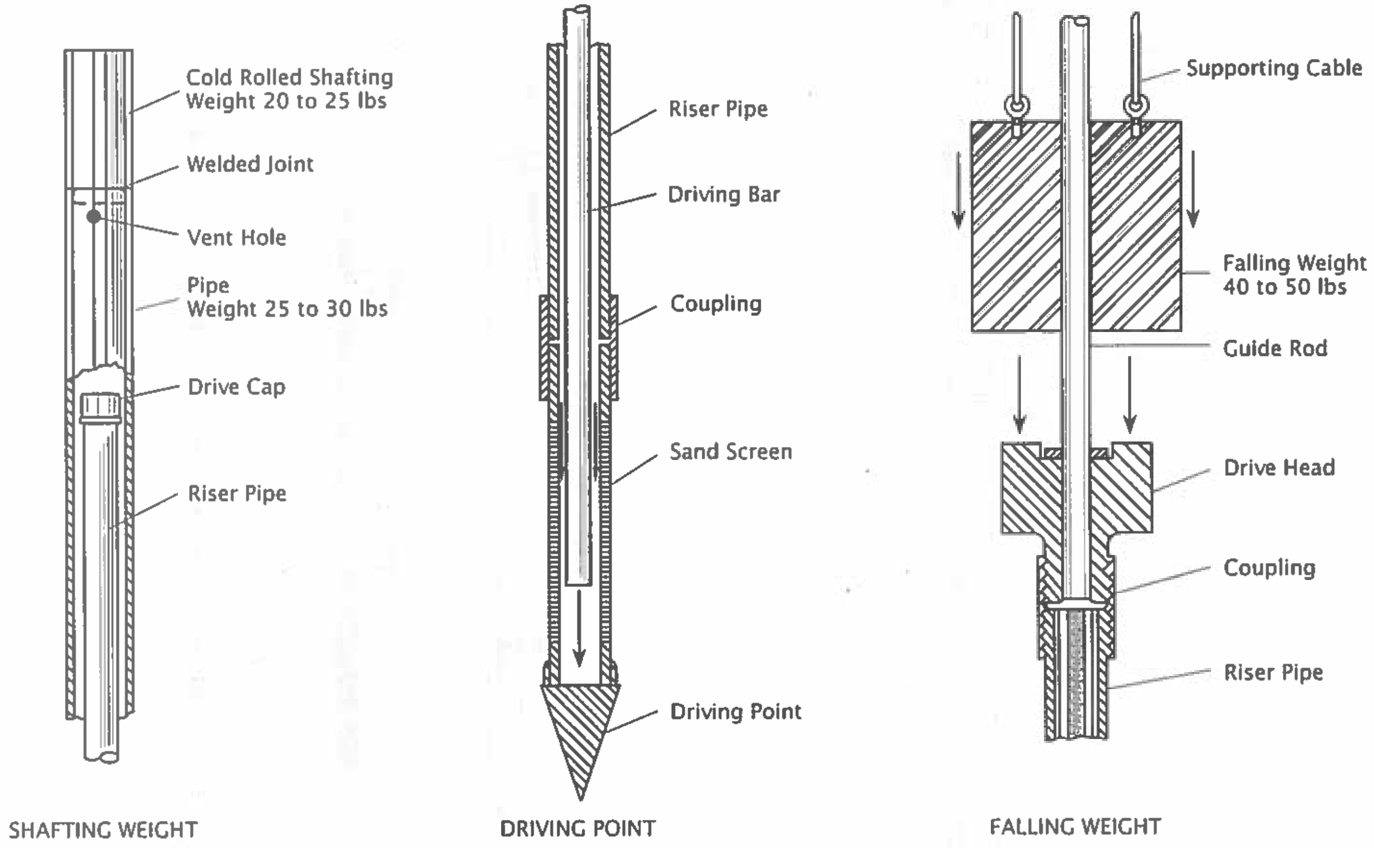
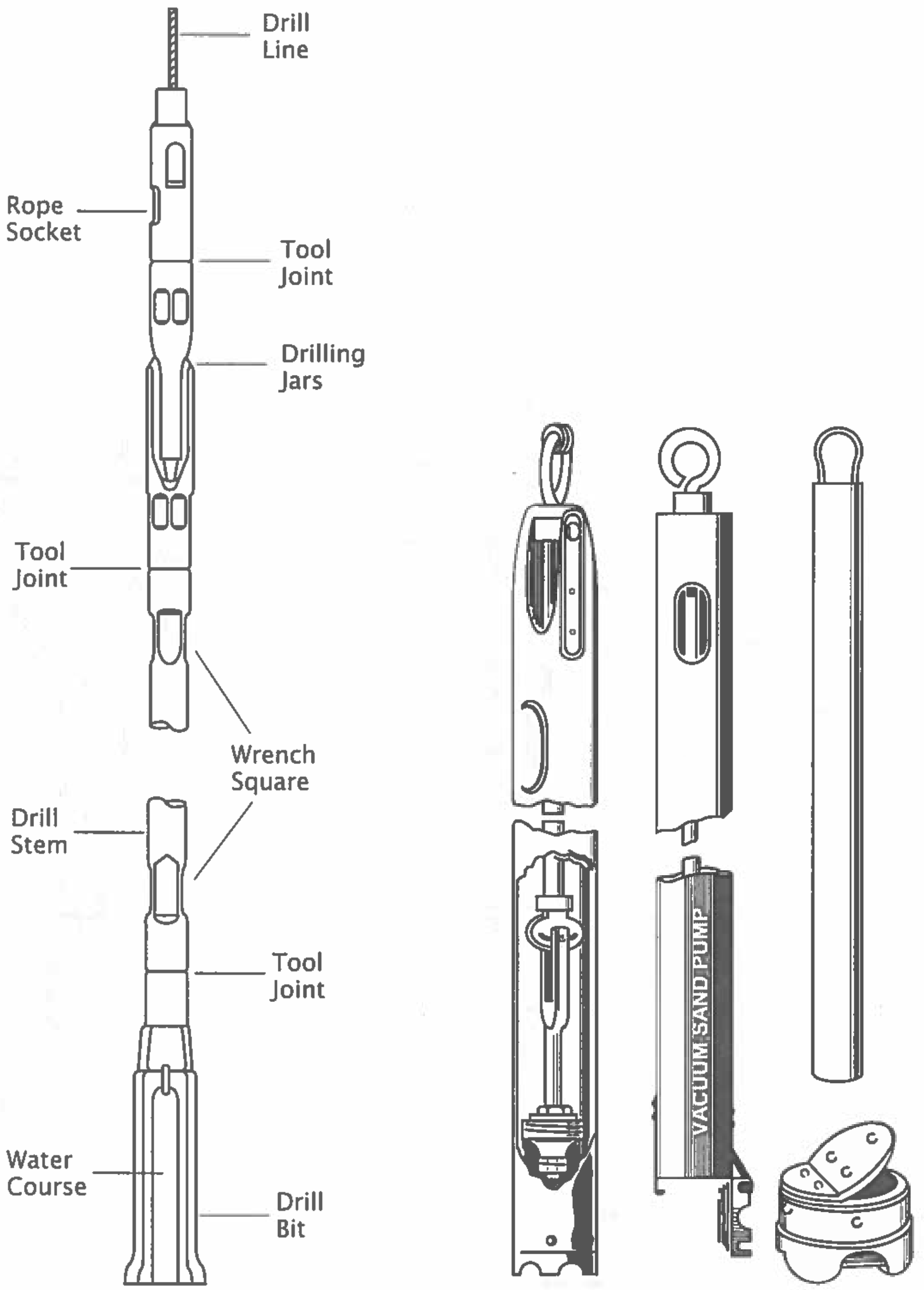


Fig. 3.45 Typical well point for driven wells

(Source: *MANUAL OF INDIVIDUAL WATER SUPPLY SYSTEMS*, US Environmental Protection Agency, Office of Water Programs, Washington, DC)



Components of the string of drill tools for cable-tool percussion drilling

Sand pumps and regular bailer, with details of flat-valve bottoms

Fig. 3.46 Percussion (cable-tool) method

(Source: *GROUNDWATER AND WELLS*, permission of Johnson Division, UOP, St. Paul, MN)

In the drilling operation, the bit breaks up the materials 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*[55] between the rotating pipe and the wall of the hole (Figure 3.47). 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.

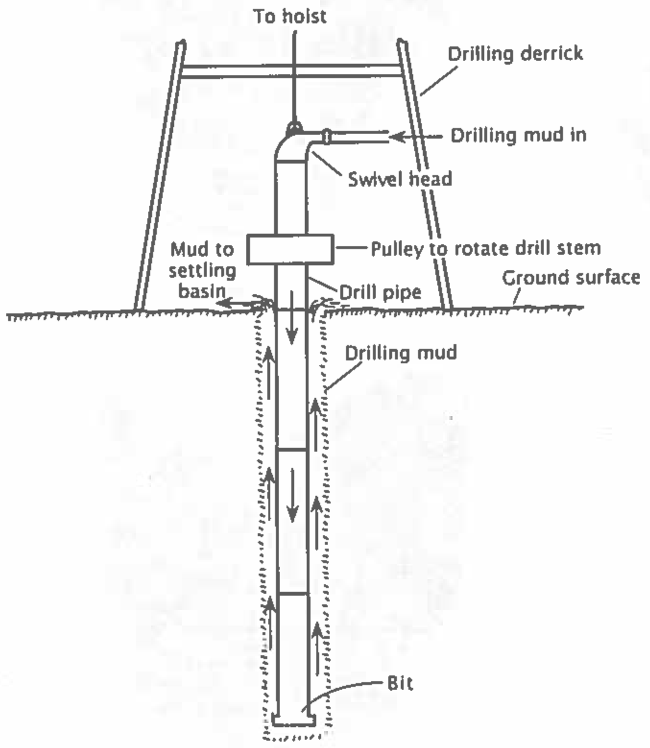


Fig. 3.47 Rotary drilling rig

(Reprinted from *WATER RESOURCES ENGINEERING*, Third Edition, by R. K. Linsley and J. B. Franzini, by permission. Copyright 1979, McGraw-Hill Book Company, New York, NY)

Two types of bits are used in direct rotary drilling (Figure 3.48). A roller or rock type is used to cut the borehole in hard *CONSOLIDATED FORMATIONS*.[56] This type of bit uses a crushing and chipping action between rotating gears to produce fine cuttings that can be carried in suspension by the drilling fluid. The other type of bit, used in sand and clay formations, is the drag type, which has blades arranged in a fishtail or three-way design to cut the borehole.

3.1332 Reverse Circulation Rotary Drilling Method

The reverse circulation rotary drilling method is normally used in drilling large-diameter wells in consolidated formations. As the drill bit rotates, a suction pump is used to pull the cuttings through the hollow drill stem to the surface. Water from a supply pit near the rig circulates through a trench and back to the open hole. This water raises the water level in the drill hole to pit level so that *HYDROSTATIC PRESSURE*[57] is applied against the wall of the open hole to prevent caving. Figure 3.49 shows how the direction of circulation is reverse to that employed in the direct rotary drilling method.

3.1333 Air Rotary Drilling Method

Rotary drilling equipment using compressed air as the drilling fluid, rather than drilling mud, is fairly popular. Air is circulated through the center of the drill pipe, out through ports in the drill bit, and upward in the annular space around the drill pipe. The air rotary method requires that air be supplied at pressures from 100 to 250 pounds per square inch (690 to 1,725 kPa or 7 to 17 kg/sq cm). To remove the cuttings, ascending air velocities of at least 3,000 feet per minute (900 m/min) are necessary. *CAUTION: Never use compressed air to dust off clothing or any part of your body because air can enter the tissues of your body or bloodstream and cause serious injury.*

Penetration rates of 20 to 30 feet per hour (6 to 9 m/hr) in hard rock are common with air rotary drilling. However, drilling with air as the circulating fluid can be done only in consolidated materials. Air rotary drilling rigs are usually equipped with a conventional mud pump in addition to a high-capacity air compressor. Drilling mud can be used, therefore, in drilling through caving materials above bedrock. Casings may have to be installed through the overburden (looser materials) before continuing with the air rotary method.

3.134 Shallow Collector Wells—Ranney Type

The water collector is a dug well from 12 to 16 feet (3.5 to 5 m) in diameter that has been sunk as a *CAISSON*[58] near the bank of a river or lake. Screen pipes are driven radially and approximately horizontally from this well into the sand and gravel deposits underlying the river (Figure 3.50). The length of these horizontal screens varies from 100 to 300 feet (30 to 90 m). With proper design features, this can be constructed in the flood plain area of certain rivers. Such wells have large capacities, some up to 10 million gallons per day (37,850 cu m/day).

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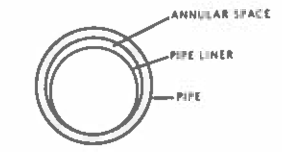
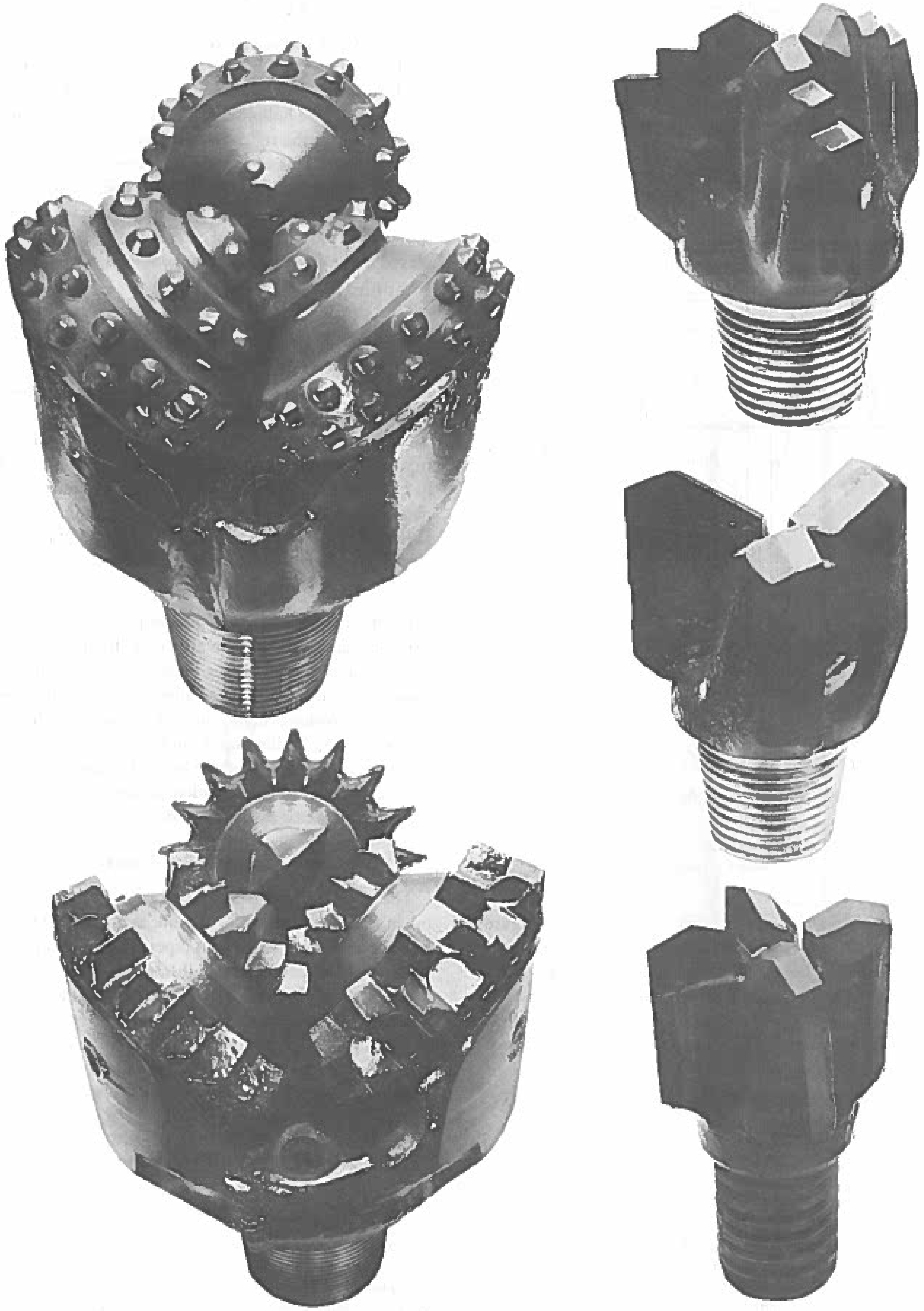
[55] *Annular* (AN-yoo-ler) *Space.* A ring-shaped space located between two circular objects. For example, the space between the outside of a pipe liner and the inside of a pipe.



[56] *Consolidated Formation.* A geologic material whose particles are stratified (layered), cemented, or firmly packed together (hard rock); usually occurring at a depth below the ground surface. Also see UNCONSOLIDATED FORMATION.

[57] *Hydrostatic* (hi-dro-STAT-ick) *Pressure.* (1) The pressure at a specific elevation exerted by a body of water at rest. (2) In the case of groundwater, the pressure at a specific elevation due to the weight of water at higher levels in the same zone of saturation.

[58] *Caisson* (KAY-sawn). A structure or chamber that is usually sunk or lowered by digging from the inside. Used to gain access to the bottom of a stream or other body of water.

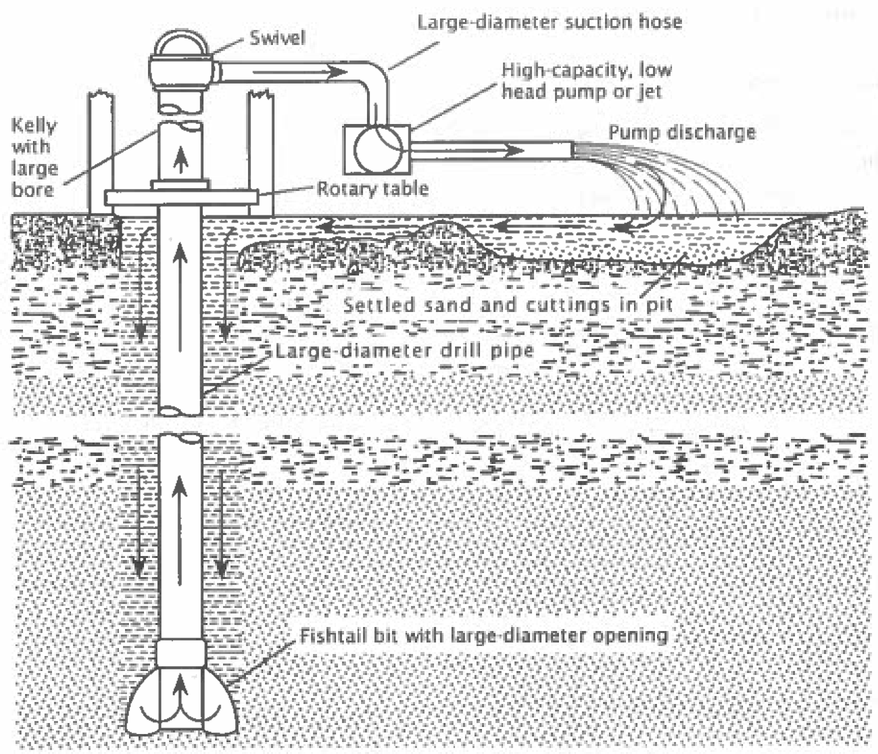


Roller or rock type

Drag or fishtail type

Fig. 3.48 Rotary drilling bits

(Permission of Varel Manufacturing Company)



NOTE: Kelly. The square section of a rod that causes the rotation of the drill bit. Torque from a drive table is applied to the square rod to cause the rotary motion. The drive table is chain- or gear-driven by an engine.

Fig. 3.49 Basic principles of reverse circulation rotary drilling are shown by this schematic diagram. Cuttings are lifted by upflow inside drill pipe.

(Source: *GROUNDWATER AND WELLS*, permission of Johnson Division, UOP, St. Paul, MN)

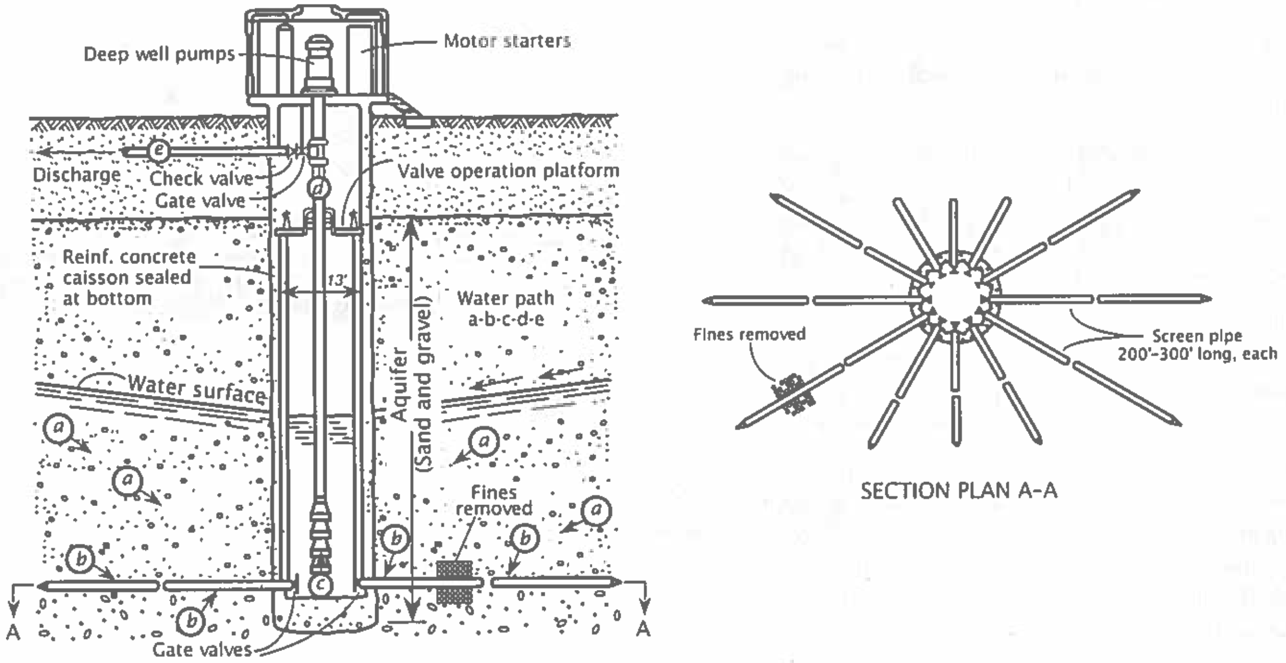


Fig. 3.50 Typical shallow collector-type well (often referred to as a Ranney collector)

(Adapted from R. Nebolsine, *J. NEW ENGL. WATER WORKS ASSOC.*, Vol. 57, p. 191)

3.14 WELL STRUCTURE AND COMPONENTS

3.140 Rules and Regulations Regarding Well Construction

The size, shape, and structure of a well can vary significantly from one region to another. State or local ordinances may establish the criteria that must be followed when constructing a well. In some cases, local customs or unusual subsurface formations will dictate the construction method, while in other areas drilling methods may be left entirely up to the well driller.

In this section, we will discuss the component parts and construction materials used in typical cable-tool, gravel-envelope, and hard-rock wells. Figure 3.51 shows typical cross-sectional views of the three different types of wells mentioned above. This section will discuss the portion of the well located below the ground surface. See Section 3.1, "Surface Features of a Well," for a description of the above-ground components of a well.

3.141 Subsurface Features of a Well

The important subsurface component parts of a typical well include the conductor casing, well casing, well screen or perforated intake section, sanitary grout seal, and the gravel pack or filtering media.

We will review each of these parts in detail, but before we do that, let us discuss the importance of the sanitary grout seal. From a sanitary health and water utility viewpoint, the most important part of any well is the portion from ground level down to the point where the sanitary grout seal ends. This upper zone of the well must be effectively sealed to protect the well against contamination or pollution by surface or shallow subsurface waters, and against improper disposal of liquid wastes and wastewater-related hazards. If this section of the well is not properly designed and installed, then the useful life of the well and also the aquifer is in jeopardy.

The component parts of the sanitary seal include the conductor casing, the upper portion of the well casing, and the grouting material itself.

Now let us review each of the subsurface components in more detail, keeping in mind that construction, design, and materials can vary significantly from one geographic area to another.

3.142 Conductor Casing

The conductor casing is the outer casing of a well (see Figure 3.51, "Gravel-Packed Wells," B, "With Conductor Casing"). The purpose of the conductor casing is to prevent contaminants from surface waters or shallow groundwaters from entering the well.

For community water supply wells, the minimum thickness of the steel conductor casing should be ¼ inch (6 mm) for single casing and 10-gauge for double casing. Steel used for conductor casing should be mild low-carbon steel similar to ASTM-A 139 Grade B. The casing should extend 18 inches (450 mm) above the ground surface.

1. Cable-Tool Wells: The conductor casing should be at least 4 inches (100 mm) larger in diameter than the well casing.
2. Gravel-Envelope Wells: The conductor casing should be at least 12 inches (300 mm) larger in diameter than the well casing.
3. Hard-Rock Wells: The conductor casing should be at least 4 inches (100 mm) larger in diameter than the well casing. However, the well casing also functions as the conductor casing in many instances.
4. Depth of Conductor Casing: The conductor casing should extend down and into an impervious stratum where no liquid can flow in or out. At a minimum, the conductor casing should be 50 feet (15 m) in depth. In some cases, the casing might extend down to 150 feet (45 m) or more if the nature of the upper stratum and the degree of hazard require the extra protection. State or county health authorities often establish guidelines for the minimum depth of a conductor casing and sanitary seal.

3.143 Well Casing

The functions of the well casing are: (1) to maintain the well hole by preventing its walls from collapsing, (2) to provide a way to get the water to the pumping unit, (3) to form a chamber or housing for the well pump, and (4) to protect the quality of water pumped.

The diameter of the well casing is generally determined by the amount of water that the water utility desires to pump from the well and by the safe yield of the well. Table 3.11 shows the recommended casing diameters for various ranges of well yields or pumping rates.

A careful review of this table shows that, in most cases, the casing should be at least 4 inches (100 mm) larger in diameter than the *PUMP BOWL*.[59] The two-inch (50-mm) clearance on all sides allows the pump bowl and column assembly to move freely in the well during installation and removal. This much clearance is necessary in case a well is slightly crooked or out of plumb. In some cases, however, the size of the well casing may be determined by the drilling capability of drilling rigs in the area and availability of well casing.

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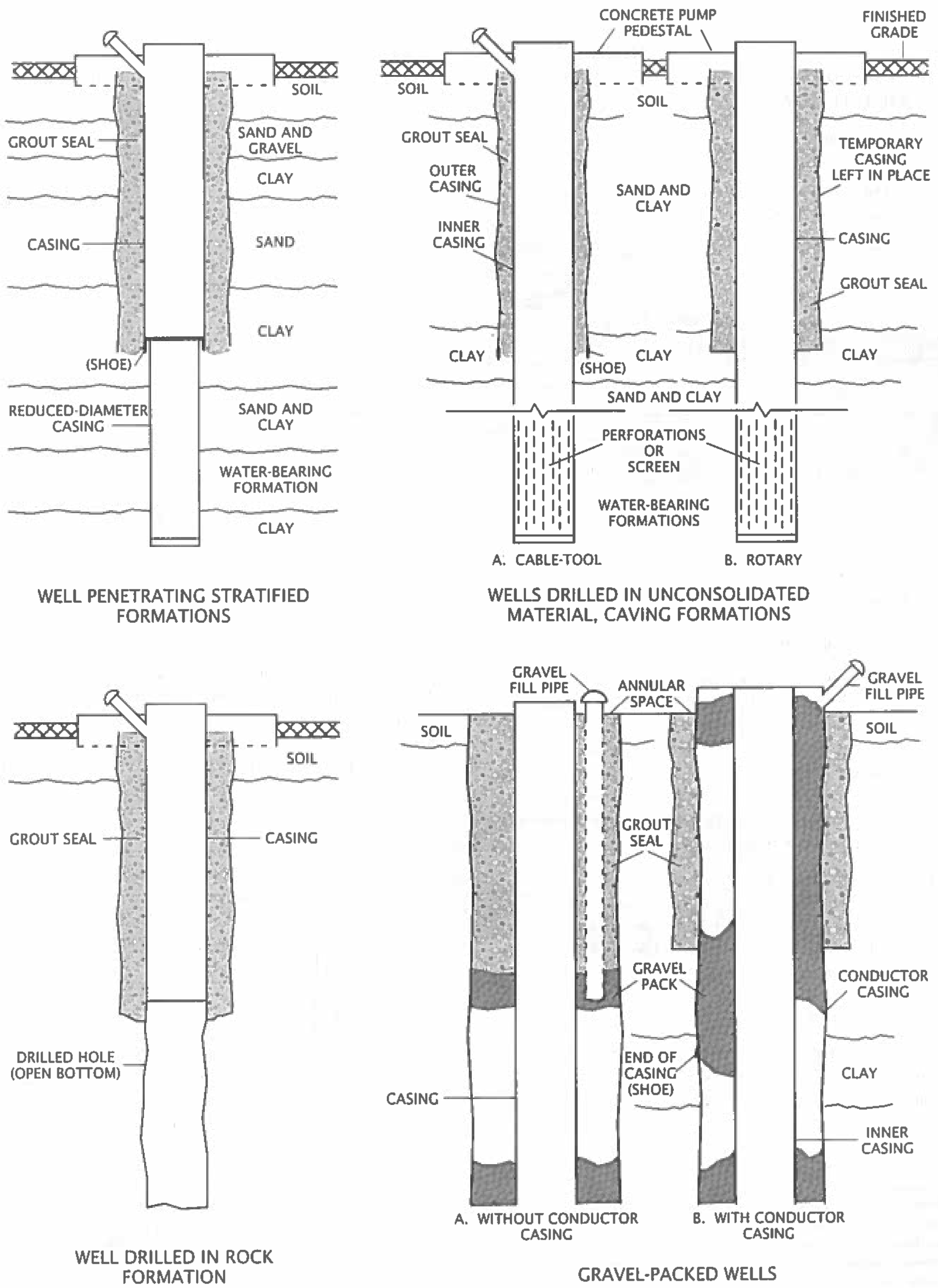
[59] *Pump Bowl.* The submerged pumping unit in a well, including the shaft, impellers, and housing.



A. CABLE-TOOL

B. ROTARY

WELL PENETRATING STRATIFIED FORMATIONS

WELLS DRILLED IN UNCONSOLIDATED MATERIAL, CAVING FORMATIONS

WELL DRILLED IN ROCK FORMATION

A. WITHOUT CONDUCTOR CASING

B. WITH CONDUCTOR CASING

GRAVEL-PACKED WELLS

Fig. 3.51 Typical cross-sectional views of different types of wells

TABLE 3.11 RECOMMENDED WELL DIAMETERS

Anticipated Well Yield, GPM	Nominal Size of Pump Bowl, Inches	Optimum Size of Well Casing, Inches	Smallest Size of Well Casing, Inches
Fewer than 100	4	6 ID[a]	5 ID
75 to 175	5	8 ID	6 ID
150 to 400	6	10 ID	8 ID
350 to 650	8	12 ID	10 ID
600 to 900	10	14 ID	12 ID
850 to 1,300	12	16 OD[b]	14 OD
1,200 to 1,800	14	20 OD	16 OD
1,600 to 3,000	16	24 OD	20 OD

[a] ID. Inside Diameter

[b] OD. Outside Diameter

3.144 Intake Section of a Well

3.1440 Purpose of Intake Section

Another important subsurface feature of a well is the intake section located at or near the bottom of the well and attached to the end of the well casing. The intake section of the well permits the free flow of water from water-bearing formations into the well itself, while at the same time it supports the water-bearing formations and prevents the drill hole from collapsing. In most cases, the intake section also performs the important function of preventing sand from entering the well.

The intake section may take the form of: (1) a well screen, (2) mill-cut slots, (3) formed louvers, (4) torch-cut/chisel-cut slots, and (5) slots made by a mechanical perforator after the well has been completed. These five types of intake sections are described in the following paragraphs.

3.1441 Well Screens

The three basic types of well screens are continuous slot, bar, and wire wound. They are generally constructed of stainless steel, monel metal, special nickel alloys, silicon red brass, red brass, special alloy steel, and plastic.

The length and diameter of the screen section are typically based on the expected yield of the well. Frequently, screen sections are installed at more than one location in the well to fully utilize all of the desirable water-producing formations. The size of the screen openings may vary from formation to formation, depending on the various aquifer materials that might clog them. The size of the screen openings is determined by the *EFFECTIVE SIZE*[60] and *UNIFORMITY COEFFICIENT*[61] of the sands in the water-bearing strata.

The slots or openings in the screen should have sufficient open area so that the water flowing from the water-bearing formations through the screen openings does not exceed a recommended velocity of 0.1 foot per second (0.03 m/sec). This recommended velocity may vary according to local conditions, health departments, and manufacturers. Figure 3.52 illustrates a few typical sections of well screens.

3.1442 Mill-Cut Slots

Mill-cut slotted intake sections are typically made at the well casing manufacturer's plant from the same type and diameter of well casing that was selected for the well. The openings are machine milled (cut) into the wall of the casing pipe parallel to the

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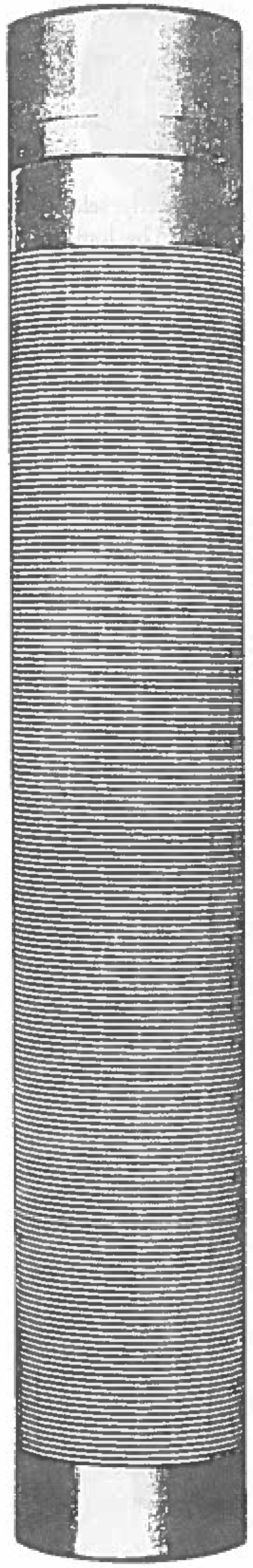
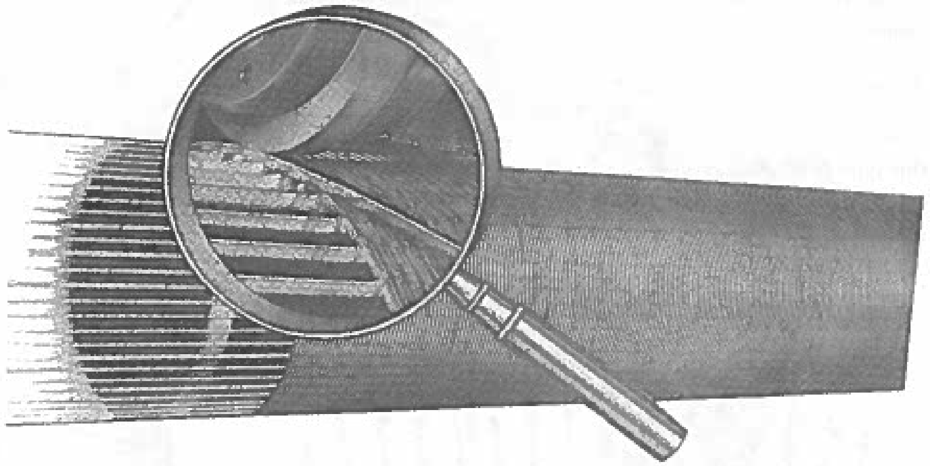
[60] *Effective Size (ES).* The diameter of the particles in a granular sample (filter media) for which 10 percent of the total grains are smaller and 90 percent larger on a weight basis. Effective size is obtained by passing granular material through sieves with varying dimensions of mesh and weighing the material retained by each sieve. The effective size is also approximately the average size of the grains.

[61] *Uniformity Coefficient (UC).* The ratio of (1) the diameter of a grain (particle) of a size that is barely too large to pass through a sieve that allows 60 percent of the material (by weight) to pass through, to (2) the diameter of a grain (particle) of a size that is barely too large to pass through a sieve that allows 10 percent of the material (by weight) to pass through. The resulting ratio is a measure of the degree of uniformity in a granular material, such as filter media.

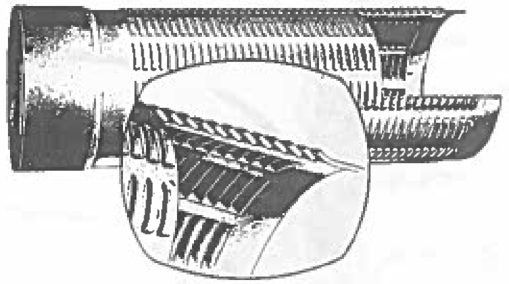
$$\text{Uniformity Coefficient} = \frac{\text{Particle Diameter}_{60\%}}{\text{Particle Diameter}_{10\%}}$$





Fabricating the Johnson Well Screen—an all-welded, continuous-slot well screen for water wells and oil wells. Screen may be made of any metal or alloy that can be resistance welded.

(Source: *GROUNDWATER AND WELLS*, permission of Johnson Division, UOP, St. Paul, MN)



Sections through well screens.

(Permission of Layne and Bowler, Inc. Memphis, TN)

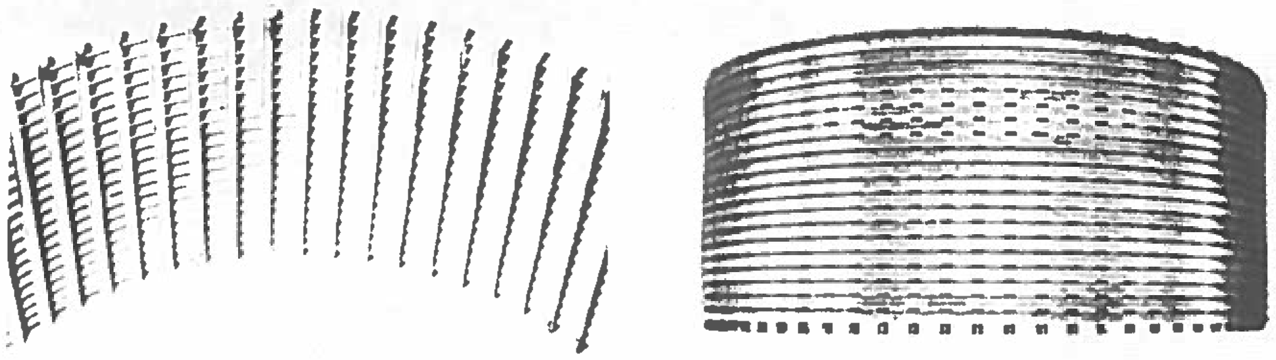
Fig. 3.52 Typical sections of well screens axis of the casing and uniformly spaced around the casing pipe at approximately 2-inch (50-mm) intervals. The slot openings are typically 1⁄16 to 1⁄8 inch (1.5 to 3 mm) wide by 2 to 6 inches (50 to 300 mm) long. The slot width is determined by the size of the aquifer material it must keep out. The rows are sometimes staggered and placed several inches apart. Figure 3.53 illustrates several different types of mill-cut slotted intake sections. Mill-cut slots are still used but may be on the decline due to the increased popularity of the louvered casing.

3.1443 Formed Louvers

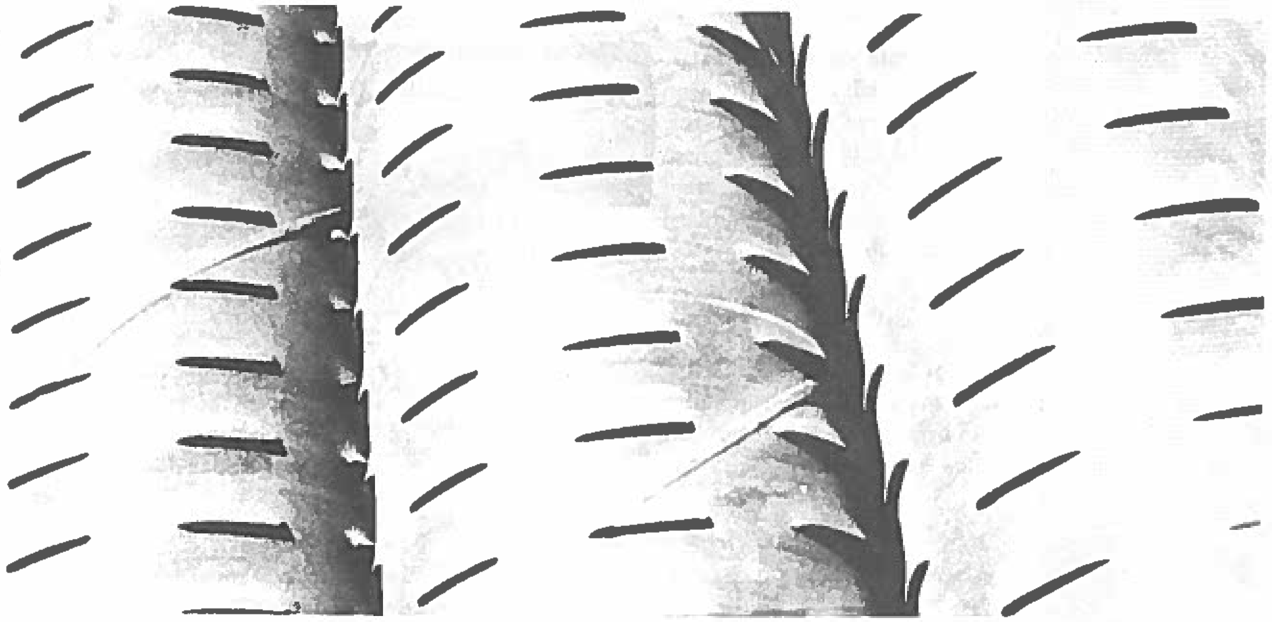
Research and development of the formed louver have made this type of intake section a very popular product. The openings or louvers in the well casing are machine made, horizontal to the axis of the casing, with the openings facing downward. The louvers are shaped to create an upward flow as water enters the well. The louvers are spaced close together in vertical rows as shown in Figure 3.54. As with other types of intake sections, the size of the openings is determined by the aquifer material.

Louvered casing is available in a variety of materials ranging from stainless steel to mild steel. The diameter of the louvered casing is usually the same diameter as the well casing and is available in 10-, 15-, and 20-foot (3-, 4.5- and 6-m) lengths.

Use of properly sized openings and properly selected and sized gravel will produce optimum results. The louvered sections are usually installed directly opposite the desired water-bearing strata. However, in situations where the water-bearing strata are separated by thin layers of consolidated material, a continuous length of louvered casing is often used rather than



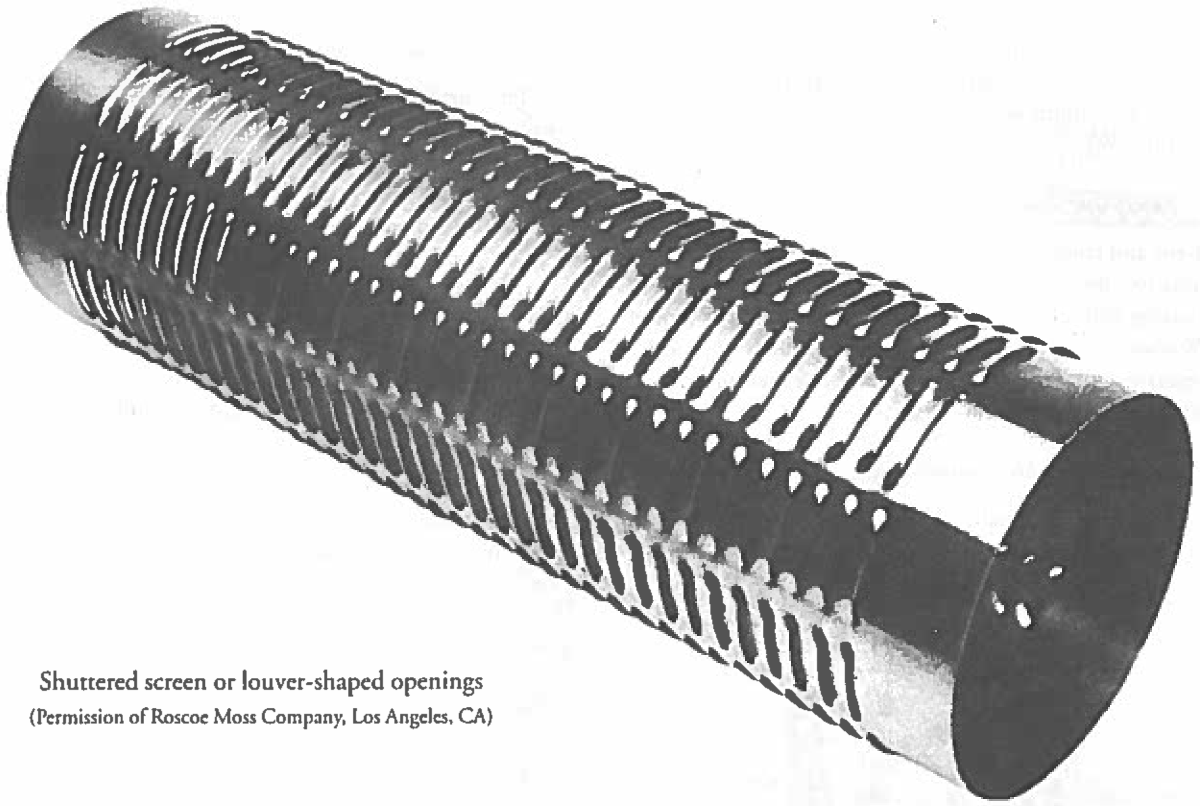
Continuous slot well screen and perforations



Perforated casing

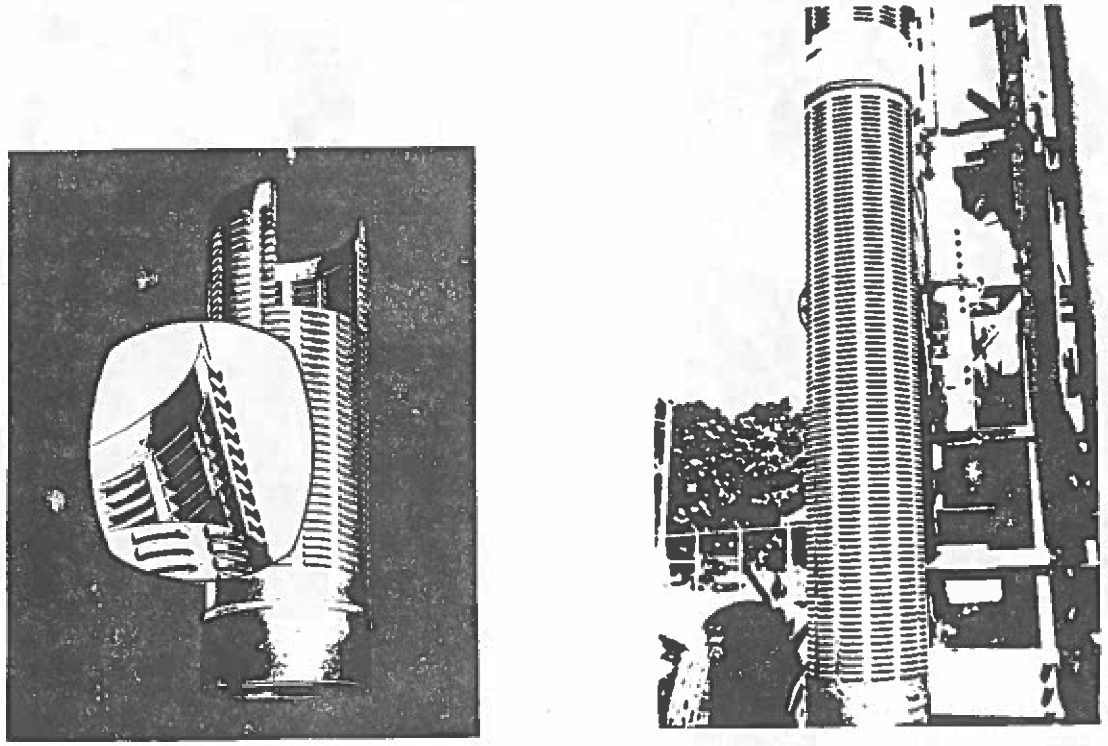
Fig. 3.53 Different types of intake sections

(Source: *WATER WELLS AND PUMPS: THEIR DESIGN, CONSTRUCTION, OPERATION AND MAINTENANCE,* Division of Agricultural Sciences, University of California, Davis)



Shuttered screen or louver-shaped openings

(Permission of Roscoe Moss Company, Los Angeles, CA)



Well-casing louvers

(Permission of Layne & Bowler, Inc., Memphis, TN)

Fig. 3.54 Well-casing openings or louvers inserting short lengths of blank (nonlouvered) well casing. This practice allows for better placing and setting of the gravel pack, quicker well cleanup and shorter development time, and tends to draw the maximum water yield from the selected water-bearing formations.

3.1444 Torch-Cut Slots

Torch-cut and chisel-cut slots should be avoided. Well drillers find it next to impossible to control the size of the openings in the well casing and to maintain the correct open area per foot of casing. Without this type of control, the well is likely to produce sand in excessive quantities. See Figure 3.55 for examples of unacceptable torch-cut and chisel-cut slots.

3.1445 Hydraulic or Mechanical Slots

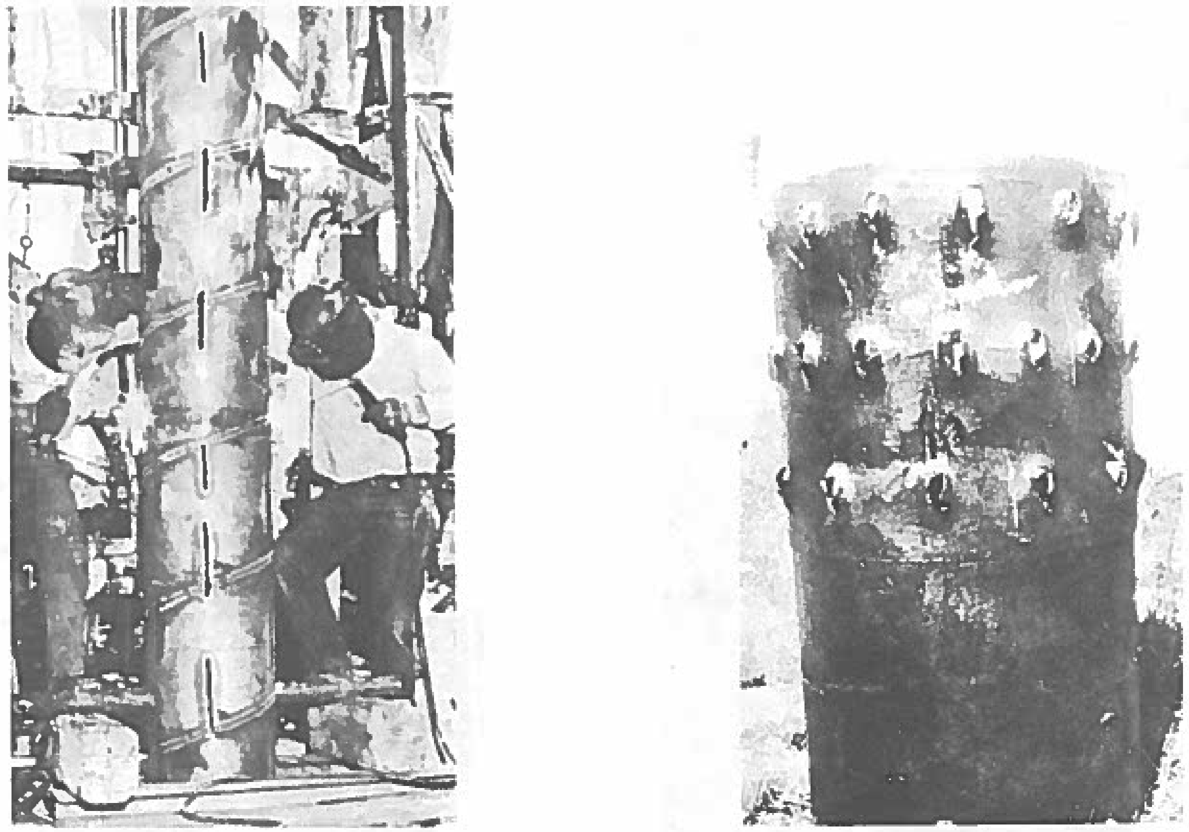
Cable-tool wells are usually slotted after the well has been drilled. The openings are made opposite the water-bearing formations by means of a casing perforator tool lowered into the well and activated from the drill rig.

This method of producing openings or slots in the well casing has serious limitations because the openings cannot be closely spaced, the percentage of open area is low, the opening size and shape can vary, and the correct size openings to control fine or medium sand are almost impossible to produce.

3.145 **Annular Grout Seal** (Figure 3.56)

The purpose of the annular grout seal is to seal out water of any unsatisfactory chemical or bacterial quality, to protect the well casing or conductor casing pipe against exterior corrosion, and to stabilize soil formations that are of a caving nature.

Grouting or cementing is simply filling with cement or other suitable material: (1) the annular space between the well casing and the conductor casing, (2) the space between the conductor



In torch-cut, slotted pipe, percent open area is low and width of slots is too large to permit developing well to sand-free condition.

Casing perforator produces crude, jagged openings of uncontrolled size.

Fig. 3.55 Examples of unacceptable torch-cut and chisel-cut slots
(Source: *GROUNDWATER AND WELLS*, permission of Johnson Division, UOP, Inc., St. Paul, MN)

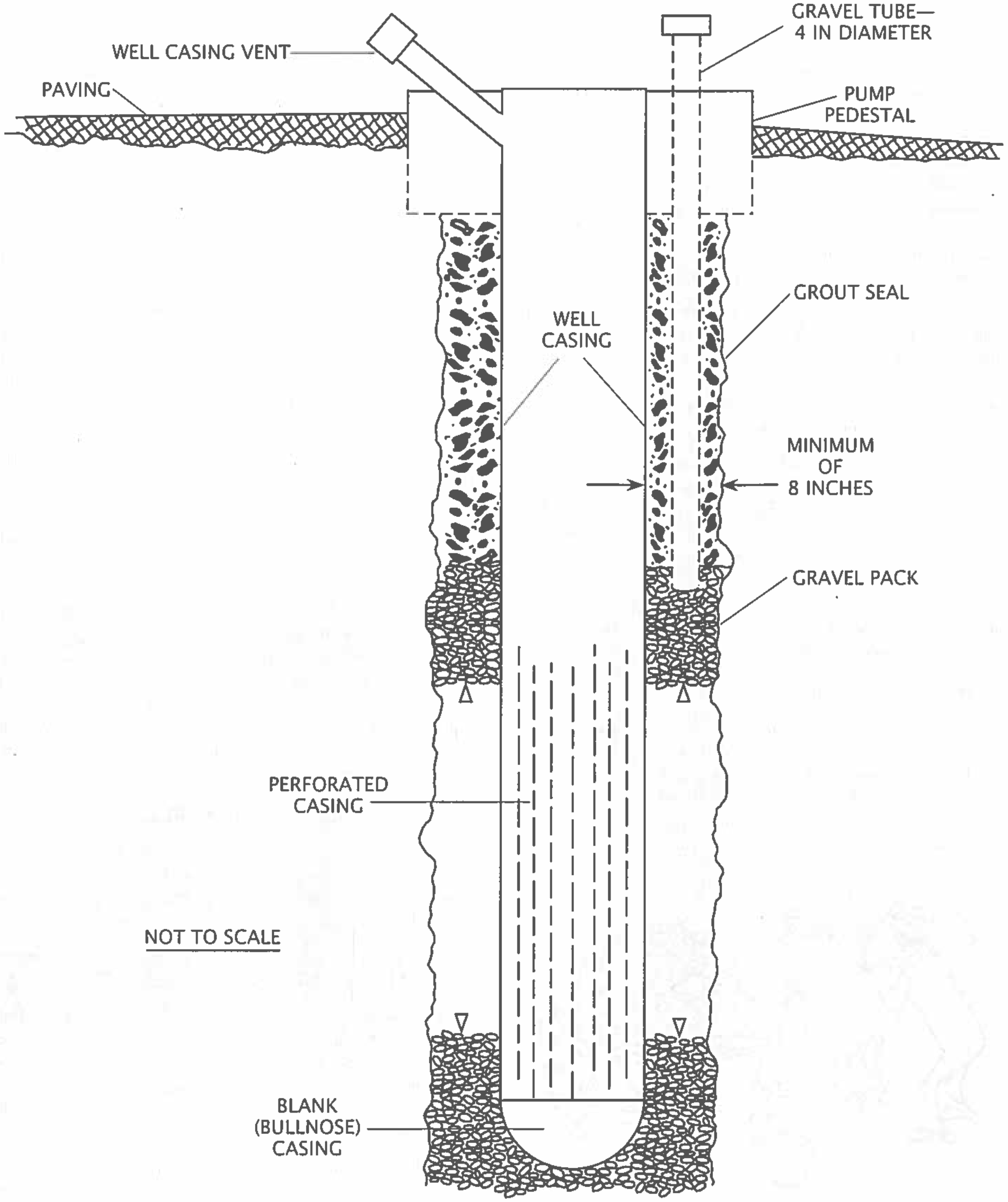


Fig. 3.56 Sanitary sealing method for gravel-envelope wells

casing and the borehole, or (3) the space between the well casing and the borehole.

However, an optional sanitary sealing method (Figure 3.63, page 181) also has been used for gravel-envelope wells. The typical outside conductor casing is eliminated and the annular space between the well casing and the oversize borehole is cemented. In order to provide access for further graveling, a 4-inch (100-mm) standard steel pipe is placed in the annular space extending from above ground down to the area where the gravel envelope is needed. In order to ensure a good seal around the 4-inch (100-mm) graveling pipe, the thickness of the grout is usually increased to 6 or 8 inches (150 to 200 mm).

This new optional method requires an extra thick grout seal and a 4-inch (100-mm) pipe for adding gravel, but does eliminate the expensive outside conductor casing and borehole. On a typical 14-inch (350-mm) diameter well, the conductor casing is 30 inches (750 mm) in diameter and the borehole for the conductor casing is 36 inches (900 mm) across.

Hard-Rock Wells: In consolidated formations, the general practice is to extend the well casing down and into the water-bearing rock formation for a minimum distance of 5 feet (1.5 m). Then the annular space between the well casing and the borehole is cemented. This grout seal should also be a minimum of 2 inches (50 mm) thick. The balance of the borehole through the water-bearing rock formations is left uncased. Water enters the uncased area of the well by way of the fissures and voids in the rock formations.

3.146 Sealing Material

The material used for sealing grout should consist of neat cement grout, sand-cement grout, or bentonite clay. Cement used for sealing mixtures must meet the requirements of ASTM C-150 "Standard Specifications for Portland Cement" Type I (common construction cement) or Type III (high early strength).

3.147 Placement of Sealing Material

Before placing the sealing material in position, all loose cuttings, drilling mud, or other obstructions should be removed from the annular space by flushing with water.

There are three basic methods for placing the sealing material in the annular space when a conductor casing is used. The methods are grout pipe outside casing, grout pipe inside casing, and the Halliburton Method.

No drilling or work in the well should be permitted until the cement grouting materials have developed sufficient strength to prevent damage to the seal.

3.148 Gravel Pack

The purpose of the gravel pack is to control the entrance of sand into the well. The size (or combination of sizes) of gravel selected for the gravel pack is determined by an analysis of the grain size of the water-bearing aquifer materials encountered during the drilling operation. The goal is to select a gravel pack that, while still maintaining sand control, will allow the largest possible screen or slot opening and thus increase the flow into the well.

Whenever placing gravel in a well, the gravel must be disinfected with a strong chlorine solution (50 mg/*L*) before installation to avoid contaminating the well.

Another type of gravel-envelope construction is the "Layne Underreamed Gravel Wall" method developed by Layne and Bowler, Inc., of Memphis, Tennessee. With this method, the water-bearing formation is underreamed (the hole is made larger under the clay layer, Figure 3.57), after the permanent upper casing is set in place. A screen or louvered section of the proper diameter and length is centered in the larger diameter of the underreamed hole. Selected and graded gravel is placed around the screen or louvered section, resulting in a gravel envelope held in place by a long-lasting intake section. This design allows for a maximum flow of water into the well and is a very efficient groundwater-producing unit.

3.15 DETERMINATION OF WORKING PRESSURE

Hydropneumatic pressure tanks are used to provide a consistent range of suitable pressures in the distribution system despite changing demands and pump cycling. Other reasons for using a hydropneumatic pressure tank system are:

1. Gravity storage may not be practical or available due to the lack of elevation differentials within the service area.
2. By using the best operating pressure differential and control levels in the tank (referred to as "tank efficiency"), the time period between start/stop operation of the pump can be extended considerably, thereby reducing the cycling frequency of the pump. Excessive pump cycling increases the wear on the pump and its parts, plus using additional energy.
3. Hydropneumatic tanks maintain distribution system pressures within predetermined limits by maintaining a cushion of compressed air in the top portion of the tank. In effect, this provides stored energy to force the water out as the pressure in the distribution system drops.
4. The compressed air in the tank greatly reduces the hydraulic shock load on the system when the well pump starts and stops.

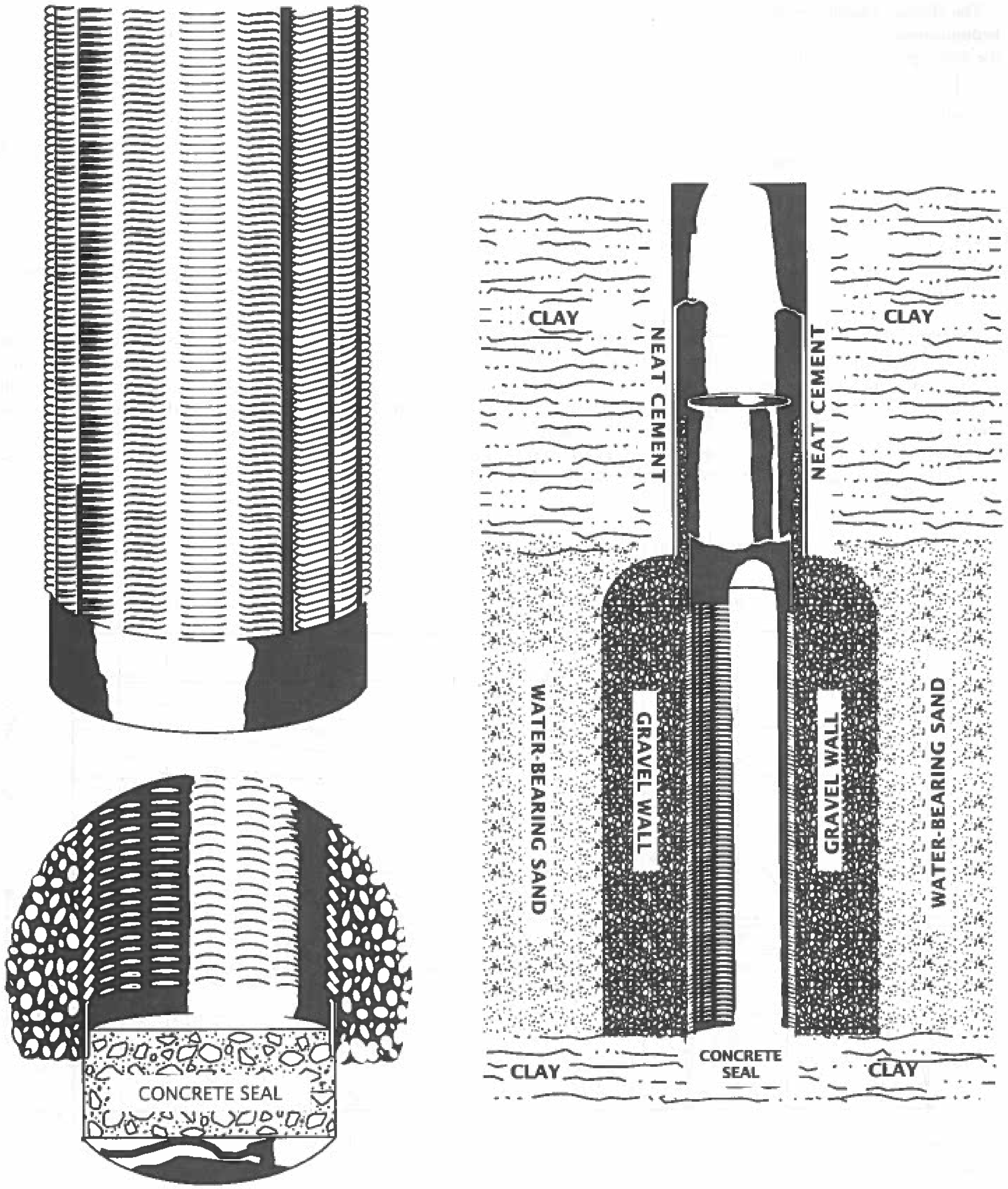


Fig. 3.57 Layne Underreamed Gravel Wall

(Permission of Layne and Bowler, Inc., Memphis, TN)

The effective (usable) water storage capacity in a horizontal hydropneumatic tank is limited to approximately 25 percent of the total capacity of the tank.

You can select the best operating pressure differential, the control levels in the tank, the pumping differential, and the tank efficiency and tank size by studying Figures 3.58 and 3.59 and working through the following examples.

As an example, let us study a typical 5,000-gallon capacity horizontal tank, six feet in diameter by approximately 25 feet in length, with the inlet and outlet connections in the bottom of the tank, and an *OPERATING PRESSURE DIFFERENTIAL*[62] of 20 psi (from 40 to 60 psi). For this example, the most efficient tank operating criteria would require the pump start point or low water level (LWL) to be set at 12 inches (30 cm) above the bottom of the tank; set the pump stop point or high water level (HWL) at 27 inches (67 cm) above the bottom of the tank. If the tank is constructed with an outlet connection that extends up into the tank (generally 6 to 10 inches (15 to 25 cm)) as is a common practice if the well produces sand, then the LWL in the tank must be maintained at a minimum of 10 inches (25 cm) above the top rim of the outlet connection so that the possibility of air loss into the piping system will be minimized. This would require the HWL to be raised to the optimum level (27 inches or 67 cm).

Because we have the guidelines for our tank, let us proceed through an example of how we derived the HWL and check to see if the 20 psi (138 kPa or 1.4 kg/sq cm) differential is the most desirable for our situation.

EXAMPLE 1: Pressure Differential and Efficiency Determination

Refer to Figure 3.58. Start at the point indicating a reserve of 10 percent by volume in the tank and follow this line horizontally to where it intersects the vertical 40 psi pressure line. Follow the closest pressure curve (in this case the 35 psi curve) to where it intersects the vertical 60 psi line. Then, by interpolation, determine the point that indicates that the water will occupy approximately 34 percent of the total tank capacity when the air has been compressed from 40 psi to 60 psi. The water level equivalent to 34 percent of the tank volume established the desired HWL.

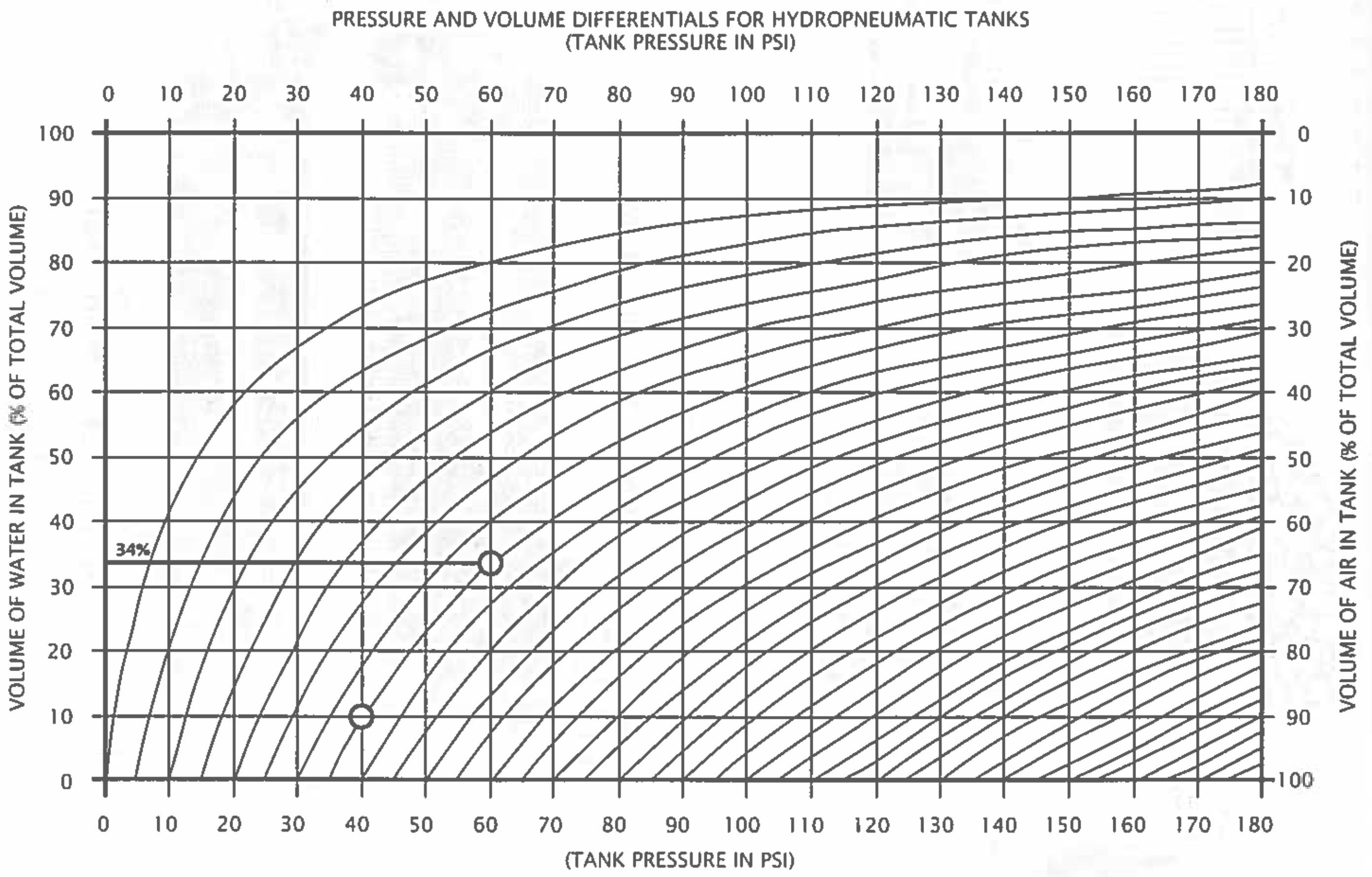


Fig. 3.58 Pressure/volume determination chart

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[62] *Operating Pressure Differential.* The operating pressure range for a hydropneumatic system. For example, when the pressure drops below 40 psi in a system designed to operate between 40 psi and 60 psi, the pump will come on and stay on until the pressure builds up to 60 psi. When the pressure reaches 60 psi the pump will shut off. The operating pressure differential in this example is 20 psi.

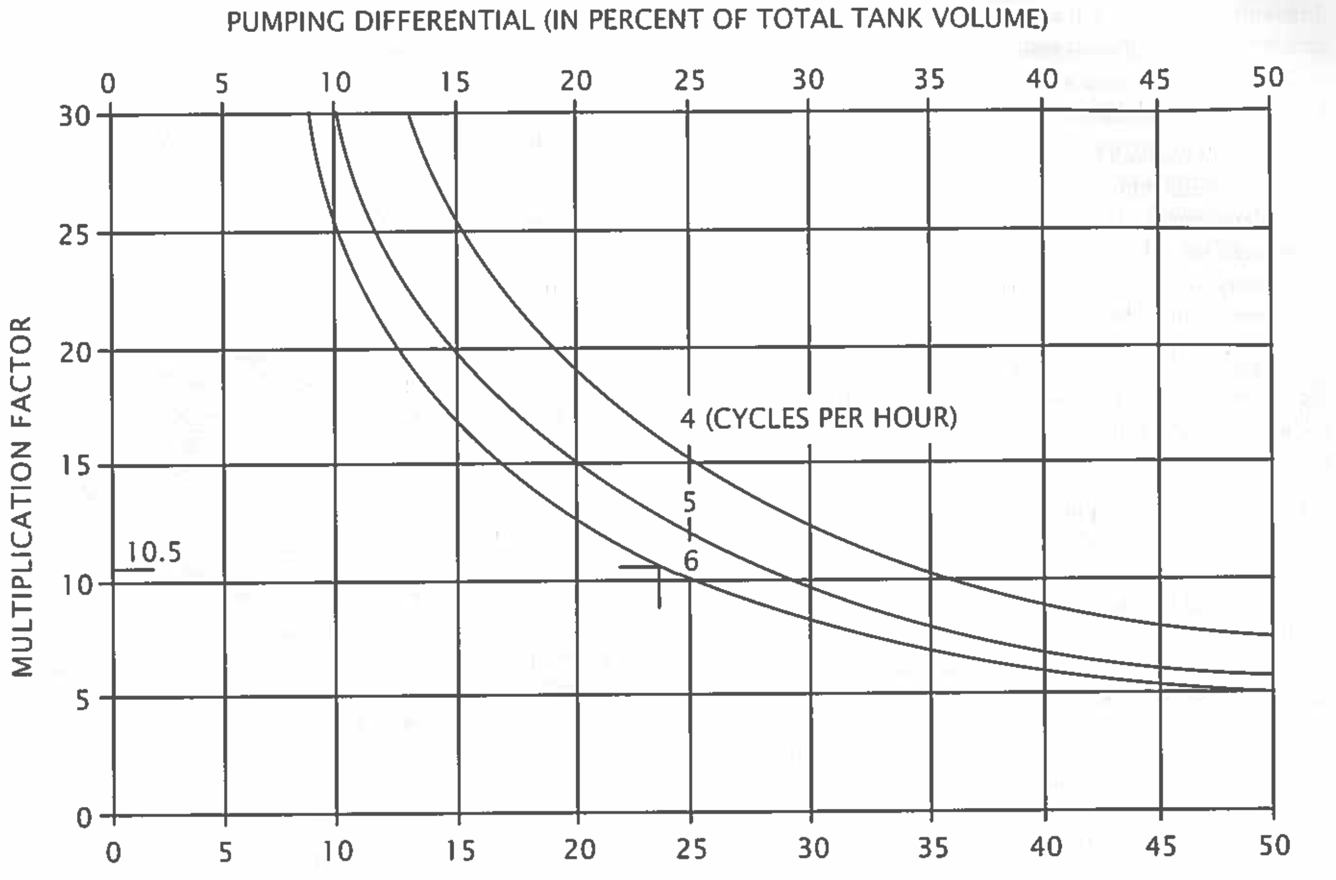
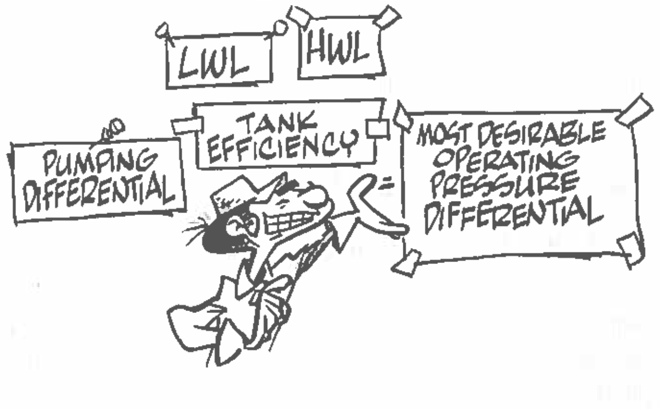


Fig. 3.59 Pressure tank volume requirements

The pumping differential is the difference in volume between the HWL and LWL in the tank. This differential expressed in percent also indicates the tank efficiency. Thus, 34 percent minus 10 percent indicates that the pumping differential is 24 percent of the total tank volume. With 24 percent of the total tank volume available for pumping, the tank efficiency also is 24 percent.

The actual HWL and LWL in the tank may now be established. The volume in a cylindrical, vertical tank is proportional to the height. Assume that a vertical tank is 72 inches high and the tank discharge is located in the tank bottom. Then the LWL is (10/100) 72 or 7.2 inches above the bottom of the tank and the HWL is (34/100) 72 or 24.28 inches above the bottom of the tank.

The volume in a cylindrical, horizontal tank is not proportional to the diameter (height) so volume height calculations must be made. These calculations will not be done here. To summarize, we have now established how to determine the LWL, the HWL, the pumping differential, and the tank efficiency. The remaining consideration is for determining the most desirable operating pressure differential.



Assume, for example, that the pressure differential is to be 30 psi with 40 psi at LWL and 70 psi at HWL. Proceed as described above and determine that at 70 psi the water will occupy approximately 42 percent of the total tank volume. The pumping differential is 32 percent of the total tank volume and the tank efficiency is also 32 percent. This is a gain of 8 points over the 40 to 60 psi pressure selection. The pumping differential governs the size of the tank that will be required and also may affect the size of the pump because of the range in the pressure differential. Costs of each arrangement must be evaluated to determine the most efficient system.

EXAMPLE 2: Tank Volume Determination

The size of the tank is governed by both the established pumping volume differential and the number of pumping cycles desired. Experience indicates that the average number of pumping cycles need never be greater than six per hour and very seldom is it necessary to provide for fewer than four cycles per hour. However, cases of 30 cycles per hour have been encountered.

The greater the number of pumping cycles, the smaller will be the size of the required tank. This must be given serious consideration when the initial cost of an installation is of prime importance.

Fewer cycles will require the use of a larger tank but sometimes other important considerations besides initial cost assume greater importance. Fewer pumping cycles are recommended for installations in hospitals, sanitariums, and hotels where frequent starting and stopping may be annoying, and when greater reserve is desired or required, for example, when the installation is used for fire protection.

To determine the tank size, let us assume the required pump capacity has been determined at 50 GPM, the pumping differential is 24 percent of the total tank capacity, and that six pumping cycles per hour are desired.

Refer to Figure 3.59. This curve is based on the assumption that the average system demand is equivalent to one-half of the pump capacity. So, with a pumping differential of 24 percent, we determine from the curve for six pumping cycles per hour that the multiplication factor is 10.5 × 50 = 525 gallons or the total volume for the required tank.

Some very small well pumping installations may be equipped with one or more small conventional vertical mounted hydropneumatic tanks *MANIFOLDED*[63] to the pump discharge. These tanks could range from 40 to 330 gallons (150 to 1,250 liters) capacity and be equipped with a flexible or bag-type diaphragm.

3.16 WELL TESTING AND EVALUATION

3.160 Well Performance Testing

Well testing for quantity of water is an important phase of well construction. Information obtained during pumping tests provides data necessary to determine well and pump efficiency, pump installation depth settings, aquifer characteristics, capacity of the well, well recharge potential, and other factors that will be of use in the long-term operation and maintenance of the well. The type of test for a specific well depends on intended use, size of well, and costs of the test. Performance tests should be consistent with the dimensions and capacity of the well and the rate at which it will be pumped when placed in service. Care must be taken to avoid excessive pumping rates that would damage the aquifer.

Depending on the size and proposed use of the well, performance testing may range from a simple bailing test of short duration to tests lasting 72 hours or longer. The driller normally has sole responsibility for small facilities. For larger wells, the operation will usually be under the direction of a competent engineer or geologist. In the latter case, the responsibility of the driller will be to operate the equipment and make the necessary measurements of flow and drawdown.

Measurements of water levels must be taken before, during, and after performance testing. A static or nonpumping level must be established for comparison of the measurements made during pumping and recovery. This static level can be determined by making periodic measurements of water level for a period of time equal to, or longer than, the duration of the proposed test prior to its start. Water levels can be measured with a steel tape, by flagging (marking distances on) the bailer line, by an electric sounder, or by reading pressure on an air line. Recovery readings are also an important part of well testing and should be started immediately upon shutdown of the pumping test and continued at some specific interval.

With small-capacity wells that operate intermittently or irregularly, testing should continue until an apparent stability of bailing or pumping level is achieved. Ideally, with large-capacity wells, pumping should be continued at a uniform rate of discharge until the *CONE OF INFLUENCE*[64] reflects any boundary condition that could affect future performance of the well. This probably will not exceed 24 hours for an artesian well, and 72 hours for a water table well. Large well testing should be supervised by someone with adequate qualifications and experience and may require use of observation wells.

Comprehensive aquifer tests require a minimum of one or two observation wells, depending on the purpose of the test results or the well. In typical situations, observation wells may be from 100 to 300 feet (30 to 90 m) from the production well and about the same depth. Observation wells may be smaller in diameter, however. For testing relatively thick artesian aquifers, observation well distances of 300 to 700 feet (90 to 210 m) from the pumped well are occasionally used.

The amount and rate of drawdown and recovery of the water level with time are the most critical items of data needed to evaluate the initial efficiency of the well and the hydraulic characteristics of the aquifer.

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[63] *Manifold.* A large pipe to which the ends of a series of smaller pipes are connected. Also called a HEADER.

[64] *Cone of Influence.* The depression, roughly conical in shape, produced in the water table by the pumping of water from a well. Also called the CONE OF DEPRESSION. Also see CIRCLE OF INFLUENCE.

3.161 Types of Pumping Tests

Several procedures for testing well yield are available. They range from the very simple bailing procedure to the more complex step-continuous method. The bailing test method and the air blow test method are used to make rough estimates of the yield of a well without installing a pump. The variable rate method uses a pump in a well. These methods are not adequate for a well-acceptance test for well yield for public water supply wells in some states.

3.1610 Bailing Test Method

The first step is to determine the *STATIC WATER LEVEL*[65] in the well. First, use a bailer of known volume to bail (remove water from) the well until the water level reaches a static level below which it cannot be lowered by further bailing. Lower the bailer until it just touches the water (if the bailer is dropped, it will make a splash as it hits the water surface). Mark the bailing line clearly at two points: one point at the top of the casing when the bailer is just on top of the static water level, and at a second point one bailer length above the first point. At even time intervals, lower the bailer until the second mark is just level with the top of the casing. The bailer must be full each trip. If the bailer is not full, increase the time per round trip until the bailer comes out full each time. Once this procedure continuously produces the same amount of water in equal time periods, the yield of that particular depth can be determined. The gallons per minute for that well at that depth is equal to the volume of the bailer (in gallons) divided by the time (in minutes) per round trip.

If the bailer cannot be completely submerged, the same procedure is used except that the volume must be measured and the time period adjusted for each trip until a constant volume is retrieved at regular intervals.

Bailing can be used successfully in low-yield wells, but other procedures are commonly used when the well has a high yield.

3.1611 Air Blow Test Method

This procedure requires the injection of air at the bottom of the well in sufficient quantity to blow water out of the well. As pressures must be high, some kind of deflector will be needed at the top of the well to capture and measure the water. Again, as with the bailing procedure, accurate measurements of water levels must be kept. For a measured period of time and volume of water taken out of the well, the rate of flow (GPM) can be calculated.

3.1612 Variable Rate Method

This method requires pumping the well at a series of constant rates and measuring the variation in drawdown during pumping. Install the pump at the lowest production point in the well and pump at a constant rate until the pump breaks suction. If the pump runs for more than 24 hours without breaking suction, further testing is probably not needed. (Essentially, the test would then be a constant rate test.) If the pump breaks suction, decrease the pumping rate until the water level in the well stabilizes approximately two feet (0.6 m) above the pump intake. Then, decrease the pump rate by 5 percent and pump until the water level has been stabilized for at least four hours. The drawdown and pumping rate at that level are considered to be representative of the production rate and pumping level for that particular well.

3.1613 Constant Rate Method

When a well is pumped at a constant rate, the water level will continuously drop at a decreasing rate until a certain water level is reached and maintained. As the water level is lowered during the test, the flow rate of the pump may change due to the head/flow characteristics of the pump. Since this is a constant rate test, however, a valve for throttling and a meter for measuring flow must be used to ensure that the pumping rate remains constant. Adjustments during testing should be made as needed to keep the flow constant.

Again, as in other test procedures, the static or nonpumping level should be established before testing starts. Frequent measurements should be made during the drawdown and recovery periods according to the following schedule: 0 to 10 minutes—every minute; 10 to 45 minutes—every 5 minutes; 45 to 105 minutes—every 10 minutes; 105 to 180 minutes—every 15 minutes; and from 3 to 24 hours—every hour. This schedule can be modified somewhat, but the purpose is to develop a good relationship between time and drawdown at a constant pumping rate.

If more than one drawdown test is to be conducted, the pump should be capable of providing flow rates from approximately 125 percent of design capacity to about 60 percent capacity. For a thorough understanding of the well and aquifer characteristics, more than one test is recommended. This procedure should

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[65] *Static Water Level.* (1) The elevation or level of the water table in a well when the pump is not operating. (2) The level or elevation to which water would rise in a tube connected to an artesian aquifer, basin, or conduit under pressure.

result in some very accurate information about the well and its production capacity.

The constant rate method is used for well-acceptance testing for public water supply wells. This method is commonly used to determine specific capacity. The constant rate test is typically used to determine several aquifer and confining unit hydraulic characteristics (aquifer transmissivity (T), hydraulic conductivity (K), and storativity (S), and confining unit vertical hydraulic conductivity (Kv)) that are required to design a well field (Section 3.123). Where nearly all the groundwater comes from aquifer storage, aquifer T and K can be determined from a single well test (only the pumping well is used). The problem is that you must know this condition exists before the test. Storativity (S) cannot be determined from this test, but an experienced hydrogeologist can make a good estimate so that the required hydraulic characteristics needed for well field design are available. Where nearly all of the groundwater comes from leakage through the overlying confining unit, aquifer T, K, and S, and confining unit vertical hydraulic conductivity (Kv) can be determined, but a multiple well test (observation wells included) is required. From these constant rate test data, drawdown over time and distance at various pumping rates can be determined. A well field design can be made from this information.

3.1614 Step-Continuous Composite Method

There are several variations or modifications of this test method. In this procedure, the well is tested at approximately ½, ¾, 1, and 1½ times the pump design capacity and usually runs for 24 hours or more. The test would start at ½ capacity for 6 hours, then ¾ capacity for 6 hours, then design capacity for 6 hours, and then 1½ capacity for 6 hours. Pumping times must be the same at each step in this test.

Also, important to this test are the measurement periods that should be taken at even time intervals and in the same manner as for the constant rate method with one modification. Each time the pumping rate is increased, a new set of measurements is to be started. Recovery measurements should be taken once the drawdown is completed.

This method is often run by the well driller to see if the well has been properly developed and is used as a method of well development. Specific capacity can be calculated from data obtained from this method.

3.17 PUMP TESTING AND EVALUATION

3.170 Mechanical Wear of Pumps

Well pumps, like other pieces of moving machinery, are subject to some degree of mechanical wear. This wear can be accelerated if the pump was not correctly installed, the well is crooked, or the pump received inadequate lubrication. In addition, sand in the water can cause excessive and rapid wear of the bowl unit. If the well water is highly corrosive, a chemical reaction may occur that results in localized pitting and possible penetration of the well casing, bowl unit, or pump column pipe.

3.171 Guidelines for Testing

Well pump performance tests should be made on a routine basis to determine if excessive wear is occurring. These tests also reflect the yield characteristics of the well and are indicators of potential well problems. Well pumps should be tested once every other year. If there are clues that pump performance is rapidly changing, then more frequent testing is strongly advised. Tests should be run at about the same time each year to minimize the impact of seasonal variations in groundwater conditions. The same test point on the pump curve should be used. Therefore, if the discharge pressure at the pump was maintained at 50 psi (345 kPa or 3.5 kg/sq cm)(115.5 feet or 35.2 m of discharge head) during the previous test, then subsequent tests should also be made at the 50 psi point.

If the well pump installation is equipped with a flowmeter, discharge pressure gauge, and air line or probe device to measure water levels, then the operator can run one or more simple field tests to check well and pump performance. Tests for flow, pressure, drawdown, well yield, and gallons per minute per foot of drawdown can be readily made, and the results compared with previous tests to determine any changes in performance. Figure 3.60 illustrates the basic configuration and mechanical apparatus used during the field testing of a well pump.

If the operator is unable to perform these tests, then assistance should be requested from the local power supplier. Many power companies offer this testing service free of charge. In larger communities, some of the water well drillers or pump suppliers can perform this service for a small fee.

3.172 Operator Responsibility

Most small or medium-sized water companies are not equipped to perform full-scale accurate field pump efficiency tests, nor is the average operator expected to have the knowledge and skills to perform these tests. However, a good operator should be capable of understanding the terminology (Section 3.173) and how the calculations (Section 3.174) are made, and be able to evaluate the test results to the degree that the operator is aware when performance values (Section 3.175) indicate that repair work to the pump is justified.

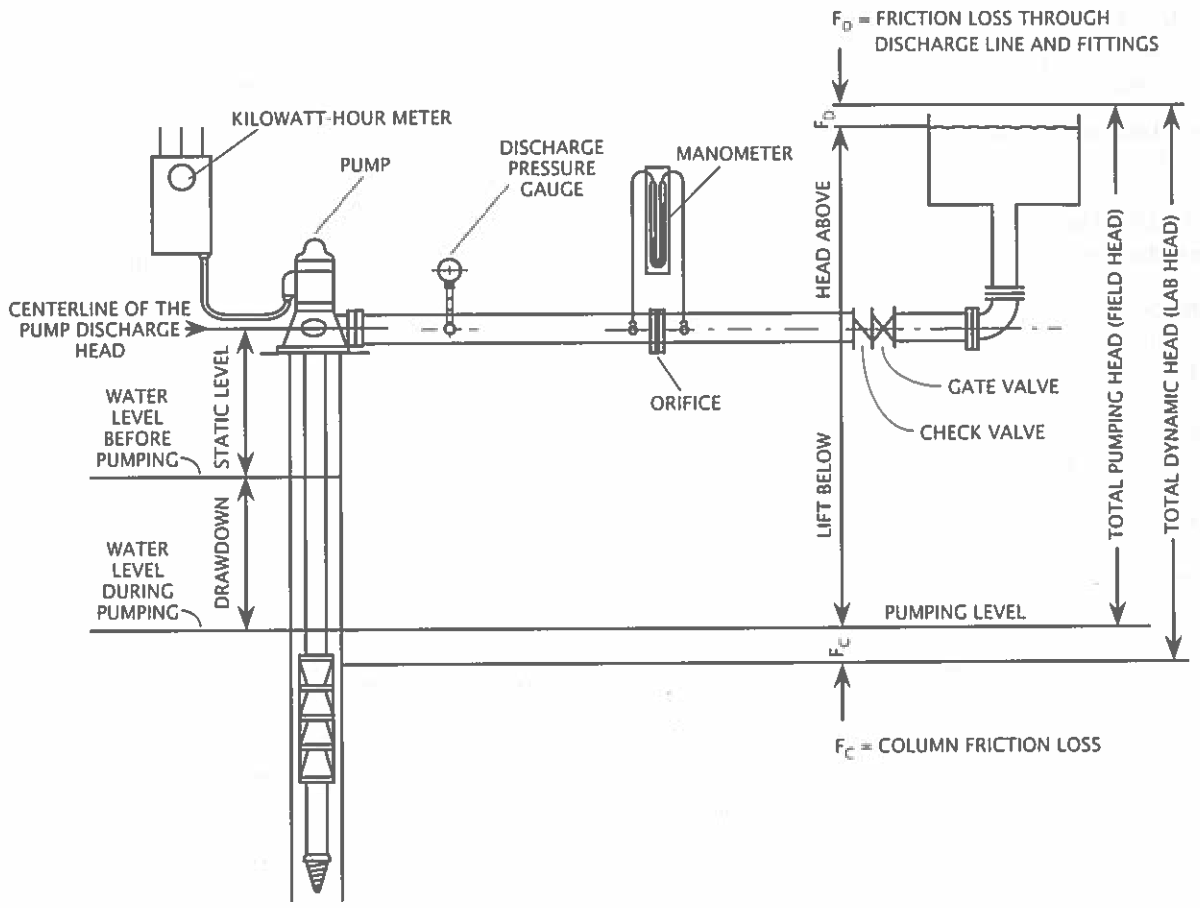


Fig. 3.60 Layout for field testing a well pump

3.173 Terminology

The operator should have a working knowledge of the definitions in this section.

1. *STATIC WATER DEPTH.* The vertical distance in feet (or meters) from the centerline of the pump discharge down to the surface level of the free pool while no water is being drawn from the pool or water table.
2. *DRAWDOWN.* The drop in the water table or level of water in the ground when water is being pumped from a well. The difference in feet between the pumping water level and the static water level.
3. *PUMPING WATER LEVEL.* The vertical distance from the centerline of the pump discharge to the level of the free pool while water is being drawn from the pool. (This is also the sum of the static water depth and drawdown.)
4. *DISCHARGE HEAD.* The pressure (in pounds per square inch (psi) or kilopascals (kPa)) measured at the centerline of the pump discharge and very close to the discharge flange, converted into feet or meters. The pressure is measured from the centerline of the pump to the hydraulic grade line of the water in the discharge pipe.

$$\text{Discharge Head, ft} = (\text{Discharge Pressure, psi})(2.31\ \text{ft/psi})$$

or

$$\text{Discharge Head, m} = (\text{Discharge Pressure, kPa})(1\ \text{m}/9.8\ \text{kPa})$$

5. *TOTAL PUMPING HEAD* (Field Head). The total pumping head equals the lift below the discharge plus the head (or pressure (psi) for water × 2.31 ft/psi) above the discharge. The latter item (head above the discharge) must include friction losses through any discharge pipe and fittings.
6. *COLUMN FRICTION LOSS.* The feet of head of friction loss in the column. This is dependent upon the length and size of column and shaft used. Column friction loss is tabulated in feet of head per hundred feet of column and shaft in column friction loss charts.

7. *TOTAL DYNAMIC HEAD* (Lab Head). The total head on the pump bowl; equal to total pumping head plus column friction loss.

$$\text{Total Dynamic Head} = \text{Total Pumping Head} + \text{Column Friction Loss}$$

8. *CAPACITY.* The rate of flow in liquid measure per unit of time (gallons per minute).

9. *LABORATORY EFFICIENCY* (Bowl Efficiency). This value is read directly from the performance curve based on total head in feet and pumping capacity in gallons per minute.

10. *LABORATORY HORSEPOWER.* The horsepower required at the impeller shaft to deliver the required capacity against the total dynamic head. Laboratory horsepower is calculated from the formula:

$$\text{Laboratory BHP} = \frac{(\text{Total Dynamic Head, ft})(\text{Capacity, GPM})(100\%)}{(3{,}960^*)(\text{Laboratory Efficiency, \%})}$$

$$^*3{,}960 = \frac{33{,}000 \text{ ft-lb/min-HP}}{8.34 \text{ lbs/gal}}$$ Where 3,960 converts ft-GPM to BHP.

11. *SHAFT LOSS HORSEPOWER.* The energy lost in the shaft measured in horsepower and determined by the length and the size of shaft and the speed of the pump. To find the shaft loss, refer to shaft loss charts supplied by the pump manufacturer. The values on these charts are expressed in horsepower per hundred feet of shafting.

12. *BRAKE HORSEPOWER (BHP)* (Field Horsepower). The horsepower required at the top of a pump shaft (input to a pump). The brake horsepower is the sum of Laboratory Horsepower and Shaft Loss Horsepower.

$$\text{Brake Horsepower} = \text{Laboratory Horsepower} + \text{Shaft Loss Horsepower}$$

13. *PUMP FIELD EFFICIENCY.* The efficiency of the complete pump with all losses between laboratory performance and field performance accounted for. Pump field efficiency is calculated by means of the formula:

$$\text{Pump Field Efficiency, \%} = \frac{(\text{Total Pumping Head, ft})(\text{Capacity, GPM})}{(3{,}960)(\text{Brake Horsepower, BHP})}(100\%)$$

14. *MOTOR EFFICIENCY* (Without Thrust Load). Supplied by the motor manufacturer. These values are normally given for full, ¾, and ½ load, but vary so little near full load that the full load value can be used for slight under- or overloads on the motor.

15. *INPUT HORSEPOWER.* The total power used in operating a pump and motor. This is the brake horsepower divided by the motor efficiency without thrust load.

$$\text{Input Horsepower, HP} = \frac{(\text{Brake Horsepower, BHP})(100\%)}{\text{Motor Efficiency, \%}}$$

16. *THRUST BEARING LOSS.* The horsepower lost in the thrust bearings. This is dependent upon the type of thrust bearing and the total thrust load on the bearing. Bearing manufacturers indicate the loss in an angular contact ball bearing to be approximately 0.0075 HP per 100 RPM per 1,000 lb thrust load.

17. *MOTOR EFFICIENCY.* The ratio of energy delivered by a motor to the energy supplied to it during a fixed period or cycle. Motor efficiency ratings will vary depending on motor manufacturer and usually will be near 90.0 percent.

18. *OVERALL PUMP EFFICIENCY.* The combined efficiency of a pump and motor together. Also called the "wire-to-water" efficiency.

$$\text{Overall Pump Efficiency} = (\text{Pump Field Efficiency})(\text{Motor Efficiency})$$

3.174 Calculations

Operators should be aware of the calculations involved in determining well pump efficiencies. At first glance, you may feel that the calculations are too difficult, but if taken step by step, you should be able to understand the procedure and, in time, become comfortable with the method.

As an example, let us calculate the overall pump efficiency based on specifications as follows:

Known

Pump—4 stage, 1,760 RPM

Motor—60 HP, 4 pole, 440 volt, 3 phase, 60 cycle, vertical hollow shaft

Static Water Depth, ft	= 150 ft
Drawdown, ft	= 30 ft
Pumping Water Level, ft	= 180 ft
Discharge Head, ft	= 10 ft
Total Pumping Head, ft	= 190 ft
Column Size, in	= 8 in
Tube Size, in	= 2 in
Capacity, GPM	= 990 GPM
Brake Horsepower (BHP)	= 59.58 BHP
Shaft Size, in	= 1¼ in
Shaft, RPM	= 1,760 RPM
Shaft Length, ft	= 200 ft
Motor Efficiency Without Thrust Load, % (from motor manufacturer)	= 90%

To calculate the overall pump efficiency, try to obtain the above "Known" information for the pump using Table 3.12 as a guide. After identifying the "Known" information, continue with Section 3.175 on page 176.

TABLE 3.12 PROCEDURE TO COMPLETELY EVALUATE PUMP PERFORMANCE IN WATER WELL APPLICATIONS

	1. Static water depth	150 ft	Measured from centerline of the pump discharge down to the water surface before the pump is started.
	2. Drawdown	30 ft	Measured from the water surface before the pump is started to the water surface after the pump has operated at a specified capacity for a specified time.
	3. Pumping water level	180 ft	Sum of Lines 1 and 2.
(a)	4. Discharge head Discharge Pressure, psi × 2.31 ft/psi	10 ft	Gauge reading in psi times 2.31 ft/psi plus or minus a correction value. The correction value is the measurement in feet from the discharge pressure gauge to the centerline of the pump discharge head. Add the correction value when the discharge pressure gauge is above the centerline of the pump discharge head (as shown in Figure 3.60) and subtract the correction value when the gauge is below the centerline.
(b)	5. Total pumping head	190 ft	Sum of Lines 3 and 4.
	6. Column friction loss	6 ft	From Table 3.13, for a column size of 8", a tube size of 2", and a capacity (rate of flow) of 990 GPM, column friction loss is approximately 3.1 feet per 100 feet of column. Multiply 3.1 feet/100 feet of column times feet of column or pumping water level in feet (Line 3): $\text{Column Friction Loss, ft} = \frac{3.1 \text{ ft}}{100 \text{ ft}} \times 180 \text{ ft} = 5.58 \text{ ft or about 6 ft}$
	7. Total dynamic head	196 ft	Sum of Lines 5 and 6. Use this value for selection from curves in Figure 3.61. *NOTE:* Total Dynamic Head, ft/stage = 49 ft/stage. Because the pump is a 4-stage pump, we multiply 49 ft/stage by 4 stages. Thus, Total Dynamic Head, ft/stage × 4 stages = 49 ft/stage × 4 stages = 196 ft.
	8. Capacity (rate of flow)	990 GPM	
(c)	9. Laboratory efficiency	84.5%	From curves in Figure 3.61 for a total dynamic head of 49 ft/stage and a capacity (rate of flow) of 990 GPM. From a capacity of 990 GPM, draw a vertical line and from a total head of 49 ft/stage, draw a horizontal line. Where these lines meet, read the efficiency of 84.5%.
	10. Laboratory horsepower	58.0 BHP	$\text{Laboratory BHP} = \frac{\text{Line 7} \times \text{Line 8} \times 100\%}{3{,}960^* \times \text{Line 9}} = \frac{(196 \text{ ft})(990 \text{ GPM})(100\%)}{(3{,}960)(84.5\%)} = 57.98 \text{ or about } 58.0 \text{ BHP}$ $^*3{,}960 = \frac{33{,}000 \text{ ft-lb/min-HP}}{8.34 \text{ lbs/gal}}$ Where 3,960 converts ft-GPM to BHP.
	11. Shaft loss horsepower	1.58 BHP	From Table 3.14, for a shaft size of 1¼ inches and a shaft RPM of 1,760, friction is 0.79 BHP/100 ft of shaft. Shaft loss horsepower for 200 feet of shaft is 1.58 BHP.
(d)	12. Brake horsepower	59.58 BHP	Sum of Lines 10 and 11.
(e)	13. Pump field efficiency	79.7%	$\text{Pump Field Efficiency, \%} = \frac{\text{Line 5} \times \text{Line 8} \times 100\%}{3{,}960 \times \text{Line 12}} = \frac{(190 \text{ ft})(990 \text{ GPM})(100\%)}{(3{,}960)(59.58 \text{ BHP})} = 79.7\%$
(f)	14. Motor efficiency without thrust load	90%	From motor manufacturer.
	15. Input horsepower to motor without thrust bearing loss	66.2 HP	$\text{Input, HP} = \frac{\text{Line 12} \times 100\%}{\text{Line 14}} = \frac{(59.58 \text{ BHP})(100\%)}{90\%} = 66.2 \text{ HP}$
	16. Thrust bearing loss	0.42 HP	0.0075 HP per 100 RPM per 1,000 lbs thrust - - - - (g)
	17. Motor efficiency (with thrust load included)	89.4%	$\text{Motor Efficiency, \%} = \frac{\text{Line 12} \times 100\%}{\text{Line 15} + \text{Line 16}} = \frac{(59.58 \text{ BHP})(100\%)}{66.2 \text{ HP} + 0.42 \text{ HP}} = 89.4\%$
(h)	18. Overall pump efficiency	71.3%	$\text{Overall Pump Efficiency, \%} = \frac{\text{Line 13} \times \text{Line 17}}{100\%} = \frac{(79.7\%)(89.4\%)}{100\%} = 71.3\%$

(a) Discharge head or discharge pressure is zero when the pump discharges directly into the atmosphere through no more than 10 feet of horizontal discharge pipe.

(b) Total pumping head is sometimes called "field head."

(c) Caution should be exercised in adjusting the values shown on curves for the number of stages used because the values can change as the number of stages increases.

(d) This value should be used for selection of motors or gears, which should not be overloaded more than 15%

(e) Frequently called "water-to-water" efficiency.

(f) These values are normally given for full, ¾, and ½ load, but vary so little near full load that load value can be used for slight under- or overloads on the motor.

(g) Thrust bearing loss is approximate only. The values obtained should be checked against thrust bearing capacities given for motor (or gear) to avoid overload. Load is the weight of water in the column or Column Diameter × Height of Water.

(h) Frequently called "wire-to-water" efficiency.

$$\text{Wire-to-Water Efficiency, \%} = \frac{(\text{Flow, GPM})(\text{TDH, ft})(100\%)}{(\text{Voltage, volts})(\text{Current, amps})(5.308)}$$

Where 5.308 converts volts-amps to GPM-ft for the efficiency calculation.

TABLE 3.13 FRICTION LOSS TABLE FOR STANDARD PIPE COLUMN[a]

	Column Friction Loss (in feet) Per 100 Feet of Column																							
Column Size	4"			5"			6"			8"			10"				12"				14" OD			
Tube Size	1¼"	1½"	2"	1¼"	1½"	2"	1½"	2"	2½"	2"	2½"	3"	2"	2½"	3"	3½"	2"	2½"	3"	3½"	2½"	3"	3½"	4"
50[b]	.65	.86	1.6																					
75	1.3	1.7	3.3																					
100	2.2	2.8	5.3	.54	.65	.94																		
125	3.2	4.2	7.8	.81	.96	1.4																		
150	4.4	5.8		1.1	1.3	1.9																		
175	5.8	7.5		1.5	1.7	2.5																		
200	7.3	9.4		1.8	2.2	3.1	.73	.96	1.4															
225				2.3	2.7	3.9	.90	1.2	1.7															
250				2.7	3.3	4.7	1.1	1.4	2.0															
275				3.3	3.9	5.6	1.3	1.7	2.4															
300				3.8	4.5	6.4	1.5	2.0	2.8															
325				4.4	5.2	7.4	1.7	2.3	3.2															
350				5.0	6.0	8.4	2.0	2.6	3.6															
375				5.6	6.7	9.5	2.2	2.9	4.1															
400				6.3	7.5		2.5	3.3	4.6	.61	.74	1.0												
450				7.8	9.3		3.1	4.1	5.7	.77	.91	1.3												
500							3.7	5.0	6.9	.93	1.1	1.5												
550							4.4	5.8		1.1	1.3	1.8												
600							5.2	6.8		1.3	1.5	2.1												
650							6.0			1.5	1.8	2.5												
700										1.7	2.0	2.8												
750										1.9	2.3	3.2												
800										2.2	2.6	3.6	.57	.65	.77	.95								
850										2.4	2.9	4.0	.63	.72	.86	1.1								
900										2.7	3.2	4.5	.70	.80	.96	1.2								
950										2.9	3.5	4.9	.77	.88	1.1	1.3								
1000										3.2	3.9	5.4	.85	.97	1.2	1.4	.34	.38	.44	.50				
1200										4.5	5.4	7.6	1.2	1.4	1.6	2.0	.47	.54	.62	.71				
1400										6.0	7.2	10.	1.6	1.8	2.2	2.7	.62	.71	.82	.94				
1600										7.6	9.1	13.	2.0	2.3	2.8	3.4	.80	.90	1.1	1.2	.47	.53	.59	.67
1800										9.4	11.		2.5	2.8	3.4	4.3	.99	1.1	1.3	1.5	.58	.65	.73	.84
2000										11.	13.		3.0	3.5	4.2	5.2	1.2	1.4	1.6	1.8	.71	.80	.89	1.0
2200													3.6	4.1	5.0	6.1	1.4	1.6	1.9	2.1	.85	.95	1.1	1.2
2400													4.2	4.9	5.8	7.2	1.7	1.9	2.2	2.5	.99	1.1	1.2	1.4
2600													4.9	5.6	6.8	8.2	1.9	2.2	2.5	2.9	1.1	1.3	1.4	1.6
2800													5.6	6.4	7.8	9.6	2.2	2.5	2.8	3.3	1.3	1.5	1.6	1.9
3000													6.4	7.4	8.8	10.	2.5	2.9	3.3	3.8	1.5	1.7	1.9	2.1
3200																	2.8	3.2	3.7	4.3	1.7	1.9	2.1	2.4
3400																	3.2	3.6	4.2	4.8	1.9	2.1	2.4	2.7
3600																	3.5	4.0	4.7	5.3	2.1	2.4	2.6	2.9
3800																	3.9	4.4	5.1	5.9	2.3	2.6	2.9	3.3
4000																	4.3	4.9	5.6	6.4	2.5	2.9	3.2	3.6
4200																	4.7	5.3	6.2	7.1	2.8	3.1	3.5	3.9
4400																	5.1	5.8	6.7	7.7	3.0	3.4	3.8	4.3
4600																	5.6	6.3	7.4	8.4	3.3	3.7	4.1	4.6
4800																	6.0	6.8	7.9	9.0	3.5	4.0	4.4	5.0
5000																					3.8	4.3	4.8	5.4
5200																					4.2	4.7	5.2	5.9
5500																					4.6	5.1	5.7	6.4
5750																					5.0	5.5	6.2	6.9
6000																					5.4	6.0	6.7	

[a] Floway Turbine Pumps, Peabody Floway Inc., Fresno, CA.
[b] This column is flow in GPM.

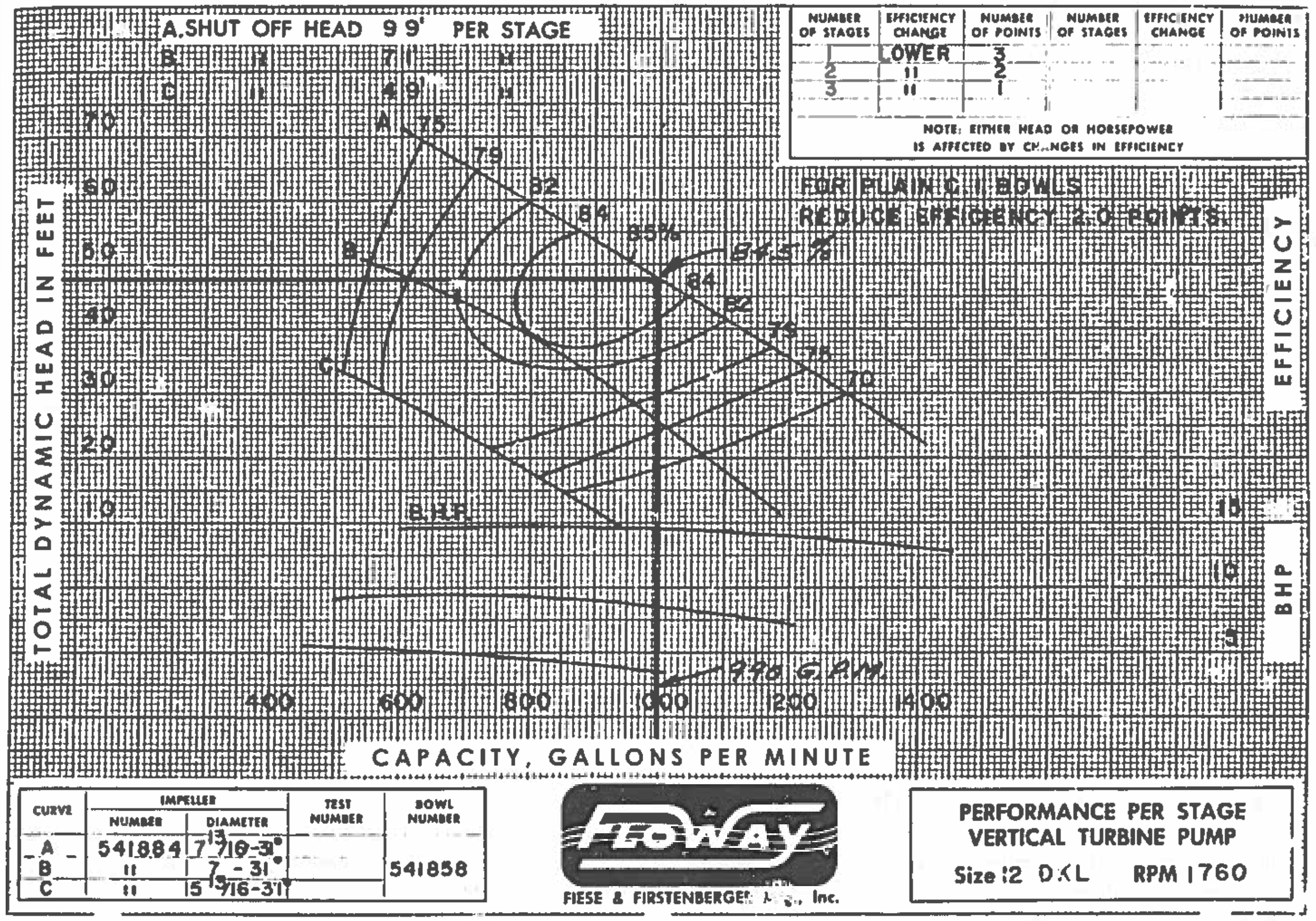


Fig. 3.61 Performance per stage for vertical turbine pump

(Permission of Peabody Floway Inc., Fresno, CA)

TABLE 3.14 MECHANICAL FRICTION IN BHP PER 100 FEET OF PUMP SHAFT[a,b]

Shaft Size, Inches	RPM of Shaft								
	3,460	2,900	1,760	1,450	1,160	960	860	720	690
¾	.60	.51	.31	.26	.20	.17			
1	1.05	.87	.53	.44	.35	.29	.26	.25	
1¼	1.60	1.33	.79	.67	.52	.44	.39	.34	
1½	2.20	1.90	1.14	.96	.74	.63	.56	.47	.44
1¾		2.50	1.50	1.25	.97	.83	.74	.64	.59
2			1.90	1.60	1.25	1.05	.95	.81	.76
2¼			2.40	2.00	1.55	1.35	1.20	1.00	.96

[a] The horsepower loss due to mechanical friction in pump column shaft rotation may be determined from the chart.
[b] Floway Turbine Pumps, Peabody Floway Inc., Fresno, CA.

3.175 Performance Values

The operator should be able to evaluate the pump performance test.

Figure 3.62 is a copy of a typical well pump test report. Using the data and computations shown on this report, we can make a good performance evaluation of this well pumping facility. Under "Remarks," the test engineer has already summarized the general conditions at this pumping facility. Two important items to consider on this report are: (1) the "Overall Pump Efficiency," and (2) the "Horsepower Input to Motor." Let us look at these two items in more detail.

1. Overall Pump Efficiency (OPE)

   The OPE is 62.8 percent and the test engineer has commented that this is fair and rightly so; a new 100 HP pumping plant would have an OPE in excess of 72 percent. This plant, at 62.8 percent, is fair but should be tested annually for a further reduction in OPE. If the OPE was between 50 and 58 percent, then you should consider replacing the pumping unit.

2. Horsepower Input to Motor

   The test engineer has noted that the motor is underloaded approximately 16 percent at 91.6 HP. If we assume that the correct bowl unit was installed at this plant, then the horsepower input should be from 100 to 110 HP. This report does not indicate if the bowl unit is a semi-open or fully enclosed impeller type. If the impeller is semi-open, then it would have been possible to adjust the impeller clearance and perhaps increase the load on the motor, which, in turn, would also raise the OPE to a higher value. If the impeller was fully enclosed, then no impeller adjustment could be made, and we would assume that the reason for the fair OPE and the 16 percent motor underload is a result of wear to the pumping unit.

Two other important factors must be considered in the overall performance evaluation of a well pumping station: (1) the frequency of use, and (2) the energy use. These two factors are interrelated and should be carefully considered before determining if pump replacement is economically justified.

1. Frequency of Use

   If the pumping station is used only to meet peak summer demands or emergencies, then an OPE rating between 50 and 55 percent may be acceptable. An OPE rating under 50 percent would qualify almost any deep well turbine pump for replacement.

   If the pumping station is a lead facility operating between 20 and 40 percent of the time, then an OPE rating of 55 to 60 percent could justify replacing the pump.

2. Energy Use

   The high cost of energy may be the major factor in determining when a pumping unit should be replaced. Using the pump values as shown on the pump test report (Figure 3.62) and the energy use data (from Table 3.15), we can estimate power consumption for various OPE ratings.

Assuming that the well pump in this report is a lead pump operating 30 percent of the time and we use OPE ratings of 72 percent (new facility), 63 percent (pump under evaluation), and 52 percent (a worn pump), then we can estimate what the annual energy use would be based on the above-mentioned OPE ratings. The calculations are as follows:

Overall Efficiency Pump Unit	Kilowatts per 1,000 Gallons at one foot TH*		Total Lift, feet		Kilowatts per 1,000 Gallons at Total Lift
72%	.00435	×	173	=	.753
63%	.00498	×	173	=	.862
52%	.00603	×	173	=	1.043

* Values from Table 3.15.

Therefore, 30 percent pumping time for 1 year (365 days × 24 hr/day × 60 min/hr × 0.30 = 157,680 minutes) × pumping rate (1,319 GPM) = 207,979,920 gallons or 207,980 thousand gallons pumped in 1 year. With the three OPE ratings we are using, we will have yearly power consumptions as follows:

(1) OPE	(2) Annual Water Production in 1,000 Gallons	(3) Kilowatts per 1,000 Gallons at Total Lift	(4) Annual Kilowatts Used*	(5) % Additional Energy Required**
72%	207,980	.753	156,609	0
63%	207,980	.862	179,279	14.48
52%	207,980	1.043	216,923	38.51

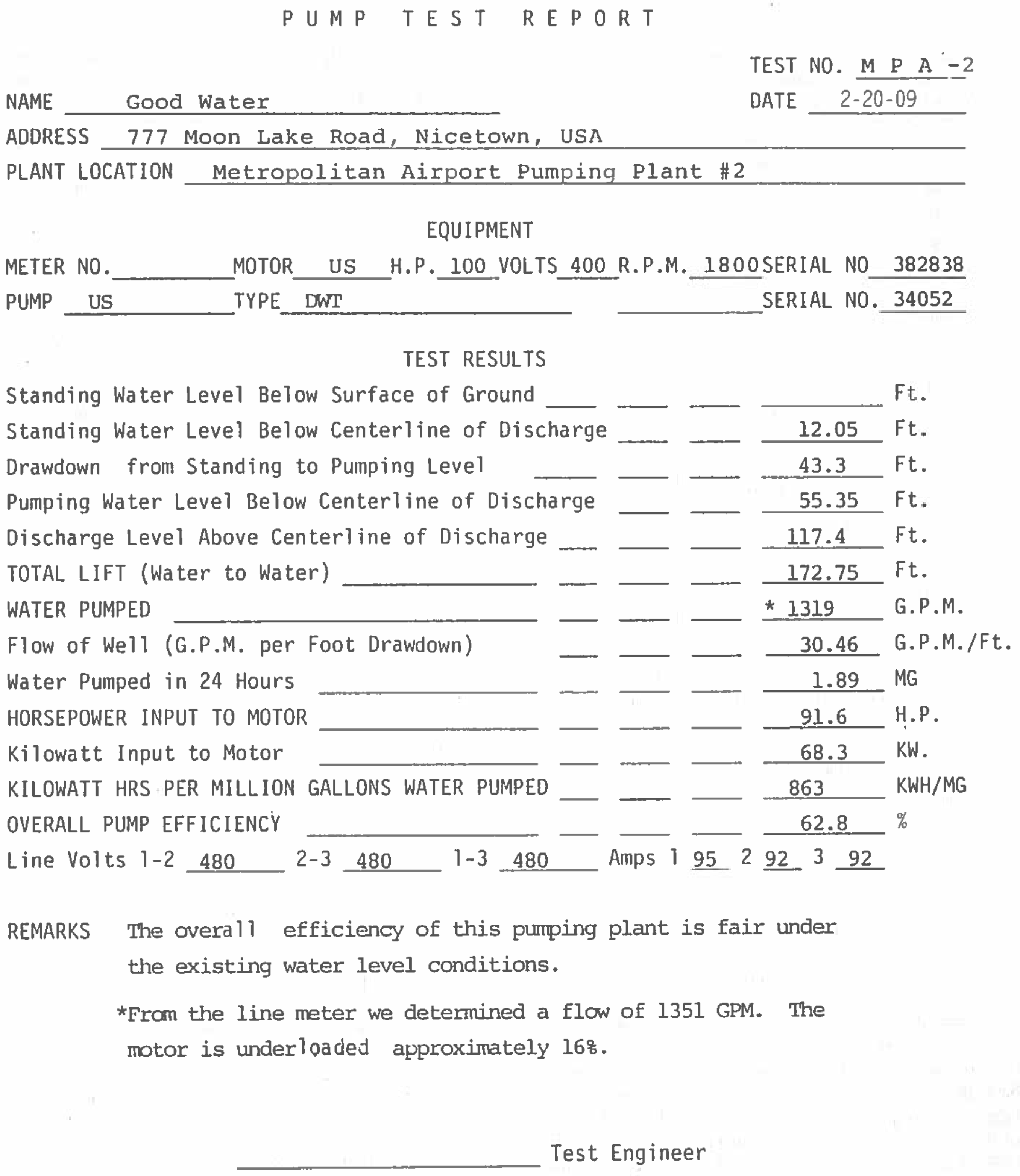
* (2)(3) = (207,980)(0.753) = 156,609

** $\frac{((4) - 156{,}609)(100\%)}{156{,}609} = \frac{(179{,}279 - 156{,}609)(100\%)}{156{,}609} = 14.48\%$

Using the values in column (5) we can see that the well pump tested in Figure 3.62 with an OPE of 63 percent will use 14.48 percent more energy than a new or reconditioned pump with an OPE of 72 percent. If the OPE drops to 52 percent, then 38.51 percent more energy would be used to pump the same amount of water. When we compare the additional energy used by a worn pump with today's high cost of energy, we can readily understand the importance of routine pump performance tests and evaluation. A good operator should be capable of evaluating well pumping plants and determining when it is economically justified to replace a worn pumping unit.

3.176 Pump Electrical

Operators of small water systems, particularly those located in rural areas, should be aware of the common but little understood problem of unbalanced current. Operating a pumping unit with unbalanced current can seriously damage three-phase motors



P U M P T E S T R E P O R T

TEST NO. M P A -2

NAME Good Water

DATE 2-20-09

ADDRESS 777 Moon Lake Road, Nicetown, USA

PLANT LOCATION Metropolitan Airport Pumping Plant #2

EQUIPMENT

METER NO. ______ MOTOR US H.P. 100 VOLTS 400 R.P.M. 1800 SERIAL NO 382838

PUMP US TYPE DWT ______ SERIAL NO. 34052

TEST RESULTS

Standing Water Level Below Surface of Ground ______ Ft.

Standing Water Level Below Centerline of Discharge 12.05 Ft.

Drawdown from Standing to Pumping Level 43.3 Ft.

Pumping Water Level Below Centerline of Discharge 55.35 Ft.

Discharge Level Above Centerline of Discharge 117.4 Ft.

TOTAL LIFT (Water to Water) 172.75 Ft.

WATER PUMPED * 1319 G.P.M.

Flow of Well (G.P.M. per Foot Drawdown) 30.46 G.P.M./Ft.

Water Pumped in 24 Hours 1.89 MG

HORSEPOWER INPUT TO MOTOR 91.6 H.P.

Kilowatt Input to Motor 68.3 KW.

KILOWATT HRS PER MILLION GALLONS WATER PUMPED 863 KWH/MG

OVERALL PUMP EFFICIENCY 62.8 %

Line Volts 1-2 480 2-3 480 1-3 480 Amps 1 95 2 92 3 92

REMARKS The overall efficiency of this pumping plant is fair under the existing water level conditions.

*From the line meter we determined a flow of 1351 GPM. The motor is underloaded approximately 16%.

______ Test Engineer

Fig. 3.62 Well pump test report

TABLE 3.15 ENERGY USE DATA[a]

Overall Efficiency Pump Unit[b]	Kilowatts per 1,000 Gallons at one foot TH	Overall Efficiency Pump Unit[b]	Kilowatts per 1,000 Gallons at one foot TH	Overall Efficiency Pump Unit[b]	Kilowatts per 1,000 Gallons at one foot TH
32	.00980	52	.00603	72	.00435
33	.00951	53	.00592	73	.00430
34	.00922	54	.00581	74	.00424
35	.00896	55	.00570	75	.00418
36	.00871	56	.00560	76	.00413
37	.00848	57	.00550	77	.00407
38	.00826	58	.00541	78	.00402
39	.00804	59	.00532	79	.00397
40	.00784	60	.00523	80	.00392
41	.00765	61	.00514	81	.00387
42	.00747	62	.00506	82	.00382
43	.00730	63	.00498	83	.00378
44	.00713	64	.00490	84	.00373
45	.00697	65	.00482	85	.00369
46	.00682	66	.00475	86	.00365
47	.00667	67	.00468	87	.00360
48	.00653	68	.00461	88	.00356
49	.00640	69	.00454	89	.00352
50	.00627	70	.00448	90	.00348
51	.00615	71	.00442		

[a] Source: *ENGINEERING DATA*, Peabody Floway Inc., Fresno, CA.

[b] Overall efficiency as indicated is the input-output efficiency including all losses in the pump unit, pumping 1,000 gallons of clear water one foot total head. Therefore, in determining the kilowatts per 1,000 gallons pumped, it is only necessary to multiply the factor corresponding to the overall efficiency by the number of feet head at which the total dynamic head has been calculated. Example:

Assume an overall efficiency of 65% and a total head of 200 feet.
Kilowatts per 1,000 gallons = .00482 × 200 = .964

and cause early motor failure. Unbalanced current reduces the starting torque of the motor and can cause overload tripping, excessive heat, vibration, and overall poor performance.

It is common practice for electrical utility companies to furnish power to three-phase customers in open delta or wye configurations. An open delta or wye system is a two-transformer bank that is a suitable configuration where lighting loads are large and three-phase loads are light. This is the exact opposite of the configuration needed by most pumping facilities where three-phase loads are large. (Examples of three-transformer banks include Y-delta, delta-Y, and Y-Y.) In most cases, three-phase motors should be fed from three-transformer banks for proper balance. The capacity of a two-transformer bank is only 57 percent of the capacity of a three-transformer bank. The two-transformer configuration can cause one leg of the three-phase current to furnish higher amperage to one leg of the motor, which will greatly shorten its life.

Operators should acquaint themselves with the configuration of their electric power supply. When an open delta or wye configuration is used, operators should calculate the degree of current imbalance existing between legs of their polyphase motors. A small percentage voltage imbalance will result in a much larger percentage current imbalance. If you are unsure about how to determine the configuration of your system or how to calculate the percentage of current imbalance, always consult a qualified electrician. Current imbalance between legs should never exceed 5 percent under normal operating conditions (NEMA Standards MGI-14.35).

Another serious consideration for operators is voltage fluctuation caused by neighborhood demands. A pump motor in near perfect balance (for example, 3 percent imbalance) at 9:00 am could be as much as 17 percent unbalanced by 4:00 pm on a hot day due to the use of air conditioners by customers on the same grid. Also, the hookup of a small market or a new home to the power grid can cause a significant change in the degree of current imbalance in other parts of the power grid. Because energy demands are constantly changing, water system operators should have a qualified electrician check the current balances between legs of their three-phase motors at least once a year.

Do not rely entirely on the power company to detect unbalanced current. Complaints of suspected power problems are frequently met with the explanation that all voltages are within the percentages allowed by law and no mention is made of the percentage of current imbalance, which can be a major source of problems with three-phase motors. A little research of your own can pay large benefits. For example, a small water company in Central California configured with an open delta system (and running three-phase imbalances as high as 17 percent as a result) was routinely spending $14,000 a year for energy and burning out a 10-HP motor on the average of every 1½ years (six 10-HP motors in 9 years). After consultation, the local power utility agreed to add a third transformer to each power board to bring the system into better balance. Pump drop leads were then rotated bringing overall current imbalances down to an average of 3 percent; heavy-duty, three-phase capacitors were added to absorb the prevalent voltage surges in the area; and computerized controls were added to the pumps to shut them off when pumping volumes got too low. These modifications resulted in a saving in energy costs the first year alone of $5,500.00.

FORMULAS

Percentage of current unbalance can be calculated by using the following formulas and procedures:

$$\text{Average Current} = \frac{\text{Total of Current Value Measured on Each Leg}}{3}$$

$$\text{\% Current Unbalance} = \frac{\text{Greatest Amp Difference from the Average}}{\text{Average Current}} \times 100\%$$

PROCEDURES

A. Measure and record current readings in amps for each leg (Hookup 1). Disconnect power.

B. Shift or roll the motor leads from left to right so the drop cable lead that was on terminal 1 is now on 2, lead on 2 is now on 3, and lead on 3 is now on 1 (Hookup 2). Rolling the motor leads in this manner will not reverse the motor rotation. Start the motor, measure and record current reading on each leg. Disconnect power.

C. Again, shift drop cable leads from left to right so the lead on terminal 1 goes to 2, 2 goes to 3, and 3 to 1 (Hookup 3). Start pump, measure and record current reading on each leg. Disconnect power.

D. Add the values for each hookup.

E. Divide the total by 3 to obtain the average.

F. Compare each single leg reading to the average current amount to obtain the greatest amp difference from the average.

G. Divide this difference by the average to obtain the percentage of unbalance.

H. Use the wiring hookup that provides the lowest percentage of unbalance.

EXAMPLE: Correcting the Three-Phase Power Unbalance

Example: Check for current unbalance for a 230-volt, 3-phase, 60-Hz submersible pump motor, 18.6 full load amps.

Solution: Steps 1 to 3 measure and record amps on each motor drop lead for Hookups 1, 2, and 3.

	Step 1 (Hookup 1)	Step 2 (Hookup 2)	Step 3 (Hookup 3)
(T_1)	DL_1 = 25.5 amps	DL_3 = 25 amps	DL_2 = 25.0 amps
(T_2)	DL_2 = 23.0 amps	DL_1 = 24 amps	DL_3 = 24.5 amps
(T_3)	DL_3 = 26.5 amps	DL_2 = 26 amps	DL_1 = 25.5 amps
Step 4	Total = 75 amps	Total = 75 amps	Total = 75 amps

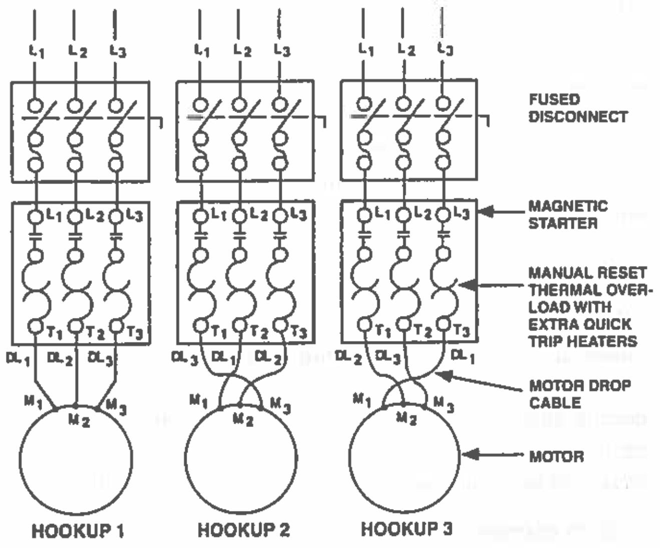
Step 5 Average Current $= \frac{\text{Total Current}}{\text{3 readings}} = \frac{75}{3} = 25$ amps

Step 6	Greatest amp difference from the average:	(Hookup 1)	= 25 − 23	= 2
		(Hookup 2)	= 26 − 25	= 1
		(Hookup 3)	= 25.5 − 25	= .5
Step 7	% Unbalance	(Hookup 1)	= 2/25 × 100	= 8
		(Hookup 2)	= 1/25 × 100	= 4
		(Hookup 3)	= 0.5/25 × 100	= 2

As can be seen, Hookup 3 should be used since it shows the least amount of current unbalance. Therefore, the motor will operate at maximum efficiency and reliability on Hookup 3.

By comparing the current values recorded on each leg, you will note the highest value was always on the same leg, L_3. This indicates the unbalance is in the power source. If the high current values were on a different leg each time the leads were changed, the unbalance would be caused by the motor or a poor connection.

If the current unbalance is greater than 5 percent, contact your power company for help.



ACKNOWLEDGMENT

Material in this section was provided by James W. Cannell, President, Canyon Meadows Mutual Water Company, Inc., Bodfish, California. His contribution is greatly appreciated.

3.18 ABANDONING AND PLUGGING WELLS

3.180 Reasons for Abandoning and Plugging

Eventually, a water well reaches the end of its useful life. Many are simply abandoned and become a safety hazard and a threat to the groundwater supply.

A well that is no longer useful must be properly abandoned and plugged:

1. To ensure that the groundwater supply is protected and preserved for further use
2. To eliminate the potential physical hazard to people
3. To protect nearby wells from contamination

Private wells that no longer serve any useful purpose should also be abandoned and plugged. When a home is connected to a public water supply, the old well could cause *CROSS CONNECTION*[66] problems if it is not adequately and permanently disconnected from the public water system.

We all have an interest in our groundwater resources and, therefore, an obligation to protect them for their present and continued use. This concept holds true whether the issue is construction or abandoning of a well.

3.181 Objectives

All abandoned wells should be properly plugged. A well could be generally classified as "abandoned" when it has not been used for a period of one year, the pumping unit has been removed, and the well serves no useful purpose. The objective of abandoning and plugging is to restore as nearly as practical, those subsurface conditions that existed prior to the construction of the well. Another important objective is to prevent the possible cross contamination between different aquifers.

3.182 Evaluation

An investigation should be made to determine the condition of the well to be abandoned and plugged, details of its construction, and whether there are obstructions or objects in the well that may hinder the filling and sealing process. Visual inspection using downhole television and photography can be very useful tools in determining the overall condition of a well.

3.183 Permits

In most cases, a permit is required before a well can be abandoned and plugged. This permit may be issued at the local, state, or federal level, and its purpose is to set forth well abandoning and plugging guidelines and inspection to ensure the protection of the groundwater basin. In certain areas, the protection of the groundwater basin is especially important.

As an example, within California alone there are 400 significant groundwater basins; of these, many have been identified as critical basins where the interchange of water between aquifers will result in a significant deterioration of the quality of water in one or more aquifers. Problem areas occur in coastal aquifers that have been invaded by sea water, and in areas where saline water underlies an area at varying depths.

3.184 Abandoning and Plugging Guidelines

Abandoning and plugging procedures and methods will vary according to whether the well is situated in: (1) unconsolidated material in an unconfined groundwater zone, (2) creviced or fractured rock, (3) noncreviced consolidated formation, or (4) where several aquifers or formations have been penetrated and an aquifer seal is required to prevent the vertical movement of water between aquifers. Some operators refer to these procedures as well destruction because they destroy the opportunity for aquifers to become contaminated and they prevent the opportunity for people and animals to fall into wells.

The enforcing agency will often establish the procedures to be followed when abandoning and plugging a well. In some cases, the water purveyor will be required to seek the advice of a geologist or a well expert to determine the appropriate methods to use.

Following this paragraph is a brief procedure for abandoning and plugging a well. This procedure reflects the desired end results and may be applicable for many old wells that are likely to be abandoned and plugged. Remember that this is a general guideline only, and that local requirements and ordinances will prevail, plus special conditions may be encountered due to the construction of the well, or the formations penetrated.

1. The well to be abandoned and plugged must be cleaned of foreign debris. This may require the use of a small drilling rig.
2. Drill out the old well to the estimated depth of its original construction, but in no case less than 100 feet (30 m).
3. With the drilling rig in position, air pump the well for two hours at its maximum capacity or at a minimum rate of 100 GPM (6 liters/sec).
4. Disinfect the well by adding a chlorine compound to produce a chlorine dose of 200 mg/*L*. If a dry chemical is used, it should be mixed with water to form a chlorine solution prior to placing it into the well.
5. Fill the well to within 25 feet (7.5 m) of ground elevation with suitable fill materials such as neat cement, cement grout, concrete, bentonite clay, or clean sand.
6. Excavate a hole around the well casing to a depth of 5 feet (1.5 m) and cut off the well casing 6 inches (150 mm) above the bottom of the excavation.
7. Fill the upper portion of the well with cement grout or concrete and allow it to spill over into the excavation to form a cap at least one foot (0.3 m) thick.
8. After the sealing material has set, fill the excavation with native soil.

See Figures 3.63, 3.64, and 3.65 for cross-sectional views of properly abandoned and plugged wells.

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[66] *Cross Connection.* (1) A connection between drinking (potable) water and an unapproved water supply. (2) A connection between a storm drain system and a sanitary collection system. (3) Less frequently used to mean a connection between two sections of a collection system to handle anticipated overloads of one system.

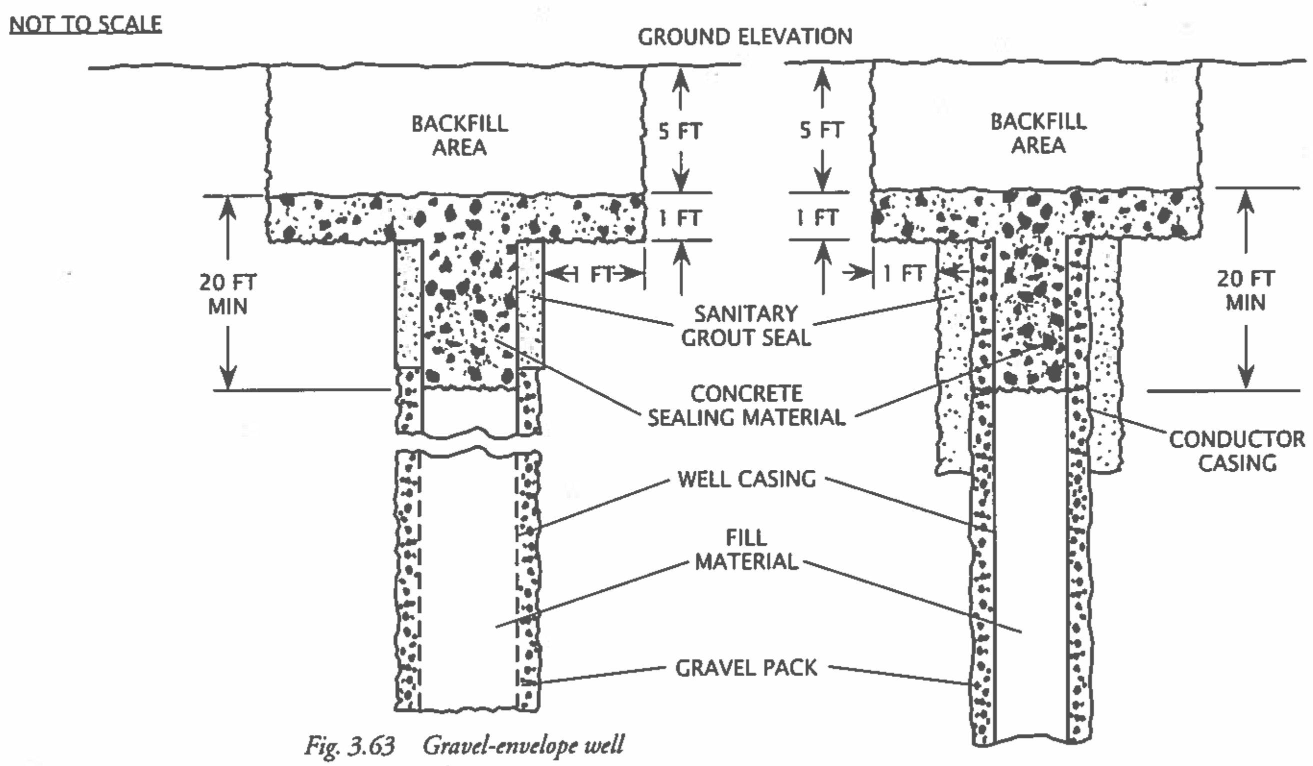

Fig. 3.63 Gravel-envelope well
No conductor casing

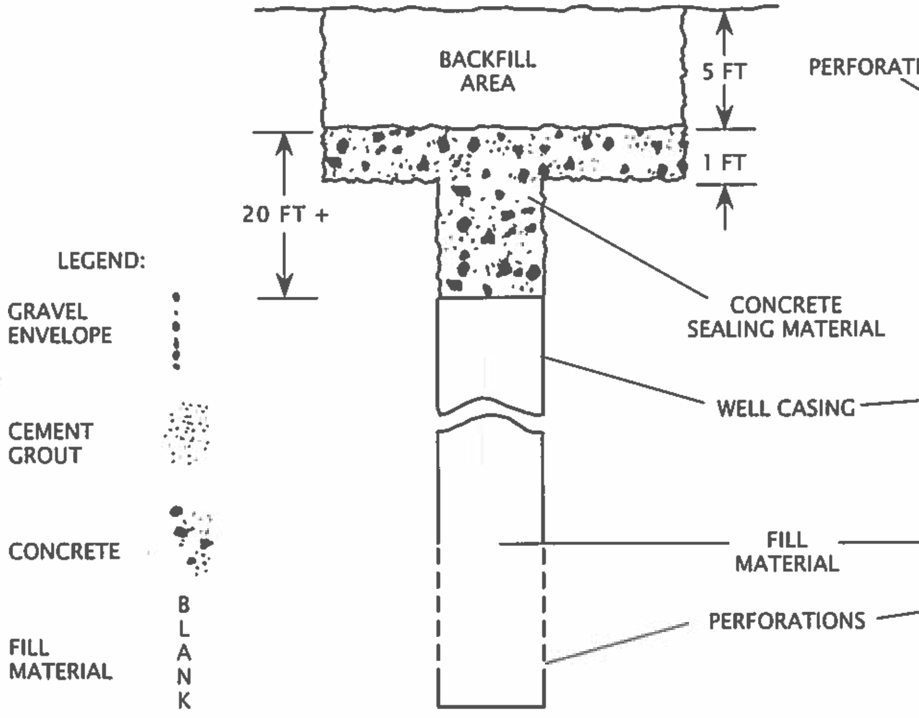

Fig. 3.64 Old cable tool well
No sanitary grout seal

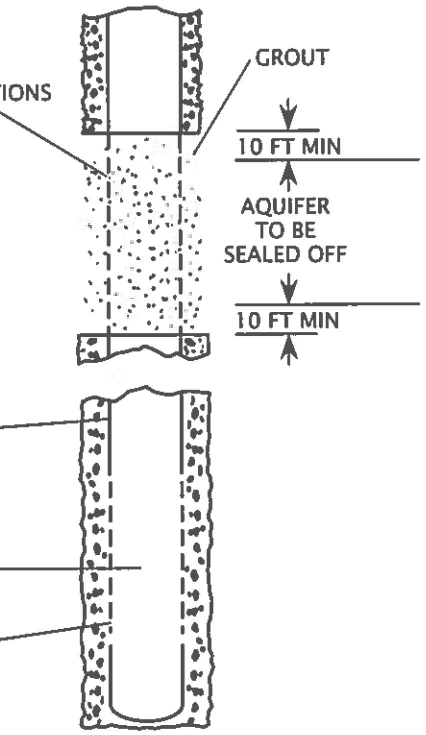

Fig. 3.65 Well with aquifer seal