A GROUND WATER MANUAL FOR SMALL COMMUNITIES

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PREFACE

The purpose of this manual is to give the leaders of small communities an introduction to the administrative and technical aspects of establishing a community water system. It is not intended as a "how to" manual. Rather, the intent is to present basic information about small water systems so community leaders can communicate more effectively with regulatory agencies, funding sources, consultants, and contractors. Each chapter has been written as an individual unit so that the reader can refer to the manual on a chapter by chapter basis as questions or problems arise during the establishment of a community water system.

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CHAPTER 1

REASONS FOR ESTABLISHING A COMMUNITY WATER SYSTEM

According to the 1970 census, 3.6 million people in the United States live in housing without running water. Although accurate statistics are sparse, it would be fair to say that most of these people live in rural areas or in communities with fewer than 500 residents. One recent study estimated that 95 percent live in communities of 10,000 people or less. These people often collect water in cisterns or haul water from nearby wells, springs, ponds or streams. According to a 1978 study, the majority of these people believe that such individual water supplies are inadequate and many would participate in a community water supply system if they could afford it (1).

One of the reasons for preferring community supplies is that individual wells have high rates of contamination. A 1968 study, for example, estimated that 18 million people in communities of 10,000 and under use contaminated water (2). Although some individuals accepted the notion of poor water and low cost, many individual well owners expressed a willingness to participate in a community water supply system if the increased cost could be accompanied by an improvement in water quality. By pooling resources a community may be able to either find and develop a better water source or construct and operate treatment facilities for water obtained from the old source.

FACTORS AFFECTING THE ESTABLISHMENT OF COMMUNITY WATER SYSTEMS

Availability, cost, and socio-economic factors affect the likelihood of development of community water systems. Individual well supply is a problem in some areas. Over-pumping has significantly lowered the water table in many parts of the United States. Dropping water tables may cause individual wells to "dry up." Deeper wells can be drilled but drilling costs and energy costs for pumping are high and are likely to increase. Community systems can afford to drill deeper wells or to locate and develop new sources of water for the community.

Cost is always a crucial factor in the decision to develop a community water system. Prospective residents and residents with inadequate wells or no wells are usually willing to support a community system. Individual wells are expensive -- construction costs can range from $1200 to $7000 per well (3) and operation and maintenance costs vary from $3.00 to $9.00 per month depending on the quality of the ground water and the degree of treatment (4). For comparison, the National Water Demonstration Project found that the average monthly water bill for community water systems serving 10,000 or less was $12.00 (5). If one takes into account the fact that the capital costs of new individual wells are often financed through loans (at market rates of 10 percent to 20 percent currently), the cost of supplying a family with water from an individual well may exceed the cost of water from a community system (see example calculations in Table 1.1). By supporting a community water system, prospective residents and residents with unsatisfactory wells are able to avoid the costs of installing expensive individual wells.

Residents with reliable wells, on the other hand, may have a different point of view. They have already made the initial investment in an individual water supply system. To join a community water system, it may be necessary to pay a "hook-on" charge. It is also possible that the operation and maintenance costs of an individual well will be lower than the monthly water bill for a community water system.

Although water quality, declining water tables, and cost are primary considerations, there are also social and economic impacts which affect the demands for a community water system. Improved health resulting from cleaner water and reduced fire losses and insurance premiums due to improved fire protection are two commonly cited benefits of community water supply systems. Table 1.2 lists some community water supply system impacts.

Table 1.1

Estimated Monthly Costs for an Individual Well

	Monthly Cost
Monthly cost of a new well and pumping system*	$20
Operation and maintenance	$ 4
Treatment (water softening and disinfection)	$ 8
Total	$32

*Based on a $2000 investment at 10% interest and a 20 year system life.

Source: From data presented in Drinking Water Supplies in Rural America, Washington, D. C.: National Demonstration Water Project, 1978, pp. 47-48.

Table 1.2

Impacts that the Development of Water Facilities May Have on Rural Communities

1. Improved housing, due to
   a. Increased household water consumption;
   b. Increased number of houses having piped water;
   c. Increased use of water-using appliances;
   d. Better sanitary conditions;
   e. Increased housing values.
2. Decreased incidence of waterborne disease, due to
   a. Reductions in intestinal disorders, such as paratyphoid, cholera, infectious hepatitis, gastroenteritis, diarrhea, dysentery, and worms;
   b. Reductions in typhoid fever;
   c. Reduction in skin diseases.
3. Decreased health costs, due to
   a. Fewer visits to hospitals by infants with diarrhea;
   b. Decreased usage of health services.
4. Increased labor productivity, due to
   a. Better general health and vitality;
   b. Lower morbidity rates;
   c. Longer productive lives.
5. Increased economic development, due to
   a. Attraction of water-oriented industries or expansion of existing ones;
   b. Expansion of commercial farming operations;
   c. Better employment opportunities;
   d. Increased areal income and revenues;
   e. Income redistribution;
   f. Increased real estate values;
   g. Increased residential building;
   h. Reductions in water-related expenditures, such as water revenues, costs of hauling water, and costs of repairing and replacing pumping equipment and water-using appliances.
6. Increased fire protection, due to
   a. Decreased fire losses;
   b. Decreased fire insurance rates.
7. Stabilized rural populations, due to
   a. Attraction of new rural nonfarm residents;
   b. Slowing of out-migration to urban areas;
   c. Retention of the rural young.
8. Improved school performance, due to
   a. Reduced absenteeism for health reasons;
   b. Improved personal hygiene affecting social acceptance by fellow students and teachers.
9. Improved community attitudes, due to
   a. Better sanitary conditions;
   b. Improved personal hygiene;
   c. Perceived new capabilities for community growth.
10. Greater community participation due to
    a. Stronger local leadership;
    b. Improved community attitudes towards cooperation.
11. Increased amenities, due to
    a. Reduced anxiety concerning water shortages;
    b. New laundry and car wash facilities;
    c. Increased capability for lawn and garden watering;
    d. Better sanitary conditions;
    e. Greater convenience regarding food preparation, personal and household cleanliness, and excreta disposal.

Source: Drinking Water Supplies in Rural America, Washington, D. C.: National Demonstration Water Project, 1978, p. 53.

Reasons for Not Establishing a Community Water System

Even though rural residents are often dissatisfied with their current water supply, they still may oppose efforts to establish a community system, regardless of its benefits. Four reasons for this opposition, in addition to the cost considerations previously mentioned, are listed in Table 1.3.

THE IMPORTANCE OF LEADERSHIP

Community water projects are typically initiated by a small group of local citizens who recognize the need for a community system. This small group may be an ad hoc organization of residents who are dissatisfied with their current water supply, or it may be a committee within an existing civic organization. Occasionally, a strong local leader or public official may initiate the project on his own.

Local leadership is a key ingredient to the successful development of a community water system. State and federal agencies may provide technical and financial assistance, but it takes local support to initiate the project and to keep it going. It can take up to seven years or more to complete a community water system. During this time local citizens must remain convinced of the merits of the proposed community system so that the appropriate consultants may be hired, agencies contacted, and forms completed. A lack of leadership

Table 1.3

Reasons for Community Opposition to the Development of a Community Water System

1. Some rural communities want to remain as they are. They don't want another bill to pay or another utility with which to deal.

2. Other rural communities may oppose change for environmental reasons. Community water systems often promote development, and with development comes pollution and changes in rural landscape.

3. Some communities have become frustrated by previous attempts to establish community water systems. Naturally, they will be skeptical of any new attempts.

4. Rural communities may lack leadership with the expertise necessary to pursue the long complicated process of developing a community water system.

Source: Adapted from Drinking Water Supplies in Rural America, Washington, D.C.: National Demonstration Water Project, 1978, pp. 95-96.

at any point in the process will inevitably prolong the project.

The first step in the process is the establishment of a water supply organization. Chapter 2 discusses the most common types of water system ownership. The regulation and financing of water systems are presented in Chapters 3 and 4 respectively. Once a water system organization is established and its financing options determined, the technical aspects of building a water supply system can then be addressed. These technical aspects are discussed in Chapters 5 through 12.

REFERENCES

1. Drinking Water Supplies in Rural America, Washington, D.C.: National Demonstration Water Project, 1978, pp. 95-96.

2. Lucia H. Beverly, "Status of Water and Sewage Facilities in Communities Without Public Systems," Agricultural Economic Report No. 143, Economic Research Service, U.S. Dept. of Agriculture, Oct. 1968, as cited in Drinking Water Supplies in Rural America, 1978, p. 31.

3. John T. Massey-Norton, Doug Bacon, Michael Eberle, and Tyler R. Gass, Rural Water Supplies: A Cost Comparison of Central, Cluster, and Individual Source Systems, Worthington, Ohio: National Water Well Association, 1979, p. 4.

4. Drinking Water Supplies in Rural America, 1978, p. 48.

5. Ibid, p. 40.

CHAPTER 2

TYPES OF OWNERSHIP

Community water systems may be privately owned or publicly owned. Small systems serving less than 500 people are typically privately owned. Larger systems are usually owned by local governments. Table 2.1 shows the distribution of community water systems by ownership as reported in a 1975 EPA survey.

PUBLIC SYSTEMS

Public water systems may be owned by municipal governments, counties, townships, or by special water districts. If a community is incorporated, the municipal government usually has the power to construct, own, and operate a water supply system provided such authority has been granted in the city's charter or by its voters. The municipal water system may be established in the following ways:

- As an independent municipal department with a manager who reports directly to the mayor.
- As a section of a larger municipal agency such as a department of public works.
- As a special autonomous department in city government.

Table 2.1

Distribution of Systems by Ownership
1975

Population Category

	25-99	100-499	500-999	1,000-2,499	2,500-9,999	5,000-9,999	10,000-99,999	100,000-999,999	1 million	Total
Public	12	98	77	100	54	39	70	162	10	622
Private	133	137	18	16	9	3	15	30	1	362
Total	145	235	95	116	63	42	85	192	11	984

Source: Temple, Barker, and Sloane, Inc., Survey of Operating and Financial Characteristics of Community Water Systems, Washington, D. C.: Office of Water Supply, U. S. Environmental Protection Agency, April 1977, p. IV-3.

Municipal water systems are expected to be self-supporting. Water service charges should provide sufficient revenue for the system's operation, maintenance and debt retirement. Since water can be sold to users, some municipal water systems are actually able to produce revenue in excess of their financial requirements. These funds are often used to support other municipal services.

Small communities that want to establish public water systems but cannot or would rather not incorporate may choose to establish special water districts. These districts are special-purpose governmental units which are independent of cities and counties. Water districts have the authority to supply water and other water-related services to residents within a designated area, which may vary from a few acres to several counties.

Water districts may be created as a result of local initiative or as a result of state legislative action. State legislatures have the authority to create water districts by passing special laws which define the organizational structure and jurisdiction of the district. If a certain percentage of taxpaying residents in a community sign a petition for the creation of a water district, then the petition is reviewed and hearings are held by a state agency or county commissioner's court. Elections are usually required to obtain approval from the voters in the proposed service area.

PRIVATE SYSTEMS

Private water systems may be profit-making proprietorships, partnerships or corporations, or they may be non-profit water supply corporations. Private water systems do not need the approval of voters or local public officials in order to operate in an area. However, profit-making water systems must pay taxes. Furthermore, the initial investment for water systems is very high and profit-making systems are not eligible for various state and federal grants or loans. Profit-making systems are required to meet all federal and state drinking water standards and, due to the lack of access to financial aid, may be at a competitive disadvantage to public systems.

Non-profit water supply corporations, on the other hand, have many of the advantages of both public and private water systems. A non-profit water supply corporation can be formed by three or more citizens who apply to the appropriate state agency for a charter of incorporation on a not-for-profit basis. As a result of its non-profit status, a water supply corporation is granted more authority than a private system. In some states, it can exercise eminent domain and it may issue bonds. Non-profit water supply corporations also receive important tax benefits. As with private water systems, the voters' approval is not needed for the creation of a non-profit water supply corporation and there are no jurisdictional limits to its service area.

Rural water systems serving less than 10,000 people have typically been owned by special water districts or by non-profit water supply corporations. However, a community should compare all the ownership options before deciding what type is best to meet its water supply needs. Two important factors to consider in making the decision are the regulation and financing of the water system. These factors are discussed in more detail in Chapters 3 and 4.

CHAPTER 3

REGULATION

Although water supply is primarily a local responsibility, state and federal governments as well as private organizations have a lot to say about the establishment, design, and operation of water supply systems in the United States. Governmental regulation occurs because (a) a water system must obtain a legal right to operate and to draw water, (b) it operates as a utility, and (c) it has a direct impact on the health and environment of a community. Water systems may also be indirectly regulated by governmental agencies which provide financial aid to small communities for the construction of water supply systems. A few private organizations indirectly regulate community water systems. The American Water Works Association, a professional organization of water utility personnel, actively promotes mandatory certification of water operators, conducts training programs for operators, and develops standards for the water supply industry. Another important regulator is the National Board of Fire Underwriters. This group evaluates water supply systems for their adequacy in providing fire protection. If fire protection and lower fire insurance rates are among a community's goals in establishing a water system, then water system developers should consult the standards of the National Board of Fire Underwriters.

OPERATING RIGHTS AND WATER RIGHTS

All publicly owned water supply systems must comply with the state laws regarding their creation and operation. City charters must also be consulted and petitions or votes may be necessary to establish a water system in an area. Private water systems must either file for incorporation or must legally establish a proprietorship or partnership according to the laws of each state.

A water system must also be able to obtain water to distribute to the community. Surface water is often owned and regulated by the state. Thus, water supply systems may need to apply to a unit of state government (often a state water commission) for a permit to withdraw water from a surface water source such as a lake, reservoir, or river. The use of ground water is also regulated in many states, either by a state water commission or by a special ground water protection district. In other states, such as Texas, landowners are entitled to any water that can be captured from beneath their land. Thus, water supply systems need only to own land with adequate ground water beneath the surface in order to be assured of the use of that water. This doctrine has resulted in problems in many areas since ground water is not stationary but moves from one place to the next without respect for property lines on the surface.

HEALTH AND ENVIRONMENT

Water supply systems have important effects on the health of a community's citizens as water is used by individuals for drinking, bathing, and cooking. As a result, water systems are regulated by state health departments to ensure that the public water is of sufficient quality and quantity to promote health. State health departments are concerned with the design of a water system, the operation and maintenance of the system, and the quality of the water delivered to the public. Some of the ways in which state health departments regulate water supply systems are listed in Table 3.1.

With the passage of the federal Safe Drinking Water Act (Public Law 93-523) in 1974, the U.S. Environmental Protection Agency (EPA) has also become involved in the regulation of drinking water quality. This act directs the EPA to establish and enforce water quality standards for all water systems which regularly serve at least 25 individuals or have at least 15 service connections. In most cases, EPA has designated state health departments to enforce the new drinking water standards within each state. Thus, the state

Table 3.1

Some Principal Ways in Which
State Health Departments Regulate Water Supply Systems

1. Plans and specifications for new water supply facilities or for renovations to existing water supply facilities must be submitted to and approved by the state health department before construction may begin.

2. Water supply operators must be certified through the health department's certification program.

3. Water samples must be submitted to the health department at regular intervals to ensure that the water is safe. State health departments are also authorized to collect their own samples from non compliant water systems if necessary.

health department is responsible for ensuring that water supply systems meet federal as well as state drinking water quality requirements.

WATER UTILITY REGULATION

Water supply systems, whether publicly or privately owned, operate as monopolies in the areas in which they serve. Thus, their rates, assets, and financial policies are usually regulated. Most states have some type of public utilities commission which reviews private water system rates and, in some states, public system rates as well. In general, the purpose of these utility commissions is to ensure that the water system's revenues equal the water system's costs plus a fair rate of return. The fair rate of return is usually calculated as a percentage of a rate base which the utility commission determines by evaluating the plant investment. Usually, the public utility commission has the power to require that the water supply company justify all rate increases.

In most states, municipal systems and other publicly owned water systems can charge whatever the local citizens feel is reasonable. Some public systems charge only what is necessary to meet the system's costs. However, many municipal systems are able to charge more than that which is necessary to meet costs, and they use the surplus revenues to support other municipal programs.

Except for EPA's responsibility in establishing National Drinking Water Standards, most federal regulation of water supply systems is indirect. Nevertheless, this indirect federal regulation can be substantial for rural community water supply systems. The Farmers Home Administration (FmHA), a primary federal funding source, must approve the design and construction of all water supply systems which it funds. FmHA's Washington office issues broad regulations on the planning, bidding, contracting, and construction of water systems, and state FmHA offices may supplement these regulations with formal design standards if they wish. FmHA offices in states such as Texas, Ohio, and Mississippi have established standards related to instantaneous flow and storage capacities.

Since most small communities obtain funds through state or federal financing programs, it is important to determine the most likely funding source. This will allow an engineer to incorporate the applicable standards and requirements into the water system design. The following chapter outlines the financing options available to small communities.

CHAPTER 4

FINANCING

Three phases of water system development require financing: planning, construction, and operation. Before discussing the financing for each phase, it is useful to separate private profit-making water systems from all other types of ownership. Planning and construction of a profit-making water system almost always must be financed using private capital. Government funds are seldom available to these private systems. The expected income from water rates charged to customers during the operating phase must be attractive enough for private investors to risk an investment in a water supply project.

There are exceptions, however. Private investor owned water systems are often found in residential developments, "planned" communities, and trailer parks. In these cases, water supply system costs are just one portion of the overall project development cost. Some private water systems, those found in trailer parks for example, do not even use water service charges to recover their investment. These charges are often included in the overall charges for trailer space.

If private investors were to find that it would be profitable to construct and operate a water system in an established community, then community leaders should have little trouble in getting the investors to establish a water system. Today, this situation would be unusual. Most small communities have found that government grants and low-interest loans are necessary to establish water systems which their citizens will be able to afford. Since government loans and grants are only available to publicly-owned systems and non-profit corporations, the remainder of this chapter will concentrate on the financing options available to these water systems.

PLANNING AND CONSTRUCTION

There is no federal program which provides funds directly to small communities for water supply planning or feasibility studies. Planning assistance is available in a few states. North Carolina, for example, provides interest-free planning advances for the comprehensive planning of regional water supply systems. The state of Washington offers loans to communities for comprehensive water supply planning and for preconstruction engineering (1). Financial assistance for community water supply planning is not available in most states, however.

Communities may be able to obtain planning assistance from regional planning commissions or Councils of Government (COGs). Some of these associations of local governments have developed comprehensive water system feasibility studies which can be used by local governments. The COGs can also assist communities in identifying available sources of funding. If federal funds are desired for the construction phase, the local COG should definitely be contacted by community leaders, as COGs often administer the A-95 federal coordination review and comment system. Under this system, the COG reviews federal grant applications to determine if local water supply projects are consistent with regional water supply plans.

In most cases, communities obtain local funds for the planning phase of their water supply system. The planning phase usually does not involve large sums of money. In fact, some engineering firms will undertake water system planning or feasibility studies at bargain prices with the understanding that they will be awarded with future design contracts.

The construction phase of a community water supply project is much more difficult to finance. This phase includes the detailed engineering design, the submittal of the design to state regulatory agencies, the construction of the system, and in most cases, the start up costs. Large capital costs are involved. Communities usually obtain the necessary revenues from a variety of sources, but some funding sources are not available to certain types of water systems. Table 4.1 shows what types of funding are available for each water system ownership type.

General Obligation Bonds

General obligation bonds are guaranteed by the full faith and credit of the entity which issues the bond. Bond owners hold a claim against the general revenue or other income of the entity and not just the income from the water system.

State constitutions and/or legislatures usually limit the general obligation borrowing power of local governments. Limitations may be direct, by limiting local indebtedness to a certain percentage of the local government's property base, or indirect, by requiring a local referendum before the debt can be issued, or both. Table 4.2 rates the states according to the degree of debt restrictiveness placed on local governments.

Revenue Bonds

Revenue bonds are repaid only from the revenues of the facility being built. They are not guaranteed but are backed by trust and, as a result, carry higher interest rates. Legal limitations on local debt do not apply to revenue bonds in many states. Consequently, revenue bonds have become more common in recent years.

Table 4.1

Funding Sources and Types of Water System Ownership

Funding Source	Ownership Type: Public		Ownership Type: Private	
	Municipal	Special Water District	Non-Profit Corporation	Profit Making
General Obligation Bonds[1]	X			
Revenue Bonds[1]	X			
Federal Loans and Grants[2]	X	X	X	
State Loans and Grants[3]	X	X		
Current Revenues	X	X	X	X
Private Investment			X	X

[1]This table serves only as a general guide. Bonding powers vary from state to state.
[2]For a more detailed description of federal programs and eligibility requirements, see Table 4.3.
[3]See Table 4.6 for eligibility requirements for each state.

Table 4.2

Local Governments: Debt Restrictiveness

Group I	Group II	Group III		
Conn.	Calif.	Ala.	Ky.	S.C.
Del.	Me.	Ariz.	La.	S.D.
Kan.	Mass.	Ark.	Mich.	Tex.
Md.	Miss.	Colo.	Mo.	Utah
Minn.	Neb.	Fla.	Mont.	Wash.
N.H.	Nev.	Ga.	N.M.	W. Va.
N.J.	N.Y.	Ida.	Ohio	Wis.
N.C.	N.D.	Ill.	Okla.	Wyo.
R.I.	Tenn.	Ind.	Ore.	
Vt.	Va.	Iowa	Pa.	

Group III Most Restrictive. Constitutional limitation with a simple or special majority referendum.

Group II Less Restrictive. Constitutional limitation but legislative action to authorize debt issues *or* a special majority authorization requirement coupled with a statutory debt limitation.

Group I Least Restrictive. Statutory debt limitation and either legislative action or a simple majority referendum necessary to authorize debt issues.

Source: *State and Local Capability to Share Financial Responsibility of Water Development with the Federal Government*. Washington, D.C.: U.S. Water Resources Council, 1971, as cited in *Drinking Water Supplies in Rural Communities*, Washington, D.C.: National Demonstration Water Project, 1978, p. 73.

Federal Loans and Grants

Federal funds for small community water system construction are available primarily from the Farmers Home Administration (FmHA) and the Department of Housing and Urban Development (HUD). Funds have also been available through the Economic Development Administration (EDA). The Environmental Protection Agency (EPA) has been authorized to provide loans to assist communities to comply with the Safe Drinking Water Act, but Congress has not yet appropriated any funds for the loan program. Table 4.3 lists the federal programs by agency, describes the type of aid available, and lists the types of water systems which are eligible for funds under each program.

FmHA is the most important source of federal funds for small community water projects. In 1976, FmHA provided rural areas and small communities with $443 million in small loans and $147 million in grants for water and sewer projects (2). Some states have more active FmHA programs than others. Table 4.4 shows which states and regions of the United States received the largest amount of FmHA grants and loans. Table 4.5 lists some of the criteria which must be met for FmHA loans and grants.

State Loans and Grants

Twenty-five states have funding programs for water facilities but the majority of the programs are not

Table 4.3

Federal Sources of Financial Assistance to Small Public Water Systems

Agency	Program	Type of Aid	Clients
Farmer's Home Administration	Rural Water and Waste Disposal Systems	loans & grants	political subdivisions, private or public non-profit corporations
Economic Development Administration	Public Works Facilities	grants	associations representing an EDA-designated area or EDC, such as: -political subdivisions -Indian tribes -private or public non-profit corporations
	Supplemental 304 Projects	grants & loans	
Department of Housing and Urban Development	Community Development	grants	SMSA or non-SMSA local governments
Environmental Protection Agency	Safe Drinking Water Act	loans	public water systems

Source: Adapted from Junek, Larry J., and Aileen C. Whitfill, "Financial Assistance for Safe Water; A Guide to Small Water Systems on Obtaining Aid," Austin, Texas: Safe Drinking Water Policy Research Project, Lyndon B. Johnson School of Public Affairs, The University of Texas at Austin, 1978.

Table 4.4

Geography of FmHA Grant and Loan Programs
FY 1976

States Receiving Largest Amount of Grant Dollars in FY 1976

State	Percent of All Grant Dollars
Texas	6.3%
North Carolina	5.4
Pennsylvania	4.9
Virginia	4.6
Georgia	4.6
Ohio	4.5

States Receiving Largest Amount of Loan Dollars in FY 1976

State	Percent of All Loan Dollars
Mississippi	5.5%
Pennsylvania	4.9
North Carolina	4.9
Texas	4.7
New York	4.1
Ohio	3.7

Regions Receiving Largest Amount of Grant Dollars in FY 1976

Region	Percent of All Grant Dollars
Southeast	25.3%
Great Lakes	19.3
Southwest	14.6
Mid-Atlantic	14.3
Midwest	5.5
N.Y. — N.J.	4.8
Rocky Mtns.	4.8
Pacific SW	4.8
Pacific NW	3.5
New England	2.4

Regions Receiving Largest Amount of Loan Dollars in FY 1976

Region	Percent of All Loan Dollars
Southeast	28.4
Great Lakes	17.2
Southwest	11.6
Mid-Atlantic	11.0
N.Y. — N.J.	9.7
Midwest	6.0
Rocky Mtns.	5.4
New England	4.0
Pacific SW	3.7
Pacific NW	3.0

Source: Farmers Home Administration, as cited in Drinking Water Supplies in Rural America, Washington, D. C.: National Water Project, 1978, p. 81.

Table 4.5

Major Requirements for Farmers Home Administration
Grants and Loans

1. The water system must be located in a rural area which was defined in the 1972 Amendments to the Consolidated Farm and Rural Development Act as an area containing no city or town over 10,000 in population.

2. The system must primarily benefit farmers, farmworkers, and other rural residents.

3. The facility must be consistent with areawide plans.

4. It must be able to serve the present population and the forseeable growth needs of the area.

5. The system must be located in an area which is not expected to decline in population below the level for which the project was designed.

6. The residents of the area must be able to afford the system, including the repayment of the FmHA loan.

specifically for community water supply projects. Only Texas and New Mexico provide major financial support for domestic water supply needs (3). Table 4.6 lists those states which have financial assistance programs and provides basic information about the programs.

In general, state financial assistance programs for water system construction are much smaller than federal programs. In fact, state funds are often intended only to supplement funds obtained from federal or other sources. In North Carolina and Kansas, state funds are contingent upon the eligibility of the proposed water supply project for federal funds.

Current Revenues (Operating Surplus)

Established, operating water systems sometimes finance a portion of their capital improvements through the use of excess revenues. Of course, a new water supply system will not have this option, except in the case of an existing local government which has surplus income from other sources and is considering using this surplus income to partially finance the capital cost of a new water system. Most local governments finance their share of the water facility construction costs through bond issues rather than current revenues.

The results of an EPA survey are shown in Table 4.7 which describes the sources of funding used by water systems to finance capital expenditures from 1970-1975. This table

Table 4.6

State Financial Assistance Programs for Water Facilities

State	*Principal Administering Department*	*Eligible Applicants*[1]	*Total Funding*[2]	*Type*[3]	*Basic Terms*[4]
Alabama	Public Health	Community water systems	Annual Appropriation	G	Up to $300 per system user
Alaska	Environmental Conservation	a. Villages (25-600 persons living within a two-mile radius)	a. $4.2 million	G	Up to 100% construction costs
		b. Incorporated local communities	b. no information	G	Up to 50% construction costs
Arkansas	Local Services	Cities, towns, and counties	$3 million	G&L	Up to 25% total project costs
California	Water Resources	Domestic water systems serving at least 25 persons or 15 service connections	$175 million	L	Max. $1,500,000/50 yrs. Max. $400,000
Colorado	Water Conservation Board	Domestic water supply systems	$10 million	L	Up to 100%/50 yrs.
Georgia	Natural Resources	Local units of government	Annual Appropriation	G	Up to 100% but no more than 1/8 annual appropriation or $500,000
Indiana	Natural Resources	Cities, towns, conservation on special taxing districts with populations of not more than 1,250	$2 million	L	Max. $150,000/20 yrs./1.5% 1st 5 yrs., 8% remaining 15 yrs.
Kansas	Board of Agriculture	Rural water districts	$2 million	G	Max. 59% total development costs
Missouri	Natural Resources	No information	Annual Appropriation	G	Up to $600 per system connection
Nebraska	Office of Planning & Programming	Not identified	$2 million	G&L	No information
New Mexico	Health & Social Services	Incorporated local governmental units, water cooperative or mutual domestic association, or sanitation district	Annual Appropriation	G L	Max. $100,000 Max. $100,000/20 yrs./5½% interest
North Carolina	Human Resources	Local unit of government	$70 million	G L	Up to 25% project costs
North Dakota	State Water Commission	Municipal water supply systems	No information	G	50% or $200,000
Ohio	Environmental Protection Agency	Villages with populations under 5,000	No information	L	Interest free/10 yrs.
Pennsylvania	Commerce	Boroughs or townships with population under 12,000	Harness Race Wagering Revenues	G	75% or $75,000 of eligible costs
South Carolina	Health & Environmental Control	Rural water systems serving communities under 1,500 population	$700,000	G	Max. 25% or $300 per connection or $200,000
South Dakota	Natural Resources	Nonprofit or governmental entities supplying water to rural areas	$2 million	G	Up to 10% or $300,000
Tennessee	Public Health	Local units of government with taxing ability	$45 million	L	Up to 100% but not more than 25% annual appropriation/30 yrs. variable interest rate

Table 4.6 (Cont'd.)

State	*Principal Administering Department*	*Eligible Applicants*[1]	*Total Funding*[2]	*Type*[3]	*Basic Terms*[4]
Texas	Water Development Board	Local units of government	$500 million	L	3½ to 4% interest rate
Utah	Community Affairs	Municipalities	$4 million	L	No max./no interest rate
Vermont	Water Resources	Municipalities	No information	G	Max. 35% eligible costs
Washington	Social & Health Services	Public bodies	$50 million	G L	Up to 40% eligible costs Up to 100%/no interest/5 yrs.
Wisconsin	Natural Resources	Public water supply systems serving municipalities	$1 million Annual Appropriation	G	Up to 25% or $100,000 or 10% of annual appropriation
Wyoming	Public Lands and Farm Loans	Local units of government	$120 million State Land Lease Revenue	G L	Up to 100% No max./5½% interest rate

[1] Special exceptions are permitted for most programs.
[2] Total multi-year funding unless indicated.
[3] G–Grant; L–Loan.
[4] For more complete information contact administering state agency.
Source: Adapted from *Drinking Water Supplies in Rural America* (Washington, D.C.: National Demonstration Water Project, 1978), pp. 75-77.

Table 4.7

Sources of Financing Capital Expenditures For Systems Reporting Specific Sources*

(six-year period 1970-1975)

	Population Category								
	25-99	100-499	500-999	1,000-2,499	2,500-4,999	5,000-9,999	10,000-99,999	100,000-999,999	> 1 million
Percentage of Capital Expenditures Financed Through:									
Bonds	8.1%	39.6%	39.8%	32.8%	29.8%	28.0%	39.2%	58.9%	22.9%
Revenue Bonds and Special Debt	-	18.4%	-	5.0%	6.5%	12.7%	6.2%	14.4%	37.5%
Federal Loans	0.7%	13.5%	16.8%	38.3%	54.4%	14.3%	6.9%	0.6%	-
New Equity Issues	2.6%	5.3%	17.9%	5.0%	3.3%	0.1%	7.5%	1.3%	9.6%
Operating Surplus plus Other Internal Sources	88.6%	23.2%	25.5%	18.9%	6.0%	44.9%	40.2%	24.8%	30.0%
TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Number of Systems Financing Through:									
Bonds	3	9	7	13	7	5	15	70	3
Revenue Bonds and Special Debt	-	1	-	2	2	2	3	19	2
Federal Loans	1	7	4	11	5	3	5	5	-
New Equity Issues	2	7	4	6	4	1	5	3	1
Operating Surplus plus Other Internal Sources	35	40	19	26	10	9	32	57	2

*Based upon systems reporting sources of financing; excludes multiple financing sources reported for a single expenditure.

Source: Temple, Barker, and Sloane, Inc., Survey of Operating and Financial Characteristics of Community Water Systems, Washington, D. C.: Office of Water Supply, U. S. Environmental Protection Agency, April 1977, p. VIII-23.

includes capital expenditures for water system improvements as well as for new water systems. Construction financing is usually a complicated and difficult process, but local Councils of Governments (COGs), FmHA, state health department employees, and engineers can help a small community in locating funding sources. More than one outside funding source is often used, but local citizens will always be called upon to put up a substantial portion of the construction financing through local means.*

OPERATION

There are no state or federal programs which offer subsidies to water systems once the system is operational. A recent research project found that there "is deep-rooted belief that users ought to pay for water service, whatever its cost" (4).

Costs during the operating phase include operation and maintenance costs, debt service or interest expenses, taxes or payments in lieu of taxes, and depreciation. Water systems meet these costs through a variety of income sources: water rates, connection fees, budget appropriations from local

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* FmHA is authorized to provide up to 50% of the eligible project costs of water facilities, but the agency has consistently underfunded water supply projects. See Drinking Water Supplies in Rural America, NDWP, 1978, pp. 144-145.

government entities, and labor contributions.

Water Rates

Water rates are the most important source of income for most water systems. Four of the most common types of water rates used by small community water systems are flat rates, uniform rates, step rates, and declining block rates.

Some small systems charge a flat rate for providing water service, regardless of how much water each customer uses. Flat rates are most common in water systems serving populations of less than 5,000. The advantage of using flat rates is that meters and meter-readers are not necessary. The disadvantage is that low-volume users pay more than their share of the system's costs.

Under a uniform rate structure, customers pay a certain price per unit of water consumed; for example, each customer pays one dollar for each 1000 gallons of water consumed. Metering is required, but water bills are simple to administer.

Water systems using a step rate structure base each customer's water rate on the quantity of water consumed by that customer. For example, customers who use 4000 gallons per month or less may pay $1.00 per 1000 gallons, while customers using over 4000 gallons may pay only $0.80 per 1000 gallons. Step rates are only slightly more complicated to administer than uniform rates, but they are not popular because low-use customers must pay higher water rates than high-use customers. Step rate structures also encourage waste because some customers may actually lower their water bills by using more water.

The most common water rate structure found in small rural communities is the declining block rate. Under this rate structure a customer pays a certain rate for water consumed within each consumption block. Each successively larger consumption block is associated with a lower water rate. A customer may pay $1.00 per 1000 gallons for the first 4000 gallons, $0.80 per 1000 gallons for the next 4000 gallons, and $0.60 per 1000 gallons for water consumed over 8000 gallons. Declining block rates are difficult to administer and also tend to discriminate against low-use customers. Suppliers can justify declining rates because the unit cost of supplying each customer with water service usually declines as that customer's consumption increases.

Community water systems often use more than one rate structure. For example, residential customers may be billed according to a flat rate while industry is billed at a uniform rate. Water systems which make use of a "minimum water service charge" are actually combining a flat rate with some other water rate structure.

Average water rates vary considerably from system to system. Residential water rates for systems serving different population categories are shown in Table 4.8. In general, water rates decrease with the larger water systems, with the exception of the smallest population category (25-99 people served). Water rates (and water systems costs) may be lower for this category as a result of donated services, unattributed costs, and differences in treatment levels. Water rates also vary from state to state. Figure 4.9 lists the average annual and monthly water payments for FmHA funded water systems in 36 states.

Connection Fees

Connection fees or "tap-in" fees are probably the second most important source of revenue for many water systems. Connection fees are often collected at a set rate, for example $50 per connection. Such fees can also be varied according to the customer's expected usage or the cost the water system must incur to provide the customer with service. These fees provide the water system with "front-end" cash which could be used to reduce the debt service. Furthermore, connection fees force residents to make a commitment to the water supply project.

Budget Appropriations from Local Government Entities

Publicly-owned water systems may receive local budget appropriations for one of two reasons. First, budget

Table 4.8

Reported Residential Rates
Based on Family Usage of 100,000 Gallons per Year*
1975

(cents per thousand gallons of deliveries)**

	Population Category								
	25-99	100-499	500-999	1,000-2,499	2,500-4,999	5,000-9,999	10,000-99,999	100,000-999,999	> 1 million
Mean	73.5	89.0	78.5	85.2	93.6	79.2	71.7	65.2	53.6
Standard Deviation	51.1	51.0	50.0	46.8	65.3	44.4	37.3	31.4	18.0
Median	60.0	75.0	69.0	76.0	83.0	69.5	64.0	60.0	52.0
(# obs.)	(51)	(148)	(82)	(97)	(58)	(40)	(79)	(188)	(10)

*Equivalent to approximately 90 gallons per capita per day for a family of three.

**Same numbers also represent dollars per year per family at this level (i.e., 100 thousand gallons x cents per thousand gallons).

Source: Temple, Barker, and Sloane, Inc., Survey of Operating and Financial Characteristics of Community Water Systems, Washington, D. C.: Office of Water Supply, U. S. Environmental Protection Agency, April 1977, p. VI-14.

Table 4.9

Average User Payment in FmHA Funded Systems by State, First Half of FY76

State	Number of Projects Funded	Average Annual User Payment	Average Monthly User Payment
Alabama	10	$108	$ 9.00
Arizona	4	253	21.10
Arkansas	15	121	10.10
California	5	186	15.50
Colorado	1	152	12.67
Florida	1	150	12.50
Georgia	3	91	7.50
Idaho	1	175	14.58
Illinois	4	158	13.17
Indiana	2	200	16.67
Iowa	2	130	10.83
Kansas	4	286	23.83
Kentucky	6	122	10.17
Louisiana	2	91	7.58
Michigan	2	140	11.67
Minnesota	1	404	33.67
Mississippi	8	120	10.00
Missouri	4	135	11.25
New Mexico	2	160	13.33
New York	2	235	19.58
North Carolina	10	100	8.33
North Dakota	4	254	21.16
Ohio	3	199	16.58
Oklahoma	6	159	13.25
Oregon	7	153	12.75
Pennsylvania	2	134	11.16
South Carolina	3	106	8.83
South Dakota	1	161	13.33
Tennessee	25	106	8.83
Texas	14	168	14.00
Utah	1	123	10.25
Virginia	2	101	8.42
Washington	2	180	15.00
West Virginia	6	123	10.25
Wisconsin	2	129	10.75
Wyoming	4	166	13.83

Data not available for all states.

Source: Drinking Water Supplies in Rural America, National Demonstration Water Project, 1978, p. 39.

appropriations may be necessary to supplement revenues from water sales. Budget appropriations to supplement inadequate water sales revenues are the exception rather than the rule, as the water sales of many municipal systems are often greater than the total operating costs of the system.

Some municipal water systems do not receive revenues from water sales. These revenues go directly to the city or town's general fund. Systems such as these must rely on budget appropriations even though the system's water sales may equal or exceed its operating expenses.

Labor Contributions

Although not really a source of revenue, labor contributions can be an important way of supplementing other revenues for very small community water systems. Approximately one-third of a water system's annual operating cost may be in the form of wages (5). Water systems serving less than 100 people will rarely be able to hire full-time water operators. These communities usually rely on members of the community who are familiar with water supply equipment for the operation and maintenance of these systems.

After a community estimates future revenues from water sales and selects the funding sources for its capital expenditures, then the community can determine the size and type of water system that its citizens will be able to afford. The size of the water system depends on the service area and the expected water demand within the area. The methods used to determine water requirements are discussed in Chapter 5. The remaining chapters discuss the technical aspects of selecting a water source and a water system which will best meet the water requirements of the community.

REFERENCES

1. Drinking Water Supplies in Rural America, Washington, D. C.: National Demonstration Water Project, 1978, pp. 88-89.
2. Ibid, p. 78.
3. Ibid, p. 74.
4. Ibid, p. 142.
5. Ibid, p. 121.

CHAPTER 5

DETERMINING WATER REQUIREMENTS

One of the most important steps in developing a community water system is the determination of the community's present and future water requirements. These estimated water requirements are the basis for the design of the system's wells, pumps, treatment plant, storage facilities, and distribution lines. Underestimating a community's water requirements may lead to an under-designed water system resulting in dissatisfied customers and possible health risks. On the other hand, over-estimating water requirements will result in a larger capacity water system than the community needs. The additional capital costs required for the excess capacity then become an unnecessary financial burden for the community.

WATER USE

Communities need water for domestic or residential use, for fire fighting, and for commercial, industrial and agricultural use. The water requirements for each category of use must be estimated to adequately design a community water system.

Residential or Domestic Water Requirements

Present and future domestic water requirements are based on population and per capita water consumption estimates. The U.S. Bureau of the Census is the most widely used source of population data, but state and local censuses are also used. By using mathematical formulas or graphical methods, past population data can be used to estimate a community's present or future population.

To obtain the domestic water requirement, a community's estimated population is multiplied by an appropriate domestic per capita water consumption estimate. The average American uses approximately 75 gallons per day (gpd) domestically (1), but per capita domestic water consumption can range from 20 gpd for some communities to over 90 gpd for others. Domestic water consumption varies with economic conditions, temperature and precipitation, type of sewage facilities, water rates, the use of meters, water quality, and distribution system pressure. State health departments often provide data and guidelines which enable small communities to estimate per capita water requirements. Water consumption data from nearby communities may also be helpful.

Sometimes the number of dwellings and the water usage per dwelling are used to estimate a community's water requirements. Existing dwellings are first surveyed and growth projections are then made. Finally, the daily water consumption rate per dwelling must be determined. Some typical dwelling unit consumption rates for different regions of the United States are shown in Table 5.1.

Lawn Sprinkling

The quantity of water required for lawn or garden sprinkling varies considerably with the climate, housing density, and economic conditions of the community. This quantity can be calculated using precipitation and evapotranspiration data combined with estimates of the lawn and garden acreage in the community.

Alternately, an engineer may not attempt to distinguish between water used for domestic purposes and water used for lawn sprinkling since both are included on an individual's water bill. Instead, water for sprinkling can be considered as a part of the domestic water requirement.

Fire Fighting

Although the flow of water required during a fire is substantial, on a monthly or weekly basis the quantity of water used to control fires is usually small in comparison with other water requirements. Table 5.2 lists the recommendations of the American Insurance Association for fire flow, fire reserves, and hydrant spacing.

Table 5.1

Water Consumption by Dwelling Unit

	Gallons per day per Dwelling unit		
	Average Day	Maximum Day	Peak Hour
Federal Housing Administration Standards	400	800	2000
Observed Drafts - Metered Dwellings			
National average	400	870	2120
West	460	980	2480
East	310	790	1830
Unmetered Dwellings			
National average	690	2350	5170
Unsewered Dwellings			
National average	250	730	1840

Source: Adapted from Fair, Gordon Maskew, John Charles Geyer, and Daniel Alexander Okun, Elements of Water Supply and Wastewater Disposal, 2nd ed., New York: John Wiley and Sons, Inc., 1971, p. 33.

Table 5.2

Required Fire Flow, Fire Reserve, and Hydrant Spacing Recommended by the American Insurance Association

Population	Fire Flow gpm	Fire Flow mgd	Duration, hr	Fire, Reserve, mg	Area per Hydrant sq. ft. Engine Streams	Area per Hydrant sq. ft. Hydrant Streams
1,000	1,000	1.4	4	0.2	120,000	100,000
2,000	1,500	2.2	6	0.5	---	90,000
4,000	2,000	2.9	8	1.0	110,000	85,000
6,000	2,500	3.6	10	1.5	---	78,000
10,000	3,000	4.3	10	1.8	100,000	70,000

Source: Fair, Gordon Maskew, John Charles Geyer, and Daniel Alexander Okun, Elements of Water Supply and Wastewater Disposal, 2nd ed., New York: John Wiley and Sons, Inc., 1971, p. 196.

Commercial, Industrial and Institutional Water Requirements

Commercial and industrial water requirements can be determined on a case by case basis since most small communities have relatively small commercial and industrial sectors. Large industries should be contacted directly before determining water requirements. It should be noted that many industries prefer to develop their own water supply systems. The water requirements of small and medium-sized businesses can be estimated using Table 5.3.

Agricultural Water Requirements

Agricultural water consumption, like industrial water consumption, varies considerably from case to case. The consumption values shown in Table 5.4 can be used as general guides.

Water Losses

A recent EPA survey (2) found that ten percent of the water produced by community water systems could not be accounted for when compared with water deliveries. Water losses for new systems are probably less than ten percent, but some increase in the overall water requirements of the community should be made to account for possible water losses.

Table 5.3

Guide for Estimating Commercial, Industrial, and Institutional Water Requirements:

Type of Establishment	Average Daily Use (gpd)
Airport (per passenger)	3-5
Assembly Halls (per seat)	1
Churches (per member)	1
Factories, sanitary uses (per employee - per shift)	15-35
Food Service - Restaurants (per customer)	7-10
- Restaurants (with bars)	9-12
- Fast Food	2
Hotels (two persons per room)	60
Institutions - Hospitals (per bed)	250-400
- Nursing Home (per bed)	150-200
- Others	75-125
Office Buildings (per employee)	15-30
Laundries, self-service (per customer)	50
Retail Stores (per toilet)	400
Schools - Day, no showers or cafeteria (per student)	15
- Day, with cafeteria	20
- Day, with showers and cafeteria	25
- Residential Types	75-100
Shopping Centers, per sq. ft. of sales area	0.16
Theaters - Drive-in (per car)	3-5
- Others (per seat)	3

Note: The values listed in Table 5.3 are for normal water requirements and do not include special needs or unusual conditions. Additional allowance should be made for frequent lawn watering, swimming pool maintenance, industrial or commercial process water, cooling water, fire fighting, and other special uses.

Source: Small Water Systems Serving the Public, Troy, New York: Conference of State Sanitary Engineers, 1979, pp. 3-7 and 3-8.

Table 5.4

Guide for Estimating Agricultural Water Requirements

Farm Animals (water requirements per animal):	
Dairy cows	20 gpd
Horses, mules, and steers	12 gpd
Hogs	4 gpd
Sheep	2 gpd
Turkeys	0.07 gpd
Chickens	0.04 gpd
Dairies (for cleaning and cooling water)	15 gpd per cow
Greenhouses	70 gpd per 1000 square feet
Garden Crops	35 gpd per 1000 square feet

Source: Fair, Gordon Maskew, John Charles Geyer, and Daniel Alexander Okun, Elements of Water Supply and Wastewater Disposal, 2nd ed., New York: John Wiley and Sons, Inc., 1971, p. 32.

WATER SYSTEM DESIGN CONSIDERATIONS

The average daily water requirement of a community is determined by adding the average daily requirement for each of the categories of water use described above. However, it is not sufficient to look only at average daily water requirements. Water consumption varies with the season of the year, the day of the week, and the time of day. Each component of the water system must be designed to meet the demand during peak water consumption periods. Three different water consumption peaks are used in the design of water systems: the peak day demand, the peak hour demand and the instantaneous peak demand.

The peak day demand is the maximum flow of water required per connection during a 24 hour period. The peak day demand is usually about twice the average daily water requirement. This peak is used in the design of water intakes, treatment plants, and storage reservoirs for relatively large community water systems.

The peak hour demand is the maximum flow of water required per connection during a one hour period. It is usually about 5 times the average daily water requirement. Small treatment plants, pumping stations, and distribution mains are often designed to meet the peak hour demand.

The instantaneous peak demand or peak demand is the maximum amount of water which will be used per connection during any one minute period. It is important in the design of distribution lines and, for small systems, in the design of storage tanks. The instantaneous peak may range from 5 to 10 times the average daily water requirement. Special studies of rural water systems show that the instantaneous peak may be as low as 0.32 gpm per connection to as high as 4.00 gpm per connection (3). The Farmers Home Administration recommends an instantaneous peak demand of 2.0 gpm per connection for systems or parts of systems with 20 or more connections.

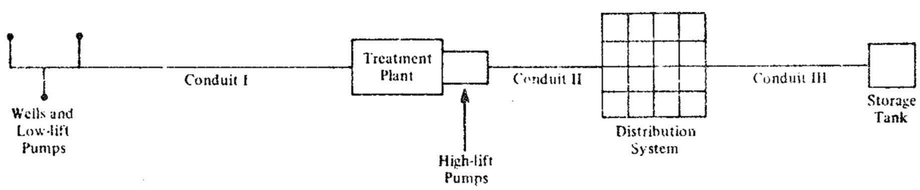
If federal funds are desired, the components of a water system must comply with the minimum standards of the appropriate agency. The national office of the Farmers Home Administration, as well as state FmHA offices, issue flow standards for treatment facilities, supply lines, storage, and distribution lines. Minimum flow standards are often issued by state health departments as well.

Each component in a water system must be designed to meet a community's existing and future water requirements. In determining the design period of a water system component, a designer considers the following factors:

1. The expected life of the structure or equipment.
2. The ease with which enlargements or additions can be made.
3. The interest rate.
4. The population growth in the area and any expected changes in the rate of water consumption.

Figure 5.1

Design Criteria for the Various Components of a Typical Water System



Component	*Recommended Design Criteria*
Wells and Low-lift Pumps	Peak day demand plus reserve
Conduit I	Peak day demand
Treatment Plant	Peak day demand plus reserve
High-lift Pump	Peak hour demand plus reserve
Conduit II	Peak day demand
Distribution System	Instantaneous peak demand
Conduit III	Peak hour demand
Storage Tank	Peak hour demand plus fire reserve

Source: Gordon M. Fair, John C. Geyer, and Daniel A. Okun, *Elements of Water Supply and Wastewater Disposal*, 2nd ed. (New York: John Wiley and Sons, 1971), p. 35.

Recommended design periods for selected components are given in Table 5.5.

Using the techniques described in this chapter, an engineer will determine the overall water requirements of a community. The remaining chapters of this manual will describe the methods of obtaining and delivering water, especially ground water, to meet those needs.

REFERENCES

1. Drinking Water Supplies in Rural America, Washington, D. C.: National Demonstration Water Project, 1978, p. 115.

2. Temple, Barker and Sloane, Inc., Survey of Operating and Financial Characteristics of Community Water Systems, Washington, D. C.: Office of Water Supply, U. S. Environmental Protection Agency, April 1977, p. V-7.

3. Drinking Water Supplies in Rural America, 1978, p. 115.

Table 5.5

Recommended Design Periods for Water System Components

Component	Design Period: Low growth, Low interest rates	Design Period: High growth, High interest rates
Wells	20-25 years	10-15 years
Treatment plants	20-25 years	10-15 years
Distribution System:		
Laterals and secondary mains (pipes less than 12 inches in diameter)	Full development	
Mains (pipes more than 12 inches in diameter)	20-25 years	

Source: Fair, Gordon Maskew, John Charles Geyer, and Daniel Alexander Okun, Elements of Water Supply and Wastewater Disposal, 2nd ed., New York: John Wiley and Sons, Inc., 1971, p. 18.

CHAPTER 6

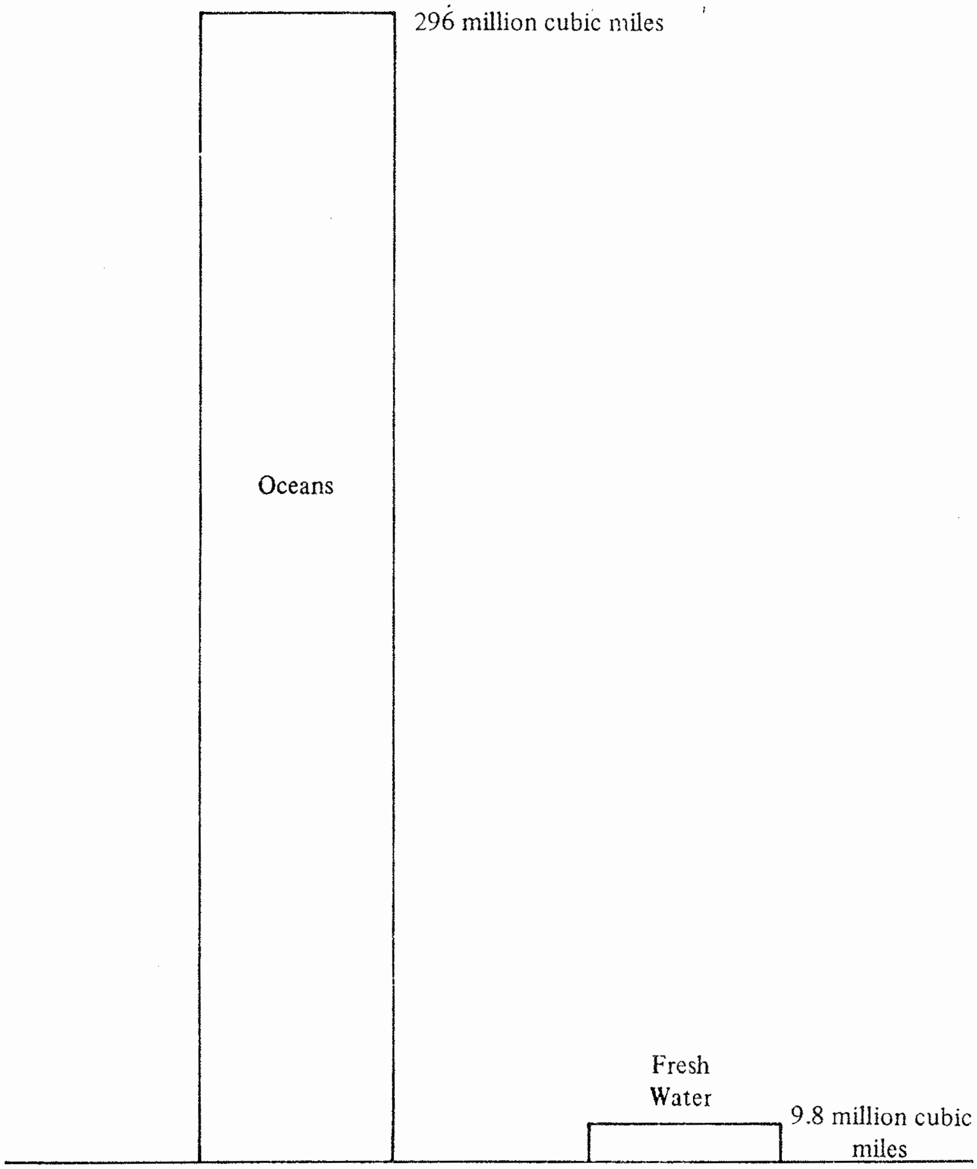
SELECTION OF A WATER SOURCE

Three-fourth's of the earth's surface is covered by an estimated 306 million cubic miles of water. However, only a fraction of this water is suitable for community water supplies. The oceans and polar ice caps contain 99 percent of the earth's water. Almost half of the remaining water is "deep" ground water lying more than 2500 feet below the earth's surface; this water is often inaccessible using current drilling techniques and too hot to serve as drinking water. A small amount of the earth's water is in the form of atmospheric moisture and soil moisture, and cannot be used. Thus, only 1.09 million cubic miles, or approximately 0.36 percent of the earth's water, is available as fresh water for human consumption or use. The sources of this fresh water include lakes, rivers, streams, and ground water less than 2500 feet below the earth's surface.

About 97 percent of the useable fresh water in the continental United States is in the form of ground water and about three percent is contained in the nation's lakes, rivers, and streams. Over 75 percent of the water systems in the United States use ground water as a supply source, but only 32 percent of the U. S. population receive

Figure 6.1

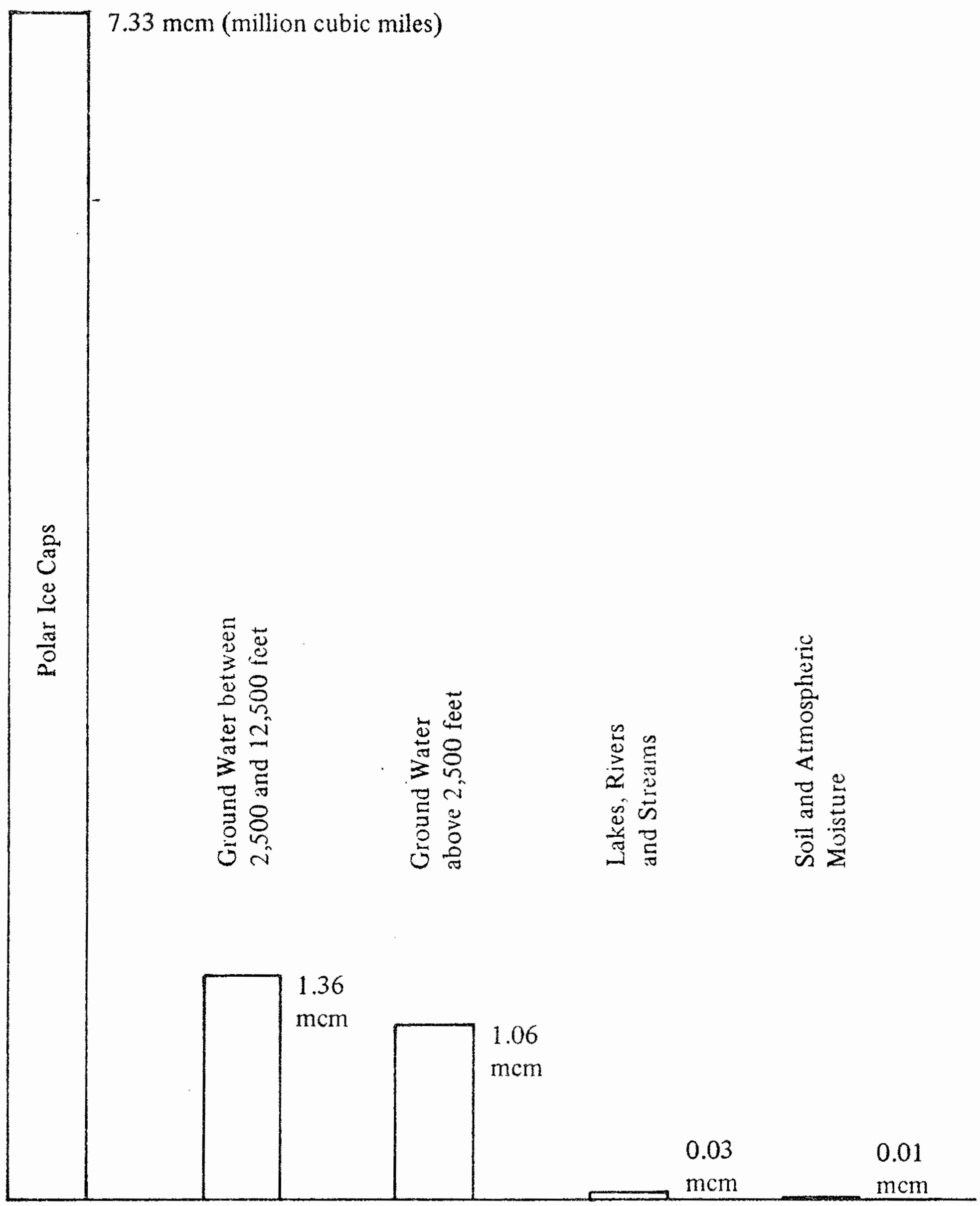
Total Volume of Water on Earth



Source: Adapted from E.E. "Skeet" Arasmith, *Introduction to Surface Water Sources, Raw Water Storage, Raw Water Intakes* (Albany, Oreg.: Lynn-Benton Community College, 1977), pp. 2-3.

Figure 6.2

The Earth's Fresh Water



Source: Adapted from E.E. "Skeet" Arasmith, *Introduction to Surface Water Sources, Raw Water Storage, Raw Water Intakes* (Albany, Oreg.: Lynn-Benton Community College, 1977), pp. 2-3.

their water from ground water supplies. Ground water is typically the source of water for supplying small cities, towns, and individual water systems, while surface water is the principal water source for major metropolitan areas.

THE HYDROLOGICAL CYCLE

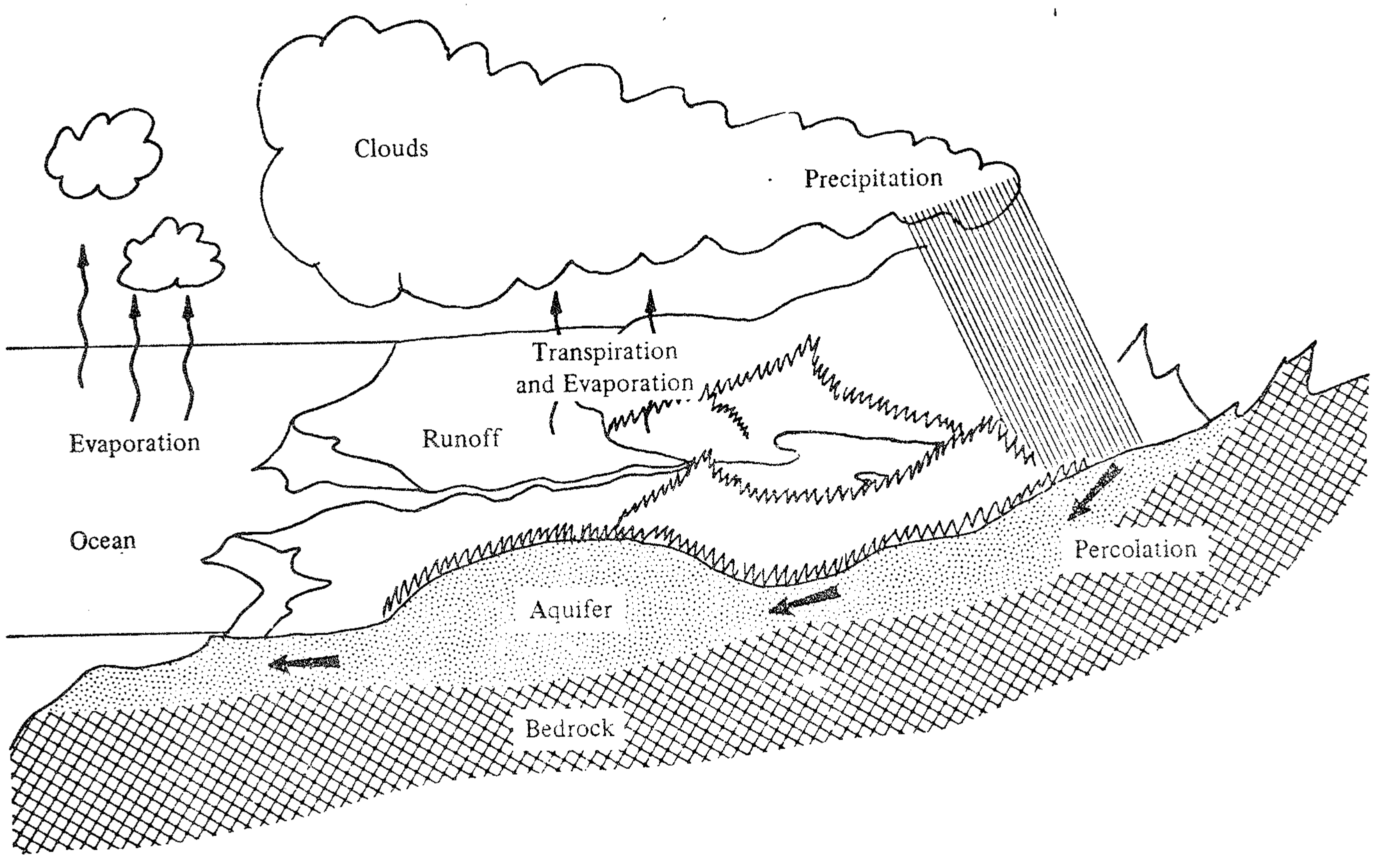
Water is constantly being exchanged between the earth and the atmosphere, between fresh water systems and salt water systems, and between ground water systems and surface water systems. This continuous circulation of the earth's water is called the hydrologic cycle (see Figure 6.3).

Water falls to the earth in some form of precipitation, as rain, snow, sleet, or hail. Some of this precipitation falls directly on lakes, rivers and oceans and the rest falls on the land areas of the earth. During a rain storm, the first water to fall on the land is often absorbed by the soil and stored as soil moisture. As more water falls, it begins to percolate into the soil to become ground water. If the rate of rainfall exceeds the rate at which the water infiltrates into the soil, the rainwater begins to flow over the land as run-off. Run-off flows downhill to the nearest rill or creek, then to larger streams and rivers and eventually to the ocean.

Water which percolates into the soil as ground water may be used by trees and other plants, or it may seep down

Figure 6.3

The Hydrologic Cycle



Source: Adapted from E.E. "Skeet" Arasmith, *Introduction to Surface Water Sources, Raw Water Storage, Raw Water Intakes* (Albany, Oreg.: Lynn-Benton Community College, 1977), p.

through the earth's crust until it reaches an aquifer, which is a rock or soil which contains and transmits water. Ground water also flows, although more slowly than surface water, to nearby lakes, streams and rivers, and finally to the oceans.

Water returns to the atmosphere by means of evaporation or transpiration. Water evaporates from the land, from lakes and rivers, and from the oceans. Water which is taken up by trees and other plants is either used in plant tissue or transpired by the plants through their leaves. Evaporation and transpiration produce water vapor which is carried by the air until it condenses to form clouds and then rain or snow, thus completing the cycle.

Water can be obtained for water supply systems by temporarily drawing the water out of the natural hydrologic cycle in one or more of the following ways:

- By collecting rainwater as it falls on roofs or other catchment structures.
- By drawing surface water from streams, rivers, lakes, and reservoirs.
- By removing water from ground water aquifers.

Water supplies are occasionally obtained from the oceans using desalinization plants, but this method of obtaining water is expensive and has been used only in coastal communities where no other source of fresh water is available.

RAINWATER

Water which falls on the earth as rain or snow may be used directly for water supply. Rainwater often has a very "flat" or "dull" taste and may contain pollutants such as soot, rust, nitric acid, sulphuric acid, ammonia, and micro-organisms, especially in industrial areas. However, the main problem with precipitation is its irregularity. Precipitation is not likely to be a reliable source of water for small communities because its quantity, quality, and frequency cannot be predicted.

SURFACE WATER

Precipitation, which makes its way to streams and rivers, may also be used for water supply if the stream flow is adequate to meet a community's water needs throughout the year. Unfortunately, stream flow usually varies considerably from season to season; in arid or semi-arid areas even large streams can dry up completely for several months. Lakes and reservoirs are more reliable sources of surface water. Although they are also fed ultimately by precipitation, natural lakes and reservoirs may retain large quantities of water during periods of high stream flow for discharge or use during periods of low stream flow.

Surface water quality is highly variable from one stream to another, along different reaches of the same stream, and from one season to the next at the same point on a given stream. Except in the upper reaches of some mountain streams, surface waters contain large amounts of silt, clay, bacteria, and organic contaminants. Since the concentration of these contaminants may vary considerably from season to season, water treatment is often expensive and requires well trained treatment plant operators. The water quality of lakes and reservoirs is generally more stable, but natural lakes are scarce in many parts of the United States. In the entire state of Texas, for example, there is only one natural fresh water lake. Reservoirs, on the other hand, are expensive to construct; the costs are likely to be beyond the financial means of small communities. Occasionally, communities can secure water from existing or planned reservoirs which are built by state or federal agencies for other purposes, such as flood control or power generation.

GROUND WATER

According to a recent EPA survey, about 76 percent of U.S. communities with populations of 10,000 or less obtain their water from ground water sources (1). Ground water is available in varying amounts throughout most of the United

States. Furthermore, it has been estimated that the U.S. is presently using only about 10 percent of the water which is recharged to aquifers every year (2).

The physical or biological quality of ground water is generally better than surface water due to natural filtration by the soil. Water comes into contact with a variety of substances as it falls through the air and flows over or through the top layer of soil. Water picks up minerals, gases and other contaminants from the atmosphere, and soil particles, bacteria, organic matter, and gases of decomposition from the soil humus. As water seeps downward into the soil and underlying rocks, soil particles, bacteria, and organic matter are removed by natural filtration. Dissolved substances, such as gases and minerals, are not removed by this natural filtration process. In general, the quantity of dissolved substances in ground water increases as the water flows through the various soil layers, thus making the water "hard."

Ground water can usually be supplied to communities far less expensively than surface water. Ground water offers three economic advantages over surface water:

- Ground water can be obtained on a pay-as-you-go approach. New wells may be added as the community grows.
- Ground water can usually be obtained under or near the community so water transportation costs are relatively low.

- Since ground water is usually free of biological and physical pollutants and chemical contaminant concentrations are stable, treatment costs for ground water are usually less than those for surface water.

SPRINGS AND INFILTRATION GALLERIES

Springs and infiltration galleries are two additional sources of fresh water and cannot be easily classified as ground water or surface water.

Springs are openings in the ground from which ground water flows. They often occur along stream and river banks or on the sides of hills and mountains where aquifers are intersected by the ground surface. Essentially, a spring is a place where ground water becomes surface water. Thus, spring water has many of the same features as ground water from a well, but the flow may vary considerably. If the flow from a spring is very irregular, then the spring is probably fed by local rainfall or melting snow. In these cases, there may be only a minimum amount of natural filtration and bacteria and other organic matter may be present in the water. Unless a spring has a relatively constant flow rate and its water is free of organic contaminants, then the costs of obtaining and treating the spring water will be high, making it more like surface water than ground water.

Infiltration galleries are drainage systems which are laid underneath or adjacent to a stream or river. Essentially, infiltration galleries are used to collect surface water flowing in the stream, but the system takes advantage of the natural filtration process that reduces the amount of physical and biological contaminants in ground water. The surface water must travel through a short distance of sand or other filter material before it is collected by the system of drains. This short artificial filtration process is partially effective in removing soil particles, organic matter, and bacteria, but viruses and some bacteria may not be removed. Infiltration galleries are an inexpensive method of obtaining surface water and have been used successfully, especially when small volumes of water are involved.

SELECTING THE "RIGHT" SOURCE

Table 6.1 lists the advantages and disadvantages of each of the water sources mentioned above. To decide which source to use, an engineer or other consultant can conduct a feasibility study which should include the following:

- A list of the water sources available to the community and a discussion of the quantity, quality and reliability of each source.

Table 6.1

Summary Comparison of Water Sources

Water Source	Advantages	Disadvantages
Rainwater	Easily obtained.	Unreliable. Requires large storage facilities. Usually has a flat or dull taste.
Surface water	Easy to find and to determine quantity available. Water intake facilities are inexpensive unless a reservoir is necessary. Water is usually "soft" (few dissolved minerals).	Flow may vary considerably. If a reservior is necessary, initial costs can be high. Transportation costs can be high if the source is far from the community. Treatment can be expensive and complicated. Water quality can be highly variable. Large amounts of physical and biological contaminants can be present. Susceptible to pollution.

Table 6.1 (Cont'd.)

Water Source	Advantages	Disadvantages
Ground water	Is more widespread than surface water. Transportation costs are low. Additional wells can be drilled as they are needed. Treatment is often simple and inexpensive. Water quality is often stable and free of physical and biological contaminants. Less susceptible to pollution than surface water.	Exploration can be expensive. Well drilling can be expensive if aquifer is deep. Water is often "hard" (many dissolved minerals).
Springs	Easy to find. Well drilling is not necessary.	Flow may be irregular. Quality is similar to that of groundwater but springs are more susceptible to pollution.
Infiltration galleries	Inexpensive to construct. Treatment can be less expensive than for normal surface water.	Suitable locations may be difficult to find. Quantity is usually limited by surface water flow. Water may still contain biological contaminants.

- An estimate of the costs of exploration and testing of the alternate sources of water.

- Initial construction cost and operating cost estimates of the water intake facility and treatment plant for each alternate.

The alternate water sources can be evaluated using the following criteria:

Economic: How much can the community afford? What is its bonding capacity? What will the water rates be?

Legal: Is the water legally obtainable? Can water rights be secured?

Quality: Will the water meet health standards after reasonable treatment?

Time: When will the community need the water? Can the water facility be designed and constructed soon enough to meet the demand?

Operation and Maintenance: Are trained operators available and can the community afford to hire them? Will the community be able to maintain the system?

Community leaders may obtain assistance in evaluating these criteria from the consulting engineer, from federal agencies (such as the Farmers Home Administration), from state health departments or water resource agencies, and from nearby communities who have recently built community water systems of their own.

Although most small communities obtain their water supplies from ground water sources, some do choose to meet their water needs using surface water sources. This manual is concerned only with the development of ground water sources; information concerning the use of surface water for community water systems can be obtained from the following sources:

Twort, A. C., R. C. Hoather, and F. M. Law, Water Supply, London: Edward Arnold Ltd., 1974.

Wagner, E. G., and J. N. Lanoix, Water Supply for Rural Areas and Small Communities, Geneva: World Health Organization, 1969.

REFERENCES

1. Temple, Barker, and Sloane, Inc., Survey of Operating and Financial Characteristics of Community Water Systems, Washington, D. C.: Office of Water Supply, U. S. Environmental Protection Agency, April 1977, p. IV-12.

2. Alexander Zaporozee, "Changing Patterns of Ground Water Use in the United States," Ground Water, Vol. 17, No. 2, March-April 1979, p. 203.

CHAPTER 7

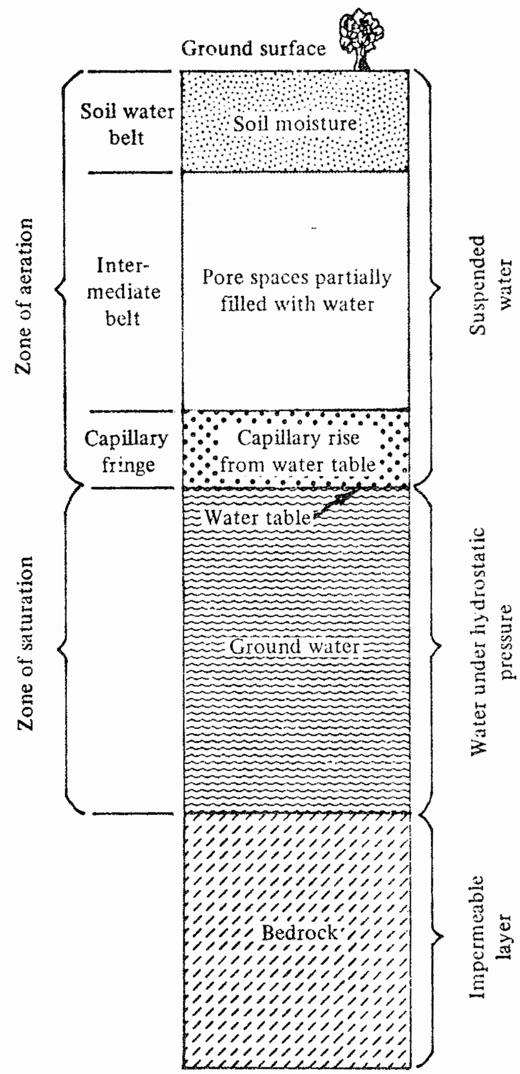
GROUND WATER AND AQUIFERS

Only part of the water below the earth's surface is called ground water. Geologists divide the outer part of the earth's crust into a zone of aeration and a zone of saturation (see figure 7.1). The zone of aeration is the upper strata of earth's crust where the openings between soil particles are only partly filled with water. Precipitation which enters the soil seeps downward under the force of gravity through three belts within the zone of aeration: the soil moisture belt, the intermediate belt, and the capillary fringe. Water which percolates downward through the zone of aeration is not available for water supply until it reaches the zone of saturation, where all of the openings between the soil particles are filled with water. Water which occurs within the zone of saturation is referred to as ground water.

Geologic formations which are porous and contain ground water are referred to as aquifers. Not all aquifers are desirable sources of water for community water systems. Some aquifers may be too small to serve as reliable sources of water; others may contain water of very poor quality. The following criteria are often considered in selecting an

Figure 7.1

The Occurrence of Subsurface Water



aquifer:

- the type of aquifer,
- the type of geologic formation,
- the hydrologic properties of the aquifer,
- the quality of the water contained in the aquifer.

TYPES OF AQUIFERS

Three types of aquifers are illustrated in Figure 7.2: water table aquifers, perched aquifers, and artesian aquifers. Water table aquifers, or unconfined aquifers, are those whose upper limit is the water table. Perched aquifers are water table aquifers which occur when local impervious soil layers intercept percolating water in the zone of aeration and accumulate the water in pockets above the impervious strata. Artesian aquifers, or confined aquifers, are those which are bounded on both the top and the bottom by impermeable layers. The upper confining layer causes the water in the aquifer to be under pressure.

For unconfined aquifers, the water table elevation defines the depth of the aquifer. Water tables are not stationary but may fluctuate seasonally or may show long term trends. The water table rises as more water percolates downward to the saturated zone or drops as ground water flows out of the aquifer into streams and lakes or through springs and wells. In some areas of the United States, ground water is being pumped from wells faster than water can percolate through the soil to recharge the aquifer. For example, the water table near Plainview, Texas, dropped 100 feet between 1940 and 1970. Large quantities of ground water were being pumped from the Ogallala aquifer for irrigation and there was esstentially no aquifer recharge (1).

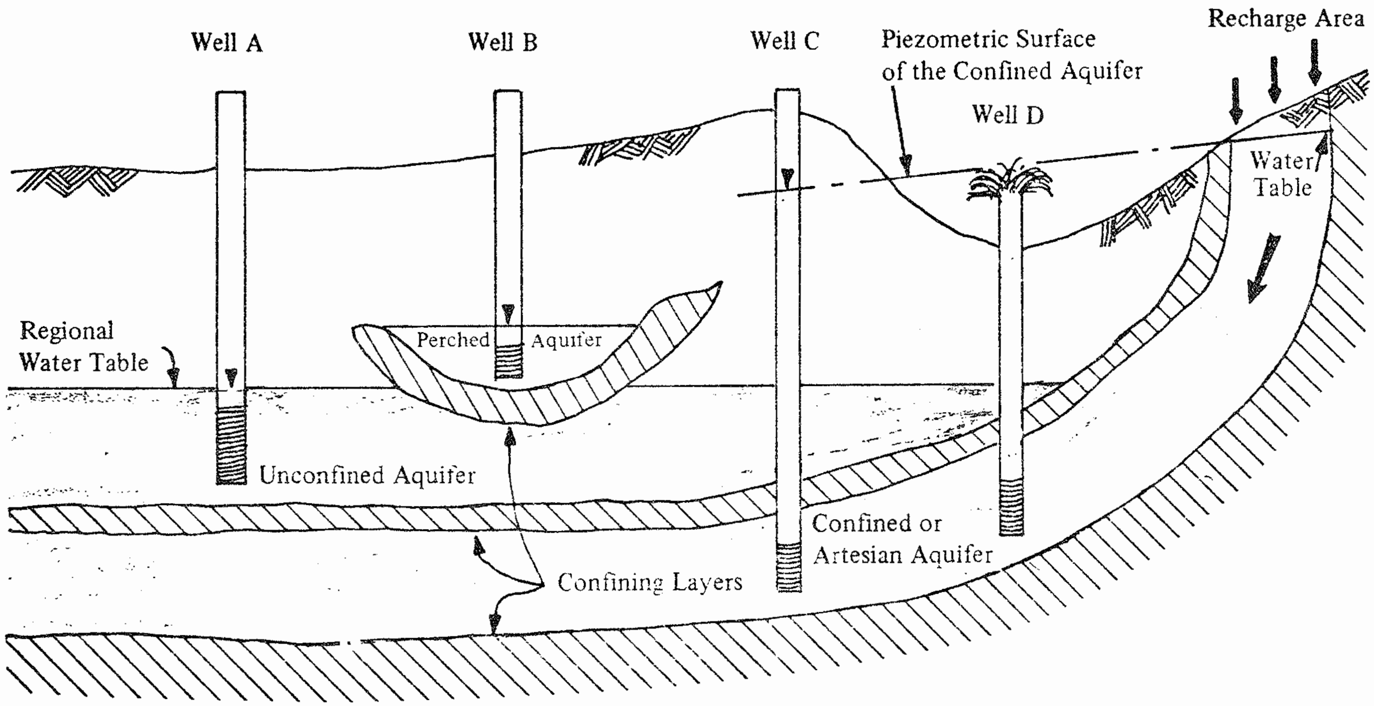
If a well is drilled into a water table aquifer, the resulting water level in the well will stand at the same elevation as the water table in the aquifer (Well A). Wells drilled into perched aquifers behave like wells drilled in water table aquifers (Well B).

If a well is drilled into an artesian aquifer, the water in the well will rise to a level where the hydrostatic pressure of the water in the well above the top of the aquifer equals the water pressure in the aquifer (Well C). Some artesian aquifers are under enough pressure to actually cause the water to flow out of the well at the ground surface (Well D).

All three types of aquifers may be used for community water supplies although perched aquifers may be less desirable because they may only hold a limited amount of ground water. An artesian aquifer has three advantages over the other types of aquifers. First, wells in artesian aquifers are more reliable because fluctuations in the hydrostatic pressure in the

Figure 7.2

Types of Aquifers



aquifer cause only minor changes in the capacity of the well. Second, pumping costs are lower because the natural pressure in the aquifer forces the water towards the surface. Third, the quality of the water is generally better due to the presence of confining layers and more extensive natural filtration.

Water table aquifers are widely used as water sources. Fluctuating water tables, however, can result in serious water supply problems. The capacity of a well depends on the water table elevation in the aquifer. The capacity drops as the water table drops. In severe cases, the water table may drop below the bottom of the well.

TYPES OF GEOLOGIC FORMATIONS

Geologists use the term "rock" to include loose unconsolidated materials. They divide the materials found in the earth's crust into three classes: igneous, sedimentary, and metamorphic rocks. Any rock formation may be an aquifer if it is porous and permeable.

Igneous rocks are formed when hot magma from the earth's core cools and solidifies. Magma at or near the earth's surface is called lava. Igneous rocks derived from lava, such as basalt, are typically fine textured or glassy. Sometimes basalt can be highly porous due to gas bubbles which developed as the lava cooled. If magma solidifies within the earth's surface, the resulting igneous rocks, such as granite, are coarse textured and seldom porous.

Sedimentary rocks consist of rock fragments and chemical precipitates which are deposited by water, ice, or wind. They include unconsolidated formations, such as sand, gravel and clay, and consolidated formations, such as limestone, sandstone, and shale. Sedimentary rocks are excellent water-bearing formations. Although they make up only five percent of the earth's crust, they contain about 95 percent of the earth's ground water (2).

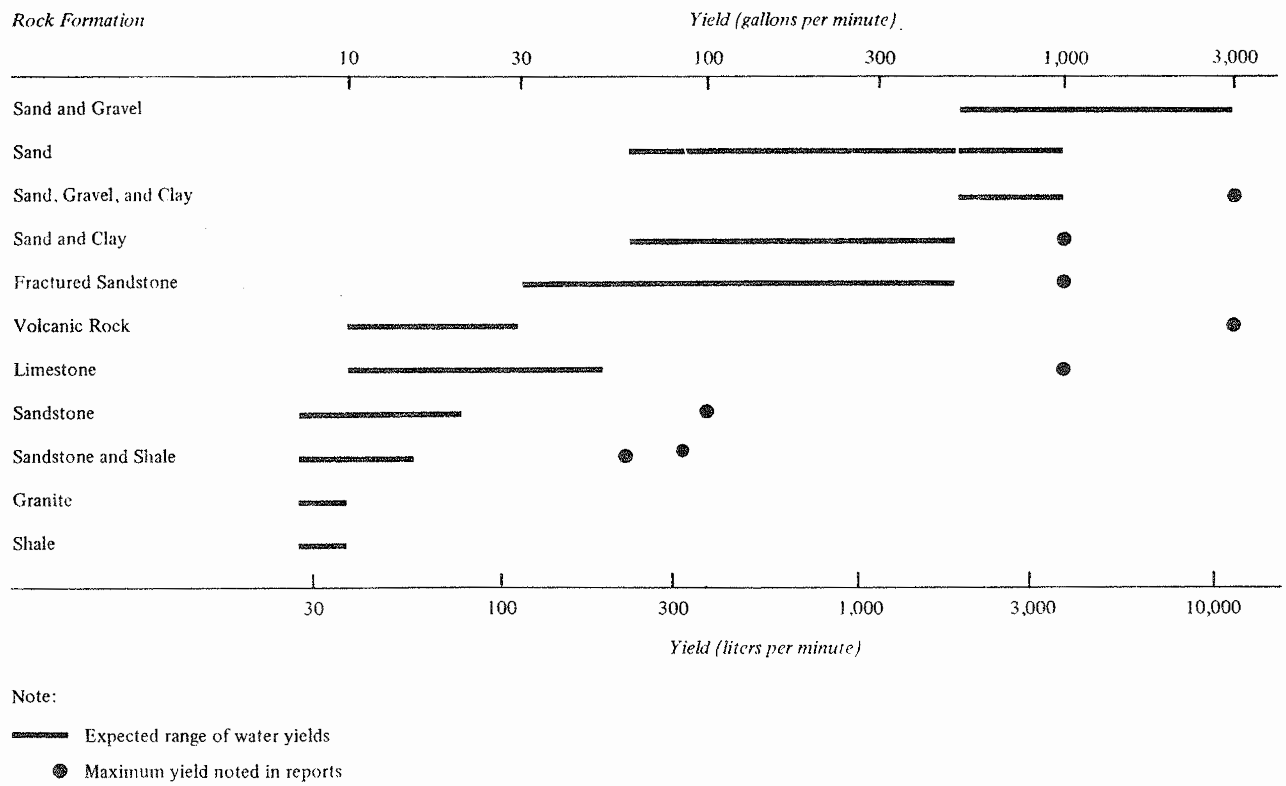
Coarse grained sedimentary rocks, such as sand, gravel, and sandstone, make the best aquifers. Clays and shales, which are very fine grained, are usually not aquifers, although shales may sometimes yield small quantities of water if earth movements have fractured these formations. Limestone and dolomite are also fine grained sedimentary rocks, but fractures and solution channels often make these formations excellent aquifers.

When igneous and sedimentary rocks become altered by heat and pressure deep within the earth's crust, they become metamorphic rocks. Granite becomes gneiss, limestone becomes marble, and shale becomes slate. Metamorphic rocks are generally poor aquifers because of their hardness and density.

Figure 7.3 shows the estimated water yields of wells in various types of rock formations. Sand and gravel deposits

Figure 7.3

Expected Water Yields from Various Rock Formations



Source: Adapted from *Village Technology Handbook* (Mt. Rainier, Md.: VITA, 1975), pp. 8-9.

make the best aquifers, even when they contain limited amounts of clay. Limestone and sandstone, when fractured, and basalt can also yield large quantities of ground water.

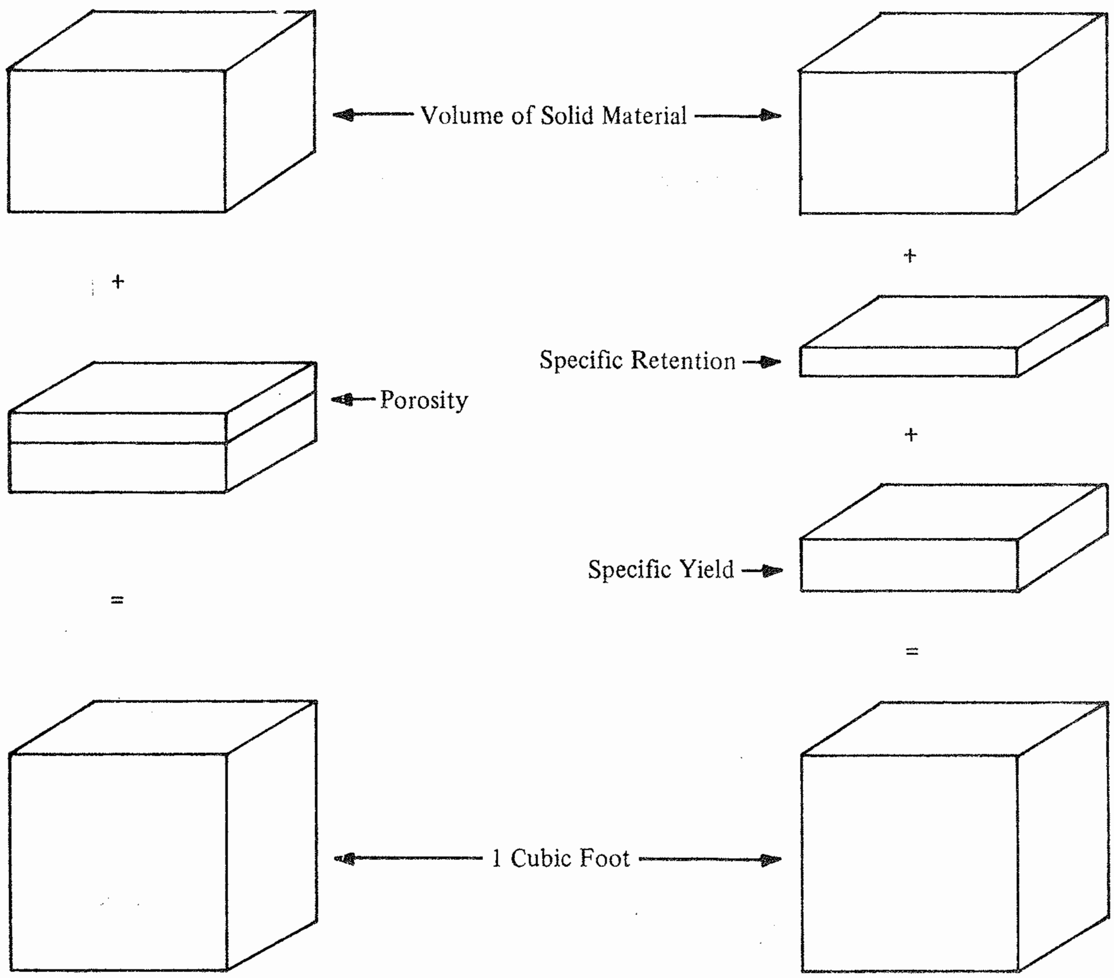
HYDROLOGIC PROPERTIES OF AQUIFERS

To be a good aquifer, a rock formation must be porous and permeable. The porosity of a material is that part of its volume which is not occupied by solid material. Porosity is usually expressed as the percentage of voids or openings to the total volume of the material.

The porosity of an aquifer represents the amount of water the aquifer is capable of holding. However, porosity does not indicate how much water can be drained from the aquifer. Some water will remain attached to soil particles because of molecular attraction between the soil particles and water molecules and because of capillary action. The quantity of water that will drain from a unit volume of material due to gravity is called the specific yield. The quantity of water retained between the soil particles is called the specific retention. Both specific yield and specific retention are usually expressed as percentages of the total volume of material. Figure 7.4 illustrates the relationships between porosity, specific yield, and specific retention.

Figure 7.4

The Relationship Between Porosity, Specific Yield, and Specific Retention



In addition to being porous, a good aquifer must also be able to transmit water. Clays, for example, can be very porous and contain large quantities of water, but because their pores are not connected, clays transmit little water. The ability of a material to transmit water is defined as its permeability. The permeability of a material is related to the material's grain size, the uniformity of grading, and the degree to which the pores or voids are connected. Coarse, uniformly graded formations, such as gravel and coarse sand, have high permeabilities.

The permeability of a material is usually expressed in terms of a coefficient of permeability. The coefficient of permeability is the rate in gallons per day at which water will flow through a one square foot cross sectional area under a hydraulic gradient of 1.00 (see Figure 7.5).

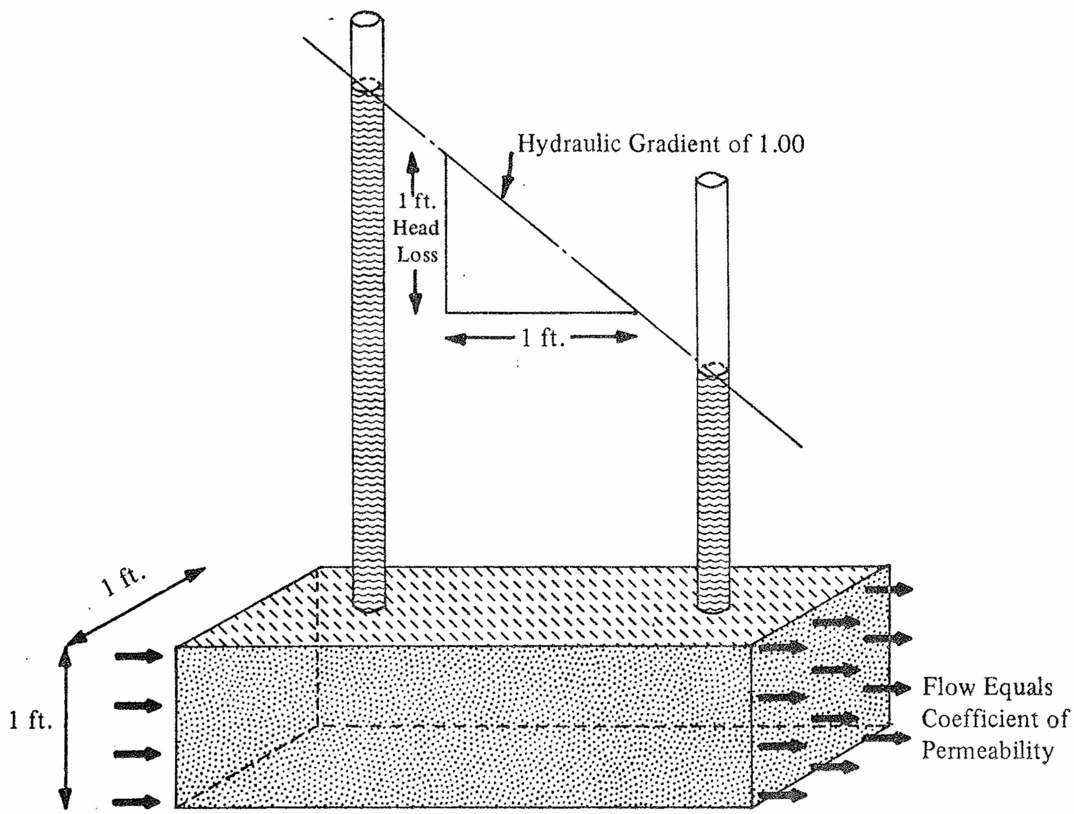
A related term is the coefficient of transmissibility, which is defined as the rate of flow in gallons per day through a vertical section of an aquifer under a hydraulic gradient of 1.00. The width of the section is one foot and the height is the thickness of the aquifer.

QUALITY OF WATER WITHIN AN AQUIFER

The water quality of an aquifer depends on external factors and on the characteristics of the aquifer itself.

Figure 7.5

The Coefficient of Permeability



External factors, such as pollution, are usually more serious in shallow aquifers and in fractured limestone aquifers where natural filtration of percolating water does not occur. Pollution can also enter deep aquifers through injection wells or poorly constructed water wells. Salt water intrusion is often a problem in coastal areas where heavy pumping of fresh water aquifers causes salt water to invade these aquifers.

The water in some aquifers may have naturally high salt or mineral content (see Table 7.1). Marine sediment deposits sometimes contain ground water with high salt concentrations of calcium and carbonate. On the other hand, the water found in metamorphic rock aquifers contains few minerals because these rocks are relatively insoluble.

Ground water studies by the U. S. Geological Survey and by state water resources agencies provide a great deal of information about the characteristics of major aquifers and the quality of the water found in these aquifers. The Appendix briefly describes the major aquifer regions found in the United States.

Ground water studies provided by government agencies or from other sources may help a community decide if a reliable aquifer exists near the community and such studies may also help the community to choose which aquifer will best meet their needs. These studies will not be able to provide the specific information necessary for the design of the community's water supply system. For site-specific information,

Table 7.1

Influence of Water Bearing Strata
on the Quality of Water

Rocks	Quality of Water
Granite	Dissolved substances negligible—more or less chemically pure
Gneiss	Comparatively larger potash content
Slate	Organic matter in small quantities
Diabase, Syenite Diorite	Slight presence of iron (if rocks are weathered)
Pure quartz	Very shoft water
Pure sand stone	Small quantities of dissolved matter, free from humus, often very pure, soft water
Lime stone	Hard, dissolved matter present
Gypsum and anhydrite	Sulfate is present, hard water
Salt dome	Dissolved matter in large quantities, salty
Marble, Dolomite	Very hard water
Loess, Basic crystalline rock	Rich in dissolved matter especially lime, free from humus

Source: Al-Layla, M. Anis, Shamim Ahmad, and E. Joe Middlebrooks, Water Supply Engineering Design, Ann Arbor, Michigan: Ann Arbor Science Publishers, Inc., 1977, p. 19.

a community will generally need to obtain the services of a consulting engineer, geologist, or hydrologist who can conduct a ground water exploration study in the vicinity of the community. The purposes and techniques of the exploration program are described in Chapter 8.

REFERENCES

1. E. T. Baker, Jr., and James R. Wall, "Summary Appraisals of the Nation's Ground Water Resources - Texas Gulf Region," Geological Survey Professional Paper 813F, Washington, D. C.: U. S. Government Printing Office, 1976, pp. F19-F20.

2. Ground Water and Wells, St. Paul, Minnesota: Johnson Division, UOP Inc., 1975, p. 30.

CHAPTER 8

GROUND WATER EXPLORATION

It has been estimated that there are vast reserves of ground water under the continental United States. However, there is no guarantee that adequate quantities of reasonably pure fresh water can be found in any given location, as ground water is not distributed equally across the country.

In the past, dowsing or "water witching" has been used to find underground water. Dowsing is the practice of using a divining rod (forked stick or other object) to find underground water or minerals. Scientific methods have now largely replaced dowsing, although dowsers are still employed to locate wells in many countries including the United States.

In order to exploit ground water, it is necessary to ascertain:

- the location, depth, and thickness of the aquifers in the study area, and the quality of their water;
- the most suitable location for wells, springs, or infiltration galleries and to estimate their yield; and
- the effects of the new water intake structures on ground water quality and on water table levels in the area.

Ground water exploration can be costly and time consuming; the extent and complexity of the investigation must be balanced with the financing and time available. Information acquired during exploration is used to design wells, springs, infiltration galleries as well as water treatment plants. Inadequate exploration may result in unnecessary construction and operation expenses. Over-pumping of an aquifer may lead to land subsidence or to excessive lowering of the water table which reduces the capacities of nearby wells.

The exploration is usually conducted by a ground water engineer, ground water geologist, or hydrologist, either under direct contract with the water supply organization or under subcontract with the engineering consulting firm responsible for the overall design of the water supply system. The exploration is usually divided into three stages: preliminary reconnaissance, qualitative investigation, and quantitative investigation.

THE PRELIMINARY RECONNAISSANCE STAGE

The purpose of the preliminary reconnaissance stage is to obtain existing data about an area in order to design a program for the expensive subsequent investigations. This basic data includes information about the area's topography, geology, vegetation, climate, surface water, and existing wells and springs. Occasionally, detailed information about aquifers can be obtained if prior studies have been conducted in an area. Preliminary reconnaissance data may be obtained from a variety of sources. Some of the most common sources and the type of information available from each source are listed in Table 8.1.

Aerial photographs can be an important source of information during the preliminary reconnaissance stage of ground water exploration. These can be obtained from government agencies, such as the Soil Conservation Service, or from aerial photography companies. It is sometimes desirable to employ one of these companies to furnish detailed photographs of a specific study area. Aerial photographs can be used to obtain valuable information about surface water areas, soil types, seepage areas, stream courses, vegetative cover, snow and ice cover, etc.

Satellite photographs as well as infrared, radar and microwave imaging have also been used in ground water exploration, but these methods are usually too expensive for small communities. Nevertheless, this information may be already available if prior studies of the area have been conducted by others.

Preliminary reconnaissance expenses are usually small, but a few extra dollars spent on this first stage

Table 8.1

Sources of Ground Water Information

Name of Source	Type of Information Available
Federal Agencies:	
U.S. Geological Survey	Geology, hydrology, maps, special studies.
U.S. Dept. of Agriculture	Local vegetation.
National Weather Service	Rainfall data, climate.
State or Local Agencies:	
State geological surveys	Geology, maps, special studies.
State water resource centers	Hydrology, maps, special studies.
State health departments	Ground water quality.
Ground water management districts or authorities	Depths of aquifers, expected yields, ground water quality.
Universities, especially engineering and geology departments	Special ground water studies, geology, hydrology.
Private:	
Local water well drilling contractors	Depths of producing wells in the area.
Oil and Mining companies	Geology.
Local water well owners and operators	Ground water quality, water well yields.

can save hundreds or thousands of dollars in subsequent stages of the investigation. After these data are collected and reviewed, the engineer or geologist will usually prepare topographic maps, geologic maps, aquifer maps, geologic profiles and cross sections for the study area. These maps and sections are then analyzed by the engineer in order to select the most promising locations for further, more detailed investigations.

QUALITATIVE INVESTIGATION

One purpose of the qualitative investigation is to verify that surface and subsurface conditions are indeed as the preliminary reconnaissance show them to be. A second goal is to obtain more detailed information about these conditions in the sites selected for further studies. The qualitative investigation usually consists of a combination of geophysical surveys and test hole sampling and logging.

Geophysical surveys consist of surface measurements and interpretations of variations in certain earth forces, which are either natural or artificially generated in the ground. These variations are measured using sensitive geophysical instruments. The most common geophysical methods used for ground water exploration are electrical resistivity surveys and the seismic refraction surveys.

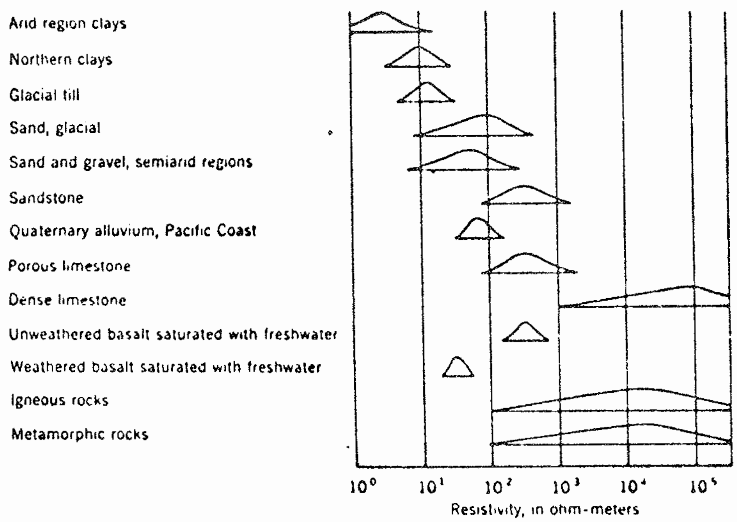
Electrical resistivity surveys are based on the fact that materials in the Earth's crust have different electrical resistivities depending on the type of soil or rock and the hydrological conditions in the formation (see Figure 8.1). The electrical resistivity of a material is its resistance to the passage of an electrical current. Clay has a much lower electrical resistivity than sand, and the electrical resistivity of fresh water is much higher than that of salt water.

By injecting an electrical current into the ground through two metal stakes (electrodes) and then measuring the resulting voltage between two other metal stakes (see Figure 8.2), a geophysicist can obtain information about the resistivity of the subsurface materials. The apparent resistivity of progressively deeper layers can be measured by increasing the distance between the four electrodes.

Seismic refraction surveys make use of the fact that shock waves travel at different speeds through various materials depending on the consolidation or density of the material (see Figure 8.3). A shock source is placed at one location (see Figure 8.4) and detectors are placed at various distances from this source. After the blast is set off, the arrival time of the first shock wave at each detector is carefully measured using a seismograph. Shock waves travel directly through the upper soil layers to the

Figure 8.1

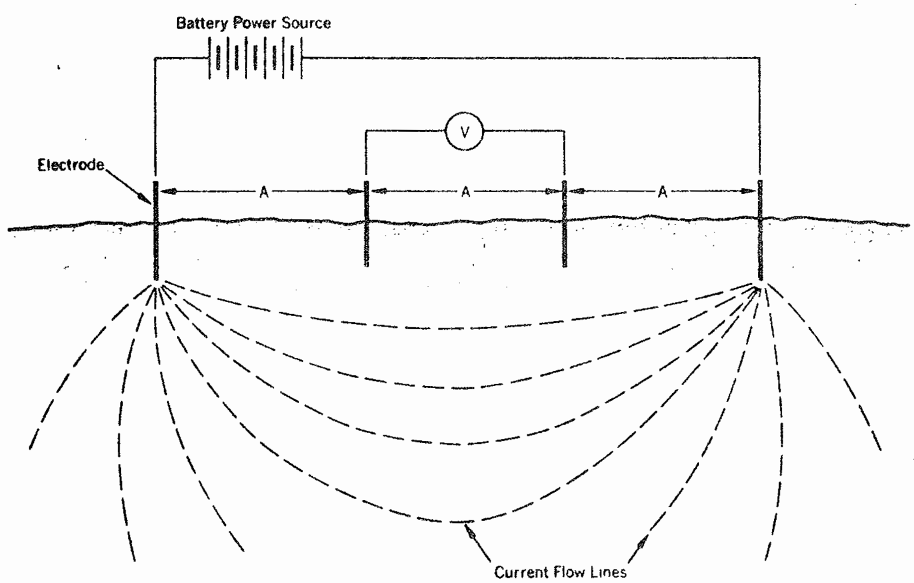
Electrical Resistivity of Some Common Earth Materials



Source: Ground Water Management, Manuals and Reports on Engineering Practice No. 40, New York, N. Y.: American Society of Civil Engineers, 1972, p. 149.

Figure 8.2

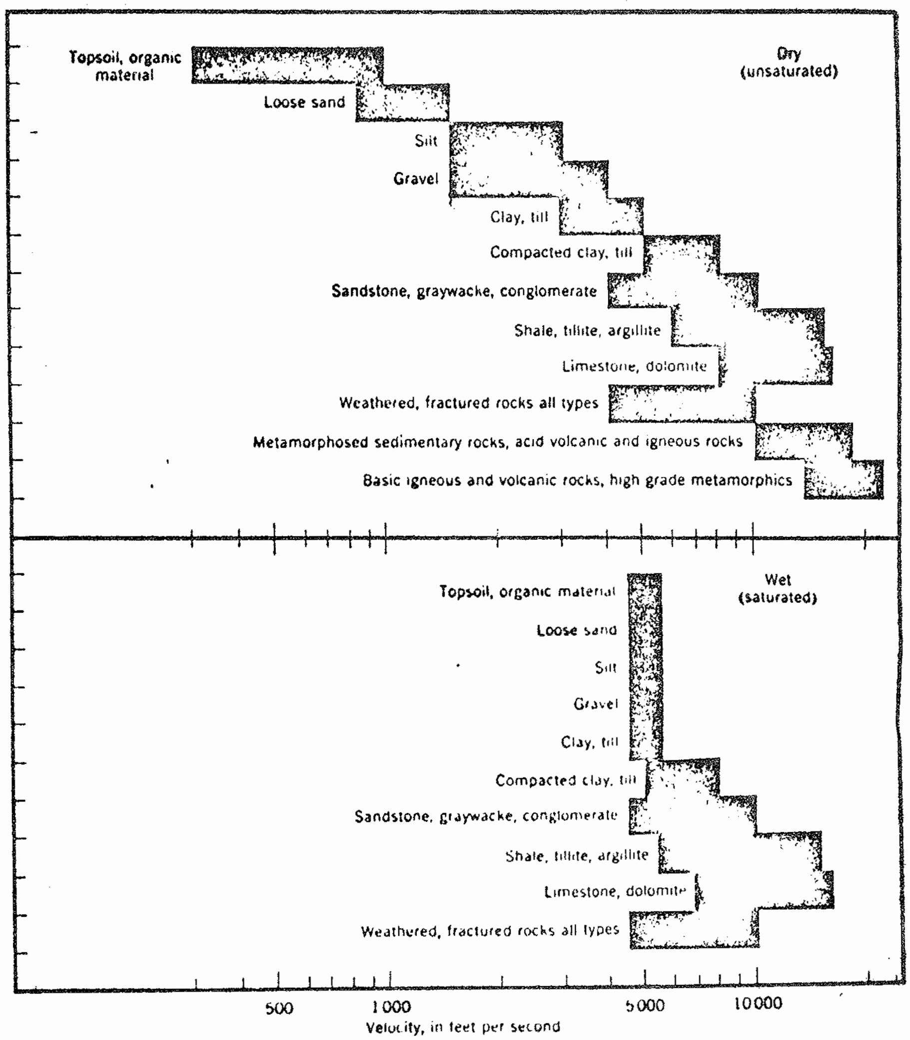
The Resistivity Method of Exploration



Source: Ground Water, AWWA Manual M21, New York, N.Y.: American Water Works Association, 1973, p.17. Reprinted by permission of AWWA.

Figure 8.3

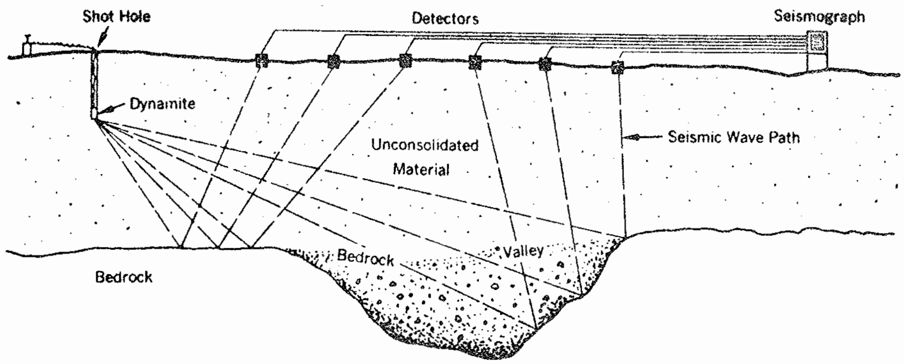
Seismic Velocities of Some Geologic Materials



Source: Ground Water Management, Manuals and Reports on Engineering Practice No. 40, New York, N.Y.: American Society of Civil Engineers, 1972, p. 154.

Figure 8.4

The Seismic Method of Exploration



Source: Ground Water, AWWA Manual M21, New York, N.Y.: American Water Works Association, 1973, p. 16.
Reprinted by permission of AWWA.

closest detectors, but more distant detectors will sense waves which have traveled some distance through underlying denser formations which have higher seismic velocities. These seismic data provide information about the nature of the underlying materials and their depth. Seismic methods are most often used in determining detailed bedrock profiles or in measuring water table elevations in sand and gravel.

These relatively inexpensive and quick methods should be supplemented by the drilling of test holes. Test holes are necessary to interpret geophysical data and to obtain precise data about aquifers, hydrogeological conditions, and geological structures.

Test holes are expensive to drill but it is not always necessary to drill a new test hole. Existing and abandoned wells can be used for test wells. Sometimes, drilled test holes can later be used for pumping so some of the costs can be recovered.

Well logs also provide information about the geologic strata which are penetrated by a test hole. The two most common types of well logs are electrical logs and radiation logs. In both types of logs, a probe is lowered into the hole and readings are taken at various probe depths. In electric logs, the potential difference between the ground and the probe, or between probes, is measured.

Natural or transmitted radiation is measured by gamma-ray radiation logging. Figure 8.5 shows a typical gamma-ray profile and electrical resistivity profile for a single test hole.

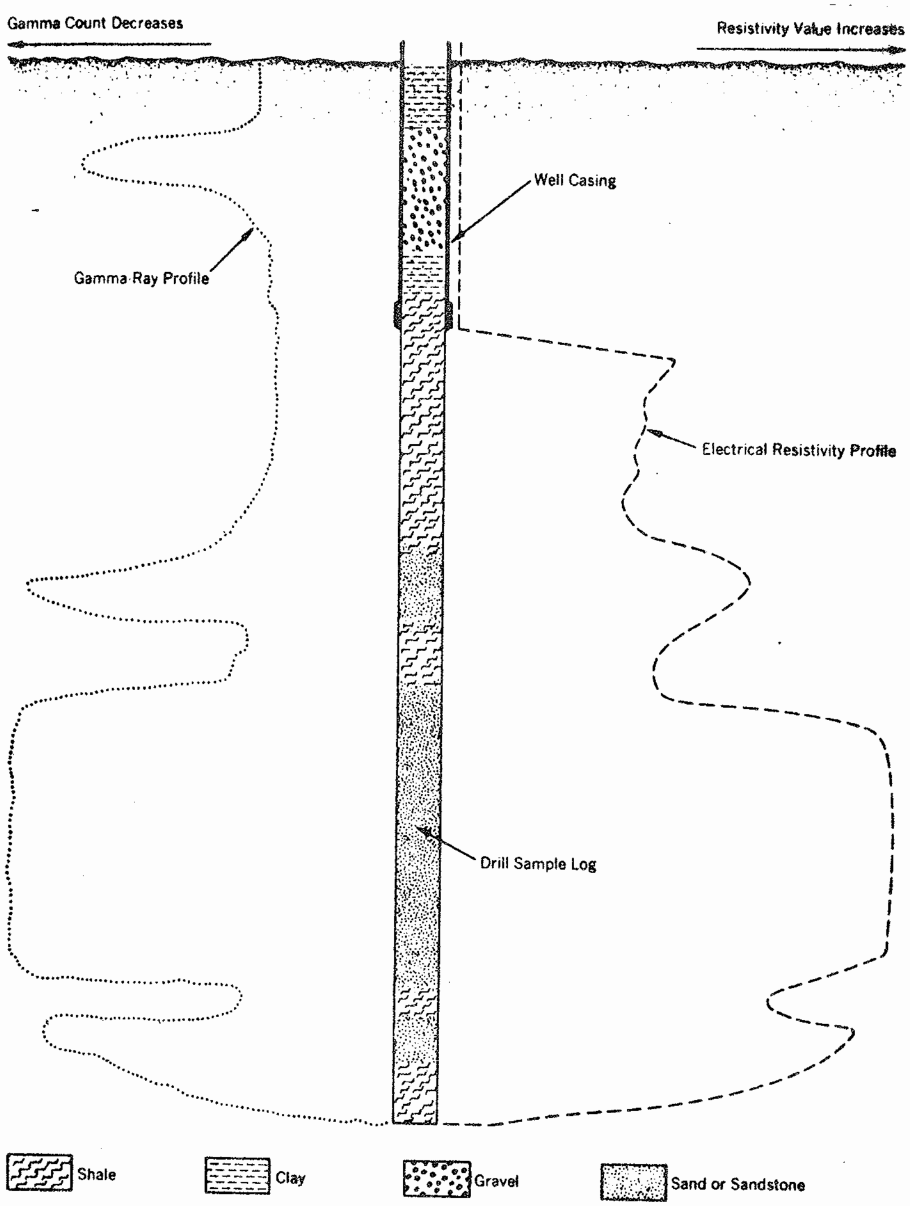
QUANTITATIVE INVESTIGATION

Although the qualitative stage of exploration gives the engineer or hydrologist detailed information about soil types and aquifers and their depth and location, some quantitative information is also needed. An investigator must know how much water an aquifer will yield in order to determine the number, size, and depth of wells that a water supply system should construct. Obtaining this information is the objective of the quantitative stage of exploration.

A pumping test is the most common method of obtaining quantitative information about an aquifer. Pumping tests are conducted in test holes or in holes which will eventually be used by water systems as producing wells. In a pumping test, investigators measure (a) the water level in the pumping well and in at least one nearby observation hole, and (b) the rate of discharge from the pump at specific time intervals after the pumping starts. As the well is pumped, a cone of depression forms around the well (see Figure 8.6). Water levels in the well and

Figure 8.5

Typical Electric and Gamma-Ray Logs



Source: Ground Water, AWWA Manual M21, New York, N.Y.: American Water Works Association, 1973, p. 18.
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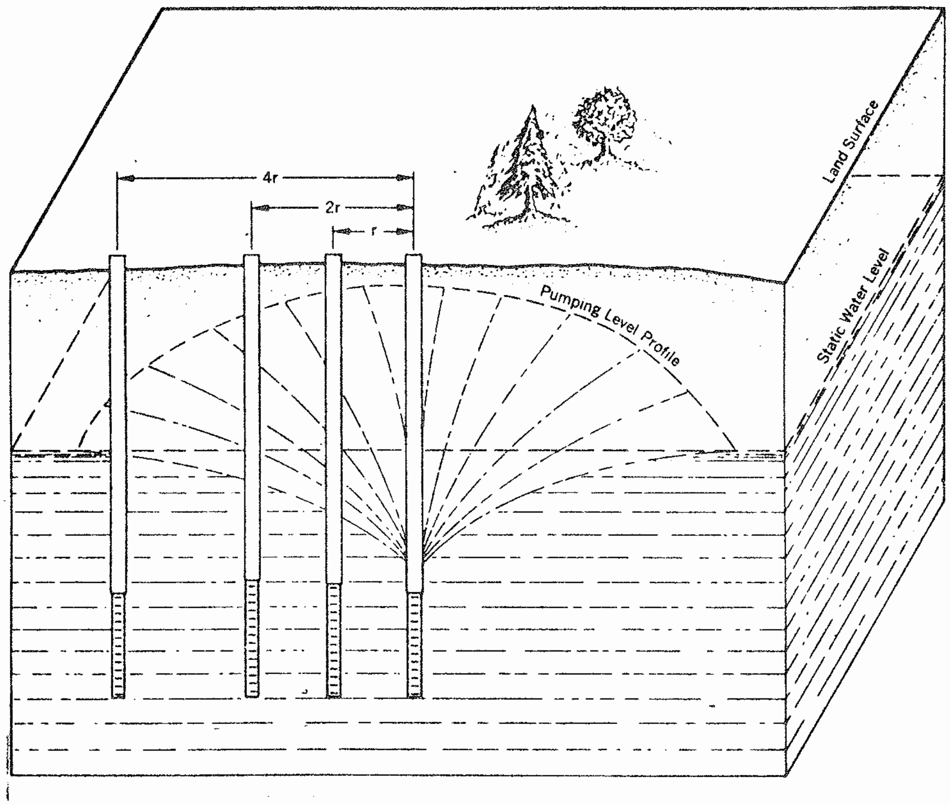
Figure 8.6

Development of a Cone of Depression in the Vicinity of a Pumping Well



Source: Ground Water, AWWA Manual M21, New York, N.Y.: American Water Works Association, 1973, p. 66.
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in nearby observation holes begin to drop. Eventually the water level in the well will stabilize. When stabilization occurs, the aquifer in the vicinity of the well is being recharged at a rate equal to the pumping rate. Sometimes it may take weeks or even months to achieve equilibrium. In these cases, investigators do the best they can with the data collected in the first few days of the test.

When the pumping test is complete, the pump is turned off and water levels are again measured at specific time intervals as the aquifer returns to its previous equilibrium position. This second set of data is used to confirm the information obtained during the pumping stage of the test. Completed measurements are then entered into standard mathematical formulas to compute the coefficients of permeability, transmissivity, and storage of the aquifer. The engineer uses these coefficients to determine how much water can be obtained from an aquifer using a single well or multiple wells in a well field.

Pumping tests provide valuable information but they can be expensive. They may cost from $2,500 to over $7,500, not including the cost of constructing the well (1). Small water systems may not be able to afford these tests. These water systems will rely on information obtained from existing nearby wells to estimate aquifer yields in the area.

After the three stages of exploration are complete, an engineer can use the data collected to design the wells, pumps, storage facilities, distribution lines, and treatment processes for a water supply system. The remaining chapters in this manual will describe the various kinds of equipment and processes that are available to the engineer. The discussion is limited to those methods of construction and types of equipment and processes which are most applicable to water supply systems for small communities.

REFERENCES

1. Massey-Norton, John T., Doug Bacon, Michael Eberle, and Tyler E. Gass, _Rural Water Supplies: A Cost Comparison of Central, Cluster, and Individual Source Systems_, Worthington, Ohio: National Water Well Association, 1979, p. 69.

CHAPTER 9

WELLS, SPRINGS, AND INFILTRATION GALLERIES

Ground water in relatively deep aquifers is reached by constructing vertical shafts or wells through the earth's crust. Shallow, exposed aquifers, which yield water naturally through springs, can be developed as ground water sources by providing adequate sanitary protection for the springs. Infiltration galleries or radial wells are used to obtain water from the shallow aquifers which lay adjacent to surface water sources. The various methods of constructing and developing these water intakes are discussed in this chapter.

THE COMPONENTS OF A WELL

In general, a vertical well consists of three parts, the shaft or hole, the well casing, and the well screen. The vertical shaft is dug or drilled in order to reach the underground aquifer. Well types are distinguished by the method used to construct the well shaft. These construction methods will be described in the following section.

Well casings support the sides of the shaft and prevent undesirable surface or ground water from entering the well. Casings must be watertight and strong enough to resist the pressure of the soil. Steel, iron, asbestos-cement, and plastic pipe are commonly used for water well casings. The corrosiveness of the water is an important factor to consider when selecting the casing material. Non-metallic pipes and metal pipes made from special alloys are most resistant to corrosion. Plastic pipe is lightweight, easy to install, and inexpensive. Polyvinyl chloride (PVC), polyethylene, and acrylonitrile butadiene styrene (ABS) plastic pipe have been used successfully for well casing, mostly in wells 6 inches in diameter or less. The disadvantage of plastic pipe is that it lacks the elasticity and the strength of steel.

A well screen allows ground water to enter a well but prevents sand from being carried into the well with the water. The selection of a proper screen is an extremely important and often complicated step in the design of a well. Since the grain size of the aquifer formation is the principal factor affecting the proper design of a screen, the final selection often cannot be made until the well shaft is drilled and a soil sample obtained from the water-bearing formation. An engineering service or screen manufacturer can make a mechanical sieve analysis of the soil sample and recommend a type of screen and a size of screen opening or slot.

Well screens are manufactured by punching holes or slots into metal pipe, by winding cold drawn wire spirally around a circular array of longitudinal rods (see Figure 9.1), or by wrapping a perforated pipe with a wire mesh or fabric screen. As with well casings, corrosion is an important factor to consider in the selection of a screen material. Brass, stainless steel, and galvanized steel screens are fairly resistant to corrosion, and specialized materials can be used for unusually corrosive waters. Plastic screens, made by cutting radial slots in plastic pipe, are often used when wells are cased with plastic pipe.

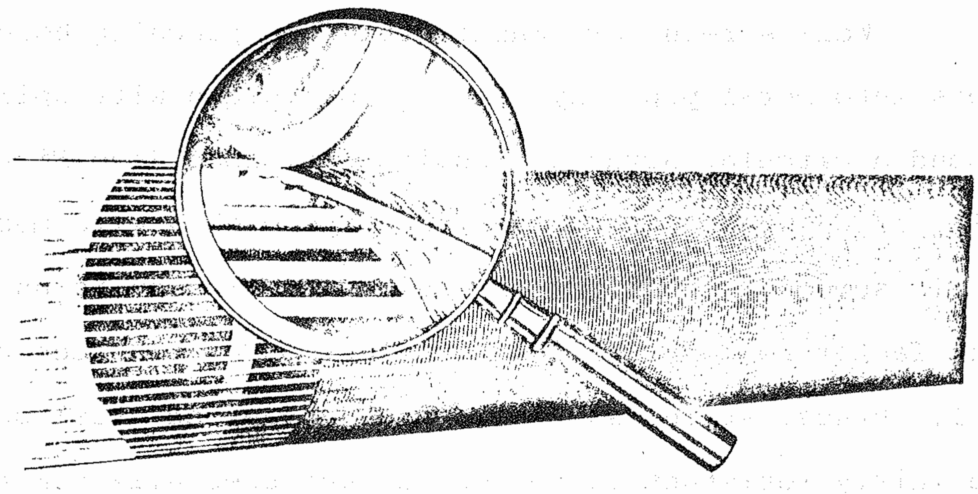
Well screens are typically installed by lowering the screen down the installed well casing until the top of the screen is slightly above the bottom of the casing. A "packer" is then used to seal the annular space between the screen and the casing.

Additions or modifications to these well components may be appropriate in certain circumstances. Screens are sometimes omitted in consolidated rock formations; Figure 9.2 illustrates two such examples.

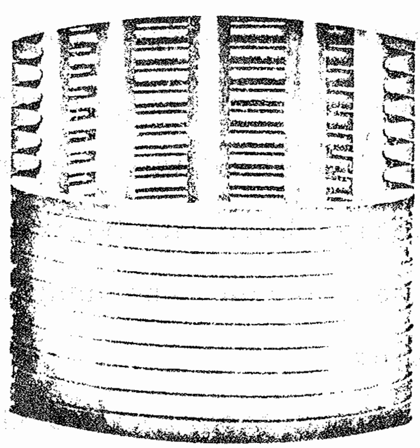
Another modification involves the installation of a gravel envelope around the well screen. Gravel-wall wells

Figure 9.1

The All-welded, Continuous-slot Johnson Well Screen



a. Fabrication of the screen.

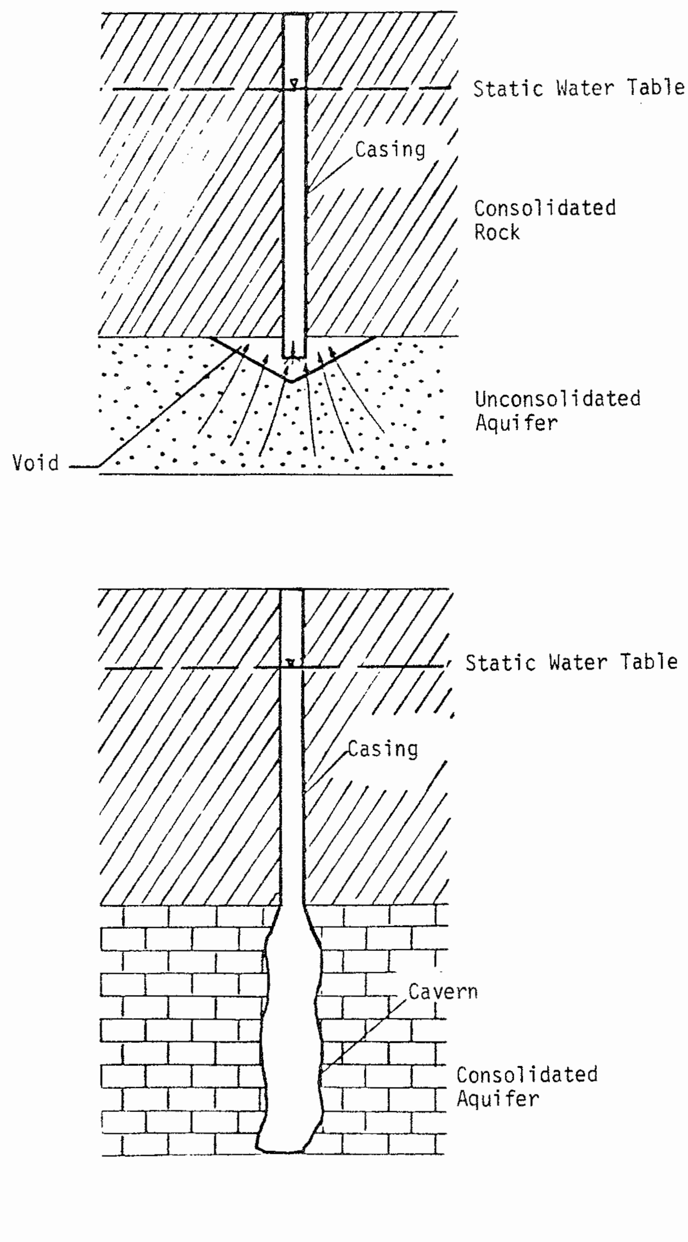


b. Section showing V-shaped openings.

Source: Ground Water and Wells, St. Paul, Minnesota: Johnson Division, UOP Inc., 1975, p. 146.

Figure 9.2

Two Examples of Wells Where Screens
Are Not Required

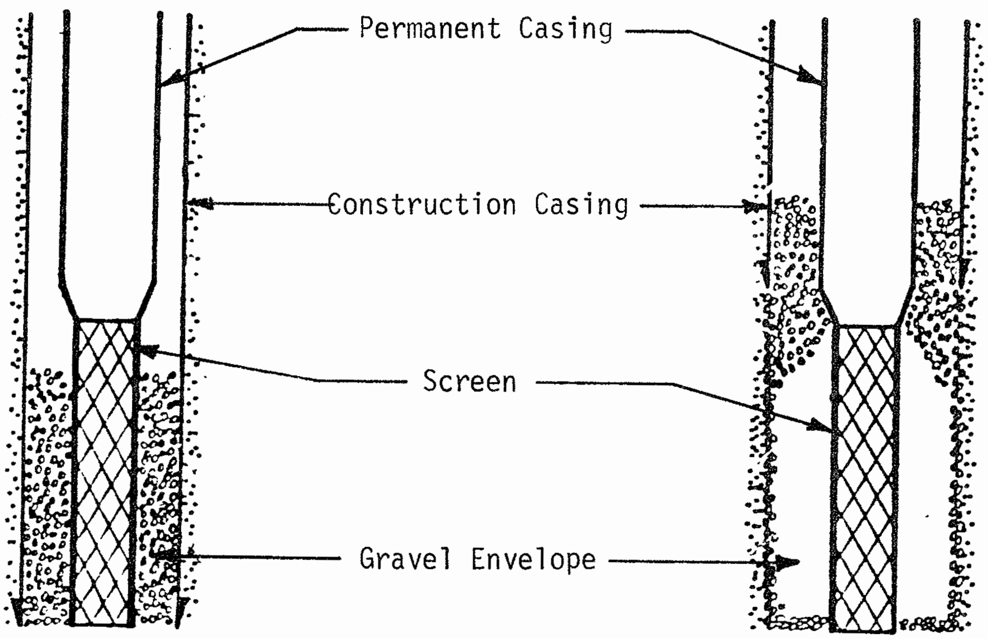


or gravel-packed wells are especially useful in thick artesian aquifers and in aquifers composed of fine material of uniform grain size. The gravel envelope permits the use of larger openings or slots in the screen, thereby increasing the flow of water into the well. Gravel-packed wells are more expensive than normal wells because a larger hole must be drilled in order to install the gravel, but the additional costs are offset by increased well capacity and shorter development time.

Gravel-packed wells are constructed by first sinking a construction casing to the bottom of the aquifer formation. The diameter of the construction casing may vary from 18 to 48 inches. The permanent casing and screen are then installed inside the construction casing. Clean, well-rounded gravel of a specific size is then installed in the annular space between the screen and the construction casing (see Figure 9.3). As the gravel is installed, the construction casing is pulled up taking care not to raise the bottom of the construction casing above the top of the gravel envelope. This process is continued until the gravel pack extends some distance above the top of the screen. Then the construction casing is removed from the well shaft.

Figure 9.3

Construction of a Gravel Packed Well



First layer of gravel has been installed and the construction casing is ready for partial removal.

Gravel envelope is complete and the construction casing is ready for complete removal.

THE CONSTRUCTION OF WELLS

Vertical wells can be dug, drilled, driven, bored, or jetted; they can be cased or un-cased; and they can be installed with or without screens. The construction method used in a particular case will depend on geologic conditions, aquifer depth, desired well diameter, and the drilling equipment available as indicated in Table 9.1.

Dug Wells

Dug wells can be constructed by hand or by using clamshell buckets with power hoists. They are generally shallow with depths ranging from 20-50 feet and have large diameters (3-20 feet). In the past, hand-dug wells were a common source of drinking water. Today hand-dug wells are generally regarded as unsuitable for community water supply because of their susceptibility to pollution. Their yield is also limited because ground water must flow into the well from only the bottom of the shaft (see Figure 9.4).

Bored Wells

Bored wells are constructed with either hand or power augers. Soil is cut by the auger blade and then collected in the bucket of the auger as it is turned. Every so often, the auger must be lifted out of the hole to

Table 9.1

Suitability of Well Construction Methods to Different Geological Conditions

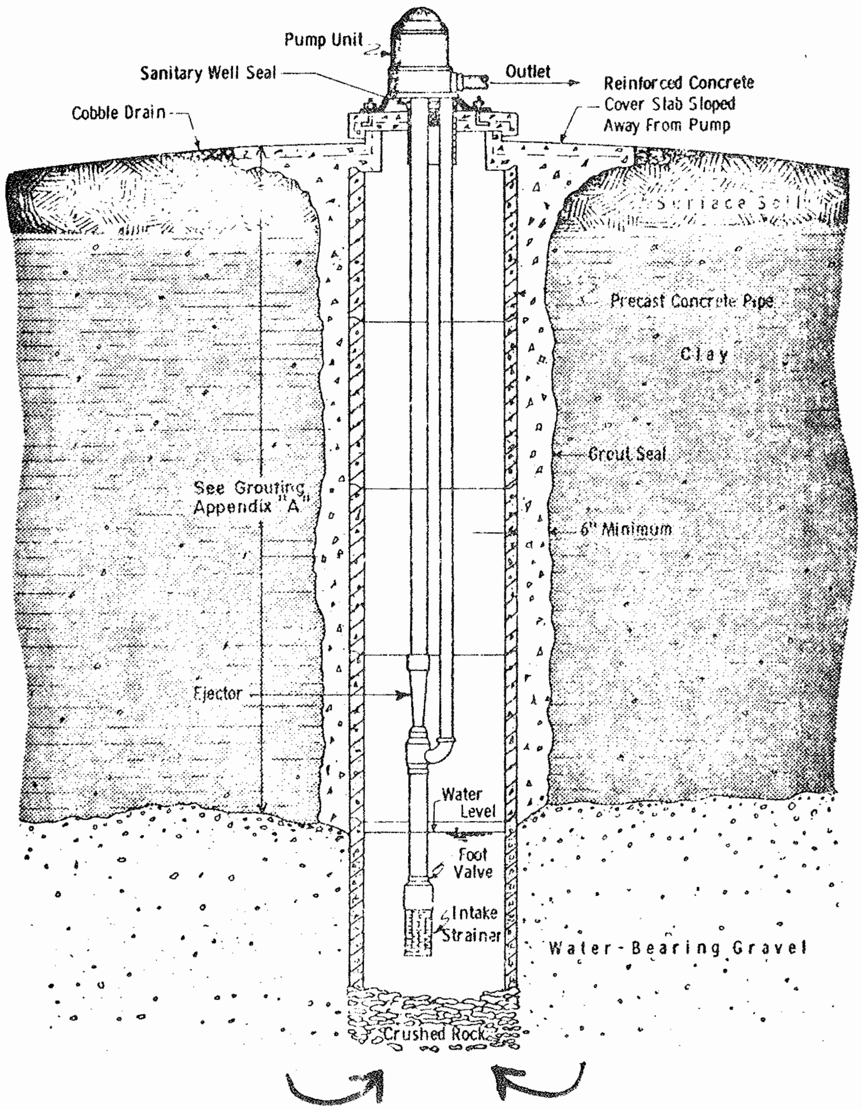
Characteristics	Dug	Bored	Driven	Drilled			Jetted
				Percussion	Rotary		
					Hydraulic	Air	
Range of practical depths (general order of magnitude)	0-50 feet	0-100 feet	0-50 feet	0-1,000 feet	0-1,000 feet	0-750 feet	0-100 feet
Diameter	3-20 feet	2-30 inches	1¼-2 inches	4-18 inches	4-24 inches	4-10 inches	2-12 inches
Type of geologic formation:							
Clay	Yes	Yes	Yes	Yes	Yes	No	Yes
Silt	Yes	Yes	Yes	Yes	Yes	No	Yes
Sand	Yes	Yes	Yes	Yes	Yes	No	Yes
Gravel	Yes	Yes	Fine	Yes	Yes	No	¼-inch pea gravel
Cemented gravel	Yes	No	No	Yes	Yes	No	No
Boulders	Yes	Yes, if less than well diameter	No	Yes, when in firm bedding	(Difficult)	No	No
Sandstone	Yes, if soft and/or fractured	Yes, if soft and/or fractured	Thin layers only	Yes	Yes	Yes	No
Limestone	Yes, if soft and/or fractured	Yes, if soft and/or fractured	No	Yes	Yes	Yes	No
Dense igneous rock	No	No	No	Yes	Yes	Yes	No

[1]The ranges of values in this table are based upon general conditions. They may be exceeded for specific areas or conditions.

Source: Office of Water Programs, Water Supply Division, U. S. Environmental Protection Agency, Manual of Individual Water Supply Systems, Washington, D. C.: U. S. Government Printing Office, 1975, p. 31.

Figure 9.4

Dug Well Showing Water Entry Through the Bottom of the Well Only



Source: Office of Water Programs, Water Supply Division, U. S. Environmental Protection Agency, Manual of Individual Water Supply Systems, Washington, D. C.: U. S. Government Printing Office, 1975, p. 34.

remove the soil from the hole. If the sides of the hole cannot stand without support, a well casing is lowered into the hole and then forced down as the boring progresses.

Bored wells are inexpensive to construct in unconsolidated formations, such as alluvial valley deposits, but are generally limited to a depth of about 100 feet. Thus, bored wells are also unsuited for community water supply because these shallow aquifers within 100 feet of the surface usually contain poor quality water and are easily polluted.

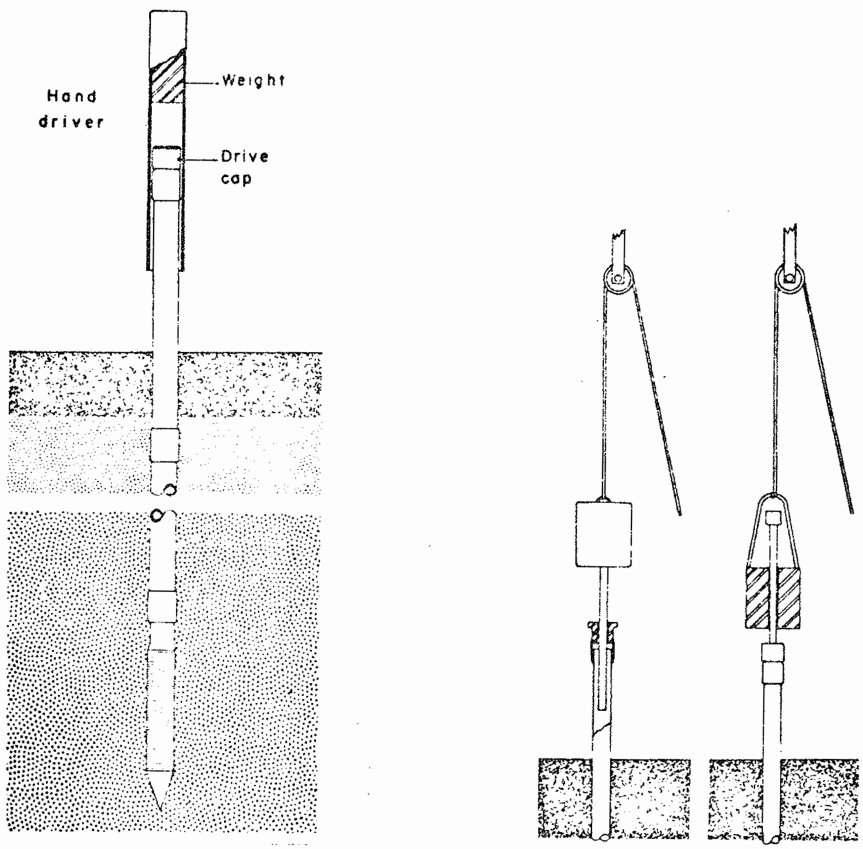
Driven Wells

Driven wells are simple and inexpensive to construct, but they can only be used in soft formations which are relatively free of cobbles or boulders. In driven wells, the drive point, screen, and casing are driven into the soil as an integral unit using hand or power operated driving tools (see Figure 9.5).

Driven wells, like dug and bored wells, are generally unsuitable for community water supplies because they can only be used to reach shallow aquifers. In addition, the diameter of a driven well is small, usually no more than 2 inches; only certain types of pumps can be used in these small diameter wells. In fact, driven wells are usually pumped by suction lift, which means that the pump is located

Figure 9.5

Tools for Driving Well Points



a. Simple hand driver

b. Heavier drive block assemblies commonly operated by drilling rig or with tackle.

Source: Ground Water and Wells, St. Paul, Minnesota: Johnson Division, UOP Inc., 1975, p. 232.

above the ground water table, usually at the ground surface. Since water can only be pumped about 15 feet using suction lift, only very shallow aquifers can be utilized. Furthermore, the capacity of a driven well is low. Even under favorable conditions, the capacity is limited to about 30 gpm; in fine sand or sandy clay formations of limited thickness, the yield of a driven well may not exceed 5 gpm.

Driven wells are sometimes used in conjunction with other kinds of wells to increase their capacity. By driving a well point into the aquifer at the bottom of a dug or bored well, the screen area of the well is increased, thereby allowing more water to enter the well (see Figure 9.6).

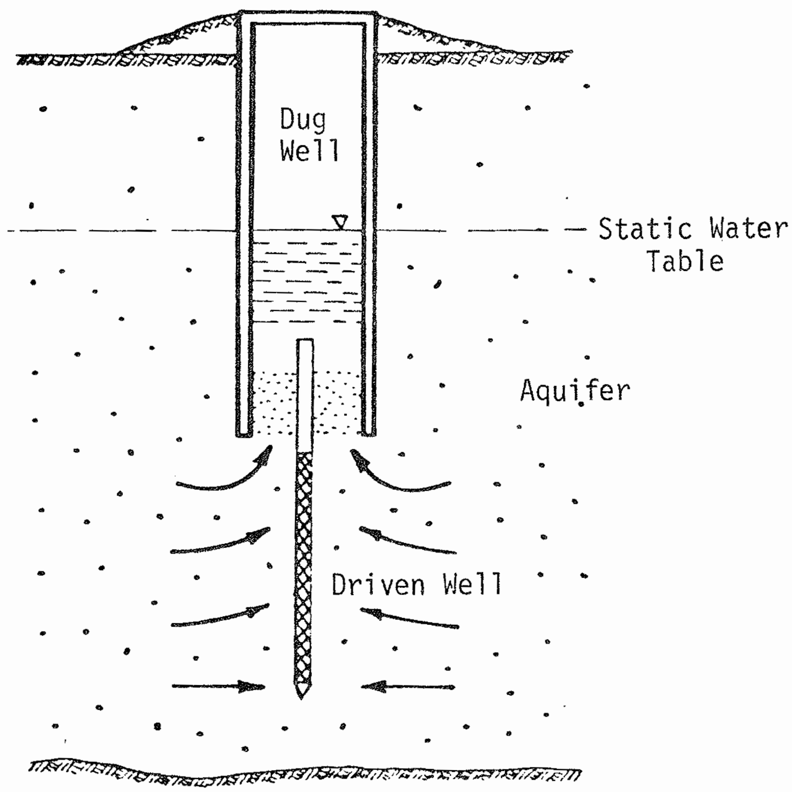
Drilled Wells

Drilled wells are suited for all types of geologic formations and can be used to develop water from shallow or deep aquifers. The diameter of a drilled well can range from 2 inches up to 48 inches and above. In productive formations, drilled wells can yield up to thousands of gallons per minute (1). For these reasons, drilled wells are the most common type of well used in community water systems.

Drilled wells are constructed using one of the following three methods: the percussion or cable tool method,

Figure 9.6

Driven Well Used to Increase the
Capacity of a Dug Well



the hydraulic rotary method, and the air rotary method. The cable tool method has been used by man for centuries to drill water wells. In its simplest form, the cable tool consists of a heavy drill bit which is repeatedly raised and then dropped into a hole. This bit loosens soft, unconsolidated rocks and breaks or crushes hard rock into small fragments. The back and forth action of the heavy bit mixes the rock particles with water to form a slurry which is periodically removed from the hole using a bailer. In the past, manpower was commonly used to lift and drop the drill bit. With modern machinery, bigger and heavier drill bits can be used and drilling proceeds at a much faster rate but the basic principle is still the same.

The hydraulic rotary method relies on the rapid rotation of a bit, rather than the up and down motion of a cable tool, to loosen, break, or crush rock formations. The loosened material is also removed in a different manner. A clay and water slurry is pumped down the drill pipe and through openings in the drill bit. The slurry picks up particles loosened by drilling and carries them to the surface through the annular space between the drill pipe and the casing or bore hole wall.

The air rotary method is similar to the hydraulic rotary method except that compressed air, rather than a water and clay slurry, is used to transport the loosened material to the surface. This method is used successively in consolidated rock formations, especially limestone. Since loosened material is continuously being removed in both the hydraulic and air rotary methods, drilling can proceed uninterrupted. In the cable tool method, drilling must be stopped and the drill pipe and bit removed for bailing operations.

Jetted Wells

The jetting method is most useful in penetrating sandy soils at shallow depths. This method can be used to construct wells at much greater depths, although other drilling methods are usually more popular. In the jetting method, water is pumped down the drill pipe under moderate or high pressure. As the water is forced out of the pipe through small holes or nozzles in a chisel-shaped bit, it loosens the material being penetrated and then carries the material to the surface.

THE DEVELOPMENT OF WELLS

After a well is drilled and casings and screens are installed, the well must be developed. Well development removes any clay or other foreign matter which may have clogged the water-bearing formation during the drilling operation. It also removes fine sand and clay from the aquifer in the vicinity of the well, thereby increasing the porosity and the permeability of the natural formation. Well development also stabilizes the formation around the well so that the well yields water free of sand.

High rate pumping or over-pumping is the simplest method of well development. The well is pumped at a rate greater than the anticipated rate of production in order to flush out the well and the adjacent aquifer materials. This method has been used satisfactorily in consolidated rock formations. It can also be used as a final step after other development methods to clean up the well and to demonstrate that the well will perform satisfactorily at lower pumping rates.

Surging is another simple method of developing a well. It can be done manually by driving a plunger up and down in the well casing. This action forces the water in and out of the formation, thereby loosening the fine materials which are removed periodically by pumping or bailing. Surging can also be done mechanically using compressed air or alternate pumping and backwashing with water.

Wells can be developed quickly and effectively by using a jetting tool which concentrates a fluid jet stream on the face of the bore hole and penetrates a short distance into the aquifer. The high velocity fluid breaks down dense compacted materials and drilling muds. These materials are removed by simultaneously pumping the well at a rate that is 15-20 percent greater than the rate at which fluid is introduced into the well through the jets. High velocity jetting has been successfully used to develop wells with continuously slotted well screens, but is less effective with perforated pipe screens where the openings are only a small percentage of the total screen area.

Chemical agents, such as polyphosphates and acids, and explosives are sometimes used in combination with one of the other methods to increase the effectiveness of well development. Polyphosphates disperse clay particles and prevent them from sticking to sand grains. Acids are used in limestone or dolomite aquifers to increase the size of the openings in the rock in the area near the well. In consolidated rock aquifers, explosives can be used to fracture the rock around the well, thereby increasing the number of passageways for ground water to enter the well.

SANITARY PROTECTION OF WELLS

It is important to locate wells a safe distance from all potential sources of pollution. Many contaminants are removed from ground water by the natural filtration process in the soil. The meaning of "a safe distance" between a source of pollution and a producing well depends on the local geological structure, the type of rock formation, the direction of flow of the ground water, the level of the water table, and the type and concentration of the pollutant. Table 9.2 can be used as a general guide in determining safe distances. Ground water pollution is discussed in more detail in Chapter 11.

After construction, a well must be properly sealed to prevent surface water and undesirable ground water from entering the well and the aquifer. The well drilling operation produces an annular space between the casing and the wall of the well shaft. This opening tends to close and be self-sealing in caving formations such as sand. In clay, shale and rock, this annular space provides a channel for the vertical movement of water between the surface and an aquifer and between different aquifers. Contaminants could then be carried into the well with surface water or with polluted ground water from shallow aquifers. This channel also allows ground water from artesian aquifers to escape, thus, decreasing the natural water pressure in these aquifers in the vicinity of the well.

Wells are sealed by placing a watertight cement grout in the annular space between the casing and the wall of the well shaft for either the entire length of the casing or only in those places where it is necessary. In general,

Table 9.2

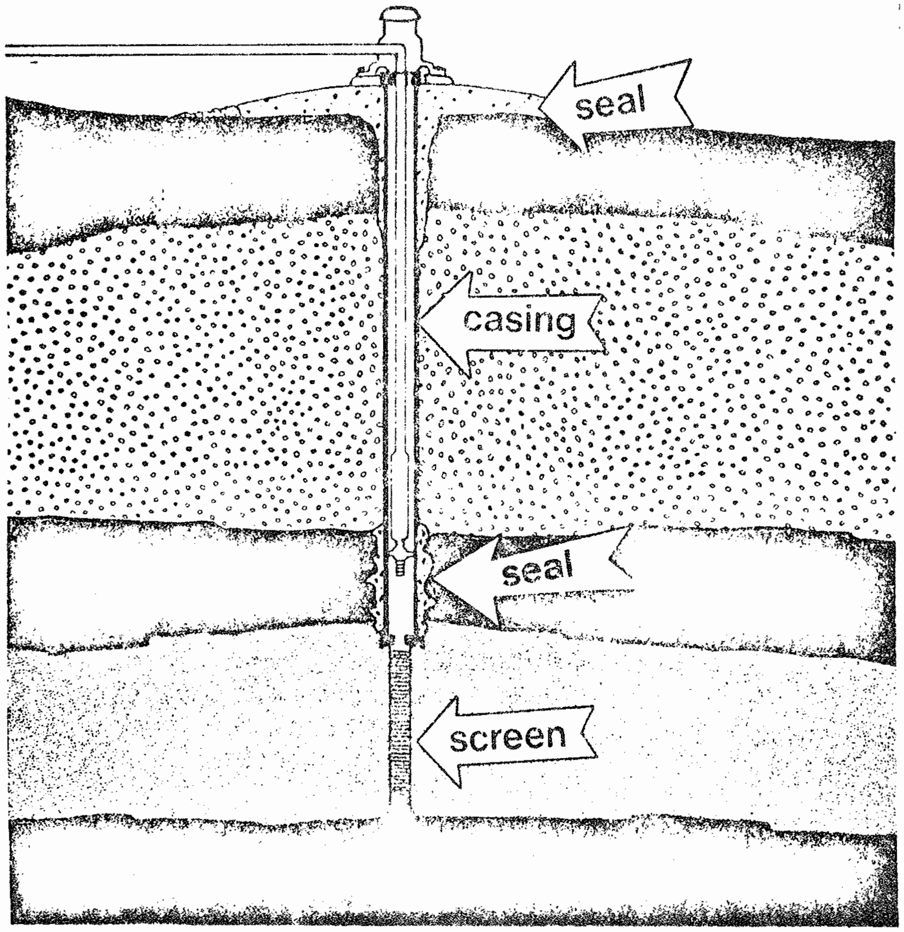
Guide for Determining "Safe Distances" between Wells and Sources of Contamination

Formations	Minimum acceptable distance from well to source of contamination	
Favorable/unconsolidated	50 feet	Lesser distances only on health department approval following comprehensive sanitary survey of proposed site and immediate surroundings.
Unknown	50 feet	only after comprehensive geological survey of the site and its surroundings has established, to the satisfaction of the health agency, that favorable formations do exist.
Poor (consolidated)		safe distances can be established only following both the comprehensive geological and comprehensive sanitary surveys. These surveys also permit determining the direction in which a well may be located with respect to sources of contamination. In no case should the acceptable distance be less than 50 feet.

Source: Office of Water Programs, Water Supply Division, U. S. Environmental Protection Agency, Manual of Individual Water Supply Systems, Washington, D. C.: U. S. Government Printing Office, 1975, p. 25.

Figure 9.7

Recommended Locations of Grout Seals



Source: E.E. "Skeet" Arasmith, Introduction to Ground Water Sources, Albany, Oregon: Linn-Benton Community College, 1977, p. 27.

the uppermost part of the casing should be grouted to prevent surface water contamination. All sections in impermeable formations should be sealed to prevent the migration of ground water from one aquifer to the next. Casings should be provided with tight-fitting covers to keep contaminated water or other material out of the well. In areas subject to flooding, the casing should extend at least two feet above the highest known flood level.

DISINFECTION OF WELLS

Disinfection is necessary to kill any organisms that may have contaminated the well during construction. Wells are usually disinfected using various chlorine solutions, such as calcium hypochlorite or sodium hypochlorite. These solutions are introduced into the well and allowed to stand for some period, usually about 24 hours. The well is then pumped to waste until there is no odor or taste of chlorine in the discharge. When wells are constructed with gravel packs, a disinfectant, such as calcium hypochlorite, is usually mixed with the gravel as it is installed in the well.

SPRINGS

Natural springs can be used for community water supply if the flow is sufficient to meet the needs of the community and if the water quality is acceptable. In general, springs large enough to supply whole communities with water are rare. Many springs have "dried up" due to extensive pumping of aquifers.

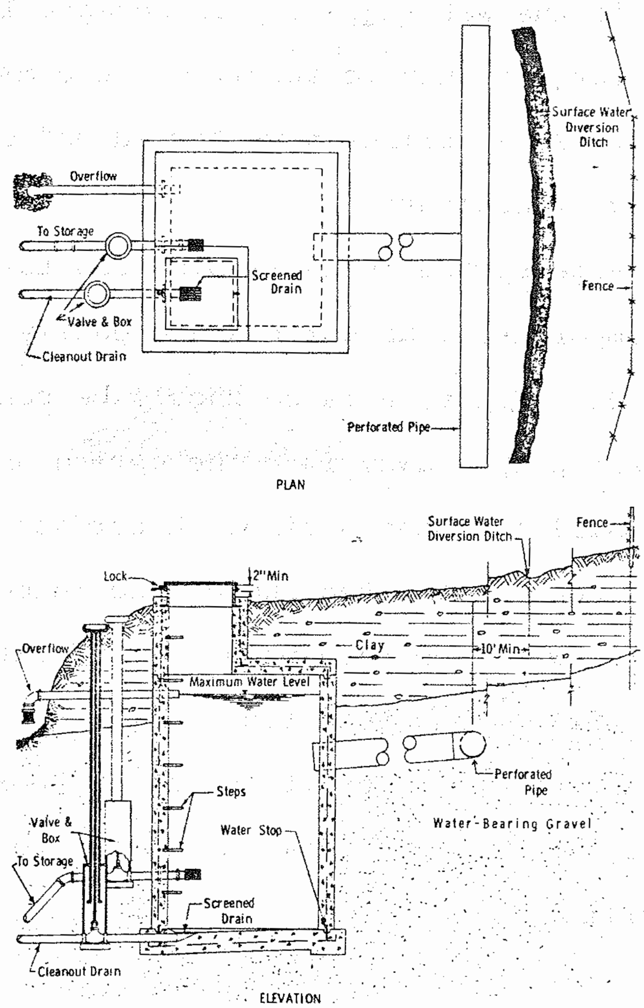
If a large spring is available, sanitary protection is of utmost importance, as springs are easily contaminated by surface water. First, a fence should be constructed to keep animals and people away from the spring and the area immediately uphill from the spring. A surface water diversion ditch is then constructed inside the fence to divert surface run-off away from the spring. Perforated pipe is laid in the water-bearing formation to intercept the ground water and channel it to a watertight spring box or manhole. Ground water is then pumped from the spring to storage or treatment facilities.

INFILTRATION GALLERIES

Infiltration galleries are used to collect water associated with surface water sources such as lakes and rivers. They are constructed as a series of horizontal wells which radiate from a large central well or pit, as a

Figure 9.8

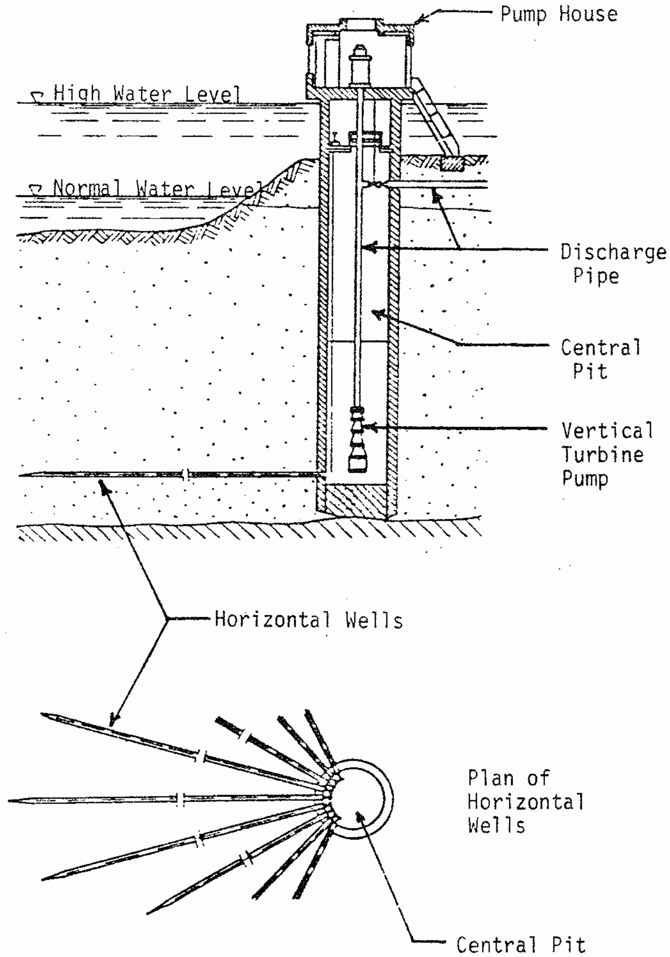
Construction Details for the Exploitation and Protection of a Spring



Source: Office of Water Programs, Water Supply Division, U. S. Environmental Protection Agency, Manual of Individual Water Supply Systems, Washington, D. C.: U. S. Government Printing Office, 1975, p. 57.

Figure 9.9

Ranney Type Radial Well



Source: J. Wierzbicki and D. Szpinder, Water Supply and Wastewater Disposal in Rural Areas, Warsaw: 1978 (in Polish).

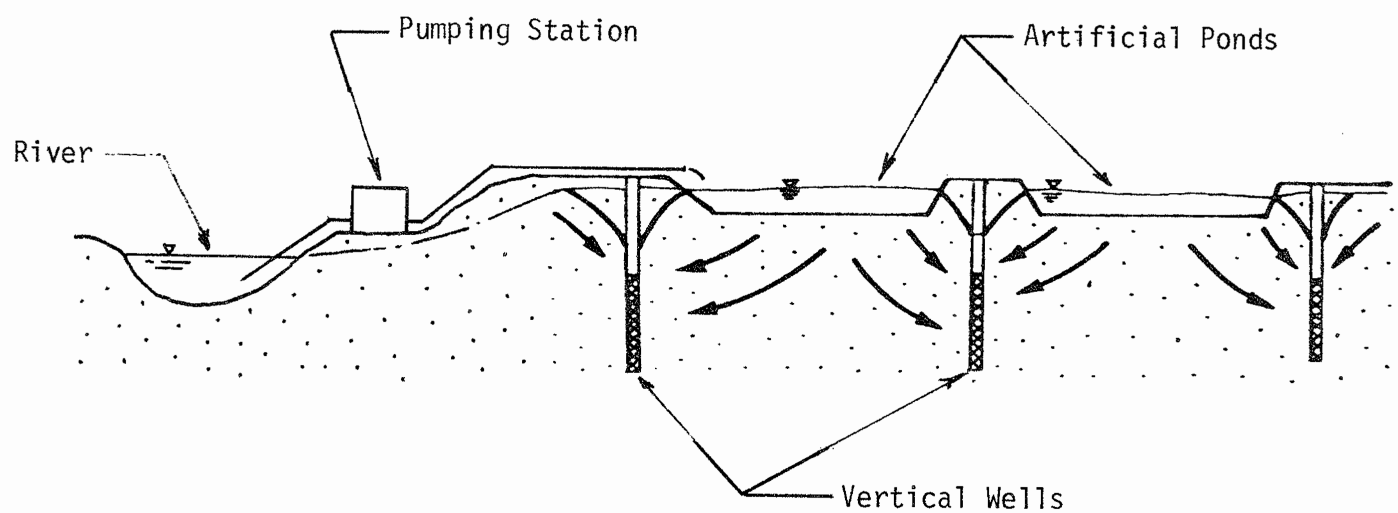
system of perforated drains or tunnels, or as standard vertical wells at intervals along a river, lake, or pond. In all cases, infiltration galleries take advantage of the natural filtration properties of the soil to improve the quality of surface water. The water obtained from infiltration galleries is usually of lower quality than most ground water and may still require additional treatment. Both the quantity and quality of the water from infiltration galleries depend upon the surface water source.

Sometimes artificial ponds are used in conjunction with infiltration galleries to make use of surface water (see Figure 9.10). Water from a river or stream is pumped into man-made ponds with permeable sides and bottoms. The water percolates through the permeable soil to a series of drains underneath the ponds or to a system of wells located adjacent to the ponds.

The capacity of a well depends on the details of its construction and the geologic and hydrologic conditions at the site. If its capacity is less than expected, more wells may be needed. Each well or series of wells is equipped with a pump which is matched to the well's capacity and to the pressure requirements of the treatment and distribution systems. The following chapter describes the types of pumps used in small water supply systems and the criteria used for their selection.

Figure 9.10

Artificial Ponds and Vertical Wells to Collect Surface Water



REFERENCES

1. Ground Water, A. W. W. A. Manual M21, New York: American Water Works Association, 1973, p. 25.

CHAPTER 10

PUMPS

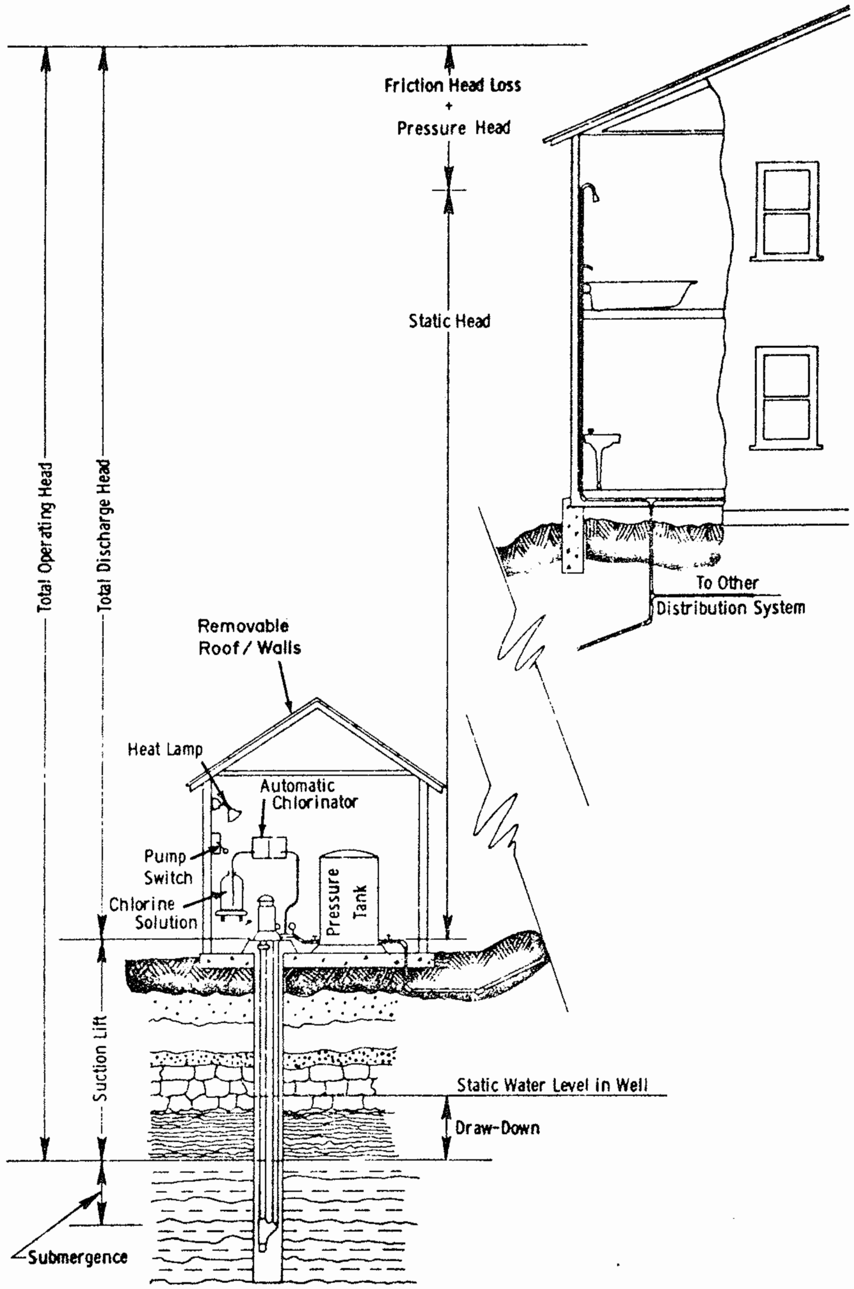
After a well is constructed, some kind of pump is installed in the well so that the ground water can be delivered to the community. A pump lifts water out of the aquifer and forces it through pipes to storage and treatment facilities and then into the distribution system. The pump motor or engine first converts electrical or other energy into mechanical energy. The pump itself then converts this mechanical energy into the kinetic energy of a moving fluid or into the potential energy of a body of fluid stored at a higher elevation. The following sections discuss the various types of water well pumps and the criteria and methods used in pump selection.

To deliver water where it is needed, a pump must overcome the total operating head in the water system (see Figure 10.1). The total operating head is the sum of the following:

- The total vertical lift from the pumping level in the well to the point of delivery in the water system, expressed in feet. This total vertical lift is made up of two parts, the suction lift which is that part of vertical lift below the pump, and the static head which is that part of the vertical lift above the pump.

Figure 10.1

Components of the Total Operating Head



Source: Office of Water Programs, Water Supply Division, U. S. Environmental Protection Agency, Manual of Individual Water Supply Systems, Washington, D. C.: U. S. Government Printing Office, 1975, p. 102.

- The friction head losses in the water system, expressed in feet.
- The pressure or velocity head, in feet, required to produce flow in the system.

The capacity of a particular type and size pump is defined by its capability of delivering certain quantities of water under various operating heads. This relationship between operating head and pump discharge is the most important criteria used in the selection of a water pump.

TYPES OF PUMPS

Pumps are classified in many ways. There are shallow well and deep well pumps; positive displacement, centrifugal and jet pumps; constant displacement and variable displacement pumps. Table 10.1 divides pumps commonly used in water systems into four categories: reciprocating, centrifugal, jet, and rotary pumps. Each category is further classified as shallow well or deep well pumps. A shallow well pump is installed above a well and takes water from the well by suction lift. Suction lift is accomplished by a pump by developing a partial vacuum, or negative pressure, in the intake pipe (see Figure 10.2). Atmospheric pressure on the water surface in the well forces water up into the intake pipe. Suction lift is normally limited to 20-25 feet. Water cannot be pumped by suction lifts greater than

Table 10.1

Types of Pumps

Type of pump	Practical suction lift[1]	Usual well-pumping depth	Usual pressure heads	Advantages	Disadvantages	Remarks
Reciprocating:						
1. Shallow well	22-25 ft.	22-25 ft.	100-200 ft.	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).
2. Deep well	22-25 ft.	Up to 600 ft.	Up to 600 ft. above cylinder.			
Centrifugal:						
1. Shallow well						
a. Straight centrifugal (single stage)	20 ft. max.	10-20 ft.	100-150 ft.	1. Smooth, even flow. 2. Pumps water containing sand and silt. 3. Pressure on system is even and 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 and speed.	1. Very efficient pump for capacities above 60 gpm and heads up to about 150 ft.
b. Regenerative vane turbine type (single impeller)	28 ft. max.	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 with 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. 2. All electrical components are accessible, above ground.	1. Efficiency depends on operating under design head and speed. 2. Requires straight well large enough for turbine bowls and housing. 3. Lubrication and alignment of shaft critical. 4. Abrasion from sand.	

Table 10.1 (Cont'd.)

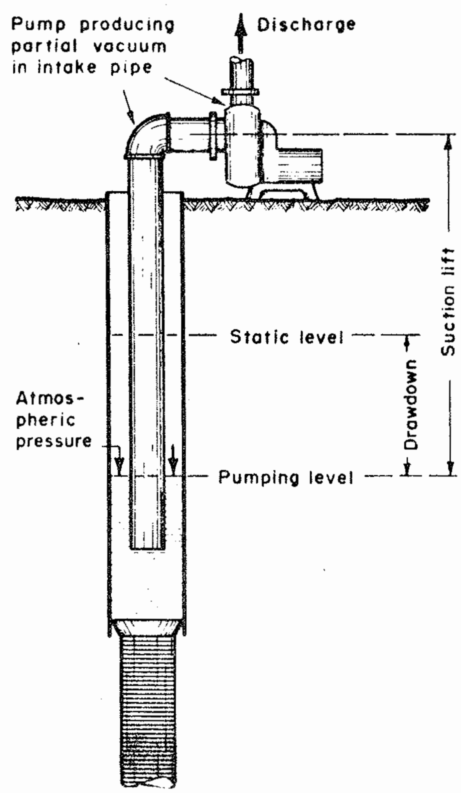
Type of pump	Practical suction lift[1]	Usual well-pumping depth	Usual pressure heads	Advantages	Disadvantages	Remarks
b. Submersible turbine (multistage)	Pump and motor submerged.	50-400 ft.	50-400 ft.	1. Same as shallow well turbine. 2. Easy to frost-proof installation. 3. Short pump shaft to motor. 4. Quiet operation. 5. Well straightness not critical.	1. Repair to motor or pump requires pulling from well. 2. Sealing of electrical equipment from water vapor critical. 3. Abrasion from sand.	1. 3500 RPM models, while popular because of smaller diameters or greater capacities, are more vulnerable to wear and failure from sand and other causes.
Jet:						
1. Shallow well	15-20 ft. below ejector.	Up to 15-20 ft. below ejector.	80-150 ft.	1. High capacity at low heads. 2. Simple in operation. 3. Does not have to be installed over the well. 4. No moving parts in the well.	1. Capacity reduces as lift increases. 2. Air in suction or return line will stop pumping.	
2. Deep well	15-20 ft. below ejector.	25-120 ft. 200 ft. max.	80-150 ft.	1. Same as shallow well jet. 2. Well straightness not critical.	1. Same as shallow well jet. 2. Lower efficiency, especially at greater lifts.	1. The amount of water returned to ejector increases with increased lift – 50% of total water pumped at 50-ft. lift and 75% at 100-ft. lift.
Rotary:						
1. Shallow well .... (gear type)	22 ft.	22 ft.	50-250 ft.	1. Positive action. 2. Discharge constant under variable heads. 3. Efficient operation.	1. Subject to rapid wear if water contains sand or silt. 2. Wear of gears reduces efficiency.	
2. Deep well .... (helical rotary type).	Usually submerged.	50-500 ft.	100-500 ft.	1. Same as shallow well rotary. 2. Only one moving pump device in well.	1. Same as shallow well rotary except no gear wear.	1. A cutless rubber stator increases life of pump. Flexible drive coupling has been weak point in pump. Best adapted for low capacity and high heads.

[1] Practical suction lift at sea level. Reduce lift 1 foot for each 1,000 ft. above sea level.

Source: Office of Water Programs, Water Supply Division, U. S. Environmental Protection Agency, Manual of Individual Water Supply Systems, Washington, D. C.: U. S. Government Printing Office, 1975, pp. 100-101.

Figure 10.2

Suction Lift in a Shallow Well Pump



Source: Ground Water and Wells, St. Paul, Minnesota: Johnson Division, UOP Inc., 1975, p. 377.

about 25 feet because high negative pressures cause water to vaporize. Thus, shallow well pumps can only be used where the expected pumping level in the well is less than 25 feet below the top of the well.

Deep well pumps are installed in the well at some depth below the surface. The pump itself is usually submerged below the pumping level so that the pump inlet is under a positive pressure head.

Reciprocating Pumps

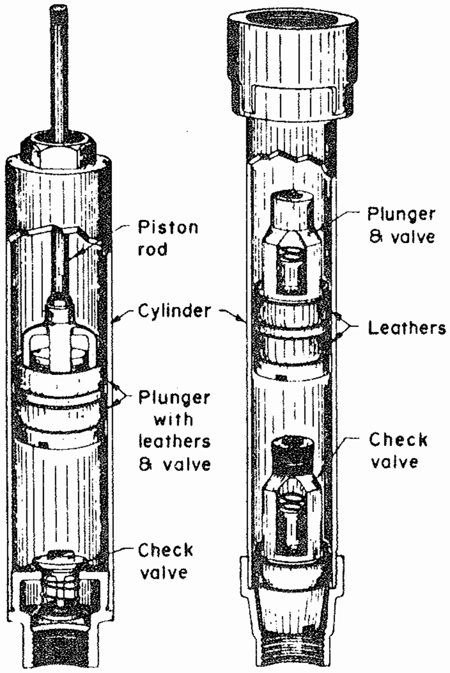
A reciprocating pump is a type of positive displacement pump that lifts water through the back and forth motion of a piston in a cylinder (see Figure 10.3). Since these pumps move approximately the same amount of water at each stroke of the piston regardless of the pressure of operating head, they are called constant displacement pumps. If installed as deep well pumps, they can be used to pump water from depths as great as 600 feet.

Centrifugal Pumps

Centrifugal pumps use centrifugal force to lift and move water from a well. As water enters the pump, a rotating impeller causes it to move radially at a high velocity (see Figure 10.4). Vanes or an expanding case change this velocity head into a pressure head as the water goes

Figure 10.3

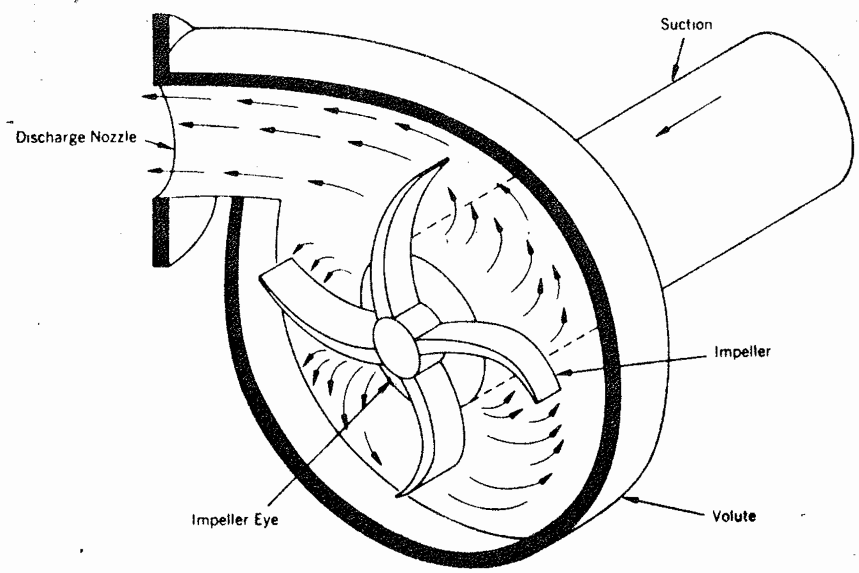
Single-Acting Piston Pumps



Source: Ground Water and Wells, St. Paul, Minnesota: Johnson Division, UOP Inc., 1975, p. 379.

Figure 10.4

Basic Components of a Centrifugal Pump



Source: Ground Water, AWWA Manual M21, New York: American Water Works Association, 1973, p. 90.
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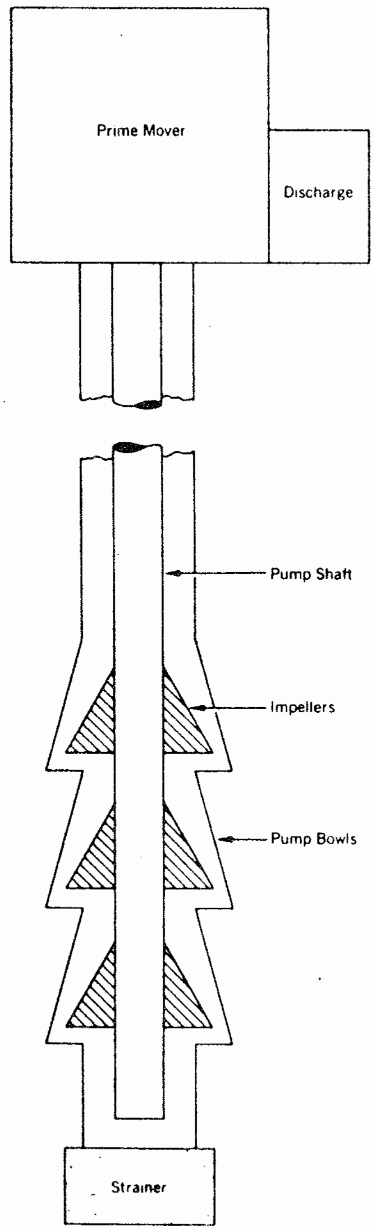
into the discharge line of the pump.

There are two types of shallow well centrifugal pumps, straight centrifugal and the regenerative vane turbine pumps. Straight centrifugal pumps use only centrifugal force to lift and move water. The impeller is housed in a spiral-shaped case which reduces the velocity and thus, increases the pressure as the water leaves the pump. Regenerative vane turbine pumps use both centrifugal force and positive displacement. In these pumps, the impeller rotates in a relatively close fitting housing. A series of vanes or fins enables regenerative vane turbine pumps to develop pressures several times that of pumps relying solely on centrifugal force. Since both types of shallow well centrifugal pumps can be used only where the pumping level in the well is no more than 20 to 28 feet below the pump, they are unsuited for community water systems which must obtain ground water from greater depths.

For deep wells, the centrifugal pump has been modified so that the pump assembly can be lowered into the well and usually submerged below the pumping level. The vertical line shaft turbine pump uses a series of impellers which are mounted vertically along the drive shaft of the pump (see Figure 10.5). Each impeller and matching casing represents a stage, and a pump with more than one stage is called a multistage pump. Water passing up through a multistage pump

Figure 10.5

Components of a Vertical Deep Well Turbine Pump



Source: Ground Water, AWWA Manual M21, New York: American Water Works Association, 1973, p. 93.
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receives an increase in pressure at each successive stage. The motor is mounted at the top of the well and is connected to the pump below by means of a drive shaft.

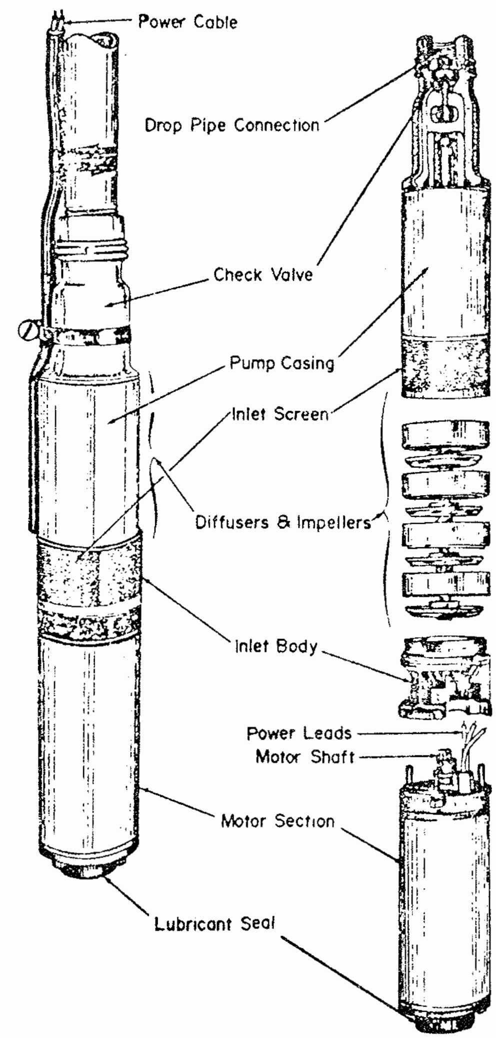
This long drive shaft is eliminated in submersible pumps where the pump and electric motor are closely coupled and lowered into the well as a unit (see Figure 10.6). Both the electrical wiring and the electric motor must be watertight. Submersible pumps are commonly used in community water supply systems because of the advantages listed in Table 10.2.

Jet Pumps

In a jet pump, water is forced down a pressure pipe to a nozzle by a conventional centrifugal pump which is mounted at the top of the well (see Figure 10.7). The water forms a jet as it is discharged from the nozzle into a venturi diffuser at a high velocity. This causes a low pressure area in the throat of the venturi such that additional water is drawn into the venturi through the intake pipe of the pump. This additional water mixes with the circulating water as it travels up the suction pipe. After returning to the centrifugal pump, some of the water is discharged while the rest is circulated back down the pressure pipe. Jet pumps can be used in shallow or deep wells but are best suited for small capacity wells (less

Figure 10.6

Exploded View of a Submersible Pump



Source: Office of Water Programs, Water Supply Division, U. S. Environmental Protection Agency, Manual of Individual Water Supply Systems, Washington, D. C.: U. S. Government Printing Office, 1975, p. 95.

Table 10.2

Advantages of Submersible Pumps

1. Only a minimum amount of surface equipment and structure is needed.

2. Their operation is relatively noiseless.

3. In flood prone areas, the well can be completely sealed.

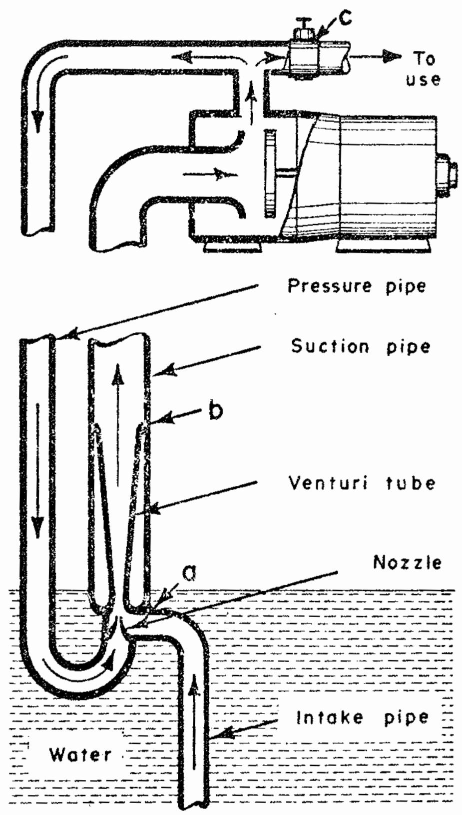
4. Because the conventional drive shaft and its associated bearings are eliminated, friction losses are reduced and well straightness is not as critical as in the vertical line shaft turbine pump.

5. Installation is simple.

6. They are equipped with a factory installed and sealed lubrication system that eliminates oil leakage into the well.

Figure 10.7

Operating Principles of a Jet Pump



Source: Ground Water and Wells, St. Paul, Minnesota: Johnson Division, UOP Inc., 1975, p. 387.

than 50 gpm) with pumping levels 100-200 feet deep.

Rotary Pumps

Rotary pumps are positive displacement pumps that squeeze the water between specially designed rotating runners. Although widely used, rotary pumps wear quickly when the water being pumped contains sand or silt.

There are two kinds of rotary pumps, the gear type and the helical type. The rotary gear pump is only used on shallow wells as the rotating gears are mounted at the top of the well. As the gear teeth move away from each other as at point A in Figure 10.8, a partial vacuum is developed which draws water into the pump through the suction pipe. When the teeth mesh at point C, water is forced out of the pump through the discharge pipe.

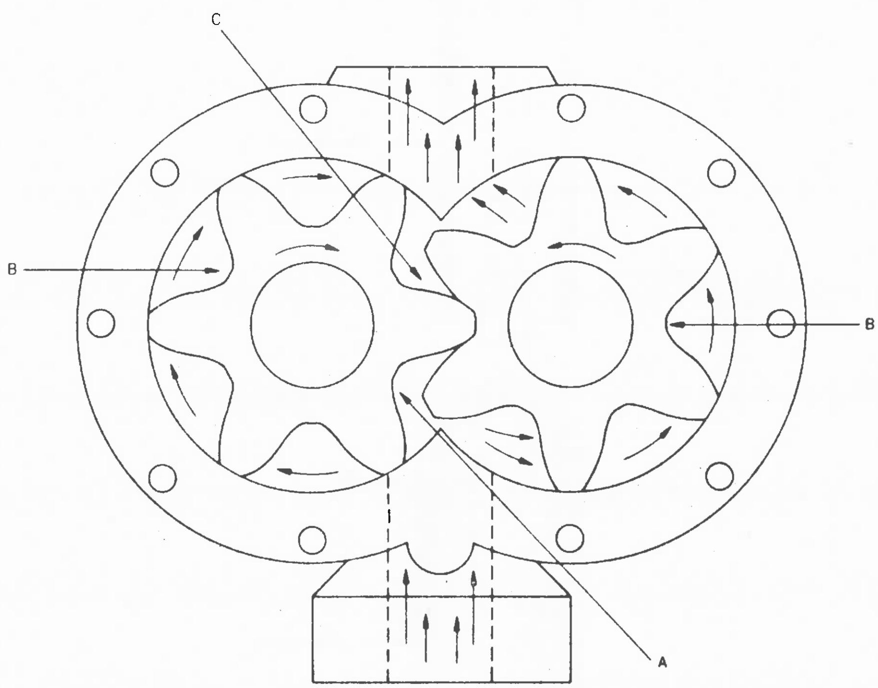
A helical rotary pump is suitable for deep wells because all but the motor can be lowered into the well and submerged. The pumping element consists of helical worm threads which force water up as they rotate (see Figure 10.9).

SELECTING A PUMP

Selecting the best pump from the hundreds of water well pumps currently on the market is a complicated but

Figure 10.8

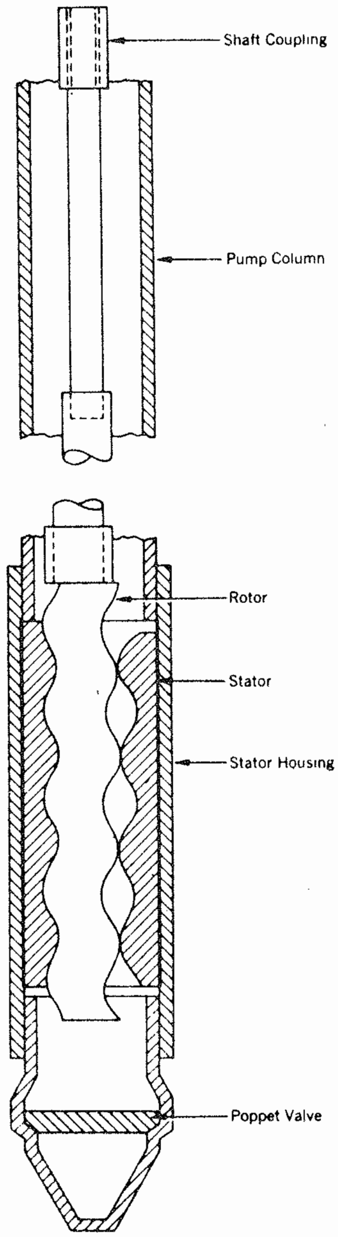
The Rotary Gear Pump



Source: Ground Water, AWWA Manual M21, New York: American Water Works Association, 1974, p. 96. Reprinted by permission of AWWA.

Figure 10.9

Components of a Rotary-Displacement Pump



Source: Ground Water, AWWA Manual M21, New York: American Water Works Association, 1973, p. 95.
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critical part of the water system design. The pump must be adequate to meet the requirements of the system. It should be reliable and it should be economical both in terms of first costs and operating costs. Some of the specific factors that should be considered in selecting a particular type of pump are listed in Table 10.3.

It has already been stated that the relationship between operating head and pump discharge is the most important criteria used in the selection of a pump. This relationship for the pump is expressed in a set of curves, called pump characteristic curves, which are published by the pump manufacturer.

Characteristic curves for a centrifugal pump are shown in Figure 10.10. The head capacity curve shows the flow rate which will be delivered by the pump as the total head varies. The pump always operates at a specific point on the curve at any given time. For example, if the total head in the system is 155 feet, then the pump will deliver 200 gallons per minute. By drawing a vertical line through this point on the head capacity curve such that the line also crosses the efficiency and brake horsepower curves, the designer can determine the efficiency of the pump and the power needed to drive the pump at that particular operating point on the curve.

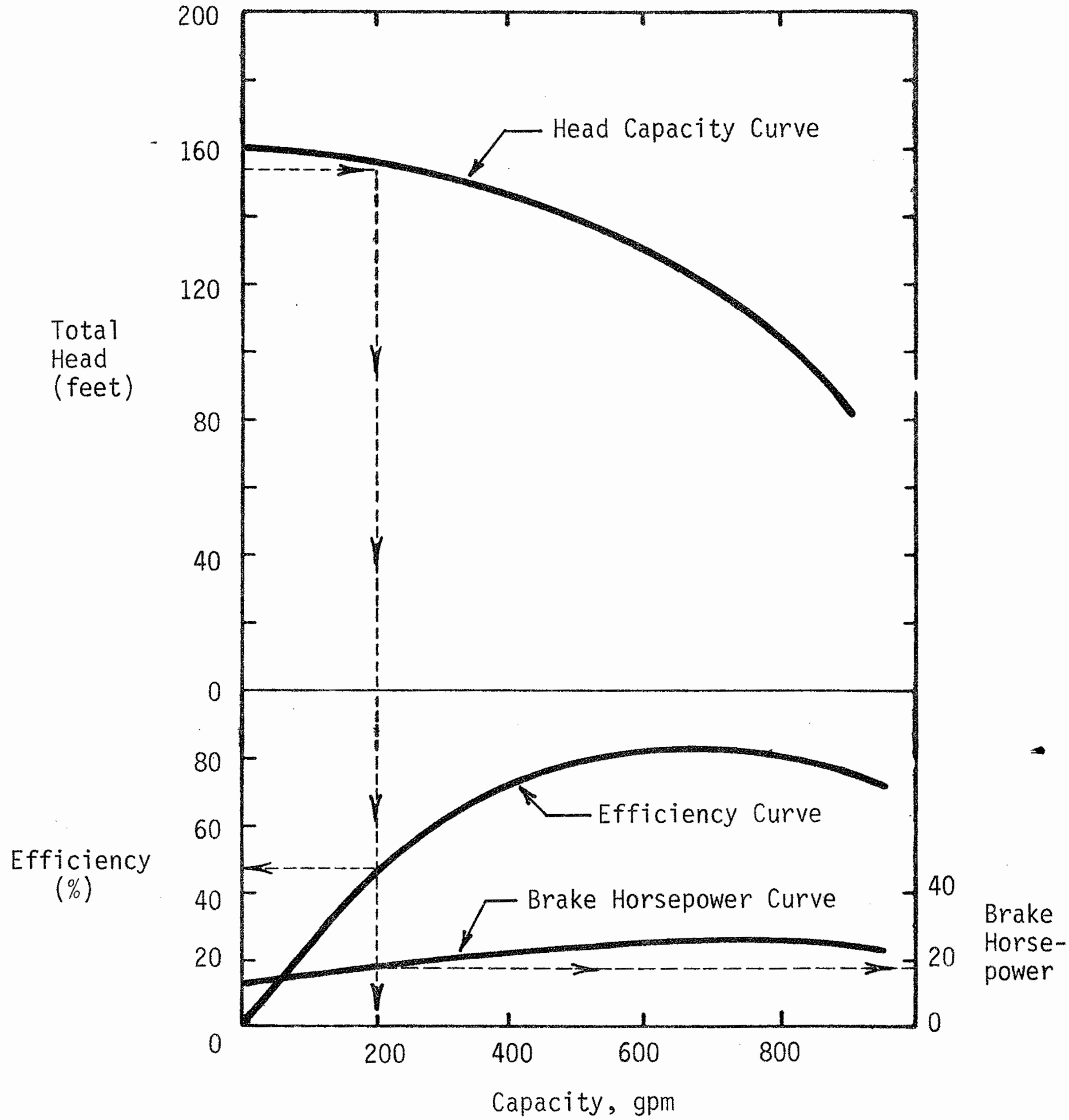
Table 10.3

Factors to Consider in Selecting a Pump

1. The available yield of the well itself.
2. The maximum capacity or flow that may be demanded of the pump, usually expressed in gallons per minute (gpm).
3. Total operating head under average, maximum, and minimum conditions of pumping.
4. The depth of the well and the expected pumping level.
5. Types of power available and the costs of power.
6. The size and alignment of the well bore or casing, and the space available at the surface for pumps, and other equipment.
7. The temperature, abrasiveness, and corrosiveness of the ground water.

Figure 10.10

Pump Characteristic Curves
For a Centrifugal Pump



The relationship between discharge and operating head for the rest of the water system is called the system head curve. The system head curve describes the yield or capacity possibilities of the well, the piping before the pump, and the piping and storage after the pump. The curve is plotted using information obtained during the yield-drawdown test of a well combined with friction loss and velocity head calculations for the water system piping. A typical system head curve is shown in Figure 10.11. The total operating head in the system increases with increasing flow, because friction losses, velocity heads, and draw-down in the well all increase as the flow is increased.

To select an individual pump for a particular situation, a designer compares the system head curve with the characteristic curves of various pumps. A typical system head curve and the characteristic curves of two pumps are shown in Figure 10.12. Each pump will operate at the point where the system head curve crosses its head capacity curve. Pump #1 will operate at point A and pump #2 will operate at point B. By drawing vertical lines through both points, the efficiencies and horsepower requirements of each pump can be determined. On the basis of efficiency, pump #2 should be selected for this particular water system. Before making the final decision, however, the first cost, reliability and durability of each pump must also be considered.

Figure 10.11

System Head Curve

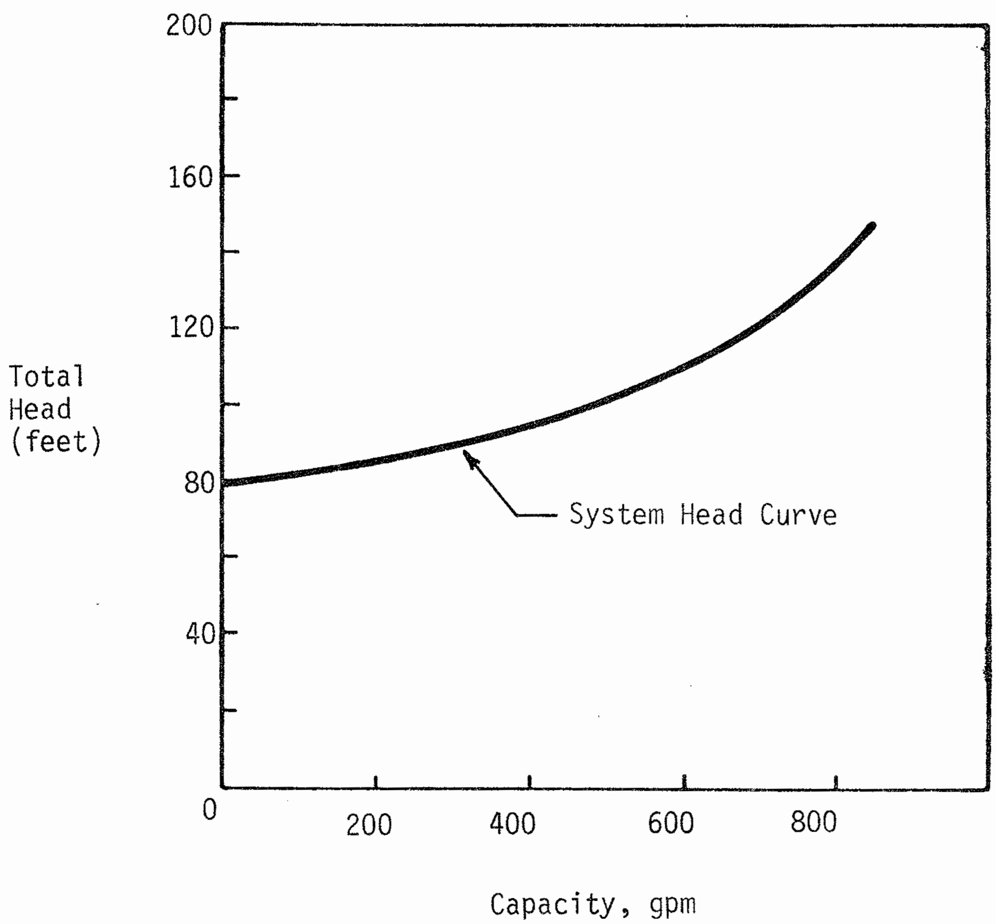
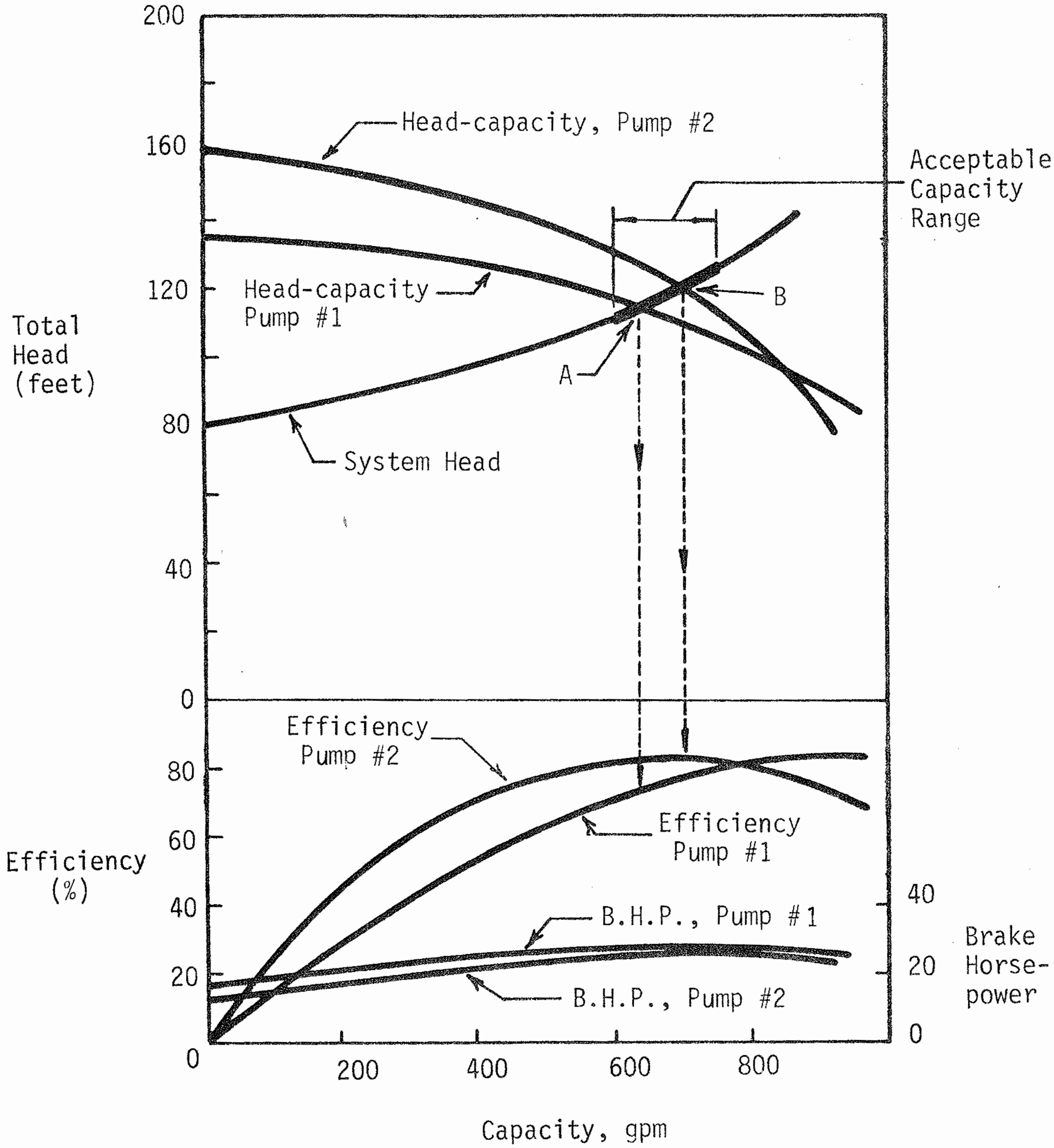


Figure 10.12

Selecting the Most Efficient Pump



INSTALLATION OF PUMPS

Special care is required when installing the pumping equipment in a water system. The following items should always be considered: support, depth and alignment, weatherproofing, provisions for inspection, disinfection, and sanitary protection.

Pumping equipment is heavy and subject to vibration during operation. Adequate support must be provided to prevent damage to the pump, well, piping, and other equipment. Most water well pumps are supported by some sort of flange which is attached to the top of the well casing. A submersible pump, for example, is suspended in a well on a drop pipe which is usually supported at the top of the well by a steel plate welded to the casing. Shallow well rotary, reciprocating, and centrifugal pumps are sometimes mounted on the well casing as well. In these cases, the well casing must be strong and securely grouted in the well bore.

Jet pumps and some shallow well centrifugal pumps do not need to be mounted directly over the well. These pumps can be mounted on a concrete foundation and secured by anchor bolts.

In deep wells, care must be taken to ensure that the pumping element is installed at the proper depth. Most deep well pumps are designed to operate under positive head conditions, so the pump must be installed below the expected pumping level in the well. Alignment of the drop pipe and line shaft is critical in vertical turbine pumps since the long shafts must rotate at high speeds.

Alignment of the discharge piping is also important. Piping should be supported independently of the pump and should line up naturally and should not be forced into place with flange bolts. A gate valve and check valve should be installed in the discharge piping to protect the pump from water hammer effects and to prevent water from returning into the well through the pump when it is not running.

Pumphouses are usually required to protect the pump and its motor. These structures should be constructed with a watertight concrete floor which slopes away from the well casing. The house should be provided with lights and with a heater and insulation where necessary. Lightning arresters can be installed to protect the pump from damage due to lightning. If the water system does not have storage facilities large enough to supply water to the community during power failures, the pump can be provided with an alternate power source, such as a gasoline or diesel generator.

Submersible pumps do not require a pumphouse since both the pump and its motor are submersed in the well. After the pump is installed, the well casing is sealed to prevent contamination of the well.

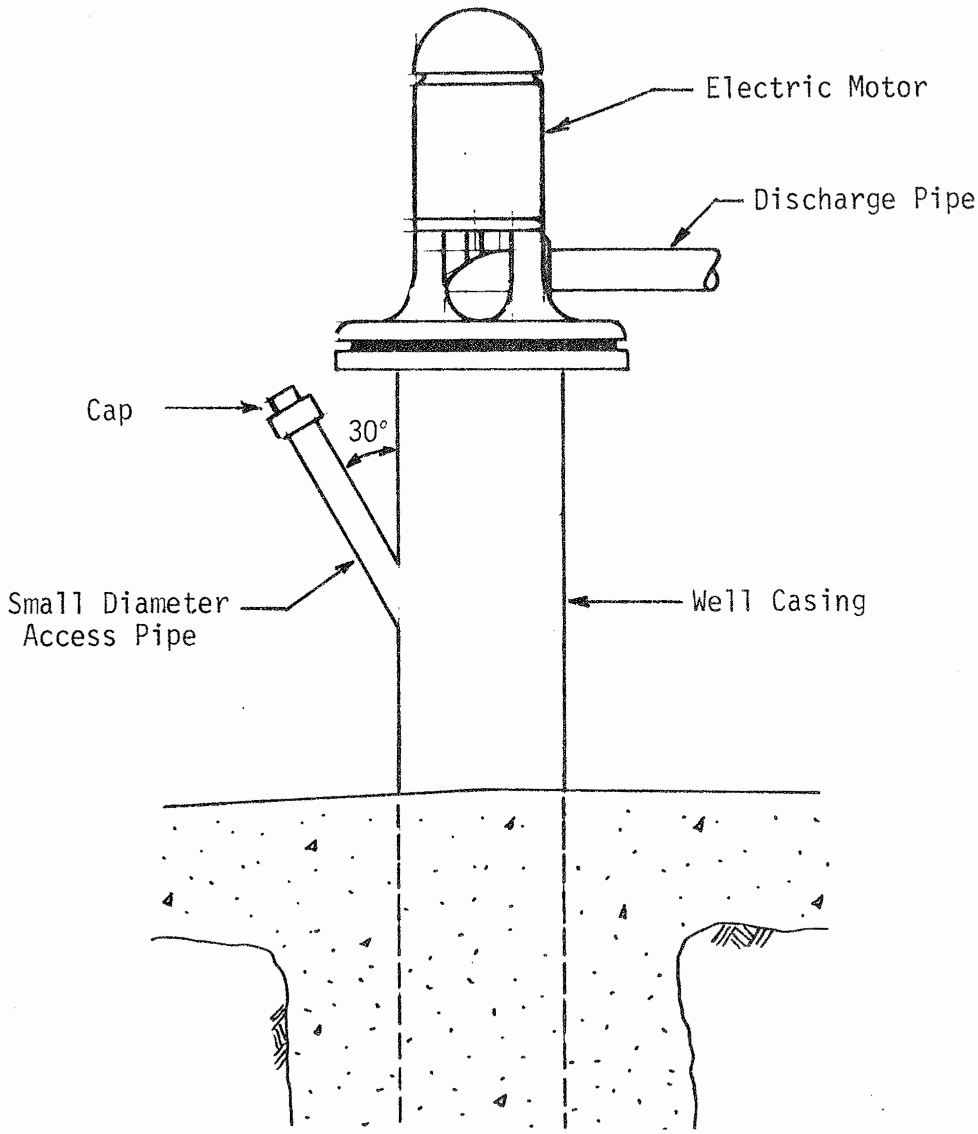
Wells and pumps should be inspected periodically to ensure that they are operating smoothly. For this reason, the pumphouse should be constructed so that the pump is easily accessible. Sometimes the pumphouse is designed so that the walls and roof are removable. A crane or other hoisting device can then be used to remove and replace a damaged or worn pump, motor, or well screen.

Access to the inside of the well casing should also be provided so that water level measurements can be made while the pump is operating. Special access must be provided on most wells since the pumping equipment often covers the top of the casing. One way to provide access to the well casing is shown in Figure 10.13. A small diameter steel pipe is welded to the top of the casing at an angle such that a water level measuring device can be lowered into the well.

All pumping equipment must be disinfected to remove any contamination that may have occurred during installation. The pump and the well are often disinfected as a single unit using a chlorine solution (see Chapter 9). During operation, the pumping equipment and the well must be checked regularly to ensure that surface water, lubricating oil, and other contaminants are not leaking into the well through faulty seals or damaged well casings. The following chapter describes how the presence of certain contaminants can indicate

Figure 10.13

Vertical Turbine Pump with Side Access
to Well Casing Provided



that surface water is entering the well in some manner.

The following two chapters deal with water treatment, storage, and distribution. It should be noted that the selection of a particular pump for a water system depends on the type of treatment process to be used and on the details of the storage and distribution system. Thus, the pump is usually selected after the treatment and distribution systems have been designed.

CHAPTER 11

TREATMENT

Ground water is often of such quality that it can be pumped directly from a well or spring into a public water distribution system. Nevertheless, all drinking water should be disinfected, but for ground water this is often just a precautionary measure. In some areas, ground water does require some form of treatment to remove harmful organisms and chemicals which may be present. It is also desirable to remove contaminants which, although not harmful, may be a nuisance to water users. It should be noted that all public water supplies must meet the National Interim Primary Drinking Water Regulations and state drinking water standards.

CONTAMINANTS FOUND IN GROUND WATER

Since many chemicals and gases are water-soluble, ground water always contains impurities. Some impurities are harmful, some are bothersome, and some are even medicinal. Most of the impurities or contaminants that can be found in ground water are listed in Table 11.1. Some of these contaminants occur naturally in ground water; others are

Table 11.1

Ground Water Contaminants

Type of Contaminant	Source	Effect
Inorganic Chemicals:		
Arsenic	Dissolved from rocks or soils Leaching of mine tailings Pesticides, herbicides, insecticides	Toxic
Barium	Dissolved from rocks or soils Oil and gas well drillings Certain industrial processes	Toxic Affects the heart, blood vessels and nerves
Cadmium	Dissolved from rocks or soils May leach from galvanized pipes	Toxic Associated with hypertension
Chromium	Industrial processes	Toxic Related to lung tumors
Fluoride	Dissolved from rocks or soils Industrial processes	1 mg Fl/l reduces the incidence of dental caries High, continuous consumption related to fluorosis
Lead	Dissolved from rocks or soils Industrial processes Lead pipes, if water corrosive	Causes brain damage and kidney damage, especially in children
Mercury	Industrial processes Herbicides and fungicides	Toxic Affects brain and central nervous system
Nitrate	Municipal wastewater Animal excrement Agricultural fertilizers Industrial discharges from fertilizer manufacturing Dissolved from rocks or soils	Related to methemoglobinemia in infants
Radium	Natural uranium deposits	May cause cancer
Selenium	Dissolved from rocks or soils Industrial processes	Toxic in large amounts
Silver	Industrial processes	Toxic
Chloride	Leaching of marine sedimentary deposits Intrusion of sea water Pollution from brine, industrial and domestic wastes	In excess of 250 mg/l, chloride gives a noticeable taste to water May indicate pollution of source by sewage
Copper	Dissolved from rocks or soils Copper pipes, if water corrosive	Gives water an undesirable taste
Iron	Dissolved from rocks or soils Iron pipes, if water corrosive	Gives laundered goods a brownish color Affects the taste of beverages, such as tea and coffee

Table 11.1 (Cont'd.)

Ground Water Contaminants

Type of Contaminant	Source	Effect
Manganese	Dissolved from rocks or soils	Gives laundered goods a brownish color Affects the test of beverages, such as tea and coffee
Sodium	Dissolved from rocks or soils Intrusion of sea water	Affects persons on low-sodium diets
Sulfate	Dissolved from rocks or soils Biological oxidation of sulfides Industrial processes	Produces laxative effects
Zinc	Dissolved from rocks or soils	Gives water an undesirable taste
Gases:		
Carbon Dioxide (CO_2)	Limestone deposits Dissolved from soil and air	Corrosive to metals
Ammonia (NH_4)	Product of organic decomposition (present in shallow aquifers where water table is at or near the surface)	Dangerous to infants May indicate contamination of source by sewage Gives water an undesirable odor
Hydrogen Sulfide (H_2S)	Dissolved from anaerobic soil zones Generated by decomposition of organic materials	Corrosive to metals Produces objectional odors (like "rotten eggs")
Oxygen (O_2)	Dissolved as water passes through the atmosphere and the aerated soil zone	Corrosive to metals
Methane (CH_4)	Dissolved as water passes through soil humus Seepage from sanitary landfills Sometimes present in deep aquifers where petroleum deposits are present	Explosive
Hardness:		
Calcium and Magnesium Salts	Natural deposits	Retards cleaning action of soaps and detergents Deposits a hard scale on pipes, kettles, and cooking utensils
pH:		
Bicarbonates, Carbonates, and Hydroxides (alkilinity)		Affects water treatment processes

Table 11.1 (Cont'd.)

Ground Water Contaminants

Type of Contaminant	Source	Effect
Hydrogen ions		Corrosive Affects water treatment processes
Miscellaneous:		
Detergents	Municipal and industrial sewage	Produces foam May indicate presence of other hazardous materials found in sewage
Iron and Manganese Fixing Bacteria	Present with dissolved iron or manganese and oxygen	Clogs filters, pumps, and pipes Causes unpleasant taste and odor Discolors fabrics and plumbing fixtures
Endrin, Lindane, Toxaphene, and Methoxychlor	Insecticides	Affects the nervous system Causes headaches, dizziness, numbness Severe exposures cause spasms Possibly carcinogenic
2,4-D and 2,4,5-TP (Silvex)	Herbicides	Possibly carcinogenic Causes genetic mutation

present as a result of the actions of man. The sources and effects of each contaminant are also listed in Table 11.1.

Natural filtration of water through soil and rock usually removes coliform and associated pathogenic bacteria as well as turbidity. Turbid and bacteria-infested ground water may be present in shallow aquifers or in limestone aquifers where the ground water flows in underground cracks and channels rather than by filtration. Otherwise, the presence of these contaminants indicates pollution of the aquifer by surface water, usually caused by poor well construction.

If chromium, mercury, silver, organic contaminants (insecticides and herbicides), and detergents are found in ground water, their presence indicates pollution of the aquifer. In some cases, it may be easier to find and correct the source of the pollution or to locate a different aquifer than to provide treatment for these contaminants.

MAXIMUM CONTAMINANT LEVELS

The U. S. Environmental Protection Agency has established primary and secondary drinking water regulations which apply to all public water systems.* These regulations set limits on certain contaminants. These limits, or Maximum Contaminant Levels (MCLs), are the highest permissible concentration of each contaminant in water. The limits apply whether the contaminant occurs naturally or as a result of man's actions.

The Maximum Contaminant Levels for inorganic and organic chemicals, turbidity, microbiological contaminants, and radiological contaminants are listed in Table 11.2. Community water systems, which serve residents, must monitor more contaminants than non-community water systems, which serve travelers and intermittent users. Ground water systems are not required to monitor turbidity since only surface waters are usually turbid.

These Maximum Contaminant Levels, as well as other parts of the regulations, are to be enforced by the states. In addition, most states have established drinking water standards of their own. The federal standards are to be enforced unless they are exceeded by state standards. The appropriate state agency, usually the state health department, should be contacted to see what standards are to be used as a basis for the design of the water system's

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*A public water system is defined by the Safe Drinking Water Act as any publicly or privately owned water system that has at least 15 service connections which are used at least 60 days out of the year or that serves an average of at least 25 people at least 60 days out of the year.

Table 11.2

Maximum Contaminant Levels

Type of Contaminant (Community Systems)	Type of Contaminant (Non-Community Systems)		Maximum Contaminant Levels (MCLs)
Inorganic Chemicals All Water Systems **	Inorganic Chemicals All Water Systems—** *Nitrate only** (all other contaminants at state option)	• Arsenic	0.05 mg/l
		• Barium	1. mg/l
		• Cadmium	0.010 mg/l
		• Chromium	0.05 mg/l
		• Lead	0.05 mg/l
		• Mercury	0.002 mg/l
		• Selenium	0.01 mg/l
		• Silver	0.05 mg/l
		• Fluoride (Annual average of maximum daily air temperatures.)	
		a) 53.7F & below	2.4 mg/l
		b) 53.8-58.3F	2.2 mg/l
		c) 58.4-63.8F	2.0 mg/l
		d) 63.9-70.6F	1.8 mg/l
		e) 70.7-79.2F	1.6 mg/l
		f) 79.3-90.0F	1.4 mg/l
		• Nitrate (as N)	10 mg/l
Organic Chemicals Surface Water Systems Only	Organic Chemicals (at state option)	• Endrin	0.0002 mg/l
		• Lindane	0.004 mg/l
		• Methoxychlor	0.1 mg/l
		• Toxaphene	0.005 mg/l
		• 2, 4-D	0.1 mg/l
		• 2, 4, 5-TP (Silvex)	0.01 mg/l
Turbidity Surface Water Systems Only	Turbidity Surface Water Systems Only	• 1 TU monthly average (5 TU monthly average may apply at state option) —OR— • 5 TU average of two consecutive days	
Microbiological Contaminants All Water Systems **	Microbiological Contaminants All Water Systems **	<u>When using membrane filter test:</u>	
		• 1 colony/100 ml for the average of all monthly samples —OR—	
		• 4 colonies/100 ml in more than one sample if less than 20 samples are collected per month —OR—	
		• 4 colonies/100 ml in more than 5 per cent of the samples if 20 or more samples are examined per month.	
		<u>When using multiple-tube fermentation test:</u> (10-ml portions)	
		• Coliform shall not be present in more than 10 per cent of the portions per month.	
		• Not more than one sample may have three or more portions positive when less than 20 samples are examined per month, or	
		• Not more than 5 per cent of the samples may have three or more portions positive when 20 or more samples are examined per month.	
Radiological Contaminants (Natural)— All Water Systems **	Radiological Contaminants (Natural)— (at state option)	• Gross Alpha	15 pCi/l
		• Combined Ra-226 and Ra-228	5 pCi/l
Radiological Contaminants (Man-made)— Surface water systems serving polulations greater than 100 000	Radiological Contaminants (Man-made)— (at state option)	• Gross Beta	50 pCi/l
		• Tritium	20 000 pCi/l
		• Strontium-90	8 pCi/l

*For all non-community water systems, *initial sampling and testing* must be conducted for nitrates. *Routine sampling and testing*, however, is at *state option*.

**Systems using surface and/or groundwater

Source: <u>The Safe Drinking Water Act Self-Study Handbook, Community Water Systems</u>. Denver, Colorado: American Water Works Association, 1978, p. 6.
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treatment facilities.

The drinking water standards define the desired quality of the water as it enters the distribution system and is delivered to the users. The quality of the raw water is determined by obtaining water samples from the aquifer. Test holes, nearby existing wells, and pilot holes can be used to obtain samples. Usually, water samples will be taken along with soil samples as a hole is drilled. These water samples are analyzed to determine the nature and the concentration of the contaminants in the ground water. Treatment facilities are designed on the basis of a comparison between the raw water quality and the desired water quality.

UNIT OPERATIONS

There are a variety of treatment techniques commonly used in the water supply industry. Water supply engineers refer to these treatment techniques as unit operations. Each unit operation is a distinct activity that affects water according to the principles of physics, chemistry, or biology. To obtain the desired water quality, unit operations are combined in a treatment plant in such a manner as to reduce all the contaminants to acceptable levels. The following unit operations are important in the treatment of ground water: aeration, filtration, coagulation-flocculation, sedimentation, lime softening, ion exchange, adsorption, reverse osmosis, disinfection.

Aeration

Aeration is the process of bringing air and water into contact with each other in order to remove undesirable gases, such as methane and hydrogen sulfide, and to increase the dissolved oxygen content of the water. Soluble iron and manganese are oxidized by the additional oxygen thereby facilitating the removal of these contaminants.

Aeration is accomplished by using gravity, mechanical draft, or diffused aerators. In gravity aerators, water flows by gravity over stacks of trays which are often filled with contact media. A mechanical aerator consists of a system of blowers or fans and a tower which houses a series of trays filled with contact media. The blowers force air up through the water which is trickled down the tower. Diffused aerators force compressed air through orifices or nozzles which are installed near the bottom of water-filled basins.

Filtration

As water passes through a porous medium, such as sand or granular coal, suspended matter is removed by the process of filtration. The suspended particles are attracted to the surface of the medium and are held there by surface forces.

Both gravity filters and pressure filters are used in small water systems. In gravity filters, water is distributed in open basins which are filled with the filter medium. The water flows by gravity through the tanks. Pressure filters are popular in small water systems because they can be connected directly to the water distribution main without the necessity of a pumping stage after treatment. Pressure filters are similar to gravity filters, except that the filter medium and underdrains are enclosed in a steel tank and the water flows through the tank by pressure rather than gravity. In both systems, the filter medium is cleaned by backwashing, or the running of water backwards through the filter beds to remove the trapped particles from the filter medium.

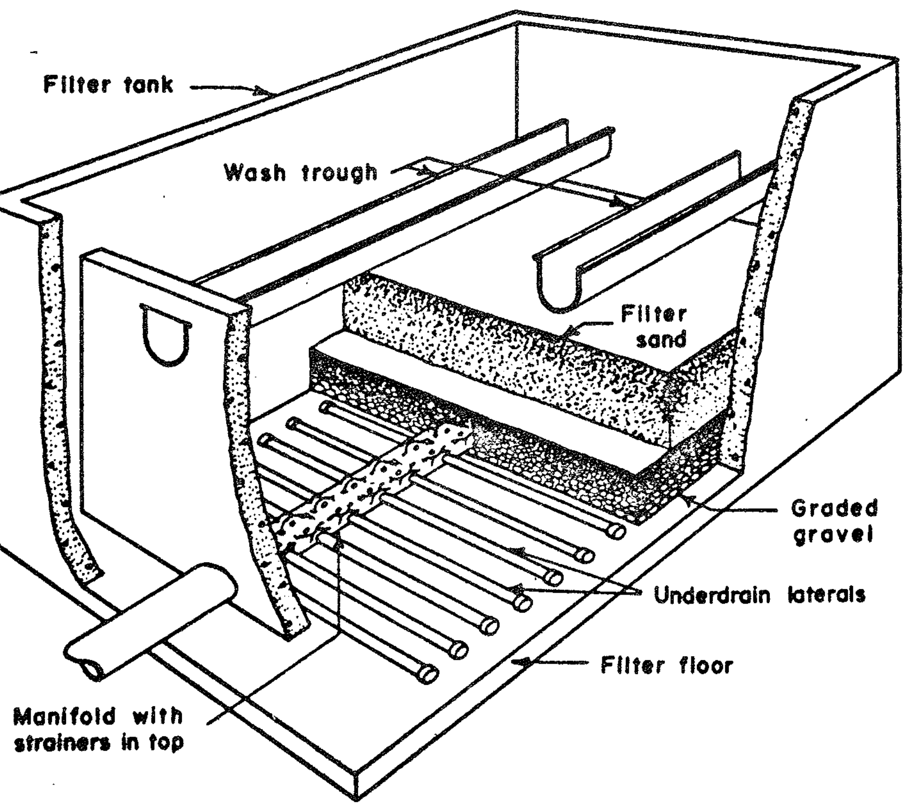
Coagulation-Flocculation

The coagulation-flocculation process is commonly used to remove suspended matter from surface waters. For systems using ground water as a source, flocculation is used in combination with lime softening to remove water hardness.

The first step in this process is the rapid mixing of a coagulant, such as aluminum sulfate (alum), with the raw water. The coagulant combines with the alkalinity in

Figure 11.1

Typical Gravity Sand Filter



Source: Ground Water and Wells, St. Paul, Minnesota: Johnson Division, UOP Inc., 1975, p. 349.

the water to form sticky, positively charged material. This material decreases the negative electrical charges associated with suspended matter in the water and causes the suspended matter to gather together into gelatinous masses called floc. Flocculation is enhanced by slow mechanical mixing of the water with rotating paddles.

Sedimentation

After coagulation-flocculation, the water passes through a large sedimentation basin or tank. Sedimentation is the process of using gravity to cause the settling of comparatively heavy suspended material, such as floc. Sedimentation tanks must be large so that the water moves very slowly through the basins. The resulting sediment or sludge which is deposited on the bottom of the tank is usually removed by slow-moving, mechanical scrapers which force the sludge into hoppers in the bottom of the tank.

Sometimes small sedimentation basins are required prior to any other treatment in order to remove heavy particles, such as sand. This is generally unnecessary for systems using ground water except where excessive amounts of sand are pumped from the wells.

Lime Softening

Water is softened to reduce the hardness caused by the presence of dissolved minerals, principally calcium and magnesium. Softening is accomplished by the lime-soda process or by ion exchange.

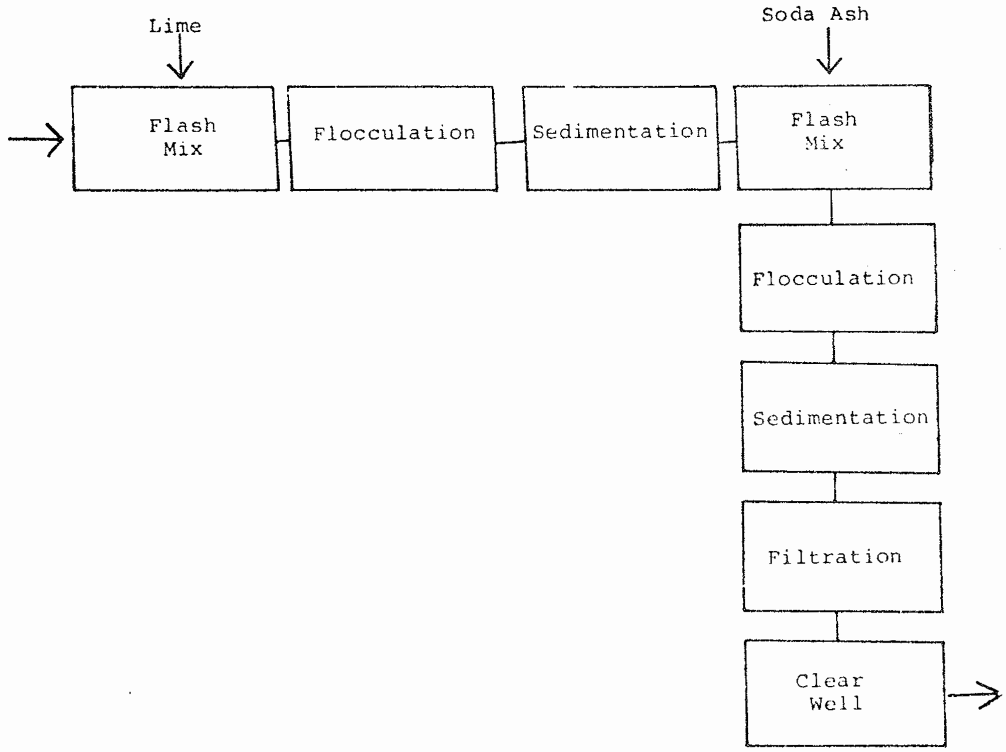
In the lime-soda or lime softening process, calcium hydroxide is first mixed with raw water in order to remove carbonate hardness. Carbonate hardness is the hardness that results from bicarbonates of calcium and magnesium. The lime reacts chemically with the carbonate hardness to form mainly calcium carbonate, a precipitate which is only slightly soluble in water. After mixing, the water and lime are flocculated to enhance the formation of calcium carbonate floc which is then allowed to settle in a sedimentation basin.

Non-carbonate hardness, or hardness caused by salts of calcium and magnesium, is subsequently removed by the addition of sodium carbonate (soda ash). Flocculation and sedimentation must follow the addition and mixing of the soda ash with the water. A schematic drawing of one type of lime-soda softening plant is shown in Figure 11.2. Such a plant requires a large number of steps and tanks or basins. The second stage of mixing, flocculation, and sedimentation can be eliminated if the more expensive caustic soda is added in place of separate additions of lime and soda ash.

Lime softening is often followed by recarbonation, which is the addition of carbon dioxide for pH adjustment and to convert hydroxide and carbonate alkalinity to

Figure 11.2

Schematic of a Typical Lime Soda Softening Plant



Source: E. E. "Skeet" Arasmith, Introduction to Water Treatment, Albany, Oregon: Linn-Benton Community College, 1977, p. 24.

bicarbonate alkalinity.

Ion Exchange

The lime-soda softening process not only requires a large number of tanks and thus space, but also requires specially trained operators. Thus, small water systems tend to favor the ion exchange softening process where only a minimum amount of technical training is required. In addition, ion exchange is usually accomplished in enclosed tanks which take very little space and operate under pressure. Ion exchange softening is the process of exchanging calcium and magnesium ions in the water for ions which do not cause hardness, such as sodium ions.

In the ion exchange or zeolite process, water is passed through a bed of zeolites, which are natural or man-made compounds containing a high quantity of sodium ions. As water passes through the zeolite medium, calcium and magnesium ions in the water are exchanged for sodium ions attached to the zeolite. Sodium continues to replace calcium and magnesium until all the sodium ions in the zeolite are exhausted. The zeolite bed is regenerated periodically by passing a salt (sodium chloride) solution through the medium. Sodium ions replace the calcium and magnesium ions which are then washed out of the zeolite with the remaining chloride ions in the solution.

The ion exchange process can remove all of the water hardness. Since it is not economical or desirable to soften the entire water supply to zero hardness, most systems blend 100 percent softened water with unsoftened bypass water to obtain water with an acceptable level of hardness.

One disadvantage of the ion exchange process is that it increases the sodium content of the water. This can be a health concern for persons on low sodium diets.

Adsorption

Adsorption is the process by which arsenic, fluoride, and organic pollutants in water are attracted and accumulated on the surface of an adsorptive medium. The most important adsorptive media used in the water supply industry are activated alumina and activated carbon. An activated carbon particle contains many pores and crevices which markedly increase the surface area of the particle, thus making activated carbon an exceptionally effective adsorptive medium.

Adsorption is accomplished using contact tanks or columns containing alumina or granular activated carbon, or by adding and mixing powdered activated carbon to the water in a slurry or dry form. If a tank or column is used, the media must be replaced periodically with new or regenerated material. Large water systems are often equipped with carbon regeneration furnaces, but on-site regeneration for small systems is usually uneconomical. Small systems must either buy new activated carbon or have their carbon regenerated at the nearest regeneration facility.

Reverse Osmosis

Osmotic pressure forces pure water through a permeable membrane from a solution with a low concentration of dissolved solids to a solution with a high concentration of dissolved solids. By applying an external pressure in excess of the osmotic pressure to the more concentrated solution, the flow of pure water can be reversed. Thus, in the reverse osmosis process, highly mineralized water is delivered under pressure to a vessel containing a semipermeable membrane. Pure water filters through the membrane and leaves the vessel at a much lower pressure. Meanwhile, a highly mineralized waste solution or brine is drained out of the vessel to prevent excessive buildup of salts in the vessel.

The semipermeable membrane is the critical element in the reverse osmosis process. It must be capable of withstanding the high pressures of operation, the buildup of scale, and the attack of bacterial growth. Cellulose acetate and polymide membranes are most often used. They may be arranged in the pressure vessel in a number of configurations. One configuration which is commonly used is the hollow fiber configuration illustrated in Figure 11.3.

Reverse osmosis is most often used in the treatment of brackish waters but it is also effective in removing arsenic, barium, cadmium, chromium, fluoride, lead, and a number of other contaminants. Its chief disadvantage lies in the power requirements necessary for developing high operating pressures.

Disinfection

Disinfection is the destruction or deactivation of pathogenic or otherwise undesirable organisms. Disinfection is accomplished by the addition of a strong oxidant, such as chlorine, ozone, iodine, or bromine, or by exposure to an energy source such as ultraviolet light. Chlorine is the most common disinfection agent used for water supply purposes, and chlorination and disinfection are often used interchangeably.

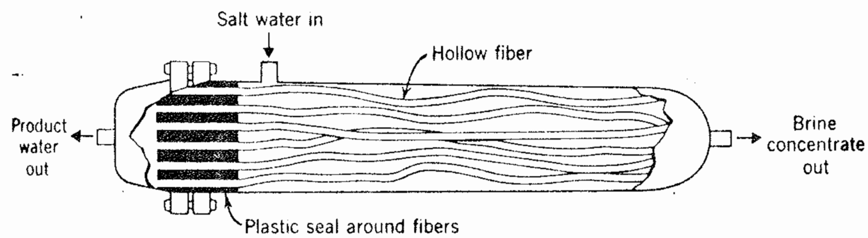
When chlorine is first added to water, it reacts with the water to form hydrogen ions, chlorine ions, and hypochlorous acid. The hypochlorous acid then dissociates into hydrogen ions and hypochlorite ions.

$$Cl_2 + H_2O \rightleftharpoons HOCl + H^+ + Cl^-$$

$$HOCl \rightleftharpoons H^+ + OCl^-$$

Figure 11.3

Reverse Osmosis Membrane With a Hollow Fiber Configuration



Source: Gordon M. Fair, John C. Geyer, and Daniel A. Okun, Elements of Water Supply and Waste Water Disposal, New York: John Wiley and Sons, Inc., 1971, p. 453.

Any chlorine which exists in the form of the chlorine ion (Cl^-) or the hypochlorite ion (OCl^-) is defined as "free available chlorine".

Various forms of chlorine, but especially hypochlorous acid (HOCl), are effective in destroying pathogenic and other organisms which are found in water. Although the means by which chlorine destroys organisms is not totally understood, it is suspected that the chlorine compounds penetrate the cell membrane and interfere or destroy enzymes which are critical to the metabolism of the organism.

Since chlorine is an extremely active element, it reacts not only with organisms, but also with many organic and inorganic compounds as well. Chlorine oxidizes hydrogen sulfide, ferrous iron, and nitrates. It reacts with organic substances to form undesirable chloro-organic compounds, such as chlorophenol and trihalomethane. Chlorine which reacts with these substances is not available for the destruction of organisms. For these reasons, it is desirable to chlorinate only after all other treatment processes are complete.

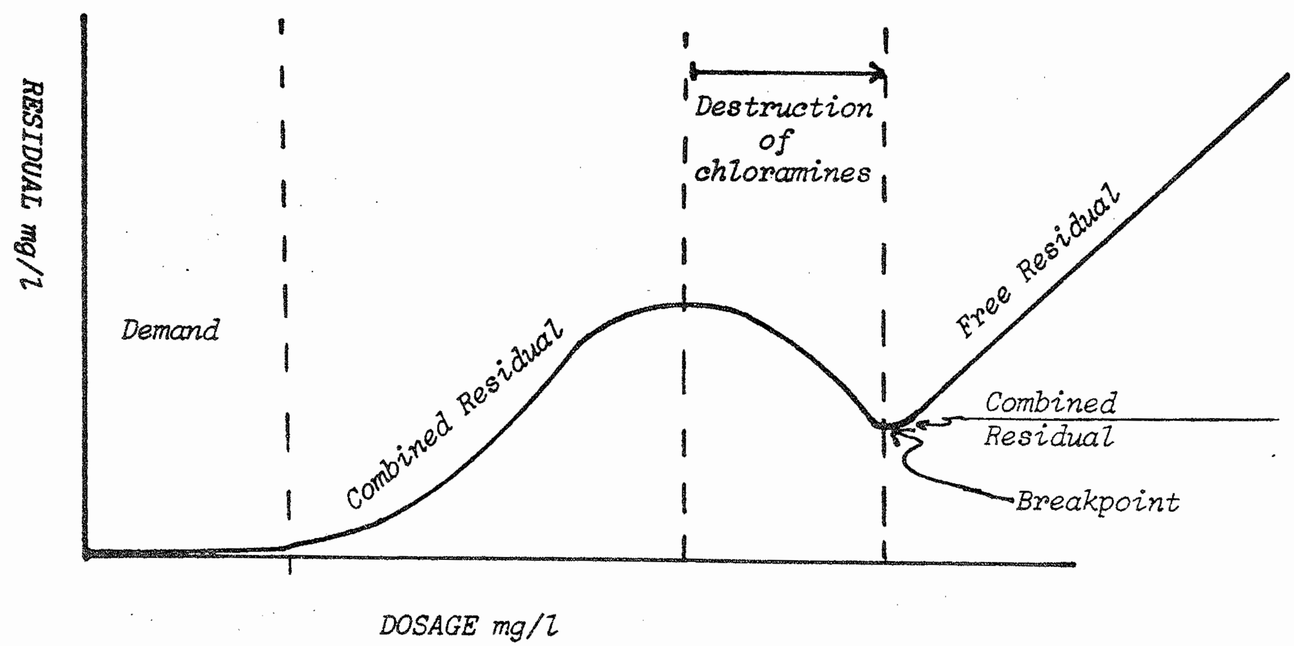
Chlorine also reacts with nitrogen compounds, such as ammonia, to form chloramines. Chlorine in this form is referred to as "combined available chlorine". Chloramines do destroy the pathogenic organisms found in water, but they require a longer detention time to act as effectively as free available chlorine. Sometimes chloramines give water an undesirable taste and odor.

To take advantage of the effectiveness of free available chlorine in destroying organisms and to destroy taste and odor causing compounds, drinking water is usually clorinated to the "breakpoint." The breakpoint phenomena can be explained using Figure 11.4. With small applications of chlorine, all of the chlorine reacts with various substances in the water and no residual is present. This is referred to as the chlorine demand. As more chlorine is added, the chlorine begins to react with nitrogen to form chloramines, and a combined residual can be measured. Still more chlorine begins to destroy the chloramines and the chlorine residual drops. At the breakpoint dosage, chlorine first becomes available as a free residual.

Gaseous or liquid chlorine is added to the water by means of direct feeders or solution feeders. The feeders can be manually or automatically operated. Since chlorine cylinders are difficult and dangerous to handle, some small water systems use sodium or calcium hypochlorite (bleach) for disinfection. The bleach is mixed with water to obtain a relatively strong solution which is then fed into the water using a chemical feed pump (see Figure 11.5).

Figure 11.4

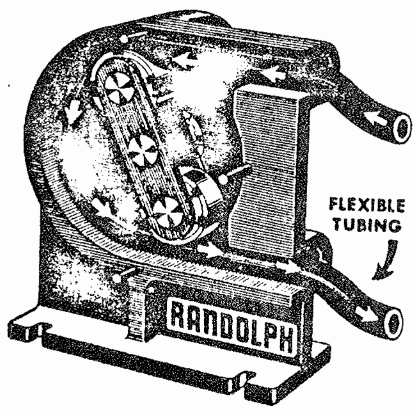
Chlorine Breakpoint Phenomena



Source: Arasmith, E. E. "Skeet," Introduction to Disinfection - Chlorination, Albany, Oregon: Linn-Benton Community College, 1977, p. 10.

Figure 11.5

Squeeze Type Chemical Feed Pump



Source: Ground Water and Wells, St. Paul, Minnesota: Johnson Division, UOP Inc., 1975, p. 381.

Some ground water is so pure that chlorination is the only treatment needed. In fact, the slower combined chlorine residual is sometimes all that is necessary for disinfection. Most ground waters do not contain enough chloramine-forming compounds to cause taste and odor problems.

TREATMENT SYSTEMS

Water treatment plants will usually use disinfection in combination with one or more other unit operations. The selection and design of a treatment system is based on the nature and concentration of the contaminants in the ground water, the construction and operating costs associated with each unit operation, and the availability of skilled operators for plant supervision.

The most common contaminants found in ground water are listed in Table 11.3. Also listed are the treatment methods, or unit operation combinations, which are effective in removing each contaminant. Generally, a ground water source will have only one or two troublesome contaminants and the treatment system will be designed primarily for these contaminants. If an extensive treatment system is required because the source contains many contaminants, it may be advisable to find another water source.

Table 11.3

Most Effective Treatment Methods for Contaminant Removal

Contaminant	Aeration	Aeration/ Filtration	Filtration (Diatomite)	Coagulation/ Flocculation, Sedimentation, Filtration	Lime Softening	Excess Lime Softening	Ion Exchange	Adsorption	Reverse Osmosis	Electrodialysis	Ion Exchange/ Adsorption	Chlorination
Arsenic				V	V		V	H	Hp	Mp		
Barium						H	H		Hp			
Cadmium							Hp		Hp	M		
Chromium, soluble							Hp		Hp	Mp		
Chromium III, insoluble				V	V							
Chromium VI, insoluble				V								
Fluoride									Hp	Mp	Hp	
Lead, soluble							Hp		Hp	Mp		
Lead, insoluble				V	H							
Mercury, inorganic forms				V	V		H		Hp	Mp		
Mercury, organic forms				V			H	M	Hp	Mp		
Nitrate							H		H	M		
Radium				V		V		H				
Selenium				V			H		H	Mp		
Silver				V	V		Hp		Hp	Mp		
Chloride									H	M		
Copper				V	V		H		H	M		
Hydrogen Sulfide	V											
Iron		V	V	V			H		H	M		
Manganese		V	V				H		H	M		

Table 11.3 (Cont'd.)

Most Effective Treatment Methods for Contaminant Removal

Contaminant	Aeration	Aeration/ Filtration	Filtration (Diatomite)	Coagulation/ Flocculation, Sedimentation, Filtration	Lime Softening	Excess Lime Softening	Ion Exchange	Adsorption	Reverse Osmosis	Electrodialysis	Ion Exchange/ Adsorption	Chlorination
Ammonia	V							V				
Organic Chemicals (insecticides and herbicides)								V				
Methane	V											
Coliform organisms				V								H
Carbon Dioxide												
Sulfate							H		H	M		
Zinc					V		H		H	M		
Hardness (calcium & magnesium salts)					V		H		H			
Detergents								H				

Notes:

H - High rates of removal; usually 90% or more
Hp- High rates of removal predicted but not experienced
M - Medium rates of removal; usually 75-90%
Mp- Medium rates of removal predicted but not experienced
V - Percent removal varies

Sources:

1. U.S. Environmental Protection Agency, Office of Water Supply, State of the Art of Small Water Treatment Systems, August 1977, pp. III-2 to III-35.

2. U.S. Environmental Protection Agency, Estimating Costs for Water Treatment, August 1978, p. 9

3. Ground Water, AWWA Manual M21, New York: American Water Works Association, 1973, pp. 122-128.

Even though the quality of each ground water source is unique, the water supply industry has manufactured package treatment plants which have been used successfully to treat ground waters of varying quality. Since package treatment plants can be less expensive than conventional facilities and they are often fully automatic, they have often been used for small water systems. Certain unit operations, such as ion exchange and carbon adsorption, are also available as a package unit. These units are often used in combination with conventional facilities.

IMPORTANCE OF TREATMENT

The widespread use of chlorination and other treatment methods has drastically reduced the likelihood of a waterborne disease outbreak. Although the control and removal of pathogenic organisms is still important, more and more attention is being focused on the removal of toxic and cancer-causing chemicals. The Safe Drinking Water Act of 1974 has resulted in regulations which will require more extensive water treatment facilities and more careful water quality monitoring for most small water systems.

At the same time that drinking water quality standards are becoming stricter, ground water quality in many areas is deteriorating. This is due to overpumping of aquifers, the intrusion of salt water in coastal areas, or the pollution of ground water aquifers as a result of improperly designed water wells, injection wells, and landfills. Thus, treatment is likely to become an increasingly important aspect in the design and operation of community water systems.

CHAPTER 12

STORAGE AND DISTRIBUTION

The last and usually the most expensive component in a water supply project is the distribution system. Its function is to deliver a sufficient quantity of water at adequate pressures to all water users in the community. The water distribution system includes water mains, storage facilities, fittings, fire hydrants, valves, meters, and booster pumps; in short, everything between the treatment facilities or high lift pumps and the customer's water meter.

The key decisions which must be made in the design of a distribution system are as follows:

1. What kind of storage will be provided and what will its capacity be?
2. What type of distribution network will be used?
3. What will be the location and the size of each water main, and what type of pipe will be used?
4. Are booster pumps, air release valves, and pressure reducers needed and if so, where should they be located?

STORAGE

Storage facilities are provided in a water supply system for the following reasons:

1. Water storage is necessary to meet the peak demands and fire-fighting requirements of the community.

2. With storage, water line pressure can be maintained at more constant levels.

3. Water storage enables a water system to provide uninterrupted water service during emergencies.

4. With storage facilities, pumps can be run at more uniform rates with fewer starts and stops resulting in lower pumping costs and longer pump life.

5. In many areas, storage can be used to lower power costs by pumping water into the storage facilities at night when electric rates are low.

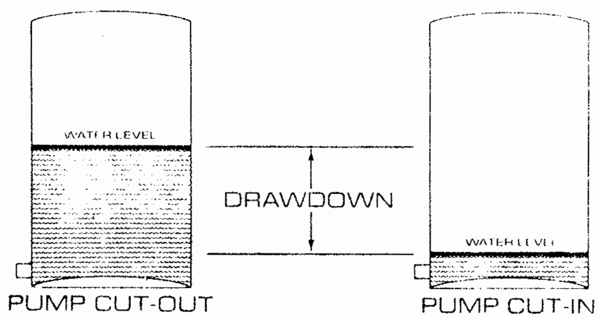
There are two types of storage used in municipal water systems: pressure or hydropneumatic systems, and gravity systems. Hydropneumatic systems are used extensively in small communities while larger communities usually find gravity systems more advantageous. These systems are described and compared in the following sections.

Hydropneumatic Storage Systems

In hydropneumatic systems, water is pumped into a pressure tank which is partially filled with air (see Figure 12.1). As more and more water enters the tank, the air is

Figure 12.1

Hydropneumatic Water Storage System



Source: Water Systems Hand Book, 6th Edition, Chicago, Illinois: Water Systems Council, 1976-77, p. 59.

compressed. The pressure inside the tank increases until it reaches a predetermined value at which time the pump cuts off. Stored water can then leave the tank and enter the distribution network as it is needed. As the water level inside the tank decreases, the pressure also decreases. At a second predetermined pressure level, the pump is switched on, refilling the tank and forcing the pressure up again.

The storage capacity of a pressure tank is generally small. For one thing, only about 20 percent of the total tank volume can be counted as effective or usable storage. The rest of the tank is filled with air or unuseable water. Most tanks are designed to supply no more than 20-30 minutes of water at the instantaneous peak rate. As a result, hydropneumatic systems usually do not provide adequate water storage for fire-fighting or other emergencies. In addition, water pressures in the systems are not maintained at constant levels, but fluctuate constantly between mininum and maximum levels. On the other hand, hydropneumatic storage systems are inexpensive, they provide enough storage to meet short-term peaks, and they decrease pump cycling (starting and stopping). For these reasons, hydropneumatic systems are popular in domestic and small community water systems.

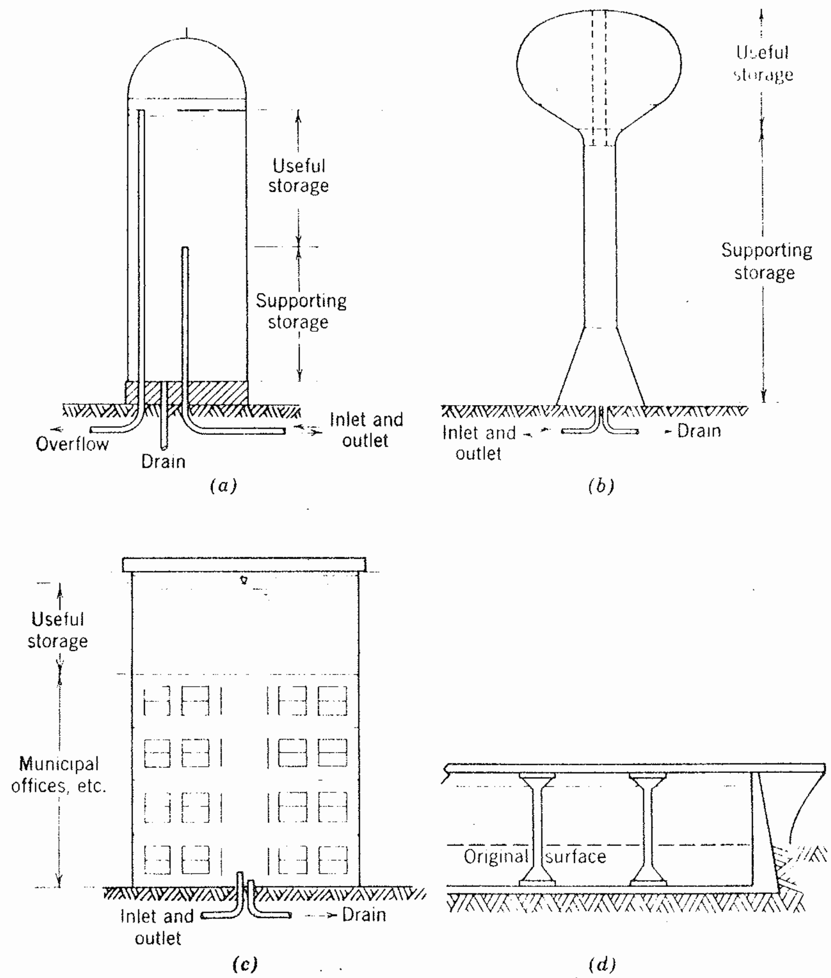
Gravity Storage Systems

In gravity storage systems, water is pumped into elevated storage tanks or ground level reservoirs. Gravity tanks are usually covered, but they are always vented to the atmosphere so there is no pressure buildup in the tanks. Gravity tanks are designed and built so that water flows out of the tanks and into the distribution system by gravity. The water level in a gravity tank should be kept at least 80 feet above the highest point in the distribution system in order to produce a minimum operating pressure of 35 psi.

The effective storage volume in gravity tanks is usually quite large. The capacity is often dictated by fire-fighting requirements or standards, and can vary from one-half to two or more days of the average daily demand. These large storage capacities allow water systems with gravity storage to take advantage of all the factors listed at the beginning of this section. However, gravity storage tanks are expensive unless the local topography is suited to ground level tanks or reservoirs. Elevated tanks are not only expensive, but they are difficult to maintain or inspect and they may be unsightly.

Figure 12.2

Types of Gravity Storage Systems



Source: Gordon M. Fair, John C. Geyer, and Daniel A. Okun, Elements of Water Supply and Waste Water Disposal, New York: John Wiley and Sons, Inc., 1971, p. 219.

DISTRIBUTION

The first step in the design of a distribution system is the establishment of a piping network. Two basic types of networks are used in community water systems: branching or dendritic networks, and gridiron networks (see Figure 12.3). Gridiron networks are preferable because dead-end lines are avoided. On the other hand, since many rural communities develop along major roads and highways, their growth tends to be in a branching pattern. In such cases a gridiron or looped system may be too expensive. The usual practice is to loop as many lines as possible and to provide fire hydrants, flushing hydrants, or blow-off valves at all dead ends.

Types of Water Pipes

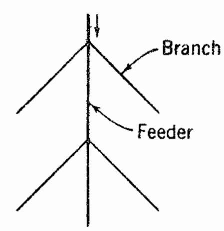
Water pipe is manufactured from a variety of materials: cast iron, steel, concrete, plastic, copper, and asbestos-cement. The advantages and disadvantages of each type of pipe are listed in Table 12.1. The selection of a pipe type is based on the following factors:

1. Local conditions, such as soil type, depth of frost penetration, and soil or water corrosiveness.

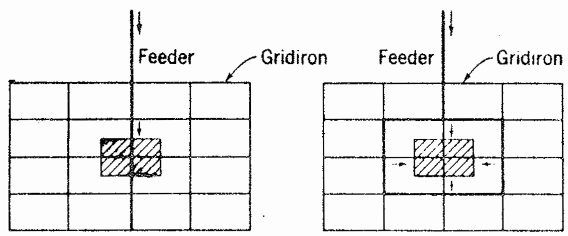
2. System conditions, such as expected operating pressures and laying depths.

Figure 12.3

Types of Distribution Networks



a. Branching pattern with dead ends



b. Gridiron pattern with centrial feeder

c. Gridiron pattern with looped feeder

High-value district is cross-hatched

Source: Gordon M. Fair, John C. Geyer, and Daniel A. Okun, Elements of Water Supply and Waste Water Disposal, New York: John Wiley and Sons, Inc., 1971, p. 191.

Table 12.1

Advantages and Disadvantages of
the Most Common Types of Water Pipe

Type of Material	Advantages	Disadvantages
Gray cast iron pipe	Durability Resistence to corrosion Withstands high internal pressures	Weight Difficult to handle Low tensile strength Breaks easily on impact
Ductile iron pipe	Withstands extreme internal and external pressures	Weight Susceptibility to corrosion
Steel pipe	Strength Ease of fabrication	High susceptibility to corrosion
Plastic pipe	Low cost Non-corrosive Good hydraulic properties Ease of installation Light weight	Low strength
Concrete pipe	Low maintenance Long life Low installation cost for large diameters	Easily damaged during transportation and installation
Asbestos-cement	Ease of installation Lightweight	Easily damaged during transportation and installation
Copper	Long life Good hydraulic properties	Extremely high cost Weight

3. Availability.

4. Design life.

5. Construction and maintenance factors (some types are much easier to lay and maintain and require less skilled workers.

6. Standards, especially when water projects are funded by the state or federal agencies.

7. Personal preferences of the design engineer.

Plastic pipe is used extensively in small water systems. The principal advantage of plastic pipe is its low cost; it is also lightweight and easy to install, requiring a minimum amount of equipment and skilled labor. The four types of plastic commonly used for making water pipe are polyethylene acryonitrile butadiene styrene (ABS), polyvinyl chloride (PVC) and polybutylene.

Sizing Water Pipes

Each pipe or main in a water system must be adequately sized to meet user needs. If a pipe is too small, inadequate flows or pressures may result because of excessive friction head losses in the pipe. On the other hand, oversized pipes result in increased capital costs and are a financial burden to the water users.

The capacity of a pipe depends on its diameter, length, and interior surface condition. Each type of pipe has a different interior surface condition or roughness coefficient, C, (see Table 12.2). Since the length of pipe is determined by the piping network and the roughness coefficient is established by the pipe material chosen, the pipe diameter is usually the variable which must be selected to meet the capacity and head loss requirements for each pipe section.

The following example illustrates the sizing of a water pipe. Suppose a community has an elevated storage tank with a water surface elevation at 400 feet (see Figure 12.4). According to the piping network, a fire hydrant is to be located at the end of a cast iron water main (assume C = 100) whose length is 2,000 feet. For simplicity, assume there are no valves or elbows, and that there are no connections to this main. The desired flow and pressure at the fire hydrant are 1,500 gpm (2.16 mgd) and 70 psi, respectively. The elevation of the hydrant is 200 feet.

The desired pressure head at the hydrant is determined by multiplying 70 psi by a conversion factor of 2.31:

Desired pressure head = 70 psi x 2.31 feet of head/1 psi
= 162 feet of head

Since the difference in elevation or total head between the storage tank and the hydrant is 200 feet, the available head loss is computed as follows:

Available head loss = total head - desired pressure head
= 200 feet - 162 feet
= 38 feet

Table 12.2

Values of the Hazen-Williams Roughness Coefficient C for Various Conduit Materials

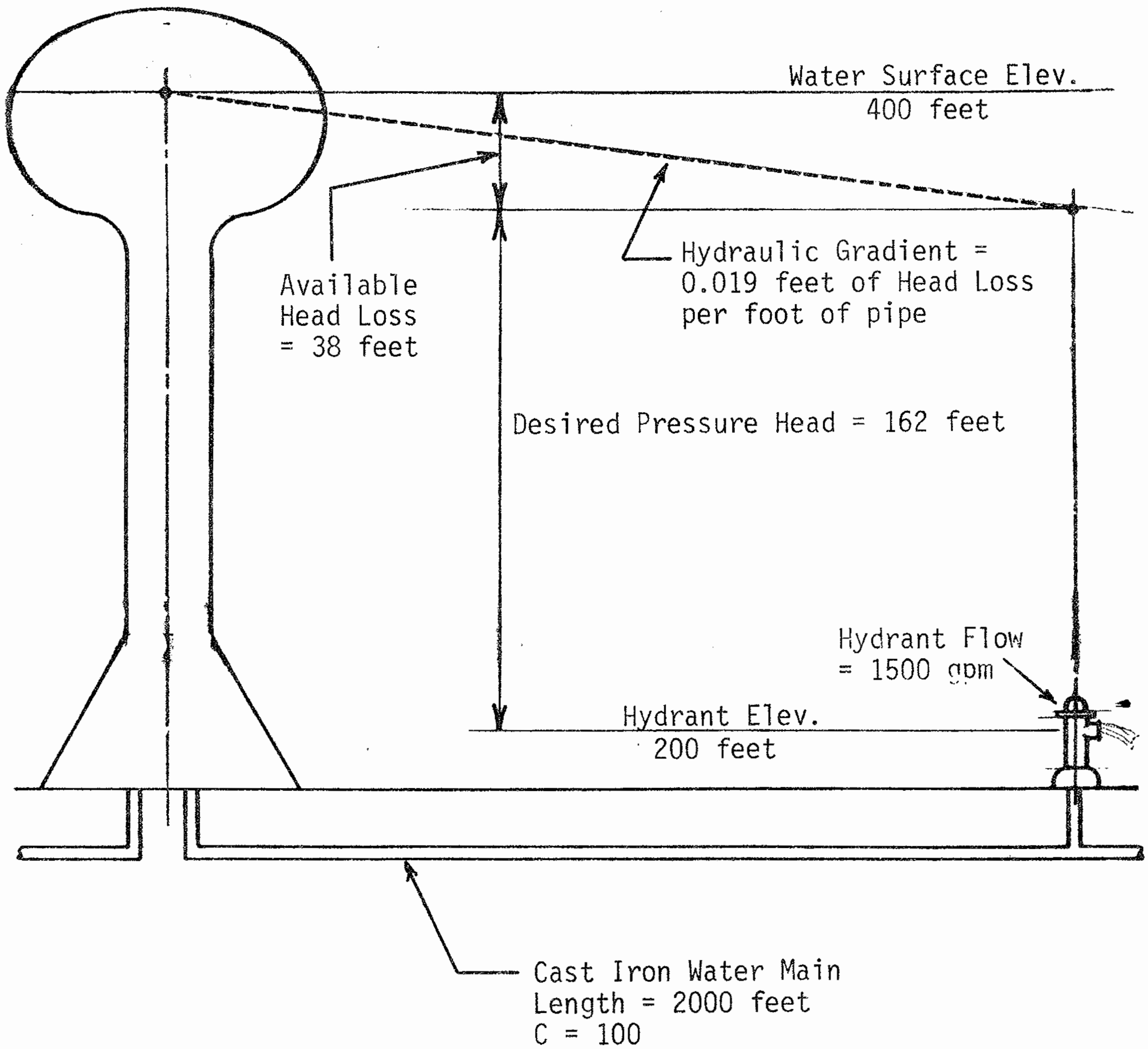
Conduit Material	Age	
	New	Uncertain
Cast-iron pipe, coated (inside and outside)	130	100
Cast-iron pipe, lined with cement or bituminous enamel	130[a]	130[a]
Steel, riveted joints, coated	110	90
Steel, welded joints, coated	140	100
Steel, welded joints, lined with cement or bituminous enamel	140[a]	130[a]
Concrete	140	130
Wood stave	130	130
Cement-asbestos and plastic pipe	140	130

[a] For use with the nominal diameter, i.e., diameter of unlined pipe.

Source: Gordon M. Fair, John C. Geyer, and Daniel A. Okun, Elements of Water Supply and Waste Water Disposal, New York: John Wiley and Sons, Inc., 1971, p. 167.

Figure 12.4

Example: The Sizing of a Water Pipe



By dividing the available head loss by the pipe length, the head loss per foot of pipe, or the hydraulic gradient, is determined:

Hydraulic gradient = available head loss ÷ pipe length
= 38 feet ÷ 2000 feet
= 0.019 feet of head loss/foot
= 19 feet of head loss/1000 feet of pipe

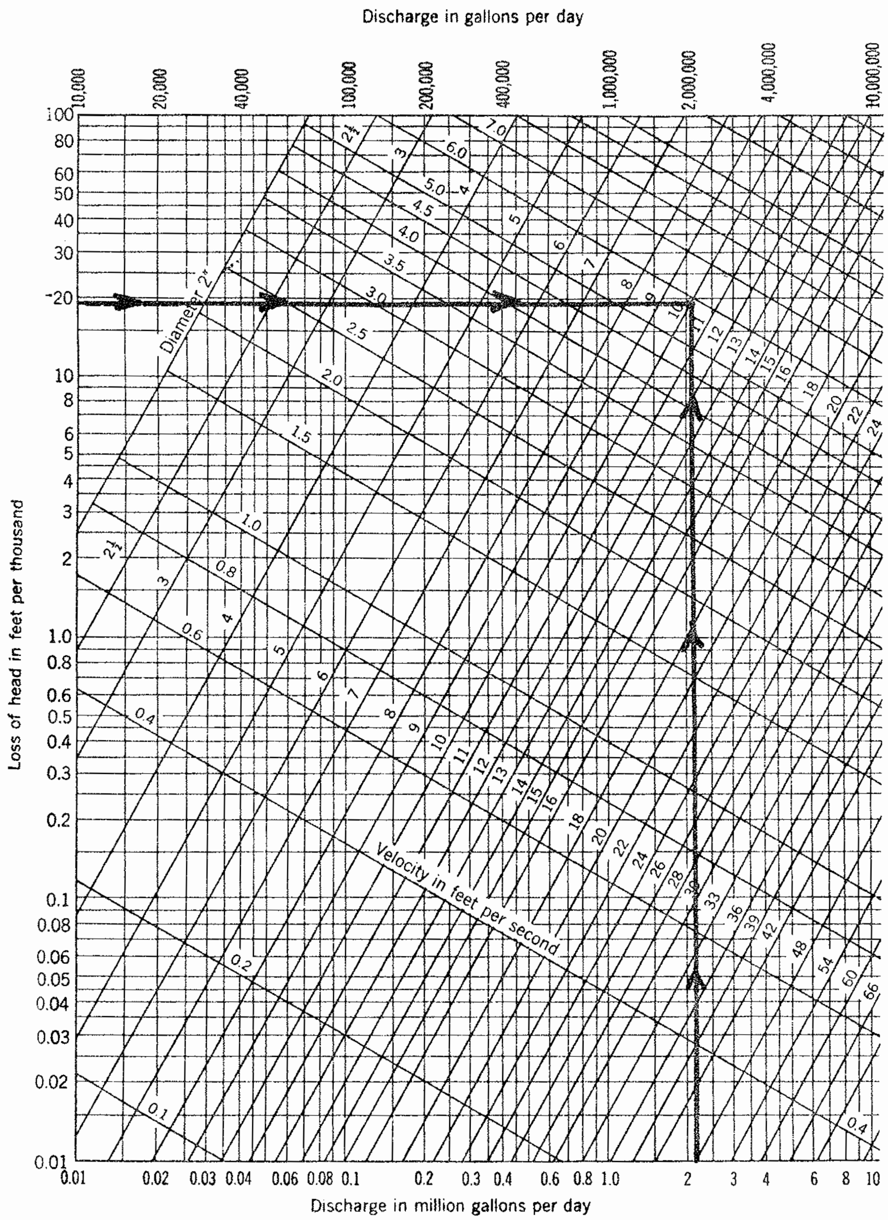
The required pipe size can then be determined by using a graph as shown in Figure 12.5. In this case a 10 inch pipe is required.

The design of a complete water distribution system is much more complicated than merely repeating the above exercise for each length of pipe. Each of the valves, elbows, meters, etc., have head losses associated with them. This problem is most often solved by substituting an "equivalent length of pipe" for each valve or fitting in the line (see Table 12.3). The design length used to calculate hydraulic gradient is the actual length plus the sum of the "equivalent lengths."

More important, however, is the fact that a water system does not consist of many single pipes or mains but is made up of an interconnecting network of pipes. The pressure and flow in each pipe affects the pressure and head in all the other pipes. An engineer will use computer programs or trial and error manual methods to analyze the

Figure 12.5

Hazen-Williams Pipe-flow Diagram for C = 100



Note: For C other than 100, multiply given discharge by 100/C.

Source: Gordon M. Fair, John C. Geyer, and Daniel A. Okun, Elements of Water Supply and Waste Water Disposal, New York: John Wiley and Sons, Inc., 1971, p. 699.

Table 12.3

Allowance in Equivalent Length of Pipe for Friction Loss in Valves and Threaded Fittings

Diameter of fitting	90° std. ell	45° std. ell	90° side tee	Coupling or straight run	Gate valve	Globe valve	Angle valve
Inches	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
3/8	1	0.6	1.5	0.3	0.2	8	4
1/2	2	1.2	3	0.6	0.4	15	8
3/4	2.5	1.5	4	0.8	0.5	20	12
1	3	1.8	5	0.9	0.6	25	15
1-1/4	4	2.4	6	1.2	0.8	35	18
1-1/2	5	3	7	1.5	1.0	45	22
2	7	4	10	2	1.3	55	28
2-1/2	8	5	12	2.5	1.6	65	34
3	10	6	15	3	2	80	40
3-1/2	12	7	18	3.6	2.4	100	50
4	14	8	21	4	2.7	125	55
5	17	10	25	5	3.3	140	70
6	20	12	30	6	4	165	80

Source: Office of Water Programs, Water Supply Division, U. S. Environmental Protection Agency, Manual of Individual Water Supply Systems, Washington, D. C.: U. S. Government Printing Office, 1975, p. 122.

network and determine the most efficient size for each pipe.

Appurtenances

The distribution system consists not only of pipes but of valves, meters, booster pumps, etc. Some of the commonly used appurtenances and their purposes are described here.

Gate valves. Gate valves are located at particular points throughout the system so that convenient lengths of pipe can be isolated for repairs and maintenance without interrupting water service for any but a few users. Normally, valves are placed adjacent to pipe intersections. Gate valves are also provided between fire hydrants and water mains so damaged hydrants can be replaced or repaired.

Fire hydrants. Fire hydrants are provided for firefighting, for flushing water mains, and for testing system pressures. The spacing of fire hydrants should follow the recommendations of the National Board of Fire Underwriters.

Pressure relief valves. Pressure relief valves are provided to relieve excessive pressures that develop in the system due to water hammer effects. Water hammer is caused by sudden changes in the velocity as when a valve is closed too rapidly in a water main. The build-up energy of the moving water produces a pressure wave which travels back along the main and, if not relieved, can cause damage to pumps and valves.

Air release valves. The role of air valves is to automatically release displaced air. Air is displaced as a water main is being filled or as air gathers in pockets and impedes the flow of water in the main during normal operation. Air release valves are placed at high points in the system where air normally collects.

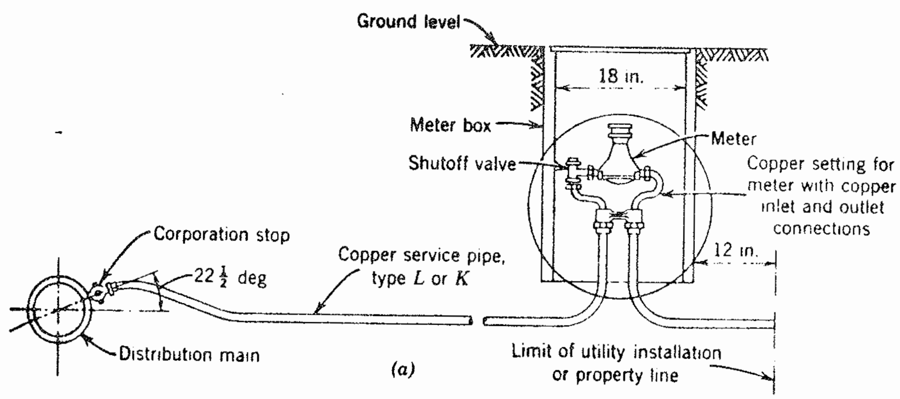
Meters. Where water service is metered, water meters are located within the utility easement or right-of-way adjacent to each user's property (see Figure 12.6). Sometimes a water meter may be placed somewhere in the water distribution system to measure the flow going to various parts of the system. As large head losses occur in a water meter, they are used sparingly.

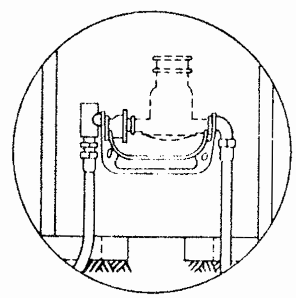
Anchorages. Water pipes must be anchored to resist the tendency of pipes to pull apart at bends, tees, size reductions, valves, and dead ends due to changes in the velocity and direction of the flowing water. Anchorage must also be provided where water mains cross streams, unstable slopes, and other places where excessive forces affect the pipe. Anchorages are typically constructed of concrete blocks with steel straps or rods to hold the pipe against the block when necessary.

Booster pumps and pressure reducers. When there are large differences in elevation in a community, booster

Figure 12.6

Typical Residential Water Meter Installations





(a) Typical house service; (b) alternate method of mounting meter.

Source: Gordon M. Fair, John C. Geyer, and Daniel A. Okun, Elements of Water Supply and Waste Water Disposal, New York: John Wiley and Sons, Inc., 1971, p. 193.

pumps and pressure reducers may be needed to maintain acceptable pressures at all points in the distribution system. A booster pump takes water from a distribution main and delivers it at a higher pressure to another main serving parts of the community at a higher elevation. Pressure reducers, on the other hand, take water from a high pressure main and discharge to a lower pressure main so that low parts of the distribution system will not be subjected to excessive water pressures.

DISINFECTION AND SANITARY PROTECTION

Storage tanks and distribution lines must be disinfected after their initial construction and after any repairs or maintenance in order to remove contamination from the water system. Disinfection is usually accomplished using calcium hypochlorite tablets or some other chlorine source. The following sanitary protection measures should be followed to reduce the chances of contamination:

1. Storage tanks should be covered and locked.
2. Water mains should be laid at least 10 feet horizontally and 2 feet vertically from all sewer lines.
3. There should be no cross connections between the public water distribution system and private water systems.

4. All dead ends shall be provided with flushing hydrants or blow-off valves.

5. During construction, water pipe should not be laid or placed in trenches which are filled with water.

Once a water system is operating, the operators must always be on the alert for possible contamination in the distribution system. Broken lines, poor construction, and improper connections are all potential sources of contamination. These problems are discussed in more detail in Chapter 13.

CHAPTER 13

OPERATION AND MAINTENANCE

A community's water supply is likely to experience operation and maintenance problems once the system is constructed. There are numerous chores and emergencies which must be attended to by the operators or by other personnel. Pumps and other equipment must be serviced, water samples taken, treatment operations monitored, meters read, and bills prepared and mailed. Electrical and equipment failures must also be corrected promptly to avoid water service interruptions as much as possible and to prevent equipment damage.

Routine tasks of an operating water system can be divided into two categories: technical tasks and administrative tasks. Trained water supply operators are responsible for performing technical tasks while administrative tasks are the responsibility of an office staff. The operator of a small system may have to perform both the technical and administrative tasks. Sometimes these tasks are shared by the members of a small community so that it is not necessary to hire a full-time operator. Nevertheless, the community should designate an individual as the "operator in charge" to ensure that all the tasks are completed and to be available in case of an emergency.

TECHNICAL TASKS

The water supply operator should perform preventive and emergency maintenance in order to keep each component of the water system operating efficiently. The operator is also responsible for ensuring that the finished product meets all the applicable water quality standards set by law. Some of the most common problems a water system operator faces are described in the following sections.

Maintaining Well Yield

Most water wells experience a reduction in yield with well age. Some wells may be pumped 20 years or more with little reduction in yield while others experience severe reductions in two or three years. Decreases in well yield are caused by a lowering of the static water table in the vicinity of the well, by excessive pump wear, and by clogging, corrosion, or incrustation of the well screen.

The static water table in an aquifer may drop for a number of reasons. First, there may be seasonal variations or natural long-term trends. Second, over-pumping may cause a local or areawide drop in the water table. In both cases, the yield of a well can often be restored by lowering the pump or by installing a more powerfull pump.*

Pump wear reduces a pump's capacity. Well yield can be restored by installing a new pump or by rebuilding the old one. Excessive pump wear is often caused by sand pumping. Sand in excess of 0.3 cubic feet per million gallons of water causes excessive pump wear and clogs water meters, control orifices, and sprinkler heads (1). Sand pumping is most often caused by the improper design, construction, or development of a well.

Decreased well yield can also be caused by clogging of the material around the well screen or by clogging of the screen itself. There are four ways in which a well can become clogged. First, incrustation can clog the openings in the well screen and fill the pores in the formation around the screen. Incrustation is caused by iron and manganese compounds, as well as

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*There are limits to these solutions. First, a pump should not be lowered below the top of the screen. Second, if a long-term dropping trend is evident, such measures will only temporarily restore will yield. The water system operator should find out how long the aquifer will be able to meet the community's water needs and should begin looking for alternate water sources if necessary.

calcium and magnesium carbonates, which presipitate out of ground water as the velocity increases in the vicinity of the well screen. The resulting deposits resemble the hard, brittle scale that forms in a teakettle.

Clogging can also be caused by iron bacteria when ground water contains significant amounts of iron. Iron bacteria produce a slimy, gelatinous material which combines with iron and manganese compounds precipitated by the bacteria to clog the openings in the well screen.

Corrosion can not only cause clogging but can also result in the collapse of a well screen or casing. When corrosive waters attack the components of a well, the products of corrosion can become trapped in the well screen openings thus causing a decrease in well yield. On the other hand, corrosion can also cause the enlargement of screen openings resulting in sand pumping. Severe corrosion can eventually cause the collapse of a well screen or casing.

Clogging can also be caused by the deposition of small soil particles, such as silt and clay, in the vicinity of the well screen.

There is no sure way to prevent incrustation and other types of clogging, but these problems can be controlled if the well is designed and constructed properly and cleaned periodically. In areas where incrustation is a problem, cleaning should be done once a year (2). Many water will drillers offer well cleaning and rehabilitation services.

All too often clogging problems are neglected until a well's yield is drastically reduced and cannot be restored without a major rehabilitation effort. The first step in such an effort is to determine the cause of the clogging. This is done by obtaining samples of the material on the sides of the screen and at the bottom of the well. Photographic surveys are sometimes used to view the inside of the well screen. By chemically testing the samples or by examining the photographs, an expert can determine the particular type of clogging problem and make recommendations for the rehabilitation of the well. The most common methods of treating various types of clogging problems are listed in Table 13.1.

Maintaining Pumps and Other Equipment

Most equipment failures can be prevented if a routine maintenance schedule is prepared and followed for each piece of equipment in the system. These schedules can be easily prepared by using the operation manuals furnished by the pump or equipment manufacturer.

Even if a water system has a good preventive maintenance program, unexpected equipment failures are

Table 13.1

Well Rehabilitation Methods

Problem	Methods of Treatment
Incrustation due to iron and manganese compounds	Hydrochloric (muriatic) acid with a stabilizer Glassy phosphates (polyphosphates)
Incrustation due to calcium and magnesium carbonates	Hydrochloric acid Sulfamic acid
Bacteria growths and slime deposits	Chlorine solutions
Corrosion	Install non-corrosive screens and casings
Silt and Clay	Glassy phosphates or other dispersing agents

bound to occur. For this reason, the water system operator should be sure that specialized tools, replacement parts, and electrical fuses are always on hand. The operator should also become familiar with the electrical and mechanical components of each pump so that he can recognize a problem as it develops.*

Water Quality Sampling and Testing

The water system operator is responsible not only for keeping each component of the treatment plant working efficiently, but also for ensuring that the water delivered to the customers meets all the water quality standards set by law (see Chapter 11). The National Primary Drinking Water Regulations establish specific sampling procedures which must be followed by all public water systems. These procedures state what kinds of samples must be taken and how often, how the samples are to be tested and recorded, and how the results of the tests are to be reported to the public and to the enforcing state agency.

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*For a complete trouble-shooting guide for all types of pumps used in small water systems, see the Water Systems Handbook published by the Water Systems Council 221 North LaSalle Street, Chicago, Illinois 60601.

Table 13.2 summarizes the types of samples required, how often they must be taken, and where in the water system they must be collected. The requirements vary with the type of contaminant, the size of the water system, and the source of water. In general, water systems using ground water must meet fewer sampling requirements than systems using surface water. Note that many requirements are left up to the enforcing agency to decide. Thus, it is important for the water system operator to become familiar with the sampling procedures required by the appropriate state agency.*

For systems using ground water only, three tests are required by the Interim Primary Drinking Water Regulations. These are the tests for inorganic chemicals, for natural radiochemicals, and for coliform bacteria. The first two are complicated and must be performed at certified private or public laboratories. Fortunately, the inorganic chemicals test and the natural radiochemicals test must only be done at three and four year intervals respectively.

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*Although the Safe Drinking Water Act sets the responsibility for meeting the National Primary Drinking Water Regulations on the individual water system, the enforcing agencies in many states offer various kinds of assistance to public water systems to aid them in meeting the requirements of the Act. In Texas, Health Department employees collect water samples and perform chemical and radiological tests for many water systems.

Table 13.2

Required Sampling for Community Water Systems

Type of Contaminant	Population Served	How Often: Systems Using Ground Water Only	How Often: Systems Using Surface Water	Where Samples are to be Taken
Inorganic Chemicals	All systems	Every 3 years	Every year	At the consumer's faucet.[1]
Organic Chemicals	All systems	State option	Every 3 years	At the consumer's faucet.[1]
Turbidity	All systems	State option	Daily	At the point(s) where water enters the distribution system.
Coliform Bacteria	25 - 1,000	1 per month		At the consumer's faucet.[1]
	1,000 - 2,500	2 per month		
	2,501 - 3,300	3 per month		
	3,301 - 4,100	4 per month		
	4,101 - 4,900	5 per month		
	4,901 - 5,800	6 per month		
	5,801 - 6,700	7 per month		
	6,701 - 7,600	8 per month		
	7,601 - 8,500	9 per month		
	8,501 - 9,400	10 per month		
	9,401 - 10,300	11 per month		
Natural Radiochemicals	All systems	Every 4 years		At the consumer's faucet.[1]
Man-made Radiochemicals	All small systems (under 100,000)	State option		At the consumer's faucet.[1]

Note: 1. The faucets selected must be representative of conditions within the distribution system.

Source: The Safe Drinking Water Act Self-Study Handbook, Community Water Systems, Denver, Colorado: American Water Works Association, (1973), p. 16.

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The coliform bacteria test must be done at frequent intervals and the larger the system, the more frequently the test is required. A complete coliform analysis must be done by a certified testing laboratory but the free chlorine residual test can be used as a substitute for the coliform analysis for up to 75 percent of the tests required (3). The principles of chlorination have been described in Chapter 11. The important thing to remember is that if there is a free available chlorine residual present in the water sample, then chlorine has been added in sufficient quantities to ensure that vegetative bacteria in the water have been destroyed.

The DPD* method for determining chlorine residual is the only method that is approved under the primary drinking water regulations (4). DPD color comparator test kits are readily available from water analysis equipment manufacturers. The test takes only five minutes to complete and can be conducted by any person acceptable to the state regulatory agency. The test procedure is described in detail in Table 13.3.

Distribution System Repairs and Maintenance

According to a 1976 survey of community and rural water systems, pipe leakage and pipe damage are the most frequently occuring problems that water system personnel must

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*The initials DPD refer to the color forming reagent, N,N-diethyl-p-phenylenediamine, which is usually supplied with the test kits.

Table 13.3

Test Procedure for Using DPD Color Wheel Comparator Test Kits

To test for free available chlorine residual:	To test for total chlorine residual:	To calculate results:
1. Rinse the sample tubes. 2. Fill one sample tube to the mark with clear water and place it in the left-hand or color-wheel portion of the color comparator. 3. Fill the other tube to the mark with the water to be tested. 4. Add the DPD *free chlorine* chemical to the test sample. Swirl to mix and place it in the comparator. 5. Hold the comparator up to natural light (daylight) and view through the front openings. Rotate color disc until color match is made. *Read* the mg/l free available chlorine residual through the scale window within one minute of adding the chemical. Record result.	1. Rinse the sample tubes. 2. Fill one sample tube to the mark with clear water and place it in the left-hand or color-wheel portion of the comparator. 3. Fill the other tube to the mark with the water sample to be tested. 4. Add the DPD *total chlorine* chemical to the test sample; swirl to mix; let stand for three minutes; and place in the comparator. 5. Hold the comparator up to natural light (daylight) and view through the front openings. Rotate color disc until color match is made. *Read* the milligrams per litre of free available chlorine residual through the scale window within one minute of adding the chemical. Record result.	No calculations are required for the free available or total residuals. The results are read directly from the color comparator. To determine combined chlorine residual you subtract the free residual from the total residual: Total Residual − Free Residual Combined Residual

Source: The Safe Drinking Water Act, Self-Study Handbook, Community Water Systems, Denver, Colorado: American Water Works Association, (1978), p. 32

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face (5). Major leaks and breaks cause pressure reductions which are often reported by consumers. Operators may also become aware of a major break by noticing an unexpected increase in the amount of water being pumped into the distribution system. Minor leaks frequently go unnoticed and can be difficult to locate. Leaks and breaks are located using one of the following methods:

- In dry weather, wet spots along water lines may indicate leaks or breaks.
- Listening devices, such as geophones or a steel bar held against a pipe or valve, can be used to locate pipe sections where the sound of escaping water is loudest.
- If the system has a mastermeter, leaks can be located by valving off short sections of the distribution system while observing closely the flow rate at the mastermeter.

There is no way to completely eliminate the occurrence of breaks and leaks, but the inconvenience they cause can be minimized by making sure that adequate repair clamps and sleeves are always on hand.

Some other water distribution problems are listed in Table 13.4 along with the symptoms and suggested solutions associated with each problem.

ADMINISTRATIVE TASKS

A water system administrator is responsible for keeping records, filing reports, billing customers, dealing

Table 13.4

Distribution System - Problems and Solutions

Problem	Symptoms	Solutions
Deposits in stagnant water pipes	Complaints about taste, odor, and turbidity from consumers	Adopt routine flushing program. Water should be flushed from hydrants or blowoff valves until clear.
Incrustation in water pipes	Loss of water pressure and reduction of water flow	Adopt routine flushing program. In severe cases, mechanical pipe cleaning may be necessary.
Biological growths (slime growth) on pipe walls	Complaints about water taste and odor	Increase chlorine dosage gradually until growth is controlled. Disinfect water pipes with heavy doses of chlorine followed by vigorous flushing.
Corrosion of steel pipes	Pipe deterioration and eventually pipe breakage	Provide cathodic protection of pipelines. Use non-corrosive pipe such as asbestos cement and plastic pipe.
Defective valves	Frozen or leaky valves	Close and open all valves at least twice a year. Replace defective valves.

Source: <u>Small Water Systems Serving the Public</u>, Troy, New York: Conference of State Sanitary Engineers, 1979, pp. 13-6 to 13-8.

with the public, keeping the books, and obtaining financing when needed for repairs or additions. An administrator depends on the water system operator for the data he needs to complete administrative tasks such as filing reports and billing customers, so coordination between the operator and administrator is essential. This is rarely a problem for very small water systems because one individual often performs both the technical and administrative tasks. The following sections briefly describe two administrative tasks that have been substantially changed as a result of the Safe Drinking Water Act.

Record Keeping

Accurate records are essential for the proper operation of a community water system. Records aid in well, pump, and equipment maintenance programs and in checking the adequacy of the water source. They are also necessary to determine the costs of producing water and the proper amortization of investments (7). Finally, certain kinds of records are required under the federal drinking water regulations. Table 13.5 lists the types of records required under the federal regulations and the length of time these records must be kept. A more comprehensive record-keeping guide is presented in Table 13.6. Small water systems without full-time operators may find it impossible and unnecessary to keep all the records shown in Table 13.6. Nevertheless, the gen-

Table 13.5

Recordkeeping Requirements under the Primary Drinking Water Regulation

Record	Minimum Years of Retention
• Bacteriological analyses	5
• Chemical analyses	10
• Written reports such as sanitary surveys, engineering reports, etc.	10*
• Variances or exemption	5†
• Action taken to correct violation	3‡

*Following completion of survey, reports, etc.
†Following expiration of variance or exemption.
‡After last action with respect to violation.

Source: American Water Works Association, <u>The Safe Drinking Water Act, Self-Study Handbook, Community Water Systems</u>, Denver, Colorado: American Water Works Association (1978), p. 36.
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Table 13.6

A Recordkeeping Guide for Small Water Systems

Well and Pump Records

1. Site plans showing wells and potential sources of pollution.
2. Individual well logs.
3. Water quality analyses.
4. Results of pumping tests.
5. Construction features at each well.
6. Pump design and maintenance records.
7. Pumping and non-pumping water levels in each well.
8. Water meter readings at each well.
9. Pump discharge pressures.
10. Total hours of pump operation per day.
11. Changes in piping

Treatment Records

1. Engineering plans of treatment plants.
2. Equipment instruction manuals, operational records, and maintenance records.
3. Amount of water treated per day.
4. Chlorine and other chemical dosage.
5. Total quantity of chlorine and other chemicals used per day.
6. Date, time, and location of water quality samples collected.
7. Results of all laboratory analyses.
8. Training programs attended and certificates held by water system operators.

Distribution System Records

1. Plans of pumping stations and storage facilities.
2. Piping system plans and modifications.
3. Equipment instruction manuals, operational records, and maintenance records.
4. Storage reservoir water levels.
5. Air-water ratios of hydropneumatic tanks.
6. Time, location, and results of chlorine residual tests.
7. Water pressures at key points in the system.
8. Customer meter readings.

Sources: 1. Small Water Systems Serving the Public, Troy, N. Y.: Conference of State Sanitary Engineers, 1979, pp. 14-2 to 14-4.

2. American Water Works Association, Ground Water (AWWA Manual M21), New York: American Water Works Association, 1973, p. 106.

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eral rule is that the more records kept now, the easier it will be to solve problems later.

Filing Reports

The Safe Drinking Water Act and subsequent regulations specify procedures for reporting to the state regulatory agencies and to the public. Water systems administrators must file three types of reports with the state: routine water sample reports, check sample reports, and violation reports. Analysis results of routine samples must be reported monthly. Check sample reports are only required when the results of a routine analysis show that an MCL is exceeded. Violation reporting is required when check samples show that an MCL has indeed been exceeded. When a violation of an MCL occurs, it must be reported to the state and to the public. The public must also be notified of other violations, variances, and exemptions as outlined in Table 13.7.

An administrator must also ensure that customers are billed and accounting records are kept. Water rates have already been described in detail in Chapter 4 on financing. Table 13.8 shows an outline of a typical water system schedule of accounts. For more information on setting water rates, establishing billing and bookkeeping systems, and conforming with state and federal regulations, an administrator should contact the American Water Works Association (AWWA), 6666 W. Quincy Avenue, Denver, Colorado 80235. The AWWA has published

Table 13.7

Public Notification Requirements

Type of Violation	Required Notification		
	Mail	News-paper	Broad-cast
Violation of an MCL	X	X	X
Failure to comply with the approved analytical testing procedure	X		
Variance or exemption has been granted to the system*	X		
Failure to perform any required monitoring	X		
Compliance schedule is not followed	X		

*This public notification has to be repeated at least once every three months as long as the system failure continues or the variance or exemption remains in effect.

Source: The Safe Drinking Water Act, Self-Study Handbook, Community Water Systems, Denver, Colorado: American Water Works Association, (1978), p. 42.
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Table 13.8

Outline of a Typical Water System Schedule of Accounts

Balance Sheet Accounts	
Assets and Other Debits	
Plant and Equipment	Account No. 100
Construction Work in Progress	Account No. 120
Invested and Special Funds	Account No. 130
Current and Accrued Assets	Account No. 140
Deferred Debits	Account No. 150
Liabilities and Other Credits	
Long-Term Debt	Account No. 200
Short-Term Debt	Account No. 220
Current and Accrued Liabilities	Account No. 230
Deferred Credits	Account No. 240
Reserves	Account No. 250
Surplus	Account No. 260
Income Accounts	
Revenues	
Sales of Water	Account No. 300
Other Revenues	Account No. 320
Expenditures and Income Deductions	
Source-of-Supply Expenses	Account No. 400
Pumping Expenses	Account No. 410
Water Treatment Expenses	Account No. 420
Transmission and Distribution Expenses	Account No. 430
Customers' Accounting Expenses	Account No. 440
Administrative and General Expenses	Account No. 450
Taxes	Account No. 460
Miscellaneous Unclassified Expenses	Account No. 470
Depreciation	Account No. 475
Income Deductions	Account No. 480
Balance of Income	Account No. 490

Source: Newsom, Reeves, Simplified System of Accounts for Municipally Owned Water Utilities (AWWA Manual M10), Denver, Colorado: American Water Works Association, 1963, p. 3.
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a number of helpful manuals, handbooks, and pamphlets, some of which are listed in the Bibliography of this manual.

OPERATION AND MAINTENANCE COSTS

Although this manual is primarily concerned with the establishment of a community water system, operation and maintenance costs are discussed because they are important in determining if a community can afford to build and operate a water system.

At least half of a customer's water bill is usually associated with operation and maintenance costs. Operation and maintenance costs have been rising steadily primarily because of increases in the cost of electricity, chemicals and repairs. Additional increases are expected as the new federal drinking water standards are implemented.

Since few operation and maintenance cost studies of small water systems have been published, general conclusions about future cost trends are difficult to make. The results of an EPA study are shown in Table 13.9. In general, operating costs decrease with increasing system size, but there can be significant variations from system to system because of different levels of treatment and different methods of reporting costs. As mentioned previously, the smallest systems often rely on donated labor and services which are

Table 13.9

Total Operating Expenses

1975

(cents per thousand gallons produced)

	Population Category								
	25-99	100-499.	500-999	1,000-2,499	2,500-4,999	5,000-9,999	10,000-99,999	100,000-999,999	Over 1 million
Mean Total Operating Expense	77.8	64.8	75.8	62.4	57.5	52.6	39.9	31.9	23.5
Standard Deviation	72.1	58.2	56.5	47.3	41.2	39.3	24.1	19.4	9.9
Median	53.3	50.6	62.6	55.2	45.0	36.9	35.8	28.2	18.5
(# obs.)	(48)	(119)	(68)	(88)	(55)	(40)	(80)	(189)	(9)

*For systems with total operating expenses and production greater than zero and operating expenses less than $3.00 per thousand gallons produced.

Source: Temple, Barker, and Sloane, Inc., Survey of Operating and Financial Characteristics of Community Water Systems, Washington, D. C.: Office of Water Supply, U. S. Environmental Protection Agency, April 1977, p. VII-3.

difficult to include in an operation and maintenance cost study.

A breakdown of operation and maintenance costs for Farmers Home Administration financed water systems in Illinois for 1975 is shown in Table 13.10. Labor is typically the largest cost, representing a third of the total operation and maintenance cost. The same study in Illinois states that total operation and maintenance costs increased 8% annually during the period between 1971 to 1975 (8).

Since operation and maintenance costs vary widely, it is difficult to project what a particular water system's operation and maintenance costs will be. State health departments can sometimes provide information, but other nearby communities that have operating water systems are probably the best sources of information about operation and maintenance costs as well as the many other facets of establishing a community water system.

REFERENCES

1. American Water Works Association, Ground Water (AWWA Manual M21). New York: American Water Works Association, 1973, p. 115.

2. Ibid, p. 111.

3. American Water Works Association, The Safe Drinking Water Act, Self-Study Handbook, Community Water Systems, Denver, Colorado: American Water Works Association. 1978, p. 28.

Table 13.10

Average Annual Operating Cost for FmHA Financed Well-Supplied Water Systems in Illinois, 1975

Item	Average Cost per User[2]	Percent of Total Cost
Wages	14.76	33
Repairs and Maintenance	9.31	21
Utilities and Gas	6.89	15
Chemicals and Supplies	5.71	13
Taxes, Insurance, and Bonds	3.36	8
Office Supplies, Accounting, Auditing and Legal	2.88	6
Miscellaneous	1.58	4
Total	44.49	100

[1]FmHA, Illinois Instruction 442.1A, Guide 8, p. 1.
[2]This is the average cost per user for 45 systems with an average size per system of 127 users.

Source: Miller, William L., The Cost Factor in Rural Water Systems, Rural Water View No. 9, National Demonstration Water Project, 1976, as cited in Drinking Water Supplies in Rural America, Washington, D. C.: National Demonstration Water Project, 1978, p. 121.

4. *Ibid*, p. 31.

5. William L. Miller, *The Cost Factor in Rural Water Systems*, Rural Water View No. 9, NDWP, 1976, as cited in *Drinking Water Supplies in Rural America*, Washington, D. C.: National Demonstration Water Project, 1978, pp. 124 and 126.

6. *Small Water Systems Serving the Public*, Troy, New York: Conference of State Sanitary Engineers, 1979, p. 13-6.

7. American Water Works Association, *Ground Water*, 1973, p. 106.

8. Miller, William L., *The Cost Factor in Rural Water Systems*, Rural Water View No. 9, National Demonstration Water Project, 1976, as cited in *Drinking Water Supplies in Rural America*, Washington, D. C.: National Demonstration Water Project, 1978, p. 123.

APPENDIX*

MAJOR AQUIFER REGIONS OF THE UNITED STATES

The concept of ten U. S. ground water provinces (as introduced by H. E. Thomas in 1952) is convenient for large-scale analysis of ground water conditions (Figure A-1). The ten-province scheme also has considerable potential as a tool for comparison of well construction costs. Because the lithology and ground water availability within each region are fairly homogeneous, the types of drilling equipment and well construction methods used in a given region represent only a few of the many diverse drilling methods being used in the nation at large. Moreover, the type of equipment used, the average depth from surface to ground water, and the ease of drilling are the primary determinants of well construction costs in each region.

Following are brief descriptions of each of the ten U. S. ground water provinces and drilling conditions for each.

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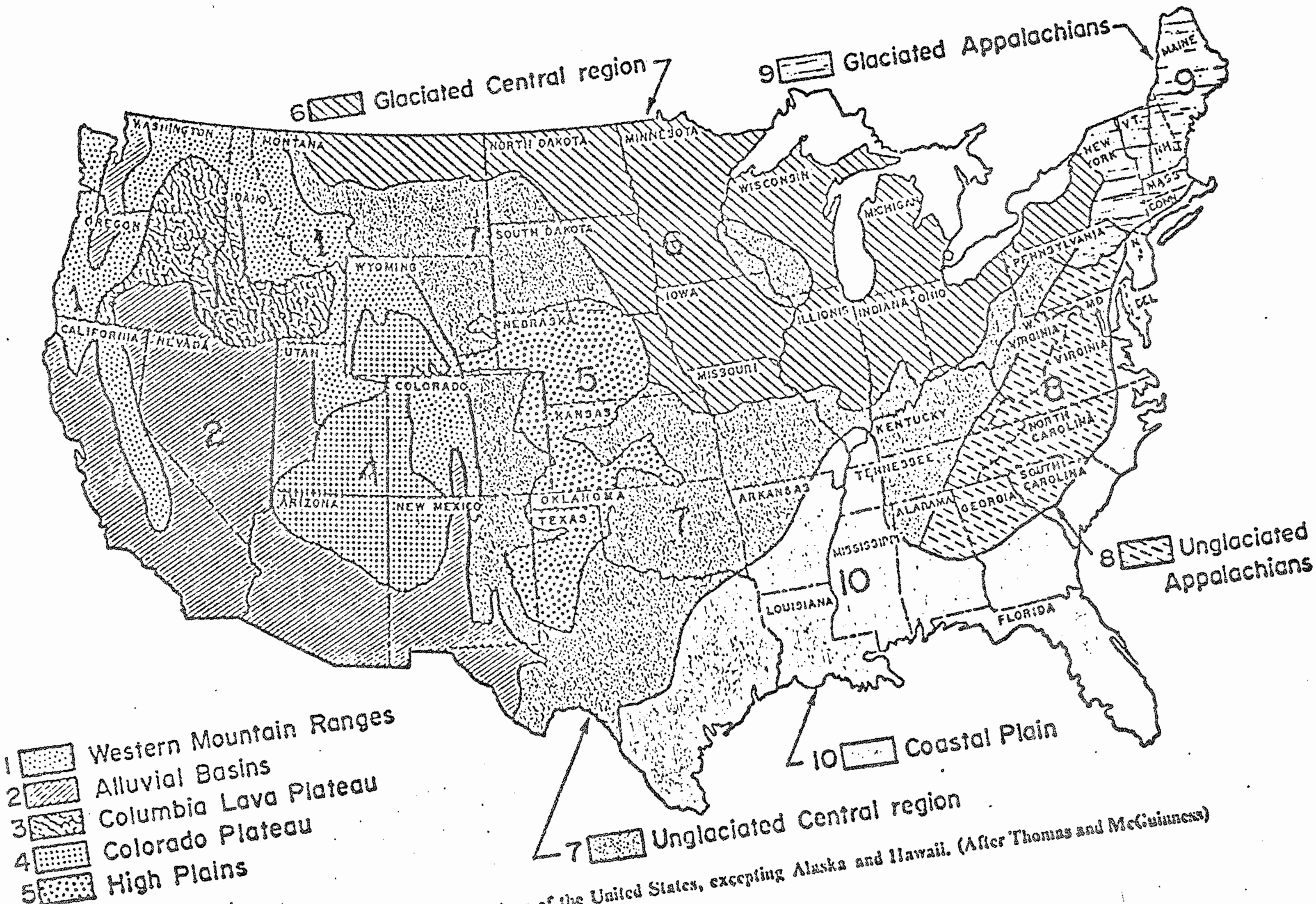
*Source: The Appendix is taken from John T. Massey-Norton, Doug Bacon, Michael Eberle, and Tyler E. Gass, Rural Water Supplies: A Cost Comparison of Central, Cluster, and Individual Source Systems, Worthington, Ohio: National Water Well Association, 1979, pp. A-1 to A-13.



Ten major ground-water regions of the United States, excepting Alaska and Hawaii. (After Thomas and McGuinness)

FIGURE A.1

1. WESTERN MOUNTAIN RANGES

The Western Mountain Ranges Region is an area of rugged, high mountains composed of hard, dense and impermeable crystalline rocks. Fault zones in some areas may act as conduits or barriers to ground water flow. Alluvial aquifers in valleys provide much of the region's ground water.

Two types of wells are drilled in the Western Mountain Range, the rock well and the alluvial well. Rock wells are drilled using air/mud rotary rigs with a downhole hammer. Development in hard rock consists of air surging or hydraulic fracturing. Alluvial wells are drilled using the mud rotary method. These wells are usually less than 100 feet deep and are gravel packed. They must be carefully cased and grouted to seal off contaminated water.

2. THE ALLUVIAL BASINS

The Alluvial Basins Region flanks the mountains and plateaus of the west and southwestern United States. Included in this region are the Great Basin of Utah, Nevada and California, sections of the Basin and Range Province, the southern and eastern flanks of the Colorado Plateau, California's central and northern valley systems, and the

Puget-Willamette trough in Oregon and Washington. The region is characterized by extensive alluvial fill; its coarser sands and gravels provide the best aquifers.

Saline ground water and declining water levels from overdevelopment are two problems plaguing the Alluvial Basins. Saline water results from the occurrence of evaporites at shallow levels (which are fortunately localized), and from upconing of deep salt water due to heavy pumpage of overlying fresh water. Drilling in the Alluvial Basins is generally fast and easy compared to the adjacent hardrock highlands. Boulder fields can frequently be avoided through careful mapping. Thick clay beds and quicksands can slow the drilling process and hamper casing installation.

3. COLUMBIA LAVA PLATEAU

The Columbia Lava Plateau is a large highland area formed from rocks extruded by volcanic eruptions and overlain by alluvial and lake sediments. Use of ground water for irrigation and industry is increasing due to decreased rainfall. In the spring, the region's lavas receive vast quantities of ground water from infiltrating surface water and discharge by springs at a relatively constant rate throughout the summer. Throughout the region's western section, interflow zones are most permeable and are natural targets for well drillers. Farther east, ground water is found in faults and fracture zones. Unconsolidated sand and gravel beds are important ground water sources throughout the region.

Nearly all wells are drilled by either cable tool or air rotary method, with a roller-cone bit used in gravel and fractured basalt and a downhole hammer in massive basalt. Well dimensions vary widely depending on the nature of the rock and the depth of the fracture zone. Domestic wells are six inches in diameter and irrigation wells are usually 16 inches. Both sizes produce more than adequate high quality water supplies.

4. COLORADO PLATEAU

The Colorado Plateau region is one of the nation's least populated areas, since population is concentrated in small areas of fertile alluvial soil and in mining districts. Opportunities for surface water use are severely limited. Ground water reservoirs are mostly sandstone, although a good many wells obtain their water from limestone formations and, in some isolated areas, ground water occurs in sand and gravel deposits of alluvial origin. Folding and faulting of sandstone sometimes create confining conditions which cause wells to flow at the surface, however, very deep wells are not uncommon.

Air rotary and cable tool drilling methods predominate in the area. Wells drilled in flood plain sands and gravels may be as shallow as 50 or 60 feet, while domestic sandstone wells range from 200 to 1000 feet.

5. HIGH PLAINS

The High Plains ground water region is a narrow discontinuous belt that stretches from southern South Dakota to southwestern Texas. The ground water supply occurs primarily in the Ogallala formation, the massive alluvial apron formed at the foot of the Rocky Mountains which was subsequently uplifted. This deposit covers an eroded surface to a thickness that exceeds 500 feet in some places. Ground water storage is estimated at two billion acre-feet. Except for some areas in Nebraska, recharge rates are generally thought to be less than 1 percent of rainfall. Because ground water pumpage throughout the High Plains exceeds 8,000,000 gallons per day (9,000,000 acre-feet annually), increased utilization of water management techniques will be necessary to avoid severe shortages in the area.

Typical wells in the High Plains are of gravel pack construction, drilled by conventional or reverse rotary methods using either clear water or small amounts of mud.

The sands encountered during drilling are easily penetrated, while clays in the formation help maintain hole stability. Boulders and "slip clay" occasionally pose drilling problems.

6. GLACIATED CENTRAL REGION

The Glaciated Central Region extends from the Rocky Mountains on the west to the Appalachians on the east and is characterized primarily by a sheet of glacial drift which varies substantially in thickness, permeability and storage capacity. Areas where the drift is thick and permeable have plentiful ground water supplies, both in the drift itself and in the various types of bedrock aquifers which underlie the region. Even in these parts where glacial deposits are thinner and less promising as reservoirs, there are occasional channels of outwash along which large ground water supplies can be found. In spite of generally good water availability, localized shortages have occurred in some heavily industrialized communities. However, the outlook for further ground-water development is bright if careful planning and management techniques are used.

Drilling for domestic water supplies poses few problems in the Glaciated Central region. The drift deposits are easily penetrated and, if unhampered by boulders, quicksands, or hardpan clays, drilling proceeds at a fairly rapid rate. Straight mud rotary has become the most prevalent drilling method although cable tool and air rotary techniques are not uncommon. Domestic wells throughout the region are normally found between the range of 50-400 feet, the average well being around 150 feet deep.

7. UNGLACIATED CENTRAL REGION

The Unglaciated Central region is vast, sprawling across the interior of the United States. The region completely surrounds the High Plains ground-water region and is bordered by six other regions, sharing at those borders some of the same hydrogeological characteristics of its neighboring regions.

The Unglaciated Central region has undergone only the changes brought about by the gradational processes that typically occur on the land surface: wind and water erosion and transportation of sediment. Especially significant are the massive sediment loads deposited by torrents of water from the melting glaciers at the end of each glacial period.

The region is diverse in climate, in topography, and in geology, with rocks ranging in age from Precambrian to Recent and with considerable variety in geologic structure. Most of the extensive aquifers in the region are consolidated sedimentary rocks.

Sand and gravel deposits constitute the other major type of aquifer found throughout the region, however, these deposits are restricted to present day stream valleys. In the region as a whole, limestone is the most productive single aquifer type, though some sandstones are locally capable of yielding 1000 gpm or more to individual wells.

Because so much of the drilling in the area is in hard rock, air rotary and downhole hammer methods are widely used. Domestic well depths range from 25 to 2000 feet in this region. However, the majority are between 100 and 400 feet.

8. UNGLACIATED APPALACHIAN REGION

The Unglaciated Appalachian Region extends from Pennsylvania, along the Appalachian Mountains into Georgia and Alabama. The region receives abundant rainfall and has rugged terrain composed primarily of hard rocks. The bedrock is covered by an extensive thick layer of weathered rock material. Although the physiography of the region varies significantly, the hydrogeology is much the same throughout. Ground water occurs at considerable depth in bedrock joints or fractures, and in the loose and weathered surface material. Aquifers in the region provide a good source of water for domestic wells, although such wells frequently have low yields. Municipal and industrial wells are not as numerous and are harder to locate than domestic supplies, but are still viable alternatives to surface water development.

Air rotary drilling methods with downhole hammer are fast and efficient in these formations, and are constantly gaining in popularity. Few drilling problems are encountered in this area, and well development techniques are not normally used in the hard rock formations.

9. GLACIATED APPALACHIAN REGION

The Glaciated Appalachian region encompasses most of the North Atlantic states and extends to southern New York, and northern Pennsylvania. It receives abundant rainfall and has rugged, hard rock terrain. Valleys are filled with sand and gravel outwash, and the entire area is irregularly blanketed with glacial till. This overburden is largely unsorted, and occasional large boulders can pose problems to drillers. There are many highly productive aquifers in surface deposits of the region, and several major cities in this area obtain their water from permeable glacial deposits. Because of the high cost of large diameter municipal and industrial wells, test holes are usually drilled and analyzed prior to site selections.

Mud-rotary and cable-tool methods are usually chosen for drilling unconsolidated formation in this area; cable-tool and air hammer methods are commonly used in bedrock. The water that occurs in the bedrock is usually found in cracks and joints. The average domestic well provides about 5 gpm of generally good quality water.

10. ATLANTIC AND GULF COASTAL PLAIN REGION

The Atlantic and Gulf Coastal Plain Region is one of the largest and most prolific ground water provinces in the United States. It is formed from a thick wedge of clay, silt, sand, gravel, and limestone strata. Most of the region is underlain by several aquifers capable of yielding over 500 gpm to individual small diameter wells.

Major aquifers consist of unconsolidated sand, and sand and gravel formations. Some of the more notable are the Raritan and Magothy Formations of the northeast Atlantic Coastal Plain, the Floridian and Biscayne aquifers of Florida, the sand, and sand and gravel aquifers of Louisiana, and the deep aquifers of Texas. Coastal Plain ground-water quality is excellent with the exception of hardness in the limestone areas and light iron concentrations throughout the region.

A variety of well drilling techniques are employed, ranging from reverse rotary for large diameter municipal wells to air rotary for 10-12 inches irrigation wells, and combined cable tool-rotary for 2-inch domestic wells.

BIBLIOGRAPHY

Al-Layla, M. Anis, Ahmad, Shamim, Middlebrooks, E. Joe. Water Supply Engineering Design. Ann Arbor, Michigan: Ann Arbor Science Publishers Inc., 1977.

Arasmith, E. E. "Skeet". "Introduction to Disinfection-Chlorination." Albany, Oregon: Linn-Benton Community College, 1977.

Arasmith, E. E. "Skeet". "Introduction to Water Treatment." Albany, Oregon: Linn-Benton Community College, 1977.

Baker, E. T.,Jr., and Wall, James R. "Summary Appraisals of the Nation's Ground Water Resources - Texas Gulf Region," Geological Survey Professional Paper 813F. Washington, D. C.: U. S. Government Printing Office, 1976.

Basic Level Water Treatment Operator's Practices (AWWA Manual of Water Supply Practices No. M18). Denver, Colorado: American Water Works Association, 1971.

Cairncross, Sandy, and Feachem, Richard. Small Water Supplies (Ross Bulletin No. 10). London: The Ross Institute, 1978.

Drinking Water Supplies in Rural America. Washington, D. C.: National Demonstration Water Project, 1978.

Eaton, David J., and the Safe Drinking Water Policy Research Project. "Options for Coping with the Safe Drinking Water Act," Safe Drinking Water, Clifford Russel, ed. Baltimore, Maryland: The John Hopkins University Press, 1978, pp. 411-443.

Fair, Gordon M., Geyer, John C., Okun, Daniel A. Elements of Water Supply and Wastewater Disposal. New York: John Wiley and Sons, Inc., 1971.

Ground Water (AWWA Manual No. M21). New York: American Water Works Association, 1973.

Ground Water and Wells. Saint Paul, Minnesota: Johnson Division, U.O.P. Inc., 1975.

Ground Water Management, ASCE Manuals and Reports on Engineering Practice No. 40. New York: American Society of Civil Engineers, 1972.

Hanke, Steve H., and Boland, John J. "Water Requirements or Water Demands?", American Water Works Association Journal, Vol. 63, November 1971, pp. 677-687.

Hedge, Russell K. "A Guide to Cooperative Service Arrangements for Community Water Systems." The Safe Drinking Water Policy Research Project, Lyndon B. Johnson School of Public Affairs, The University of Texas at Austin, 1978.

Junek, Larry J., and Whitfill, Aileen C. "Financial Assistance for Safe Water; A Guide to Small Water Systems on Obtaining Aid." The Safe Drinking Water Policy Research Project, Lyndon B. Johnson School of Public Affairs, The University of Texas at Austin, 1978.

Mann, H. T., and Williamson, D. Water Treatment and Sanitation, Simple Methods for Rural Areas. London: Intermediate Technology Publications, 1976.

Massey-Norton, John T., Bacon, Doug, Eberle, Michael, and Gass, Tyler E. Rural Water Supplies: A Cost Comparison of Central, Cluster, and Individual Source Systems. Worthington, Ohio: National Water Well Association, 1979.

Newsom, Reeves. Simplified System of Accounts for Municipally Owned Water Utilities (AWWA Manual M10). Denver, Colorado: American Water Works Association, 1963.

The Safe Drinking Water Act Self-Study Handbook, Community Water Systems. Denver, Colorado: American Water Works Association, 1978.

The Safe Drinking Water Policy Research Project. Impact of the Safe Drinking Water Act on Texas. Austin, Texas: Lyndon B. Johnson School of Public Affairs, The University of Texas at Austin, 1978.

Small Water Systems Serving the Public. Troy, New York: Conference of State Sanitary Engineers, 1979.

Temple, Barker, and Sloane, Inc. Survey of Operating and Financial Characteristics of Community Water Systems. Washington, D. C.: U. S. Environmental Protection Agency, April 1977.

U. S. Department of Health, Education, and Welfare. Community Water Supply Study: Analysis of National Survey Findings. Washington, D.C.: U. S. Government Printing Office, 1970.

U. S. Department of the Interior, Bureau of Reclamation. Ground Water Manual, A Water Resources Technical Publication. Washington, D.C.: U. S. Government Printing Office, 1977.

U. S. Environmental Protection Agency. Manual of Individual Water Supply Systems (EPA-430/9-74-007). Washington D.C.: U. S. Government Printing Office, 1975.

U. S. Environmental Protection Agency, Office of Water Supply. State of the Art of Small Water Treatment Systems. Washington, D.C.: U. S. Government Printing Office, 1977.

U. S. General Accounting Office. Improved Federal and State Programs Needed to Insure the Purity and Safety of Drinking Water in the United States. Washington, D.C.: U. S. Government Printing Office, 1973.

Water Rates Manual (AWWA Manual M1, Second Edition). New York: American Water Works Association, 1972.

Wright, Forrest B. Rural Water Supply and Sanitation. Huntington, New York: Robert E. Krieger Publishing Company, 1977.

Zaporozec, Alexander. "Changing Patterns of Ground Water Use in the United States." Ground Water, Vol. 17, No. 2, March-April 1979, pp. 199-204.