PDHonline Course C546 (8 PDH)

An Introduction to Water Supply Systems

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2020

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CHAPTER 1
INTRODUCTION

1.1 PURPOSE AND SCOPE. This course provides an introduction to selecting water sources and determining water requirements for developing suitable sources of supply from ground or surface sources.

1.2 APPLICABILITY. These guidelines are applicable to the selection of water sources and planning and designing supply systems.

1.3 REFERENCES. There are many professional references available in the literature to engineers interested in water supply principles and practices.

1.4 DEFINITIONS.

1.4.1 GENERAL DEFINITIONS. The following are general definitions relating to water supplies.

1.4.1.1 WATER WORKS. All construction (structures, pipe, equipment) required for the collection, transportation, pumping, treatment, storage and distribution of water.

1.4.1.2 SUPPLY WORKS. Dams, impounding reservoirs, intake structures, pumping stations, wells and all other construction required for the development of a water supply source.

1.4.1.3 SUPPLY LINE. The pipeline from the supply source to the treatment works or distribution system.

1.4.1.4 TREATMENT WORKS. All basins, filters, buildings and equipment for the conditioning of water to render it acceptable for a specific use.

1.4.1.5 DISTRIBUTION SYSTEM. A system of pipes and appurtenances by which water is provided for domestic and industrial use and fire fighting.

1.4.1.6 FEEDER MAINS. The principal pipelines of a distribution system.

1.4.1.7 DISTRIBUTION MAINS. The pipelines that constitute the distribution system.

1.4.1.8 SERVICE LINE. The pipeline extending from the distribution main to building served.

1.4.1.9 EFFECTIVE POPULATION. This includes resident personnel plus an allowance for nonresident personnel, derived as follows: The design allowance for nonresidents is 190 L (50 gal)/person/day whereas that for residents is 570 L (150 gal)/person/day. Therefore, an "effective-population" value can be obtained by adding one-third of the population figure for nonresidents to the figure for residents.

Effective Population = (Nonresident Population/3) + Resident Population

1.4.1.10 CAPACITY FACTOR. The multiplier which is applied to the effective population figure to provide an allowance for reasonable population increase, variations in water demand, uncertainties as to actual water requirements, and for unusual peak demands whose magnitude cannot be accurately estimated in advance. The Capacity Factor varies inversely with the magnitude of the population in the water service area.

1.4.1.11 DESIGN POPULATION. The population figure obtained by multiplying the effective-population figure by the appropriate capacity factor.

Design Population = Effective Population x Capacity Factor

1.4.1.12 REQUIRED DAILY DEMAND. The total daily water requirement. Its value is obtained by multiplying the design population by the appropriate per capita domestic water allowance and adding to this quantity any special industrial, aircraft-wash, irrigation, air-conditioning, or other demands. Other demands include the amount necessary to replenish in 48 hours the storage required for fire protection and normal operation. Where the supply is from wells, the quantity available in 48 hours of continuous operation of the wells will be used in calculating the total supply available for replenishing storage and maintaining fire and domestic demands and industrial requirements that cannot be curtailed.

1.4.1.13 PEAK DOMESTIC DEMAND. For system design purposes, the peak domestic demand is considered to be the greater of—

- Maximum day demand, i.e., 2.5 times the required daily demand.
- The fire flow plus fifty percent of the required daily demand.

1.4.1.14 FIRE FLOW. The required number of L/min (gal/min) at a specified pressure at the site of the fire for a specified period of time.

1.4.1.15 FIRE DEMAND. The required rate of flow of water in L/min (gal/min) during a specified fire period. Fire demand includes fire flow plus 50 percent of the required daily demand and, in addition, any industrial or other demand that cannot be reduced during a fire period. The residual pressure is specified for either the fire flow or essential industrial demand, whichever is higher. Fire demand must include flow required for automatic sprinkler and standpipe operation, as well as direct hydrant flow demand, when the sprinklers are served directly by the water supply system.

1.4.1.16 RATED CAPACITY. The rated capacity of a supply line, intake structure, treatment plant or pumping unit is the amount of water which can be passed through the unit when it is operating under design conditions.

1.4.1.17 CROSS CONNECTION. Two types recognized are:

- A direct cross connection is a physical connection between a supervised, potable water supply and an unsupervised supply of unknown quality. An example of a direct cross connection is a piping system connecting a raw water supply, used for industrial fire fighting, to a municipal water system.

- An indirect cross connection is an arrangement whereby unsafe water, or other liquid, may be blown, siphoned or otherwise diverted into a safe water system. Such arrangements include unprotected potable water inlets in tanks, toilets, and lavatories that can be submerged in unsafe water or other liquid. Under conditions of peak usage of potable water or potable water shutoff for repairs, unsafe water or other liquid may backflow directly or be back-siphoned through the inlet into the potable system. Indirect cross connections are often termed "backflow connections" or "back-siphonage connections." An example is a direct potable water connection to a sewage pump for intermittent use for flushing or priming.

1.4.2 GROUND WATER SUPPLY DEFINITIONS. The meanings of several terms used in relation to wells and ground waters are as follows:

1.4.2.1 SPECIFIC CAPACITY. The specific capacity of a well is its yield per foot of drawdown and is commonly expressed as liters per minute per meter (Lpm/m) of drawdown (gpm/ft).

1.4.2.2 VERTICAL LINE SHAFT TURBINE PUMP. A vertical line shaft turbine pump is a centrifugal pump, usually having from 1 to 20 stages, used in wells. The pump is located at or near the pumping level of water in the well, but is driven by an electric motor or internal combustion engine on the ground surface. Power is transmitted from the motor to the pump by a vertical drive shaft.

1.4.2.3 SUBMERSIBLE TURBINE PUMP. A submersible turbine pump is a centrifugal turbine pump driven by an electric motor which can operate when submerged in water.

The motor is usually located directly below the pump intake in the same housing as the pump. Electric cables run from the ground surface down to the electric motor.

CHAPTER 2
WATER REQUIREMENTS

2.1 DOMESTIC REQUIREMENTS. The per-capita allowances, given in table 2-1 are *illustrative only* of domestic water requirements. These allowances do not include special purpose water uses, such as industrial, commercial, institutional, air-conditioning, and irrigation.

Table 2-1
Illustrative Domestic Water Allowance

Use	Liters/Capita/Day	Gallons/Capita/Day
Residential	570	150
Hospitals	2300/bed	600/bed
Hotels	260	70
Industrial/Commercial	190/employee/8-hour shift	50/employee/8-hour shift

2.2 FIRE-FLOW REQUIREMENTS. The system must be capable of supplying the fire flow specified plus any other demand that cannot be reduced during the fire period at the required residual pressure and for the required duration. The requirements of each system must be analyzed to determine whether the capacity of the system is fixed by the domestic requirements, by the fire demands, or by a combination of both. Where fire-flow demands are relatively high, or required for long duration, and population and/or industrial use is relatively low, the total required capacity will be determined by the prevailing fire demand. In some exceptional cases, this may warrant consideration of a special water system for fire purposes, separate, in part or in whole, from the domestic system. However, such separate systems will be appropriate only under exceptional circumstances and, in general, are to be avoided.

2.3 IRRIGATION. The allowances indicated in table 2-1 include water for limited watering or planted and grassed areas. However, these allowances do not include major lawn or other irrigation uses. Lawn irrigation provisions for facilities, such as family quarters and temporary structures, in all regions will be limited to hose bibs on the outside of buildings and risers for hose connections. Where substantial irrigation is deemed necessary and water is available, underground sprinkler systems may be considered. In general, such systems should receive consideration only in arid or semiarid areas where rainfall is less than about 635 mm (25 in) annually.

2.3.1 BACKFLOW PREVENTION. Backflow prevention devices, such as a vacuum breaker or an air gap, will be provided for all irrigation systems connected to potable water systems. Installation of backflow preventers will be in accordance with the applicable local plumbing code. Single or multiple check valves are not acceptable backflow prevention devices and will not be used. Direct cross connections between potable and nonpotable water systems will not be permitted under any circumstances.

2.3.2 USE OF TREATED WASTEWATER. Effluent from wastewater treatment plants can be used for irrigation when authorized. Only treated effluent having a detectable chlorine residual at the most remote discharge point will be used. Where state or local regulations require additional treatment for irrigation, such requirement will be complied with. The effluent irrigation system must be physically separated from any distribution systems carrying potable water. A detailed plan will be provided showing the location of the effluent irrigation system in relation to the potable water distribution system and buildings. Provision will be made either for locking the sprinkler irrigation control valves or removing the valve handles so that only authorized personnel can operate the system. In addition, readily identifiable "nonpotable" or "contaminated" notices, markings or codings for wastewater conveyance facilities and appurtenances will be provided. Another possibility for reuse of treated effluent is for industrial operations where substantial volumes of water for washing or cooling purposes are required.
For any re use situation, great care must be exercised to avoid direct cross connections between the reclaimed water system and the potable water system.

CHAPTER 3
CAPACITY OF WATER SUPPLY SYSTEM

3.1 CAPACITY FACTORS. Capacity factors, as a function of "Effective Population" are shown in table 3-1, as follows:

Table 3-1
Capacity Factors

Effective Population	Capacity Factors
5,000 or less	1.50
5,001 to 10,000	1.50
10,001 to 20,000	1.25
20,001 to 30,000	1.15
30,001 to 40,000	1.10
40,001 to 50,000	1.05
50,001 or more	1.00

3.2 USE OF CAPACITY FACTOR. The "Capacity Factor" will be used in planning water supplies for all projects, including general hospitals. The proper "Capacity Factor" as given in table 3-1 is multiplied by the "Effective Population" to obtain the "Design Population." Arithmetic interpolation should be used to determine the appropriate Capacity Factor for intermediate project population. (For example, for an "Effective Population" of 7,200 in interpolation, obtain a "Capacity Factor" of 1.39.) Capacity factors will be applied in determining the required capacity of the supply works, supply lines, treatment works, principal feeder mains and storage reservoirs. Capacity factors will NOT be used for hotels and similar structures. Capacity factors will NOT be applied to fire flows, irrigation requirements, or industrial demands.

3.3 SYSTEM DESIGN CAPACITY. The design of elements of the water supply system, except as noted, should be based on the "Design Population."

3.4 SPECIAL DESIGN CAPACITY. Where special demands for water exist, such as those resulting from unusual fire fighting requirements, irrigation, industrial processes and cooling water usage, consideration must be given to these special demands in determining the design capacity of the water supply system.

3.5 EXPANSION OF EXISTING SYSTEMS. Few, if any, entirely new water supply systems will be constructed. Generally, the project will involve upgrading and/or expansion of existing systems. Where existing systems are adequate to supply existing demands, plus the expansion proposed without inclusion of the Capacity Factor, no additional facilities will be provided except necessary extension of water mains. In designing main extensions, consideration will be given to planned future development in adjoining areas so that mains will be properly sized to serve the planned developments. Where existing facilities are inadequate for current requirements and new construction is necessary, the Capacity Factor will be applied to the proposed total Effective Population and the expanded facilities planned accordingly.

CHAPTER 4
WATER SUPPLY SOURCES

4.1 GENERAL. Water supplies may be obtained from surface or ground sources, by expansion of existing systems, or by purchase from other systems. The selection of a source of supply will be based on water availability, adequacy, quality, cost of development and operation and the expected life of the project to be served. In general, all alternative sources of supply should be evaluated to the extent necessary to provide a valid assessment of their value for a specific installation. Alternative sources of supply include purchase of water as well as consideration of development or expansion of independent ground and surface sources. A combination of surface and ground water, while not generally employed, may be advantageous under some circumstances and should receive consideration. Economic, as well as physical, factor must be evaluated. The final selection of the water source will be determined by feasibility studies, considering all engineering, economic, energy and environmental factors.

4.2 USE OF EXISTING SYSTEMS. Most water supply projects involve expansion or upgrading of existing supply works rather than development of new sources. If there is an existing water supply, thorough investigation will be made to determine its capacity and reliability and the possible arrangements that might be made for its use with or without enlargement. The economics of utilizing the existing supply should be compared with the economics of reasonable alternatives. If the amount of water taken from an existing source is to be increased, the ability of the existing source to supply estimated water requirements during drought periods must be fully addressed. Also, potential changes in the quality of the raw water due to the increased rate of withdrawal must receive consideration.

4.3 OTHER WATER SYSTEMS. If the development is located near a municipality or other public or private agency operating a water supply system, this system should be investigated to determine its ability to provide reliable water service to the installation at reasonable cost. The investigation must consider future as well as current needs of the existing system and, in addition, the impact of the military project on the water supply requirements in the existing water service area. Among the important matters that must be considered are: quality of the supply; adequacy of the supply during severe droughts; reliability and adequacy of raw water pumping and transmission facilities; treatment plant and equipment; high service pumping; storage and distribution facilities; facilities for transmission from the existing supply system, and costs. In situations where a long supply line is required between the existing supply and the installation, a study will be made of the economic size of the pipeline, taking into consideration cost of construction, useful life, cost of operation, and minimum use of materials. A further requirement is an assessment of the adequacy of management, operation, and maintenance of the public water supply system.

4.4 ENVIRONMENTAL CONSIDERATION. Environmental policies, objectives, and guidelines must be observed.

4.5 WATER QUALITY CONSIDERATIONS. Guidelines for determining the adequacy of a potential raw water supply for producing an acceptable finished water supply with conventional treatment practices must be observed.

4.5.1 HARDNESS. The hardness of water supplies is classified as shown in table 4-1.

Table 4-1
Water Hardness Classification

Total Hardness (mg/L as $CaCO_3$)	Classification
0-100	Very Soft to Soft
100-200	Soft to Moderately Hard
200-300	Hard to Very Hard
Over 300	Extremely Hard

Softening is generally considered when the hardness exceeds about 200 to 250 mg/L. While hardness can be reduced by softening treatment, this may significantly increase the sodium content of the water, where zeolite softening is employed, as well as the cost of treatment.

4.5.2 TOTAL DISSOLVED SOLIDS (TDS). In addition to hardness, the quality of ground water may be judged on the basis of dissolved mineral solids. In general, dissolved solids should not exceed 500 mg/L, with 1,000 mg/L as the approximate upper limit.

4.5.3 CHLORIDE AND SULFATE. Sulfate and chloride cannot be removed by conventional treatment processes and their presence in concentrations greater than about 250 mg/L reduces the value of the supply for domestic and industrial use and may justify its rejection if development of an alternative source of better quality is feasible. Saline water conversion systems, such as electrodialysis or reverse osmosis, are required for removal of excessive chloride or sulfate and also certain other dissolved substances, including sodium and nitrate.

4.5.4 OTHER CONSTITUENTS. The presence of certain toxic heavy metals, fluoride, pesticides, and radioactivity in concentrations exceeding recognized standards, will make rejection of the supply mandatory unless unusually sophisticated treatment is provided.

4.5.5 WATER QUALITY DATA. Water quality investigations or analysis of available data at or near the proposed point of diversion should include biological, bacteriological, physical, chemical, and radiological parameters covering several years and reflecting seasonal variations. Sources of water quality data are local records, U.S. Geological Survey District or Regional offices and Water Quality Laboratories, U.S. Environmental Protection Agency regional offices, state geological surveys, state water resources agencies, state and local health departments, and nearby water utilities, including those serving power and industrial plants, which utilize the proposed source. Careful study of historical water quality data is usually more productive than attempting to assess quality from analysis of a few samples, especially on streams. Only if a thorough search fails to locate existing, reliable water quality data should a sampling program be initiated. If such a program is required, the advice and assistance of an appropriate state water agency will be obtained. Special precautions are required to obtain representative samples and reliable analytical results. Great caution must be exercised in interpreting any results obtained from analysis of relatively few samples.

4.5.6 CHECKLIST FOR EXISTING SOURCES OF SUPPLY. The following items, as well as others, if circumstances warrant, will be covered in the investigation of existing sources.

- Quality history of the supply; estimates of future quality.
- Permits from regulating authorities and compliance history.
- Description of source.
- Water rights.
- Reliability of supply.
- Quantity now developed.
- Ultimate quantity available.
- Excess supply not already allocated.
- Raw water pumping and transmission facilities.

- Treatment works.
- Treated water storage.
- High service pumping and transmission facilities.
- Rates in gal/min at which supply is available.
- Current and estimated future cost per 1,000 gallons.
- Current and estimated future cost per 1,000 gallons of water from alternative sources.
- Distance from installation site to existing supply.
- Pressure variations at point of diversion from existing system.
- Ground elevations at points of diversion and use
- Energy requirements for proposed system.
- Sources of pollution, existing and potential.
- Assessment of adequacy of management, operation, and maintenance.
- Modifications required to meet additional water demands resulting from supplying water system expansion

CHAPTER 5
GROUND WATER SUPPLIES

5.1 GENERAL. Ground water is subsurface water occupying the zone of saturation. A water bearing geologic formation which is composed of permeable rock, gravel, sand, earth, etc., and yields water in sufficient quantity to be economical is called an aquifer. Unconfined water is found in aquifers above the first impervious layer of soil or rock. This zone is often referred to as the water table. Water infiltrates by downward percolation through the air-filled pore spaces of the overlying soil material. The water table is subjected to atmospheric and climatic conditions, falling during periods of drought or rising in response to precipitation and infiltration*.* A confined aquifer is defined as the aquifer underlying an impervious bed. Areas of infiltration and recharge are often some distance away from the point of discharge. This water is often referred to as being under artesian conditions. When a well is installed into an artesian aquifer, the water in the well will rise in response to atmospheric pressure in the well. The level to which water rises above the top of the aquifer represents the confining pressure exerted on the aquifer. Materials with interconnecting pore spaces such as unconsolidated formations of loose sand and gravel may yield large quantities of water and, therefore, are the primary target for location of wells. Dense rocks such as granite from poor aquifers and wells constructed in them do not yield large quantities of water. However, wells placed in fractured rock formations may yield sufficient water for many purposes.

5.1.1 ECONOMY. The economy of ground water versus surface water supplies needs to be carefully examined. The study should include an appraisal of operating and maintenance costs as well as capital costs. No absolute rules can be given for choosing between ground and surface water sources. Where water requirements are within the capacity of an aquifer, ground water is nearly always more economical than surface water. The available yield of an aquifer dictates the number of wells required and thus the capital costs of well construction. System operating and maintenance costs will depend upon the number of wells. In general, groundwater capital costs include the wells, disinfection, pumping, and storage with a minimum of other treatment. Surface water supply costs include intake structures, sedimentation, filtration, disinfection, pumping, and storage. Annual operating costs include the costs of chemicals for treatment, power supply, utilities, and maintenance. Each situation must be examined on its merits with due consideration for all factors involved.

5.1.2 COORDINATION WITH STATE AND LOCAL AUTHORITIES. Some States require that a representative of the state witness the grouting of the casing and collect an uncontaminated biological sample before the well is used as a public water supply. Some States require a permit to withdraw water from the well and limit the amount of water that can be withdrawn. All wells and well fields must be located and designed in accordance with State Well Head Protection Programs and the Safe Drinking Water Act.

5.1.3 ARCTIC WELL CONSIDERATIONS. Construction of wells in arctic and subarctic areas requires special considerations. The water must be protected from freezing and the permafrost must be maintained in a frozen state.

5.2 WATER AVAILABILITY EVALUATION. After the projected water demand and proposed usage use have been determined, the next step is to evaluate the quality of available water resources. The quality of the groundwater will be influenced by its ph or corrosivity; and the presence of constituents such as iron, lead, calcium, zinc, and gasses such as carbon dioxide, nitrogen, oxygen, and sulphur dioxide. Recommended quality standards for domestic and municipal water are published by the US Environmental Protection Agency***.*** Step-by-step procedures are illustrated in figure 5.1***.***

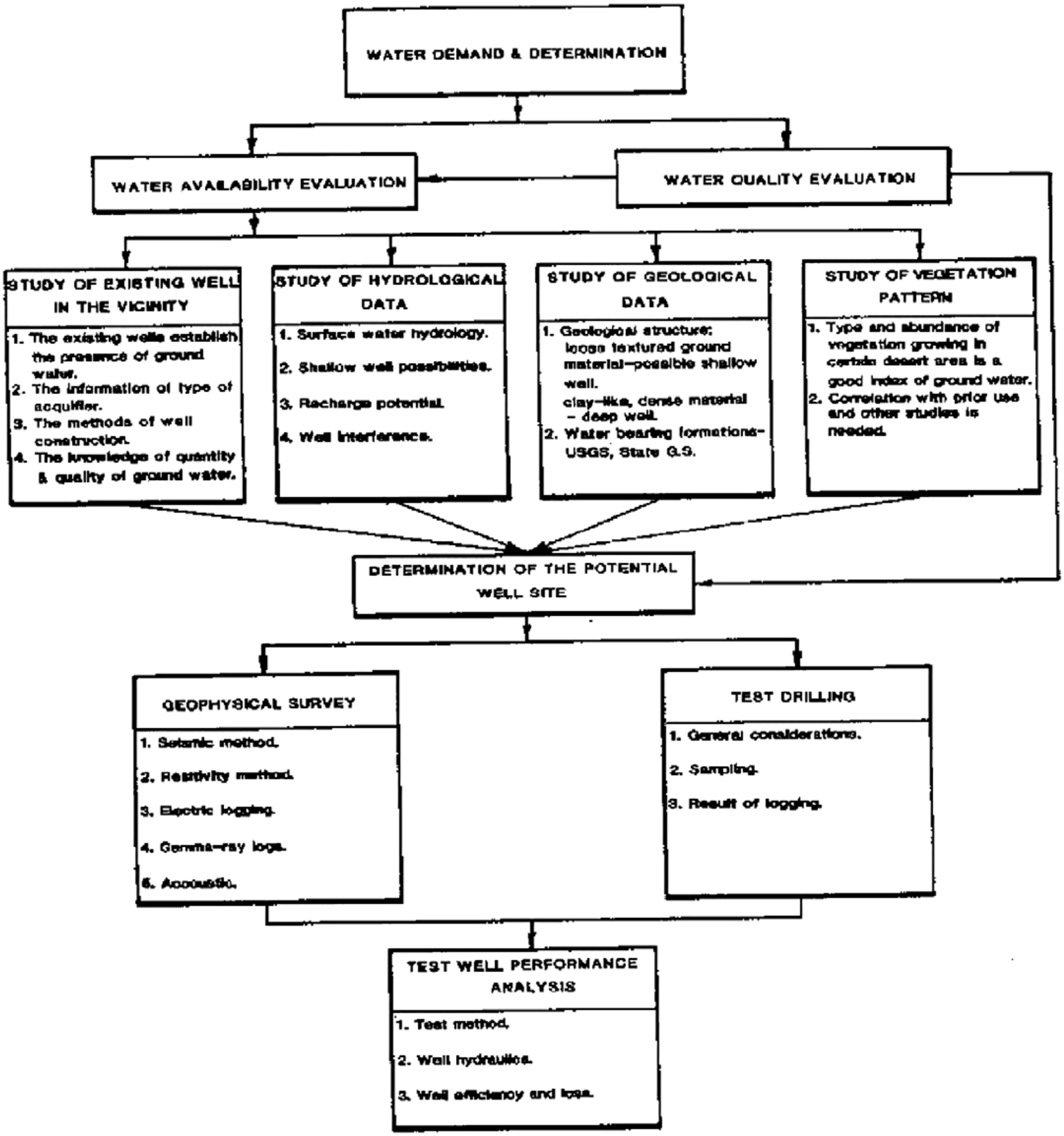

Figure 5-1

Water Availability Evaluation

5.3 TYPES OF WELLS AND CONSTRUCTION METHODS.

5.3.1 CONSTRUCTION METHODS. Wells are constructed by a variety of methods. There is no single optimum method; the choice depends on the purpose of the well, size, depth, formations being drilled through, experience of local well contractors, and cost. The most common methods of installing wells are compared in table 5-1. The performance of different drilling methods in different formations is given in "Groundwater and Well." The most common type of small diameter well is the driven well.

Type	Diameter	Maximum Depth (ft)	Lining or Casing	Suitability	Disadvantages	Method of Construction
Dug	3 to 30 feet	40	wood, masonry, concrete or metal	Water near surface. May be constructed with hand tools.	Large number of manhours required for construction. Hazard to diggers.	Excavation from within well.
Driven	2 to 4 inches	50	pipe	Simple using hand tools.	Formations must be soft and boulder free.	Hammering a pipe into the ground.
Jetted	3 or 4 inches	200	pipe	Small dia. wells on sand.	Only possible in loose sand formations.	High pressure water pumped through drill pipe.
Bored	up to 36 inches	50	pipe	Useful in clay formations.	Difficult on loose sand or cobbles.	Rotating earth auger bracket.
Collector	15 feet	130	Reinforced concrete caisson	Used adjacent to surface recharge source such as river, lake or ocean.	Limited number of Installation Contractors	Caisson is sunk into aquifer. Preformed radial pipes are jacked horizontally through ports near bottom.
Drilled	Up to 60 inches	4000	pipe	Suitable for variety of formations.	Requires experienced Contractor & specialized tools.	a. Hydraulic rotary* b. Cable tool percussion* c. reverse circulation rotary d. hydraulic–percussion e. air rotary

Table 5-1

Types and Methods of Well Installation

5.3.2 SPECIAL CONSIDERATIONS. In some geologic environments, the aquifer may be too thin or for some other reason is unable to provide the required quantity of water to a standard vertical well. In such instances, it may be economical to install collector wells. A collector well is typically constructed with a large caisson having one or more horizontal screens extending into the saturated zone (figure 5-2). The caisson can be used as a storage tank. The disadvantage of this system is that collector wells are more expensive than standard vertical wells.

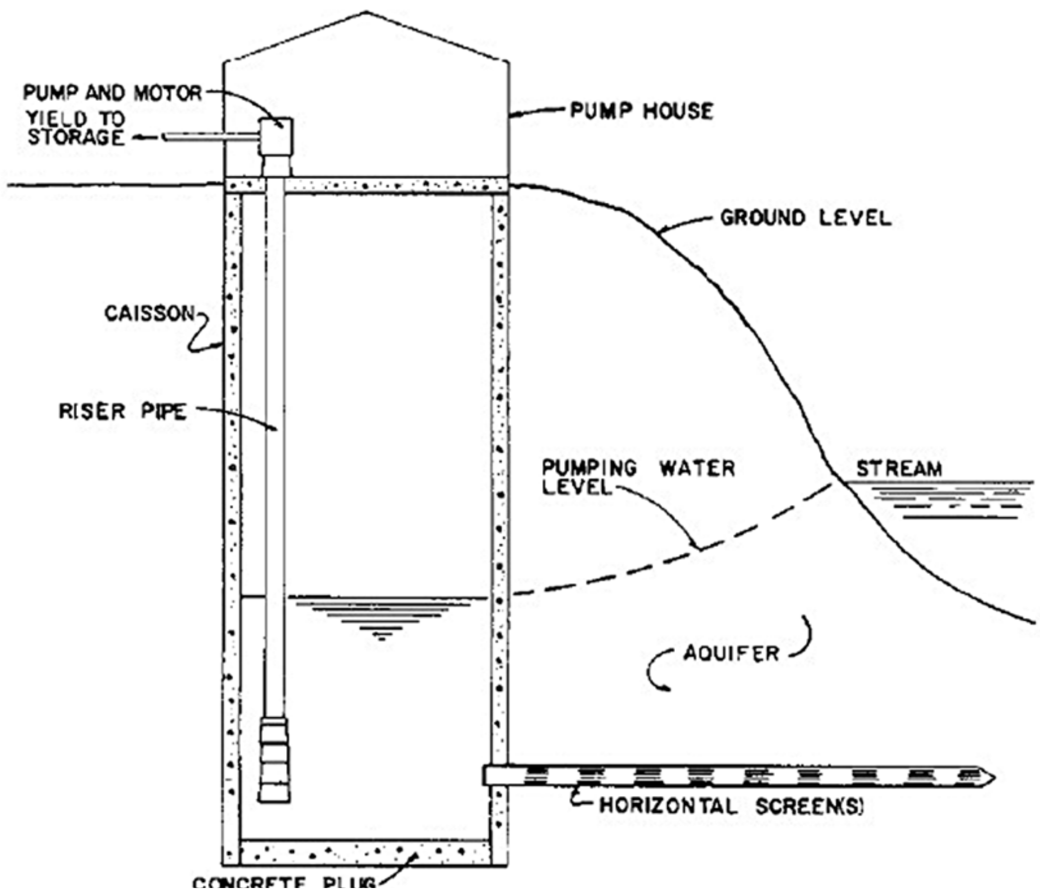

Figure 5-2

Collector Well

5.4 WATER QUALITY EVALUATION. Both well location and method of construction are of major importance in protecting the quality of water derived from a well.

Groundwater may become contaminated as a result of leakage from sources as diverse as improperly sealed wells, septic tanks, garbage dumps, industrial and animal wastes.

5.4.1 SELECTION OF A WELL SITE. Prior to selecting the well location, a thorough survey of the area should be undertaken. The following information should be obtained and analyzed:

5.4.1.1 Local hydro geology such as terrain, soil type, depth, and thickness of water bearing zone.

5.4.1.2 Location, construction, and disposal practices of nearby sewage and industrial facilities.

5.4.1.3 Locations of sewers, septic tanks, cesspools, animal farms, pastures, and feed lots.

5.4.1.4 Chemical and bacteriological quality of ground water, especially the quality of water from nearby wells.

5.4.1.5 Histories of water, oil, and gas well exploration and development in area.

5.4.1.6 Location and operating practices of nearby industrial and municipal landfills and dumps.

5.4.1.7 Direction and rate of travel of ground water. Recommended minimum distances for well sites from commonly encountered potential sources of pollution are shown in table 5-2. It is emphasized that these are minimum distances which can serve as rough guides for locating a well from a potential source of groundwater contamination. The distance may be greater, depending on the geology of the area. In general, very fine sand and silt filter contaminants in ground water better than limestone, fractured rock, coarse sand and gravel. Chemical contaminants may persist indefinitely in untreated groundwater. If at all possible, a well should be located up gradient of any known nearby or potential sources of contamination. It is a good practice to consult local authorities for aid in establishing safe distances consistent with the subsurface geology of the area. Dry wells should be abandoned and plugged in conformance to local regulations.

Table 5-2
Minimum Distances from Pollution Sources

Source	Minimum Horizontal Distance	
	Meters	Feet
Building Sewer	15	50
Disposal Field/Septic Tank	30	100
Seepage Pit	30	100
Dry Well	15	50
Cesspool/leaching pits	45	150

Note: The above minimum horizontal distances apply to wells at all depths. Greater distances are recommended when feasible.

5.4.2 SAMPLING AND ANALYSIS. It is mandatory to review the stipulations contained in the current U.S. Environmental Protection Agency's drinking water standards and state/local regulations and to collect and chemically analyze samples as required for the determination of all constituents named in the drinking water standards. Heavy metals and arsenic are rarely encountered in significant concentrations in natural ground waters, however, they may be of concern in areas with metamorphic rock. Radioactive minerals may cause occasional high readings in granite wells.

5.5 WELL HYDRAULICS.

5.5.1 DEFINITIONS. The following definitions are necessary to an understanding of well hydraulics:

5.5.1.1 STATIC WATER LEVEL. The distance from the ground surface to the water level in a well when no water is being pumped.

5.5.1.2 PUMPING LEVEL. The distance from the ground surface to the water level in a well when water is being pumped. Also called dynamic water level.

5.5.1.3 DRAWDOWN. The difference between static water level and pumping water level.

5.5.1.4 CONE OF DEPRESSION. The funnel shape of the water surface or piezometric level which is formed as water is withdrawn from the well.

5.5.1.5 RADIUS OF INFLUENCE. The distance from the well to the edge of the cone of depression.

5.5.1.6 PERMEABILITY. The ease of which water moves through the rock or sediment.

5.5.1.7 HYDRAULIC CONDUCTIVITY. Also called coefficient of permeability. The rate at which water moves through the formation (gallons per day per square foot. It is governed by the size and shape of the pore spaces.

5.5.2 WELL DISCHARGE FORMULAS. The following formulas assume certain simplifying conditions. However, these assumptions do not severely limit the use of the formulas. The aquifer is of constant thickness, is not stratified and is of uniform permeability. The piezometric surface is level, laminar flow exists and the cone of depression has reached equilibrium. The pumping well reaches the bottom of the aquifer and is 100 percent efficient. There are two basic formulas (Ground Water and

Wells) one for water table wells and one for artesian wells. Figure 5-3 shows the relationship of the terms used in the following formula for available yield from a water table well.

$$Q = \frac{K(H^2 - h^2)}{1055 \log (R/r)} \qquad \text{(eq. 5-1)}$$

where:

Q = pumping rate in gpm

K = hydraulic conductivity of water bearing unit in gpd/ft2

H = static head from bottom of aquifer in feet.

h = pumping head from bottom of aquifer in feet

R = radius of influence in feet

r = radius of well in feet

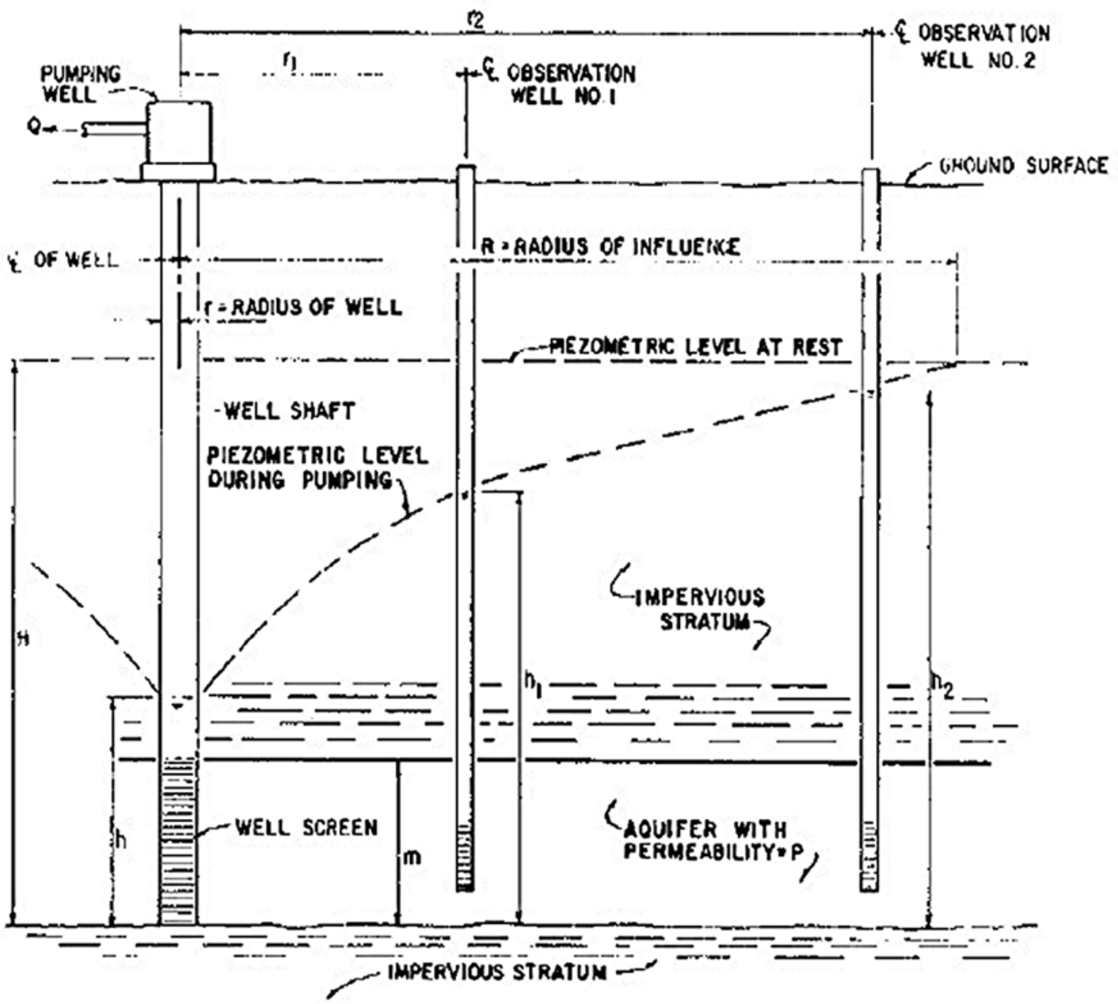

Figure 5-3

Diagram of Water Table Well (unconfined aquifer)

In an artesian aquifer, the water-bearing formation is confined between the two impervious strata. Figure 5-4 shows the relationship of the terms used in the following formula for available yield from an artesian well:

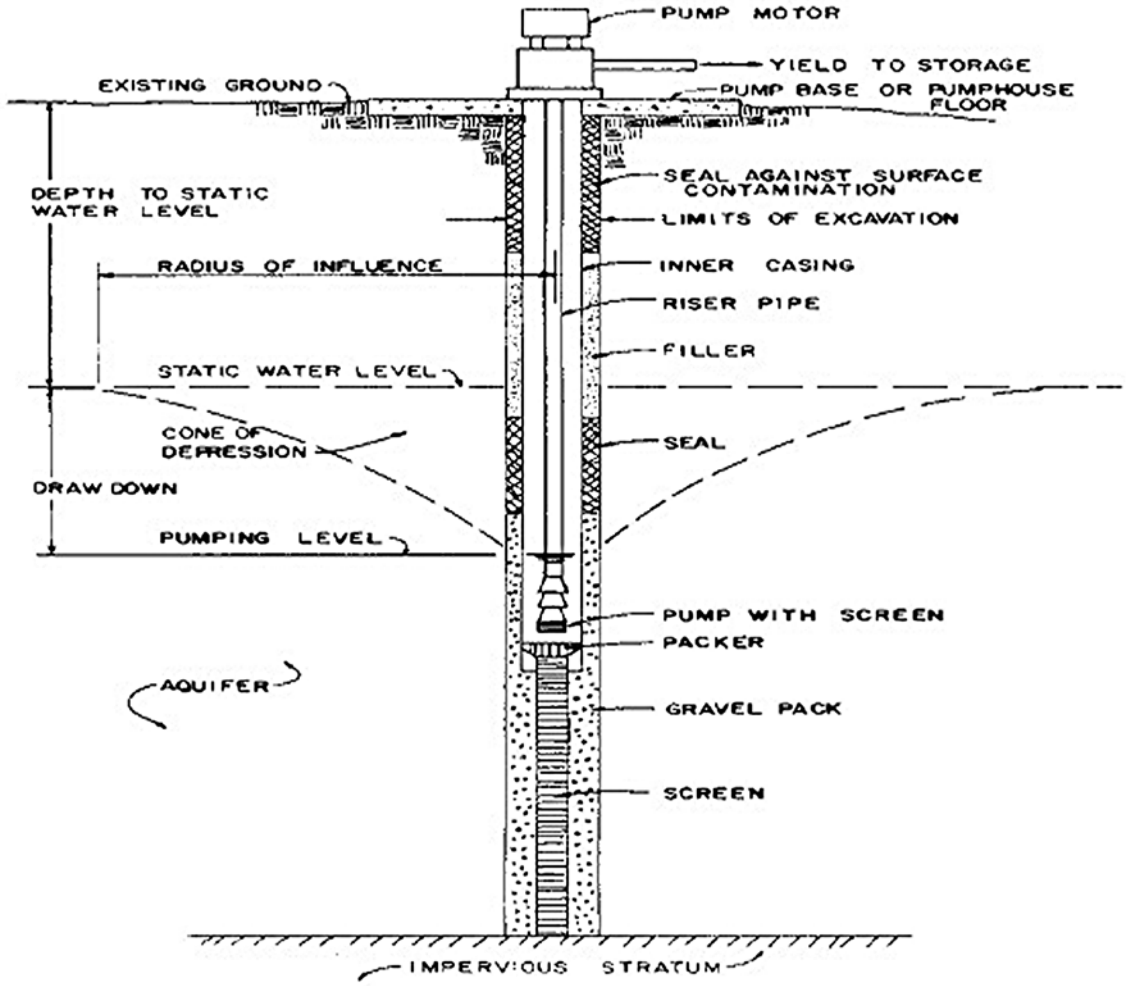

Figure 5-4

Diagram of well in artesian aquifer.

5.5.3 DETERMINATION OF VALUES. The well driller's log provides the dimensions of H, h, and b. The value of R usually lies between 100 and 10,000 feet. It may be determined from observation wells or estimated. K may be determined from laboratory tests or field tests. A pumping test and observation wells may provide the values for all of these equations. Equation 5-3 shows the values for calculating K in water table aquifer:

$$K = \frac{1055\, Q \log (r_2/r_1)}{(h_2^2 - h_1^2)} \qquad \text{(eq. 5-3)}$$

where:

r_1 = distance to nearest observation well in feet

r_2 = distance to farthest observation well

h_1 = saturated thickness in feet at nearest observation well

h_2 = saturated thickness at farthest observation well

$$K = \frac{528\, Q \log (r_2/r_1)}{b\,(h_2^2 - h_1^2)} \qquad \text{(eq. 5-4)}$$

where:

h_1 = head in feet at nearest observation well

h_2 = head at farthest observation well

5.5.4 AQUIFER TESTING. Where existing wells or other data are insufficient to determine aquifer characteristics, a pumping test may be necessary to establish values used for design. Testing consists of pumping from one well and noting the change in water table at other wells as indicated in figures 5-3 and 5-4. Observation wells are generally set at 15 to 150 m (50-500 ft) from a pumped well, although for artesian aquifers they may be placed at distances up to 300 m (1000 ft). A greater number of wells allows the slope of the drawdown curve to be more accurately determined. The most common methods of aquifer testing are:

- **Step Drawdown Method.** Involves pumping one well and observing what happens in observation wells. The well is pumped at slow constant rate until the water level stabilizes. It is then pumped at a higher rate until the water level again stabilizes. At least three steps are normally performed.

- **Recovery Method.** Involves shutting down the pumping well and noting the recovery water levels in the pumping well and its observation wells.

- **Slug Test.** Involves the introduction or removal of a “slug” or volume of water into the well then measuring the rise or fall in water level. The test can also be performed by inserting and removing a solid cylinder into the water.

- **Bailer Test.** Water is removed from the well using a bailer of known volume, as rapidly as possibly until the well is empty or the water level stabilizes. The volume and unit of time are noted.

5.5.5 TESTING OBJECTIVES. A simplified example is given in appendix B. When conducting aquifer tests by methods such as the drawdown method, it is important to note accurately the yield and corresponding drawdown. A good testing program, conducted by an experienced geologist, will account for, or help to define, the following aquifer characteristics:

- Type of aquifer
    - -water table
    - -confined
    - -artesian

- Slope of aquifer

- Direction of flow

- Boundary effects

- Influence of recharge
    - -stream or river
    - -lake

- Non-homogeneity

- Leaks from aquifer

5.6 WELL DESIGN AND CONSTRUCTION. Well design methods and construction techniques are basically the same for wells constructed in consolidated or unconsolidated formations and only one aquifer is being penetrated. Typically, wells constructed in an unconsolidated formation require a screen to line the lower portion of the borehole. An artificial gravel pack may or may not be required. A diagrammatic section of a gravel packed well is shown on figure 5-5. Wells constructed in sandstone, limestone or other creviced rock formations can utilize an uncased borehole in the aquifer. Screens and the gravel pack are not usually required. A well in rock formation is shown in figure 5-6. Additional well designs for consolidated and unconsolidated formations are shown in AWWA A100.

5.6.1 DIAMETER. The diameter of a well has a significant effect on the well's construction cost. The diameter need not be uniform from top to bottom. Construction may be initiated with a certain size casing, but drilling conditions may make it desirable to reduce the casing size at some depth. However, the diameter must be large enough to accommodate the pump and the diameter of the intake section must be consistent with hydraulic efficiency. The well shall be designed to be straight and plumb. The factors that control diameter are (1) yield of the well, (2) intake entrance velocity, (3) pump size, and (4) construction method. The pump size, which is related to yield, usually dominates. Approximate well diameters for various yields are shown in table 5-3. Well diameter affects well yield but not to a major degree. Doubling the diameter of the well will produce only about 10-15 percent more water. Table 5-4 gives the theoretical change in yield that results from changing from one well diameter to a new well diameter. For artesian wells, the yield increase resulting from diameter doubling is generally less than 10 percent. Consideration should be given to future expansion and installation of a larger pump. This may be likely in cases where the capacity of the aquifer is greater than the yield required.

5.6.2 DEPTH. Depth of a well is usually determined from the logs of test holes or from logs of other nearby wells that utilize the same aquifer. A well that is screened the full length of the water bearing stratum has a potential for greater discharge than a unit that is not fully screened. Where the water bearing formations are thick, cost may be the deciding factor in how deep the wells are installed. Cost, however, usually is balanced by the savings from a potentially long-term source of water.

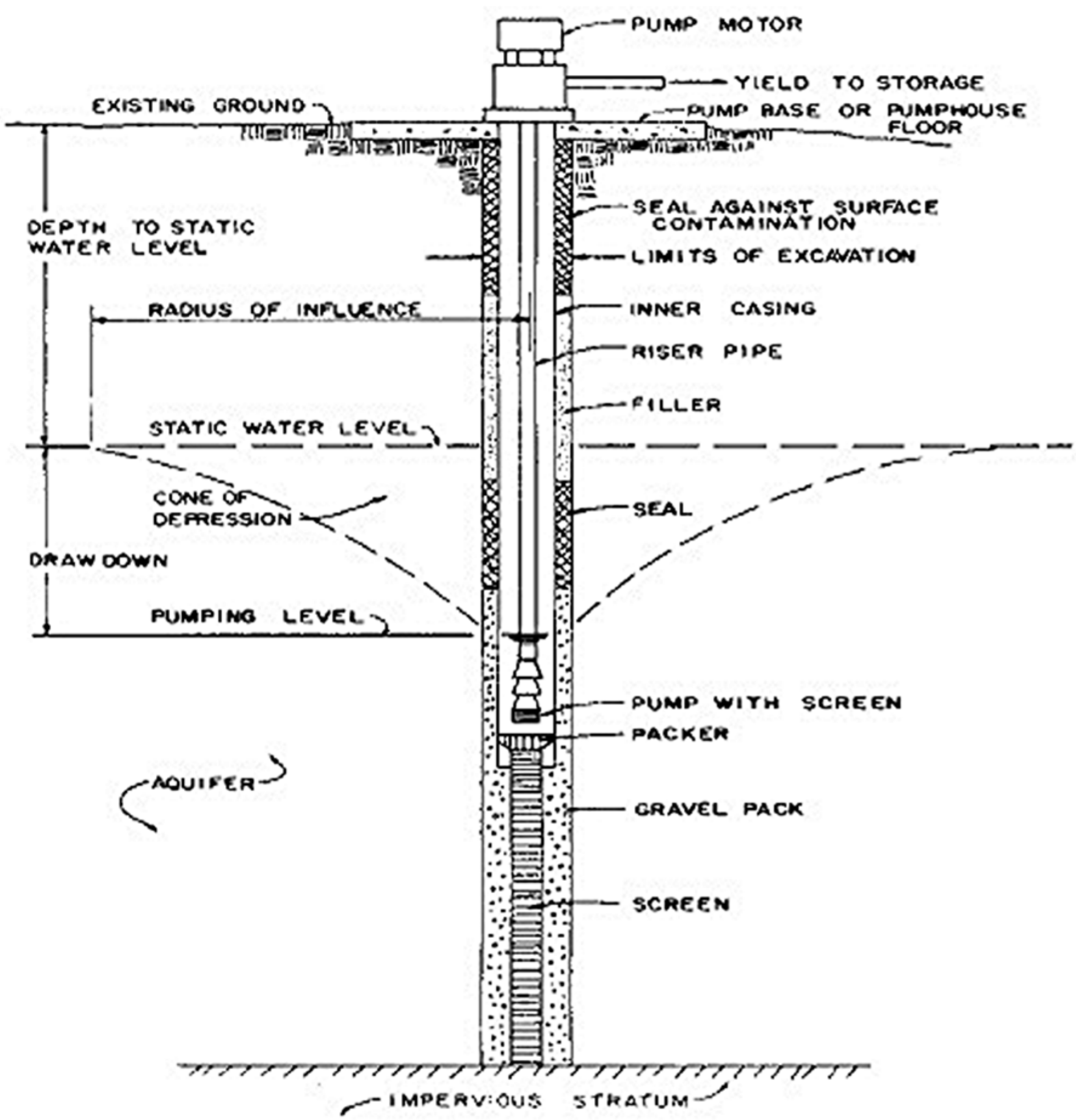

Figure 5-5

Diagrammatic Section of Gravel-packed Well

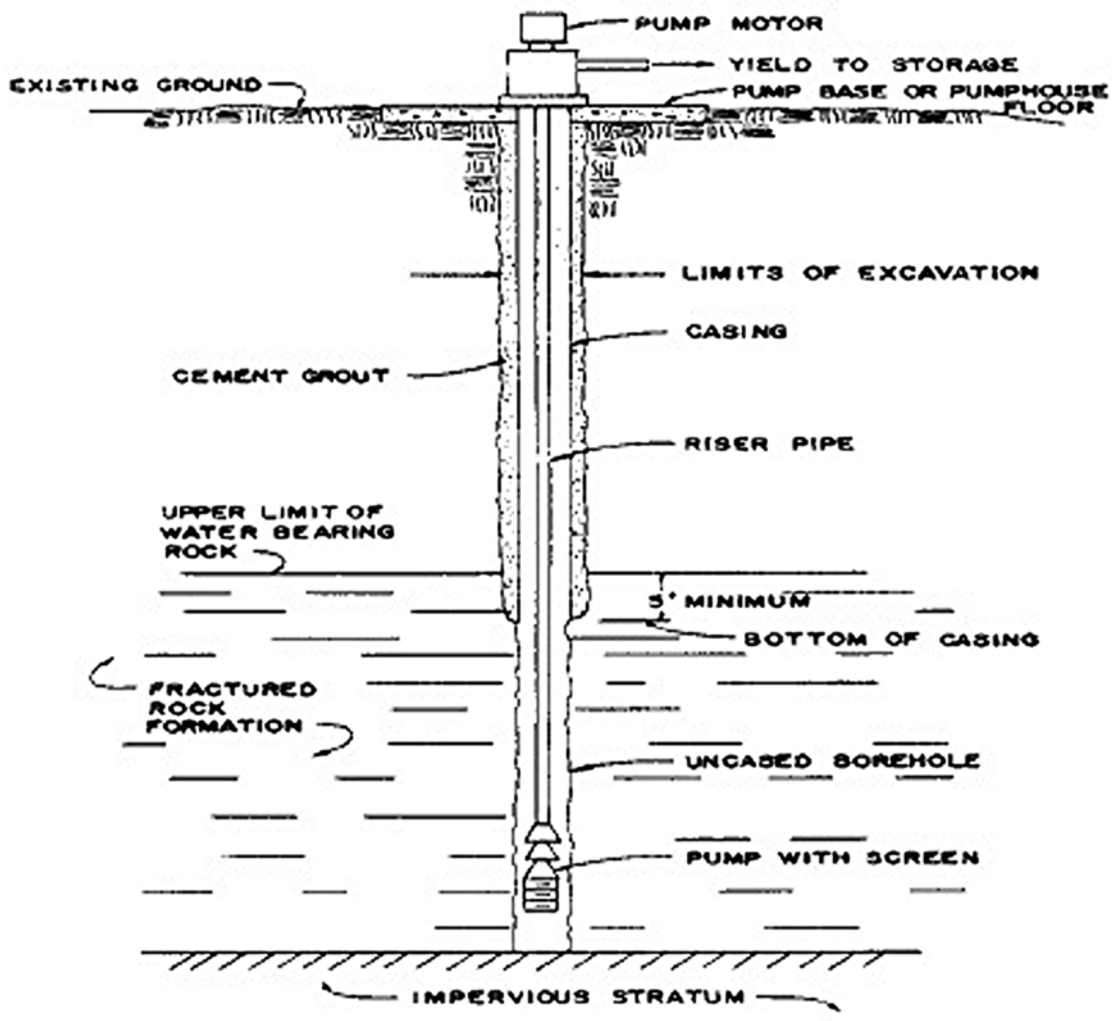

Figure 5-6

Well in Rock Formation

Anticipated Well Yield (L/minute)	Nominal Size of Pump Bowls (mm)	Optimum Size Well Casing (mm)	Smallest Size Well Casing (mm)
<380	100	150 ID	125 ID
285-660	125	200 ID	150 ID
570-1515	150	250 ID	200 ID
1325-2460	200	300 ID	250 ID
2270-3400	250	350 OD	300 ID
3200-4900	300	400 OD	350 OD
4550-6800	350	500 OD	400 OD
6050-11400	400	600 OD	500 OD
<100	4	6 ID	5 ID
75-175	5	8 ID	6 ID
150-400	6	10 ID	8 ID
350-650	8	12 ID	10 ID
600-900	10	14 OD	12 ID
850-1300	12	16 OD	14 OD
1200-1800	14	20 OD	16 OD
1600-3000	16	24 OD	20 OD
3000-6000	20	30 OD	24 OD

Table 5-3

Well Diameter vs. Anticipated Yield

Original Well Diameter	New Well Diameter 150 mm (6")	300 mm (12")	450 mm (18")	600 mm (24")	750 mm (30")	900 mm (36")	1200 mm (48")
150 mm (6")	100%	110%	117%	122%	127%	131%	137%
300 mm (12")	90	100	106	111	116	119	125
450 mm (18")	84	93	100	104	108	112	117
600 mm (24")	79	88	95	100	104	107	112
750 mm (30")	76	85	91	96	100	103	108
900 mm (36")	73	82	88	92	96	100	105
1200 mm (48")	69	77	82	87	91	94	100

Note: The above gives the theoretical increase or decrease in yield that results from changing the original well diameter to the new well diameter. For example, if a 300 mm well is enlarged to a 900mm well, the yield will be increased by 19 percent. The values in the above table are valid only for wells in unconfined aquifers (water table wells) and are based on the following equation:

$$Y2/Y1 = (\log R/r1) / (\log R/r2)$$

where:

Y2 = yield of new well
Y1 = yield of original well
R = radius of cone of depression, in mm (the value of R used for this table is 120 m).
r2 = diameter of new well, in mm
r1 = diameter of original well, in mm

Table 5-4

Change in Yield for Variation in Well Diameter

5.6.3 CASING. In a well developed in a sand and gravel formation, the casing should extend to a minimum of 1,500 mm (5 ft) below the lowest estimated pumping level. In consolidated formations, the casing should be driven 1,500 mm (5 ft) into bedrock and cemented in place for its full depth. The minimum wall thickness for steel pipe used for casing is 8 mm (1/4-inch). For various diameters, the EPA recommends the following wall thicknesses:

Nominal Diameter, mm (in)	Wall Thickness, mm (in)
150 (6)	8 (.250)
200 (8)	8 (.250)
250 (10)	8 (.279)
300 (12)	9 (.330)
350 (14)	10 (.375)
400 (16)	10 (.375)
450 (18)	10 (.375)
500 (20)	10 (.375)

In the percussion method of drilling, and where sloughing is a problem, it is customary to drill and drive the casing to the lower extremity of the aquifer to be screened and then install the appropriate size screen inside the casing before pulling the casing back and exposing the screen to the water bearing formation.

5.6.4 SCREENS. Wells completed in sand and gravel with open-end casings, not equipped with a screen on the bottom, usually have limited capacity due to the small intake area (open end of casing pipe) and tend to pump large amounts of sand. A well designed screen permits utilizing the permeability of the water bearing materials around the screen. For a well completed in a sand-gravel formation, use of a well screen will usually provide much more water than if the installation is left open-ended. The screen functions to restrain sand and gravel from entering the well, which would diminish yield, damage pumping equipment, and deteriorate the quality of the water produced. Wells developed in hard rock areas do not need screens if the wall is sufficiently stable and sand pumping is not a problem.

5.6.4.1 APERTURE SIZE. The well screen aperture opening, called slot size, is selected based on sieve analysis data of the aquifer material for a naturally developed well. For a homogeneous formation, the slot size is selected as one that will retain 40 to 50 percent of the sand. Use 40 percent where the water is not particularly corrosive and a reliable sample is obtained. Use 50 percent where water is very corrosive and/or the sample may be questionable. Where a formation to be screened has layers of differing grain sizes and graduations, multiple screen slot sizes may be used. Where fine sand overlies a coarser material, extend the fine slot size at least 3 feet into the coarser material. This reduces the possibility that slumping of the lower material will allow finer sand to enter the coarse screen. The coarse aperture size should not be greater than twice the fine size. For a filter packed well, the screen should retain 85 to 100 percent of the filter material. Screen aperture size should be determined by a laboratory experienced in this work, based on a sieve analysis of the material to be screened. Consult manufacturer's literature for current data on screens.

5.6.4.2 LENGTH. Screen length depends on aquifer characteristics, aquifer thickness, and available drawdown. For a homogeneous, confined, artesian aquifer, 70 to 80 percent of the aquifer should be screened and the maximum drawdown should not exceed the distance from the static water level to the top of the aquifer. For a non-homogeneous, artesian aquifer, it is usually best to screen the most permeable strata. Determinations of permeability are conducted in the laboratory on representative samples of the various strata. Homogeneous, unconfined (water-table) aquifers are commonly equipped with screen covering the lower one-third to one-half of the aquifer. A water-table well is usually operated so that the pumping water level is slightly above the top of the screen. For a screen length of one-third the aquifer depth, the permissible drawdown will be nearly two-thirds of the maximum possible drawdown. This draw-down corresponds to nearly 90 percent of the maximum yield. Screens for nonhomogeneous watertable aquifers are positioned in the lower portions of the most permeable strata in order to permit maximum available drawdown. The following equation is used to determine screen length:

$$L = \frac{Q}{AV\,(7.48)} \qquad \text{(eq. 5-5)}$$

where:

L = length of screen (feet)
Q = discharge (gpm)
A = effective open area per foot of screen length (sq. ft. per ft.) (approximately one-half of the actual open area which can be obtained from screen manufacturers.)
V = velocity (fpm) above which a sand particle is transported; is related to permeability as follows:

P (gpd/ft^2)	V (ft/min)
5000	10 (Max)
4000	9
3000	8
2500	7
2000	6
1500	5
1000	4
500	3
0-500	2 (Min)

5.6.4.3 DIAMETER. The screen diameter shall be selected so that the entrance velocity through the screen openings will not exceed 0.1 foot per second. The entrance velocity is calculated by dividing the well yield in cubic feet per second by the total area of the screen openings in square feet. This will ensure the following:

- The hydraulic losses in the screen opening will be negligible.
- the rate of incrustation will be minimal,
- the rate of corrosion will be minimal.

5.6.4.4 INSTALLATION. Various procedures may be used for installation of well screens.

- For cable-tool percussion and rotary drilled wells, the pull-back method may be used. A telescope screen, that is one of such a diameter that it will pass through a standard pipe of the same size, is used. The casing is installed to the full depth of the well, the screen is lowered inside the casing, and then the casing is pulled back to expose the screen to the aquifer.

- In the bail down method, the well and casing are completed to the finished grade of the casing; and the screen, fitted with a bail-down shoe is let down through the casing in telescope fashion. The sand is removed from below the screen and the screen settles down into the final position.

- For the wash-down method, the screen is set as on the bail-down method. The screen is lowered to the bottom and a high velocity jet of fluid is directed through a self closing bottom fitting on the screen, loosens the sand and allowing the screen to sink to it final position. If filter packing is used, it is placed around the screen after being set by one of the above methods. A seal, called a packer, is provided at the top of the screen. Lead packers are expanded with a swedge block. Neoprene packers are self sealing.

- In the hydraulic rotary method of drilling, the screen may be attached directly to the bottom of the casing before lowering the whole assembly into the well.

5.6.4.5 FILTER PACKING. Filter packing (sometimes referred to as gravel packing) is primarily sand placed around the well screen to stabilize the aquifer and provide a radius of high permeability around the screen. This differs from the naturally developed well in that the zone around the screen is made more permeable by the addition of coarse material. Filter-pack material is more effective when it is composed of clean rounded silicious sand or gravel.

- **SIZE.** Grain size of the filter pack is selected on the basis of information obtained from sieve analyses of the material in the aquifer. The well screen aperture size will be selected so that between 85 and 100 percent of the filter pack is larger than the screen openings. Criteria for sizing the filter pack are as follows:

  - Perform sieve analyses on all strata within the aquifer. The sieve sizes to be used in performing these analyses are:

80 mm (3 in)	No. 4
50 mm (2 in)	No. 10
40 mm (1-1/2 in)	No. 20
25 mm (1 in)	No. 40
20 mm (3/4 in)	No. 60
< 20 mm (3/4 in)	No. 140

The results of the analysis of any particular sample should be recorded as the percent (by weight) of the sample retained on each sieve and the cumulative percent retained on each sieve (i.e., the total of the percentages for that sieve and all larger sieve sizes). Based on these sieve analyses, determine the aquifer stratum which is composed of the finest material.

- Using the results of the sieve analysis for the finest aquifer material, plot the cumulative percent of the aquifer material retained versus the size of the mesh for each sieve. Fit a smooth curve to these points. Find the size corresponding to a 70 percent cumulative retention of aquifer material. This size should be multiplied by a factor between 4 and 6, 4 if the formation is fine and uniform and 6 if the formation is coarse and nonuniform. Use 9 if the formation includes silt. The product is the 70 percent retained size (i.e., the sieve size on which a cumulative 70 percent of the sample would be retained) of the material to be used in the packing.

- A uniformity coefficient of 2.5 for the filter pack is desirable. The uniformity coefficient is defined as 40 percent of the retained grain size divided by 90 percent retained size.

- Lower size represents a more uniform material and is more meaningful for values less than 5.

- The plot of cumulative percent retention versus grain size for the filter pack should be approximately parallel to same plot for the aquifer material, should pass through the 70 percent retention value and should have 40 and 90 percent retention values such that the uniformity coefficient is less than 2.5. Filter pack material will be specified by determining the sieve sizes that cover the range of the curve and then defining an allowable range for the percent retention on each sieve.

- **THICKNESS.** The thickness of the filter pack will range from a minimum of 80 mm (3 in) to approximately 200 mm (8 in). A filter envelope thicker than about 200 mm (8 in) will not greatly improve yield and can adversely affect removal of fines, at the aquifer-filter pack interface, during well development.

- **PACK LENGTH.** Filter pack should extend full length of the screen but not above the top of the aquifer. A tremie pipe may be used to evenly distribute the filter material around the screen and also to prevent bridging of the sand grains. A filter -pack well has been shown schematically in figure 5-5.

- **DISINFECTION.** It is important that the filter used for packing be clean and that it also be disinfected by immersion in strong chlorine solution (200 mg/L or greater available chlorine concentration, prepared by dissolving fresh chlorinated lime or other chlorine compound in water) just prior to placement. Dirty filter must be thoroughly washed with clean water prior to disinfection and then handled in a manner that will maintain it in as clean a state as possible.

5.6.4.6 GROUTING AND SEALING. The well should be constructed to prevent water that is polluted or of otherwise unsuitable quality from entering the well. Grout should extend from the surface to the top of the bentonite seal overlying filter pack of the well. Grouting and sealing of wells are necessary to protect the water supply from pollution, to seal out water of unsatisfactory chemical quality, to protect the casing from exterior corrosion and to stabilize soil, sand or rock formations which tend to cave. When a well is constructed there is normally produced an annular space between the drill hole and the casing, which, unless sealed by grouting, provides a potential pollution channel. A bentonite seal with a minimum thickness of two feet should be placed directly above the filter pack to prevent vertical infiltration of contaminants through filter material into the well. The wellhead must be grouted and sealed at the surface to prevent contaminants from migrating along the casing into the aquifer.

- **PREVENTION OF CONTAMINATION FROM SURFACE.** The well casing and the grout seal should extend from the surface to the depth necessary to prevent surface contamination via channels through soil and rock strata. The depth required is dependent on the character of the formations involved and the proximity of sources of pollution, such as sink holes and sewage disposal systems. The grout around the casing should extend from the top of the bentonite seal to the surface of the well. Local regulations may govern the composition and placement of the grout. Materials for sealing and grouting should be durable and readily placed. Normally, Portland cement grout will meet these requirements. Grout is customarily specified as a neat cement mixture having a water-cement ration of not over 23 L (6 gal) per 43 kg (94-pound) sack of cement. Small amounts of bentonite clay may be used to improve fluidity and reduce shrinkage. Grout can be placed by various methods, but to ensure a satisfactory seal, it is essential that grouting be:
    - done as one continuous operation
    - completely placed before the initial set occurs
    - introduced at the bottom of the space to be grouted

Establishment of good circulation of water through the annular space to be grouted is a highly desirable initial step toward a good grouting job. This assures that the space is open and provides for the removal of foreign material.

- **PREVENTION OF SUBSURFACE CONTAMINATION.** Formations containing water of poor quality above the target aquifer may be sealed off by grouting an outer casing in place before installing the deeper well casing. If the undesirable aquifer is the lower one, care should be taken during drilling so as not to penetrate or breach the confining unit separating the two aquifers. Any portion of the confining unit that is breached should be replaced with grout.

5.6.4.7 ACCESSIBILITY. The well location shall be readily accessible for pump repair, cleaning, disinfection, testing and inspection. The top of the well shall never be below surface grade. At least 600 mm (2 ft) of clearance beyond any building projection shall be provided.

5.6.4.8 DETAILS RELATING TO WATER QUALITY. In addition to grouting and sealing, features that are related to water quality protection are:

- **Surface grading.** The well or wells should be located on the highest ground practicable, certainly on ground higher than nearby potential sources of surface pollution. The surface near the site should be built up, by fill if necessary, so that surface drainage will be away from the well in all directions. Where flooding is a problem, special design will be necessary to insure protection of wells and pumping equipment from contamination and damage during flood periods and to facilitate operation during a flood.

- **Surface slab.** The well casing should be surrounded at the surface by a concrete slab having a minimum thickness of 100 mm (4 in) and extending outward from the casing a minimum of 600 mm (2 ft) in all directions. The slab should be finished a little above ground level and slope slightly to provide drainage away from the casing in all directions.

- **Casing.** The well casing should extend at least 300 mm (12 in) above the level of the concrete surface slab in order to provide ample space for a tight surface seal at the top of the casing. The type of seal to be employed depends on the pumping equipment specified.

- **Well house.** While not universally required, it is usually advisable to construct a permanent well house, the floor of which can be an enlarged version of the surface slab. The floor of the well house should slope away from the casing toward a floor drain at the rate of about 1 mm per 50 mm (1/8 inch per foot). Floor drains should discharge through carefully jointed 100 mm (4 in) or larger pipe of durable water-tight material to the ground surface 6 m (20 ft) or more from the well. The end of the drain should be fitted with a coarse screen. Well house floor drains ordinarily should not be connected to storm or sanitary sewers to prevent contamination from backup. The well house should have a large entry door that opens outward and extends to the floor. The door should be equipped with a good quality lock. The well house design should be such that the well pumps motor, and drop-pipe can be removed readily. The well house protects valves and pumping equipment and also provides some freeze protection for the pump discharge piping beyond the check valve. Where freezing is a problem, the well house should be insulated and a heating unit installed. The well house should be of fireproof construction. The well house also protects other essential items. These include:

    - Flow Meter

    - Depth Gage

    - Pressure Gage

- Screened Casing Vent
- Sampling Tap
- Water Treatment Equipment (if required)
- Well Operating Records

If climatic or other conditions are such that a well house is not necessary, then the well should be protected from vandals or unauthorized use by a security fence having a lockable gate.

- **Pit construction.** Pit construction is only acceptable under limited conditions such as temporary or intermittent use installations where the well pump must be protected from the elements when not in use. The design must allow for cleaning and disinfection. Underground pitless construction for piping and wiring may be adequate for submersible pump installations. These designs may be used only when approved by the responsible installation medical authority.

5.6.4.9 SPACING AND LOCATION. The grouping of wells must be carefully considered because of mutual interference between wells when their cones of depression overlap. Minimum well spacing shall be 75 m (250 ft).

- Drawdown interference. The drawdown at a well or any other location on the water table is a function of the following:
  - number of wells being pumped
  - distance from point of measurement to pumping wells

- volume of discharge at each well
- penetration of each well into aquifer.

- For simple systems of 2 or 3 wells, the method of super position may be used. The procedure is to calculate the drawdown at the point (well) of consideration and then to add the drawdown for each well in the field. For multiple wells, the discharge must be recalculated for each combination of wells, since multiple wells have the effect of changing the depth of water in equations 5-1 and 5-2. For large systems the following conditions should be noted:
  - boundary conditions may change
  - change in recharge could occur
  - recharge may change water temperature, an increase in water temperature increases the coefficient of permeability
  - computer analysis may be helpful to recalculate the combinations.

- It is seldom practicable to eliminate interference entirely because of pipeline and other costs, but it can be reduced to manageable proportions by careful well field design. When an aquifer is recharged in roughly equal amounts from all directions, the cone of depression is nearly symmetrical about the well and "R" is about the same in all directions. If, however, substantially more recharge is obtained from one direction; e.g., a stream, then the surface elevation of the water table is distorted, being considerable higher in the direction of the stream. The surface of the cone of depression will be depressed in the direction of an impermeable boundary because little or no recharge is obtained from the direction of the impermeable boundary.

- Location. Where a source of recharge such as a stream, exists near the proposed well field, the best location for the wells is spaced out along a line as close as practicable to and roughly parallel to the stream. On the other hand, multiple water supply wells should be located parallel to and as far as possible from an impermeable boundary. Where the field is located over a buried valley, the wells should be located along and as close to the valley's center as possible. In hard rock country, wells are best located along fault zones and lineaments in the landscape where recharge is greatest. These are often visible using aerial photographs. Special care should be exercised to avoid contamination in these terrains since natural filtration is limited.

5.6.4.10 PUMPS. Many types of well pumps are on the market to suit the wide variety of capacity requirements, depth to water and power source. Electric power is used for the majority of pumping installations. Where power failure would be serious, the design should permit at least one pump to be driven by an auxiliary engine, usually gasoline, diesel or propane. The most appropriate type is dictated by many factors for each specific well. Factors that should be considered for installation are:

  - capacity of well - power source
  - capacity of system - standby equipment
  - size of well - well drawdown
  - depth of water - total dynamic head
  - type of well

- **TYPE.** There are several types of well pumps. The most common are line shaft turbine, submersible turbine, or jet pumps. The first two operate on exactly the same principal. The difference being where the motor is located. Line shaft turbine pumps have the motor mounted above the waterline of the well and submersible turbine pumps have the motor mounted below the water line of the well. Jet pumps operate on the principal of suction lift. A vacuum is created sufficient to "pull" water from the well. This type of pump is limited to wells where the water line is generally no more than 8 m (25 ft) below the pump suction. It also has small capacity capability.

- **CHOICE.** Domestic systems commonly employ jet pumps or small submersible turbine pumps for lifts under 8 m (25 ft). For deeper wells with high capacity requirements, submersible or line shaft turbine pumps are usually used and are driven by electric motors. A number of pump bowls may be mounted in series, one above the other to provide the necessary discharge pressure. Characteristics for various types of pumps used in wells are listed in table 5-5.

Type of Pump	Practical suction lift	Usual well-pumping depths	Usual pressure heads	Advantages	Disadvantages	Remarks
Reciprocating: 1. Shallow well . . . 2. Deep well . . .	22–26 ft. 22–25 ft.	22–26 ft. Up to 600 feet	100–200 ft. Up to 600 feet above cylinder.	1. Positive action. 2. Discharge against variable heads. 3. Pumps water containing sand and silt. 4. Especially adapted to low capacity and high lifts.	1. Pulsating discharge. 2. Subject to vibration and noise. 3. Maintenance cost may be high. 4. May cause destructive pressure if operated against closed valve.	1. Best suited for capacities of 5–25 gpm against moderate to high heads. 2. Adaptable to hand operation. 3. Can be installed in very small diameter wells (2" casing). 4. Pump must be set directly over well (deep well only).
Centrifugal: 1. Shallow well a. straight centrifugal (single stage)	20 ft. maximum	10–20 ft.	100–150 ft.	1. Smooth, even flow. 2. Pumps water containing sand and silt. 3. Pressure on system is even & free from shock. 4. Low-starting torque. 5. Usually reliable and good service life.	1. Loses prime easily. 2. Efficiency depends on operating under design heads & speed	1. Very efficient pump for capacities above 50 gpm & heads up to about 150 feet.
b. Regenerative vane turbine type (single impeller)	28 ft. maximum	28 ft.	100–200 ft.	1. Same as straight centrifugal except not suitable for pumping water containing sand or silt. 2. They are self-priming.	1. Same as straight centrifugal except maintains priming easily.	1. Reduction in pressure w/increased capacity not as severe as straight centrifugal.
2. Deep well a. Vertical line shaft turbine (multi-stage)	Impellers submerged	50–300 ft.	100–800 ft.	1. Same as shallow well turbine.	1. Efficiency depends on operating under design head & speed. 2. Requires straight well large enough for turbine bowls and housing. 3. Lubrication & alignment of shaft critical. 4. Abrasion from sand.	

Table 5-5

Characteristics of Pumps Used in Water Supply Systems

- **CAPACITY SELECTION.** The design capacity of the pump must exceed the system requirements. However, the capacity of the pump must not exceed the capacity of the well. Pump manufacturers publish charts giving the pump discharge capacity for their particular pumps at various operating pressures. The total dynamic head (TDH) of the system must be calculated accurately from the physical arrangement and is represented by the following equation:

$$TDH = H_S + H_D + H_F + V^2/2g \qquad \text{(eq. 5-6)}$$

where:

H_S = suction lift; vertical distance from the waterline at drawdown under full capacity, to the pump centerline

H_D = discharge head; vertical distance from the pump centerline to the pressure level of the discharge pipe system

H_F = friction head; loss of head on pipe lines and fittings

$V^2/2g$ = velocity head; head necessary to maintain flow

The brake horsepower of the motor used to drive the pump may be calculated from the following equation:

$$P = (H \times Q)/(3960 \times e) \qquad \text{(eq. 5-7)}$$

where:

P = brake horsepower required

H = total dynamic head in feet

Q = volume of water in gpm

e = combined efficiency of pump and motor

5.7 DEVELOPMENT AND DISINFECTION. After the structure of the well is installed, there remain two very important operations to be performed before the well can be put into service. Well development is the process of removing the finer material from the aquifer around the well screen, thereby cleaning out and opening up passages in the formation so that water can enter the well more freely. Disinfection is the process of cleaning and decontaminating the well of bacteria that may be present due to the drilling action

5.7.1 DEVELOPMENT. Three beneficial aspects of well development are to correct any damage or clogging of the water bearing formation which occurred as a side effect of drilling, to increase the permeability of the formation in the vicinity of the well and to stabilize the formation around a screened well so that the well will yield sand-free water.

5.7.1.1 A naturally developed well relies on the development process to generate a highly permeable zone around the well screen or open rock face. This process depends upon pulling out the finer materials from the formation, bringing them into the well, and pumping them out of the well. Development work should continue until the movement of fine material from the aquifer ceases and the formation is stabilized.

5.7.1.2 Artificial filter packing provides a second method of providing a highly porous material around the screen. This involves placement of a specially graded filter in the annular space between the screen and the wall of the excavation. Development work is required if maximum capacity is to be attained.

5.7.1.3 Development is necessary because many drilling methods cause increase in the density of the formation around the hole. Methods utilizing drilling fluids tend to form a mud cake. Good development will eliminate this "skin effect" and loosen up the sand around a screen. Removal of fines leaves a zone of high porosity and high permeability around the well. Water can then move through this zone with negligible head loss.

5.7.1.4 Methods of development in unconsolidated formations include the following:

- Mechanical surging is the vigorous operation of a plunger up and down in the well, like a piston in a cylinder. This causes rapid movement of water which loosen the fines around the well and they can be removed by pumping. This may be unsatisfactory where the aquifer contains clay streaks or balls. The plunger should only be operated when a free flow of water has been established so that the tool runs freely.

- Air surging involves injecting air into a well under high pressure. Air is pumped into a well below the water level causing water to flow out. The flow is continued until it is free of sand. The air flow is stopped and pressure in an air tank builds to 700 to 1,000 kilopascals (100 to150 psi). Then the air is released into the well causing water to surge outward through the screen openings.

- Over pumping is simply pumping at a higher rate than design. This seldom brings best results when used alone. It may leave sand grains bridged in the formation and requires high capacity equipment.

- Back washing involves reversal of flow. Water is pumped up in the well and then is allowed to flow back into the aquifer. This usually does not supply the vigorous action which can be obtained through mechanical surging.

- High velocity jetting utilizes nozzles to direct a stream of high pressure water outward through the screen openings to rearrange the sand and gravel surrounding the screen. The jetting tool is slowly rotated and raised and lowered to get the action to all parts of the screen. This method works better on continuous slot well screens better than perforated types of screens.

5.7.1.5 Development in rock wells can be accomplished by one of the surging methods listed above or by one of the following methods.

- Explosives can be used to break rock formations. However it may be difficult to tell in advance if the shooting operation will produce the required result.

- Acidizing can be used in wells in limestone formations. Fractures and crevices are opened up in the aquifer surrounding the well hole by the action of the acid dissolving the limestone.

- Sand fracking is the action of forcing high pressure water containing sand or plastic beads in to the fractures surround a well. This serves to force the crevices open.

5.7.2 DISINFECTION OF COMPLETED WELL. The disinfection of the completed well shall conform to AWWA A100. Bacteriological samples must be collected and examined in accordance with *Standard Methods for the Examination of Water and Wastewater*.

5.7.3 DISINFECTION OF FLOWING ARTESIAN WELLS. Flowing artesian wells often require no disinfection, but if a bacteriological test, following completion of the well, shows contamination, disinfection is required. This can be accomplished as follows. The flow from the well will be controlled either by a cap or a standpipe. If a cap is required, it should be equipped with a one-inch valve and a drop-pipe extending to a point near the bottom of the well. With the cap valve closed, stock chlorine solution will be injected, under pressure, into the well through the drop-pipe in an amount such that when the chlorine solution is dispersed throughout all the water in the well, the resultant chlorine concentration will be between 50 and 100 mg/L. After injection of the required amount of stock chlorine solution, compressed air will be injected through the drop-pipe, while simultaneously partially opening the cap valve. This will permit the chlorine solution to be mixed with the water in the well. As soon as chlorine is detected in the water discharged through the cap valve, the air injection will be stopped, the cap valve closed and the chlorinated water allowed to remain in the well for 12 hours. The well will then be allowed to flow to waste until tests show the absence of residual chlorine. Finally, samples for bacteriological examination will be collected in accordance with Standard *Methods for the Examination of Water and Wastewater.* If the well flow can be controlled by means of a standpipe, disinfection can be accomplished as described for a water table well.

5.8 RENOVATION OF EXISTING WELLS. Well yield can be maintained by proper operating procedures. The most common cause of declining capacity in a well is incrustation which results from material being deposited on the well screen and thereby clogging the openings. A second cause is corrosion of the screen which is a chemical reaction of the metal. This action results in the screen being dissolved and enlarging the openings, allowing caving to occur. Records of pump performance and pumping levels are very important in a good maintenance program.

5.8.1 INCRUSTATION. The effect of incrustation is usually decreased capacity due to clogging of the screen openings. For incrustation due to calcium deposits or precipitation of iron and manganese compounds, treatment with an acid solution will dissolve the deposits and open up the screen. For bacterial growths and slime deposits, a strong chlorine solution has been found effective. In some instances, explosives may be used to break up incrustation from wells in consolidated rock aquifers.

5.8.2 CORROSION. The best method to prevent corrosion is to use a metal which is resistant to the attack. Once a screen has deteriorated, the only method of rehabilitation may be to remove it and install a new screen. The design of the initial installation should allow for removal of the screen in the future. Corrosion is also a problem in pumps. The use of pumps constructed of special non-corrosive materials will help. Care should be taken to use pumps with single metal types. Chemical inhibitors can be injected into wells to prevent corrosion, but this is costly.

5.8.3 DOWN HOLE INSPECTIONS. Special television equipment has been developed to permit a visual inspection of a well. Special lighting will permit high resolution pictures even under water. Wells as deep as 900 m (3000 ft), in casings as small as 100 mm (4 in) diameter can be inspected. The entire inspection can be videotaped for later review.

5.8.4 WELL CLEANING. Where incrustation is a problem, periodic well cleaning (also called "well stimulation" or "well rehabilitation") may be practiced. An effective cleaning procedure should be developed and applied annually or more often if necessary. Maintenance procedures are given in *"Ground Water and Wells" by Driscoll, Fletcher G.*

5.9 ABANDONMENT OF WELLS AND TEST HOLES . It is essential that wells, test wells, and test holes that have served their purpose and are abandoned, be effectively sealed for safety and to prevent pollution of the ground water resources in the area. The abandonment of wells shall follow the guidance of AWWA A100 and state/local regulations. Figure 5-5 illustrates the configuration of a filter-packed well in operational condition and figure 5-7 illustrates a well after sealing.

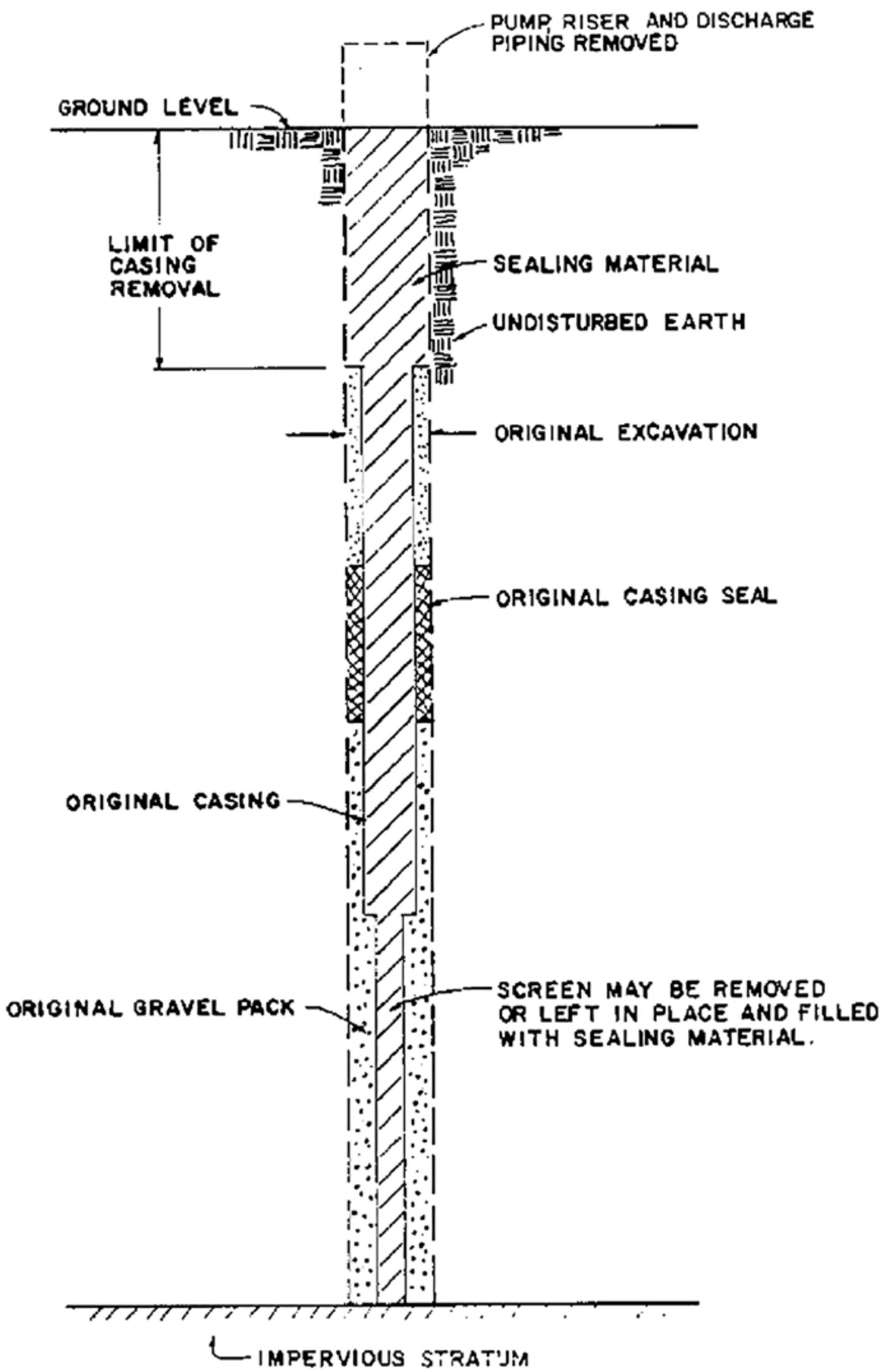

Figure 5-7

Sealed Well

5.10 CHECK LIST FOR DESIGN.

- Topographic maps of area where wells could be located.
- Reports on area geology and ground water resources from U.S. Geological Survey, State Geological Survey, and other state and local agencies that have an interest in or have conducted ground water investigations. Records obtained from drilling contractors familiar with the area. Reports of test drilling and pumping.
- Copies of logs of existing water supply wells, drawdown data, pumpage, water table elevations. Estimates of safe yield of aquifers.
- Records of physical, chemical, and bacteriological analyses of water from existing wells.
- Assessment of probable treatment requirements, such as iron, manganese, and sulfide removal; softening; and corrosion control.
- Summary of sanitary survey findings, including identification of possible sources of pollution.
- Probable location, number, type, depth, diameter and spacing of proposed water supply wells. Significant problems associated with well operation.
- Energy requirement of proposed system.
- Summary of applicable State water laws, rules, regulations, and procedures necessary to establish water use rights. Impact of proposed use on established rights of others.

5.11 TREATMENT REQUIREMENTS.

5.11.1 GROUNDWATER UNDER THE DIRECT INFLUENCE OF SURFACE WATER. According to 40 CFR 141, "groundwater under the direct influence of surface water means any water beneath the surface of the ground with (1) significant occurrence of insects or other macro-organisms, algae, or large-diameter pathogens such as Giardia lamblia, or (2) significant and relatively rapid shifts in water characteristics such as turbidity, temperature, conductivity, or pH which closely correlate to climatological or surface water conditions." Direct influence is determined by the State or should be determined by the installation's environmental office based on criteria established by the State. Per Subpart H of 40 CFR 141, groundwater determined to be under the direct influence of surface water must meet the same source water quality requirements as surface water and will in most cases require filtration. Disinfection must be provided in all cases.

5.11.2 GROUNDWATER NOT UNDER THE DIRECT INFLUENCE OF SURFACE WATER. In most of the United States, upper aquifers are directly influenced by surface water but groundwater from lower aquifers has been filtered by the formation through which it passes. Water from lower aquifers does not have to meet the specific treatment requirements of 40 CFR 141 (filtration and disinfection) but must still comply with standards which establish maximum contamination levels. Other treatment such as softening, iron removal, or pH adjustment may also be necessary. It should be noted that the natural filtering system can be short-circuited by sink holes, fractured rocks or shallow soils that provide paths for animal wastes and other contaminants to enter the groundwater from the surface. This is most likely to occur after heavy storms or snow melts. If the State determines that a groundwater source is under the direct influence of surface water, the installation must provide treatment within 18 months of written notice from the State.

CHAPTER 6
SURFACE WATER SUPPLIES

6.1 SURFACE WATER SOURCES. Surface water supply sources include streams, lakes, and impounding reservoirs. Large supplies of surface water are generally available throughout much of the eastern half of the United States where rainfall averages about 900 mm (35 in) or more annually and is reasonably well distributed through the year. On the other hand, good surface water sources are much more limited in many western regions with the exception of the Pacific Northwest, where surface water is plentiful.

6.2 WATER LAWS. Any investigation directed toward development of new or additional sources of supply must include consideration of applicable State water laws. Most of the States in roughly the eastern half of the United States follow the riparian law of water rights, and only a few have permit systems. Under this doctrine, the right to use water is associated with ownership of the land through which the stream flows. The riparian rights doctrine is essentially a legal principle which may be used, in some form, to settle disputes. It does not automatically provide for State water management and record keeping. Planning for water supply systems under the riparian doctrine is not absolutely certain for present and future water availability and security. In contrast, western law is based largely on the doctrine of "prior appropriation." In the 17 Western States where this doctrine prevails, sophisticated legal, administrative and management machinery exists. In these States, water rights and land ownership are separable and most Western States authorize a water-right owner to sell the right to another. The new owner is permitted to transfer the water to another point of use or put it to a different use, provided the transfer conforms to the State's administrative requirements.

6.3 QUALITY OF SURFACE WATERS. The quality of stream and lake waters varies geographically and seasonally. Streams, in particular, often exhibit fairly wide seasonal fluctuations in mineral quality, principally as a result of variations in stream flow. In general, streams and lakes east of the 95th meridian, which includes most of

Minnesota, Iowa, Missouri, Arkansas, Louisiana, and states east thereof, exhibit dissolved mineral solids in the range of 100 or less to about 700 milligrams per liter (mg/L). The water from these sources, after conventional treatment in a well-designed filtration plant, will meet standards prescribed for potable water. Unusual local conditions; e.g., pollution may render some eastern waters unsuitable as a source of supply; but in general, eastern streams and lakes are a satisfactory raw water source. Similar comments are applicable to surface waters of the Pacific Northwest area. Streams in many other areas west of the 95th meridian are much less satisfactory, often showing dissolved mineral solids in the range of 700 to 1,800 mg/L. High concentrations of hardness- producing and other minerals such as sulfate and chloride are found in some western surface waters.

6.4 WATERSHED CONTROL AND SURVEILLANCE. Raw water supplies should be of the best practicable quality even though extensive treatment, including filtration, is provided. Strict watershed control is usually impractical in the case of water supplies obtained from streams. However, some measure of control can be exercised over adverse influences, such as waste water discharges, in the vicinity of the water supply intake. For supplies derived from impounding reservoirs, it is generally feasible to establish and maintain a control and surveillance program whose objective is protection of the quality of raw water obtained from the reservoir. At reservoirs whose sole purpose is to provide a source of water supply, recreational use of the reservoir and shoreline areas should be rigorously controlled to protect the water supply quality.

6.5 CHECKLIST FOR SURFACE WATER INVESTIGATIONS. The investigations will cover the following items, as well as others, as circumstances warrant.

- Topographic maps showing pertinent drainage areas.

- Hydrologic data, as required for project evaluations; e.g., rainfall, runoff, evaporation, assessment of ground water resources and their potential as the sole source or supplementary source of supply.

- Sanitary survey findings.
- Intake location.
- Water quality data at or near proposed intake site.
- Feasibility of developing supply without reservoir construction.
- Reservoir location if reservoir is required.
- Plans for other reservoirs on watershed.
- Pertinent geological data that may affect dam foundation or ability of reservoir to hold water.
- Locations for pumping stations, supply lines, treatment plant.
- Energy requirements for proposed system
.
- State water laws, rules and regulations, procedure for obtaining right to use water, impact of proposed use on rights of other users.
- Disposition of water supply sludge from treatment plant.

6.6 TREATMENT REQUIREMENTS. Surface water sources must meet contaminant level requirements for fecal coliform and turbidity, or provide filtration. In most case, filtration should be anticipated. Disinfection must be provided for all surface water sources of potable water. Additional treatment may be required to remove other contaminants.

CHAPTER 7
INTAKES

7.1 GENERAL. The intake is an important feature of surface-water collection works. For fairly deep streams, whose flow always exceeds water demands, the raw water collection facilities generally consist of an intake structure located in or near the stream, an intake conduit and a raw water pumping station. Often the intake and pumping station are combined in a single structure. On smaller, shallow streams, a channel dam may be required to provide adequate intake submergence and ice protection. Inlet cribs of heavy-timber construction, surrounding multiple-inlet conduits, are frequently employed in large natural lakes. For impounding reservoirs, multiple-inlet towers, which permit varying the depth of withdrawal, are commonly used. Hydraulically or mechanically- cleaned coarse screens are usually provided to protect pumping equipment from debris. Debris removed from screens must be hauled to a landfill or other satisfactory disposal site. It may be necessary to obtain a permit for construction of an intake from both State and Federal agencies. If the stream is used for navigation, the intake design should include consideration of navigation use and of impact from boats or barges out of control. A permit from the U.S. Army District Engineer is required for any construction on navigable waterways.

7.2 CAPACITY AND RELIABILITY. The intake system must have sufficient capacity to meet the maximum anticipated demand for water under all conditions during the period of its useful life. Also, it should be capable of supplying water of the best quality economically available from the source. Reliability is of major importance in intake design because functional failure of the intake means failure of the water system. Intakes are subject to numerous hazards such as navigation or flood damage, clogging with fish, sand, gravel, silt, ice, debris, extreme low water not contemplated during design, and structural failure of major components. Many streams carry heavy suspended silt loads. In addition to suspended silt, there is also a movement of heavier material along the bed of the stream. The intake must be designed so that openings and conduits will not be clogged by bed-load deposits. An additional problem, caused by suspended silt and sand, is serious abrasion of pumps and other mechanical equipment. Excessive silt and sand may also cause severe problems at treatment plants. Liberal margins of safety must be provided against flood hazards and also against low-water conditions. A depression dredged in the stream bed to provide submergence is not a solution to he low-water problem because it will be filled by bedload movement. A self-scouring channel dam may be the only means of assuring adequate water depth. As an alternative to unusually difficult intake construction, gravel-packed wells and horizontal collector infiltration systems located in the alluvium near the river are often worthy of investigation. Water obtained from such systems will usually be a mixture of ground water and induced flow from the stream.

7.3 ICE PROBLEMS. In northern lakes, frazil ice (a slushy accumulation of ice crystals in moving water) and anchor ice (ice formed beneath the water surface and attached to submerged objects) are significant hazards, while on large rivers, floating ice has caused damage. Intake design must include ample allowances for avoiding or coping with these hazards. The intake location and inlet size are important aspects of design. Excessive inlet water velocities have been responsible for major clogging problems caused by both sand and ice. Inlet velocities in the range of 75 mm to 150 mm (0.25 to 0.5 ft) per second are desirable for avoiding ice clogging of intakes. Where ice is a problem, river intakes must have the structural stability to resist the thrust of ice jams and the openings must be deep enough to avoid slush ice which has been reported as deep as 2 to 2.5 m (6 to 8 ft). Frazil and anchor ice can also cause difficulties, but on rivers, floating ice is usually the greater hazard. Steam heating has been employed to cope with ice problems at some northern lake intakes. Nonferrous materials are preferred for cold-climate inlet construction because their lower heat conductivity discourages ice formation.

7.4 INTAKE LOCATION. Meandering streams in deep alluviums pose especially difficult intake problems. Here, expensive dikes, jetties and channel protection may be required to prevent the river channel from moving away from the intake or cutting behind it. On such streams, careful consideration must be given to intake location.

Generally, the intake site should be on the outside bank of a well established bend where the flow is usually swiftest and deepest. If the outside bend site includes a rock bank, a reliable intake probably can be placed there. Inside bends are to be avoided because of shallow water and sand bars. Sufficient depth at extreme low stage must also be a consideration. In addition to structural and hydraulic considerations, water quality is of major importance in connection with intake design and location, and the water quality aspects of a proposed location should be carefully examined. The location study should include a sanitary survey whose objective is evaluation of the effects of existing and potential sources of pollution on water quality at the intake site. The survey should include a summary of historical water quality data at the site plus an assessment of the probable impact of all wastewater discharges likely to influence present or future quality.

CHAPTER 8
RAW WATER PUMPING FACILITIES

8.1 SURFACE WATER SOURCES.

8.1.1 PUMPING STATION ARRANGEMENT. The location and arrangement of raw water pumping stations will depend upon the requirements of the local situation and only general comments can be given. Raw water pumping stations and intakes are often combined in a single structure, but this is not mandatory. The depth of the structure is a function of the type and arrangement of the pumps used. Horizontal centrifugal pumps are often employed and will give satisfactory performance and good operating economy. However, if the supply is from a variable stream and the pump suctions are to be under positive pressure under all operating conditions, a station of considerable depth probably will be required. Deep stations of the dry-pit type commonly used for horizontal centrifugal pumps should be compartmented so that rupture of pump discharge piping within the station will not flood all other pumps and motors. The depth may be reduced, with some loss in reliability, by installing the pumps at an elevation such that suction lift prevails under some operating conditions. Equipment for priming is a requirement when suction lift is employed. Use of vertical type wet-pit pumps, which requires less space in plan, permits a somewhat shallower station and does not require priming, may prove an economical alternative. Among other pumping arrangements that could be used are: vertical-type pumps or end- or side-suction centrifugals, with their shafts in a vertical position, located on a submerged suction header. The latter permits location of the pump drive units at an elevation where they are protected from flooding and readily accessible.

8.1.2 PUMP PROTECTION. Pumps, particularly those located on streams, must have protection against debris. In order to prevent or at least minimize screen clogging, the size of the screen openings should be consistent with the capacity of the pump to pass solids. The pump manufacturer can supply information on the largest sphere that the pump will pass. Plants with flows of 3.8 million liters per day (1 mgd) or larger and obtaining their water from streams will use hydraulically cleaned traveling screens. For smaller installations or those not obtaining water from streams, a fixed bar screen or strainers can be used. For such arrangements, provision must be made for cleaning. This can be accomplished by backflushing. In general, screening should be held to the minimum required for protection of the pumps. Excessively fine screens, strainers or bar racks are sometimes subject to rapid clogging and will require frequent cleaning. Debris removed by mechanically cleaned screens must be collected and hauled to a landfill or other acceptable disposal site. Screenings may be stored temporarily at the station in dump carts from which they are discharged to a truck for transport to a disposal site.

8.1.3 STRUCTURAL CONSIDERATIONS. Substructures will usually be of reinforced concrete. Superstructures should be of incombustible materials such as reinforced concrete, brick or other masonry. Wood frame construction should not be used except for temporary or minor installations. Structural design should include consideration of requirements for pump and motor servicing and removal for major repairs.

8.1.4 VENTILATION. Where a gravity ventilation system is deemed inadequate to supply fresh air and remove fumes and heated air from the pump station, a forced ventilation system should be provided. The ventilation system should be capable of removing waste heat from the motors without allowing more than a 6^{o} K (10^{o} F) rise in the temperature of the air in the pump station. For occupied areas, the ventilation system will have a capacity of about six air changes per hour. If dust-producing chemicals are to be handled at the station, special dust exhaust systems will also be provided. Where chemicals are used in the pump station, precautions should be taken to ensure that the exhaust from the ventilation system complies with air pollution prevention requirements.

8.1.5 PUMPING EQUIPMENT. In general, pumping equipment shall be sized to conform to the rated capacity of the water treatment plant and will include a minimum of three electric motor driven pumps. With the largest of the three pumps out of service, the remaining two pumps will be capable of supplying raw water at a rate equal to the rated capacity of the plant. To ensure water service in the event of a major power outage, a sufficient number of pumps must be equipped for operation when normal electric power is not available. These pumps will be capable of supplying at least 50 percent of the rated capacity of the treatment plant, except where greater capacity is essential. Standby power for emergency operation can be provided by gas-turbine or diesel engine generators or by engines arranged to provide for pump operation by direct engine drives during the emergency.

8.2 GROUND WATER SOURCES. For most applications, either vertical line shaft turbine pumps or submersible turbine pumps will be used. For small capacity or low-head applications, rotary or reciprocating (piston) pumps may be more appropriate. Factors influencing the selection of pumping equipment include well size, maximum pumping rate, range in pumping rate, maximum total head requirements, range in total head requirements, and type of power available. Final selection of pumping equipment will be based on life cycle cost considerations. If all pumps use electric power as the primary energy source, a sufficient number of the pumps must be equipped for emergency operation when normal electric power is not available. Emergency power can be provided by gas-turbine or diesel engine generators or by engines arranged to provide for pump operation by direct engine drives during the emergency. These standby-powered pumps will be capable of supplying at least 50 percent of the required daily demand, except where greater capacity is essential.

8.3 ELECTRIC POWER. If dual electric power feeders, breakers, transformers and switchgear can be provided, they will increase the station's reliability but may add appreciably to its cost. If a high degree of reliability is deemed necessary, the station should be served by independent transmission lines that are connected to independent power sources or have automatic switch over to direct drive engines.

8.4 CONTROL OF PUMPING FACILITIES. Supervisory or remote control of electric motor-driven pumping units will be provided if such control will substantially reduce operator time at the facilities. Life cycle cost will apply.

CHAPTER 9
WATER SYSTEM DESIGN PROCEDURE

9.1 GENERAL. Water supply is an essential feature of any large project and water system planning should be coordinated with the design of the project elements, in order to insure orderly progress toward project completion, and with an installation's comprehensive water resource management plan, required in AR 420-46. Major elements of the water system, such as supply works, usually can be located and designed in advance of detailed project site planning. On the other hand, the design of the distribution system must be deferred until completion of topographic surveys and the development of the final site plan. The preparation of plans and specifications for water supply works, pumping stations, treatment works, supply lines, storage facilities and distribution systems requires the services of professional engineers thoroughly versed in water works practice. Cross-connections between potable and nonpotable water systems are prohibited.

9.2 SELECTION OF MATERIALS AND EQUIPMENT.

9.2.1 GENERAL. Selection of materials, pipe, and equipment should be consistent with system operating and reliability considerations, energy conservation, and the expected useful life of the project. To avoid delivery delays, standard equipment that can be supplied by several manufacturers should be specified. Delivery schedules must be investigated prior to purchase commitments for mechanical equipment. As a general rule, patented equipment, furnished by a single manufacturer, should be placed in competition with functionally similar equipment available from other suppliers. Equipment of an experimental nature or equipment unproved by actual, full-scale use should not be used unless specifically approved.

9.2.1 RESTRICTIONS. Materials, such as lead, copper, and asbestos, have in the past been commonly used in pipes and other components of water supply facilities but have been determined by the Environmental Protection Agency to be detrimental to public health. Any pipe and fittings used in a system providing water for human consumption shall contain no more than 8.0 percent lead and any solder or flux used shall contain no more than 0.2 percent lead. Copper contamination is a byproduct of the corrosion of copper pipe and fittings. Acidic groundwater is a common cause of corrosion of copper pipe - therefore copper materials should not come into contact with acidic water until after it has been neutralized. Since copper piping is common in plumbing systems, *National Primary Drinking Water Regulations* require that optimum corrosion control procedures be used for potable water systems. Asbestos and asbestos-cement products shall not be used.

9.3 ENERGY CONSERVATION. For each water supply alternative considered, energy requirements will be clearly identified and the design analysis will include consideration of all energy conservation measures consistent with system adequacy and reliability.

APPENDIX A
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APPENDIX B
SAMPLE WELL DESIGN

B.1 THE SITUATION. The owner has purchased approximately 100 acres for use as a site for a light manufacturing plant in the Midwest. The site is generally situated between two small towns on the western bank at a large river. Existing roads from the boundaries of the north and west sides, a railroad is on the east and undeveloped land on the south. A creek crosses from west to east along the northern portion and a large flat area exists for the facility. The site is generally overgrown with hardwoods and pines. The northern portion, at the base of the slope, is relatively flat and was once farmland. The small commercial area on the east and both towns are served by wells located in the plains between the river and the hilly area. A search of records, review of aerial photos and discussions with local residents indicates that no dumps or other potential sources of pollution exist in the watershed. A plan of the site is shown on figure B-1.

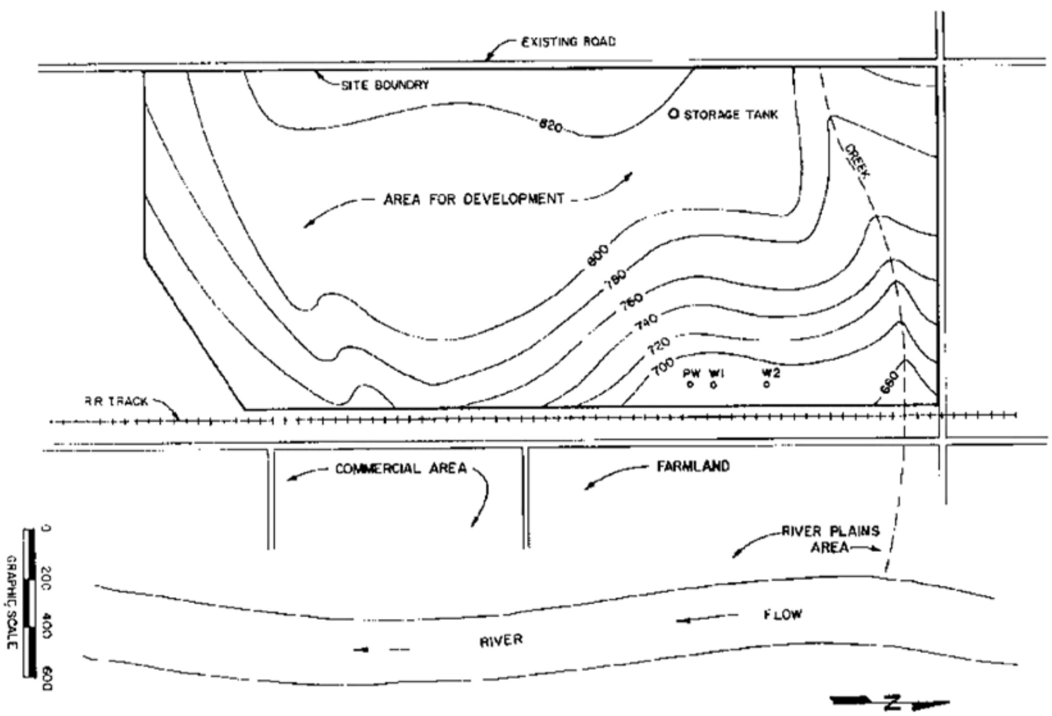

Figure B-1

Plan of Proposed Site

B.2 SITE SELECTION. Figure B-1 has been prepared from a U.S.G.S. topographic map. Contours, drainage and land use have been shown but vegetation has been omitted for clarity. The well must be located within the site boundary for security and to minimize the length of pipelines. Since the existing towns use the river plains area as a source of ground water, the flatland in the northeast has been chosen as a site for test drilling. It has good potential for recharge from the surface drainage and from the river. Available records indicate the 100 year flood level to be approximately at elevation 675 feet; therefore, the site is not subject to flooding. Three test wells were driven in the locations shown on figure B-1 and indicated by PW (pumping well), W1 and W2 (observation wells). A cross section of these three wells is represented by figure 5-3. The depth to the bottom of the aquifer is found to be 150 feet. Depth to static water level is 100 ft. A pumping test gives the following data:

Q = 200 gpm
r1 = 50.0 ft
h1 = 47.5 ft
r2 = 300.0 ft
h2 = 49.0 ft

Calculate aquifer permeability using equation 5-3:

$$P = \frac{1055\, Q \log (r_2/r_1)}{(h_2^2 - h_1^2)}$$

$$P = \frac{(1055)\,(200) \log (300/50)}{(49.0^2 - 47.5^2)}$$

$$P = 1134 \text{ gpd/sf}$$

B.3 SIZE THE WELL. A yield of 350 gpm is required. Table 5-3 indicates that a pump of 6-inch diameter will be required and the smallest well casing (and screen size) should be 8 inches. (Current pump manufacturers and screen manufacturers literature should be reviewed to confirm this.) Assuming R = 1000 ft. and a maximum drawdown of 15 ft. as depicted in figure 5-4, calculate the available yield:

$$Q = \frac{P\,(H^2 - h^2)}{1055 \log (R/r)}$$

$$Q = \frac{(1134)\,(50^2 - 35^2)}{(1055) \log (1000/.33)}$$

$$Q = 394 \text{ gpm (available from aquifer)}$$

The well should be designed to be drilled to the bottom of the aquifer. Screen manufacturer's literature shows that an 8" diameter telescoping screen has an intake area of 113 sq. in. per ft. of length; calculate length of screen required using equation 5-5:

$$L = \frac{Q}{A\,V\,(7.48)}$$

$$L = \frac{350}{(113/2/144)\,(4)\,(7.48)}$$

$$L = 30 \text{ ft.}$$

Note that the pumping water level will be above the top of the screen. Check screen entrance velocity:

$$V = \frac{(350 \text{ gal/min}) (.00223 \text{ cu. ft.-min/gal-sec})}{(30 \text{ ft}) (113 \text{ sq. in/ft})}$$

$$V = .01 \text{ ft/sec (ok)}$$

B.4 LOCATION. The well should be installed near the test pumping well (PW) and observation well (Wl) as shown on figure B-1. The exact location may be influenced by location of access roads, fences and other details. This leaves room for construction of an additional well for future expansion of the facility, north of the observation well (W2) which would be beyond the 250 ft. minimum spacing required.

B.5 WATER QUALITY. Samples are taken and analyzed in accordance with Standard Methods. Although the water quality is such that no treatment is required, chlorine will be added as a disinfectant in accordance with standard practice.

B.6 PUMP SELECTION. An elevated storage tank will be installed in the area of the facility to maintain a 40 psi minimum distribution system pressure at the maximum ground elevation of 820 ft. Approximately 1500 lin. ft. of 6-inch pipe will be required from the well to the tank. Calculate the TDH using equation 5-6:

B.6.1 Suction head is the distance from the ground (pump level) to the lowest elevation of water in the well. Assume this would be at the top of the screen. Add the distance to the water table plus depth of top of screen.

$H_S = 100 + 20 = 120$ ft.

B.6.2 Discharge head is the difference in elevation from the pump to the water level in the storage tank. Calculate the difference in ground elevation and add the required pressure. Assume the well is at El. 695.

$H_D = (820 - 695) + (40) (2.31) = 217$ ft.

B.6.3 Friction head is calculated by standard methods. Add head loss in pipe plus loss in fittings.

$$H_F = (18\text{ ft}/1000)\ (1.5) + 10 = 37\text{ ft.}$$

B.6.4 Velocity loss is calculated from the equation.

$$\frac{V^2}{2g} = \frac{(4)^2}{(2)\ (32.2)} = 0.25\text{ ft.}$$

B.6.5 Total dynamic head is the sum of the above.

$$TDH = 120 + 217 + 37 + 0.25 = 374\text{ ft.}$$

Calculate the pump horsepower using equation 5-7. Efficiency can be found in manufacturer's literature.

$$P = [(303)\ (350)]/[\ (3960)\ (0.65)] = 41.2\text{ hp}$$

B.7 SPECIFICATION PREPARATION. Given the above information, the designer can review manufacturer's literature and consult with their representatives to determine types of pumps and motor drives which are available to meet the operating conditions. The calculations can then be refined to account for actual pump and well characteristics. Although not a function of well design, the engineer may want to oversize the transmission main from the well to the storage tank to allow for future expansion or make other modifications in the design. The calculations should be reviewed when all systems are finally sized. The well diameter may be oversized to allow for future installation of a larger pump, but the pump installed should not exceed the capacity of the well. This procedure gives sufficient information to specify a water well.

B.8 CONSTRUCTION DETAILS. Since this area is subject to freezing temperatures and other climatic conditions which would be detrimental to an exposed pump and motor, a small building should be erected for protection. The floor of the building should be raised above grade and the foundation extended below frost depth. A separate room with access only from the outside should be provided for the chlorination equipment. The well casing should be extended above the floor approximately 12 inches and concrete placed to this level for the pump base. Electric power can be provided from the main facility. Some small parts storage may be provided.

APPENDIX C
DRILLED WELLS

C.1 METHODS. Drilled wells are normally constructed by one of the following methods:

- Hydraulic Rotary
- Cable Tool Percussion
- Reverse Circulation Rotary
- Hydraulic-Percussion
- Air Rotary

These methods are suitable for drilling in a variety of formations. Diameters may be as large as 60 inches for wells constructed by the reverse circulation method. Smaller diameter wells may be constructed by drilling to depths of 3000 or 4000 feet. For a detailed discussion of these methods, see *Ground Water and Wells* by Johnson Division, UOP Inc. The first two methods listed are the most common in well construction and a brief description of each follows:

C.1.1 In the hydraulic-rotary method of drilling, the hole is formed by rotating suitable tools that cut, chip, and abrade the rock formations into small particles. The equipment consists of a derrick, a hoist to handle the tools and lower the casing into the hole, a rotary table to rotate the drill pipe and bit, pumps to handle mud-laden fluid, and a suitable source of power. As the drill pipe and bit are rotated, drilling mud is pumped through the drill pipe, through openings in the bit, and up to the surface in the space between the drill pipe and the wall of the hole, washing the drill cuttings out of the hole at the same time. The borehole is kept full of a relatively heavy mud fluid. Due to its viscosity, this fluid exerts a greater pressure against the walls of the hold than the water flowing in from the water-bearing bed. Therefore, the mud tends to penetrate and seal the pore spaces in the walls, and prevents caving. Water under low hydrostatic pressure (pressure exerted by the weight of the water in the water zone) cannot force its way into the hole.

C.1.2 In the cable tool percussion method of drilling, the hole is formed by the pounding and cutting action of a drilling bit that is alternately raised and dropped. This operation is known as spudding. The drill bit is a club-like, chisel-type tool, suspended from a cable. As the bit is raised and lowered, the cable unwinds and rewinds, which gives the bit a grinding motion as well as a chisel-type action. It breaks hard formations into small fragments and loosens soft formations. The reciprocating motion of the drilling tools mixes the loosened material into a slurry that is removed from the hole at intervals by a bailer or sand pump.