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manual

SMALL WATER SYSTEMS SERVING THE PUBLIC

correlated with

NATIONAL DRINKING WATER REGULATIONS

CONFERENCE OF STATE SANITARY ENGINEERS

in cooperation with

OFFICE OF DRINKING WATER

U.S. ENVIRONMENTAL PROTECTION AGENCY

WASHINGTON, D.C., 20460

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FRANK R. LIGUORI, PE, Technical Writer

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OFFICE OF DRINKING WATER

U.S. ENVIRONMENTAL PROTECTION AGENCY

WASHINGTON, D.C., 20460

PREFACE

This Manual was developed through the Conference of State Sanitary Engineers under U.S. Environmental Protection Agency Grant No. T900624010, to fulfill a need for a manual covering small water supply systems serving the public. The Manual is designed to provide guidance in the planning, design, development, maintenance, operation and evaluation of small water systems and is correlated with the National Drinking Water Regulations. It is prepared as a service to:

- Owners and operators of public water systems serving small communities of about 50 connections or less and the non-community type systems.
- The design engineer who may be called upon to design small water systems.
- State and local enforcing agencies as a tool to assist in evaluation and inspection responsibilities.

The Manual was prepared by Frank R. Liguori, P.E., Sanitary Engineer, Ithaca, NY, who served as the technical writer under the guidance of a special C.S.S.E. Task Group. The Task Group reviewed the various drafts, provided technical advice and material, and approved this final manuscript. The Task Group included the following:

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The Conference of State Sanitary Engineers acknowledges the guidance and input provided by the U.S. Environmental Protection Agency including: Victor Kim, Assistant Deputy Administrator; John Mannion, Special Assistant; George C. Kent, Sanitary Engineer, Office of Drinking Water; and Peter Y. Bengtson, Sanitary Engineer, Office of Drinking Water. However, participation by EPA does not imply that the contents necessarily reflect the views or policies of the Environmental Protection Agency, nor does the mention of trade names or commercial products constitute endorsement or recommendation thereof.

Material used in the preparation of the Manual was derived from many sources. Where material is used in its direct original form or adapted from an original publication, permission has been received for its use and credits are shown.

MANUAL

SMALL WATER SYSTEMS SERVING THE PUBLIC

Correlated With
National Drinking Water Regulations

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The owner of a water system serving the public has a legal responsibility to provide a safe, potable and adequate supply of water at all times. In 1974, the Congress of the United States passed the Safe Drinking Water Act as a means of assuring safe public water systems and directed the Environmental Protection Agency to establish nationwide drinking water regulations. All public water systems are regulated by the provisions of the National Safe Drinking Water Act and the National Drinking Water Regulations[1] adopted by the U.S. Environmental Protection Agency pursuant to the Act. Individual State agencies which accept and qualify for enforcement responsibilities will enforce the regulations and may also enforce certain regulations of their own. (See Appendix B for a listing of State agencies.)

Some of the pertinent definitions follow:

Public Water System means a system which provides piped water to the public for human consumption, if the system has at least fifteen (15) service connections or regularly serves an average of at least twenty-five (25) individuals at least sixty days out of the year. There are basically two types of public water systems, community and non-community.

Community Water System means a public water system which serves at least fifteen (15) service connections used by year around residents or regularly serves twenty-five (25) year around residents.

(1) National Interim Primary Drinking Water Regulations, U.S. Environmental Protection Agency, available through State enforcing agencies. See Chapter 12 for more details.

Non-Community Water System means a public water system that is not a community water system, basically one that serves the transient public.

Examples of the classes and types of water systems regulated under the Act and the Drinking Water Regulations are listed below.

Community Water Systems

Municipal systems and public water utilities

Mobile home parks

Condominiums

Residential Institutions and schools, including hospitals, nursing homes, homes for the aged, colleges, etc.

Housing developments, public and private

Multi-family housing complexes (all varieties)

Non-Community Water Systems (with separate water systems)

Motels-hotels-resort areas

Schools (non resident)

Restaurant and other food service places

Parks

Recreation areas

Migrant labor and construction camps

Children and adult camps

Gasoline service stations

Industries

Churches

Campgrounds

Highway rest areas

Marinas

Airports

Medical Care Facilities

Shopping Centers

Office and commercial buildings

Public buildings and public assembly

Social and recreation clubs

Swimming pools and beaches

It is the purpose of this Manual to provide planning, design, development, operation and maintenance guidance for the numerous public water systems serving the non-community grouping and the small community systems serving up to about fifty connections. In order to increase its usefulness, the Manual is correlated with the National Drinking Water Regulations.

Other manuals and textbooks are readily available to provide guidance for the larger municipal (community) water systems. In addition, pamphlets are readily available to assist the individual home owner and the farmer in developing small individual water systems. However, much of the available published information on the small public water systems which fall between these extremes is scattered in a variety of miscellaneous publications. This Manual brings together some of the information into a single volume. It is written primarily to meet the needs of owners and operators of small public water systems throughout the nation. But it is also hoped that the Manual will be of value to the professional engineer who will be called upon to design these small water systems and the water technicians who will assist in administering surveillance programs for federal and state agencies. To increase its usefulness, the Manual includes design capacity guidance for the various components of a water system and guidance on the sanitary protection of the system.

More often than not small public water systems utilize wells with gravity storage reservoirs, or hydropneumatic systems, with comparatively small distribution systems without provisions for fire flow protection. These are discussed in some detail. Occasionally, springs, infiltration galleries or surface water sources are utilized and these too are covered but in less detail.

The information provided in the Manual represents a broad consensus of acceptable water supply practices throughout the nation. However, conditions vary over the expanse of the country and the water purveyor is encouraged to consult with the individual State regulatory agencies for specific requirements and criteria which may be applicable within a particular State. The Environmental Protection Agency has authorized certain counterpart State agencies (which qualify and accept a primary enforcement role) to assume the basic responsibility for surveillance and enforcement of the Act and the Drinking Water Regulations. The current listing of these State agencies may be found in Appendix B. If no State agency is listed, the applicable EPA Regional Office should be consulted. Companion State regulations also apply. It is particularly important to consult with the State agency for special requirements on design, plan submission, sampling and testing, record keeping, reporting, construction permits and operating permits.

The Manual is divided into three parts with each part further subdivided into Chapters. An introduction provides a synopsis of the content of each Chapter. The Table of Contents provides a sequential listing of the contents of each Chapter.

PART I - PLANNING, DESIGN AND DEVELOPMENT

The chapters in this part follow the logical sequence of planning, design and development of a new water system. Guidance is also provided for expansion of an existing system or the addition of treatment units, including chlorination. It also provides a tool for the evaluation of an existing system to assess how well the system meets acceptable criteria.

PART II - OPERATION AND MAINTENANCE

This part will be particularly useful to the person responsible for the day to day operation and maintenance of a system and for compliance with the water quality and other legal requirements.

The Interim Primary National Drinking Water Regulations are summarized. Separate chapters are devoted to maintenance and record keeping. The operator is also alerted to certain special problems and emergencies.

PART III - APPENDICES

Appendix A is a glossary of the more common terms used in water supply practice.

Appendix B is a listing of the State regulatory agencies and EPA Regional Offices.

Appendix C provides a listing of reference publications.

CHAPTER AND PAGE NUMBERING

The pages in the Chapters which follow are numbered consecutively but the page number is preceded by the Chapter number. As an example, page 2-10 is page 10 of Chapter 2. Likewise, the Figures and Tables are numbered consecutively, preceded by the Chapter number. As an example, Table 3-1 is Table 1 of Chapter 3.

PART I

PLANNING - DESIGN - DEVELOPMENT

CHAPTERS 1 through 11

CHAPTER I

WATER MEASURING TERMS AND UNITS	English and Metric, With Conversions

INTRODUCTION

A basic knowledge of the "language" of water technicians is an essential tool for the proper understanding of planning, design, operation, maintenance and management of a water system. This language forms the basis for communication, both verbal and written. There follows an introduction to some of the more common units used to measure quantity, pressure and quality, and definitions of some of these terms. For a more extensive reference of water system terms in alphabetized form, see the GLOSSARY, Appendix A.

ENGLISH AND METRIC UNITS

The metric system of measure has several advantages over the americanized English system. It is in common use as the international measuring language and the United States is committed to a gradual change-over from English to metric. The reader will do well to become thoroughly familiar with the metric system and to use the terms whenever possible. For this reason, both the English and metric terms are used in the manual. In order to avoid confusion at this stage of "going metric", the familiar American terms are used, followed by metric terms. However, where the use of both becomes cumbersome, only the American term is used.

The principal advantage of the metric system is the use of the uniform decimal system wherein all units are multiples of ten, not unlike our monetary system. In comparison, the English system is a hodgepodge of units with no basic uniformity. As an example, there are 12 inches in one foot, 3 feet in one yard and 5,280 feet in one mile. In the metric system there are 1,000 millimeters in a meter and 1,000 meters in a kilometer, the metric "mile".

In the metric system, the following prefixes are used.

mega (M) means 1,000,000	deci (d) means 1/10
kilo (k) means 1,000	centi (c) means 1/100
hecto (h) means 100	milli (m) means 1/1000
deca (da) means 10	micro (μ) means 1/1,000,000

For instance, when the "meter" is preceded by "kilo", it produces "kilometer", meaning 1000 meters.

MEASURING UNITS

Linear Measure

The basic unit of length in the metric system is the meter.

1 meter (m) = 39.37 inches = 3.25 feet.

The meter (m) is divided into larger or smaller units up and down the scale in multiples of ten, as are all metric units.

1 meter (m) = 10 decameters (dam) = 100 centimeters (cm) = 1000 millimeters (mm)

1000 meters = 1 kilometer (km) = 0.62 miles (English)

Mass (Weight) Measure

The metric unit for weight (more correctly the mass) is the kilogram.

1 kilogram (kg) = 1000 grams (gm) = 2.2 pounds (English)

1 gram (gm) = 1000 milligrams (mg)

1000 kilograms = 1 kiloton

Volume Measure

The common metric unit of volume is the liter.

1 liter (l) = 1000 milliliters (ml) = 1.06 quarts (English)

1 milliliter is about 1 thimble full of water.

1000 liters(l) = 1 cubic meter (cu. m) = 264.2 gallons (English)

Rate of Water Flow

The common American term for the rate of water flow is gallons per minute (gpm), gallons per hour (gph), gallons per day (gpd) or millions gallons per day (mgd).

In the metric system, the liter is the most appropriate volume measure for small water systems. Since the liter is about equal to one quart, it is more appropriate to use liters per second than liters per minute.

One liter per second (1/sec.) = 16 gallons per minute (gpm) (approximately)

Where larger flows are involved, the metric term, cubic meters per minute, is appropriate.

1 cubic meter per minute (cu.m/min.) = 264.2 gallons per minute (gpm)

Pressure Units

The American term for pressure is pounds per square inch (psi), the force in pounds exerted on one square inch of surface. Two terms are in common use in the metric system. First, there is the kilogram per square centimeter which is nearly equivalent to one standard atmosphere or 14.7 psi and secondly, the kilopascal (kpa). One psi is equal to about 7 kpa.

In water works practice, pressure is also referred to as a "head". Water standing in a pipe or tank exerts a head which is dependent upon the height of the column of water. A pipe filled with water to a depth of one foot exerts a pressure at the bottom of the pipe equivalent to 0.43 pounds per square inch.

1 foot of water head = 0.43 psi

2.31 feet of water head = 1.0 psi

231 feet of water head = 100 psi

Height and pressure are therefore inter-related. In a "static system", the pressure head depends only on the height of the column of water and the size of the pipe is immaterial. A "static system" is when no water is flowing and the resulting pressure is called the "static pressure". The pressures exerted in a flowing water system is called the "dynamic pressure".

Temperature

In the English system, temperature is measured in the familiar degrees Fahrenheit (^{o}F) on a scale where water freezes at 32^{o} F and boils at 212^{o} F (at standard sea level). On the metric scale, degrees Celsius (^{o}C), water freezes at 0^{o} C and boils at 100^{o} C.

Conversion of Common Terms

There follows Table 1-1 which lists commonly used English and metric equivalents. It is common practice to round off decimals where high accuracy is not important. Table 1-2 is a listing of handy (approximate) conversion factors to simplify conversions from one term to another.

Table 1-1: English Units and Metric Equivalents

English	Metric	English	Metric
LENGTH		**AREA**	
1.0 inch (in.)	2.54 centimeter (cm)	1.0 sq. inch	6.45 sq. centimeter (sq.cm)
0.3937 inch	1.0 centimeter	0.155 sq. inch	1.00 sq. centimeter
1.0 foot (ft.)	30.48 centimeter	1.0 sq. feet	0.09 sq. meter (sq.m)
3.28 feet	1.0 meter (m)	10.76 sq. feet	1.0 sq. meter
39.37 inches	1.0 meter	1.0 acres	0.405 hectare
1.0 miles (mi.)	1.61 kilometer (km)	2.47 acres	1.0 hectare (10,000 sq. meters)
0.62 miles	1.0 kilometer	1.0 sq. mi.	259.0 hectare (259 sq.km)
		0.386 sq. mi.	1.0 sq. km (100 hectare)
VOLUME		**VOLUME**	
1.0 cubic inch (cu.in.)	16.39 cu. centimeter (cc)	1.0 quart (qt.)	0.946 liter (l)
0.06 cubic inch	1.0 cu. centimeter (cc)	1.057 quart	1.00 liter
1.0 cubic feet	0.028 cu. meter (cu.m)	1.0 gallon (gal.)	3.79 liter
35.31 cubic feet	1.0 cu. meter	0.26 gallon	1.00 liter
1.0 ounce	29.57 milliliter (ml)	1.0 gallon	0.003785 cu. meter
		264.2 gallon	1.0 cu. meter (cu.m)
WEIGHT (MASS)		**RATE OF FLOW**	
1.0 ounce (oz.)	28.35 grams (gm)	1.0 gal. per mi. (gpm)	0.003785 cu. meter/min.
0.035 ounce	1.0 gram	264.2 gpm	1.0 cu. meter/min.
1.0 pound (lbs.)	0.454 kilogram (kg.)	1.0 gpm	3.79 liter per min.
2.205 pound	1.0 kilogram	0.264 gpm	1.0 liter per min.
		15.85 gpm	1.0 liter per sec.
PRESSURE		**PRESSURE**	
1.0 pound/sq.inch (psi)	0.070 kilograms/sq.cm	0.145 psi	1.0 kpa (kilopascal)
14.7 psi (1 atmosphere)	1.03 kilograms/sq.cm	1 psi	6.9 kpa

Table 1-2: Approximate Conversions

When you know	Multiply by	To Find
Inches (in.)	25	Millimeters (mm)
Millimeters	0.04	Inches (in.)
Inches (in.)	2.5	Centimeters (cm)
Centimeters	0.4	Inches (in.)
Feet (ft.)	0.3	Meters (m)
Meters (m)	3.3	Feet (ft.)
Miles (mi.)	1.6	Kilometers (km)
Kilometers	0.6	Miles (mi.)
Ounces (oz.)	28	Grams (g)
Grams (gr.)	0.035	Ounces (oz.)
Pounds (lb.)	0.45	Kilograms (kg)
Kilograms (kg)	2.2	Pounds (lb.)
Gallons (gal.)	3.8	Liters (l)
Liters (l)	0.26	Gallons (gal.)
Pounds per square inch (psi)	7.0	Kilopascals (kpa)
Kilopascals (kpa)	0.14	Pounds per square inch (psi)
Feet of water head (ft.)	0.43	Pounds per square inch (psi)
Pounds per square inch (psi)	2.3	Feet of water head
Fahrenheit temperature (^{o}F)	0.56 (after subtracting 32)	Celsius temperature (^{o}C)
Celsius temperature (^{o}C)	1.8 (then add 32)	Fahrenheit temperature (^{o}F)
Gallons per minute (gpm)	60	Gallons per hour (gph)
Gallons per minute (gpm)	1440	Gallons per day (gpd)

WATER QUALITY

The term "water quality" is a generalized expression of the suitability of water for human consumption or food processing. The contaminates in water determine its quality. Hard waters containing calcium and magnesium salts may be clear and free from micro-organisms, but may be objectionable because of the high consumption of soap in washing, the formation of scums and the scaling of boilers and hot water systems. On the other hand, an overly soft water may be corrosive causing rapid deterioration of pipes and appurtenances. An otherwise good quality water may contain objectionable amounts of iron or manganese causing the staining of fixtures, laundry and imparting taste to the water. Water may look perfectly clear but may be contaminated with micro-organisms which renders the water unsafe for human consumption unless properly treated.

The word "pollution" is also a general term implying the fouling of water by sewage or other waste water, rendering it unfit for use as a water supply.

"Contamination or contaminate" implies a specific type of pollution whether it be particulate matter, a chemical in solution, micro-organisms, or radioactive substances. Contaminates which cause illness, death, or adverse physical effects to humans are called "primary contaminates" and the National Primary Drinking Water Regulations specify the maximum allowable concentrations or contaminate levels of these substances. These are described in Chapter 12. Other forms of contaminates tend to render the water aesthetically undesirable, including particulate matter,[1] tionable color, taste, odor, hardness, corrosiveness, etc. These latter contaminates are called "secondary contaminates". Chapter 12 lists many of these secondary contaminates along with recommended limiting

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(1) Turbidity

concentrations. These secondary contaminates are not enforceable under the Federal Act, but individual States may adopt mandatory limits for these contaminates.

"Microbiological contamination" is the fouling of water with potential disease producing organisms. These organisms are not visible with the naked eye. Because it is not practical to test for all of the potential disease organisms which might be present in a water supply, microbiological contaminates usually refers to a group of bacteria called "coliform bacteria". Coliform bacteria are a group of micro-organisms usually associated with the fecal discharges of man and animals, but also occasionally found elsewhere in nature. Their presence in water is considered evidence of serious contamination. Although these organisms are not necessarily pathogenic (capable of causing disease) they are considered presumptive evidence of the possible presence of infectious organisms. Their presence is a danger signal that the water is of questionable quality and/or that the treatment process is inadequate or that contamination has occurred.

"pH" is a measure of the hydrogen ion activity of a water solution, or more simply a measure of whether the water will react as a mild acid or an alkaline solution. The pH scale runs from 0 to 14. A pH of 7.0 is neutral, neither acid nor alkaline. If the pH is less than 7.0, the water is said to be acid, if greater than 7.0 it is alkaline. Since the scale is logarithmic, a difference of one whole unit up or down represents a ten fold change, that is a change from say pH 6.0 to 5.0 means that the water is ten times more acid. pH 8.0 is ten times more alkaline than pH 7.0. The pH of the water is influenced by the minerals or chemicals, including gases, in solution. Carbon dioxide gas in solution tends to make water acid (carbonated water). Limestone minerals tend to make it alkaline on the scale. The pH of water is important from many aspects. It has a significant effect on water treatment processes and on the efficiency of chlorine as a disinfectant. It is related to the corrosion of piping and appurtenances and the deposition of mineral deposits.

While it is convenient to express pH in terms of its reaction as acid or alkaline, the pH is not the same as "alkalinity" or "acidity". The latter terms express the reserve or buffering capacity of water to resist change in pH.

The pH of waters used for human consumption varies over a surprisingly wide range, perhaps as low as 4.0 and as high as 10.0. However, the extremes pose certain problems that can only be evaluated by a water specialist. The pH of a sample of water can often change when exposed to air or temperature changes. Therefore, sampling and testing procedures are very important. The test is made by an electronic meter or colorimeterically using dyes which change color depending on the pH.

"Turbidity" is a measure of the suspended matter(2) in water, such as clay, silt, finely divided organic matter, algae and other micro-organisms when present in large numbers. It is measured by passing a beam of light through a sample in a special tube and measuring optically the scattered and absorbed light. The measuring scale is in turbidity units(3) (NTU). A turbidity of 5 or more units is readily detectable with the naked eye in a glass of water. Turbidity is of significance because of its objectionable appearance (cloudy water) and because it will interfere with disinfection of the wat

"Chemical Units" - The chemicals present in both natural and treated water vary greatly, reflecting the environment through which the water passed and the treatment processes. Many of the substances found in water are present in trace amounts while others are present in comparatively large

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(2) A measure of the clarity of water

(3) Nephelometric Scale (NTU)

amounts. Although a variety of measuring units are used in water supply practice, metric units are used extensively in water quality determinations. On the other hand, water works practice still deals extensively in the English units.

The basic measuring units, parts per million (ppm) and milligrams per liter (mg/l) are used interchangeably, but scientifically speaking they are not exactly the same when concentrations exceed several thousand units. For all practical purposes, they may be used interchangeably. Mg/l is preferred.

Since water weighs 8.34 lbs. per gallon, one million gallons of water will weigh 8.34 million pounds. Therefore for every 8.34 lbs. of a pure chemical substance in one million gallons of water, the concentration of that chemical will be 1 part per million. One second in 11 1/2 days is equivalent to one part per million, so the unit is small indeed.

In a laboratory water is measured in metric units and the basic unit is the liter. The liter contains 1000 milliliters (ml) of water. Likewise, the gram (gr) is the basic weight measure in a water laboratory.

1000 grams = 1 kilogram

1 gram = 1000 milligrams (mg)

1 milligram = 1000 micrograms (ug)

One liter of water weighs 1000 grams. Therefore, one milligram of a pure chemical substance in one liter of water is one part per million parts of water or one milligram per liter (mg/l).

It is not convenient to measure trace amounts of chemicals in parts per million or milligrams per liter as fractions or decimal numbers will result. Therefore, the term parts per billion is often used.

1 part per billion (ppb) = 1 migrogram per liter (ug/l)
(1 second in 32 years is one ppb)

"Microbiological Units" - Biological tests to identify the many specific infectious organisms which may be potentially present in a natural or treated water supply requires considerable laboratory sophistication and is time consuming. Years ago, a relatively simple and less time consuming laboratory procedure was developed to test for the common coliform group of bacteria. The tests for these bacteria are highly perfected, standardized and accepted throughout the nation.

Two basic test methods are used. The older procedure is generally called the fermentation tube method. A series of test tubes with selective liquid growth media are inocculated with standard volumes of test water and incubated at a favorable growth temperature. The presence of coliform bacteria is indicated by gas formation during incubation in one or more tubes. Single tests should be interpreted with caution. However, a series of tests taken at specified intervals over a period of time, are highly reliable indicators of the microbiological quality of a water.

The second test method is called the membrane filter technique. A 100 ml sample of water is filtered through a special filter pad. Coliform bacteria which may be present are strained and trapped. The pad is then placed in a special growth media and incubated at a precise temperature. Individual trapped coliform bacteria grow as a visible colony. By counting the colonies, a measure of the number of coliform present in the water is obtained. This test is relatively faster and simpler than the fermentation tube method.

Both tests are approved for use under standardized procedures set forth in "Standard Methods for the Examination of Water and Waste Water" published by the American Public Health Association. However, the two methods do not necessarily produce interchangeable counts nor can one result be translated to produce an equivalent count in the other method. The Primary Drinking Water Regulations define maximum microbiological contaminate levels based upon the use of either test. Chapter 12 lists these levels.

CHAPTER 2

PLANNING, SANITARY SURVEY AND DESIGN CONSIDERATIONS

INTRODUCTION

The public has an expectation that a public water supply will be safe and adequate at all times and the purveyor has the responsibility of meeting that expectation. The potential for wide spread harm from a contaminated water system is always present. The risks will be reduced considerably by careful planning, design, and construction. A poorly planned system increases the potential for unsafe water, interruptions, and poor service and complaints are likely to follow.

This chapter discusses the steps necessary for the proper design of a new water system. These steps will also be useful when considering enlargement or expansion of an existing system. They will also be helpful in evaluating and comparing an existing water system with accepted design and construction standards. The steps include (1) the early planning considerations which are necessary prior to the design phase, (2) the sanitary survey of the potential water sources to determine the safety of the supply and water treatement requirements, (3) engineering design elements of the water system components, and (4) submission of plans to the State regulatory agency for review and approval prior to construction of the system. References are made to specific chapters in the Manual for additional details.

The chapters that follow discuss the design criteria for the various system components.

PLANNING ELEMENTS

Prior to the design of a water system, it is prudent to consider the present and long range objectives and the alternate ways of accomplishing those objectives. Costs are of course an integral part of the process and costs will most likely be a factor in the decision making process. However, cost economies which significantly reduce reliability or trade-offs which sacrifice good sanitary protection for reduced costs, are ill advised. Since a good portion of the system will be buried in the ground, quality materials and workmanship will avoid costly repairs or replacements in the future.

Some of the early planning considerations are discussed below:

1. Effective planning requires both near and long range considerations. Much of the water system will be below ground and future unanticipated changes and enlargements will be expensive. Therefore, the planning phase should consider future projections for growth and future increases in per capita or other base water consumption. With these projections, decisions can be made on how much future capacity should be built into the system during the initial construction phase and how much should be planned for future construction.

2. An early decision must be reached on the desirability of fire protection, as fire flows will dictate the sizing of most of the system components in a small system. Local fire underwriters will assist in making this decision. State laws require water for fire protection for certain types of public places and institutions. Consult local building codes for specific requirements. Chapter 3 provides some guidelines.

3. Where there is a water system, there may be a need for waste water disposal. The two systems must be properly separated as there is an inter-relation between them which must be kept under continual

control. Water lines and waste water systems operate essentially side by side, but must be kept separated to avoid contamination of the water system. Cross-connections must be avoided (see Chapter 15) and the buried water and sewer pipes must have proper separation (see Chapter 11). If the water purveyor also has responsibility for the design and operation of the waste disposal facilities, the appropriate State agency should be consulted for detailed requirements.

4. Investigate all possibilities for a connection with an existing approved public water system as opposed to developing a new source of water. The existing system must have sufficient capacity to meet the additional demands, including future growth. Booster pumps and reservoirs may be necessary where pressure differences are a problem. State agencies are usually quite receptive to the extension of approved existing systems. Also consider the possibility of a future connection to an existing approved system. As systems grow, it may be mutually desirable to consolidate into a single system.

5. Determine the water quantity requirements of the system. See Chapter 3 and Table 3-1 for some guidelines. Obtain additional data based upon local experience at similar establishments. Include all special water needs. Determine the following:

- Per capita or other unit daily needs
- Fire protection needs if appropriate
- Special needs such as lawn watering, cooling water, process water, etc.
- Project future requirements
- Determine the average daily, and maximum daily demands.
- Determine the maximum hourly and instantaneous peak demands

6. Determine possible alternative sources of water, evaluating availability, quantity, quality, engineering aspects, costs, etc. See Chapter 4 for guidance.

- First, consider possible connection to an existing approved public water system.
- Wells or springs or other ground water sources are good second choices.
- Surface water sources will require special considerations and should not be attempted without prior consultation with the State agency.

7. After evaluation of possible alternative sources, select the most appropriate for detailed sanitary survey, exploration and design using the water demand criteria to determine the required capacities.

SANITARY SURVEY OF POTENTIAL WELL AND SPRING SITES

Ground waters are by far the most appropriate source of water for small public systems. The advantages and design criteria for well water supplies are described in some detail in Chapters 4 and 5. Spring supplies are also used occasionally (see Chapter 7). Surface waters are a poor third choice and should not be used if a ground water of satisfactory quality is available. In any case, a sanitary survey of the potential sites for wells, springs and surface sources is necessary to insure that the supply can be properly protected from contamination. The State agency will provide "Sanitary Survey" forms to assist in identifying and recording data. In the absence of these forms, at least the following information should be obtained and recorded to assist in the site selection.

1. Consult well drillers, water engineers and others to determine the best well locations in the vicinity, based upon local experience and keeping in mind the convenience of the sites.

2. Determine the availability of the land. Sufficient land must be purchased or controlled to insure protection from future adjoining land use activities.

See Chapter 5 for some of the controlling factors. The water purveyor should obtain control over all land within at least 100 feet of the well. Fencing may be advisable.

3. Determine the proximity to nearby sewers, sewage and waste disposal facilities, animal pasturing and agricultural land which is under treatment with agricultural chemicals. Other potential sources of contamination should be assessed, including road salt, petroleum, and other chemical storage areas. Record data on a site plan or a survey form.

4. Determine potential for flooding and whether within 100 year flood level, available through the local National Flood Insurance Program.(1) determine direction of flow of surface run-off. Prepare basic contour map of site. USGS maps will be helpful.

5. Determine character of local geology, depth and types of soil overburden above rock and types of rock formations. Estimate probable depth to the ground water table. Well drilling records of nearby wells may prove helpful.

6. Determine probable characteristics of the ground water formations (aquifers), artesian characteristics, direction of ground water movement, etc.

7. Study nearby wells to determine quality of water, casing depth, well drawdown and yield. (See Chapter 5).

8. Limestone and similar rock formations may carry pollution great distances from the source of the pollution. Extreme care is advisable in selecting sites in these aquifers.

After compiling and evaluating the information gathered from the sanitary survey, select the site(s) which provide the best sanitary protection and offer the best opportunity for developing an adequate source of water. Test wells may be advisable to verify conditions. Chapter 5 offers criteria for the construction and development of wells. For more detailed

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(1) This information is usually available at the local government level and also at the State agency designated to assist in the administration of flood plain program.

information, the Manual of Water Well Construction Practices, EPA-570/9-75-001 (1976) may be obtained from the U.S. Government Printing Office, Washington, D.C. 20402 for a nominal charge. The manual also provides valuable information on well drilling contract documents.

SANITARY SURVEY OF POTENTIAL SURFACE WATER SUPPLIES[2]

A sanitary survey of potential surface water sources is necessary to identify and assess potential sources of pollution, assess the water quality and determine the required degree of treatment. The State regulating agency must be consulted.

1. Determine water rights and impact of taking water from watershed. Consult with the appropriate State or other agency involved with surface water rights.

2. Determine the safe yield at minimum flow conditions and compare with water use requirements.

3. Assess the character and use of upstream land in the watershed. Determine the nature and extent of all potential pollution hazards.

   - Assess agricultural, forestry, and recreation practices.
   - Identify and assess impact of sewage disposal systems.
   - Identify and assess industrial waste, mine,oil field, and solid waste disposal drainage.

4. Determine quality of the surface water over an extended period of time including low and high flow conditions. Assess impact of high flood run-off. This should include laboratory tests for turbidity, color, coliform bacteria, algae, minerals, pH, toxic contaminates and taste and odor producing substances.

5. Determine the most appropriate location and depth of the intake, taking into account seasonal water level variations, wind drift, debris accumulation, freezing and ice cover.

(2) Also see Chapter 8

WATER SYSTEM DESIGN ELEMENTS

After selecting the source of water (wells, springs or surface supplies) based upon the sanitary survey assessment and other factors, the design phase will follow. Listed below are the basic design elements. Chapter 3 provides guideline criteria for the Design Capacity of System Components. The following elements should be considered in the design.

Well Systems (See Chapters 5 and 6)

1. Select the most appropriate well site based upon the sanitary survey and other factors. Determine amount of land necessary to provide present and future protection and land for future wells if necessary.

2. Determine most appropriate well design features including: Type of well, drilling techniques, size and depth of casing, grouting requirements, well cap arrangement, screens if necessary, and other features. Keep an accurate log of the drilling process.

3. Develop the well, determine the drawdown at various yields and select the optimum yield (Chapter 5).

4. Compare the well yield with water demand requirements (Chapter 6) and determine the number of wells required to meet the demand. At least two wells are recommended to insure continuity of service if one well becomes inoperative.

5. Sample and test the water to determine the chemical, physical and bacteriological quality of the water. Determine the required treatment, if any. Consider chlorine disinfection as an added safety factor even if the State agency does not require it.

6. Determine the well pump details based upon the well yield and the system water demands and pressure requirements. Determine whether gravity storage or pressure pneumatic storage system is most appropriate (see Chapter 6). Consult with the electric company for electric service, line voltages, phasing, etc.

7. Design pumphouse, where applicable. Include adequate space for pressure storage tanks, treatment and conditioning equipment, electrical controls, sanitary protection, protection from freezing, ease of maintenance,floor drains, etc.

Spring Supply Systems (Chapter 7)

1. If the sanitary survey of the spring site proves satisfactory, determine the amount of land necessary to insure present and future protection. Fencing should be considered as should drainage diversion where necessary.

2. Determine the spring yield, including effect of seasonal and annual variations in the yield. If the yield is adequate to meet water demands, design the spring collection chamber to provide adequate protection and to capture as much of the yield as possible. Design the spring storage tank as part of the collection chamber or as a separate structure. Provide at least one days storage based on the average daily demand.

3. Sample and test the quality of the water as in Item 5 under Well Systems and determine the required treatment if any.

Surface Water Systems Including Infiltration Galleries (Chapter 8)

1. If the sanitary survey and other factors are satisfactory,determine the safe yield and the need for impoundments if any. Compare the safe yield with water demand requirements.

2. Obtain the necessary water rights and establish the measures necessary to protect the watershed from contamination.

3. Sample and test the quality of the water as in Item 5 under Well Systems. Determine the required treatment.

4. Design the impoundment (if needed) and the intake structure. Consult with the appropriate authorities before constructing a dam.

5. Design the treatment units. Continuous chlorination will be required as well as other treatment, depending upon the quality of the surface water.

6. Design the gravity storage or hydropneumatic system (Chapter 6).

Distribution System and Building Piping (Chapter 11)

1. Determine the water demands in the various parts of the system including pressure requirements.

2. Design the distribution system including type of pipes, sizes, valving and other appurtenances taking into account the above Item 1.

3. Design the various building or water use area piping systems.

Submitting Plans To The State Agency

1. Consult with the State agency early in the planning phase. Obtain special design criteria, applications, procedures, etc.

2. Submit preliminary engineering report for early review and comment. Submit required applications.

3. Submit detailed plans and specifications for approval. Include disinfection procedures for wells, springs, tanks, pumps, piping and appurtenances. Disinfection procedures are discussed in Chapters 5, 6, 7, 8 and 11 for wells, well pump systems, springs, surface water supplies and the distribution system, respectively.

During Construction

1. Construction should be in general conformance with plans and specifications. Significant deviations must have prior approval of the State agency.

2. Prepare "as built" plans for future reference. Underground facilities should be clearly referenced in relation to permanent landmarks, curbs, buildings, sidewalks, etc.

3. Disinfect all parts of the system. Advise the State agency of the time of disinfection as they may wish to observe the procedures. Do not use any part of the system until samples have been collected and tested for coliform bacteria to verify the adequacy of disinfection and treatment.

4) Establish procedures for:

- Operation and Maintenance - Chapter 13
- Sampling, Testing and Reporting - Chapter 13
- Record Keeping and Reporting - Chapter 14

CHAPTER 3

DESIGN CAPACITY OF SYSTEM COMPONENTS	Water Demands - Design Capacity of Well, Spring and Surface Water Systems - Storage - Distribution Systems and Building Piping

INTRODUCTION

A key factor in the planning and design of a water system is an accurate estimate of the quantities of water which must be supplied to meet water needs. These estimates are pivotal to the entire design including the production of water, pumping, treatment, storage, and the distribution system. Each water system component is designed to meet certain water flow requirements, all designed to insure that water will be available at the various water use points throughout the system in adequate quantities to meet demands. Over design may result in increased initial costs but under design will result in inadequate service and potential health hazards, and increased costs to correct the condition. On the whole, it is better to design for the high side of water demands than to under design.

The purpose of this Chapter is to provide guidance in estimating water demands and to provide an overall perspective for the design criteria of the various system components, based upon these estimates. The design of system components are also more fully developed in the chapters that follow, as referenced.

Insofar as possible, guidelines which have broad acceptance throughout the nation are presented. However, the great variety of small water supply types makes it impractical to include a full range of water consumption and water demand data, even if complete reliable data were available, which is not the case. Water consumption varies quite significantly throughout the country depending upon the use of water meters, economic conditions, temperature, precipitation and lawn watering practices, fire protection requirements and other factors. Therefore it will be prudent to seek local experience and requirements with similar types and sizes of water systems and to use that information in making final judgments. The State regulating agency is a good source of information on water demands and local requirements and should be consulted early in the design.

ESTIMATING BASIC WATER DEMANDS

The various components of a water system are designed to meet specific water flow criteria which are dependent upon the type of water system and the objectives of the system. Some of the more useful terms follow:

Average Daily Demand

The average daily demand is a term used to express the quantity of water used in a system in an average day. It is based upon experience from water meter readings in similar water systems over an extended period of time and reflects the normal seasonal and daily variations. For design purposes, it is usually determined by estimating the population or units of housing or other units and multiplying by an average per person or per unit water consumption derived from past experience. Other water demand terms frequently relate to this basic term. The average daily demand will be exceeded on many days so it is not appropriate to design merely for the average. For this reason other terms are used to express the probable greatest amount of water which may be used in one day, or other period of time.

Table 3-1 provides a guide for estimating the average daily demand for various types of establishments, in gallons per day per unit. The unit is persons per day unless otherwise indicated. The values shown may vary throughout the nation and the reader is advised to review local information on water systems serving similar size establishments. The State agency will provide additional guidance.

Note: Metric and English Conversions

1 gallon = 0.003785 cubic meters = 3.79 liters
1 cubic meter (1000 liters) = 264.2 gallons

Table 3-1: Guide for Estimating Average Daily Water Requirements (Adapted from various sources for small water systems)

Type of Establishment (The unit is per person unless otherwise stated)	Average Daily Use (gpd)
Airport (per passenger)	3-5
Assembly Halls (per seat)	2
Camps - Children, overnite, central facilities	40-50
- Construction	50
- Migrant Labor	35-50
- Day type, no meals served	15
Churches (per member)	1
Cottages, season occupancy	50
Clubs - Residential	100
- Non residential	25
Factories, sanitary uses, per shift	15-35
Food Service - Restaurants	7-10
- With bars	9-12
- Fast food	2
Highway Rest Areas	5
Hotels (2 persons per room)	60
Institutions - Hospitals (per bed)	250-400
- Nursing Homes (per bed)	150-200
- Others	75-125
Office Buildings	15-30
Laundries, self service (per customer)	50
Motels (per bed)	60
Parks - Day use (with flush toilets)	5
- Mobile Homes (per unit)	200
- Travel trailers (per unit)	90-100
Picnic Areas (with flush toilets)	5-10
Residential Communities	
- Multi-family (per bedroom)	120
- Rooming house and tourist homes type (per bedroom)	120
- Single family type (per house)	400
Resort Motels and Hotels	75-100
Retail Stores (per toilet room)	400

Table 3-1: (Continued)

Type of Establishment (The unit is per person unless otherwise stated)	Average Daily Use (gpd)
Schools - Day, no showers or cafeteria	15
- Day, with cafeteria	20
- Day, with showers and cafeteria	25
- Residential types	75-100
Shopping Centers, per sq. ft. sales area	0.16
Swimming Pools and Beaches	10
Theaters - Drive-in (per car)	3-5
- Others (per seat)	3

Note: The values listed in Table 3-1 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.

Maximum Daily Demand

The maximum daily demand is the greatest amount of water that a system will use in one day. Experience with small residential water systems suggests that the maximum day is 1.5 to 2 times the average day. However, this ratio may not apply to other types of water systems. In general, the smaller the water system, the greater the variation between the average and the maximum day.

Maximum Hourly Demand

The maximum hourly demand is the greatest amount of water which will be used in any hour during a day. It is sometimes referred to as the peak hour demand although there will be short term peak demand rates lasting for several minutes which will exceed the maximum hourly demand rate. Each type of system exhibits its own maximum hourly and short term peak demands and the hours of peak occurrence will vary. As an example, shopping centers usually experience hourly peaks in the early afternoon while residential communities may experience two peak hours, about 8:00 a.m. and 6:00 p.m. The maximum hourly demand is often expressed as a ratio of the average daily demand, in gallons per minute.[1] Generally speaking, the smaller the system, the greater the maximum hour rate in respect to the average daily rate.

Peak Demand

The peak (instantaneous) demand is the maximum amount of water necessary to meet the peak short term demand rate which may occur several times during a day, but usually during the peak hour period. The instantaneous peak may last for several minutes. The rate is particularly important in considering the sizing of the storage tank in a hydropneumatic system (See Chapter 6, Section on Hydropneumatic Systems). The effective storage capacity is usually designed to meet these short term peaks. In the absence of sufficient effective storage to meet extended peak demands, the wells and pumps must be capable of meeting the peak demands. The smaller the system, the greater the ratio of the peak demand to the average demand.

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(1) Experience with small residential communities suggests that the peak hourly demand may range from about 6 to over 10 times the average daily demand.

Estimating Peak Demand Based Upon Water Fixture Values

The peak demand load of a system is best determined by actual experience with similar systems of comparable size. Even so, considerable judgment must be used in applying the data to another system. If comparable data is not available, the fixture demand method may be used. The most common methods are based on the method described in the Plumbing Manual Report BMS-66 published by the National Bureau of Standards. The American Water Works Association has modified this method to provide an adjustment to reflect the effect of delivery pressure on the demand load of fixtures. This method is presented below with the permission of the American Water Works Association. The full text may be found in the AWWA Manual M22, Sizing Water Service Lines and Meters, 6666 Quincy Avenue, Denver, Colorado, 80235.

The fixture demand method of estimating the peak water demand includes a listing of commonly used water fixtures for which a fixture value has been assigned which reflects its demand producing effects, See Table 3-2. The total number of each type of fixture to be used is determined and this total is multiplied by the assigned value of the fixture. The various fixture value totals are then summed up to obtain the combined value of all fixtures. This combined value is applied to a graph (Figure 3-1 or 3-2) and the probable system demand in gallons per minute is determined. An adjustment may be made for the delivery pressure (Table 3-3) and the adjusted peak demand is thus determined.

The fixture values listed in Table 3-2 represent the flow demand of each fixture when operated with no other fixture in use and at a delivery pressure of 35 psi. As an example, a bathtub is assigned a fixture value of 8 because it will normally deliver 8 gpm at a delivery pressure of 35 psi. If a desired fixture is not listed, an estimate of its fixture value may be obtained by measuring its delivery rate at 35 psi.

The curves shown in Figures 3-1 and 3-2 compensate for the probability that as the number of fixtures increase, the relative number of fixtures which will be operating at one time will diminish. Figure 3-1 is best used for low range combined fixture values which add up to 1300 or less while Figure 3-2 may be used for combined fixtures values up to 13,000.

The fixture values shown in Table 3-2 are based upon a water delivery pressure of 35 psi. Table 3-3 lists the multiplication factors used to adjust the demand load obtained from Figure 3-1 or 3-2 for various other delivery pressures.

Table 3-2: Plumbing Fixture Values

Fixture Type	Fixture Value Based on 35 psi Operating Pressure
Bathtub	8
Bedpan washers	10
Combination sink and tray	3
Dental unit	1
Dental lavatory	2
Drinking fountain (cooler)	1
Drinking fountain (public)	2
Kitchen sink: 1/2-in. connection	3
3/4-in. connection	7
Lavatory: 3/8-in. connection	2
1/2-in. connection	4
Laundry tray: 1/2-in. connection	3
3/4-in. connection	7
Shower head (shower only)	4
Service sink: 1/2-in. connection	3
3/4-in. connection	7
Urinal: Pedestal flush valve	35
Wall or stall	12
Trough (2-ft. unit)	2
Wash sink (each set of faucets)	4
Water closet: Flush valve	35
Tank type	3
Dishwasher: o/2-in. connection	4
3/4-in. connection	10
Washing machine: 1/2-in. connection	5
3/4-in. connection	12
1-in. connection	25
Hose connections (wash down): 1/2-in.	6
3/4-in.	10
Hose (50-ft. length-wash down): 1/2-in.	6
5/8-in.	9
3/4-in.	12

Table 3-3: Multiplication Factors to Adjust Demand Load to Various Water Delivery Pressures

Design Pressure psi	Factor
20	0.74
30	0.92
35 Base	1.00
40	1.07
50	1.22
60	1.34
70	1.46
80	1.57
90	1.68
100	1.78

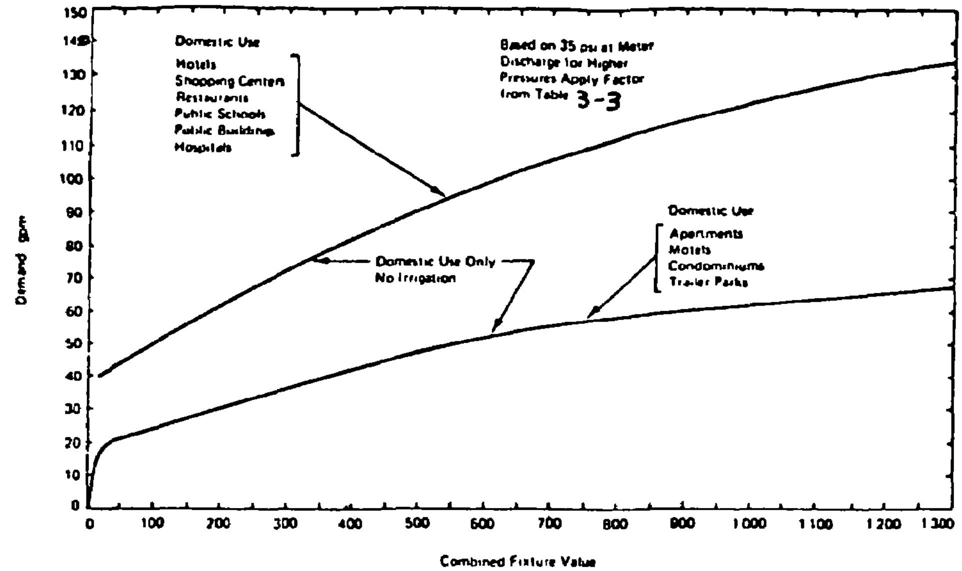


Fig. 3-1 Water-Flow Demand per Fixture Value—Low Range

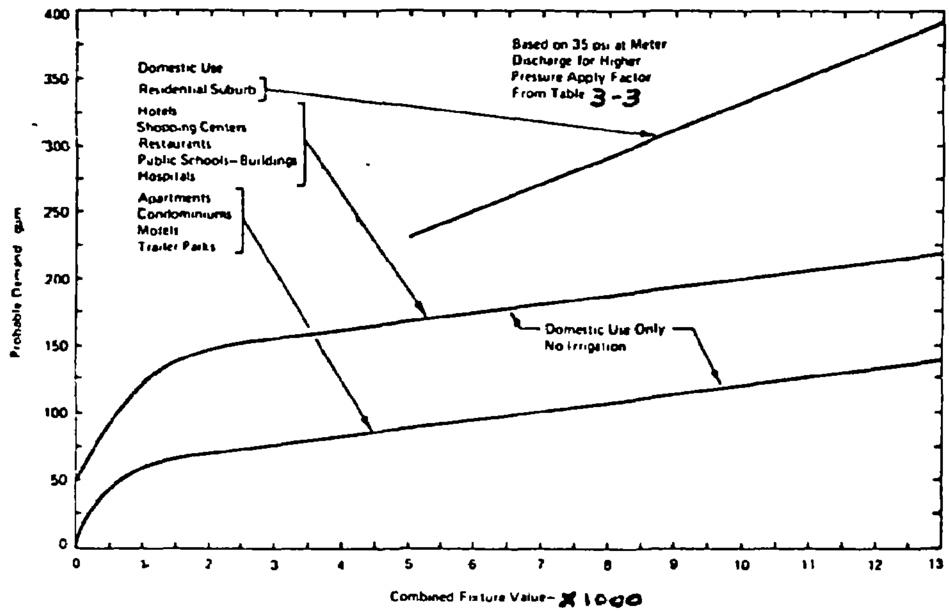


Fig 3-2 Water-Flow Demand per Fixture Value—High Range

Table 3-2 and 3-3 and the above graphs are reprinted by permission of the American Water Works Association from Manual M-22, Copyrighted 1975, 6666 West Quincy Avenue, Denver, Colorado, 80235.

An example showing the method of using the tables and curves follows:

Example: Assume a 40 unit motel with a small coffee shop and small swimming pool. Water pressure assumed at 40 psi. Air conditioners are air cooled and require no water.

DATA TABULATION

Fixture	Fixture Value at 35 psi (Table 3-2)	No. of Fixtures in Use	Total Fixture Value
Water closets, tank	3	47	141
Urinals, wall	12	2	24
Lavatory: 3/8-in. connection	2	40	80
Lavatory: 1/2-in. connection	4	4	16
Bathtubs	8	40	320
Drinking Fountains	2	1	2
Kitchen sink, 3/4-in.	7	1	7
Dishwasher, 3/4-in.	10	1	10
Wash sink	4	1	4
Hose, 50 ft., 5/8-in.	9	3	27
Swimming pool	15 (estimated)	1	15
Service sink: 1/2-in.	3	1	3
			649

Combined Fixture Value - 649

From Figure 3-1, probably peak demand based on 35 psi = 55 gpm

From Table 3-3, adjusted multiplication factor for 40 psi delivery pressure = 1.07

Adjusted (probably) peak demand = 55 x 1.07 = 59 gpm

Demand loads for lawn sprinkling systems or other special uses must be added as appropriate.

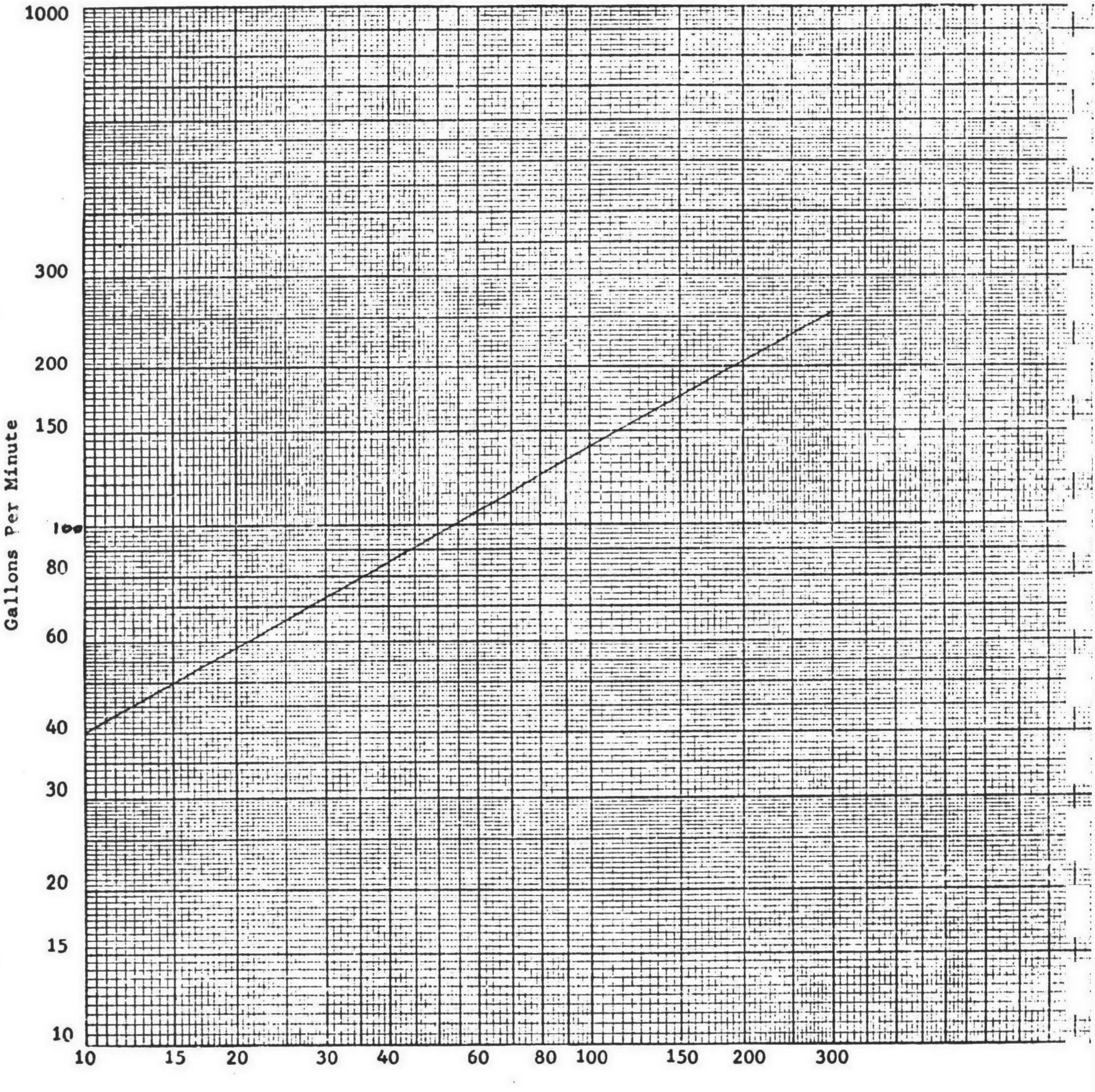
Peak Demand for Residential Communities and Mobile Home Parks

Figures 3-3 and 3-4, which follow, are curves developed from experience showing the instantaneous (peak) demands for various sizes of typical residential communities and mobile home parks.

FIGURE 3-3

INSTANTANEOUS DEMAND FOR RESIDENTIAL COMMUNITY WATER SYSTEMS

(Number of Connections vs Gallons Per Minute)

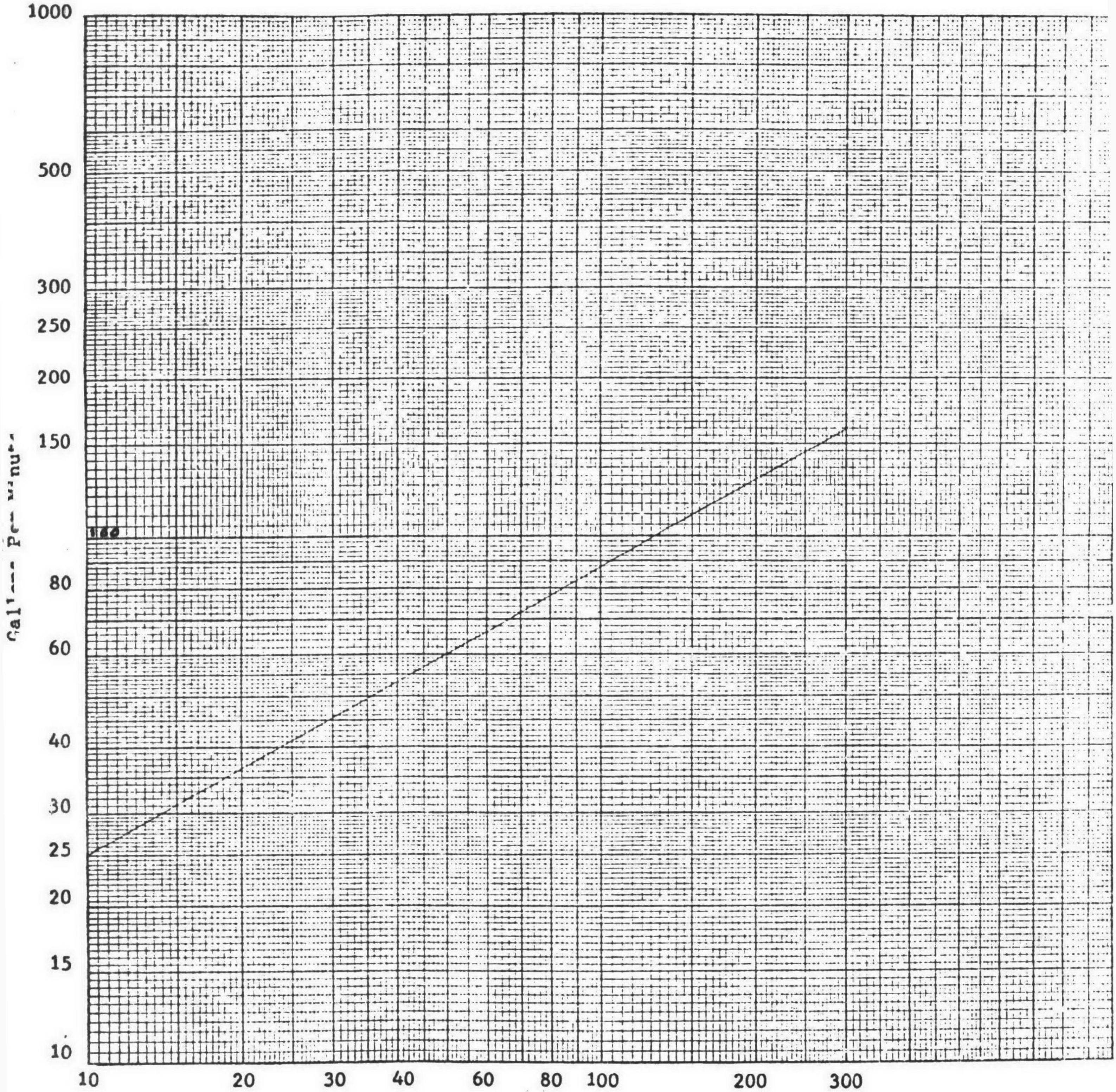


Source: Standards and Criteria for Design and Construction of Public Water Supply Systems to Serve Residential Communities: Division of Health Services - Sanitary Eng. Section, State of North Carolina, 1974

FIGURE 3-4

PEAK DEMAND FOR MOBILE HOME PARK WATER SYSTEMS

(Number of Connections vs Gallons Per Minute)



Number of Connections

Source: Standards and Criteria for Design and Construction of Public Water Supply Systems to Serve Residential Communities; Divsion of Health Services-Sanitary Engineering Section, State Of North Carolina, 1974

Fire Flow

Fire flow is the amount of water capacity which must be designed into a water system for fire fighting purposes. Fire flow is not included in the definition of average daily and maximum daily demands and must be added if fire protection is desired. Fire flows are usually expressed as gallons per minute to fight a fire of a certain duration. Local fire underwriters will provide specific requirements on request.

Water Meters

Experience has proven the value of master water meters and consumer water meters (where appropriate) for monitoring water use and demands, assessing leakage and as a means of encouraging thrift and reducing waste. Meters should be considered where appropriate, especially where the water is available in limited quantities.

ESTIMATING THE REQUIRED CAPACITY OF WELLS (Refer to Chapters 5 and 6 for design details)

It is recommended that there be a minimum of two wells with sufficient capacity in each well to insure continuity of service if one well is out of service. Wells should not be designed for pumping in excess of safe yields.

Wells With Gravity Storage and Distribution

Wells pumped to a gravity storage system with a capacity of at least one average day storage are designed on the basis of the maximum daily demand or greater. With the largest well out of service, the other(s) must be capable of meeting the average daily demand. Furthermore, it is undesirable to pump wells for a full 24 hour period without an opportunity for the wells to recover. Also the water demand is seldom exerted evenly over a full 24 hour day. Factories for instance may use essentially the full demand in an 8 hour shift. Residential systems exert essentially all of the demand in 16-18 hours. Allowances should be made for this factor.

Wells With Hydropneumatic Systems

Since pressure tank systems have limited effective storage capacity, only barely enough to meet short term instantaneous peaks, the wells and pumps must be capable of meeting maximum hourly demands and in addition, the longer peak demands which cannot be met with the pressure tank storage. Some small systems serving facilities such as highway food service or rest areas, and the end of factory shifts, may experience peaks of rather long duration which cannot be met by the limited effective storage in a pressure tank. These will require special consideration (second well cut-in) to meet needs. If the effective capacity of a storage tank cannot be counted upon to supplement the pump capacity to meet extended peak demands, the wells and pumps must be designed to meet the prevailing peak conditions.

Fire Protection

An extra allowance must be added if fire flow protection is desired. In gravity systems, this allowance is added to the storage reservoir and distribution system design. With hydropneumatic systems, it must be added directly to well(s) and pump capacity.

ESTIMATING THE REQUIRED CAPACITY OF SURFACE SUPPLIES
(Refer to Chapter 8 for design details)

Surface water supplies generally produce water of varying and questionable quality and are often difficult to protect. Furthermore, the required treatment is usually more complex and costly. State authorities must be consulted before undertaking a surface water source.

Stream run-off or flow is usually severely affected by varying rain and snow fall and the seasons of the year. If no impoundment is available, the minimum stream flow which may be experienced is the maximum safe yield, assuming that the water purveyor has the legal authority to remove all available water. If this safe yield is equal to at least the maximum day needs, an impoundment (reservoir) may not be needed. Otherwise, it will be necessary to provide an impoundment by damming the stream. Unless the amount of water to be withdrawn is small in comparison to the size of the impoundment and stream flows, a detailed analysis is necessary to determine the necessary impoundment capacity and an experienced engineer should be consulted. The appropriate State agency must be consulted before damming a stream.

If pumps are used to draw water from the source, the pumps must be capable of meeting the maximum day demands. Two pumps are recommended. With the larger pump out of service, the second pump should meet at least average day conditions. Gravity storage reservoirs are designed for at least one day storage at the average daily demand.

If a pressure tank system is to be used, the pumps must meet at least the maximum hourly conditions and in addition, the extended peak demand which cannot be met by the effective storage capacity in the pressure tank.

Infiltration galleries constructed along stream or lake shores will exhibit a safe yield similar to a well and the required capacity is similar to that of well design.

ESTIMATING REQUIRED CAPACITY OF SPRINGS (See Chapter 7 for design details)

The yield of a spring varies somewhat during seasons but much less so than surface streams. The safe yield must be determined before development. Unless information on the yield is available for extended periods, the safe yield should be estimated conservatively to compensate for reduced flows during dry periods. Springs may "dry up" during extended dry spells. Observation or experience over long periods is advisable.

Since the flow of springs is more or less constant over a 24 hour period, the average daily yield should be at least equal to the maximum day demand of the system. The spring collection chamber or separate storage tanks (if used) should have an effective capacity equal to at least the average daily demand.

SYSTEM PRESSURES

Minimum pressures in the distribution systems and at service connections should not be less than 20 psi during peak flow periods. Minimum working pressure should be 35 psi, but preferrably from 40 to 60 psi. Pressures should generally not exceed 100 psi. Pressure reducing valves may be used where necessary.

SIZING TREATMENT UNITS

Treatment units which must treat the entire water demand are sized to meet the prevailing flow conditions at the point of treatment. In hydropneumatic systems, they must be designed to meet the pump capacities.

When treatment units precede gravity reservoirs, they are usually designed for the maximum daily demand. Water conditioners which treat only part of the water (such as softeners) are designed specifically for the portion of water to be conditioned.

SIZING OF DISTRIBUTION SYSTEM

Storage reservoirs generally float on the system and are served by a single inlet and outlet but may have separate inlet and outlet. The outlet must be sized to meet the peak demand in smaller systems. If fire protection is provided, the pipe is sized to meet the maximum hourly demand or the coincident draft (maximum day plus fireflow) whichever is greater.

The distribution pipes are usually designed for the peak demands experienced by that portion of the system supplied by the pipe(s), except where it also serves as a fire system. In that case, the pipes are designed for the coincident draft (maximum day plus fire flow). An extra allowance must be made for any continuous special demands (lawn watering, etc.) tributary to the pipe(s).

SIZING OF BUILDING PIPES

These pipes are sized to meet the peak load required to serve individual or combinations of fixtures tributary to each pipe plus special uses such as air conditioners, lawn sprinklers, etc. Consult State or local plumbing codes for local requirements on building pipe sizing.

CHAPTER 4

SOURCES OF WATER	Ground Waters - Surface Waters

INTRODUCTION

The two principal sources of water supplies are surface waters and underground waters. Both originate from rain and snow. Some of the precipitation collects on the surface of the earth to form the streams, lakes and other surface waters. Some seeps downward through the earth where it accumulates in the pore spaces in the soils which overlay the rock formations. The seepage continues downward and laterally to fill the interconnecting joints, cracks, solution channels, pore spaces and other openings in the rock formations below. The ground water is not static and tends to move slowly through the substrata, some of it reappearing at the edge of streams and lakes or as springs and seepage areas. Energy from the sun evaporates water from the earth, streams, lakes and seas and promotes transpiration of moisture from growing plants to form water vapor in the atmosphere. Water vapor forms into clouds which in turn produces rain and snow to replenish the surface and ground waters. This continuous process is called the water cycle.

Ground waters are by far the most important source of water for small water supply systems. Unlike surface waters, water stored in underground reservoirs generally has a more consistent good quality, having undergone considerable natural purification through straining and prolonged storage. Furthermore, ground waters are readily available in most areas of the country in sufficient quantities to meet the needs of small water systems. Ground waters generally require little (if any) treatment prior to use, whereas surface waters invariably require rather sophisticated treatment. Therefore ground water is the preferred source unless some unusual circumstances show that a surface supply is preferrable in a particular case. Springs are ground waters which outcrop at the ground surface and are often satisfactory sources of water supply when properly developed.

This chapter discusses the nature of ground water and surface water and is followed by chapters on the construction and development of well, spring and surface water supplies.

GROUND WATER-BEARING FORMATIONS

There are two basic types of ground water-bearing formations, collectively known as aquifers: (1) unconsolidated deposits of soil including sand, gravel, silt and clay, and (2) consolidated formations of rock.

Unconsolidated Formations

Soils overlay much of the earth's rock crust at varying depths from no cover to several hundreds of feet. The soils were deposited through glacial action, alluvial outwashes and deposition in streams, lakes and seas. Soils are classified according to grain size ranging from coarse gravel, sand, silt and clay. Since the origin of soils varied in time (as did the transporting water conditions), deposits generally include alternating layers of material of varying size and grading. Sands and gravels with generous pore spaces between particles are by far the most important water bearing soils particularly where uniform sorted deposits occur in areas with good water recharge. On the other hand, mixed soils containing silts and clays are generally quite impervious to the movement of water and are poor aquifers. Silts and clays play an important role in confining the movement of ground waters and in protecting ground waters from contamination.

Consolidated Formations

The rocks that form the crust of the earth are divided into 3 classes: Igneous rocks are derived from the hot magma deep in the earth and includes granite, basalt and associated fragmental volcanic materials. Sedimentary rocks are formed by the deposition of minerals and rock fragments by water, ice or wind with subsequent compression into hardened material. Deposits of gravel, sand, silt and clay harden into rock conglomerate, sandstone, siltstone and shale, respectively. Limestone, gypsum and salt are also included. Metamorphic rocks are derived from both igneous and sedimentary rocks through great alterations of heat and pressure at great depths. They include gneiss, schist, quartzite, slate and marble.

Below a certain level in the ground, all interconnecting pores and openings in the soil and the underlying rock are filled with water. This level is called the "water table" and the soil and rock below it is called the zone of saturation. Although the pores, spaces and openings are usually individually small, collectively the total amount of water stored in the aquifers is large. The most productive aquifers are deposits of clean, coarse sand and gravel; coarse, porous sandstones; cavernous limestones; and broken lava rock. Some limestones, however, are very dense and unproductive. Most of the igneous and metamorphic rocks are hard, dense, and of low permeability. They generally yield small quantities of water. Among the most unproductive formations are the silts and clays. The openings in these materials are too small to yield water, and the formations are structurally too incoherent to maintain large opening under pressure.

If the upper surface of the ground water table is free to rise and fall with seasonal changes in recharge and the water is not confined and is free to flow, the water surface will slope more or less in the direction of the overall prevailing ground surface direction. A well sunk into this aquifer is called a water table well. If the water bearing stratum dips beneath an impervious layer, the water flow becomes confined under pressure as in a pipe. When that aquifer is tapped by a well, the water will rise in the well casing. This is called an artesian aquifer. If the water rises in the well casing so that it overflows, it is called a flowing artesian well. (See Figure 4-1)

The proper development of a ground water source requires careful consideration of the hydrological and geological conditions of the area. In order to take full advantage of the best possible available information and knowledge, it is advisable to seek the assistance of a qualified ground water engineer, ground water geologist, hydrologist, or contractor familiar with the construction of wells in the area. It is advisable to rely on facts and experience, rather than instinct or intuition. Facts on the geology and hydrology of an area are often available in publications of the U.S. Geological Survey or counterpart State agencies.

Sanitary Quality

When water seeps downward through overlying material to the water table, particles in suspension (including micro-organisms) may be removed. The extent of removal depends on the thickness and character of the overlying material. Clay soils provide effective natural protection of ground water. Silt and sand also provide good filtration, if fine enough, and in thick enough layers. The bacterial quality of the water also improves during storage in the aquifer because storage conditions are usually unfavorable for bacterial survival. Nevertheless, clarity alone does not guarantee that ground water is safe to drink as this can only be determined by laboratory testing.

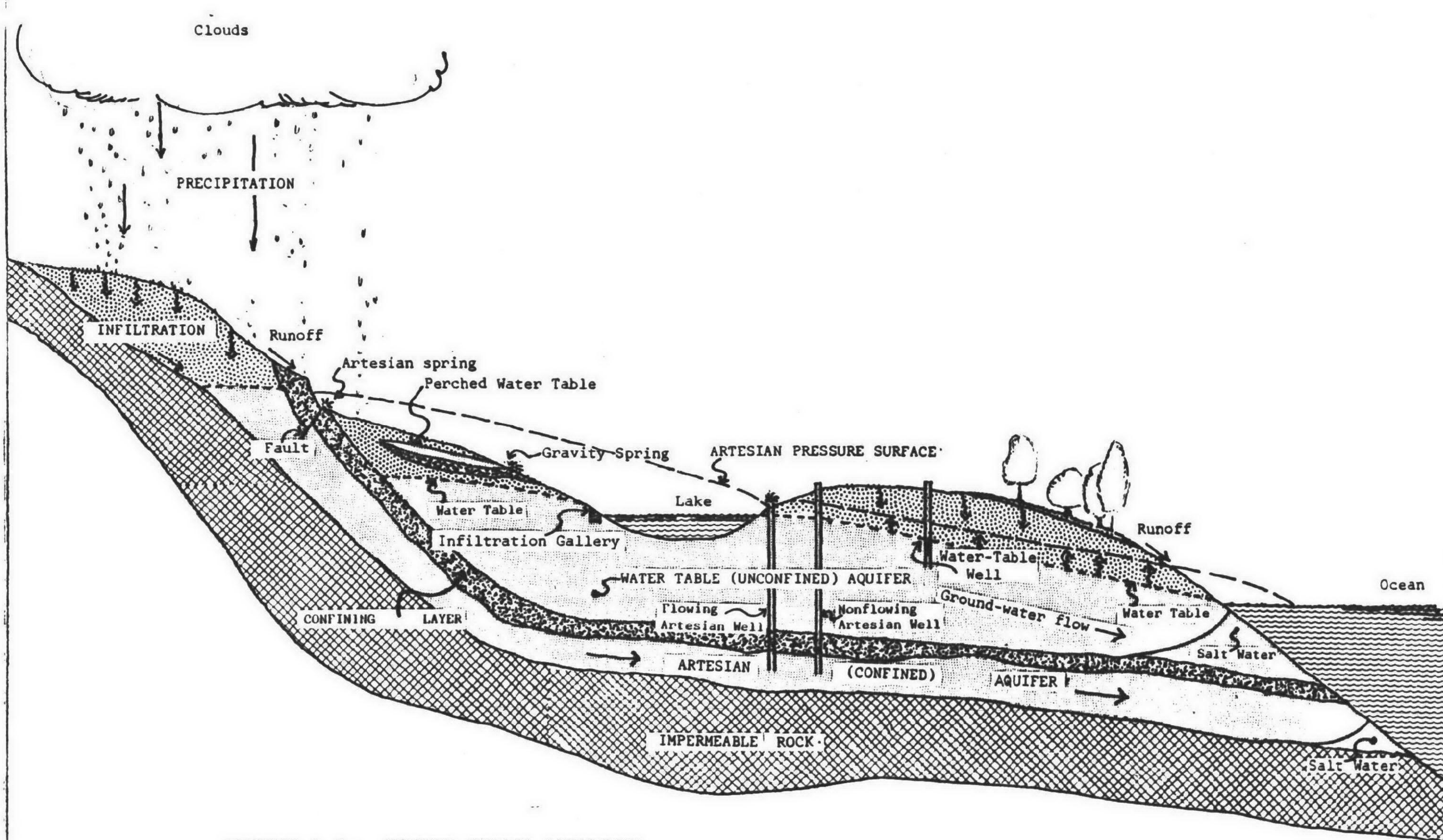


FIGURE 4-1: GROUND WATER AQUIFERS

Ground water protected by deep layers of unconsolidated soils is more likely to be safe than water coming from rock formations which have shallow overburdens of soil. Where limited filtration is provided by overlying earth materials, water of better sanitary quality can sometimes be obtained by drilling deeper. It should be recognized, however, that it is not always possible to find more and better water at greater depths because of the local geology.

In areas without central sewerage systems, sewage disposal is by means of subsurface methods including cesspools, septic tanks and leaching systems and occasionally by pit privies. Inherently, these systems contribute sewage pollution to the ground waters. Bacteria in the liquid effluents may enter shallow aquifers. Sewage effluents may also reach the water-bearing formations by way of abandoned wells or openings in rock formations. The threat of contamination may be reduced by proper well construction, and by locating it farther from the source of contamination. The direction of ground water flow often approximates (but not always) that of the prevailing overall surface flow. It is always desirable to locate a well so that the normal movement of ground water flow carries the contaminant away from the well. Chapter 5 provides additional criteria for proper well location.

<u>Chemical and Physical Quality</u>

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

Some substances found naturally in ground water, while not necessarily harmful, may impart a disagreeable taste or undesirable property to the water. Magnesium sulfate (Epson salt), sodium sulfate (Glauber's salt), and sodium chloride[1] (common table salt) are but a few of these. Iron and manganese are also often found in ground water. It is interesting to note that regular users of waters containing significant amounts of these substances, commonly become accustomed to the water and consider it to have acceptable taste!

Concentrations of chlorides and nitrates in amounts higher than normal for a particular region may be indicators of sewage pollution. This is another reason why a chemical analysis of the water should be made periodically and the results interpreted by someone familiar with the area.

Temperature

The temperature of ground water remains nearly constant throughout the year. Water from very shallow sources (less than 50 feet deep) may vary somewhat from one season to another, but water from deeper zones remains quite constant, its temperature ranging close to that for the average annual temperature at the surface. This is why water from a well may seem to be warm in winter or cold during the summer.

Contrary to popular opinion, colder water is not obtained by drilling deeper. Beyond about 100 feet of depth, the temperature of ground water increases steadily at the rate of about $1^{o}F$ for each 75 to 150 feet of depth[2]. In volcanic regions this rate of increase may be much greater.

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(1) Sodium salts in excess of 20 mg per liter may be harmful to people restricted to low sodium diets. See Chapter 12.

(2) $1^{o}C$ for each 42 to 84 meters.

Developing Ground Water Sources

Wells. The most common method of developing ground water sources is by sinking a pipe casing into the desired ground water aquifer and removing the water by means of suitable pumping equipment. Chapter 5 covers the procedures and techniques.

Springs. When ground waters issue at the surface of the ground from the water bearing soils or rock formations, they are called springs. These waters are often suitable for small public systems where properly developed. Chapter 7 discusses spring development.

SURFACE WATERS

Surface waters are used extensively as sources of water for large public systems. However, because surface waters are exposed to potentially severe contamination by both man and nature and because the quality varies considerably, a high degree of treatment is required to insure its constant safety. Generally speaking, small water systems cannot provide the high degree of treatment and supervision required, except at considerable expense. Therefore, surface supplies should not be considered as sources if good ground water sources are available. Chapter 8 discusses the development of surface water supplies.

CHAPTER 5

WELL CONSTRUCTION AND DEVELOPMENT[1]	Site Selection - Types of Wells - Construction - Development - Sanitary Protection - Disinfection

INTRODUCTION

In order to reach the ground waters underlying the earths' surface, it is necessary to construct a well vertically downward to penetrate the desired water bearing strata. These structures may be dug, driven, bored, jetted or drilled, depending upon the geological formations through which they must pass and the depth to which they must reach. Dug, driven, bored and jetted wells are usually confined to relatively soft soils overlaying rock and to shallow depths normally less than 50 feet (15 meters). Drilled wells may be used in both soft and hard soil and in rock and may be sunk to depths measuring several hundred feet.

Wells are usually classed into two broad categories, depending upon whether the ground water aquifer is under a hydrostatic head or not. These are called nonartesian (water table) and artesian wells.

Nonartesian (water table) wells are those that penetrate the upper ground water formations where the water is not confined by an overlying impermeable formation. Pumping the well lowers the water table in the vicinity of the well and water moves through the soil toward the well under the pressure differences thus created.

(1) Some of this Chapter is adapted from the Manual of Individual Water Supply Systems, EPA and the Manual of Water Well Construction Practices, EPA.

Artesian wells are those that penetrate aquifers in which the ground water is found under hydrostatic pressure, confined beneath an impermeable layer of material. Since the water is under pressure, it will rise in a well casing penetrating the aquifer. If the pressure is great enough to force the water to the ground level, it is called a flowing artesian well. The intake areas (recharge areas) of confined aquifers are commonly found at higher elevations of surface outcrops of the formations.

WELL SITE SELECTION

The selection of the well site is influenced by the ground water aquifer to be developed, depth to the aquifer and the geological character of formations to be penetrated. Other factors include: freedom from flooding and surface drainage; the relation to existing or potential sources of contamination; the quantity and quality of the water; the convenience of the location in relation to the service area; and the availability of sufficient surrounding land to insure protection from incompatible adjacent land uses. Also see Chapter 2.

The State regulatory agency should be consulted for local requirements concerning well location, particularly the minimum protective distances between the well and sources of existing or potential pollution. Table 5-1 is an example of typical minimum distances. It must be stressed that these minimum distances are based upon general experience and are not guarantees of freedom from contamination. The water purveyor should provide even greater protection where possible. There is no substitute for a detailed sanitary survey of the proposed site (see Chapter 2). The Table applies to properly constructed wells with protective casing set to a depth of at least 20 feet (6 meters) below ground surface. Other types of wells will require special considerations.

Table 5-1: Minimum Distances Between Well and Sources of Potential Pollution

Source of Pollution	Wells Cased to Depth of 20 ft. (6 Meters) or more		Remarks
	Feet	Meters	
Water-tight Sewers	50	15	Consult the State Regulatory Agency for special local requirements.
Other Sewers	100	30	
Septic Tanks	100	30	
Sewage Field, Bed or Pit	200	60	
Animal Pens and Yards	200	60	

Note: - Each well has a characteristic radius of influence which depends upon the drawdown. Care should be taken to separate the wells so they do not significantly influence the yield of each other or neighboring wells and springs.

- The water purveyor should obtain control over the use of land within at least 100 feet of the well, 200 feet is preferrable.

The lack of specific distances for other potential sources of contamination such as streams, refuse disposal sites, waste lagoon, waste treatment facilities, ponding areas, and petroleum and other chemical storage tanks, does not minimize their potential hazard. These must be evaluated in each specific situation. Wells which terminate in creviced formations, particularly where the overlying soil formation is shallow and/or highly permeable, require greater protective distances.

YIELD OF WELLS

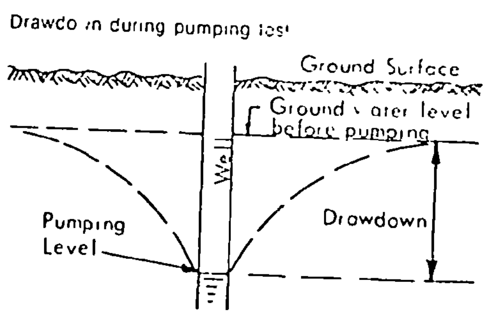
The amount of water that can be pumped from a well depends on the character of the aquifer and the construction of the well. Contrary to popular belief, the diameter of the well casing is not the critical factor. The casing diameter should be chosen to provide enough room for proper installation of the desired pumping arrangement. Table 5-2 lists the recommended well casing diameter for various anticipated well yields. Pump manufacturers and well drillers should be consulted before making final choices. In unconsolidated soils where well screens may be necessary, the required screen area may influence the casing diameter.

Table 5-2: Recommended Well Diameters (From Individual Water Supply Systems, EPA)

Anticipated Well Yield in GPM	Nominal Size of Pump Bowls in Inches *	Optimum Size of Well Casing in Inches *
Less than 100	4	6 Inside diameter
75 - 175	5	8 Inside diameter
150 - 400	6	10 Inside diameter
350 - 650	8	12 Inside diameter

* To convert to millimeters, multiply by 2.54

Figure 5-1: Drawdown During Pumping



Quite often, the capacity of a well may be increased by drilling deeper into the aquifer - assuming, of course, that the aquifer has the necessary thickness. In sand and gravel formations, the inlet area of the well screen is also important in determining the yield of the well. The amount of "open area" in the screen exposed to the aquifer may be critical. Wells completed in rock formations are usually of open hole construction; i.e., there is no casing in the aquifer itself and the amount of rock exposed in the well hole will influence the yield.

It is not always possible to predict accurately the yield of a given well before its completion. Knowledge can be gained, however, from studying the geology of the area and interpreting the results obtained from other wells constructed in the vicinity. This information will be helpful in selecting the location and type of well most likely to be successful.

A common way to describe the yield of a well is to express its capacity in relation to the drawdown during pumping. This relationship is called the specific capacity of the well and is expressed in <u>gallons per minute (gpm) per foot of drawdown</u>[2]. The specific capacity may range from less than 1 gpm per foot of drawdown for a poorly developed well or one in a tight aquifer, to more than 100 gpm per foot of drawdown for a properly developed well in a highly permeable aquifer.

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(2) Metric: Liters per second per meter of drawdown.

TYPES OF WELLS

There are several construction techniques used to desired ground water formation. Some of these methods are not considered satisfactory for public water systems because of the inherent difficulties of insuring adequate protection. These include dug, driven and bored wells. These wells are generally limited to shallow, soft aquifers. Wells using these sinking methods should not be constructed for use as public water sources unless specifically approved by the State regulatory agency. The Manual of Individual Water Supply Systems (EPA) (Ref. No. 2) contains descriptions of these methods.

The preferred method of constructing a well is by drilling, although jetting is also considered satisfactory. Drilled wells can be constructed in all instances where driven and jetted wells might otherwise be used and in many areas where dug and bored wells are constructed. The larger diameter of a drilled well as opposed to that of a driven well permits use of larger pumping equipment that can develop the full capacity of the aquifer.

Drilled Wells. Construction of a drilled well is ordinarily accomplished by one of two techniques - percussion or rotary hydraulic drilling. The selection of the method depends primarily on the geology of the site and the availability of equipment.

WELL CONSTRUCTION

It is not within the scope of this manual to describe in detail the current practices of well construction, particularly since a specific manual on the subject is readily available. The reader is referred to The Manual of Water Well Construction Practices, EPA - 570/9-75-001 prepared under the auspices of the National Water Well Association (Ref. No. 16) and published by the U.S. Environmental Protection Agency. The manual includes formats for well construction contract documents and detailed well construction technical standards.

DRILLING METHODS

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

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

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

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

When the hole is completed, the drill pipe is withdrawn and the casing placed. The drilling mud is usually left in place and pumped out after the casing and screen are positioned. The annular space between the hole wall and the casing should be grouted in non-water-bearing sections, but may be enlarged and filled with gravel at the level of water-bearing strata. (See Well Grouting in this Chapter)

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

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

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

Well Log

A well log is a record of the thickness and characteristics of the soil, rock and water formations encountered during the sinking of the well. Well casing and well grouting details should be shown. Static and pumping water levels and well yields are also recorded. The log is prepared by the driller and should be retained by the system owner for future reference. The well log is used to determine the proper casing depth, the depth and design of the well screen and to assist in the selection of the pump design. The log will also be helpful for use in the future if rehabilitation or reconstruction of the well is necessary. Some states require that the well log be filed with the State agency responsible for well construction. A well log form is shown in Figure 5-2.

Figure 5-2

WATER WELL RECORD

ACT 294 PA 1965

MICHIGAN DEPARTMENT OF PUBLIC HEALTH

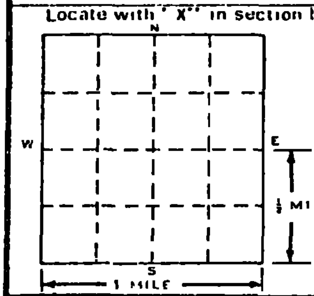
1 LOCATION OF WELL

County	Township Name	Fraction	Section Number	Town Number	Range Number
		¼ ¼ ¼		N/S	E/W

Distance And Direction from Road Intersections

Street address & City of Well Location

Locate with "X" in section below



Sketch Map

3 OWNER OF WELL

Address

4 WELL DEPTH (completed) Date of Completion

ft.

5 ☐ Cable tool ☐ Rotary ☐ Driven ☐ Dug
☐ Hollow rod ☐ Jetted ☐ Bored ☐ ______

6 USE ☐ Domestic ☐ Public Supply ☐ Industry
☐ Irrigation ☐ Air Conditioning ☐ Commercial
☐ Test Well ☐ ______

7 CASING Threaded ☐ Welded ☐

Diam

____ in to ____ ft. Depth

____ in to ____ ft. Depth

Height Above/Below Surface ______ ft

Weight ______ lbs/ft

Drive Shoe? Yes ☐ No ☐

2 FORMATION	THICKNESS OF STRATUM	DEPTH TO BOTTOM OF STRATUM
USE A 2ND SHEET IF NEEDED		

8 SCREEN

Type ______ Dia ______

Slot/Gauze ______ Length ______

Set between ______ ft and ______ ft

Fittings

9 STATIC WATER LEVEL

______ ft below land surface

10 PUMPING LEVEL below land surface

______ ft after ___ hrs. pumping ______ g p m

______ ft. after ___ hrs pumping ______ g p m

11 WATER QUALITY in Parts Per Million

Iron (Fe) ______ Chlorides (Cl) ______

Hardness ______ Other ______

12 WELL HEAD COMPLETION ☐ In Approved Pit
☐ Pitless Adapter ☐ 12" Above Grade

13 Well Grouted? ☐ Yes ☐ No
☐ Neat Cement ☐ Bentonite ☐ ______

Depth From ______ ft to ______ ft

14 Nearest Source of possible contamination

______ feet ______ Direction ______ Type

Well disinfected upon completion ☐ Yes ☐ No

15 PUMP ☐ Not installed

Manufacturer's Name ______

Model Number ______ HP ___ Volts ______

Length of Drop Pipe ______ ft capacity ______ G.P.M.

Type ☐ Submersible
☐ Jet ☐ Reciprocating

16 Remarks, elevation, source of data, etc

17 WATER WELL CONTRACTOR'S CERTIFICATION

This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.

______ REGISTERED BUSINESS NAME REGISTRATION NO

Address ______

Signed ______ Date ______

AUTHORIZED REPRESENTATIVE

067d 1000 (Rev 12-68)

DRILLING CONTRACTOR COPY

WELL CASING AND PIPE

Casing is installed in wells to prevent the collapse of the walls of the bore hole, to exclude pollutants (either surface or subsurface) from entering the water source, to provide a column of stored water and to provide a housing for the pump mechanisms and pipes.

The casings must be strong enough to resist the pressures exerted by the surrounding materials, forces imposed on it during construction, and corrosion by soil and water environments. It must be of the proper length to accomplish its purpose of providing a channel from the aquifer to the surface through unstable formations and through zones of actual or potential contamination. Casings should extend above potential levels of flooding and should be protected from flood water contamination and damage. If it is impossible to extend the casing above potential flood levels, the State agency should be consulted for advice and requirements. In unconsolidated soils, the casing should extend at least 5 feet (1.5 meters) below the estimated maximum expected drawdown level. In consolidated rock formations casings should extend 5 feet (1.5 meters) into firm bed rock and sealed into place.

Steel casing is usually used for well construction. Plastic well casing (PVC) is occasionally used in some parts of the country but should not be used unless approved by the State regulatory agency. Other less common casing types include concrete, fiberglass, asbestos-cement, stainless steel and other alloys, both ferrous and nonferrous.

A number of technical and scientific organizations are active in promulgating pipe and casing specifications. Prominent and most active are the American Society of Testing Materials (ASTM), the American Petroleum Institute (API), the American Water Works Association (AWWA), and the National Sanitation Foundation (NSF) for plastic pipe. The specifications serve an important function by providing uniform standards of construction and a quality warranty. However, not all materials are covered by standard specifications.

There are three principal types of tubular-steel products which are satisfactory for water well casing. The first is line pipe and standard pipe made to conform to standards of the American Petroleum Institute (API) or American Society for Testing Materials (ASTM). Casing fabricated from structural steel plate to conform to ASTM specifications is the second type. The third is well casing steel for which there are no standard specifications at present. The Manual of Water Well Construction Practices lists several specifications which may be used. Those most usually called for are the ASTM-A-589, ASTM A-120, ASTM A-53, API 5-L, and the Federal specification WW-P-406B.

Thermoplastic well casing pipe and couplings should conform to standards set forth in ASTM F-480-76. Only the more common sizes are covered.

Generally speaking, well casings of less than 6 inches (15.24 cm) nominal inside diameter are not recommended for wells used for public systems. Steel casing with a wall thickness of at least 1/4 inch has proven reliable and is a good choice except under very corrosive water conditions where greater thickness may be indicated.

WELL GROUTING

The annular open space left around the outside of the well casing during construction is one of the principal avenues through which undesirable water and contamination may gain access to a well. The most satisfactory way of eliminating this hazard is to fill this annular space with cement grout. To accomplish this satisfactorily, careful attention should be given to see that:

1. The grout mixture is properly prepared.

2. The grout material is placed in one continuous mass.

3. The grout material is placed starting from the bottom of the space to be grouted and continued upward.

The specific grouting requirements of a well will depend upon the existing surface conditions, especially the location of sources of pollution, and the subsurface geologic and hydrologic conditions. In order to achieve the desired protection against contamination, the annular space must be sealed to whatever depth is necessary, but in no case less than 20 feet.

Grouting materials include neat cement grout, concrete grout and sand cement grout. Methods of grout placement include: bailer dumping, gravity filling, tremie pouring, positive placement, continuous injection and the displacement methods.

Well grouting material specifications, installation methods and testing methods are described in detail in the previously mentioned Manual of Water Well Construction Practices. (Also Reference Nos. 12, 18, 19 and 20 in Appendix C.)

WELL SCREENS

Screens are installed in wells to hold back unstable aquifer material yet permit free flow of water into the well through the specially designed screen openings. The well screen should be of good quality (corrosion resistant, hydraulically efficient and good structual properties) and should be based on a sieve analysis of carefully selected samples of the water-bearing formation. The analysis is usually made by the screen manufacturer or dealer, who will provide complete information to assist in the most appropriate design.

Slotted casing or perforated pipes should not be used in place of properly designed, quality well screens. Experience has shown that slotted casings and perforated pipes corrode excessively, resulting in loss of screening effectiveness and well and pump failure.

The methods of screen installation and specifications are described in detail in the Manual of Water Well Construction Practices. The methods include: washing method, pull back method, driven through casing method, bailed through casing method, bailed or air jetted through casing method, washed through casing method, and the suspended from surface method.

DEVELOPMENT OF WELLS

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

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

One of the most effective methods of development is the high-velocity hydraulic-jetting method. Water under pressure is ejected from jet orifices and passes through the screen openings, violently agitating the aquifer material. Sand grains finer than the slot size move through the screen and settle to the bottom of the well from which they are subsequently removed by bailing or flushing out of the top of the casing with the wash water. Conventional centrifugal or piston pumps may be used, as may the mud pump of the rotary hydraulic drill. Pressures of at least 100 psi should be used, with pressure greater than 150 psi preferred. High-velocity jetting is particularly suited for screens of continuous horizontal slot design. It has also proven effective in washing out drilling mud and cuttings from crevices in hard-rock wells.

Other methods of development are interrupted pumping, air jetting, use of chemicals, and sometimes in consolidated material, explosives when used by experts. The method of development must be suited to the aquifer and the type of well construction. Proper development is an important part of well construction and will have a significant effect on the yield and "life" of the well.

TESTING WELL FOR YIELD AND DRAWDOWN

In order to properly design the well pumping systems, tests should be made after the well has been developed to determine its yield and drawdown characteristics. The tests should include pumping at predetermined constant rates for a period of at least 4 hours after the drawdown has approached stability. The water level during each pumping test is recorded, including the maximum drawdown. After each test, the pump is shut down and the well is allowed to recover. The water level during recovery is recorded hourly. Failure to recover substantially within 12 hours is reason to question the dependability of the well for that pumping rate. The safe yield will be the rate of pumping which results in an acceptable drawdown with substantially complete recovery of the water level within 12 hours. Measurements should be made accurately if the results are to be considered reliable. The tests should be done by competent drillers or engineers. Additional information regarding the testing of wells for drawdown or yield may be obtained from the U.S. Geological Survey, the State regulatory agency, or the manufacturers of well screens or pumping equipment. References 12, 18, 19 and 20 in Appendix C are also good reference sources.

Water table wells are more affected than artesian wells by seasonal fluctuations in ground water levels. When testing a water table well for yield and drawdown, it is desirable, though not always practical, to test it near the end of the dry season. When this cannot be done, it is important to estimate as nearly as possible (from other wells tapping the same formations) the additional seasonal decline in water levels which may be expected. This additional decline should then be added to the drawdown determined by the pumping test, to arrive at the ultimate pumping water level. Seasonal declines of several feet in water table wells are not unusual, resulting in reduced capacity in the dry season.

COMPARISON OF WELL YIELD WITH PEAK REQUIREMENTS

If it is planned to pump the wells into a gravity storage reservoir system (See Chapter 6), the wells should have a safe capacity (yield) at least equal to the maximum daily demand; or the average daily water demand with the largest well out of service. The storage reservoir should have a storage capacity equivalent to at least one day at the average daily water use.

If, on the other hand, it is planned to use an hydropneumatic pumping system, it is desirable that the well and pump capacities should be capable of meeting the peak system demand (See Chapter 6, Hydropneumatic Systems).

WELL HEAD COVERS OR SEALS

Every well must be provided with approved seals at the top of the casing or pipe sleeve connections to prevent contaminated water or other material from entering the well. A variety of covers and seals are available to meet the variety of conditions encountered but the principles and the objective of excluding contamination are the same.

After the casing has been sealed in the ground with a cement grout, contaminated water will not be able to seep around the casing into the aquifer. However, unless the top of the casing and any special openings which are cut or provided in the walls of the casing to carry the well pump pipes, electric supply, electrical controls, and vents are properly sealed, contaminated water may enter the well casing through these openings. If openings are cut or provided in the wall of the well casing below ground level, **pitless** adapters are inserted into the openings to serve as a conductor. These adapters must provide a water tight seal. In this case the top of the casing usually extends above ground and is covered with a special cap with an overlapping flange designed to restrict entry of foreign matter and rain, but it is not necessarily water tight. If, on the other hand, the well pipes, conduits, etc. come through the top of the casing, the water tight seal must be at that place and a special venting arrangement is necessary in most cases.

Casings should not be left open after completion of the drilling, grout sealing of the annular space and development. The casing should be covered to prevent access of foreign material and vandalism.

A well slab poured around a casing is not an effective sanitary defense when used as a substitute for cement grouting of the annular space. The cement grout formation seal must be used. However, there are situations that call for a concrete slab or floor around the well casing to facilitate cleaning and improve appearance or in the construction of an above ground pump station over the well. When such a floor is necessary, it should be placed only after the formation seal and any well seals have been inspected.

Well covers and pump platforms should be elevated above the adjacent finished ground level and should be sloped to drain away from the well casing. Well pits should not be used as they may result in contamination. Pumproom floors should be constructed of reinforced, watertight concrete, and carefully sloped to a drain away from the well so that surface and waste water cannot stand near the well. The minimum thickness of a slab or floor should be 4 inches (10.2 centimeters). Concrete slabs or floors should be poured separately from the cement formation seal and when the threat of frost heaving exists, insulated from it and the well casing by a plastic or mastic coating or sleeve to prevent bonding of the concrete with the formation seal.

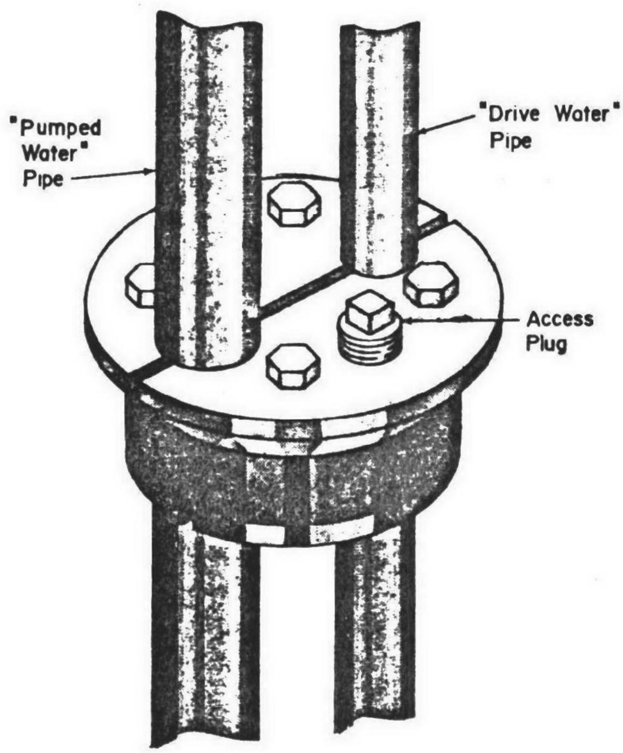
All water wells should be readily accessible at the top for inspection, servicing, and testing. This requires that any structure over the well be easily removable or an opening provided to insure full, unobstructed access for well-servicing equipment.

SEALS INSTALLED ON THE TOP OF THE CASING

Some well seals are designed for insertion into the top of the casing. Several designs are available based upon the principal of an expandable neoprene gasket compressed between steel plates and provided with openings to accept pipes, electrical cables, and a vent. See Figures 5-3 and 5-4. They are easily installed and removed for servicing. However, these seals are generally not approved for burial and should only be used where they extend 8 inches or more above the ground and are not subject to flooding. This limits their use to climates which do not experience freezing temperatures, unless the unit is enclosed by an above ground pump house or structure.

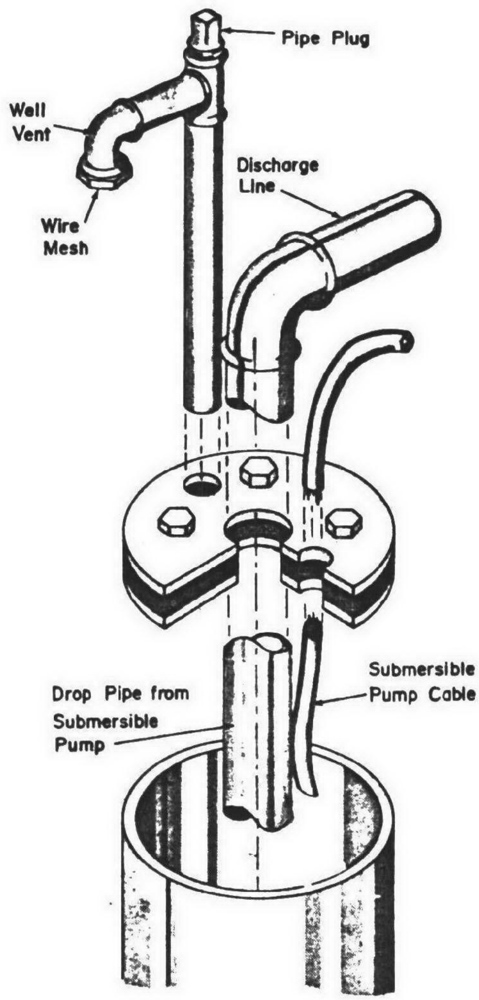
Burial of this seal under several feet of earth is unacceptable because experience has shown: (1) it discourages inspection and maintenance, (2) it is often unreliable as a seal, (3) contamination is likely during servicing, and (4) excavations to expose the top of the well risks damage to the well, seal, vent and electrical connections.

Figure 5-3: Well seal for jet pump installation



(Reproduced from EPA Manual of Individual Water Supply Systems, Figure 8, Page 46)

Figure 5-4: <u>Well seal for submersible pump installation.</u>



(Reproduced from EPA Manual of Individual Water Supply Systems, Figure 9, Page 47)

PITLESS WELL HEAD SEALS

Because of the flooding and pollution hazards involved, a well pit to house the pumping equipment or to permit accessibility to the top of the well is not recommended. Some States prohibit its use.

Commercial units generally known as "pitless adapters" or "pitless units" are readily available to eliminate the need for well pits. These units vary somewhat in design but generally include a special fitting designed for mounting on the side of the well casing or a pre-assembled casing extension. The well discharge and other piping are screw threaded into the fitting. A mated fitting is designed to support the discharge and other piping in the casing and is inserted through the top of the casing. This lift out device mates with the fitting mounted on the outside of the casing by compression and a locking arrangement, providing a seal between the mated gaskets. Under this arrangement, the top of the well casing should extend above ground level 8 inches or more and be capped with a self-draining cover with overlapping flanges to prevent entry of extraneous material. Figures 5-5 through 5-8 show some of these units. The pitless system permits the connection of the well piping to the casing underground below frost depth and at the same time provides for good accessibility to the well casing for repairs without excavation.

There are numerous makes and models of pitless adapters and units. Not all are of good design, and a few are not acceptable. The State regulatory agency should be consulted to determine what designs are acceptable.

Both the National Sanitation Foundation[3] and the Water Systems Council[4] have adopted criteria intended to assure that quality materials and workmanship are employed in the manufacture and installation of these devices. Unfortunately, the sanitary safety of the installations is highly dependent on proper installation.

There are two general types of pitless installations. One, the pitless adapter, requires cutting a hole in the side of the casing below the ground surface, usually below the frost line. Into this opening there is inserted and attached a fitting to accommodate the discharge line from the pump. Its design varies depending on whether it will accomodate only the pressure line or both pressure and suction lines (two-pipe jet pump system). The other part of the adapter is mounted inside the well casing, supporting the pumping components suspended in the well. Water-tight connection is accomplished by a system of rubber seals compressed by clamps or by the weight of the equipment itself.

The second type - the pitless unit - requires cutting off the well casing at the required depth and connecting the entire unit with all pre-assembled attachments to the casing, usually with water tight threads.

Regardless of the type of device employed, certain problems arise which call for special care, described as follows.

1. Welding below ground, in cramped quarters and under all-weather conditions, is not conducive to good workmanship. If welding must be done, the welder should be an "expert" pipe welder, and he should have ample room for freedom of movement and ease of visual inspection. A clamp-on, gasketed pitless adapter is easier to install, but requires a smooth and clean surface for the gasket.

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(3) National Sanitation Foundation, Post Office Box 1468, Ann Arbor, Michigan 48106.

(4) Water Systems Council, 221 North LaSalle Street, Chicago, Illinois 60601.

2. The pitless unit is manufactured and tested under factory conditions. However, its attachment to the casing may present special problems. If the well casing is threaded and coupled (T&C), it may be possible to set the height of one of the joints so that it is at the right height for attachment of the unit. If this cannot be done, or if welded joints have been made, the casing must be cut off at the proper depth below ground and then threaded.

3. Clamps and gaskets are used for attachment of both adapters and units. Because of their relative structural weakness, the joint may be broken or damaged during construction, or by frost-heave action, resulting in leaks and potential contamination[5].

Watertight joints require good contact between the gasket and the sealing surfaces. Machined surfaces provide better seals. When a rubber gasket is used as a seal against the casing, special care must be taken to assure that the contact surface is clean and smooth.

4. Materials used in adapters, adapter units, and accessories should be selected carefully for strength and resistance to corrosion. Dissimilar metals which may corrode by galvanic action should be insulated from each other by rubber, plastic, or other non-conductor. Care should be taken in the selection of welding materials as the welded connection may be the focal point of corrosion.

5. Excavation around the well produces unstable soil conditions, and later settlement is to be expected. Settlement of the discharge line may place a load on the adapter connection which could result in breakage or leaks. If for some reason the use of rigid pipe is necessary, these risks may be reduced by the use of non-rigid pipe connections, a "gooseneck", a "swing joint", or other devices which will adjust to the settlement without transferring the load to the adapter. Back-filling with sand settled with water will minimize settlement of the fill (See Figure 5-8).

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(5) Some States prohibit the use of "Dresser type" connections for pitless units.

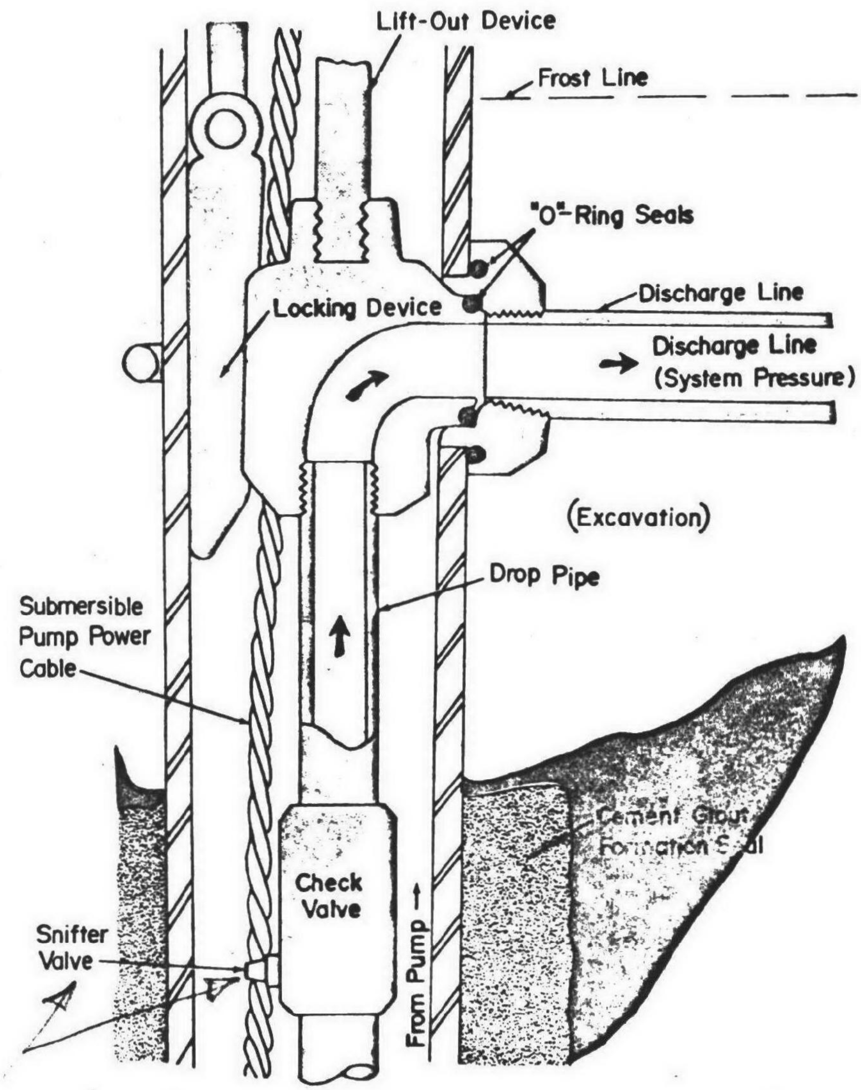
6. After a pitless unit has been installed and tested and back-filled, there remains the risk of accidental damage to the buried connections by bulldozers and other vehicles. Until all construction and grading around the area has been completed, the well should be marked with a post and flag. If the well is located in an area where motor vehicles are likely to be operated, the final installation should include protective pipe posts set in concrete. The posts should be just high enough to protect the well, but not so high that they would interfere with well servicing.

INSPECTION AND TESTING OF PITLESS DEVICES

Pitless adapters and units are installed within the upper 10 feet of the well structure, the zone of greatest potential for corrosion and contamination. The buyer should select an adapter or unit that satisfies State agency requirements and a dealer who will stand behind the product. Employing a contractor with a reputation for good work is perhaps the best assurance of getting the job done right. Inspection and testing should be included as part of the contract. Some State agencies license or certify contractors authorized by law to construct wells and install pumping systems.

Leaks found in rubber or plastic seals should be closed by tightening the clamps, if possible. If a cement sealant must be applied, it should provide a strong flexible bond between the sealing surfaces, and should be formulated to provide long service under buried conditions.

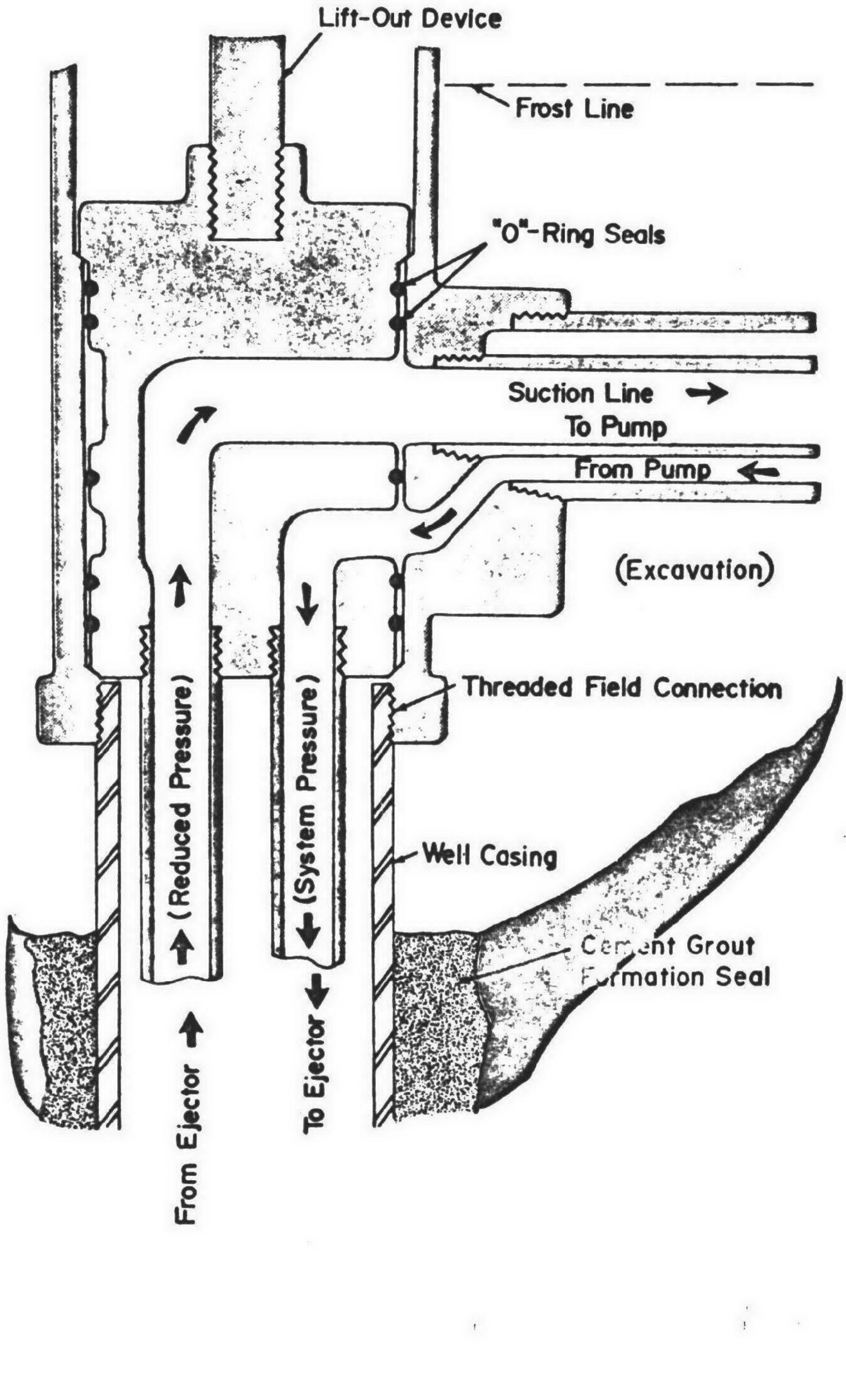
Figure 5-5: Clamp-on pitless adapter for submersible pump installation.



Remove the Snifter Valve when redrawn (editors note)

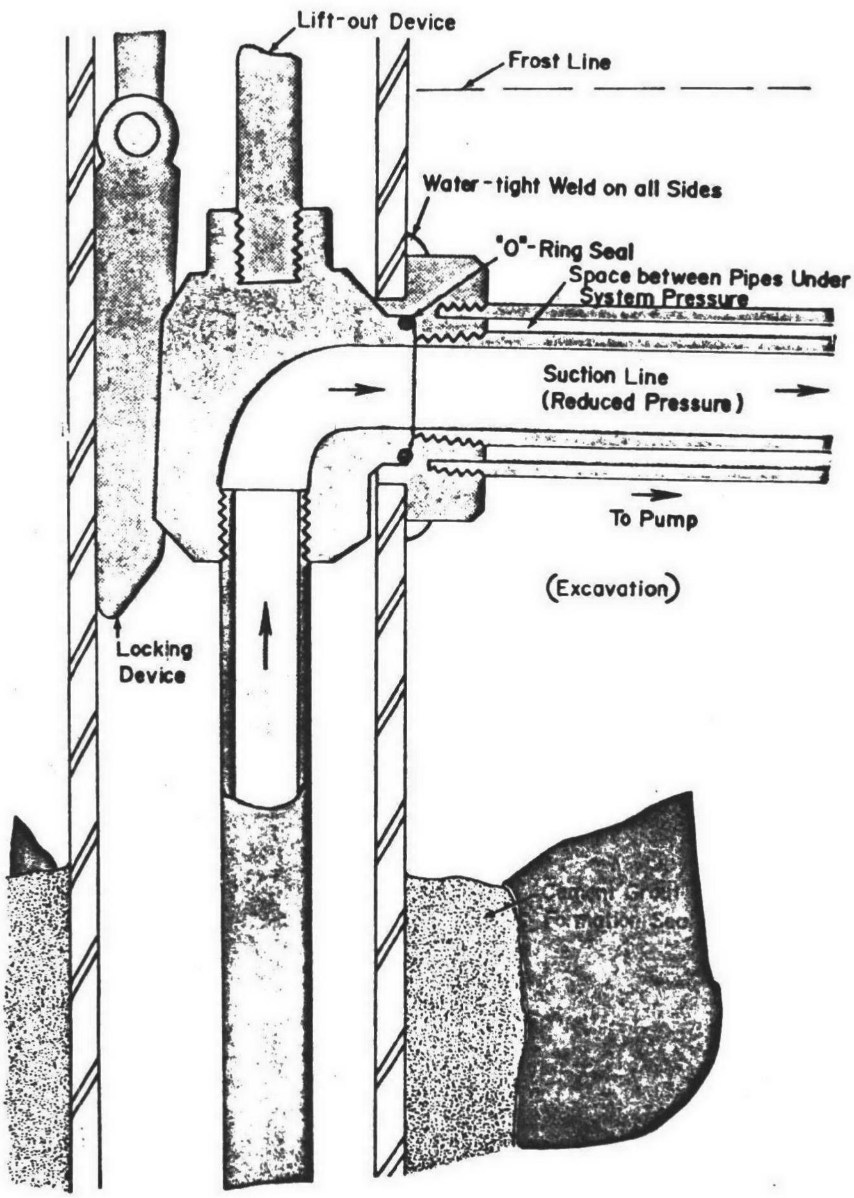
(Reproduced from EPA Manual of Individual Water Supply Systems, Figure 21, Page 111)

Figure 5-6: Pitless unit with concentric external piping for jet pump installation.



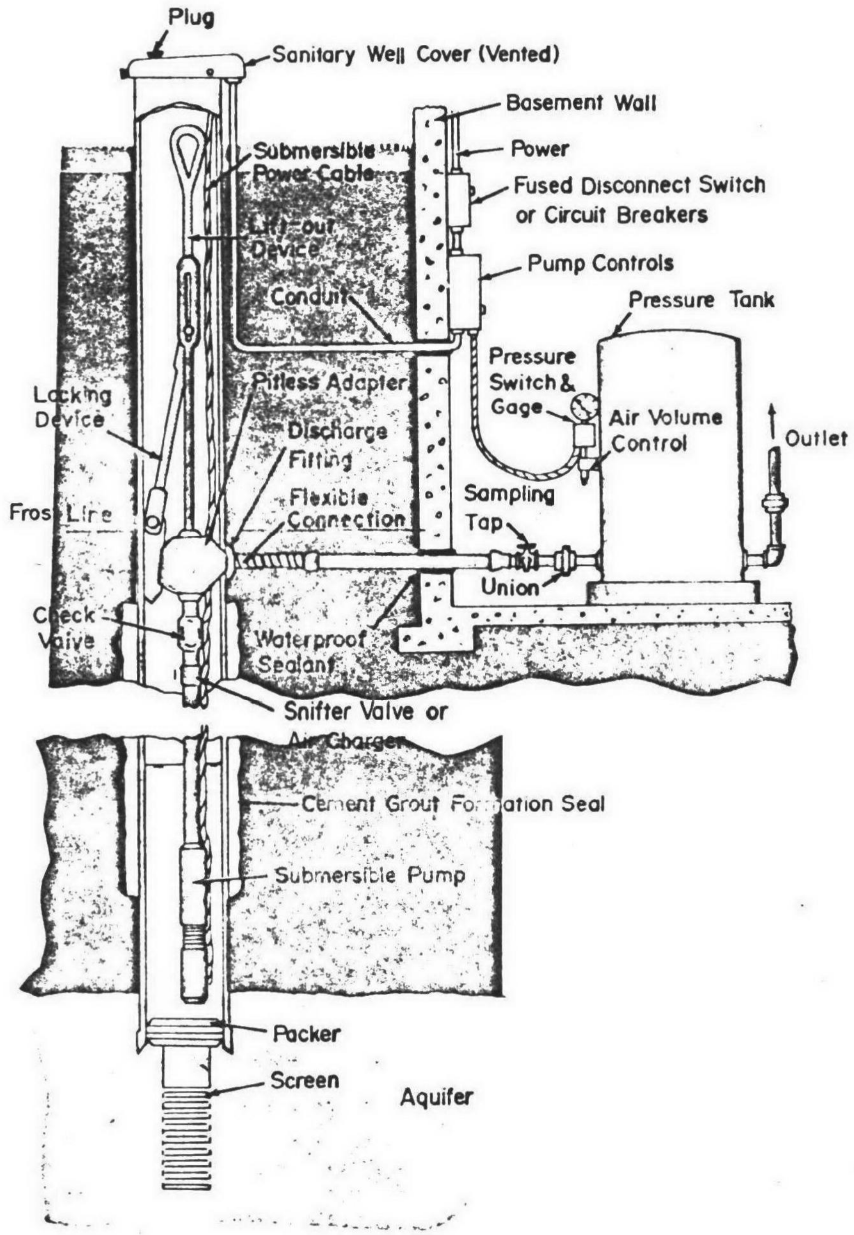
(Reproduced from EPA Manual of Individual Water Supply Systems, Figure 22, Page 112)

Figure 5-7: <u>Weld-on pitless adapter with concentric external piping for "shallow well" pump installation.</u>



(Reproduced from EPA Manual of Individual Water Supply Systems, Figure 23, Page 113)

Figure 5-8: <u>Pitless adapter with submersible pump installation for basement storage.</u>



(Reproduced from EPA Manual of Individual Water Supply Systems, Figure 24, Page 114)

WELL DISINFECTION

Disinfection is the final step in the completion of a well. Its purpose is the destruction of all potential disease-producing and other undesirable organisms introduced into the well during the various construction operations. Entry of these organisms into the well can occur through contaminated drilling water, equipment, materials, or surface drainage.

The completed well should be cleaned as thoroughly as possible of foreign substances such as soil, grease, oil and debris before disinfection. Disinfection is achieved by the addition of a strong solution of chlorine to the well. The contents of the well should then be thoroughly agitated and allowed to stand for several hours, preferably overnight (See Table 5-4). Care should also be taken to wash all surfaces above the water level in the well with the disinfecting solution. This may be done by pumping the chlorinated well and recirculating the water into the well with a hose, washing all surfaces. Following this, the well should be pumped long enough to change its contents several times and to flush out the excess chlorine.

Chlorine is available in several forms.

Calcium hypochlorite is a popular source of chlorine. It is sold in chemical supply and most hardware stores and in swimming pool supply outlets in the granular and tablet form containing 70 percent of available chlorine by weight. It is fairly stable when dry, retaining 90 percent of its original chlorine content after one year's storage. Because it loses its strength and becomes quite corrosive when moist, it should be stored under cool, dry conditions. Enough calcium hypochlorite should be added to the water standing in the well to produce a solution of strength ranging from 100 to 200 parts per million (ppm) by weight.

See Tables 5-3 and 5-4 for information on the amount of chlorine necessary to achieve satisfactory disinfection. For convenience of application, a solution is made by mixing the calcium hypochlorite in a container of water. Stir the mixture thoroughly before allowing to settle. The clearer liquid is then poured off for use in the well. The solution should be prepared in a thoroughly cleaned glass, crockery, plastic, or rubber lined container. Metal containers may be damaged by corrosion. Solutions should be prepared to meet immediate needs only, as it loses strength rapidly unless stored in tightly covered dark glass or plastic containers. Storage of the chemical in the dry form is much more desirable.

Sodium hypochlorite is a liquid form of chlorine and is more convenient to use. It may be purchased in varying strengths of up to about 15 percent available chlorine. In its most common form, household laundry bleach, it has a strength of about 5.25 percent of available chlorine. Two quarts of chlorine bleach added to each 100 gallons of water in the well produces at least 200 ppm dose of chlorine (See Tables 5-3 and 5-4).

The chlorinated water in the well should be pumped through the pump system to fill all pumps and appurtenances. The volume of water required to fill these pipes and appurtenances should be taken into account in calculating the chlorine requirements. The chlorinated water should remain in the system for at least 2 hours to 12 hours depending on the dose, then flush until the strong odor of chlorine disappears. Recirculation of the chlorinated water back into the well with a hose will insure good mixing.

The water from flowing artesian wells is generally free from contamination by disease-producing organisms after it is allowed to flow to waste for a short while. If, however analyses show persistent contamination, then the well should be disinfected by lowering a perforated

Table 5-3: Storage Capacities of Well Casing

Diameter of well (inches)	Storage in Gallons for Each Foot of Depth
4	0.654
5	1.02
6	1.47
7	2.00
8	2.62
9	3.31
10	4.09

Table 5-4: Well Disinfection Dose Per 100 Gallons of Water in Well Casing

Chlorine Dose	Calcium Hypochlorite 70%	Sodium Hypochlorite 5.25%	Contact Time
100 ppm (mg/l)	2 ounces or 4 heaped table-spoons	1 quart	12 hours
200 ppm (mg/l)	4 ounces or 8 heaped table-spoons	2 quarts	2 hours

Note: For Metric Conversion

1 inch = 2.54 centimeters
3.28 feet = 1 meter
1 quart = 0.946 liters
1 ounce by wt. = 28.35 grams

container such as a short length of tubing capped at both ends, filled with an adequate quantity of dry calcium hypochlorite, to the bottom of the well. The natural up-flow of water in the well will distribute the dissolved chlorine throughout the full depth of the well. A stuffing box can be used at the top of the well to partially, or completely, restrict the flow and so reduce the chlorine losses.

BACTERIOLOGICAL TESTS FOLLOWING DISINFECTION

After disinfection and thorough flushing to remove chlorine, a sample of the water produced should be collected for bacteriological analysis. If contamination is found, the well should be redisinfected to the satisfaction of the State regulating agency. If after repeated disinfection, the well continues to produce water showing bacterial contamination, the problem should be discussed with the State regulating agency. Continuous chlorination may be necessary.

ABANDONMENT OF WELLS

Unsealed, abandoned wells constitute a potential hazard to the public health and welfare of the surrounding area. All abandoned wells must be properly sealed to reduce these hazards. Proper sealing of a well will eliminate the physical hazard, prevent possible contamination of the ground water, conserve the yield and hydrostatic pressure of the aquifer, and reduce the chances of cross-contamination between aquifers.

The basic concept involved in the proper sealing of an abandoned well is to restore the integrity of the well hole to prevent the movement of water up or down the hole. This is accomplished by filling the well hole with concrete, cement grout, neat cement, or clays that have sealing characteristics similar to those of cement. In dug or bored wells, as much of the lining should be removed as possible so that surface water will not reach the water-bearing strata through the lining.

Abandoned wells should never be used for the disposal of sewage or other wastes.

CHAPTER 6

WELL PUMP SYSTEMS	Types of Pump and Characteristics - Sanitary Protection, Pumphouse - Hydropneumatic Systems - Gravity Storage Systems

INTRODUCTION

There is a wide choice of pumps and appurtenances to meet essentially all conditions encountered in the design and selection of well pumping systems. This Chapter discusses the more common pumping system arrangements, the various types of pumps available, pump characteristics, sanitary protection, the pumphouse and other related matters. Since the hydropneumatic (pressure tank) system is used extensively for small public systems, the design of these systems is presented in considerable detail. The use of well pump systems in conjunction with gravity storage is also discussed.

If the wells are capable of supplying water at approximately the peak water demand rate of the system, the hydropneumatic system may be used, provided the practical operating pressures are within the practical range of such systems. On the other hand, if the wells cannot be pumped at or near the peak demand rate, it may be necessary to (1) develop additional wells, (2) pump the wells at their safe yield rate into a ground level storage tank and employ a hydropneumatic system to deliver the peak demand rate at the system pressures, or (3) pump the wells at their safe yield into a gravity storage system. A cost analysis of the various practical pump systems will help in determining the most suitable arrangement.

WELL PUMPS

Three types of pumps are commonly used in small public water supply systems. They are the positive displacement, the centrifugal, and the jet. Variations include the submersibles and turbine pumps. Special types of pumps with limited application for public water supply systems include air lift pumps and hydraulic rams. Pumps are further typed as shallow-well pumps or deep-well pumps. Shallow-well pumps are limited to a maximum lift of about 22 feet (6.7 meters) as they depend upon the suction lift principal. Deep-well pumps lift and push water (depending on the design) and may be used to pump water from any practical depth.

Table 6-1, Pump Characteristics, lists the more common types of well pumps, describes how it works, the advantages and disadvantages and pertinent remarks. The Water System Handbook published by the Water Systems Council, 221 North LaSalle Street, Chicago, Illinois 60601, is a good reference publication. Appendix C lists several other publications on well pumps.

SELECTION OF PUMPING EQUIPMENT

Pumps are selected on the basis of the following fundamental considerations.

1. Yield of the individual wells.
2. Water consumption rates.
3. Choice of pumping system (hydropneumatic or gravity storage).
4. Capacity of pressure or gravity storage tank.
5. Size and alignment of the well casing.
6. Total operating head pressure of the pump at normal delivery rates, including lift and all friction losses.
7. Difference in elevation between ground level and water level in the well during pumping.

8. Availability of power.

9. Ease of maintenance and availability of replacement parts.

10. First cost and economy of operation.

11. Reliability of pumping equipment.

When the well yield is low in comparison to peak demand requirements, an appropriate increase in the storage capacity is required. The life of an electric drive motor will be reduced if there is excessive starting and stopping. Therefore, the water system should be designed so that the interval between starting and stopping is as long as is practicable. It is recommended that pump cycling rates be limited to 15 or less per hour.

The total operating head of a pump consists of the lift (vertical distance from well pumping level to the pump level), the friction and velocity head losses in the pipe and fittings, and the discharge pressure at the pump.

The vertical distance from the well pumping level to the axis of the pump is called the suction lift, and for practical purposes shallow well pumps using ordinary suction lift cannot exceed 15 to 22 feet of lift (4.6 and 6.7 meters), depending on the design of the pump and the altitude above sea level. The common shallow well pumps include the centrifugal, the piston pump and the shallow well jet pump. These pumps must be provided with a foot valve at the bottom of the suction line or a check valve in the suction line to hold a pump prime.

Submersible and turbine pumps do not generally operate under a suction lift as the pump bowls are submerged in the well. The deep well jet combines the principle of a centrifugal pump located above the well and a submerged ejector. The practical lift of the submersible and turbine is several hundred feet while the deep well jet is limited to a practical lift of 85 feet.

Table 6-1: Pump Characteristics. (Adapted from Rural Water Systems Planning and Engineering Guide)

	SUBMERSIBLE Multistage	JET (or EJECTOR) Shallow-Well or Deep Well	CENTRIFUGAL Shallow-Well
Practical Lift	To 1 000 feet	To 22 feet for shallow-well jet and to 85 feet for deep-well jet Greater depths are possible for deep-well jet but at the price of reduced efficiency	To 15 feet
How It Works	Operates the same as a shallow-well centrifugal pump except there are several impellers mounted close together on a single shaft The impellers, along with the motor are placed within a watertight housing immersed in the water source Each impeller and its diffuser (a guide to the next impeller) is called a stage Submersible pumps usually require a 4" or larger casing	Jet pumps consist of a pump (usually centrifugal) and a jet or ejector assembly The assembly is installed within the pump for shallow-well units or is installed down in the well to make a deep well unit The assembly consists of a body a nozzle and a venturi tube or throat The pump forces some water through the nozzle and venturi tube and forces the rest of the water to the distribution system	A rotating wheel or impeller develops a vacuum in the intake pipe Water fills the vacuum and the impeller increases the velocity of the water and forces it into a surrounding casing shaped to slow down the flow and convert the velocity to pressure
Advantages	Produces a smooth and even flow Easy to frost-proof installation Short pump shaft to motor	Few moving parts Both shallow-well and deep well jets can be offset from the well High capacity at low heads Can be offset from the well	Produces a smooth even flow The open impeller, but not the closed-impeller type will pump water containing small amounts of sand Usually reliable and has a good service life
Disadvantages	Repair to pump or motor requires pulling from well Easily damaged by sandy water	Easily damaged by sandy water The amount of water returned to ejector increases with increased lift 50% of the total water pumped at 50 feet lift and 75% at 100 feet lift	Loses prime easily Efficiency depends on operating under design heads and speed
Remarks	These pumps usually operate at 3500 rpm, the fastest practical speed for a 60 cycle electric motor Pump capacity depends on the design of the impeller The pressure depends on the diameter speed and number of impellers	Capacity depends on the design and number of impellers in the jet The pressure depends on the diameter speed and number of impellers	Very efficient for capacities over 50 gallons per minute and pressures less than 65 pounds per square inch An ideal pump for use as a booster pump can be offset from the water source

RECIPROCATING OR PISTON Shallow Well	 Deep Well	DEEP WELL TURBINE Multistage	SUBMERSIBLE Helical Rotor
To 22 feet	To 600 feet	To 1 500 feet	To 1 000 feet
A piston is driven within a chamber and develops a vacuum Water fills the vacuum and is forced into the water system as the piston reverses direction	A pump cylinder is attached to the bottom of the drop pipe A piston is attached to a rod in the drop pipe As the piston is forced up and down it pumps water up through the drop	Operates the same as a centrifugal pump except that there are one or more impellers mounted close together on a vertical shaft The bowls (each bowl is one stage —an impeller and its diffuser) are placed below the pumping water level with the column (discharge pipe) and shaft extending to the surface	A positive displacement pump mounted with a motor in a watertight housing
Can pump water containing small amounts of sand Can be installed over small diameter wells Positive displacement which means a constant rate of yield Adaptable to hand operation	Same as for shallow well The open type cylinder is easy to maintain	Produces a smooth and even flow Easy to frost proof installation Long drive shaft requires installation in a straight and vertical well casing	Produces a smooth and even flow Easy to frost-proof Short pump shaft to motor Will pump sand with less pump damage than any other type
Pulsating discharge and may cause vibration and noise	Same as shallow-well and the pump must be set directly over the well	Pump repair requires pulling from well	Repair to pump or motor requires pulling from well
Pump capacity depends on the size of the cylinder (displacement) and the number of strokes per minute Pressures are limited by the strength of the pumping equipment and the motor horsepower		Operates usually at either 1 760 rpm or 3 500 rpm depending on kind of power used Usually used for pumping large quantities of water from deep wells Pump capacity depends on the design, diameter and speed of the impellers The pressure depends on the diameter, speed and number of impellers	Pump capacity depends upon the design of the rotors Can be used in 4" or larger wells
Can be offset from the water source	Double acting pumping barrels are available that pump 65% more water using 15% more horsepower		

SANITARY PROTECTION OF PUMPING FACILITIES

The pump equipment should be constructed and installed to prevent the entrance of contamination or foreign material either into the well or system. The following factors should be considered.

1. Excessive use of pump lubricants may contaminate the well or water resulting in offensive tastes. Water used as a pump lubricant must be free from contamination.

2. The sanitary well seal, pitless adapter or pump base enclosure must prevent entrance of contaminated water and materials.

3. The pump intake assembly in the well should be located below the maximum drawdown to prevent loss of prime. Foot valves and or check valves should be accessible for cleaning or replacement. Only clean, safe water may be used for priming.

4. A pumphouse may be provided, where appropriate, to insure sanitary and frost protection and to house the controls and equipment, including a roof hatch for well maintenance and other accessories. See Figure 6-5.

5. A well vent is recommended on all wells except those using a packer-type jet pump which cannot work with a well vent because the casing is subjected to positive system pressure. The vent will prevent the development of a partial vacuum inside the well casing as the water level lowers. The well vent - whether built into the sanitary seal or well cover or conducted to a point remote from the well - should be protected from mechanical damage and have watertight connections.

The vent opening should be located above the highest anticipated flood level. It should be screened with durable and corrosion-resistant materials (bronze or stainless steel No. 24 mesh) or otherwise constructed so that openings exclude insects and vermin. Where appropriate, it should terminate in a downward position.

INSTALLATION OF PUMPING EQUIPMENT

The location of the pump and assembly and motor depends on the type of pump employed. The vertical turbine pump uses a power source located directly over the well and with the pumping assembly submerged within the well. The more popular submersible unit has the electric motor and the pump both submerged within the well. The jet pump may be located over the well or may be offset to another location. Because of the superior performance, better operating economy and other advantages of the submersible pump, it is used extensively in small water systems.

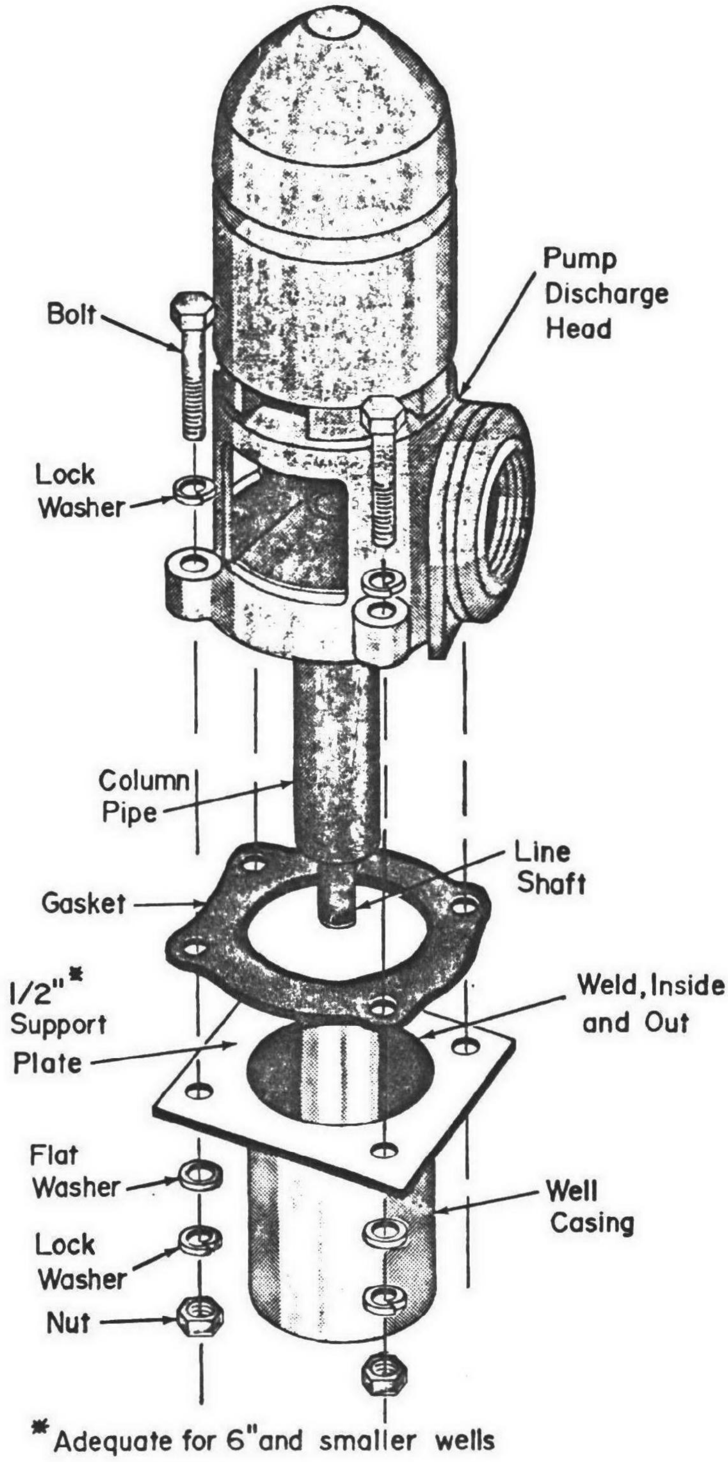
Vertical Turbine Pumps. The vertical turbine pump motor must be installed directly over the well casing. The pump bowls are submerged within the well and are connected by a shaft to the electric motor. The pump column supports the bearing system for the drive shaft and conducts the pumped water to the surface (See Figure 6-1 and 6-2).

Since the long shaft must rotate at high speed (1,800 to 3,600 rpm), correct and stable alinement of the motor, shaft, and pump is vital to good performance and long life of the equipment. Vertical turbine pumps should be installed by a competent workman.

Submersible Pumps. Because all moving parts of the submersible pump are located within the well as an integral unit, this pump can perform in mis-aligned casings that might be a problem for vertical turbine pumps. If there is any doubt about whether there is room to insert the pump in a casing without binding, a "dummy" pipe with dimensions slightly greater than those of the pump may be run through the casing to make sure that the pump will pass freely to the desired depth.

The entire weight of the pump, cable, drop pipe, column of water within the pipe, and reaction load when pumping must be supported by the

Figure 6-1: Vertical (line shaft) turbine pump mounted on well casing.



(Reproduced from EPA Manual of Individual Water Supply Systems, Figure 19, Page 105)

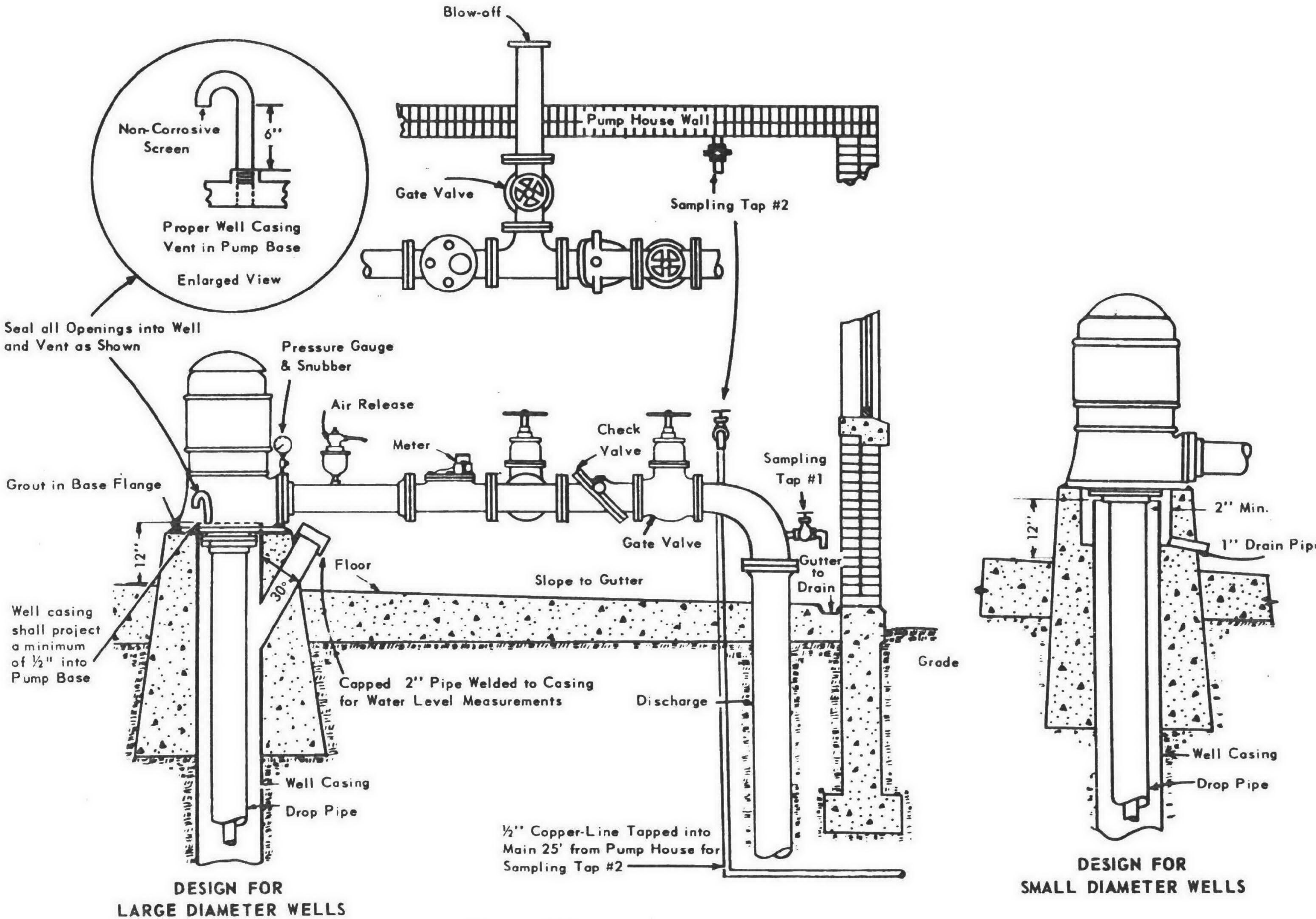
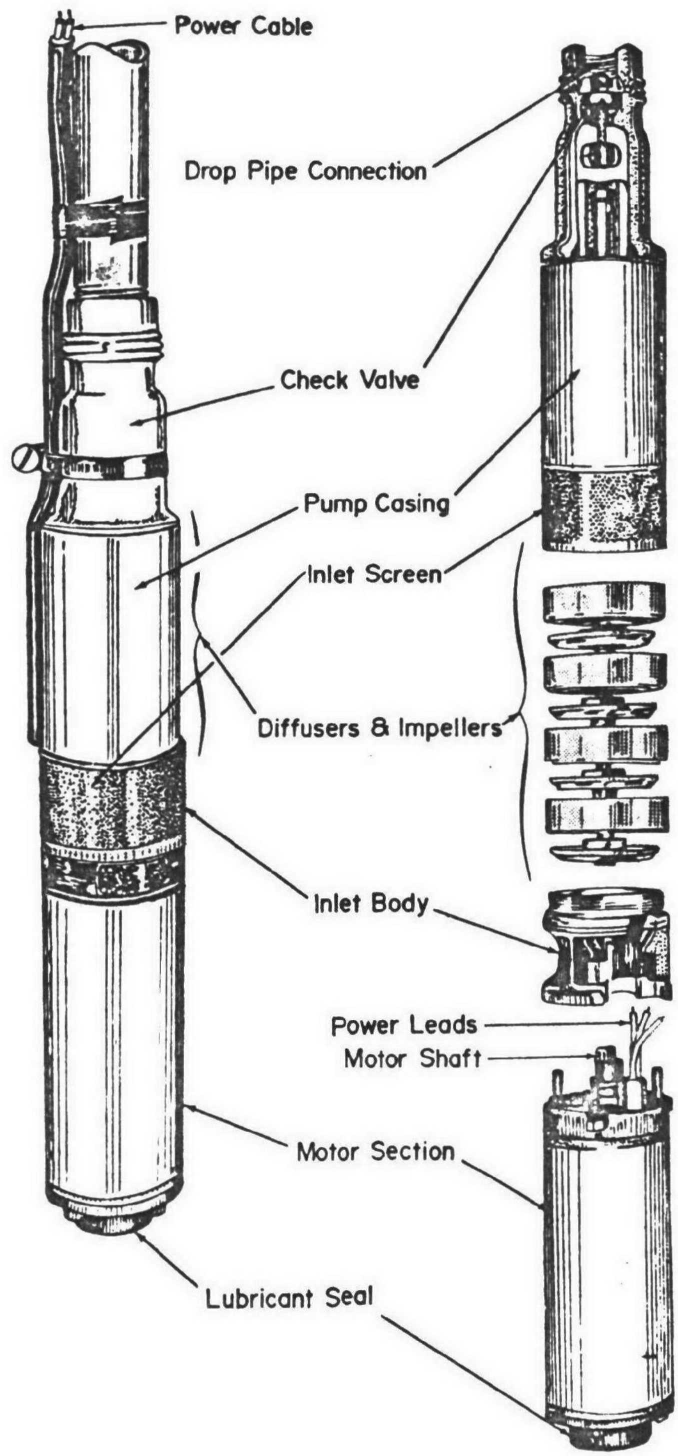


Figure 6-2

BASE DESIGNS FOR DEEP WELL TURBINE PUMPS

MICHIGAN DEPT. OF PUBLIC HEALTH

Figure 6-3: Exploded view of submersible pump.



(Reproduced from EPA Manual of Individual Water Supply Systems, Figure 15, Page 59)

drop pipe itself. It is important, therefore, that the drop pipe and couplings be of good quality, heavy duty, galvanized steel pipe. Cast-iron fittings should not be used where they must support pumps and pump columns. Furthermore, the entire load is normally suspended from the sanitary well seal or the "pitless" installation. Only durable units designed for these weights should be used. (See Chapter 5).

Jet Pumps. Jet pumps may be installed directly over the well, or off-set from it. Since there are no moving parts within the well, straightness and plumbness do not affect the jet pump's performance. The weight of equipment in the well is relatively light, being mostly pipe (often plastic), so that loads are supported easily by the sanitary well seal. There are also a number of good "pitless adapter" and "pitless unit" designs for both single and double pipe jet systems. (See Chapter 5).

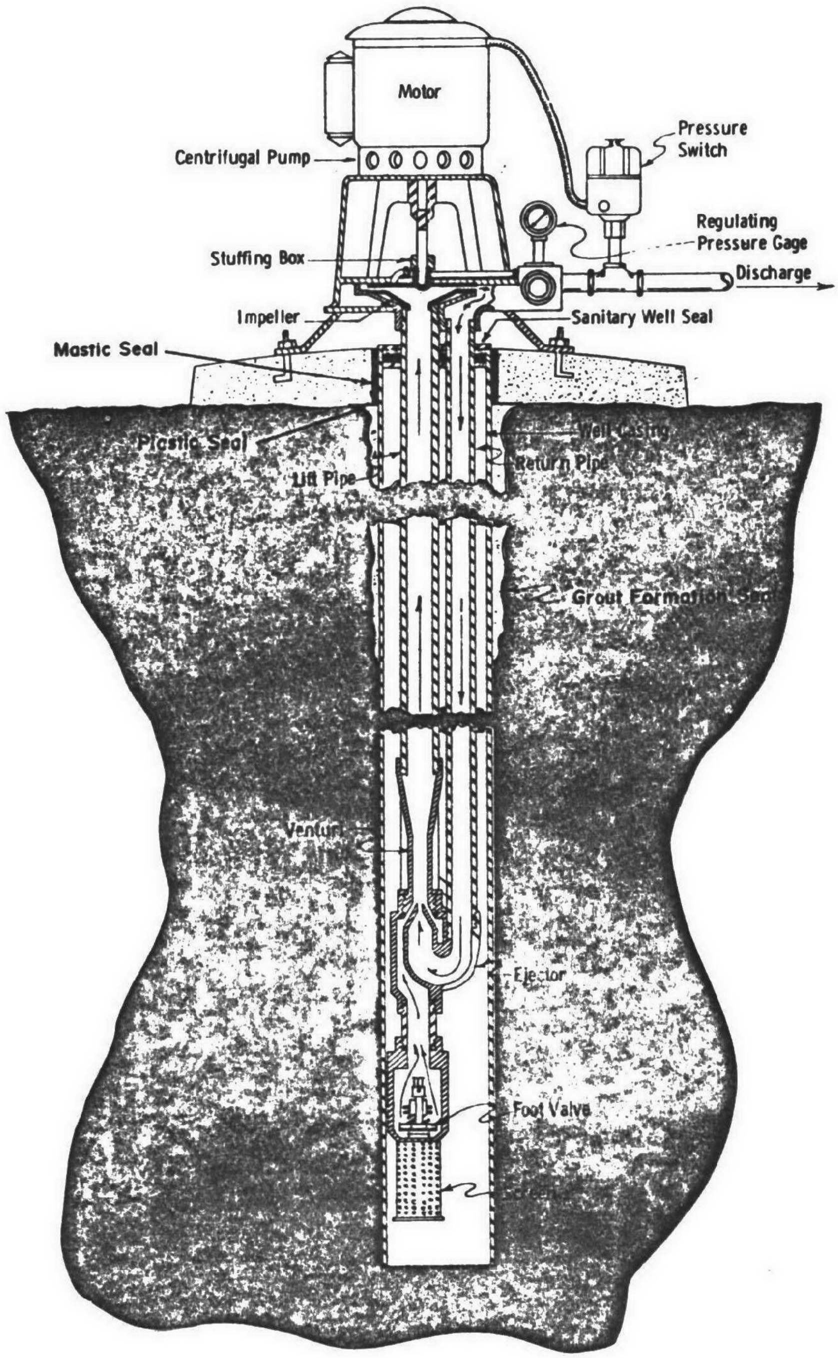
PUMPHOUSE AND APPURTENANCES (See Figure 6-5)

Where necessary a pumphouse should be installed above the surface of the ground. The pumproom floor should be of watertight concrete construction and should slope uniformly away from the well casing in all directions. A thermostatically controlled electric heater, or a heating cable will generally provide adequate protection when the pumphouse is properly insulated. In areas where power failures may occur and continuity of pump operation is critical, an emergency, gas driven power supply or pump should be considered.

LIGHTNING PROTECTION

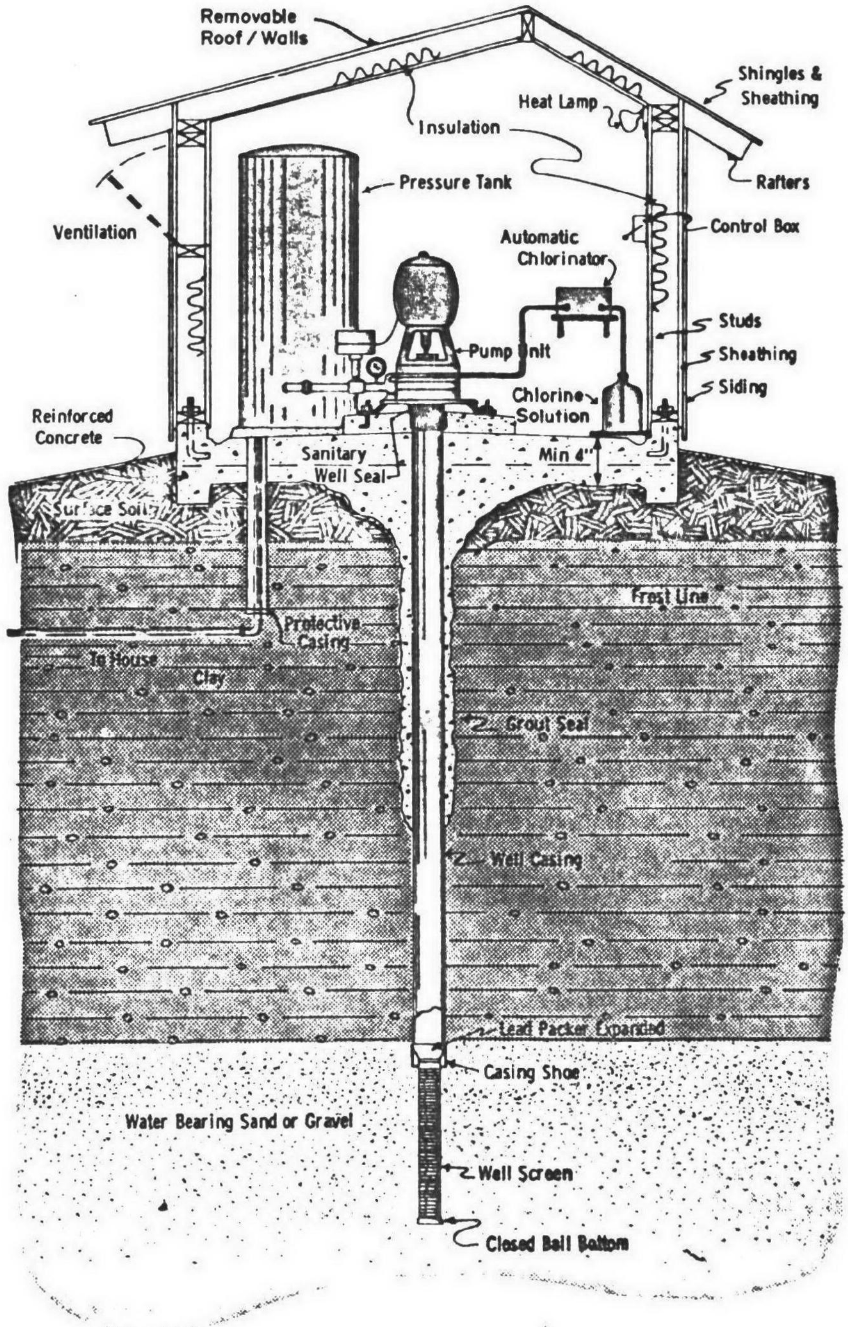
Voltage and current surges produced in powerlines by nearby lightning discharges constitute a serious threat to electric motors. The high voltage can perforate and burn the insulation between motor windings and motor frame. The submersible pump motor is somewhat more

Figure 6-4: "Over-the-well" jet pump installation.



(Reproduced from EPA Manual of Individual Water Supply Systems, Figure 16, Page 97)

Figure 6-5: Pumphouse.



(Reproduced from EPA Manual of Individual Water Supply Systems, Figure 20, Page 108)

vulnerable because it is submerged in ground water, the natural "ground" sought by the lightning discharge. Actual failure of the motor may be immediate, or it may be delayed for weeks or months.

There are simple lightning arresters available to protect motors and appliances from "near miss" lightning strikes. (They are seldom effective against direct hits.) The two common types are the valve and the expulsion units. The valve type is preferred because its "sparkover" voltage remains constant with repeated operation. Arresters must be installed according to instructions from the manufacturer and connected to a good ground. In the case of submersible pumps, this good ground can be achieved by connecting the ground terminal of the arrester to the submersible pump motor frame with a heavy stranded copper grounding wire. If the steel well casing extends into the water table, the ground can be improved by also connecting the grounding wire to the well casing. IMPORTANT NOTE. Connecting the arrester to a cooper rod driven into the ground does not satisfy grounding requirements. Similarly, if a steel casing does not reach ground water, it will not be a reliable ground.

Additional advice on the location and installation of lightning arrestors may be obtained from the electric power company serving the area.

HYDROPNEUMATIC SYSTEMS

Hydropneumatic systems are suitable for small pulic water supplies but have certain inherent limitations which should be considered before selecting them over the generally preferred gravity storage system.(1) Even when operated as pre-pressured (supercharged) systems, the effective (usable) storage is limited to less than 30 percent of the gross pressure tank capacity. This effective storage will generally amount to 2 - 30 minutes at peak demands. For this reason, it is desirable that the well yield and pump capacity approach the peak demand. If not, a ground level

(1) See Gravity Storage Systems in this Chapter for other advantages.

storage tank may precede the pressure tank to receive water from the well(s) at their safe yield(s) and store it for use by the pressure tank system. Gravity storage, on the other hand, can be provided with a full day storage or more to meet daily and peak flows on demand and in addition provide considerable backup to cover both planned or unplanned interruptions of equipment, the well(s) or other facilities. Gravity storage also has an advantage if water for fire protection is necessary.

Furthermore, pressure tank systems operate between pre-determined operating pressure ranges between pump cut-in and cut-out. This pressure difference will vary with installations but usually ranges between 20 and 30 psi. Therefore, pressure fluctuations in the system are frequent, particularly when compared to gravity storage systems.

Hydropneumatic systems, as the name implies, depend upon the maintenance of a cushion of air in the tank which is compressed by the water and in effect provides stored energy to force the water out on demand. In larger systems, the air is in direct contact with the water but smaller systems are available with a wafer, diaphragm or a bag which provides physical separation between water and air. When the air and water are in direct contact, continuous means must be provided to maintain a proper ratio of air in the tank. Several types of air-volume control devices are available depending on the characteristics of the water and the pump system. Supercharging tanks with air to achieve increased operating efficiencies and to increase the effective storage, require the installation of an air compressor and special air controls. On and off operation of pumps is achieved by the use of pressure control switches.

The following terms are in common use for hydropneumatic systems:

Capacity - the gross tank capacity in gallons.

Cycle rate - the frequency of pump start and stop per hour.

Drawdown or effective storage or usable water - the portion of the tank capacity represented by the amount of usable stored water between pump shut-off and pump cut-in.

Air volume - the portion of the tank volume occupied by air.

Pump starting pressure - a pre-determined low pressure in the water systems which activates the pressure switch to energize the pump motor (also called cut-in pressure).

Pump cut-out pressure - the pre-determined pressure which activates the pressure switch to shut off the pump motor.

Pre-pressurizing or supercharging - the periodic addition of forced air to the tank by means of an air compressor in an amount greater than the amount represented by the tank volume at atmospheric pressure. The maximum supercharging pressure must be less than the pump starting pressure, to avoid discharging air with water. Internal check valves are available to help control this situation.

Pressure storage tanks provide the following functions:

1. Prevents rapid cycling of pump motors. Most pump manufacturers recommend cycle rates less than 30 per hour.

2. Provide limited water storage under pressure to help meet short term peak demands by supplementing the pump capacity and provide water between pump cycles.

3. Provide a means of maintaining system pressures within predetermined limits.

4. Eliminate the need for large capacity gravity storage.

Types of Pressure Storage Tanks

There are 3 basic types of pressure storage tanks: (1) conventional, (2) floating wafer, and (3) flexible separators; diaphragm and bag types (See Figure 6-6).

Conventional Tanks - These tanks may be designed for vertical or horizontal placement and range in size from a few gallons (household sizes) to several thousand gallons. The outlet is located near the bottom of the tank and may be a combined inlet-outlet or they may be separated on opposite sides of the tank. Since the air cushion is in direct contact with the water, air volume controls are necessary. The air volume control is located in the upper portion of the tank and provisions are available for introduction of air for pre-pressurizing. Conventional tanks are suitable for wide range of systems from the single family size to public water system sizes with total tank capacity of 10,000 gallons and more.

Floating Wafer Tanks - This design (See Figure 6-6) employs a floating wafer to separate the water and air. Solid rigid floats and flexible rubber or plastic floats are used. The wafer rides or floats on top of the water. Since the separation of air and water is not complete, some loss of air can be expected and occasional recharging is necessary. Supercharging to pressures of about 2 - 5 psi less than the pump starting pressure is recommended. The inlet and outlet are generally combined at the bottom of the tank. In order to prevent premature loss of air due to electric outage or over water demands, an internal air check valve should be installed. These tanks are installed in the vertical position and the tank capacity is therefore limited in size by the prevailing geometry. They are therefore limited to smaller supplies.

Flexible Separators - These tanks may be either the bag type or the flexible diaphragm (See Figure 6-6). The separator is fixed or fastened around the inside of the tank to provide complete separation of air and water. Tanks are usually supercharged at the factory to pressures just below the pump starting pressure. An air recharging valve is provided but is seldom used as the complete separation of air and water results in no air loss and no air volume control is necessary. These tanks also stand in a vertical position and are therefore limited by the geometry to smaller public water systems.

Supercharging tanks provide improved cycle control and increased drawdowns. However, since the supercharging is at or just below the pump cut-in pressure, the tank is essentially empty of water at pump start-up. If the demand at the time of pump start is greater than the pump capacity, pressures in the water system will drop substantially. Therefore, separate supplemental supply tanks are desirable. The supplemental tank is supercharged at lower pressures than the primary tank and the differential pressure switch ranges are set closer.

Accessories

Pressure switches are installed on the pump discharge line near the tank inlet or in the tank itself. Switches generally have variable low pressure (pump start) settings and variable operating ranges for pump cut-off.

Pressure relief valves are necessary where high pressure pumps are used which may exceed the safe tank operating pressure rating, if the pressure switch should fail. Relief valves are installed in the inlet line as close as possible to the pump discharge. They must be large enough to relieve the maximum rated pump

Figure 6-6: Types of Pressure Tanks

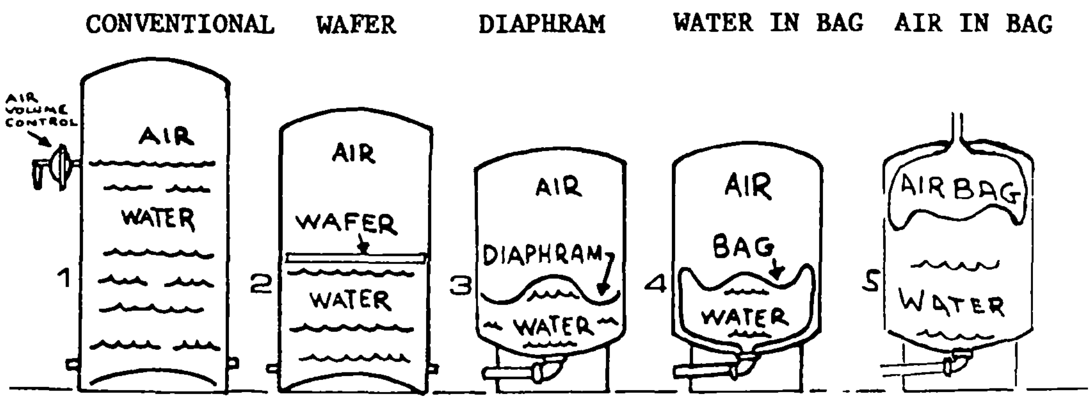
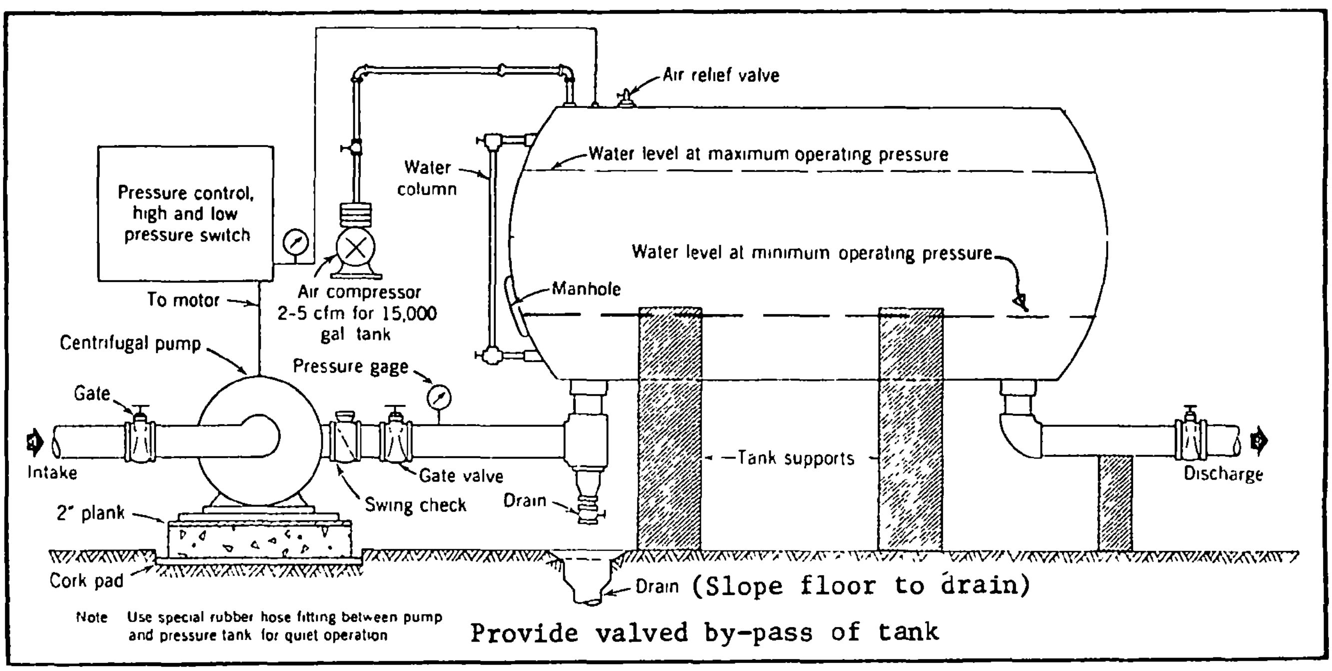


Figure 6-7: Typical installation of a pressure storage tank and centrifugal pump for a small water supply.



From *Environmental Sanitation* by Joseph A Salvato Jr published by John Wiley & Sons Inc New York 1958

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capacity at operating pressures or the working pressure of the lowest rated system component. They should be piped to a drain in such a manner as to insure no blockage of free flow.

Air Control Valves

Air controls which will add air to conventional and floating wafer tanks are available in two basic vacuum operated types. These controls are satisfactory for jet pump systems which operate at 6 feet or more of suction lift. If the suction lift is less than 6 feet as with deep well jets, a special vacuum booster pump is necessary. The air control valve must be sized for the system. Over sizing is no problem as the control operates only when more air is needed. Consult the equipment manufacturer for more details. A site glass installed on the pressure tank will readily indicate the relative air-volume ratio.

Vacuum boosters are also used in systems operating under supercharged (pre-pressurized) conditions. Over charging may be a problem and can be controlled with an internal air check valve which will prevent air from passing out of the tank when supercharging exceeds the pump cut-off pressure. Air compressors actuated by special controls are also used with supercharged systems.

Tankless (Constant Pressure) Systems

Several "tankless" type pressure systems are available. They are designed to eliminate the standard type pressure tanks but all have a small accumulator to reduce cycling. They are not applicable for public water systems except possibly as boosters for remote parts of the distribution system. Even so, a small tank type hydropneumatic system is more reliable. Many State agencies disapprove tankless systems.

Booster Pumps With Hydropneumatic Tanks

In areas where the topography varies considerably, some remote areas may experience low pressures. A booster pump and pressure tank system may be installed to boost the pressure as needed. The pump intake must be under a positive pressure from the distribution system. The hydropenumatic system is designed to meet the demand of the remote area. Boosters may be used in both hydropneumatic and gravity storage systems.

Pressure Tank Specifications

Specifications for the fabrication of hydropneumatic tanks are covered by Section VIII, Division 1, Boiler and Pressure Vessel Code, American Society of Mechanical Engineers (ASME), 345 E. 47th St., NY, NY 10017.

Determining the Required Effective Storage Capacity

Several factors must be considered in selecting a pressure tank size to meet the system needs. These include:

- The well pump capacity vs. the peak system demand (sometimes referred to as the instantaneous demand).
- Operating pressures and pressure range.
- Air volume control and supercharging.
- Pump cycling rate.

If the pump and well capacity are equal to or greater than the peak demand, a minimum size tank may be used and the pump cycling rate becomes the critical design factor (should be less than 30 cycles per hour). Peak demands are discussed in Chapter 3. If, however, the pump capacity is less than the peak demand, a pressure tank large enough to supply that part of the demand not furnished by the pump(s) should be used. The key factor then is the determination of the peak demand of the system. Once this is established, the other design criteria can be selected to meet the conditions. Unfortunately, reliable data on peak demands for the wide variety of small public water system uses is rather limited and only selected data is available at the present. Therefore considerable judgment may be necessary to arrive at a suitable peak demand. Until data is more readily available, local experience with satisfactorily functioning existing systems of a comparable type and size, will be useful.

Various rules of thumb and design criteria are used to size pressure tanks. They are based on experience and are usually expressed in terms of the required effective (usable) capacity. Some of these are listed below.

1. The minimum required effective volume of a tank (gallons) shall equal the peak demand (gpm) minus the well pumping capacity (gpm) multiplied by 20 minutes. Where the pump capacity exceeds the peak demand, the total tank capacity shall be not less than forty (40) times the number of residential units expressed in gallons but not less than 500 gallons. (A requirement of the State agency in North Carolina for residential and mobile home park systems.)

2. Based upon pump manufacturers criteria of a pump cycling rate of not more than 30 per hour, an effective minimum storage of at least 2 times the pump capacity expressed as gallons per minute is necessary. This is equivalent to 2 minutes of usable storage. This applies only if the well pump capacity is equal to or exceeds the peak demand.

3. If the wells and well pumps cannot supply the peak demand for the desired period of time (20 to 60 minutes) and it is desired to use a pressure tank system, the wells may be pumped at a safe continuous yield(s) into an intermediate storage tank located near the pressure tank system. Float switches may be provided to control on and off operation of the well pumps. This intermediate storage tank should be sized to insure sufficient stored water to meet the peak demand period. The minimum effective volume should

be the difference between the peak demand requirements and the rated well pump capacity (expressed in gallons per minute) multiplied by a time factor which will insure sufficient stored water to meet the duration of the peak demand. The hydropneumatic system pump draws water from the storage tank to meet peak demand conditions.

Sizing the Tank and Selecting Pressure Operating Conditions

After determining the required effective storage capacity of a pressure tank, the gross tank size and pressure operating conditions can be determined. Several methods of design are available, most based upon the principles of Boyles Law of Physics as it applies to the air volume-pressure conditions within a hydropneumatic tank. The method presented is particularly suited to preparing various design alternatives and the selection of the optimum design for the prevailing conditions.

Boyles Law states that the volume that a gas occupies (in this case air) varies inversely with the absolute pressure, provided the temperature does not change. When air is compressed by the water entering the tank or expands when water leaves the tank, the system follows the law for all practical purposes.

Boyles Law: $P_1V_1 = P_2V_2$

Condition 1 = Condition 2

Where: P_1 is the absolute pressure for condition 1, and is equal to the gauge pressure plus the atmospheric pressure (add 14.7 psi to gauge pressure).

V_1 is the volume or space occupied by the air in gallons at the pressure P_1.

P_2 and V_2 are the second conditions after compression or expansion of the air by water entering or leaving the tank.

If the above equation is solved for various conditions to simulate various pressure operating ranges, the results may be plotted on a chart as a family of curves. Tank size problems may be then solved graphically. A curve can be developed to simulate conventional tank operation where the tank is started with the air not pre-pressured. Other curves may be developed with the initial air pre-pressurized at various pressures. If these curves are developed for a gross tank size of 1,000 gallons, a family of curves may be prepared for all practical operating conditions for a hypothetical 1,000 gallon capacity tank. From the curves, the usable (effective) water storage volume can be determined for a 1,000 gallon hypothetical tank under any practical simulated condition of pre-pressuring from no pre-pressurizing up to say 55 psi pre-pressurization. This has been done to develop Figure 6-8. Each curve represents 5 psi increments of pre-pressurizing as labeled across the top of the chart. The bottom of the chart represents the cut-in and cut-out pressure of the pump. Figure 6-8 has been adopted from an article by C. Courchaine, P.E., Michigan Department of Public Health, published in Volume 11, No. 1 - Ground Water, January-February 1973.

Using Figure 6-8 to Size Pressure Tanks

In order to use the chart, several practical operating conditions are selected for trial. After analysis, the conditions which produce the optimum conditions are selected for sizing the tank. After sizing the tank, pressure controls and air controls (including an air compressor if necessary) are selected to best meet the selected operating conditions.

Step 1: Effective Storage Requirements: The previous section discusses the various methods of arriving at the desired or required effective storage capacity of a pressure tank necessary to meet the peak period demands. The effective storage capacity is the key factor in proceeding with the design. Once determined, proceed to Step 2.

Step 2: Pre-Pressuring: Select various conditions of pre-pressurization (super_charging) from none (zero), up to about 5 psi below the cut-in pressure. Use gauge pressure, not absolute, as the curves are developed for gauge pressure.

Step 3: Pressure Operating Range: Select various pump cut-in and cut-out operating ranges to meet the system pressure requirements at the peak demands. Common ranges for public systems are 25 to 35 psi cut-in to 45 to 65 psi cut-out. Use gauge pressures, not absolute. The pump(s) must be selected to operate efficiently under these pressure conditions.

Step 4: Using the Curves: With a given set of pressure operating conditions (including pre-pressure), proceed as follows using Figure 6-8.

- At cut-in pressure (left side of chart), draw a light pencil line to right until it intersects the selected pre-pressure curve, mark the point and draw a pencil line vertically downward to intersect at bottom of chart, "Volume of Water in Gallons."
- Do same for cut-out pressure.
- The difference between the volume of water (from the chart) for the cut-out and cut-in pressure is the usable storage for a hypothetical 1,000 gallon gross tank.

- Having chosen the "desired" usable storage capacity in Step 1, divide this by the actual usable storage in the hypothetical 1,000 gallon tank and multiply by 1,000. The result is the gross required tank size in gallons for that set of conditions.

$$\text{Required Gross Tank Size (gal.)} = \frac{\text{Desired Usable Storage}}{\text{Usable storage from chart}} \times 1000$$

- Repeat for all conditions.
- After analysis, select the optimum gross tank size to meet the required conditions.
- Select pressure and air controls to meet the selected conditions.

<u>Example</u>:

Given: Well pump capacity = 40 gpm

System peak demand = 60 gpm

Duration of peak demand = 20 minutes

Effective desired storage = (peak demand - pump capacity) x 20 minutes = (60-40) x 20 = 400 gallons

To find: Optimum conditions of prepressuring, pressure operating range and required gross tank size.

Solution: The tabulation that follows is a convenient method of setting up the problem. In this problem 7 different pressure operating conditions have been selected for analysis. Others could be chosen as desired.

The usable storage for each of the conditions (1 thru 7) is determined from Figure 6-8.

The required gross tank size for each of the 7 conditions is calculated as previously described.

An analysis of the tabulated results follows the Table.

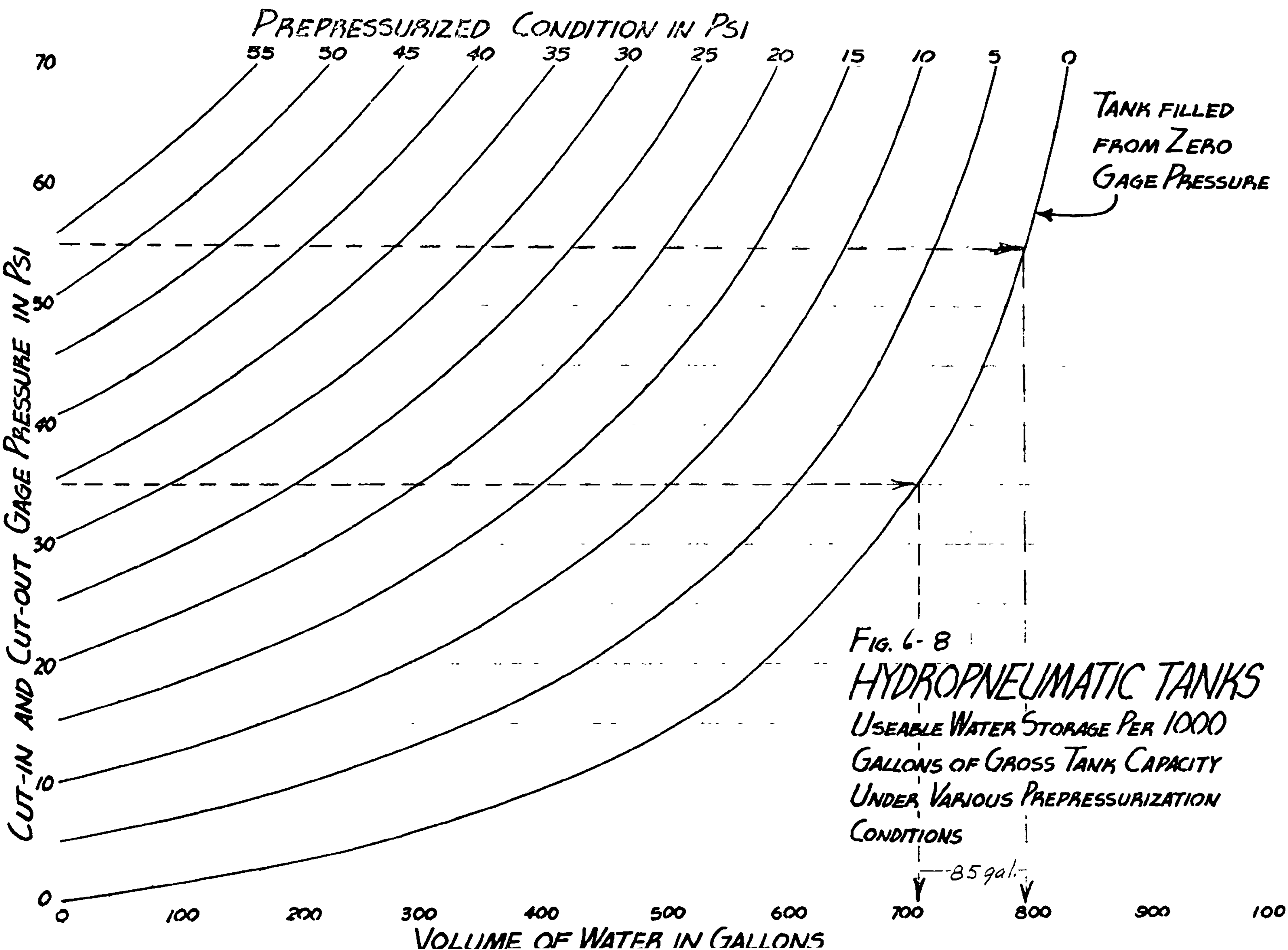

FIG. 6-8
HYDROPNEUMATIC TANKS
USEABLE WATER STORAGE PER 1000 GALLONS OF GROSS TANK CAPACITY UNDER VARIOUS PREPRESSURIZATION CONDITIONS

Tabulation to Facilitate Use of Figure 6-8 to Determine Gross Pressure Tank Size

	Conditions (Psi)			Usable Storage	Desired	
No.	Pre-Pressure	Cut-in	Cut-out	Hypothetical 1000 gal. tank	Usable Storage	Required Gross Tank Size (gal.)
1	0	35	55	85	400	400/ 85 x 1000 = 4,706
2	25	35	55	230	400	400/230 x 1000 = 1,739
3	30	35	55	250	400	400/250 x 1000 = 1,600
4	25	35	65	300	400	400/300 x 1000 = 1,333
5	0	35	65	120	400	400/120 x 1000 = 3,333
6	20	35	65	270	400	400/270 x 1000 = 1,481
7	35	40	60	245	400	400/245 x 1000 = 1,640

Analysis: Note the significant effect of pre-pressurizing on the usable capacity of the tank. Condition No. 4 appears at first to be the optimum condition, that is, pre-pressurizing to 25 psi with pump operating range of 35 psi cut-in and 65 psi cut-out, and a gross tank size of 1333 gallons. However, the 30 psi pressure difference between cut-in and cut-out may be undesirable. Also, the pre-pressurization is close to the cut-in pressure and very little water will be left in the tank at cut-in. If the demand should be higher than the pump capacity at that instant, air may spill out of the tank. Therefore, an internal air check valve is advisable.

Further analysis shows that Condition No. 3 or No. 7 will be the best overall choices.

If tanks are not manufactured in the size determined by the analysis, choose the next largest tank size.

GRAVITY STORAGE SYSTEMS

Well supplies are often pumped directly to a gravity distribution reservoir (tank) from which water flows on demand to the points of use. The wells may also be pumped directly into the distribution system with the tank floating (riding) on the system. Either arrangement is acceptable. The pumps may be controlled by water level float controls or pressure switches. The storage tank is located at an elevation which will insure adequate operating pressures.

A gravity storage system offers several advantages over the hydropneumatic systems and should be considered where topographic conditions are favorable. The larger the water system, the greater the advantages. However, even smaller systems will find the following advantages worthy of consideration.

- Less variations in pressure will occur.
- Storage for fire fighting purposes is possible.
- One to two days of storage may be provided to meet water requirements, thus improving reliability and reducing the need for duplication of facilities.
- Greater flexibility to meet peak demands.
- Wells do not need to be pumped to meet the peak system demand requirements. Therefore, lower capacity wells may be used.
- Pumps may be sized to take better advantage of electric load factors, thus reducing energy costs.
- On and off cycling of pumps is reduced.
- Several wells may be tied into the system and each pumped at its most favorable rate.

Since the gravity reservoir provides the storage necessary to meet the peak system demands, the wells need not be developed to meet the peak system capacities, as is generally necessary with pressure tank systems. The wells should be capable of meeting the maximum day demand within the period of time when water use is significant. As an example, day schools usually exert a significant water demand only over a ten to twelve hour day. The wells must, therefore, be pumped at a rate sufficient to meet the maximum day demand in a 10 to 12 hour period. Under these conditions, the reservoir (tank) should have an effective capacity equivalent to the average daily demand.

Gravity distribution reservoirs may be elevated tanks mounted on structural supports above ground, may be located partly below ground or may be tanks placed on pads or cradles on the ground surface. Elevated tanks are necessary where high ground is not available within the service area. The operating water levels of the tank should be sufficiently above the distribution system to produce minimum operating pressures of 35 psi (about 81 feet of head) but preferrably 50 psi to 75 psi (116 - 173 feet). Pressures should not exceed 125 psi (289 feet).

Note: 1 psi = 7 kilopascal (approximately)

1 ft. = 0.30 meters

Shallow reservoirs with large diameters are preferred over deep ones with smaller diameters, other things being equal. Larger diameter tanks have more water per foot of drawdown and are thus less prone to pressure fluctuations. They are also less costly to build.

Prefabricated standpipes and elevated tanks are readily available with a wide range of capacities. Pre-stressed concrete tanks are quite popular as they are not subject to corrosion and have less maintenance.

Reservoirs should be covered to prevent airborne contamination (birds and algae growths which impart tastes and odors). Access manhoes with locked covers are necessary and built-in ladders are advisable. Tanks must be vented (directed downward and screened) and overflows must be provided. Overflows should be directed away from footings. Steel tanks require painting and may require special corrosion control, such as cathodic protection devices. The State regulating agency will provide a listing of non-toxic paints suitable for interior tank use. Elevated tanks located near airports may require special lighting and should be approved by the Federal Aviation Administration or the local airport.

Over a period of time, reservoirs may accumulate organic and inorganic debris which settles to the bottom as a sludge. This sludge can contribute taste, odors and turbidity to the systems when it accumulates to a depth approaching the outlet pipe. Periodic draining of the tank and cleaning is necessary. This should be followed by disinfection before reuse.

Where the service area varies considerably in elevation, it may be necessary to employ two or more separate pressure zones, each served by a separate storage tank. An in-line centrifugal pump housed in a pump station and equipped with shut-off valves and check valves may be used to boost the pressure to the second level zone. The pump may be float or pressure controlled. In-line submersible pumps designed specifically as boosters are available. They fit into the water main and require no pump station. The suction side of booster pumps must be under a positive head at all times.

Small remote areas with low water pressure may be served by a hydropneumatic system located in a building or other structure. The system is sized to meet the tributary peak demand. The pump suction must be under positive pressure. Check valves are necessary. For design details, see the hydropneumatic system section in this Chapter.

DISINFECTION OF SYSTEM FACILITIES

Disinfection of Wells

See Chapter 5, Tables 5-3 and 5-4, for specific directions on the disinfection of wells.

Disinfection of The Well Pumping System

(See Chapter 5, Tables 5-3 and 5-4 for chlorine doses.)

After the construction or repair of a water pumping system, the system must be disinfected before use. The system should first be flushed to remove dirt and loose material.

All systems should be equipped with fitting(s) to permit the addition of chlorine disinfectants. The fittings may consist of 1/2" or 3/4" taps equipped with brass or stainless steel valves to serve as shut-offs when not in use. These may be located as follows:

1. A fitting should be connected to the well casing so that it may be disinfected when needed. If the well has a vent, the vent itself may be used for the occasional disinfection by removing the "U" turn fitting and pouring chlorine bleach into the vent.

2. A fitting should also be provided on the pressure side of the pumps between the pumps and the pressure tank if any. This same tap may be used for continuous chlorination of the water as described in Chapter 9, Chlorination. To disinfect the system, determine the amount of 5.25% chlorine bleach required for disinfection using Table 5-4 in Chapter 5 and, pump or inject this amount of bleach while filling the system, using a high capacity hypochlorinator. The chlorine bleach may also be added to the well casing to disinfect the entire well pump system as described in Chapter 5.

After disinfection at the proper contact period, and after thorough flushing to flush out the chlorine, a sample should be collected for coliform bacteria testing to verify that disinfection is complete.

Disinfection of Gravity Storage Tanks

After construction and before use, the storage tank must be disinfected to destroy micro-organisms which may be present. The tank interior must first be cleaned to remove dirt and loose material.

Large tanks may be disinfected by the direct application of a chlorine solution to the inner surface by means of a thoroughly cleaned garden type spray can. A spray can which has been previously used for spraying toxic chemicals, must not be used. Spray all inner surfaces with a 200 mg/l solution of chlorine made by adding 2 fluid ounces (59 ml) of 5.25% chlorine bleach (common household sodium hypochlorite bleach) to 4 gallons (30 liters) of clean water. The solution may also be brushed on the surfaces. The chlorine solution should remain on the surface for at least 2 hours. The tank should be ventilated to avoid inhalation hazards. After that the tank may be filled and tested as stated below.

Disinfection may also be accomplished by adding chlorine solutions to the structure as it is being filled. First determine the capacity of the tank in gallons. Add 2 quarts of 5.25% chlorine bleach for each 100 gallons of capacity for a 200 mg/l dose. High test calcium hypochlorite 70% available chlorine may also be used. Common forms are HTH and Perchloron. Use 1/2 lbs. for each 1000 gallons of tank capacity. Mix a slurry in a plastic pail and add to the tank as it is being filled. After at least 2 hours of contact, the tank may be drained. Cut the dose in half for 100 mg/l dose and increase the contact time to 12 hours. A 50 mg/ml dose (1/4 of above) may be used with a 24 hour retention time.

After disinfection, drain the tank and refill. A sample of the water in the tank should be collected and submitted to an approved laboratory for a coliform bacteria test. If the report is satisfactory, the tank may be used. If not, repeat the disinfection until the bacteria test is satisfactory.

Disinfection of the Distribution and Piping System

See Chapter 11 for details on the disinfection of the distribution and piping systems.

Discharge of Heavily Chlorinated Water to Streams

After the disinfection of a water supply system with chlorine, it is necessary to flush the system to remove the chlorinated water prior to re-sampling for testing and prior to placing the system back into service. Discharging the heavily chlorinated water to small streams or bodies of water may result in fish kills or damage to aquatic life. When this possibility exists, it may be necessary to flush gradually over an extended period of time. The flushed chlorinated water may also be stored in temporary ponds until the chlorine dissipates to less than 1 mg/l.

CHAPTER 7

DEVELOPING SPRINGS	Types - Development - Storage Systems - Disinfection

INTRODUCTION

In order to properly develop a spring supply, it is necessary to capture the natural flow of ground water as it issues at the surface of the ground, in a manner which excludes contamination of the water. Springs are subject to contamination by sewage disposal systems, animal wastes and surface drainage. Springs are also susceptible to seasonal flow variations and the yield may be reduced by the pumping of nearby wells.

Like wells, springs may be gravity or artesian.

Gravity springs occur where the water bearing stratum overlays an impermeable stratum and outcrops to the surface. They also occur where the land surface intersects the water table. This type of spring is particularly sensitive to seasonal fluctuations in ground water storage and frequently dwindles to a seep or disappears during dry periods. Gravity springs are characteristically low-yielding sources, but when properly developed they may be satisfactory for small water supply systems

Artesian springs discharge from artesian aquifers. They may occur where the confining formation over the artesian aquifer is ruptured by a fault or where the aquifer outcrops a lower elevation. Artesian springs are usually more dependable than gravity springs, but they are particularly sensitive to the pumping of wells developed in the same aquifer. As a consequence, artesian springs may be dried by nearby well pumping.

DEVELOPMENT OF SPRINGS[1]

There are three important criteria in the selection and development of a Spring: (1) selection of a spring with acceptable water quality, (2) development to the required quantity of water, and (3) sanitary protection of the spring collection system. The measures taken to develop a spring must be tailored to the prevailing geological conditions.

The main features of a spring collection system are as follows (See Figure 7-1).

- The spring flow is intercepted by a system of perforated pipes driven into the water bearing stratum or layed in gravel packed trenches. The flow is directed into a storage tank. As an alternate, a watertight concrete collection chamber is constructed with openings in the bottom and/or a side wall to intercept the flow. This chamber may also serve as the storage tank. The storage tank or chamber may be sized to provide gravity storage to meet the daily water requirements as described in Chapter 3 or the flow may be piped to a separately located storage reservoir. Where possible, the walls of the collection chamber should extend to bedrock or the impervious stratum. The watertight walls should extend 8 or more inches (20 centimeters) above ground to prevent entrance of surface water. An overlapping (shoe box) cover will prevent entrance of debris.
- A valved drain is necessary to permit draining, cleaning and maintenance.
- A screened over flow is essential.
- The valved supply pipe is inserted a few inches above the chamber or tank floor. If the supply pipe serves the distribtuion system directly, it must be sized to meet peak demands. See Chapter 3.

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(1) Consult with the State agency for special requirements.

The tank is usually constructed in place with reinforced concrete so as to intercept as much of the spring as possible. When a spring is located on a hillside, the downhill wall and sides are extended downward to bedrock or impervious soil to insure that the structure will hold back water to maintain the desired level in the chamber. Supplementary cutoff walls of concrete or impermeable clay may be used to assist in controlling the water table in the vicinity of the tank. The lower portion of the uphill wall of the tank must have an open construction to allow water to move in freely while holding back the aquifer material. Spaced or open concrete blocks work good. Backfilling with graded gravel will aid in restricting movement of aquifer material.

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

A drain pipe with an exterior valve should be placed close to a wall of the tank at the floor level to permit draining. The end of the pipe should extend far enough to allow free discharge to the ground surface, away from the tank. The discharge end of the pipe should be screened to prevent nesting by animals and insects.

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

The supply outlet should be located about 6 inches above the floor and should be screened. Care should be taken to insure good bond between pipes and the concrete structure.

SANITARY PROTECTION

Springs may become contaminated when barnyards, sewers, septic tanks, cesspools, or other sources of pollution are located on higher adjacent land. In limestone formations, however, contaminated material may enter the water-bearing strata through sink holes or other openings and may be carried along with ground water for long distances.

The following precautionary measures will help to insure spring water of a consistently high quality:

1. Provide for the diversion of surface drainage from the site. A surface drainage ditch should be located uphill from the source so as to intercept surface water runoff and carry it away from the source.

2. Construct a fence to prevent entry of livestock in the area which contributes drainage to the water bearing strata and the spring collection system.

3. Protect the spring collection system from human tampering by fencing, locked covers, and warning signs.

4. Monitor the quality of the spring water. A marked increase in turbidity or flow after a rainstorm is a good indication that surface runoff is reaching the spring.

SPRING STORAGE SYSTEMS

Gravity Storage Systems

Spring sources are quite often located at elevations considerably above the points of water use. If the elevation difference is sufficient to provide adequate pressures (35 to 100 psi, 81 to 231 ft.) at the points of consumption, a gravity supply system may be used. Since the storage capacity of the spring collection chamber will generally not have sufficient capacity to serve as an effective storage reservoir (except for very small systems), water from the spring chamber may be piped to a conveniently located gravity storage reservoir. The spring flow should be sufficient to meet the maximum daily water demands. The storage reservoir should have a minimum capacity of one day's storage calculated on the basis of the average daily demand (See Chapter 3).

Occasionally springs may require pumping to overcome elevation differences. Properly sized centrifugal pumps may be used to pump water from the spring basin and pump the water to a gravity reservoir placed at a convenient location to provide gravity distribution. The pump may be controlled by a float or pressure switch.

The design of separate gravity storage tanks (reservoirs) is discussed in more detail in Chapter 6, Well Pump Systems.

Hydropneumatic Systems

Where gravity storage reservoirs are not possible or desirable, a pressure pneumatic system may be used. The pump (usually a centrifugal pump selected for the prevailing conditions) may draw water directly from the spring collection chamber or a spring storage tank. The design details are similar to that discussed in Chapter 6, the section on Hydropneumatic Systems.

DISINFECTION

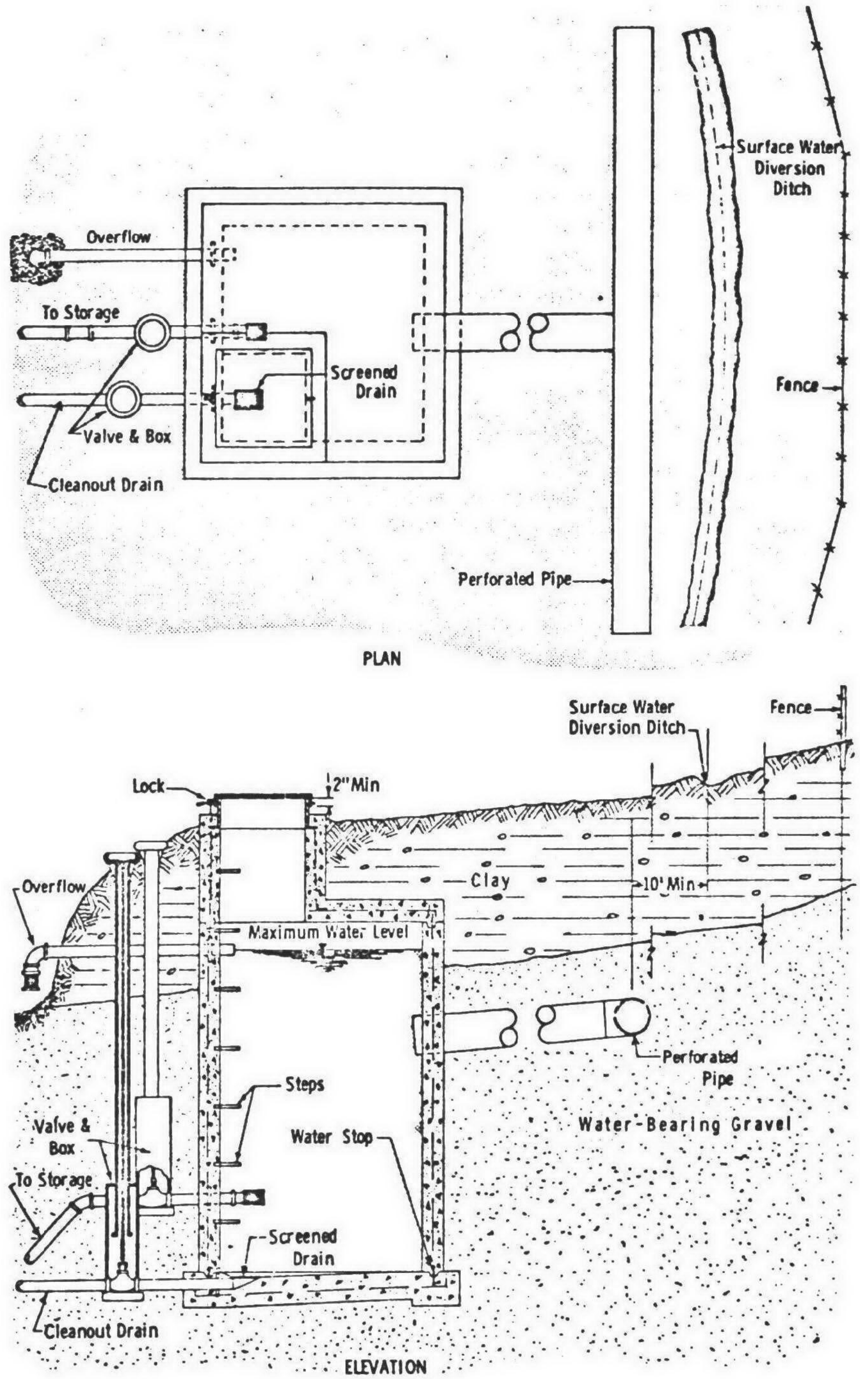
Spring collection chambers should be disinfected prior to use. Determine the capacity of the spring chamber and storage tank. For each 100 gallons of capacity, the following quantities of chlorine disinfectant should be added for a chlorine concentration of 200 mg/l (ppm). Pre-mix the chlorine compound in a pail of water and pour into the chamber or tank and mix.

Calcium Hypochlorite (HTH) 70% Available Chlorine		Sodium Hypochlorite Bleach 5.25% Available Chlorine	
Metric Units	English Units	Metric Units	English Units
300 grams per cubic meter of capacity	4 ounces per 100 gallon capacity	5 liters per cubic meter capacity	2 quarts per 100 gallons of capacity

Mix and wash interior walls above the water level using a clean broom or brush. Run water through the overflow and drain. Allow at least 2 hours of contact and then drain until the strong chlorine odor disappears. The chlorine dose may be reduced to 100 mg/l dose and the retention time increased to 12 hours.

After disinfection and flushing to remove the chlorine, collect a sample for coliform testing at an approved laboratory. If the results are unsatisfactory, repeat the disinfection process until coliform tests are acceptable.

Figure 7-1: Spring Protection



(Reproduced from EPA Manual of Individual Water Supply Systems, Figure 10, Page 57)

CHAPTER 8

DEVELOPING SURFACE WATERS	Streams-Lakes-Ponds-Reservoirs - Infiltration Galleries - Storage Systems

SURFACE WATERS

Surface waters are exposed to both natural and man induced pollution. Unlike properly developed ground waters which maintain a fairly constant quality, surface waters vary greatly in quality depending upon natural and man made events. Therefore, all surface water supplies require treatment to a greater or lesser degree depending upon the circumstances. Invariably, the treatment is more sophisticated than with ground waters and requires more diligent operation and maintenance and more costs. Also, the legal aspects involving surface water rights must be carefully considered. A professional engineer should be engaged to plan and design surface water sources.

Notwithstanding, there are occasions when the use of surface waters for a small water supply is unavoidable due to the poor quality of local ground water or the lack of adequate ground water. Under these conditions, surface supplies may be considered. Because of the more detailed requirements which must be met, it is advisable to consult with State authorities early in the considerations.

Other factors being equal, impoundments including lakes, ponds, reservoirs, etc. are preferred over streams as the quality of the water is usually less variable, reducing the extremes in quality. Treatment facilities may then be designed for these less extremes, thus reducing the sophistication of treatment and costs.

As described in Chapter 2, a complete sanitary survey of the pertinent part of the watershed must be made before proceeding with the design. Assuming that the sanitary survey shows favorable conditions and the source will provide an adequate quantity of water to meet needs, the required treatment processes can be determined, after consultation with the State agency. The design features related to the development of the source itself should include:

- Intake structure and screens.
- Pump stations or gravity flow (whichever is appropriate) to the treatment plant.
- Treatment plant design. Filtration, most likely preceded by pre-conditioning, and chlorination are usually necessary.
- Treated water storage, pumping facilities and distribution storage, as needed.
- Chemical storage, as needed.
- Waste water disposal as required by the State agency.
- Plant operating procedures and operating reports and records.
- Sampling and testing, including on-site laboratory facilities for treatment plant operation control.
- Qualification of operators (consult State authorities for requirements).
- Metering devices as appropriate.

Pre-packaged treatment units are available and are often suited for small surface water supplies. Some are highly automated and may reduce (but not eliminate) the need for manual operation.

INFILTRATION GALLERIES

Recreational or other developments located in the mountains may have access to a head water mountain stream where the watershed is generally heavily forested and uninhabited by man. However, following periods of heavy rainfall or spring thaws, debris and turbidity may cause problems at the water intake and will materially increase the required degree of treatment. If the conditions are suitable, this problem can be avoided by constructing the intake in an underground chamber (infiltration gallery) along the shore of the stream or lake.

Galleries may be considered where porous soil formations adjoin a stream or lake so that the water can be intercepted underground to take advantage of natural filtration. Any gallery access structures should be located above the level of severe flooding.

A typical installation generally involves the construction of an underdrained, sand filter trench located parallel to the stream bed and about 10 feet from the high water mark. The sand filter is usually located in a trench with a minimum width of 30 inches and a depth of about 10 feet, sufficient to intercept the water table. At the bottom of the trench, perforated or open joint tile is laid in a bed of gravel about 12 inches in thickness, with about 4 inches of graded gravel located over the tile to support the sand. The embedded tile is then covered with clean, coarse sand to a minimum depth of 24 inches, and the remainder of the trench backfilled with fairly impervious material. The collection tile drains to a watertight, concrete chamber from which water may flow to the distribution system by gravity or pump, whichever is appropriate. Chlorination will be necessary and may be done in the chamber or at another place, but prior to any use.

Where soil formations adjoining a stream are unfavorable for the location of an infiltration gallery, the debris and turbidity which may be occasionally encountered in a mountain stream may be controlled by constructing a modified infiltration gallery, constructed in the stream bed.

If a natural pool is not available in the stream bed, it will be necessary to construct a dam across the stream to form a pool. The filter is installed in the pool by laying perforated pipe in a bed of graded gravel which is then covered by at least 24 inches of clean, coarse sand. About 24 inches of free board should be allowed between the surface of the sand and the surface water level. The collection lines may terminate in a watertight, concrete basin located adjacent to the upstream face of the dam from where the water is diverted to chlorination facilities.

RAW WATER STORAGE

Surface water sources are often located at higher elevations which may permit gravity storage and distribution to the points of consumption. Where these conditions exist, a gravity system may be used.

If the surface water source has a safe yield equal to at least the maximum daily demand, a raw water (water prior to treatment) reservoir may not be necessary. A large lake or impoundment used as a small water supply source usually has sufficient storage to meet daily needs. However, an analysis should be made to remove any doubt.

If the surface water source cannot meet maximum day demands, a raw water reservoir must be provided. The reservoir should have sufficient capacity to insure maximum daily demands during dry periods. A detailed analysis is necessary to determine the proper capacity.

Surface water sources may require pumping to overcome elevation differences. Centrifugal pumps are often used to pump water from the intake structure to the treatment plant.

TREATMENT

Surface waters must be treated. Consult the State agency for requirements (also see Chapters 9 (Chlorination) and Chapter 10 (Treatment and Conditioning).

The treated water storage and distribution design is essentially the same as described in Chapter 6, Hydropneumatic and Gravity Storage Systems, and Chapter 11, Distribution System.

CHAPTER 9

CHLORINATION	Chlorination Principles - Terminology - Influencing Factors - Contact Time - Chlorinator Capacity - Preparing Stock Solutions - Residual Tests

INTRODUCTIONS

Micro-organisms are ever present in the environment. Since water is a product of the environment, it must be considered to be contaminated unless a series of biological tests prove otherwise. By no means are all micro-organisms in the water environment harmful to people, but some are pathogenic (disease producing), particularly those associated with the intestinal discharges of man or animals infected with enteric (intestinal) diseases. Pollution by sewage is by far the greatest risk but animal wastes cannot be discounted. Surface waters are highly susceptible to pollution and the normal "cleansing action" of streams and impoundments cannot be relied upon to rid the water of these pathogens. Ground waters are also subject to pollution from subsurface sewage disposal systems and leaking sewers. However, the cleansing action of water moving slowly through soil and some rock formations does have a significant affect in straining and eliminating pathogens and coliform organisms[1] in general. Therefore many well supplies, after thorough testing, may be used without disinfection. Surface waters must always be disinfected before public use. The prudent water purveyor will always provide disinfection, even if not required by the State agency.

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(1) See explanation and significance of coliform organisms in Chapters 1 and 11.

Disinfection is the process of destroying a large portion of the micro-organisms in water with the probability that all pathogenic bacteria are killed in the process. In water treatment, disinfection is almost always accomplished by adding chlorine or chlorine compounds. The practice is so effective and has such wide acceptance that the term "chlorination" is used synonymously with disinfection. Without a doubt chlorination is the most widely practiced unit treatment process, and for good reason. Disinfection is often required by State agencies where the water is of questionable bacteriological quality or where there is a potential for contamination. In other instances, the water purveyor may wish to provide disinfection as a measure to reduce risks, increase reliability, control growths in the system, oxidize odors and taste producing substances and provide a residual protection against inadvertent contamination within the distribution system. The cost of effective chlorination is surprisingly modest compared to the advantages. It is highly recommended that every public water system be continuously disinfected.

A number of chemicals and methods are available for disinfection, but none have achieved the success of chlorination. If the water purveyor wishes to consider other methods, the State agency should be consulted. The interested reader is referred to the American Water Works Association publication entitled "Water Quality and Treatment" for further discussion on the advantages and limitations of disinfectants other than chlorine.

CHLORINATION METHODS

Chlorine may be applied by two basic methods: (1) gas chlorination employing compressed chlorine gas or (2) hypochlorination employing a chemical feed pump to inject a water solution of chlorine compounds.

Gas Chlorination

Chlorine gas is available in compressed liquid form stored in steel pressurized cylinders, generally available in 100 lbs., 150 lbs. and ton containers. A gas chlorinator must be employed to meter the gas flow and mix it with water which is then injected as a water solution of pure chlorine. Small water supplies can effectively handle the 100 or 150 lb. container but the larger containers are not recommended for small systems as special hoists and cradles are required for handling. Chlorine gas is a highly toxic lung irritant and special facilities are required for storing and housing gas chlorinators. Chlorine gas dealers and chlorinator manufacturers will supply details. The advantage of this method is the convenience afforded by a relatively large quantity of chlorine available for continuous operation for several days or weeks without the need for mixing chemicals. Gas chlorinators have an advantage where variable water flow rates are encountered as they may be syncronized to feed variable rates of chlorine feed. Capital costs are somewhat greater but chemical costs may be less.

Although gas chlorination is used extensively in larger water systems, most small system operators will find the use of chlorine compounds mixed with water and fed into the system with inexpensive hypochlorinators, completely satisfactory. Gas chlorinators require special safety precautions and should not be used until the plans of a facility are approved by the State agency. (Suggested reference, Safety Practices for Water Utilities-M3, American Water Works Association, Reference No. 33.)

Hypochlorination

Chlorine compounds come in a variety of forms. They are readily available throughout the country because of their common household and swimming pool use.

- Chlorine solutions of sodium hypochlorite (NaOCl), are available as 5.25% chlorine (common household chlorine bleach) and 15% solutions available in 5 gallon carboys and larger quantities.
    - 1 gallon of 5.25% contains 0.42 lbs. of available chlorine
    - 1 gallon of 15% contains 1.25 lbs. of available chlorine

  The chlorine solution mixes easily with water to make stock water solutions of the desired strength.
- Granular form as high test calcium hypochlorite containing 65-70% available chlorine, commonly marketed as HTH, PitChlor, Perchloron, etc.

  The dry forms of chlorine require mixing with water to make a stock solution of the desired strength. Mixing is somewhat tedious and precipitates of calcium salts in the stock solution and chemical feeder requires regular maintenance. The dry forms can be stored for considerable periods in the original container, in cool dry places.

The water solutions of either the liquid or granular dry forms are prepared in predetermined stock solution strengths and are injected into the water supply using special chemical metering pumps called hypochlorinators. The positive displacement types are highly accurate and reliable and are preferred over hypochlorinators employing other feeding principals, usually based on a suction principal. Because these latter units are not accurate and reliable, State agencies generally do not approve their use where disinfection is required to insure a safe water.

Positive displacement type hypochlorinators are readily available from water conditioner suppliers at relative modest costs. These small chemical feed pumps are designed to pump (inject under pressure) an aqueous solution of chlorine into the water system. They are designed to operate against pressures as high as 100 psi but may also be used to inject chlorine solutions at atmospheric or negative head (suction side of water pump) conditions. In the latter cases, anti-siphon devices are necessary (usually built into the unit). Hypochlorinators come in various capacities ranging from 1.0 to 60 or more gallons per 24 hours. Most manufacturers make an intermediate range unit adjustable from 1 to about 24 gallons per 24 hours. This size is usually adequate for small systems.

The pumping rate is usually manually adjusted by varying the stroke of the piston or diaphragm. Once the stroke is set, the hypochlorinator feeds accurately at that rate, maintaining a constant dose. This works effectively if the water supply rate is fairly constant, as with the output of a pump. If the water supply rate varies considerably, a metering device[(1)] may be used to vary the hypochlorinator feed rate syncronized with the water rate. Where a well pump is used, the hypochlorinator is connected electrically with the on-off controls of the pump. If two or more wells are designed to operate independently, a hypochlorinator may be required for each pump output. Figure 9-1 shows a typical setup with one well pump.

In instances where chlorination is required by the State agency, spare repair kits and preferrably a standby hypochlorinator should be available at all times.

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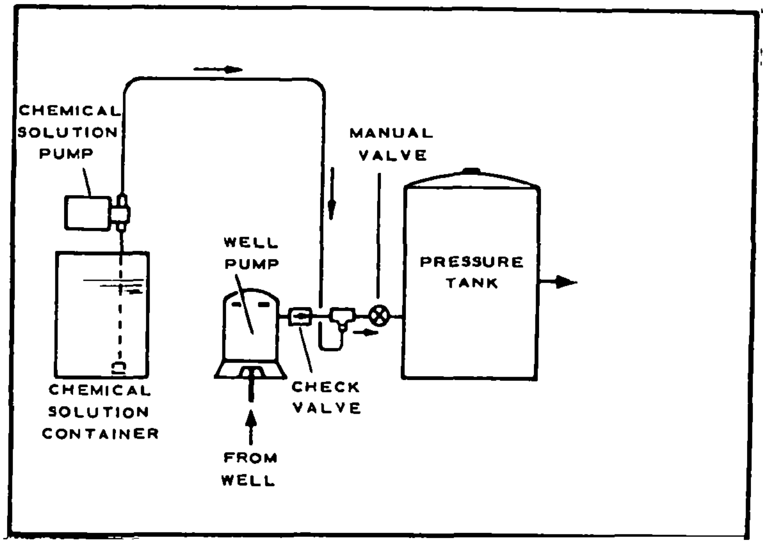
(1) Metering devices are available to vary the feed rate of both electrically powered and water powered hypochlorinators. The latter may be used where electric power is not available at the chlorination site.

Figure 9-1: Typical Hypochlorinator Installation



CHLORINATION TERMINOLOGY

Regardless of the form of chlorination, chlorine gas or chlorine compounds, the reaction in water is basically the same. The standard term for the chlorine concentration is either milligrams per liter (mg/l) or parts per million (ppm). The latter seems to be more acceptable to water plant operators and will be used in the discussion that follows:

1. Chlorine Fed or Dose: The total amount of chlorine fed into the water system by the chlorinator.

   - With gas chlorination, the dose is often expressed as pounds of chlorine per day as measured with weight scales which show the daily loss in weight of the chlorine cylinder. The pounds per day dose may be converted to ppm as follows:

     $$\text{ppm} = \frac{\text{lbs. chlorine fed/day} \times 83}{\text{gallons per minute}} \quad \text{or} \quad \frac{\text{lbs. chlorine fed/day} \times 5000}{\text{gallons per hour}}$$

   - When chlorine compounds are injected as a water solution by means of a hypochlorinator, the number of gallons of stock solution fed per day is recorded. The solution strength is usually expressed as a percentage of chlorine or simply the number of gallons of chlorine bleach (%) per gallon of water to make up the stock solution.

2. Chlorine Demand: Chlorine is a very active chemical oxidizing agent. When injected into water, it combines readily with certain inorganic substances which are oxidizable (hydrogen sulfide, nitrites, ferrous iron, etc.) and with organic impurities including micro-organisms and their decay products. These reactions consume or use up some of the chlorine before it can fully destroy micro-organisms. This amount used up is the chlorine demand.

Chlorine Demand = Chlorine Dose - Chlorine Residual

3. Chlorine Residual is the amount of chlorine (by test) present in the water after the chlorine demand is satisfied. The presence of a "free" residual of at least 0.2 - 0.4 ppm[2] (in relatively unpolluted, low turbidity water) after the chlorine demand is satisfied, usually provides a high degree of assurance that the disinfection of the water is complete. However, several other factors must be considered, including the factors discussed on page 9-11.

   A free residual also provides some protection against any chance contamination which may inadvertently enter the system. The chlorine residual test sample is usually collected before the first point in the distribution system where water is consumed. However, it is also advisable to take the test at the furthest point in the system to insure that a residual exists throughout the whole system. The residual test is the basis for increasing or decreasing the chlorinator feed rate to achieve the desired value. Too much chlorine residual will be offensive to some consumers.

Chlorine Residual = Chlorine Dose - Chlorine Demand

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(2) See Table 9-1.

4. Chlorine Contact Time: The contact time is the time interval (usually minutes) that elapses between the time when chlorine is added to the water and the time when that same slug of water passes by the sampling point. A certain minimum period of time is required for the disinfecting action to become completed. The minimum required time depends on several factors.

   (a) The chemical form of the available chlorine residual (See Item 5). "Free available chlorine" is faster acting than "combined chlorine."

   (b) The magnitude of the residual - The higher the residual, the more active and faster the disinfection.

   (c) The pH of the water - The higher the pH, the longer the time required.

   (d) Water temperature - The lower the temperature, the longer the contact time required.

   The contact time is usually a fixed condition dependent upon the rate of flow of the water and the time it takes the water to pass through the piping and storage facilities. Generally speaking, it is preferrable that the contact period be not less than 30 minutes, under the peak demand flow conditions. However, even more may be necessary under unfavorable conditions. Under those conditions it may be necessary to add a contact tank of sufficient capacity to provide the necessary contact time. Consult the State agency for further advise.

5. Chemical Forms of Chlorine Residual: Most waters contain some organic matter and the products of organic matter decay, particularly ammonium compounds, more so for surface waters but also true of ground waters. They may be of recent time origin or have an origin in the distant past history of the water. These compounds react with chlorine and often

form so-called "combined chlorine," including chloramines (ammonia compounds plus chlorine). These combined forms of chlorine are more or less weak disinfectants and they may show up as chlorine residual in some testing procedures. The excess chlorine (over and above that combined with ammonia or organics) is called "free available chlorine" and is a highly desirable, active disinfectant. The "total chlorine residual" is the sum of the combined plus free chlorine.

Total chlorine residual = combined + free chlorine

These various chemical forms of chlorine residual can be distinguished by tests.

FACTORS INFLUENCING CHLORINATION PRACTICE

1. Suspended matter (turbidity) may shield bacteria from the action of chlorine. Therefore other factors being equal, chlorination is more effective in low turbidity waters.
2. Organic matter reacts with and consumes chlorine to form weak disinfectants, which may not be effective.
3. Ammonia reacts with chlorine to form a chlorine compound having lower disinfecting qualities than free chlorine itself.
4. The pH value. Waters having pH values less than about 7.2 are more effectively disinfected than higher (alkaline) pH values. (See Table 9-1).
5. Nitrites react with and chemically remove free chlorine. Thus, more chlorine is needed to insure disinfection.
6. Hydrogen sulfide, a malodorous gas sometimes found in water, also reacts with and consumes chlorine.
7. Iron and manganese when in the reduced dissolved state also reacts with and consumes chlorine, increasing the chlorine dose required for disinfecting purposes.
8. Temperature. The higher the temperature, the more effective the disinfection.

9. Contact time. The longer the time, the more effective the disinfection.

10. Type of chlorine residual. Free chlorine is much more effective as a disinfectant than combined chlorine.

11. Chlorine concentration. The higher the concentration, the more effective the disinfection and the faster the disinfection rate.

Table 9-1: Recommended Minimum Concentrations of Free Chlorine Residual

pH Value	Minimum Concentration of Free Chlorine Residual, Contact Time at least 30 minutes.
6.0	0.20 mg/l
7.0	0.20
8.0	0.40
9.0	0.80
10.0	0.80

The above table shows the very significant effect of the pH value on the amount of chlorine residual required for effective disinfection.

CHLORINATOR CAPACITY

The chlorinator should be sized for the maximum expected conditions, but should also be capable of handling minimum conditions. The capacity of a gas chlorinator is often expressed in pounds of chlorine per 24 hours of operation. Hypochlorinators are usually rated in gallons of solution which can be pumped (injected) per 24 hours of operation. Both types of chlorinators can be regulated over a considerable practical range below the maximum. The stock solution strength of hypolchlorinators may also be varied to cover a wide range of conditions.

Gas chlorinators rated at 10 pounds of chlorine per day are capable of chlorinating over a million gallons per day at a 1.0 ppm (mg/l) chlorine dose. This is more than adequate for most small systems. It may be difficult to obtain a gas chlorinator to meet the low flow conditions of some small water systems, another reason to consider the hypochlorinator for most installations.

Positive displacement hypochlorinators with an adjustable output range of 1.0 to about 24 gallons per 24 hours of operation will effectively handle just about any dose range encountered in small water systems. Larger and smaller units are available.

DETERMINING HYPOCHLORINATOR FEED RATE AND SOLUTION STRENGTH

In order to simplify the initial determination of a hypochlorinator feed rate and the chlorine solution strength to achieve disinfection, a dose rate of 1.0 ppm (mg/l) may be tried as a practical starting point. This dose rate is usually adequate for most situations, particularly as a first trial. With this assumption, the chlorinator setting and solution strength may be determined for chlorine bleach solutions (5.25%) by using Figure 9-2.

Procedure Using Figure 9-2 (5.25% chlorine bleach)

1. Assume dose rate of 1.0 ppm (1.0 mg/l)
2. Determine well pump capacity (or other source flow rate) in gallons per hour. If two or more well pumps operate independently, and sometimes together, each may require a separate hypochlorinator setup. Make separate calculations for each if the pump capacities are different.
3. Figure 9-2 has 3 scales.
    - The scale on the right is the water pump capacity in gallons per hour.

- The scale on the left is the hypochlorinator (chemical pump) feed rate for a 1.0 ppm dose. It is also the amount of solution that will be used if the system is pumped continuously for a full 24 hours, highly unlikely.
- The center scale is the number of gallons, quarts or ounces of 5.25% bleach which must be added to make each 5 gallons of solution.

  As a first trial, assume a setting for the hypochlorinator at about the midrange scale of the unit. This will permit adjustments up or down the scale as necessary.

4. To use Figure 9-2, place a ruler at the proper well pump capacity (gph) and the mid-range scale of the hypochlorinator and draw a light line. The point where this line crosses the center scale, represents the amount of bleach necessary to prepare 5 gallons of solution of the proper strength to insure a 1.0 ppm dose.
5. Determine the number of hours that the well pump will operate in an average day. An electric clock (with compatible voltage) may be connected to the pump circuit as a simple means of determining this. If the well pump operates for 6 hours a day, the hypochlorinator will feed 6/24 or 1/4 of the amount indicated in gallons per day.
6. After the initial setting, determine the actual chlorine residuals by tests and compare with those shown in Table 9-2. If they compare favorably, the settings are about right. If not, try adjustments of the chlorinator settings or change the solution strength.

Coliform bacteria tests should be made to insure satisfactory disinfection.

Example:

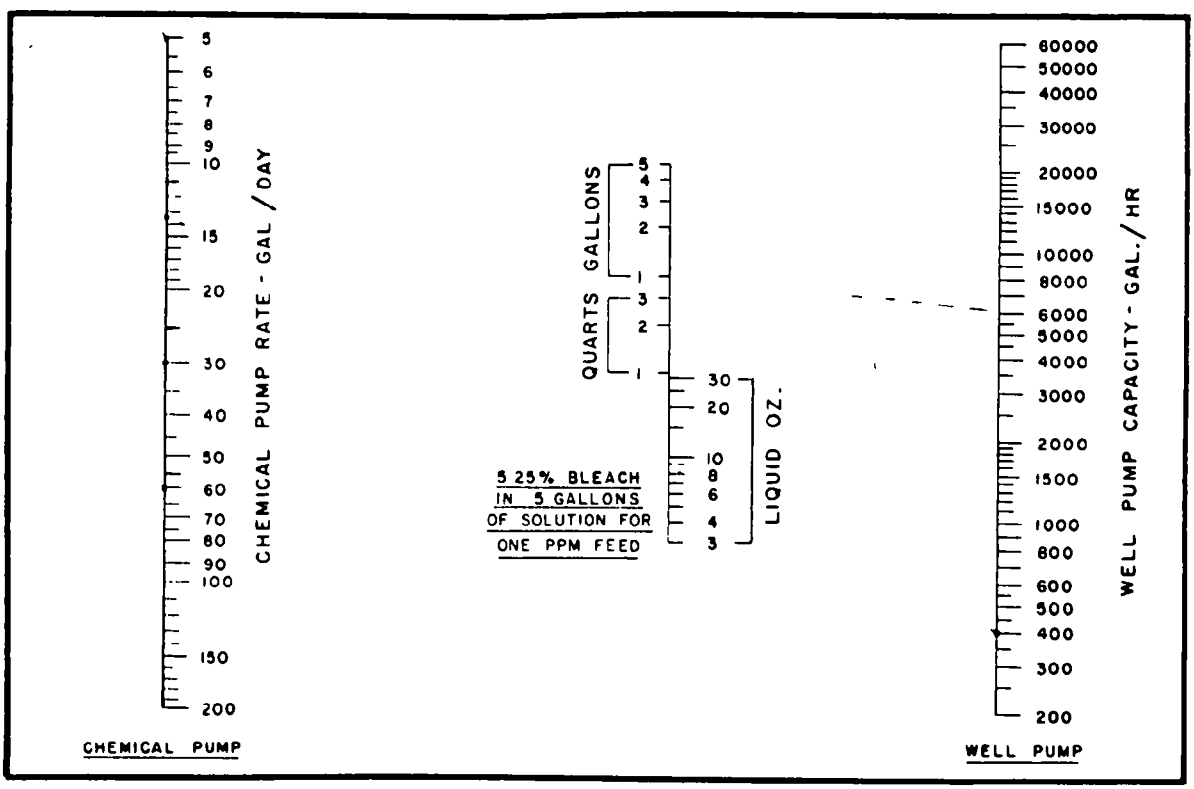
Given: - Well pump capacity = 6000 gallon per hour (100 gpm)

- Well pump operates 6 hours per day

- Hypochlorinator setting = 10

Solution: From Figure 9-2, it will take 1.0 gallons of 5.25% bleach added to every 4.0 gallons of water to produce 5.0 gallons of solution of the proper strength to dose at 1.0 ppm. If the well pump operates for 6 hours per day, 6/24 x 10 = 2.5 gallons of solution will be used per day, or 17.5 gallons per week. A 20 gallon solution tank will last for a week, which is a convenient and satisfactory arrangement.

Figure 9-2: Determining Required Amount of 5.25% Bleach to Make Solution for 1.0 PPM Feed Rate for Hypochlorinators.



Source: Bruner-Calgon Water Treatment Equipment, by permission.

TESTING FOR CHLORINE RESIDUALS

The amount of chlorine remaining in the water system (chlorine residual) is determined by a relatively simple test commonly called the DPD colorimetric test, short for the chemical name Diethyl-p-phenylene-diemine. The test may be done under "field" conditions using pill reagents which are placed in a special test tube provided with DPD kits. The presence of free chlorine residual produces a violet color which is compared with color standards to determine the quantity present. The kits are readily available from firms which specialize in the manufacture of water testing materials. A combination DPD chlorine and pH kit is available and is a worthwhile investment at a modest price. The State agency will supply a list of acceptable kits on request.

The tests must be made at least daily at a point in the system representative of the full required contact time. A residual at the extreme end of the system will assure that the chlorine residual remains in the entire system in effective amounts. This will provide good assurance that the system water is properly disinfected and will reduce the possiblity of slime growths in the system.

Excessive chlorine residuals may be objectionable to consumers. Residuals of 0.75 ppm or less are not usually objectionable. Regardless, the operator must adjust the chlorine feed to achieve effective disinfection as the primary consideration.

CHAPTER 10

TREATEMENT AND CONDITIONING	Softening - Iron and Mangenese Control - Other Ion Exchange Systems - Taste and Odors - Corrosion Control - Color - Turbidity

INTRODUCTION

Depending on the source, ground waters may often be used without treatment. Nevertheless, chlorination for disinfection is always justified.[1] Due to the nature of surface waters, they will almost always require treatment, including chlorination.

Impurities in natural waters depend largely on the source and its past history. Water destined for a ground aquifer picks up impurities as it seeps through soil and rock, including possible sewage pollution. Uptake of minerals is common. The natural straining action is significant in removing particulate matter and this combined with the relatively long retention period in the ground, has a significant effect in removing micro-organisms. Ground waters have a fairly stable quality usually not highly affected by season changes.

Surface waters, on the other hand, are highly affected by land run-off and natural pollution from the land including organic debris, clays and silts. The potential for sewage and other waste pollution is ever present. Therefore, the quality of surface water is highly variable depending upon a host of factors.

The purpose of water treatment is to condition, modify or remove undesirable impurities to obtain a water which is safe, palatable and acceptable to consumers. Those impurities which are considered important

(1) See Chapter 9, Chlorination.

to the health of consumers are specified in the National Primary Drinking Water Regulations[(2)] with maximum contaminate levels. If these contaminates are present in excess of the established limits, the water must be treated or modified to reduce the levels. Those impurities which effect the aesthetic qualities of the water are listed in the Secondary Drinking Water Regulations as guidelines. Treatment or modification of the water to achieve these desirable levels is highly recommended. Individual State agencies may establish maximum permissible levels.

The U.S. Environmental Protection Agency has commissioned a study on the "State-of-the Art of Small Water Treatment Systems." The report provides valuable assistance in evaluating the various methods of removing or reducing impurities in water supplies serving small public systems and the costs. This publication is available through the U.S. Government Printing Office. Consult the State agencies for further information.

The information on water treatment and conditioning in this Chapter is rather general and is designed to provide the water purveyor with the basic understanding of equipment and methods of treatment which are commonly available. Several water treatment and conditioning equipment firms produce a wide variety of equipment applicable to small public water systems. and a wide choice of equipment and processes are available. Some manufacturers provide related engineering service. Professional engineers should be consulted for further advice.

Chlorination for disinfection is the most widely practiced treatment process and is covered in some detail in Chapter 9.

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(2) See Chapter 12.

Surface waters of highly variable quality require extensive treatment including coagulation, sedimentation, filtration and chlorination. These treatment plants must be custom designed for the prevailing conditions by skilled design engineers. Skilled operators are required for operation and maintenance to meet the day to day (sometimes hour to hour) conditions of the raw surface water. Surface water supplies should only be considered after consulting the State agency.

Listed below are the common "contaminate groupings" which influence the quality of water and which may require treatment, removal or conditioning. The contaminates in each group are often treated by the same or similar unit processes. However, treatment to control one grouping may also improve another grouping.

1. Micro-organisms which will affect the sanitary quality--usually of human or animal origin.(3)
2. Inorganic and organic contaminates for which maximum permissible limits have been established(3), and others for which guideline limits have been set.(4)
3. Particulate matter(3) and color(4) which may affect the sanitary quality and the physical appearance--including soil, insoluble minerals, organic leachates, and certain aquatic organisms.
4. Substances which impart tastes and odors(4) including hydrogen sulfide, high concentrations of minerals, organic substances and certain micro-organisms.
5. Minerals which produce hardness and scales (calcium and magnesium salts) or stains (iron and manganese salts).(4)
6. A combination of chemical factors which result in corrosion and red water problems.(4)

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(3) Primary Drinking Water Regulations, Chapter 12.
(4) Secondary Drinking Water Guidelines, Chapter 12.

CHEMICAL, PHYSICAL AND BACTERIOLOGICAL EXAMINATION TO HELP ESTABLISH TREATMENT REQUIREMENTS

Early in the source development phase, representative samples of water should be collected for a complete bacteriological, chemical and physical examination at an approved water laboratory. Collection should be done in accordance with techniques furnished by the laboratory. The required tests may vary in different States based upon local experience but will generally include those Primary Contaminates listed as a requirement for the type of water system in question (see page 12-4 for a summary) and those Secondary Contaminates listed on page 12-22 which are specified by the State agency. Although not lised, the alkalinity and hardness of the water should also be determined.

A complete interpretation of the results should be obtained from the laboratory or others qualified to make the interpretations. The results will determine the necessary treatment of the water and the limitations on the use of the water, if any.

WATER SOFTENING

Well waters often exhibit hardness characteristics as a result of dissolved calcium and magnesium salts. Water softening is the process of removing some of the calcium and magnesium. Softening of hard water is desirable if:

1. Excessive amounts of soap are needed to produce a lather.
2. Hard scale is formed on cooking utensils or laundry basins.
3. Hard, chalklike formations coat the interiors of piping or water tanks.
4. Heat-transfer efficiency through walls of hot water heaters or heat exchange units is reduced.

No specific limits have been established for hardness but the following guidelines may be helpful: Soft water - less than 75 mg/l as calcium carbonate; Moderately soft or moderately hard - 75-150 mg/l; Hard - 150-200 mg/l; Very hard - over 200 mg/l.

The buildup of scale will cause an appreciable reduction in pipe capacities and pressures. The appearance of excessive scale from hard waters will also be aesthetically objectionable. Water hardness can be of two general types. One type, called carbonate hardness, is due to the bicarbonates of calcium and magnesium; the other type, called noncarbonate hardness, is due to salts of calcium and magnesium other than bicarbonate, usually chlorides and sulfates.

Softening or hardness removal can be accomplished by any method which will remove calcium and magnesium. Two major softening methods are used: (1) chemical precipitation (Lime-Soda Ash Process), and (2) Ion exchange. Both processes increase the sodium content of the water which may make it undesirable for people on a low-sodium diet.

Lime-Soda Ash Process

The use of the lime-soda process is not practical for a small water supply system.

Ion Exchange Process

The ion exchange method is particularly suitable for small water systems. The cylinderical units take up little space and operate under normal system pressures. No double pumping is necessary. The units remove both forms of hardness. Most units will tolerate up to 4 mg/l of iron and manganese or hydrogen sulfide in the water but manufacturers should be consulted for advice.

Softening by ion exchange removes calcium and magnesium ions by exchanging or replacing them with other ions such as sodium. Since these ions all have a positive charge, they are called "cations" and this ion exchange process is often called "cation exchange."

Removal of hardness by cation exchange is effective only as long as sodium is left on the exchange media (resin). When the sodium is all used up, it is necessary to regenerate the resin. The regeneration may be done manually or automatically. The steps are as follows:

Backwashing is the first step of the regeneration process. Clean water is forced through the bed in reverse direction at rates of 5 to 7 gpm/sq. ft. for about 10 minutes to remove any accumulated dirt and to loosen and regrade the resin material to prevent packing and channeling in subsequent re-use.

A strong brine solution is then forced through the exchange unit. This reverses the exchange reaction, and sodium from the brine displaces the accumulation of calcium and magnesium attached to the exchange media.

Rinse water is then flushed through the unit to remove the calcium and magnesium and the excess brine. The rinse water is wasted to a sewer. The entire regeneration process takes about one hour. Fully automatic units are available. Two or more units may operate in parallel to maintain a continuous flow of treated water. Regenerations may be staggered so that only one unit at a time is off the line. The softened water has little hardness but has increased sodium content. Total solids are not reduced by sodium cycle softening.

Water from the cation exchanger will have practically zero hardness until the exchange capacity is approached. Since a water without hardness is corrosive, the exchanger water may be blended with bypassed water to produce a resultant water of desirable hardness, usually between 70 and 100 ppm.

Water from the cation exchanger should be tested and when the hardness increases, the unit needs to be regenerated. Some units have sensors and regenerate automatically. The approximate interval between regenerations may also be calculated if the following are known and a water meter is available: natural water hardness, volume of exchanger media in cubic feet, and softening capacity per cubic feet. For example:

Raw water hardness = 170 ppm or 10 grains/gallon
(1 grain/gal. = 17.1 ppm)

Softening capacity - 5000 grains/cubic feet (manufacturers specification)

Volume of medium - 50 cubic feet

Total hardness removed between regenerations = 50 x 5000 = 250,000 grains

Volume of water treated between regenerations= $\frac{250,000}{10}$ = 25,000 gallons

Therefore, the unit must be regenerated after conditioning about 25,000 gallons of water.

IRON AND MANGANESE CONTROL

Iron and manganese problems are more common in well supplies than in surface supplies. They are common constituents in many soils and rocks, in varying quantities. Iron and manganese may be objectionable in concentrations greater than 0.3 mg/l and 0.05 mg/l, respectively. They cause stains in laundered clothes and fixture surfaces. When the iron content of water is high, tea or coffee may turn dark (like ink) and the taste is impaired. Iron problems may also occur as a result of corrosion of iron pipes in the distribution system. If this occurs, the water may be treated to make it less corrosive. (See the Section on Corrosion Control.) Slime growths of iron bacteria may aggravate the situation.

Although several processes are available for iron and manganese removal, the ion exchange method is perhaps the most applicable to small water systems. Most softening units are capable of removing small amounts, but it is best to employ special ion exchange resins designed for iron and manganese.

Iron Stabilization - Iron in the soluble form may be stabilized or sequestered by adding polyphosphates or organic sequestering agents. Sodium hexametaphosphates at dosages of about 5 mg per mg of iron may be used for this purpose. While this treatement will stabilize iron and manganese in suspension, it may not be suitable where iron concentrations of 1 mg/l are exceeded. Moreover, when the water is heated, the polyphosphate will lose its stabilizing properties. The application of the polyphosphate must take place ahead of any aeration or chlorination, otherwise it will not be effective.

Polyphosphate dosages should be limited to less than 10.0 mg/l, because excess phosphorous may stimulate bacterial slime growths in distribution systems. Chlorination, following the addition of polyphosphates, will help control these growths. Polyphosphates may be mixed with water and fed into the system by means of a hypochlorinator type chemical feeder. Manufacturers of polyphosphates and the State agency should be consulted for details.

Other Use of the Ion Exchange Resins and Adsorbents

Ion exchangers are quite versatile and have several other applications in water conditioning, in addition to softening and iron and manganese removal.

- Ion exchange resins may be used for partial demineralization to reduce the total mineral content (total dissolved solids).
- Resins mixed with activated carbon are effective in controlling some taste and odor problems including dechlorination (removal of chlorine) where necessary. Activated carbon filters are also available for greater effectiveness.
- If fluoride concentrates exceed maximum permissible limits, they may be reduced with special activated bone char resins.

- Organic adsorbents are capable of removing certain organic substances.
- Foaming substances, principally from household detergents, may also be removed by carbon adsorption filters.
- Resins are available which will tolerate and remove low concentrations of hydrogen sulfide gas.

TASTE AND ODOR CONTROL

Tastes and odors are aesthetically objectionable and in the case of food establishments, etc., may have an economic impact from dissatisfied customers. Taste and odors may be natural to the water (hydrogen sulfide gas, the rotten egg odor; iron and manganese, etc.) or may result from man-made contamination of chemical or sewage origin.

If the cause of the taste and odor can be determined, a specific treatment may be designed. Hydrogen sulfide may be removed by chlorination which converts (oxidizes) the odorous gas to free sulfur. The free sulfur has practically no taste but may make the water cloudy (milky color). If so, filtration may also be indicated. Sufficient chlorine must be added to not only react completely with the hydrogen sulfide, but also to produce a residual which will be effective as a disinfectant. Some ion exchange filters are also effective.

The tastes resulting from iron or manganese may be removed by ion exchange units as previously discussed.

Activated carbon filters (or resins mixed with activated carbon) are often effective in removing taste and odors attributed to some chemicals or organic decay tastes. Carbon filters will also remove chlorine tastes if this is objectionable for some special reason. It is, however, highly desirable that the water has a measurable residual throughout the system for safety purposes (See Chapter 9).

CORROSION CONTROL

Corrosivity is a complex characteristic of water related to pH, alkalinity, dissolved oxygen, total dissolved solids and other factors.

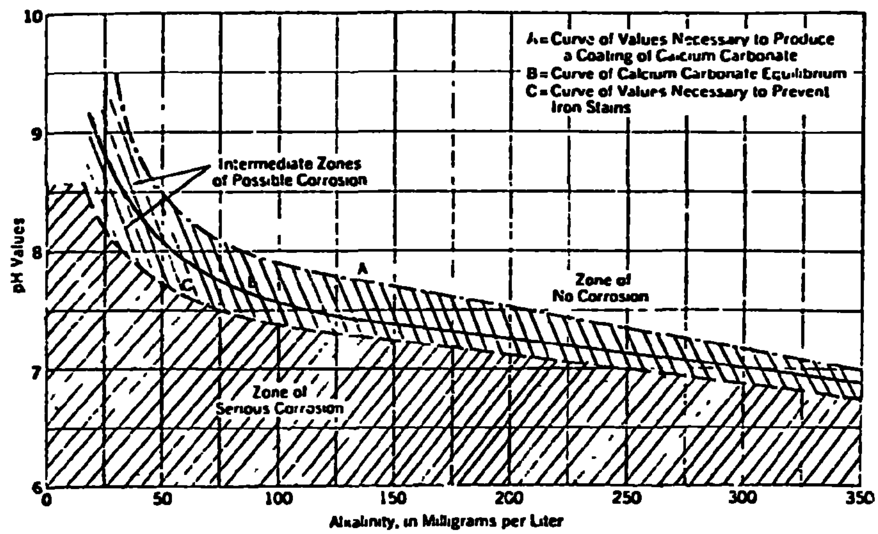
Water is said to be corrosive to a metal if it dissolves the metal or furnishes substances that react with it at the metal-water interface. In the case of iron and copper, the dissolved metals often re-precipitates to form reddish brown stains (red water) with iron and bluish-green stains with copper. These have both aesthetic and economic significance. Corrosive water may also dissolve lead and cadmium and these have health implications (See Chapter 12, Primary Regulations).

The effects of corrosive water are easily recognized but there is no completely acceptable index for measuring the corrosivity. Nevertheless, certain treatment and conditioning processes may be effective in reducing the corrosive tendency of water in varying degrees. Where evidence exists of red water problems (tuberculation or pitting of the interior of iron pipes or other indicators) an evaluation should be made to determine possible effective remedial actions.

Although the discussion of corrosion in this chapter is limited to the interior of metal pipes, tanks, etc., exterior metal surfaces may be corroded by exposure to certain soils. The resulting corrosion may also warrant remedial steps.

Figure 10-1 may be useful to assess the corrosiveness of water. The Figure shows the relationship of pH and alkalinity and the conditions which may result in reduced corrosion for a given water. To use the chart, determine the pH and alkalinity of the water over a period of a few days. From the curves, determine if the water falls within the zone of serious corrosion or the intermediate corrosion zone. If so, corrosion control may be necessary and a water engineer and the State agency should be consulted.

Figure 10-1: Alkalinity and pH. Adapted from Water Supply Control, New York Department of Health.



Factors Influencing Corrosion

The water characteristics which significantly influence the rate of corrosion of a metal include (1) the amount of dissolved oxygen; (2) the pH (hydrogen ion concentration); (3) the concentration of carbon dioxide; (4) the absolute and relative concentrations of other inorganic ions in the water, particularly calcium bicarbonate, chloride and sulfate; (5) increasing the temperature tends to increase the speed of chemical reactions in general; and (6) the velocity, i.e., the rate of flow of the water past the metal surface governs the rate at which the dissolved oxygen essential to corrosion is replenished at the metal surface.

Corrosion Control Methods

Corrosion control methods commonly used in waterworks practice include:

A. The choice of non-metallic materials or corrosion-resistant metals in construction.

   (1) Non-metallic materials include asbestos-cement and plastics.

   (2) Corrosion-resistant metals such as aluminum, stainless steel, nickel, silicon, copper, brass and bronze.

B. The choice of metallic coatings, such as zinc (galvanizing) or aluminum, to protect metals.

C. The choice of non-metallic coatings to protect metals. Appropriate materials include coal tar enamels (bituminous), asphaltics, cement mortar, epoxy resins, vinyl resins and paints, coal tar-epoxy enamels, inorganic zinc, silicate paints and organic zinc paints. Consult the State agency for approved paints.

D. The choice of the chemical treatment process to reduce corrosion.

(1) Deposition of protective coating or film on the metals by use of calcium carbonate, sodium hexametaphosphates and silicates.

(2) Removal of oxygen (generally not practical).

(3) Removal of free CO_2.

(4) pH adjustment.

E. Electrical Control (Cathodic Protection)

This process involves the application of a low voltage current which flows through the water (usually in a steel water tank) so that the external voltage renders the tank cathodic and concentrates corrosion on anodic metals which are designed to corrode, instead of the tank.

Some proprietary water conditioning units are available which may be applicable for small water systems. They are usually quite simple to install, operate and maintain and may prove effective in some situations. Manufacturers catalogs provide some details.

COLOR REMOVAL

Color in water may be indicative of dissolved organic materials such as the leachate from woodlands and wetlands. Color can also be caused by inorganic substances such as iron and manganese, previously discussed.

Color becomes objectionable to most people when levels approach 15 color units (C.U.) or more but may be detectable to the naked eye at about 5 C.U. Organic color may also affect chlorination as the organic color combines with chlorine to form chloro-organic compounds which uses up chlorine to form weak disinfectants. Sufficient chlorine must be added to insure free type residuals (See Chapter 9). The oxidation effect of chlorination may assist in removal of color.

In larger water systems employing coagulation and filtration, color is removed along with turbidity. However, small well supplies are limited for practical reasons to less sophisticated treatment such as carbon pressure filters and perhaps chlorination.

TURBIDITY REMOVAL

Properly developed well waters usually have turbidity levels below the turbidity units listed as the maximum contaminate level in the Primary Regulations (See Chapter 12). But occasionally, turbidity may become a problem. Surface waters will normally require filtration treatment to remove turbidity. Turbidity is suspended, visible matter, often caused by silt or clay extracted from soil, insoluble minerals, and suspended organic material including micro-organisms. These substances have the following significance:

1. Suspended solids may shield bacteria and thus reduce the reliability of chlorine disinfection.
2. In well supplies, turbidity may be indicative of the entrance of surface or shallow subsurface water and potential contamination.
3. In supplies employing filtration, it is indicative of inadequate treatment.

4. Turbidity may be the result of iron or manganese precipitates (reddish brown or chocolate brown) in the distribution system, either from the well source or from corrosion of the distribution system (iron pipes). Lime deposits on pipes from hard water and may subsequently flake off, resulting in turbidity.
5. Turbidity may be the result of sewage or other waste pollution, particularly if it is also associated with increased coliform bacteria counts.
6. Surface waters are highly susceptible to turbidity and will require continuous treatment.

Where turbidity is present in the water at its source, filtration (usually pre-conditioned by coagulation with alum or other coagulants and subsequent settling) is the indicated treatment. If the turbidity is the result of iron or manganese, the ion exchange system (previously described) may be used. Hard water scaling may be controlled by ion exchange softeners.

Small water systems may find the pressure sand (or other approved media) filter effective. These filters operate under system pressure and do not require double pumping. They are fabricated in both vertical and horizontal cylinderical vessels. Flow rates of 2 to 3 gallons per square foot are common. As the filter media becomes clogged, the pressure required to force water through it increases. At a pre-selected pressure drop, the filter is backwashed by reversing the flow but at a rate of 3 to 5 times the filter rate. The backwash water is discharged to waste. Care must be taken to avoid a cross-connection with a sewer (See Chapter 15). Activated carbon is sometimes mixed as part of the filter media to help remove tastes and odors. Pre-conditioning with coagulants may be necessary.

Diatomaceous earth filters are commonly used to clarify swimming pool waters but are generally not acceptable for public water supplies where turbidity is a significant problem. These filters rely on a filter cake formed on rigid porous filter elements by feeding a water mixture of diatomaceous earth. The process is not always reliable and the State agency should be consulted before its use.

CHAPTER 11

DISTRIBUTION SYSTEM	Pipe Sizing - Pipe Types - Accessories - Construction - Disinfection

INTRODUCTION

The distribution system, as the name implies, includes the network of pipes, valves, fire hydrants, meters and other associate appurtenances. Distribution storage reservoir and booster pumps are often included and are discussed in Chapter 6. This Chapter discusses the basic elements of the system design and construction.

The distribution system must be designed to meet the special conditions of each water system. Small water supply systems will vary from the single building establishment to the rather extensive system servicing mobile home parks and small communities. There are no "packaged" distribution systems. Each must be designed specially. Therefore, the services of a consulting engineer are particularly important. Furthermore, most of the distribution system is buried and replacement will be costly. It should be designed and constructed to meet long range needs, up to 50 years. Poor quality materials and/or construction is not a wise investment.

Preliminary design data and decisions should include:

- Determination of water demands in the various segments of the system. See Chapter 3 for discussion of water demands.
- Will fire flows for fire protection be provided? If so, the design must take this into account.
- Determine the elevation differences throughout the service area and the static head conditions. Assess the various options available for pumping (or gravity flow) and storage in relation to the head requirements.

- Assess the advantages and disadvantages of various piping materials and select most appropriate pipe for the system conditions.
- Assess physical characteristics of soils, depth to rock and ground water, required depth for frost protection, etc. Corrosive soils may require special considerations and may affect the choice of pipe.
- The characteristics of the water may also affect the choice of pipe and appurtenances. Water which tends to be corrosive to piping may suggest the use of plastic or asbestos cement pipe.

SITE CONDITIONS

Prior to selecting pipe materials, consideration should be given to the physical characterists of the soil as mentioned above. The assessment should include anticipated unusual earth and surface loads on the pipe as these loads will affect pipe selection. Local soil survey publications will be helpful in identifying soil types, characteristics and limitations. Consult the local Soil Conservation Service agent for information and advice. Unstable conditions may warrant special means of support.

Clay soils in some areas are severely affected by extremes of wetness and dryness, and are subjected to extraordinary shrinkage on drying. This shrinkage usually results in deep cracks in the earth's surface and may result in damage to underground structures, including pipe materials. The clay forms a tight gripping bond with the pipe structure, subjecting it to severe stresses as the clay shrinks. In such situations it is good engineering practice to bed the pipe in an envelope of several inches of tamped sand.

The depth of frost penetration will determine the minimum depth of the pipe below ground surface. Accepted local experience should be practiced. Ground water within the pipe trench will increase the cost of construction.

SELECTION OF PIPE SIZES

Selection of adequate piping sizes is important to insure an adequate supply of water to the consumers at satisfactory pressures. If the piping is undersized, large head losses will result with a corresponding reduction in water flow, reduced pressure, and an increased potential for inadvertent back siphonage from cross-connections. See Chapter 15.

A water distribution network analysis must be performed to determine proper pipe sizes for new systems or to evaluate the adequacy of an existing system. Before performing the analysis, the designer must determine the water demands throughout the system (See Chapter 3). These data, together with data on the elevation of the various components and the pressure requirements, will enable the engineer to perform the analysis.

It is a relatively simple process to determine the required pipe size for a single pipe conveying water between two points. The process becomes more complex as the single pipe becomes a network of pipes. It is not within the scope of this manual to provide the reader with sufficient technical information to perform the complex analysis. That is a job for the professional engineer. The information that follows will provide a basic understanding of the process, as it relates to a single pipe.

When water flows through a pipe, it must overcome the resistance caused by its own turbulence and the friction of the interior pipe surface. Valves, elbows and other fittings also add friction. The sum of these frictions are called "head losses" or "pressure losses" or "head drops" or simply "friction losses." The greater the water flow, the greater the friction losses. If the flow of water in gallons per minute (gpm) is doubled, the friction losses increases by about 4 times. At a given flow rate, smaller pipes have greater friction losses than larger pipes.

In addition to the friction losses which consume or use up pressure head, additional work must be supplied to lift water to a higher level and impart a velocity to the water, called velocity head. The pressures created in a flowing water system are called the "dynamic pressures." The pressures exerted when no water is flowing are called "static pressures." Moving water is the job of pumps and/or gravity and is covered in more detail in Chapter 6.

Experience has shown that the minimum water pressure at water use fixtures should not be permitted to drop below 20 psi under peak flow conditions in the system. System operating pressures in the range of 40 to 60 psi are adequate for most uses. Pressures should generally not exceed 100 psi to reduce the risk of damage to water heaters and other appurtenances. Pressure reducing valves may be used in those parts of the system where high pressures cannot be avoided.

Pipe Flow and Friction Loss-Tables and Graphs

The solution of problems dealing with pipe flow and the ensuing friction losses has been reduced to simple tables and graphs for convenience. A variety of tables and graphs are available in hydraulic text books and handbooks. These tables and graphs are suited to small network analysis but more complex problems are solved by computer techniques. Appendix C lists some references for more detailed information.

The tables that follow are intended to show the process involved in simple pipe sizing problems and are not intended for the serious reader who may wish to actually design a system.

The tables assume new pipe and the friction losses do not take into account the increased friction which will result from corrosion, tuberculation, slime growths and encrustations. A design engineer takes this "aging" of pipe into consideration in the actual design of systems. Furthermore, the tables do not take into account the loss in pressure (usually quite smal required to create the velocity of the water, called "velocity head." Hydraulic handbooks will provide detailed information.

Table 11-1 shows a typical chart which lists:

- Quantity of water in gallons per minute (gpm)
- Various pipe sizes and pipe types, in this case 1 1/4", 1 1/2", and 2" pipes, steel and plastic.
- The corresponding friction loss when water flows through the pipe, in feet of water and also in lbs. per square inch (psi), per 100 foot length of pipe.

If any 2 of the above variables are known, the 3rd may be determined from the chart.

Table 11-2 lists several pipe fittings of various sizes and the allowance which must be added in the form of equivalent length of pipe to account for friction and head losses in each fitting. Charts are available for a variety of fitting sizes and types. See Chapter 3 for estimation of peak demands.

With the two charts, simple pipe hydraulic problems may be solved.

Example 1

Given:
- Desired minimum water quantity = 40 gpm
- Type of pipe; galvanized steel
- Length of pipe (distance between two points) = 500 feet
- Fittings; straight couplings - 21
  - 90° ells - 2
  - 45° ells - 2
  - Gate Valves - 1
- Desired maximum head or pressure loss = 25 feet or 10.8 psi.

Note: 2.31 feet of head = 1 psi

Example 1 (continued)

To Find: Best pipe size.

Solution: The head losses in Table 11-1 are based upon 100 foot lenghts of pipe.

1st trial: Move along chart from 40 gpm to head loss for 1 1/2" (inside diameter) steel pipe. The head loss per 100' of pipe = 10.8 feet or 4.7 psi. Since 500' of pipe are required, the total head loss is $10.8 \times 500/_{100}$ = 54 feet

The head loss is obviously too great as only 25 feet is desirable.

2nd trial: Try a 2' pipe. The head loss is 3.1 feet per 100' or 5 x 3.1 = 15.5 feet for the 500 foot pipe.

Now add the allowance for fittings in terms of extra length of pipe. From Table 11-2, select the extra lengths as follows:

21 - 2" couplings at 2 feet each	= 42 feet of equivalent pipe
2 - 2" 90^{o} ells at 7 feet each	= 14 feet
2 - 2" 45^{o} ells at 4 feet each	= 8 feet
1 - 2" gate valve at 1.3 feet	= 1.3 feet
Allowance for fittings	= 65.3 feet
	= assume 100 feet

From Table 11-1, the fittings will add an additional 3.1 feet of head loss.

Total head loss = 15.5 feet for 500 foot of pipe
3.1 feet for fittings
18.6 feet

This is less than the desired maximum 25 feet of head loss and is satisfactory. Therefore, a 2 inch pipe is the proper size.

Example 2: Turn the problem around as follows:

Given: - Same pipe and fittings

- Diameter - 2"

- Maximum head loss = 25 feet

To Find: How much water will the pipe deliver at 25 feet head loss

Solution: Before using Table 11-1, the head losses attributable to the fittings must be first subtracted to find the head loss attributable to the pipe only. From Example 1:

25 feet - 3.1 feet = 21.9 feet (head loss of 500' of pipe)

Headloss per 100 foot of pipe = 21.9/5 = 4.4 feet

From Table 11-1, the system will deliver about 48 gpm.

Table 11-1: Friction Loss in Feet Per 100 Ft for Various Pipes at Various Water Flows

GPM	1¼"ID Steel Ft	1¼"ID Steel Psi	1¼"ID Plastic Ft	1¼"ID Plastic Psi	1½"ID Steel Ft	1½"ID Steel Psi	1½"ID Plastic Ft	1½"ID Plastic Psi	2"ID Steel Ft	2"ID Steel Psi	2"ID Plastic Ft	2"ID Plastic Psi
10	1.8	.8	1.7	.7								
12	2.5	1.1	2.3	1.0	1.2	.5	1.1	.5				
14	3.3	1.4	3.1	1.3	1.5	.7	1.4	.6				
16	4.2	1.8	4.0	1.7	2.0	.9	1.9	.8				
18	5.2	2.3	4.9	2.1	2.4	1.1	2.3	1.0				
20	6.3	2.7	6.0	2.6	2.9	1.3	2.8	1.2				
25	9.6	4.2	9.1	3.9	4.5	2.0	4.3	1.9	1.3	.6	1.3	.6
30	13.6	5.9	12.7	5.5	6.3	2.7	6.0	2.6	1.8	.8	1.8	.8
35	18.2	7.9	16.9	7.3	8.4	3.6	8.0	3.5	2.4	1.0	2.4	1.0
40	23.5	10.2	21.6	9.4	10.8	4.7	10.2	4.4	3.1	1.3	3.0	1.3
45	29.4	12.8	28.0	12.2	13.5	5.9	12.5	5.4	3.9	1.7	3.8	1.6
50	36.0	15.6	32.6	14.1	16.4	7.1	15.4	6.7	4.7	2.0	4.6	2.0
60	51.0	22.1	45.6	19.8	23.2	10.1	21.6	9.4	6.6	2.9	6.4	2.8
70	68.8	29.9	61.5	26.7	31.3	13.6	28.7	12.5	8.9	3.9	8.5	3.7
80	89.2	38.7	77.9	33.8	40.5	17.6	36.8	16.0	11.4	5.0	10.9	4.7
90	112.0	48.6	96.6	41.9	51.0	22.1	45.7	19.8	14.2	6.2	13.6	5.9
100	138.0	59.9			62.2	27.0	56.6	24.6	17.4	7.6	16.5	7.2
120					88.3	38.3			24.7	10.7	23.1	10.0
140					119.0	51.6			33.2	14.4	30.6	13.2
160					156.0	67.7			43.0	18.7	39.3	17.1
180									54.1	23.5	48.9	21.2
200									66.3	28.8	59.4	25.8
220									80.0	34.7		
240									95.0	41.2		
260									111.0	48.2		

Areas above the heavy lines are recommended for normal operation.

From: Water Systems Handbook, Water Systems Council

Table 11-2: Allowance in Equivalent Length of Pipe for Friction Loss in Valves and Threaded Fittings

Diameter of fitting (Inches)	90° std. ell (Feet)	45° std. ell (Feet)	90° side tee (Feet)	Coupling or straight run (Feet)	Gate valve (Feet)	Globee valve (Feet)	Angle valve (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

From: Manual of Individual Water Supplies, EPA

PIPE MATERIALS[1]

There is a wide choice of pipe materials available for the small distribution system. These materials include cast iron, steel, asbestos cement, wrought iron, copper, and plastic. Plastic pipe[1] is popular for the small water supply system due to its resistance to corrosion, low head loss, ease of installation and low cost. There are four principal types of plastic available for water pipe: polyethylene, acryonitrile butadiene styrene (ABS), polyvinyl chloride (PVC), and polybutylene.

Polyethylene. Polyethylene is an extruded semiflexible tubing manufactured in diameters up to 12 inches. The larger sizes are not economical to produce as polyethylene's low tensile strength requires a thick wall. It is supplied in coils of most any desirable length. The tubing should be unpacked upon delivery and stored out of the ultraviolet rays of the sunlight. Its flexibility permits it to be bent to make gradual curves.

Two types of fittings, insert and flared, are commonly used with polyethylene pipe. Flaring is accomplished by heating and softening the tubing until it can be flared with special tools. The simplest and surest connection is made with insert fittings. The fitting is inserted in the pipe endings and a stainless steel clamp is placed around the outside of the tubing and tightened to compress the tubing around the fitting.

Acryonitrile Butadiene Styrene. ABS pipe is noted for its high impact strength and is much more rigid than polyethylene. It first attracted the interest of rural water districts, parks, and small towns where there was a need for small diameter distribution pipes.

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(1) Plastic piping used in water systems must meet the standards of the National Sanitation Foundation (NSF). The American Water Works Association (AWWA) established standards for larger diameter metal pipes.

The pipe is manufactured in 20 foot lengths and is joined by solvent welding the pipe ends to molded couplings. It can be mated with iron and copper pipes using special adaptors.

Polyvinyl Chloride. Polyvinyl chloride (PVC) is mostly grey in color, very rigid, and has one of the highest tensile strengths among the thermoplastic pipes. It is used extensively for water distribution pipes, replacing ABS in popularity.

PVC is manufactured in a variety of inside diameters and lengths but usually 20 or 25 feet. Joints are made by using solvent welded fittings as with ABS or rubber gasketed bell joints.

Polybutylene. Polybutylene pipe is used in municipal water systems as a substitute for copper service lines. It should prove effective in similar situations for small water systems.

Other Pipe Materials. Cast iron, steel pipe, asbestos-cement and ductile iron, are used extensively in the larger water systems. Standards for these piping materials are available from the American Water Works Association, 6666 West Quincy Avenue, Denver, Colorado 80235.

Pipe Working Pressure

Pipe is rated according to its safe working pressure. Pipe with rated working pressures of less than 150 psi should not be used in public water systems. If operating pressure of the system exceeds 100 psi, pipes with even greater working pressures than 150 psi should be considered.

Table 11-3 shows a comparison of plastic, copper and galvanized steel, the piping materials most commonly used in the small non-municipal distribution systems.

Table 11-3: Characteristics of Piping

Item	Plastic Pipe	Copper	Galvanized Steel
Effect of Soil	Generally unaffected by any type of soil.	Affected by some soils.	Deteriorates rapidly in acid soils.
Interior Corrosion	Very resistant to inside pipe corrosion.	Will be affected by water containing free carbon dioxide, high SO_4.	Will corrode if water is acidic, alkaline, or hard.
Water Pressure	Recommended water pressures depend on type of plastic. Use pipe with pressure rating at least 150 psi.	Will withstand high water pressures.	Will withstand high water pressures.
Ease of Installation	Easiest to install.	Rigid tubing requires sweated joints which are easier than threaded. Flexible tubing requires flaring and fitting.	Requires the most time and effort. Joints must be fitted and threaded.
Cost	Usually the least expensive in materials and labor.	Usually the most expensive in materials, but has moderate labor cost.	Moderate material cost, but usually requires high labor cost.
Codes	Codes vary from one area to another. Some codes may limit the use of, or make it mandatory to use, one kind of pipe. Be sure to check local codes before starting construction.		
Limitations	Can be damaged by sharp objects. Will flatten under excessive external pressures. Most kinds cannot be used for hot-water pipes. Will absorb gas and oil which cause taste in the water. May be damaged by rodents. Also, resistance heating using an electric welder cannot be used to thaw out nonmetallic pipe.	Some soils may cause deterioration.	Should not be used for underground piping as soils often cause deterioration. Cannot be used for all kinds of water.

VALVES

Air Release Valves

Air can enter a pipeline in a number of insidious ways: through packing glands, leaky joints, and even from the water itself. Unless passage is fast enough to purge any buildup of air at high points along the pipeline, air pockets may form which will impede the flow of water. Properly located air-release valves will minimize the problem.

All air-release valves should be inspected periodically. It is best to install them in a valve vault, and below the frost line in freezing areas. Valve vaults should be properly ventilated and drained. An improperly vented vault may become pressurized during the discharge of air, and during periods of inflow the vault may be subjected to negative pressures. Inadequate draining may result in a flooded vault and back siphonage into the system resulting in a health hazard. Vault drains shall not be connected directly to any storm or sanitary sewer, whether installed in a pit, chamber, or by other means. Drainage should be made to the ground if possible, or to approved underground absorption pits. Outside vents should be screened to discourage the entrance of insects and animals. In all installations, it is suggested that an isolating valve be installed at the air valve to permit inspection and servicing.

Surge Control Valves

Surge pressures occur in systems whenever the water velocity is suddenly changed (decreased or increased). Typical causes of sudden changes of velocity are quick opening or quick closing of a line valve, sudden starting or sudden stopping of a pump.

If flow in a pipe is changed suddenly, the built-up energy of the flowing water produces a high pressure that may result in damage.

Surge pressures can reach destructively high levels unless some type of surge control is provided. The simplest form of a surge-control valve is the pressure-relief valve. This valve responds to pressure variations at its inlet and is designed to open very rapidly at an increase in pressure above the set point of the control. The pressure-relief valve is most commonly installed on the side outlet of a tee at a specific point in a system, and its discharge is to atmosphere.

Valves

Valves shall be uniformly located and mapped for ready use. A valve box, with its cover at grade, should be placed in the distribution system so that a short section of main may be repaired or serviced without interruption of service to more than one block. Valves should be located on all branches from feeder mains and between distributors and fire hydrants. Three valves should be used at crosses and two valves at tees. On arterial mains and minor distributors, valves should be placed at least every 1,200 feet.

Gate valve construction and materials should comply with the current American Water Works Association Standard C500 - Gate Valves.

Dead Ends

Dead end lines should be avoided by looping where possible. Unlooped mains should be equipped with a fire hydrant, flushing hydrant, or a blow-off. The flushing hydrant or blow-off valve shall be at least the size of the main or four inches, whichever is smaller. No flushing device shall be directly connected to a sanitary sewer or storm drain.

THRUST BACKING AND ANCHORAGE OF FITTINGS

Thrust backing is needed wherever a pipeline:

1. Changes direction as at tees, bends and crosses;
2. Changes size, as at reducers;
3. Stops, as at a dead end; and
4. Valves, at which thrust develops when closed.

Size and type of backing depends on pressure, pipe size, kind of soil and type of fitting. The following steps are used to determine the bearing area required for a thrust block

Example: A 90° bend for a 2" - 100 psi line. Soil is sand.

(1) Refer to the following and note that the thrust developed for each 100 psi water pressure at a 2" - 90° bend is 645 lbs.

Table 11-4: Source: Johns Manville Pipes, Denver, Colorado 80217

Thrust at Fittings in Lbs. at 100 Lbs. per Square Inch, Water Pressure

Pipe Size	90° Bend	45° Elbow	Tee and Deadends
1½"	415	225	295
2 "	645	350	455
2½"	935	510	660
3 "	1395	755	985
4 "	2295	1245	1620
6 "	4950	2680	3500
8 "	8375	4540	5930

(2) In Table 11-5, find the bearing power of sand as 2000 lbs. per square foot. Dividing the total force of 645 lbs. by 2000 lbs., a total area of thrust backing required of 0.32 square feet.

Table 11-5:

Safe Bearing Load of Soils	
Soil	Lbs./sq. ft.
Muck, peat and similar	0
Soft clay	1,000
Sand	2,000
Sand and Gravel	3,000
Sand and gravel cemented with clay	4,000
Hard shale	10,000

Note: Allowance in total bearing area should be made for possible water hammer in the line.

Upward Thrusts at Fittings

Where a fitting is used to make a vertical bend, anchor the fitting to a thrust block braced against undisturbed soil. The thrust block should have enough resistance to withstand upward and outward thrusts at the fitting.

Anchorage of Pipe on Slopes

Anchors on slopes are needed only when there is the possibility of backfill slipping downhill and carrying the pipe with it. Usually well drained soil, carefully tamped in layers, will not slide and pipe anchors will not be required. Where soil slippage is a possibility, anchors keyed into undisturbed soil may be fastened to every other length of pipe.

Anchorage of Valves in the Line

Under pressure conditions, valves in sizes three inches or larger, including those in hydrant run-outs, must be anchored against the thrust created when the valve is closed. Area of undisturbed soil which braces the thrust block must be large enough to withstand the thrust in whatever direction it is exerted.

SERVICE LINES AND CONNECTIONS

A service line is the piping which delivers water from the mains to the consumer or water use site. A service line of 3/4 inch to 1 inch may be ample to serve a single family service. A larger service line may be needed to furnish other needs[2]. The service connection must be sized to meet the peak demands. There is a wide choice of materials for service line piping. The minimum size and material is often prescribed by established local policy for the different types of services. Consult local plumbing codes.

Galvanized steel pipe is widely used for service lines. It is strong and reasonably priced. However, some waters and soils cause the galvanized pipe to deteriorate rapidly due to corrosion.

Copper tubing is widely used and offers several advantages: Copper tubing is easy to handle because of its flexibility. It does not corrode readily, joints are easily made and its smoothness permits a high carrying capacity.

Cast iron pipe is satisfactory for service lines. It is generally used for larger sizes of from 1 1/4 inches upwards. Sizes above two inches are the most satisfactory.

Plastic pipe is used for service lines. Manufacturers claim the following advantages: (1) Ends of pipe may be heated, flared and used with copper connections; (2) It is light in weight, therefore it can be handled easily; (3) Withstands corrosion, so it has a long life carrying capacity; (4) Withstands low temperatures; and (5) Costs less than metal pipe. On the other hand, the pipe cannot be electrically thawed or heated which may be a disadvantage in colder climates. Plastic pipe is available with adaptors to provide for simple connections to asbestos-cement, cast iron, steel and other pipe materials.

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(2) For details, consult "Sizing Water Service Lines and Meters", Manual 22, American Water Works Association, 6666 Quincy Avenue, Denver, CO. 80235.

SEPARATION OF WATER MAINS AND SEWERS

Whenever possible, water mains shall be laid at least 10 feet, horizontally, from any existing or proposed sewer. Should local conditions prevent a lateral separation of 10 feet, a water main may be laid closer than 10 feet to a sewer if the sewer is constructed with pressure pipe specifications including joints and tested at 15 psi and:

a. It is laid in a separate trench.

b. It is laid in the same trench with the sewer, provided that the water main is located on an undisturbed earth shelf above the sewer and located on one side of the sewer.

c. In either case the elevation of the bottom invert of the water main is at least 18 inches above the top (crown) of the sewer.

Whenever sewers cross under water mains, the water main shall be laid so that the bottom of the water main is at least 18 inches above the top of the sewer. This vertical separation shall be maintained for that portion of the water main located within 10 feet horizontally of any sewer it crosses.

No water main shall pass through, or come into contact with any part of a sewer manhole.

There shall be no physical connection between the distribution system and any pipes, pumps, hydrants, or tanks which are supplied or may be supplied with a water that is, or may be contaminated except as approved in writing by the State regulating agency. See cross-connections in Chapter 15.

Water mains within 10 feet of railroad tracks or crossing under railroad tracks shall be equipped with clamps or other acceptable provisions to minimize the affect of vibration. Mains crossing under waterways shall be valved at both ends of the crossing to permit isolation for repair, and testing of the section. Sampling taps shall be provided to facilitate sanitary control. These taps shall not be subject to flooding.

DISINFECTION

Even under the best conditions, the construction of new water lines subjects the interior of the pipes and fittings to possible serious contamination. The repair of faulty or ruptured water lines and fittings usually occurs under adverse conditions and the threat of contamination is ever present. Before these sections of water lines are placed into service, they must be flushed, if possible, and always disinfected with chlorine solutions. During construction, precautions should be taken to avoid unnecessary contamination. When working under adverse conditions, particularly in the repair of faulty or ruptured lines or fitting, it is prudent to spread generous amounts of 70% calcium hypochlorite, either in granular or tablet form in the working trench. The chlorine will go into solution slowly and will significantly reduce gross contamination.

Disinfection is commonly accomplished by one of four methods. All are described in an American Water Works Association manual on Water Main Disinfection, AWWA C601-68, 2 Park Avenue, New York, NY 10016.

Continuous Feed Method

This method has an advantage for disinfection of long sections of pipe. The disinfection is accomplished after construction by injecting chlorine solutions (either a gas chlorinator or hypochlorinator may be used) into the pipe through a corporation cock or other fitting. The line is first flushed to remove accumulated material. The chlorine dose is ususally 50 mg/l with a 24 hour contact period. The chlorine solution is injected as the line is being filled. This method requires careful control and specialized equipment and should not be attempted by inexperienced contractors or repair crews.

Slug Method

This method is similar to the previous method but employs high doses as high as 500 mg/liter with a 1/2 hour retention. It is particularly applicable for large diameter water mains and where the pipe must be put into service without long delays.

Tablet Method

Calcium hypochlorite (70% available chlorine) is prepared by several firms in tablet form under various labels. A swimming pool supply store is a good source. These tablets provide a simple and popular method for water line disinfection. The tablets are attached on the inside of the pipe (top side) as the line is being laid with an adhesive. Permatex No. 1 adhesive manufactured by the Permatex Company is recommended by the American Water Works Association. The tabulation that follows lists the doses suggested by AWWA. This method is considered superior to the use of granular calcium hypochlorite which will flush away quickly before dissolving. The water line should be filled slowly to reduce the chance of flushing away the tablets. The method has some disadvantages: (1) The line cannot be flushed before disinfection, (2) the tablets will not readily dissolve at water temperatures below 41°F (5°C), and (3) the tablets are difficult to insert in small diameter pipes.

Table 11-6: Chlorine Tablets Required to Produce 50 mg/l Concentration of Chlorine in Pipe Sections of Various Lengths and Diameters (AWWA C 601-68), Retention Period of 24 Hours.

Length of Pipe Section in Feet	Diameter in Inches 2	4	6	8
13 or less	1	1	2	2
18	1	1	2	3
20	1	1	2	3
30	1	2	3	5
40	1	2	4	6

Notes: - Based upon tablets of 3 3/4 grams of available chlorine.

- Retention period is 24 hours with above doses.
- Double the number of tablets for 100 mg/l dose and 12 hours retention.
- Use 4 times the number of tablets for 200 mg/l and 2 hours retention.
- For pipes less than 2 inches diameter, use the 2 inch diameter pipe dose.

The water line should be filled slowly and tested at the extreme end until a strong chlorine solution is present. Allow the chlorinated water to stand in contact with the pipe for the full retention period. Then flush until the chlorine residual by the DPD test (Chapter 9) shows a residual of 1.0 mg/l or less. A sample of water from the disinfected line should be collected for coliform test by an approved laboratory. If the test indicates ineffective disinfection, it must be repeated.

Emergency Repairs and Disinfection

Where a short section of pipe or a fitting must be repaired and placed into immediate service, the section may be thoroughly swabbed with full strength 5.25% sodium hypochlorite (common household bleach) during the repair before installation. Care should be taken to insure complete coverage of all inner surfaces.

Caution on the Storage and Use of Calcium Hypochlorite

Calcium hypochlorite is a highly reactive chemical when wet and should be stored in dry places and away from organic substances as violent reactions, including explosion and fire, may result. Potential contaminates include soap products, cleansing oils, mineral oils, petroleum products, food and beverages, paper and similar materials. Since the product is readily purchasable, avoid storing large quantities.

State Agency Approval

The State agency will be the final authority on disinfection standards and should be consulted for special requirements.

PART II

OPERATION AND MAINTENANCE

CHAPTERS 12 through 15

NATIONAL DRINKING WATER REGULATIONS	Applicability - Primary Regulations: Maximum Contaminate Levels, Monitoring, Reporting, Public Notification and Record Keeping - Secondary Regulations - Sampling Techniques

INTRODUCTION

As part of the National Safe Drinking Water Act (SDWA), the Environmental Protection Agency has promulgated National Primary Drinking Water Regulations, applicable to public water systems throughout the nation. In addition, Secondary Regulations have been prepared as guidelines. Designated counterpart State agencies(1) which accept and qualify for enforcement responsibilities will supervise and enforce the regulations and may also enforce certain additional regulations of their own. While the Primary Drinking Water Regulations are devoted to matters affecting the health of consumers, the Secondary Regulations deal with the aesthetic qualities of drinking water. Both are summarized in this Chapter.

The Primary Regulations include:

- Siting requirements for new or expanded systems
- Maximum Contaminate Levels for inorganic and organic chemicals, turbidity and microbiological (coliform) levels
- Monitoring and testing requirements
- Reporting, public notification and record keeping
- Record maintenance

The Primary Regulations apply to all public water systems but a distinction is made between "community" and "non-community"

(1) See Listing of State Agencies and EPA Regional Offices in the Appendix B.

systems. Since a community system supplies water to people at the place where they normally live and stay for extended periods, the consumers are subjected to whatever contaminates may be present on a more or less continuous basis. Therefore, the full range or maximum contaminate levels apply to community systems. On the other hand, the non-community system serves mostly transients, travelers and people with shorter term exposures and thus the requirements are less stringent. A partial list of community and non-community water systems is shown on Page 2, Purpose and Use of the Manual.

The owners or operators of public water systems are responsible, under the Safe Drinking Water Act, for establishing the procedures necessary to meet the requirements of the Primary Drinking Water Standards. The water supplier should become thoroughly familiar with the requirements. The State agency may be contacted for further information.

The summary which follows is an outline of requirements under the National (Interim)(2) Primary Drinking Water Regulations as they relate to the responsibilities of those who supply water to the public.

SUMMARY OF PRIMARY DRINKING WATER REGULATIONS

SITING REQUIREMENTS (Sec. 141.5)

Before entering into a financial committment, or initiating construction of a new public water system or increasing the capacity of an existing public water system the owner must notify the State agency.

(2) The regulations are considered interim at this time as they will undergo refinement in the future as new pertinate information becomes available.

Where the term "owner," "supplier," "water purveyor" or "operator" is used, it means the person, corporation, company, association, partnership, State, municipality or Federal agency which supplies water to the public.

Where the term "State agency" is used, it means the agency of State government which has jurisdiction over water supplies (See Appendix B).

APPLIES TO ALL PUBLIC WATER SYSTEMS

A "public water system" is defined(3) as a system for the provision to the public of piped water for human consumption, if such system has at least fifteen service connections or regularly serves an average of at least twenty-five individuals daily at least 60 days out of the year. A "community water system" is defined as a public water system which serves at least fifteen connections used by year-around residents or regularly serves at least twenty-five year-around residents. A "non-community water system" is a public water system that is not a community water system. Privately owned as well as publicly owned systems are included.

(3) National Interim Primary Drinking Water Regulation, U.S. Environmental Protection Agency, Federal Register, Volume 40, No. 248, December 24, 1975.

SUMMARY OF MONITORING REQUIREMENTS

MICROBIOLOGICAL

Contaminant	Surface Source	Ground Source
Coliform Bacteria	Monthly, based on population served. Community systems of less than 1000 people, a minimum of one per ronth. Non-community systems, a minimum of one per calendar quarter.	Same as for surface sources, except that State agency may reduce to one sample per calendar quarter.

INORGANIC CHEMICALS (Applies only to community systems except for Nitrate which applies to both community and non-community)

Contaminant	Surface Source	Ground Source
Arsenic Barium Cadmium Chromium Lead Mercury Selenium Silver Fluoride Nitrate	Analysis completed June 24, 1978. Thereafter at one year intervals.	Analysis completed within two years after effective date, Thereafter at three year intervals.

ORGANIC CHEMICALS (Applies only to community type systems)

Contaminant	Surface Source	Ground Source
Endrin Lindane Methoxychlor Toxaphene 2,4-D 2,4,5-TP Silvex	Analysis completed June 24, 1978. Thereafter at three year intervals	Analysis only if required by the State.

RADIOACTIVITY

Contaminant	Surface Source	Ground Source
Natural Radioactivity	Analysis completed June 24, 1980. Thereafter at four year intervals.	Analysis completed within three years after effective date. Thereafter at four year intervals.

Note: There is also a requirement for man-made radioactivity, but this applies only to surface source systems serving a population of over 100,000.

MONITORING AND ANALYTICAL REQUIREMENTS

MICROBIOLOGICAL (Sec. 141.14 and 141.21)[3]

Water samples for coliform bacteria shall be collected:

1. At points representative of distribution system conditions.
2. At regular time intervals and based on the population served.

Sampling Frequency

Surface waters - monthly, based on population served, with minimum of one per month for systems serving between 25 and 1000 people, except for non-community water systems which shall be sampled a minimum of once each calendar quarter during which it serves the public

Ground waters - same as surface water supplies. Systems serving 25 - 1000 may, with written permission of the State agency, reduce sampling frequency based on a history of no coliform bacterial contamination and on a sanitary survey showing the water system is supplied solely by a protected ground water source and is free of sanitary defects.

The State agency may require more frequent sampling.

Maximum Contaminant Level

Fermentation tube method - coliform bacteria shall not be present in any of the following 10 ml standards portions:

1. more than 10 percent of the portions in any reporting period;
2. three or more portions in more than one sample when less than 20 samples are examined in any reporting period; or
3. three or more portions in more than five percent of the samples when 20 or more samples are examined.

Membrane filter method - in a 100 ml sample, coliform bacteria shall not exceed:

1. one colony as the arithmetic mean of all samples examined in any reporting period;
2. four colonies in more than one sample when less than 20 are examined in that reporting period;
3. four colonies in more than five percent of the samples when 20 or more are examined.

Determination of maximum contaminant levels for coliform bacteria may, at the discretion of the State, be based upon a three month reporting period, provided the system is required to take less than four samples per month. This flexibility allows the small system (serving not more than 3300 people) to average bacteriological samples over a more representative time frame.

Action By Purveyor

When coliform in a single sample exceeds four per 100 ml by the membrane filter method - the purveyor must collect at least two consecutive daily check samples from the same point and additional needed samples until two consecutive samples show less than one coliform per 100 ml.

or,

When coliform occurs in three or more 10 ml portions of a single sample by the fermentation tube method - collect at least two consecutive daily check samples until results from two consecutive daily samples show no positive tubes.

Check samples shall not be included in calculating the total number of samples taken each month to determine compliance with the number required based on population.

When coliform presence is confirmed by any check sample the purveyor must report to the State agency within 48 hours.

When maximum contaminant levels are exceeded, the purveyor must report to the State agency and notify the public.

Chlorine Residual

Based upon a sanitary survey which has determined that a community water system is free of sanitary defects and water sources are adequately treated and/or protected, the purveyor may request State approval for substitution of chlorine residual monitoring for not more than 75 percent of the microbiological samples required, provided chlorine residual samples are taken at a frequency of at least four for each substituted microbiological sample - and at least daily residual determinations are made - and that the system maintains no less than 0.2 mg/l free chlorine residual throughout the distribution system. If less than 0.2 mg/l, retest within one hour. If original analysis is confirmed, report to the State within 48 hours, collect sample for coliform analysis and report the results to the State.

TURBIDITY SAMPLING - Applies Only to Surface Waters (Sec. 141.13 and 141.22)

Sampling Frequency

Purveyor takes samples of water at representative entry points to the distribution system at least once per day.

Maximum Contaminant Level (Measured by the Nephelometer Method)

1. One turbidity unit (TU) as a monthly average - except five or fewer TU's monthly average may be allowed by the State if the purveyor demonstrates that it does not: (Averages are rounded to nearest whole number)
   a. Interfere with disinfection.
   b. Prevent effective distribution disinfection.
   c. Interfere with microbiological determination.
2. Five turbidity units based on an average for two consecutive days. (Averages are rounded to nearest whole number)

Action by Purveyor

If turbidity exceeds maximum contaminant level - resample within one hour - if repeat sample exceeds limit, report to the State within 48 hours.

If monthly average exceeds limit or if the average of two samples taken on consecutive days exceeds five TU the supplier shall - report to the State and notify the public.

INORGANIC SAMPLING (Sec. 141.11 and 141.23) - Applies only to community systems, except for Nitrate which applies to both community and non-community systems.

Sampling Frequency

Surface waters - complete analysis by June 1978 and repeat yearly.

Ground waters - complete analysis by June 1979 and repeat at three year intervals.

Maximum Contaminant Level Other Than Fluoride

Contaminant	Level (mg/l)	Contaminant	Level (mg/l)
Arsenic	0.05	Mercury	0.002
Barium	1.	Nitrate as N	10.
Cadmium	0.010	Selenium	0.01
Chromium	0.05	Silver	0.05
Lead	0.05	Fluoride	See below

Maximum Contaminant Levels for Fluoride

When the annual average of the maximum daily air temperature for the location in which the community water system is situated is the following, the corresponding maximum level for fluoride are:

Temperature (°F)	Level (mg/l)
53.7 and below	2.4
53.8 - 58.3	2.2
58.4 - 63.8	2.0
63.9 - 70.6	1.8
70.7 - 79.2	1.6
79.3 - 90.5	1.4

Action By Purveyor

If result of an analysis exceeds maximum contaminant level - supplier shall report to the State within 7 days and initiate three additional analyses within one month. When the average of four analyses within one month exceeds maximum level, report to the State within 48 hours and notify the public.

For nitrate only, when an analysis exceeds maximum level, supplier shall take a second sample within 24 hours. When the average of two samples exceeds the maximum level, report within 48 hours and notify the public.

Monitoring after public notification shall be at a frequency determined by the State agency and shall continue until two consecutive samples do not exceed maximum contaminate level or until a schedule for enforcement action becomes effective.

ORGANIC SAMPLING (Sec. 141.12 and 141.24 - Applies only to community systems.

Sampling Frequency

Surface sources - complete by June 1978 - repeat at State agency specified intervals but no less than three year intervals.

Ground water sources - analyses completed as specified by the enforcing agency.

Maximum Contaminant Level

Contaminant	Level (ug/l)	Contaminant	Level (ug/l)
Endrin	0.2	Toxaphene..........	5.0
Lindane.............	4.0	2,4-D..............	100.
Methoxychlor........	100.	2,4,5-TP Silvex....	10.

Action By Purveyor

If analyses exceed limit, notify the enforcing agency within seven days and initiate three additional analyses within one month.

When average of four analyses exceeds maximum level, report to the State agency within 48 hours and notify the public. Monitoring after public notification shall be at a frequency designated by the State agency and shall continue until two successive samples do not exceed limit, or until the State agency establishes a schedule for enforcement.

APPROVED LABORATORIES (Sec. 141.28)

For compliance determination, water samples will be considered only if analyzed by a laboratory approved by the State agency - except that turbidity and chlorine residual may be performed by any person acceptable to the State agency.

MONITORING OF CONSECUTIVE COMMUNITY WATER SYSTEMS (Sec. 141.29)

When a purveyor supplies water to one or more other public water systems - the State agency may modify the monitoring requirements if the systems may be considered a single system. The modified system will be monitored as specified by the State agency and as concurred with by the E.P.A.

Each of the separate water systems is responsible for the modified sampling program applying to its system.

REPORTING, PUBLIC NOTIFICATION, RECORD KEEPING

REPORTING REQUIREMENTS (Sec. 141.31)

1. Report to the State within 40 days results of all tests.
2. Report to the State within 48 hours of failure to comply with any primary water regulation including monitoring.

PUBLIC NOTIFICATION (Sec. 141.32)

When a community water system fails to comply with:

1. An applicable maximum contaminant level.
2. An applicable testing procedure.
3. Scheduled corrections.
4. Required monitoring.

A. Notify persons served by the system in first set of water bills or by written notice within three months, and repeat once every three months as long as unsatisfactory conditions exist.

B. If the water system fails to meet an applicable maximum contaminant level, the supplier in addition to A (above) shall notify the public:

   1. Within 7 days of learning of the failure - by copy of notice to radio and television stations serving the area.

   2. Within 14 days of learning of the failure - by publication (three consecutive days) in a newspaper with general circulation in the area served by the system. If area is not served by a daily newspaper - publish on three consecutive weeks in a weekly newspaper. If no daily or weekly newspaper is available, post in post offices in the area served by the system.

C. Notices will be written in a manner reasonably designed to inform fully the users of the system.

   Notice shall disclose all material facts regarding the subject including the nature of the problem and, where appropriate, a clear statement that a primary drinking water regulation has been violated and any measures that should be taken by the public.

   Notices may include a balanced explanation of the significance or seriousness to public health and a fair explanation of steps taken to correct the problem.

D. Notice to the public may be given by the State on behalf of the purveyor.

E. When notification by mail is required by A (above) but notification by newspaper, radio or television is not required by B (above) the State may order the supplier to provide notification by newspaper, radio and television when circumstances make more immediate or broader notice appropriate to protect public health.

F. Notifications to the consumer and the general public by the water purveyor for non-compliance with regulations covering maximum contaminant levels is the sole responsibility of the water purveyor. Notification by the water purveyor is necessary regardless of who carries out for the purveyor the chemical, bacterial or other analyses:

   a. the water purveyor itself,

   b. a county or other local agency laboratory,

   c. the State laboratory, or

   d. a commercial laboratory.

In all cases for the analytical results to be acceptable they must have been from a laboratory approved by the State.

RECORD MAINTENANCE (Sec. 141.33)

Each water purveyor must maintain the following records of:

1. Bacteriological analyses - for at least five years. Chemical analyses - for at least 10 years. Actual laboratory reports may be kept, or data may be transferred to tabular summaries, provided that the following information is included:
   a. Date, place, time of sampling, name of person collecting.
   b. Identification of routine distribution system sample, check samples, raw or process water samples, special purpose samples.
   c. Date of analyses.
   d. Lab and person responsible for performing analysis.
   e. Analytical method used.
   f. Results of analysis.
2. Records of action taken to correct violations - for at least three years after last action was taken with respect to particular violation.
3. Copies of written reports, summaries or communications relating to sanitary surveys conducted by itself, private consultant or local, state or federal agency - for at least 10 years after completion of sanitary survey involved.
4. Records concerning scheduling of improvements - not less than five years following expiration of scheduling time.

NATIONAL SECONDARY DRINKING WATER GUIDELINES

While the Primary Regulations are devoted to constituents and regulations affecting the health of consumers, Secondary Regulations are those which deal with the aesthetic qualities of drinking water. The Secondary Guideline levels may not have a significant direct-impact on the health of consumers, but their presence in excessive quantities may discourage the utilization of a drinking water supply by the public.

The Secondary Guidelines are not Federally enforceable but are intended as guidelines for the States. The State agency should be consulted.

SECONDARY MAXIMUM CONTAMINANT LEVELS

The Secondary Drinking Water Guidelines contain maximum contaminant levels for chloride, color, copper, corosivity, foaming agents, hydrogen sulfide, iron, manganese, odor, pH, sulfate, total dissolved solids and zinc.

Chloride in reasonable concentrations is not harmful to humans, but in concentrations above 250 mg/l chloride causes a salty taste in water which is objectionable to many people. Chloride can be removed from drinking water by distillation, reverse osmosis or electrodialysis. In some cases the entry of chloride into a drinking water source can be minimized by proper aquifer selection and well construction.

Color may be indicative of dissolved organic material which may lead to generation of trihalomethanes and other organohalogen compounds during chlorination. Color can also be caused by inorganic substances such as manganese or iron. Color becomes objectionable to most people at levels over 15 C.U. (Color Units). In some cases, color can be objectionable at the 5 C.U. level. Depending on the nature of the substances causing color, conventional water treatment (flocculation and filtering), oxidation or carbon adsorption are processes used for removing color.[4]

Copper is an essential and beneficial element in human metabolism, but copper imparts an undesirable taste to drinking water. Small amounts of copper are generally regarded as nontoxic. Copper can be removed from water by ion exchange,[4] and by proper control of pH, where the source of copper is the corrosion of copper pipes.

Corrosivity is a complex characteristic of water related to pH, alkalinity, dissolved oxygen and total dissolved solids plus other factors. A corrosive water, in addition to dissolving metals with which it comes in contact, also produces objectionable stains on pumbing fixtures. Corrosivity is controlled by pH adjustment, the use of chemical stabilizers, or other means which are dependent upon the specific conditions of the water system.[4]

Foaming is a characteristic of water caused principally by the presence of detergents and similar substances. Water which foams is definitely objectionable and considered unfit for consumption. The foamability of water is measured by the quantity of methylene blue active substances (MBAS) present. Foaming substances can be removed from drinking water by carbon adsorption, but it is preferable to prevent contamination of water by foaming substances.[4]

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(4) See Chapter 10, Treatment and Conditioning

Hydrogen sulfide is an odorous gas. Its presence in drinking water is often attributed to microbial action on organic matter or the reduction of sulfate ions to sulfide. In addition to its obnoxious odor, hydrogen sulfide in association with soluble iron produces black stains on laundered items and black deposits on piping and fixtures. Hydrogen sulfide is removed from drinking water by aeration or chemical oxidation.[4]

Iron is a highly objectionable constituent of water supplies for either domestic or industrial use. Iron may impart brownish discolorations to laundered goods. The taste that it imparts to water may be described as bitter or astringent, and iron may adversely affect the taste of other beverages made from water. The amount of iron causing objectionable taste or laundry staining constitutes only a small fraction of the amount normally consumed in the daily diet and thus does not have toxicologic significance. Iron can be removed from water by water filtration treatment processes or ion exchange and also by oxidation processes followed by filtering. If the iron comes from the corrosion of iron or steel piping, the problem can often be eliminated by practicing corrosion control.[4]

Manganese, like iron, produces discoloration in laundered goods and impairs the taste in drinking water and beverages, including tea and coffee. At concentrations in excess of 0.05 milligrams per liter, manganese can occasionally cause buildup of coatings in distribution piping which can slough off and cause brown spots in laundry items and unesthetic black precipitates. Manganese can usually be removed from water by the same process used for iron removal.[4]

Odor is an important aesthetic quality of water for domestic consumers and process industries such as food, beverage and pharmaceutical manufacturers, which require water essentially free of taste and odor. It is usually impractical and often impossible to isolate and identify the odor-producing chemical. Evaluation of odors and tastes is thus dependent on the individual senses of smell and taste. In many cases, sensations ascribed to the sense of taste are actually odors. Odors are usually removed by carbon adsorption or aeration.[4]

The range of pH in public water systems may have a variety of esthetic and health effects. Corrosion effects are commonly associated with pH levels below 6.5. As pH levels are increased to about 8.5 mineral incrustations and bitter taste can occur, the germicidal activity of chlorine is substantially reduced and the rate of formation of trihalomethanes is significantly increased. However, the impact of pH in any one water system will vary depending on the overall chemistry and composition of the water so that a more or less restrictive range may be appropriate under specific circumstances.

Sulfate may cause detectable tastes at concentrations of 300-400 milligrams per liter; at concentrations above 600 milligrams per liter it may have a laxative effect. High concentrations of sulfate also contribute to the formation of scale in boilers and heat exchangers. Sulfate can be removed from drinking water by distillation, reverse osmosis or electrodialysis. The laxative effect noted above seldom affects regular users of the water but transients are particularly susceptible. For this reason it is likely that most States will institute monitoring programs for sulfate, and that transients should be notified if the sulfate content of the water is high. Such notification should include an assessment of the possible physiological effects of consumption of the water.

Total Dissolved Solids (TDS) may have an influence on the acceptability of water in general, and in addition a high TDS value may be an indication of the presence of an excessive concentration of some specific substance that would be aesthetically objectionable to the consumer. Excessive hardness, taste, mineral deposition or corrosion are common properties of highly mineralized water. Dissolved solids can be removed by chemical precipitation in some cases, but distillation, reverse osmosis, electrodialysis and ion exchange are more generally applicable.[4]

Zinc. like copper, is an essential and beneficial element in human metabolism. Zinc can also impart an undesirable taste to water. At higher concentrations, zinc salts impart a milky appearance to water. Zinc can be removed from water by water filtration treatment processes or ion-exchange. But, since the source of zinc is often the coating of galvanized iron, corrosion control will minimize the introduction of zinc into drinking water. At the same time, corrosion control will minimze the introduction of lead and cadmium into the drinking water, since lead and cadmium are often contamiants of the zinc used in galvanizing.[4]

Contaminates Considered But Not Included In The Regulations

In addition to the above contaminants, hardness, alkalinity, phenols, and sodium, were considered.

Since high levels of hardness have significant aesthetic and economic effects, the removal of hardness (softening) can be considered beneficial from a non-health standpoint. However, correlations between the softness of water and the incidence of cardiovascular disease have been shown, in some studies, so the practice of softening drinking water is being discouraged by some scientists and physicians. Available information is not sufficient at this time to balance the aesthetic desirability of setting a limit for hardness against the potential health risk of water softening.[4]

Phenols, particularly the chlorophenols, are esthetically objectionable because of the taste and odor they produce. Some of the chlorophenols produce a detectable taste or odor at concentrations as low as 1 ppb. While analysis for phenols in this concentration area might present some difficulties, the odor test can easily detect the presence of these compounds and thus makes the inclusion of a limit for phenols unnecessary.

The principal concern with respect to sodium relates to its potential health significance rather than to aesthetic effects. However, existing data did not support the establishment of a Maximum Contaminant Level for sodium in the Interim Primary Drinking Water Regulations. It has been recommended that the States institute programs for regular monitoring of the sodium content of drinking water served to the public, and for informing physicians and consumers of the sodium concentration in drinking water. By this means, those affected by high sodium concentration can make adjustments to their diets, or seek alternative sources of water to be used for drinking and food preparation.

Monitoring

Since these regulations are not federally enforceable, there are no associated uniform monitoring requirements. However, individual State agencies may establish requirements.

SUMMARY

Secondary Guideline Levels

The Secondary Maximum Contaminant Levels for public water systems are as follows:

Contaminant:	Level
Chloride	250 mg/l.
Color	15 Color Units.
Copper	1 mg/l.
Corrosivity	Non-corrosive.
Foaming Agents	0.5 mg/l.
Hydrogen Sulfide	0.05 mg/l.
Iron	0.30 mg/l.
Manganese	0.05 mg/l.
Odor	3 Threshold Odor Number.
pH	6.5-8.5
Sulfate	250 mg/l.
TDS (Total Dissolved Solids)	500 mg/l.
Zinc	5 mg/l.

SAMPLING RESPONSIBILITY AND TECHNIQUES

Sampling and testing of public water systems and the interpretation of the results is a vital part of the operation. The water purveyor is responsible for arranging for all of the sampling requirements listed in the Primary Regulations which are applicable to the particular water supply system. The operator must arrange for the examination of the samples at a laboratory approved by the State agency. Consult the State agency for advice and details.

The operator must perform certain tests for operational information, particularly the chlorine residual test. Chapter 9 on Chlorination discusses the chlorine residual test. This test may be performed by the operator using commercial test kits, purchased from the manufacturer of the chlorination equipment or firms which deal in water laboratory supplies. A list of such firms may be obtained from the State agency. Other tests may be necessary for plant operation. Tests to measure the pH are also available through water laboratory supply firms and are inexpensive. If treatment other than chlorination is practiced, the manufacturer or supplier will recommend the tests necessary to insure proper operation of the equipment.

Some State agencies require that water systems employing chlorination or other required treatment must employ operators who meet minimum qualifications. Some provide training courses. Consult with the State agency for details.

Sampling Techniques

Only sampling containers furnished by the approved laboratory should be used. This is necessary to insure proper cleaning and sterilization (where necessary) of containers. The laboratory cannot distinguish between contaminated water in the system and inadvertently contaminated containers or for that matter contamination from poor sampling techniques. The importance of good techniques cannot be overstressed.

Sampling taps should be strategically located to facilitate sampling. Special taps are advisable where sampling must be done routinely. Taps should be kept clean (may be covered where necessary with a clean paper cup or plastic bag), and should be free flowing without slop. The tap should be directed downward so that water does not leak or slop around the outside of the tap. This is particularly important for samples collected for bacteriological examination. Mixing faucets and rubber hose attachments must be avoided.

The tap should be flushed for a sufficient period of time to allow clearing of the water which may have been standing for a long time. Taps with short service lines or in heavy use areas are preferred. The sampling container should be filled to a point a about 1/2" below overflow. When filling containers, do not allow water entering the container to contact the hands.

Sterile containers for bacteriological examination should never be rinsed. On the other hand, it is advisable to rinse sampling containers used for chemical and physical tests with some of the water to be tested. This improves reliability. Containers should be sealed immediately after collection with the cap provided by the laboratory. Do not inadvertently contaminate the caps. It is best to hold it in one hand by the top while collecting the sample.

Samples collected for coliform bacteria testing should be delivered to the laboratory within 1 hour if possible. Temporary storage in a refrigerator is acceptable. In no case should the time lapse between collection and testing exceed 30 hours.

Certain chemical substances change significantly, particularly when exposed to air. The following tests should be performed immediately upon collection to insure reliable results.

- Chlorine residual
- pH and carbon dioxide
- Alkalinity and acidity
- Dissolved oxygen

CHAPTER 13

MAINTENANCE	Pumps - Controls - Treatment Equipment - Distribution Systems - Well Yield Rehabilitation

INTRODUCTION

Planned, preventive maintenance is essential to the proper operation of a water system. It is important not only to insure a reliable safe water at all times, but also to protect the capital investment and insure efficient operation. A planned maintenance program pays off in less frequent interruptions of service and fewer consumer complaints.

Since continuity of service is essential, the water purveyor should have on hand, or otherwise readily available, the specialized tools and replacement equipment or parts necessary to maintain and repair the various component parts of the system.

A schedule for routine preventative maintenance should be prepared for each pump, control, major valve, treatment unit, and other equipment. Employees should be instructed to follow the schedule and make pertinent notations and reports. The schedule need not be complex and can generally be prepared from the manufacturers instruction sheets.

Installation and operation manuals, supplied by manufacturers, for pumps, pressure pneumatic systems and controls, chemical feed equipment, and other devices should be filed for future reference. Schematic plans and as-built construction plans should be kept up to date and filed. Location of all underground facilities (pipes, valves, etc.) should be referenced to permanent markers, curbs, building corners, etc. for quick location when necessary in an emergency. Maintenance charts should be kept for equipment which may require periodic lubrication. Replacement fuses should be available for all fused electrical controls.

MAINTENANCE OF WELL PUMPS AND CONTROLS

Small water systems are usually not complex and often consist of well sources with the associated pumps, hydropneumatic systems and perhaps a hypo-chlorinator for disinfection of the water with chlorine solutions. The Water Systems Council has published a handbook entitled Water Systems Handbook which is particularly useful to the operators of small systems. The operation and servicing sections are particularly good. Copies may be obtained from the Council at 221 North LaSalle Street, Chicago, Illinois 60601. The Council has kindly given permission for the use of selected portions of their Handbook in this manual.[1]

Servicing Instruments and Test Procedures

Pumps and controls are generally powered by electrical energy. For that reason, effective maintenance requires a working knowledge of electrical circuits and circuit testing instruments. It is not implied that every water system operator should be expected to service the electrical circuits involved in pumps and controls. Electricians and pump service companies are readily available to perform these services. However, the operator will do well to understand the basics, if for no other reason than to learn how to avoid electric shocks.

Jet Pumps

The jet pump is one of the most popular well pumps, particularly for the small systems. The charts that follow were taken from the Water Systems Handbook and are intended as trouble shooting guides.

(1) See Appendix C for other manuals and handbooks.

Table 13-1: TROUBLE SHOOTING THE JET PUMP

A—PUMP WON'T START OR RUN

CAUSE OF TROUBLE	HOW TO CHECK	HOW TO CORRECT
1. Blown fuse.	Check to see if fuse is OK	If blown, replace with fuse of proper size
2. Low line voltage.	Use voltmeter to check pressure switch or terminals nearest pump	If voltage under recommended minimum, check size of wiring from main switch on property If OK, contact power company
3. Loose, broken, or incorrect wiring.	Check wiring circuit against diagram See that all connections are tight and that no short circuits exist because of worn insulation, crossed wire, etc	Rewire any incorrect circuits Tighten connections, replace defective wires
4. Defective motor.	Check to see that switch is closed	Repair or take to motor service station
5. Defective pressure switch.	Check switch setting Examine switch contacts for dirt or excessive wear	Adjust switch settings Clean contacts with emery cloth if dirty
6. Tubing to pressure switch plugged.	Remove tubing and blow through it	Clean or replace if plugged
7. Impeller or seal.	Turn off power, then use screwdriver to try to turn impeller or motor	If impeller won't turn, remove housing and locate source of binding
8 Defective start capacitor.	Use an ohmmeter to check resistance across capacitor Needle should jump when contact is made No movement means an open capacitor, no resistance means capacitor is shorted	Replace capacitor or take motor to service station
9. Motor shorted out.	If fuse blows when pump is started (and external wiring is OK) motor is shorted	Replace motor

B—MOTOR OVERHEATS AND OVERLOAD TRIPS OUT

CAUSE OF TROUBLE	HOW TO CHECK	HOW TO CORRECT
1. Incorrect line voltage.	Use voltmeter to check at pressure switch or terminals nearest pump	If voltage under recommended minimum, check size of wiring from main switch on property If OK, contact power company
2. Motor wired incorrectly.	Check motor wiring diagram	Reconnect for proper voltage as per wiring diagram
3. Inadequate ventilation.	Check air temperature where pump is located If over 100°F, overload may be tripping on external heat	Provide adequate ventilation or move pump
4. Prolonged low pressure delivery.	Continuous operation at very low pressure places heavy overload on pump This can cause overload protection to trip	Install globe valve on discharge line and throttle to reduce flow and to increase pressure

C—PUMP STARTS AND STOPS TOO OFTEN

CAUSE OF TROUBLE	HOW TO CHECK	HOW TO CORRECT
1. Leak in pressure tank.	Apply soapy water to entire surface above water line If bubbles appear, air is leaking from tank	Repair leaks or replace tank
2. Defective air volume control.	This will lead to a waterlogged tank Make sure control is operating properly If not, remove and examine for plugging	Clean or replace defective control Add air as needed.
3. Faulty pressure switch. or Water logged tank	Check switch setting Examine switch contacts for dirt or excessive wear	Adjust switch settings Clean contacts with emery cloth if dirty
4. Leak on discharge side of system.	Make sure all fixtures in plumbing system are shut off Then check all units (especially ballcocks) for leaks Listen for noise of water running.	Repair leaks as necessary
5. Leak on suction side of system.	On shallow well units, install pressure gauge on suction side On deep well systems, attach a pressure gauge to the pump Close the discharge line valve Then, using a bicycle pump or air compressor, apply about 30 psi pressure to the system If the system will not hold this pressure when the compressor is shut off, there is a leak on the suction side	Make sure above ground connections are tight Then repeat test If necessary, pull piping and repair leak
6. Leak in foot valve.	Pull piping and examine foot valve	Repair or replace defective valve

D—PUMP WON'T SHUT OFF

CAUSE OF TROUBLE	HOW TO CHECK	HOW TO CORRECT
1. Wrong pressure switch setting or setting "drift."	Lower switch setting If pump shuts off, this was the trouble	Adjust switch to proper setting
2. Defective pressure switch.	Arcing may have caused switch contacts to "weld" together in closed position Examine points and other parts of switch for defects	Replace switch if defective
3. Tubing to pressure switch plugged.	Remove tubing and blow through it	Clean or replace if plugged
4. Loss of prime.	When no water is delivered, check prime of pump and well piping	Reprime if necessary
5. Low water level in well.	Check well water against pump performance table to make sure pump and ejector are properly sized	If undersized, replace pump or ejector
6. Plugged ejector.	Remove ejector and inspect.	Clean and reinstall if dirty

E—PUMP OPERATES BUT DELIVERS LITTLE OR NO WATER

CAUSE OF TROUBLE	HOW TO CHECK	HOW TO CORRECT
1. Low line voltage.	Use voltmeter to check at pressure switch or terminals nearest pump	If voltage under recommended minimum, check size of wiring from main switch on property If OK, contact power company
2. System incompletely primed.	When no water is delivered, check prime of pump and well piping	Reprime if necessary
3. Air lock in suction line.	Check horizontal piping between well and pump. If it does not pitch upward from well to pump, an air lock may form	Rearrange piping to eliminate air lock
4. Undersized piping.	If system delivery is low, the discharge piping and/or plumbing lines may be undersized Refigure friction loss	Replace undersized piping or install pump with higher capacity
5. Leak in air volume control or tubing.	Disconnect air volume control tubing at pump and plug hole If capacity increases, a leak exists in the tubing of control	Tighten all fittings and replace control if necessary
6. Pressure regulating valve stuck or incorrectly set. (Deep well only)	Check valve setting Inspect valve for defects	Reset, clean, or replace valve as needed
7. Leak on suction side of system.	On shallow well units, install pressure gauge on suction side On deep well systems, attach a pressure gauge to the pump Close the discharge line valve Then, using a bicycle pump or air compressor, apply about 30 psi pressure to the system If the system will not hold this pressure when the compressor is shut off, there is a leak on the suction side	Make sure above ground connections are tight Then repeat test If necessary, pull piping and repair leak
8. Low well level.	Check well depth against pump performance table to make sure pump and ejector are properly sized	If undersized, replace pump or ejector
9. Wrong pump-ejector combination.	Check pump and ejector models against manufacturer's performance tables	Replace ejector if wrong model is being used
10 Low water level in well.	Shut off pump and allow well to recover Restart pump and note whether delivery drops after continuous operation	If well is "weak, lower ejector (deep well pumps), use a tail pipe (deep well pumps), or switch from shallow well to deep well equipment
11. Plugged ejector.	Remove ejector and inspect	Clean and reinstall if dirty
12. Defective or plugged foot valve and/or strainer.	Pull foot valve and inspect Partial clogging will reduce delivery Complete clogging will result in no water flow A defective foot valve may cause pump to lose prime, resulting in no delivery	Clean, repair, or replace as needed
13. Worn or defective pump parts or plugged impeller.	Low delivery may result from wear on impeller or other pump parts Disassemble and inspect	Replace worn parts or entire pump Clean parts if required

Submersible Well Pumps

Submersibles have gained favor because of their simplicity of operation and reliability. Proper servicing requires the use of certain electric instruments such as the voltmeter, ammeter and ohmmeter. With these instruments, the cause of trouble can be often pinpointed without pulling the pump unit. The six charts that follow are taken from the Water Systems Handbook and are said to cover 95% or more of problems which may cause trouble in operation.

TABLE 13-2: TROUBLE SHOOTING THE SUBMERSIBLE PUMP

A—FUSES BLOW OR CIRCUIT BREAKER TRIPS WHEN MOTOR IS STARTED

CAUSE OF TROUBLE	HOW TO CHECK	HOW TO CORRECT
1. Incorrect line voltage.	Check the line voltage terminals in the control box (or connection box in the case of the 2-wire models) with a voltmeter. Make sure that the voltage is within the minimum-maximum range prescribed by the manufacturer	If the voltage is incorrect, contact the power company to have it corrected.
2. Defective control box: **a. Defective wiring.**	Check out all motor and power-line wiring in the control box, following the wiring diagram found inside the box See that all connections are tight and that no short circuits exist because of worn insulation, crossed wires, etc	Rewire any incorrect circuits Tighten loose connections Replace worn wires.
b. Incorrect components.	Check all control box components to see that they are the type and size specified for the pump in the manufacturers' literature. In previous service work, the wrong components may have been installed	Replace any incorrect component with the size and type recommended by the manufacturer.
c. Defective starting capacitor (skip for 2-wire models).	Using an ohmmeter, determine the resistance across the starting capacitor When contact is made, the ohmmeter needle should jump forward, and then drift back slowly. No movement indicates an open capacitor (or defective relay points), no resistance means that the capacitor is shorted	Replace defective starting capacitor.
d. Defective relay (skip for 2-wire models).	Using an ohmmeter, check the relay coil Its resistance should be as shown in the manufacturer's literature Recheck ohmmeter reading across starting capacitor With a good capacitor, no movement of the needle indicates defective relay points	If coil resistance is incorrect or points defective, replace relay

3. Defective pressure switch.	Check the voltage across the pressure switch points If less than the line voltage determined in "1" above, the switch points are causing low voltage by making imperfect contact	Clean points with a mild abrasive cloth or replace pressure switch
4. Pump in crooked well.	If wedged into a crooked well, the motor and pump may become misaligned, resulting in a locked rotor	If the pump does not rotate freely, it must be pulled and the well straightened
5 Defective motor winding or cable: **a. Shorted or open motor winding.**	Check the resistance of the motor winding by using an ohmmeter on the proper terminals in the control box (see manufacturer's wiring diagram) The resistance should match the ohms specified in the manufacturer's data sheet If too low, the motor winding may be shorted, if the ohmmeter needle doesn't move, indicating high or infinite resistance, there is an open circuit in the motor winding	If the motor winding is defective—shorted or open—the pump must be pulled and the motor repaired
b. Grounded cable or winding.	Ground one lead of the ohmmeter onto the drop pipe or well casing, then touch the other lead to each motor wire terminal If the ohmmeter needle moves appreciably when this is done, there is a ground in either the cable or the motor winding	Pull the pump and inspect the cable for damage Replace damaged cable If cable checks OK, the motor winding is grounded
6. Pump sand locked.	Make pump run backwards by interchanging main and start winding (black and red) motor leads at control box Before doing, check with motor manufacturer to see if motor can be reversed	Pull pump, disassemble and clean Before replacing, make sure that sand has settled in well If well is chronically sandy, a submersible should not be used

B—PUMP OPERATES BUT DELIVERS LITTLE OR NO WATER

CAUSE OF TROUBLE	HOW TO CHECK	HOW TO CORRECT
1. Pump may be air locked.	Stop and start pump several times, waiting about one minute between cycles If pump then resumes normal delivery, air lock was the trouble	If this test fails to correct the trouble, proceed as below
2. Water level in well too low.	Well production may be too low for pump capacity Restrict flow of pump output, wait for well to recover, and start pump	If partial restriction corrects trouble, leave valve or cock at restricted setting Otherwise, lower pump in well if depth is sufficient Do not lower if sand clogging might occur
3. Discharge line check valve installed backward.	Examine check valve on discharge line to make sure that arrow indicating direction of flow points in right direction	Reverse valve if necessary
4. Leak in drop pipe.	Raise pipe and examine for leaks	Replace damaged section of drop pipe
5. Pump check valve jammed by drop pipe.	When pump is pulled after completing "4" above, examine connection of drop pipe to pump outlet If threaded section of drop pipe has been screwed in too far, it may be jamming the pump's check valve in the closed position	Unscrew drop pipe and cut off portion of threads

6. Pump intake screen blocked.	The intake screen on the pump may be blocked by sand or mud Examine	Clean screen, and when reinstalling pump, make sure that it is located several feet above the well bottom—preferably 10 feet or more
7. Pump parts worn.	The presence of abrasives in the water may result in excessive wear on the impeller, casing, and other close-clearance parts Before pulling pump, reduce setting on pressure switch to see if pump shuts off. If it does, worn parts are probably at fault	Pull pump and replace worn components
8. Motor shaft loose.	Coupling between motor and pump shaft may have worked loose Inspect for this after pulling pump and looking for worn components, as in "7" above	Tighten all connections, setscrews, etc

C—PUMP STARTS TOO FREQUENTLY

CAUSE OF TROUBLE	HOW TO CHECK	HOW TO CORRECT
1. Pressure switch defective or out of adjustment.	Check setting on pressure switch and examine for defects	Reduce pressure setting or replace switch
2. Leak in pressure tank above water level.	Apply soap solution to entire surface of tank and look for bubbles indicating air escaping	Repair or replace tank
3. Leak in plumbing system.	Examine service line to house and distribution branches for leaks	Repair leaks
4. Discharge line check valve leaking.	Remove and examine	Replace if defective
5. Air volume control plugged.	Remove and inspect air volume control	Clean or replace
6. Snifter valve plugged.	Remove and inspect snifter valve	Clean or replace

D—FUSES BLOW WHEN MOTOR IS RUNNING

CAUSE OF TROUBLE	HOW TO CHECK	HOW TO CORRECT
1. Incorrect voltage.	Check line voltage terminals in the control box (or connection box in the case of 2-wire models) with a voltmeter Make sure that the voltage is within the minimum-maximum range prescribed by the manufacturer	If voltage is incorrect, contact power company for service
2. Overheated overload protection box.	If sunlight or other source of heat has made box too hot, circuit breakers may trip or fuses blow If box is hot to the touch, this may be the problem	Ventilate or shade box, or remove from source of heat
3. Defective control box components (skip this for 2-wire models).	Using an ohmmeter, determine the resistance across the running capacitor When contact is made, the ohmmeter needle should jump forward, and then drift back slowly No movement indicates an open capacitor (or defective relay points), no resistance means that the capacitor is shorted Using an ohmmeter, check the relay coil Its resistance should be	Replace defective components

	as shown in the manufacturer's literature Recheck ohmmeter reading across running capacitor With a good capacitor, no movement of the needle indicates relay points	
4. Defective motor winding or cable.	Check the resistance of the motor winding by using an ohmmeter on the proper terminals in the control box (see manufacturer s wiring diagram) The resistance should match the ohms specified in the manufacturer's data sheet if too low, the motor winding may be shorted, if the ohmmeter needle doesn t move, indicating high or infinite resistance, there is an open circuit in the motor winding Ground one lead of the ohmmeter onto the drop line or well casing, then touch the other lead to each motor wire terminal If the ohmmeter needle moves appreciably when this is done, there is a ground in either the cable or the motor winding	If neither cable or winding is defective—shorted, grounded, or open—pump must be pulled and serviced
5. Pump becomes sand-locked.	If the fuses blow while the pump is operating, sand or grit may have become wedged in the impeller, causing the rotor to lock To check this, pull the pump	Pull pump, disassemble, and clean Before replacing, make sure that sand has settled in well If well is chronically sandy, a submersible should not be used

E—PUMP WON'T SHUT OFF

CAUSE OF TROUBLE	HOW TO CHECK	HOW TO CORRECT
1. Defective pressure switch.	Arcing may have caused pressure switch points to "weld" in closed position Examine points and other parts of switch for defects	Clean points or replace switch
2. Water level in well too low.	Well production may be too low for pump capacity Restrict flow of pump output, wait for well to recover, and start pump	If partial restriction corrects trouble, leave valve or cock at restricted setting Otherwise, lower pump in well if depth is sufficient Do not lower if sand clogging might occur
3. Leak in drop line.	Raise pipe and examine for leaks	Replace damaged section of drop pipe
4. Pump parts worn.	The presence of abrasives in the water may result in excessive wear on the impeller, casing, and other close-clearance parts Before pulling pump, reduce setting on pressure switch to see if pump shuts off If it does, worn parts are probably at fault	Pull pump and replace worn components

F—MOTOR DOES NOT START, BUT FUSES DON'T BLOW

CAUSE OF TROUBLE	HOW TO CHECK	HOW TO CORRECT
1. Overload protection out.	Check fuses or circuit breaker to see that they are operable	If fuses are blown, replace If breaker is tripped, reset

2. No power.	Check power supply to control box (or overload protection box) by placing a voltmeter across incoming power lines Voltage should approximate nominal line voltage	If no power is reaching box, contact power company for service
3. Defective control box.	Examine wiring in control box to make sure all contacts are tight. With a voltmeter, check voltage at motor wire terminals If no voltage is shown at terminals, wiring is defective in control box	Correct faulty wiring or tighten loose contacts
4. Defective pressure switch.	With a voltmeter, check voltage across pressure switch while the switch is closed If the voltage drop is equal to the line voltage, the switch is not making contact	Clean points or replace switch

Reciprocating Pumps

Although the reciprocating pump is rapidly being replaced by more efficient jet, submersible or turbine pumps, some are still in use. The following trouble shooting charts are taken from the Water Systems Handbook.

TABLE 13-3: TROUBLE SHOOTING THE RECIPROCATING PUMP

A—PUMP WON'T START OR RUN

CAUSE OF TROUBLE	HOW TO CHECK	HOW TO CORRECT
1. **Blown fuse.**	Check to see if fuse is OK	If blown, replace with fuse of proper size
2. **Low line voltage.**	With pump motor energized, use voltmeter to check at pressure switch terminals nearest pump	If voltage is under recommended minimum, check size of wiring from main switch on property If OK, contact power company
3. **Loose, broken, or incorrect wiring.**	Check wiring circuit against diagram See that all connections are tight and that no short circuits exist because of worn insulation, crossed wires, etc.	Rewire any incorrect circuits Tighten connections, replace defective wires
4. **Defective pressure switch.**	Check switch setting Examine switch contacts for dirt or excessive wear	Adjust switch settings Clean contacts with emery cloth if dirty
5. **Tubing to pressure switch plugged.**	Remove tubing and blow through it	Clean or replace if plugged
6. **Pump mechanically bound.**	Turn off power, turn pump by hand	Locate source of binding and repair
7. **Defective start capacitor.**	Disconnect capacitor from motor Use an ohmmeter to check resistance across capacitor Needle should jump when contact is made No movement means an open capacitor, no resistance means capacitor is shorted	Replace capacitor or take motor to service station
8. **Motor shorted out.**	If fuse blows when pump is started (and external wiring is OK), motor is shorted	Replace motor
9. **Overload protector cut out.**	Check manual reset overload	Correct cause of overload reset overload

B—PUMP RUNS BUT DELIVERS NO WATER

CAUSE OF TROUBLE	HOW TO CHECK	HOW TO CORRECT
1. **Low line voltage.**	With pump motor energized, use voltmeter to check at pressure switch terminals nearest pump	If voltage is under recommended minimum, check size of wiring from main switch on property If OK, contact power company
2. **Loss of prime (piston pumps).**	When no water is delivered, check prime of pump and well piping	Reprime if necessary
3. **Broken rod (working heads).**	Disconnect rod from pump head and see if it can be lifted easily	If rod is broken, remove upper part Then fish for lower part or pull drop pipe Repair break
4. **Low well level.**	On piston pumps, make sure water level is no more than 25 feet below pump (less if at elevated altitudes) On working heads, lower well cylinder by adding more drop pipe and rod If this results in water delivery, cylinder was above water level	If water level is below 25 feet, piston pump won't work Replace with submersible or deep well jet pump Leave cylinder at lower level
5. **Air lock in suction line (piston pumps).**	Check horizontal piping between well and pump If it does not pitch upward, an air lock may form	Rearrange piping to eliminate air lock
6. **Suction valves stuck in open position (piston pumps).**	Remove cover from water end of pump and inspect valves	Clean out any foreign matter between valves and valve plate Make sure a watertight closure can occur

7. Leak in suction line (piston pumps or drop pipe working heads).	On piston pumps, install a vacuum gauge on the suction side and start pump Low vacuum means a leaky suction line On working heads, attach a pressure gauge to the discharge line, upstream of the main valve Close the valve Then using a bicycle pump or air compressor, apply about 30 psi of air pressure to the system If this pressure isn't held, there is a leak in the drop pipe	Repair leaks as necessary Repair leaks as necessary
8. Open foot valve (piston pumps) or cylinder check valve (working heads).	Fill drop pipe or suction line with water If the water level drops, the lower valve may be defective Pull drop pipe and inspect foot valve (piston pumps) or cylinder check valve (working heads)	Clean, repair or replace as necessary
9. Clogged drive point.	If drive point was used in well, pull suction line and examine	Clean drive point and re-install

C—LOW CAPACITY

CAUSE OF TROUBLE	HOW TO CHECK	HOW TO CORRECT
1. Undersized piping.	If system discharge is low, the discharge piping and/or plumbing lines may be undersized Refigure friction loss	Replace undersized piping or install pump with higher discharge pressure
2. Low well capacity.	Stop pump and allow well to recover Re-start pump and note whether delivery drops after continuous operation (On working head units, low well capacity is indicated by a violent jarring of the drop pipe after continuous operation This indicates that air is entering the well cylinder)	If possible, lower suction line or well cylinder to permit greater draw-down
3. Leaky relief valve (piston pumps).	Examine built-in relief valve for defects	If relief valve is leaking, repair or replace
4. Worn parts.	On piston pumps, examine valves and valve plate, plunger leathers, and gaskets On working head units, pull rod and examine leathers	Replace worn or defective parts

D—PUMP LOSES PRIME (Piston Only)

CAUSE OF TROUBLE	HOW TO CHECK	HOW TO CORRECT
1. Suction valves stuck in open position.	Remove cover from water end of pump and inspect valves	Clean out any foreign matter between valves and valve plate Make sure a watertight closure can occur
2. Leak in suction line.	On piston pumps, install a vacuum gauge on the suction side and start the pump Low vacuum means a leaky suction line On working heads attach a pressure gauge to the discharge line, upstream of the main valve Close	Repair leaks as necessary Repair leaks as necessary

	the valve Then using a bicycle pump or air compressor, apply about 30 psi of air pressure to the system If this pressure isn't held, there is a leak in the drop pipe	
3. Defective relief valve.	Examine built-in relief valve for defects	If relief valve is leaking, repair or replace

E — PUMP STARTS AND STOPS TOO OFTEN

CAUSE OF TROUBLE	HOW TO CHECK	HOW TO CORRECT
1. Leak in pressure tank.	Apply soapy water to entire surface above water line If bubbles appear, air is leaking from tank	Repair leaks or replace tank
2. Defective air volume control.	This will lead to a water-logged tank Make sure control is operating properly If not, remove and examine for plugging	Clean or replace defective control
3. Faulty pressure switch.	Remove tubing and blow through it	Clean or replace if plugged
4. Leak on discharge side of system.	Make sure all fixtures in plumbing system are shut off Then check all units (especially ballcocks) for leaks Listen for noise of water running	Repair leaks as necessary
5. Leak in suction line (piston pumps) or drop pipe (working heads).	On piston pumps, install a vacuum gauge on the suction side and start pump Low vacuum means a leaky suction line	Repair leaks as necessary
	On working heads, attach a pressure gauge to the discharge line, upstream of the main valve Close the valve Then using a bicycle pump or air compressor, apply about 30 psi of air pressure to the system If this pressure isn't held, there is a leak in the drop pipe	Repair leaks as necessary
6 Leak in foot valve (piston pumps).	Fill drop pipe or suction line with water If the water level drops, the lower valve may be defective Pull drop pipe and inspect foot valve (piston pumps) or cylinder check valve (working heads)	Clean, repair or replace as necessary

F — PUMP WON'T SHUT OFF

CAUSE OF TROUBLE	HOW TO CHECK	HOW TO CORRECT
1. Wrong pressure switch setting or setting "drift".	Lower switch setting If pump shuts off, this was the trouble	Adjust switch to proper setting
2. Defective pressure switch.	Arcing may have caused switch contacts to "weld" together in closed position Examine points and other parts of switch for defects	Replace switch if defective
3. Tubing to pressure switch plugged.	Remove tubing and blow through it	Clean or replace if plugged
4. Loss of prime (piston pumps).	When no water is delivered, check prime of pump and well piping	Re-prime if necessary

5. Low well level.	On piston pumps, make sure water level is no more than 25 feet below pump (less if at elevated altitudes) On working heads, lower well cylinder by adding more drop pipe and rod If this results in water delivery, cylinder was above water level	If water level is below 25 feet, piston pump won't work Replace with submersible or deep well jet pump Leave cylinder at lower level

G — EXCESSIVE OPERATING NOISE

CAUSE OF TROUBLE	HOW TO CHECK	HOW TO CORRECT
1. Water-logged tank or air chamber.	Make sure control is operating properly If not, remove and examine for plugging	Clean or replace defective control
2. Undersized suction line (piston pumps).	Check manufacturer's recommendations for sizing suction line	Replace with larger diameter if suction line is undersized
3. Sticking suction valves (piston pumps).	Remove cover from water end of pump and inspect valves	Clean out any foreign matter between valves and valve plate Make sure a watertight closure can occur
4. Rod slapping against drop pipe (working heads).	Feel rod for "play", especially if it's made of steel	Install rod guides at 10 foot intervals, or replace steel rod with wood
5. Low well level.	On piston pumps, make sure water level is no more than 25 feet below pump (less if at elevated altitudes) On working heads, lower well cylinder by adding more drop pipe and rod If this results in water delivery, cylinder was above water level	If water level is below 25 feet piston pump won't work Replace with submersible or deep well jet pump Leave cylinder at lower level
6. Sticking or noisy cylinder valves (working heads).	Pull cylinder and examine valves	If valves operate sluggishly install cylinder with springloaded valves If noise is the problem switch to a cylinder with rubber-faced valves

Centrifugal Pumps

Centrifugal pumps may be single or multiple stage depending upon the desired discharge pressure. They are usually mounted on the floor of a pump station. The driving mechanism is usually an electric motor although gas engine auxiliary drive is possible. They come in both oil and water lubricated types. Care should be taken to lubricate in accordance with manufacturers recommendations.

Centrifugal pumps may require periodic priming if they do not operate under a positive pressure on the intake side. Check valves or foot valves on the intake are necessary to protect against loss of prime. The pumps are also prone to air binding and are often provided with manual or automatic vent valves on top of the pump casing. If the pump requires priming, only safe, clean water must be used. Ejectors or vacuum pumps are also available to facilitate priming.

Turbine - Vertical Shaft - Pumps

Vertical - drive turbine pumps may consist of one or more stages (bowls) submerged below the drawndown water level in a well casing. The drive unit (most often an electric motor but capable of gas engine auxiliary drive by means of a side power take-off) is mounted over the casing. A vertical shaft conveys power from the drive motor to the pumping unit. Unlike the submersible pump, a pump house is required to house the unit. The weight of the shaft and pump unit is usually suspended by a thrust bearing located in the pump head. The bearings may be lubricated by oil or water, depending upon the design. The water lubricated types are preferred from a sanitary point of view as oil may leak into the casing and contaminate the water, particularly if over lubrication occurs. Care should be taken to prevent over oiling.

The well casing should extend above the floor of the pump house 8 inchs or more to prevent floor drainage from entering the casing. Care should be taken when flushing the floor to prevent slop over to the casing.

Turbine pumps are self priming.

Hydro-pneumatic System and Controls

Pressure tank systems have four essential components: pump - tank - pressure controls and - air controls.

Pressure controls usually have an adjustable feature for cut in pressure and the pressure operating range. An occasional re-adjustment may be necessary. A spare pressure switch should be on hand or readily available for emergency replacement.

Air controls should be selected for the prevailing conditions. The purpose of the air control is to maintain a predetermined amount of air in the pressure tank. The air serves as a means of storing energy to provide water to meet short term peak demands and avoid too frequent on and off operation of the pump. Air can be absorbed by the water in the tank or on some occasions, excess air or gases are introduced into the tank with the water. Air controls can be the - air add type, - the air release type or - the constant air charge type. Some tanks provide a physical separation of air and water, but these are usually limited to rather small tanks. Regular checks should be made to insure that the air control is performing properly. Manufacturers directions should be followed.

It is advisable to provide a pressure relief valve in the system as an added precaution where high pressure pumps are used, such as positive displacement pumps or multi stage submersibles or turbine pumps. The relief valve should be set below the pressure tank safe operating pressure and should be located on the tank or discharge piping. The relief valve should be large enough to relieve the rated capacity of the pump and should be piped to a drain. The valve should be checked periodically to make sure it is not stuck.

Protection of Electrical Components and Shock

The principle cause of electric motor failure is overheating (resulting in insulation failure) caused by overloading, a locked rotor, rapid recycling or loss of cooling due to clogged or impeded ventilation or low water level in a submersible pump casing. Protection devices are installed in motor cirucits to shut off the power when overheating occurs.

Some motors are protected by a combination thermostat and overcurrent protector located in the motor. Other motors (submersibles) may have external as well as internal protective devices. Low water protectors are also often installed in wells to protect against pump operation when the water level falls below a predetermined depth. The operator should become familiar with all of these devices and must know where and how to reset them, after locating the problem (if any) causing the tripping of the circuit.

Consideration should be given to the installation of devices to protect valuable electrical equipment from electrical overloads due to lightning. Consult the local power company for advice. This becomes more important in areas subject to frequent electrical storms (See Chapter 6).

Guages

Guages are available both as indicating or with recording mechanisms. Recording guages provide a permanent record of the system's operation. However, recording pens must be re-inked and chart paper must be installed on a routine schedule to obtain continuous readings.

Indicating guages and pressure switches are usually trouble-free if properly installed. However, scales, deposits, and turbidity can effect the accuracy and operation of most devices if not looked after and periodically checked.

The water meter is another important control device in a water system. After some time, normal wear and deposits may cause the meter to record less than the actual amount of water passing through it. Therefore, it is desirable to replace, or recalibrate meters at periodic intervals based on manufacturer's recommendations.

Warning systems and operator alarms should be designed with a test mode to indicate if the circuits are functioning.

TREATMENT EQUIPMENT

Hypochlorinators and Other Liquid Chemical Feed Pumps

The most widely used treatment device in small public water systems is the hypochlorinator (chemical feed pump). Chlorination is widely practiced and is often required by State enforcing agencies. In addition, chemical feeders for sequestering agents and corrosion control buffer solutions are in general use.

All feeders must be routinely cleaned of scale and serviced to insure effective operation. This is especially true where chlorination of the water supply is a mandatory feature to insure a continuous safe supply. Deposits and scale are more prevalent when calcium hypochlorite rather than sodium hypochlorite is used as the source of chlorine. It is further aggravated in areas where the water is hard or high in dissolved iron. Sodium hypochlorite is preferrable in all respects. A mild solution (5%) of muriatic or acetic acid is helpful to remove deposits. The unit should first be flushed with water to flush out chlorine solutions. The acid should not be allowed to come in contact with the chlorine solutions as free chlorine gas may be produced. The equipment should be taken apart and serviced at intervals specified by the manufacturer. A servicing kit should be on hand at all times.

Chlorine Gas Chlorinators

Gas chlorinators require special care in installation, operation and maintenance as chlorine gas is highly toxic and corrosive. Operator and public protection is absolutely necessary. The gas chlorinator and chlorine gas supplier will provide a complete manual for installation, operation and maintenance.

Water Conditioning Equipment

A variety of water treatment equipment is available to meet just about any water conditioning problem. These include:

- Pressure filters (sand and diatomaceous earth)
- Softening to remove hardness
- Conditioners to remove iron, manganese, sulfur
- Corrosion control

The manufacturer's instructions should be followed to insure proper operation and maintenance.

DISTRIBUTION SYSTEM

Most of the distribution piping for small community water systems is underground and usually forgotten unless a main breaks. Surveys for leaks, periodic flushing, and valve maintenance will help minimize major problems, retard deterioration, and avoid complaints from consumers.

Leaky joints, splits and breaks require early repair. Repair sleeves and clamps are semi-circular devices which can be bolted together around the pipe or joint to stop the leak or cover defects in the pipe. Repair clamp kits for assorted sizes of standard pipe should be readily available or stocked.

When major leaks occur, they are often first noticed as reduced pressure and quantity of water service by the consumer, and in extreme cases no water service at all. Leaks are often followed by an unexpected increase in water pumped into the system. A mastermeter is essential to read such trends.

Locating a break can often be a frustrating experience. There are several simplified methods to aid in leak detection. The easiest method is to "walk the lines" to locate wet spots which might indicate the presence of the leak. This method is most useful during dry weather. Another method is to use listening devices. A steel bar held against the pipe or valve at various locations will help locate the leak as the sound of the escaping water will be loudest near the leak. A more sensitive listening device is a set of geophones. Since geophones are expensive, it is suggested that one be borrowed or rented if possible. Listening is best done in the early morning hours when water use is low. A final method to help locate leaks is to valve off various sections of the distribution system. This is particularly useful for systems which have a mastermeter as the flow rate will be affected immediately as the leaky section is either valved into or out of service.

In water systems serving restaurants, nursing homes, motels, etc. leaks in plumbing fixtures can be significant. All faucets and toilet tanks should be checked. While each fixture may not be leaking a large amount, the accumulated water loss from several leaky fixtures will be quite significant.

Deposits settle out in water mains where flow patterns have been unchanged or stagnant for long periods of time. Deposits settle even when the source is free from apparent turbidity. These sediments can and often do result in taste, odor and turbidity complaints from consumers. In addition, incrustations may restrict the water flow within the piping system. To avoid these problems, it is recommended that a routine flushing program be initiated. Flushing can be accomplished by opening the blowoff valves or hydrants on the end of each line. Water should be flushed until it clears. It is recommended that the flushing be done with advance notice to the consumers in the immediate area or done during the early morning hours when customer usage is minimal.

In some cases the deposits may become so incrusted that normal flushing will not improve a low flow condition. In such cases, mechanical pipe cleaning may be necessary. As the equipment for mechanical cleaning is expensive and not readily available to rent, a professional pipe cleaning and restoration service company should be consulted. In many cases it may be more economical to replace the piping in the effected area.

To isolate parts of the distribution system for leak detection or flushing, it is necessary that all the valves in the system be in good working condition. It is important to "exercise" all the valves at least twice a year. Exercising the valves accomplishes two objectives. Firstly, it determines whether or not the valve works, and secondly, it helps clean incrustation from the valve seats and gates. After reopening the valve fully, back off about a half-turn to help prevent the valve from "freezing". Any valves which do not completely close or which leak, or are otherwise defective, should be replaced.

Sometimes, biological growths (commonly called slime growths) accumulate inside pipe walls. The slime growths may add objectionable tastes and odors to the water. The growths may occasionally slough off resulting in turbidity and objectionable slugs of slime. The presence of slimes usually indicates that an effective chlorine residual is not present throughout the system. A gradual increase in the chlorine dose is usually effective in controlling the growths. Heavy doses of chlorine as described in Chapter 11, Disinfection, is also effective. The disinfection should be followed by vigorous flushing through hydrants or blowoffs.

A map of the distribution system showing accurate location of all pipes, valves and other appurtenances is essential to proper maintenance. The map should be updated as new work or repairs are made.

All work done on the distribution system should be logged in the Maintenance Records (See Chapter 14) for future reference. Special comment concerning changes in the appearance, taste, odor or other water quality indicators should be recorded as should the condition of valves, etc. A record of water pressures at various locations in the system can provide clues to loss of pump capacity, leaks or unusual water usage and incrusted pipes.

CORROSION CONTROL (See Chapter 10)

Corrosion may be a problem both inside and outside of steel pipes. Cathodic protection of pipelines against corrosion is increasingly being used. Two methods are available. The first method requires that anodes energized by a D.C. power source be installed in the soil around the pipe to be protected. The pipe is connected to the negative terminal. The second method involves the use of galvanic anodes which in themselves generate current, thus eliminating an outside power source. Unfortunately, only very low current flows are generated and many galvanic anodes are required, which can be expensive. In addition, if mechanical joints are used, each pipe section must be electrically connected or have its own anode attached.

Asbestos cement pipe and approved plastic pipe offer built-in corrosion prevention. Since they are both non-conductors of electricity, they are immune to electrolysis corrosion.

WELL YIELD REHABILITATION

After a period of time, a well may fail to produce an adequate supply of water. While there are many reasons for a well to "quit" the main causes are centered around pump problems, declining water levels, plugged or corroded screens, or accumulations of sand and mineral sediments in the well.

Before remedial actions are taken, a proper analysis should be made to determine the causes. The first step is to measure the water level in the well before, during, and after pumping. This should be compared with drawdown tests made at the time the well was constructed. Well drillers usually provide a well rehabilitation service.

When the well screen or sand about the screen becomes clogged with mineral deposits, the yield of the well decreases. When the decrease becomes significant, cleaning is required. The use of special acids and other formulated chemicals to effect the cleaning should be exercised with great care to prevent unnecessary corrosion of the pumps and screen and contamination of the well and distribution system. Manufacturer's instructions on the use of chemicals must be followed explicitly to avoid problems.

If iron bacterial growths in the well are the problem, the use of chlorine disinfection may prove helpful. Disinfection may be done as described in Chapter 5 except that at least 300 mg/l of chlorine dose is recommended. Surging the well may prove helpful. The process should be repeated at periodic intervals, based upon experience. After disinfection, the well is pumped to waste to flush out accumulated iron slime.

CHAPTER 14

RECORD KEEPING	Facility Plans - Operation and Maintenance Records - Legal Requirements

INTRODUCTION

A system of record keeping is an essential feature of good public water system management. Records provide a continuous listing of the day to day bits of important information on the operation and maintenance of the system. The organized data provides the basis for the judgments and decisions which are necessary for good management and provides the basis for accountability to the State regulatory agency and the public. Organized records have the following broad uses:

- Provides a continuous record of operation and maintenance information, including water quantity and quality.
- Serves as a tool to assist in operation and maintenance decisions.
- Serves as a reminder of things which need to be done, materials and supplies which need to be obtained, preventive maintenance schedules and repair schedules.
- Provides a means of fulfilling the record keeping and reporting requirements of the Drinking Water Regulations and the State regulatory agency. See Chapter 12.

The extent of record keeping will depend upon the volume of water processed (the number of consumers served), the complexity of the treatment processes and the applicable record keeping requirements under the EPA and State agencies regulations. The water purveyor should consult with the State agency for specific requirements and for sample forms to assist in recording data.

Small water supply systems do not need elaborate record systems, but they must be adequate to meet general purpose and special needs. Simple forms with spaces to record data are convenient and also serve as a reminder of things to be done. Some typical forms are included at the end of this Chapter and may be used as is or adapted to special needs. Prepared forms are especially applicable for recording data on plant operation, sampling and testing and maintenance. In addition, records must be kept of the actions taken to correct violations of the Drinking Water Regulations. Copies of written reports and communications relating to sanitary surveys of the system must also be kept on file.

Records must be kept on file for minimum specified periods of time (See Chapter 12) and should, therefore, be recorded in ink or ball point. Records should be filed and retained on the premises or at a location near the premises for safe keeping and easy retreaval. Properly labeled loose-leaf notebooks provide an efficient and inexpensive means of storing records, as do filing cabinets.

Entries should be made on the recording forms by the person responsible for operation, maintenance, sampling or testing. Entries should be made promptly to avoid errors or ommissions. Neat and easily read records are an asset and often reflect the care taken in operation and maintenance.

For convenience, records may be classified as Engineering Plans, Operation Records, Maintenance Records, and Reporting and Public Notification Records. Sampling and testing are usually considered part of the Operation Records.

ENGINEERING PLANS AND SPECIFICATIONS

The "as-built" engineering plans and specification used to construct the water system should be kept up to date to reflect any changes in the system. If plans do not exist, it will be prudent to prepare a basic set of plans for permanent record purposes. The plans should include the following:

- Site plans of the water supply source(s) (wells, etc.) showing the location and distances to potential sources of pollution as outlined in Chapter 2 under Sanitary Survey.
- A log of each well
- Well yield test data
- Construction features of each well
- Plans of pump stations, treatment facilities and other appurtenances
- Plans of reservoirs and storage facilities
- Plans of the distribution system showing watermain locations, sizes, valves, hydrants, blowoffs, sampling points, etc.
- Equipment instruction manuals

OPERATIONAL RECORDS

The amount of operational information needed will depend upon the amount of water treated, the type and complexity of treatment, and the extent of other facilities in the system. Each system has critical features for which data is necessary or desirable. The following minimum operational records include the items which may be applicable to small water systems.

General Operating Records

Drawdown and static levels of wells

Pump pressures (input and output)

Pumping hours per day (total hours of operation)

Quantity of water pumped or delivered by gravity per day

Air - water ratio of hydropneumatic tanks

Treatment Records

Amount of water treated per day

Chlorine dosage in mg/l (ppm)

Total quantity of chlorine used per day (in weight or liquid measure)

Other chemical dosage and quantity per day

Records on the operation of sofeners, filters and other water conditioning units

Record of samples collected (date, time and location)

Results of bacteriological, physical and chemical tests (before and after treatment, where applicable)

Distribution System Records

Chlorine residual tests, time, location and amount in mg/l (ppm)

Bacteriological tests

Meter readings at consumer points

Pressures at key locations

Storage reservoir water levels

MAINTENANCE RECORDS

A good system of maintenance record keeping will provide the basis for preventive work which may obviate emergencies or unscheduled shut-downs.

Manufacturers of equipment provide information manuals which should be retained and used for future reference. The information should include the following:

- Installation instructions
- Pump characteristics
- Lubrication instructions
- Operating instructions
- Procedures for dismantling and re-assembling
- Parts list and ordering instructions

Electrical motors and controls are used extensively in water systems. Experience has shown that ninety per cent of motor failures are due to five causes: dirt, moisture, friction, vibration and overheating. A routine cleaning schedule will eliminate dirt; anti-moisture precautions will combat moisture; prudent lubrication will control friction; and proper alignment and bolt tightening will control vibrations. Control equipment should also be checked regularly. Overheat and overload controls should be provided on all electric motors (See Chapter 13).

Lubrication is one of the most important features of a maintenance program. It cannot be overstressed that the manufacturers' recommendation should be carefully followed. It is important not to over lubricate parts, especially electric motor bearings.

As most duties are routine, schedules can be prepared for completion of the various activities, including the following:

- Lubrication
- Inspection (motors, bearings, pumps, etc.)
- Electrical facilities checks
- General facilities checks (exercising valves, hydrants, etc.)

Work done on each piece of equipment should be kept separately. Keeping records on file cards or in a notebook is simple and effective. Typical equipment record forms are shown at the end of this Chapter.

LEGAL REQUIREMENTS FOR RECORD KEEPING, REPORTING AND PUBLIC NOTIFICATION

The National Drinking Water Regulations establish minimum requirements for monitoring, testing, maximum contaminate levels, chlorine residuals (for disinfection) and the required actions by the owners of public water systems under specific circumstances. These are summarized in Chapter 12, under the heading-Reporting, Public Notification and Record Keeping. The water purveyor and the water system operator must become thoroughly familiar with these requirements and must establish the procedures necessary to insure full compliance.

Figure 14-1; EQUIPMENT INSPECTION AND REPAIR RECORD

Name of Equipment ______________________________

Pertinent Data ______________________________

Date	Inspection Results and Work Done	Initials	Remarks

Typical Equipment Inspection Sheet

Figure 14-2

REPORT ON OPERATION OF HYPO-CHLORINATOR MONTH OF ______ 19__

NAME OF ESTABLISHMENT ______

LOCATION ______

TYPE AND MANUFACTURER'S NAME ______

SODIUM HYPOCHLORITE SOLUTION STRENGTH No. of quarts of 5.25% bleach/gallon of water.
_____ quarts/gallon of water

Date	Amount of Water treated-gallons or cubic meters	Results of Chlorine Residual (Mg per liter)						Qts. or Liters of Solution
		Location	Time	Result	Location	Time	Result	
1								
2								
3								
4								
5								
6								
7								
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OPERATOR'S SIGNATURE ______ DATE ______

CHAPTER 15

EMERGENCIES AND SPECIAL PROBLEMS	Planning for Emergencies - Emergency Disinfection - Cross-connections - Chemical and Biological Contamination

INTRODUCTION

Not-with-standing careful planning, design, operation and maintenance, unforseen problems and emergencies occasionally arise which require immediate attention to insure continuity of water service and a safe water supply at all times. The purpose of this Chapter is to (1) alert the water purveyor to some of the potential problems and emergencies (2) provide some guidance, and (3) to stimulate the water purveyor to plan ahead for emergencies so that the impact may be confined and controlled. Supplying water to the public is a serious responsibility. Before an emergency suddenly developes and there is a danger of contaminated water or prolonged interruption of service, the water operator will do well to ask himself in advance - "What will I do if?"

- There is a prolonged interruption of electric power.
- A key well pump motor or bearing "burns out."
- A key chlorinator or treatment unit fails.
- Flooding occurs with the threat of contamination.
- Tests indicate that the water is contaminated with micro-organisms of sewage origin, or potentially harmful chemicals or substances.
- A key watermain ruptures
- Et cetera

If these and other potential emergencies are thought out in advance, and mitigating procedures are planned in advance, potentially big emergencies will become small ones. Chapter 13 on Maintenance discusses many of the routine items which ought to be done as preventive maintenance. Having on hand, or readily available, certain key replacement parts or repair parts is important and should be carefully considered.

The National Drinking Water Regulations (Chapter 12) requires certain reporting procedures to the State agency (and in some cases the public) in the event of contamination of the water in excess of the established limits. The water purveyor will do well to also notify the State agency in the event of other major emergencies, as they will be of help in advising on how best to overcome the emergency. This is particularly important if the emergency poses a threat of unsafe water, the need to seek an emergency source of water or the addition of a chemical to the water. No matter how dire the emergency, the water purveyor should not connect an unapproved source of water into the system without the specific approval of the State agency.

EMERGENCY DISINFECTION

In the event of inadvertent or suspected contamination of the water, the State agency should be notified immediately. The State agency, after evaluation, may issue a "boil order" or may require immediate emergency chlorination of the entire system. The water purveyor will do well to have on hand a standby chlorinator and established chlorine injection taps even if the State agency has not required chlorination on a routine basis. As pointed out in Chapter 9, a standby chlorinator which can be put into immediate service, is a good investment.

If a "boil order" is required, consumers should be instructed to use one of the following procedures:

1. Boiling. Vigorous boiling of water for 2 minutes will destroy disease causing bacteria present in water. Boiled water may have a flat taste. Letting it stand for a few hours or beating with a clean mixer will add air and improve the taste. A pinch of salt per quart of water will also help.

2. Chlorine Disinfection. Common household chlorine bleach is an effective disinfectant. Containers usually describe disinfection procedures. If not, read the label to determine the chlorine strength, and use the following guide:[1]

% Chlorine *	Drops per quart of clear water **
1%	10
4- 6%	2
7-10%	1

* If strength is not known, use 10 drops

** Double amount for dirty or colored water

(1) Manual of Individual Water Supplies, EPA

CROSS-CONNECTIONS

A cross-connection is any physical connection between a potable[2] water supply system and any source of pollution, whereby the source of pollution can enter into the potable water supply system. It includes, among others, physical connections between a potable water supply system and:

- Any waste, soil, sewer or drain pipe
- Any unapproved water source or system
- Any contaminating liquid, gas or solid
- Any potable water outlet which is submerged or can be submerged in a waste water or any other source of contamination or source of water of questionable safety.

All State regulating agencies prohibit cross-connections except when and where suitable protective devices approved by the agency are installed, tested, and maintained to insure proper operation on a continuing basis. These devices are generally called back-flow preventers.

The water purveyor should be aware of any conditions in the water supply system which may result in a cross-connection and should take such measures as may be necessary to ensure that the system is protected from contamination, including the installation of back-flow prevention devices or the discontinuance of the service, consistent with the degree of the hazard. Detailed information on cross-connection control may be obtained from the State agency. An

(2) A water which is intended for human consumption

excellent manual, Cross-Connection Control Manual, U.S. Environmental Protection Agency, may be obtained from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

Public health records abound with case histories of water supply systems which have become contaminated through the illegal use of cross-connections, resulting in serious disease or intoxication with toxic substances. Although the detection and elimination of cross-connections may seem elementary and obvious, they may appear in many subtle forms and in unsuspected places. They occur all to frequently for a variety of reasons.

- Plumbing is frequently installed by persons who are unaware of the inherent dangers of cross-connections.
- Cross-connections are often made as a simple matter of convenience without regard to the dangerous situation which they create.
- A cross-connection is made with a reliance on a simple valve or other inadequate mechanical device.

The contamination of a potable water supply system through a cross-connection occurs when the polluted source exceeds the pressure of the potable water system. The action is called back-flow. Back siphonage is a back-flow which occurs when a negative pressure (partial vacuum) is created in the potable water system. Essentially, the condition is a reversal of hydraulic pressures which may be produced by a variety of circumstances. It is therefore essential that the water pressures throughout the distribution system be maintained at a pressure of not less than 20 psi during peak flow conditions to minimize the opportunity for back siphonage.

Two basic types of cross-connection occur in potable water systems; (1) the direct pipe connection between the water supply system and the polluting source, often separated by a simple valve and (2) an outlet of the water supply system which is submerged into a tank, fixture or device containing potential pollution. Both types are prohibited, except where and when approved back-flow preventers are installed. Listed below are partial lists of both types, presented as illustration of potentially hazardous fixtures.

Table/5-1: PARTIAL LIST OF PLUMBING HAZARDS(3)

Fixtures with Direct Connections

Air conditioning, air washer
Air conditioning, chilled water
Air conditioning, condenser water
Air line
Aspirator, laboratory
Aspirator, medical
Aspirator, weedicide and fertilizer sprayer
Autoclave and sterilizer
Auxiliary system, industrial
Auxiliary system, surface water
Auxiliary system, unapproved well supply
Boiler system
Chemical feeder, pot-type
Chlorinator
Coffee urn
Cooling system
Dishwasher
Fire standpipe or sprinkler system
Fountain, ornamental
Hydraulic equipment
Laboratory equipment
Lubrication, pump bearings
Photostat equipment
Plumber's friend, pneumatic
Pump, pneumatic ejector
Pump, prime line
Pump, water operated ejector
Sewer, sanitary
Sewer, storm
Swimming pool

(3) From Cross-connection Control Manual, U.S. Environmental Protection Agency

TABLE 15-1: (Continued)

Fixtures with Submerged Inlets

Baptismal fount
Bathtub
Bedpan washer, flushing rim
Bidet
Brine tank
Cooling tower
Cuspidor
Drinking fountain
Floor drain, flushing rim
Garbage can washer
Ice maker
Laboratory sink, serrated nozzle
Laundry machine
Lavatory
Lawn sprinkler system
Photo laboratory sink
Sewer flushing manhole
Slop sink, flushing rim
Slop sink, threaded supply
Steam table
Swimming pool
Urinal, siphon jet blowout
Vegetable peeler
Water closet, flush tank, ball cock
Water closet, flush valve, siphon jet

Direct, solid pipe connections are often inadvertently made to continuous or intermittent waste lines where it is assumed that the flow will always be in one direction. They are also often installed where it is necessary to supply water to an auxiliary piping system. Under conditions of back-flow or back-siphonage, the polluting source can enter into the potable water supply.

Submerged inlets are found in many common plumbing fixtures and are often a built-in feature of the fixture. Modern sanitary design has minimized or eliminated the hazard in new fixtures. Chemical and industrial process vats sometimes have submerged inlets where the water supply pressure is used as an aid in diffusion, dispersion or agitation. Back-siphonage is an ever present danger. Submerged inlets are often found in swimming pools. These can be readily eliminated by discharging the potable water (used for filling the pool) at least 2 pipe diameters above the maximum pool water level.

Wherever possible, it is preferable to eliminate the cross-connection by removal of the physical link, thus eliminating the possibility of failure of a mechanical control device. Where this is not possible, approved control devices must be used.

CONTAMINATION BY PETROLEUM PRODUCTS

Petroleum products are in such common use that the inadvertent contamination of water supplies is not uncommon. Groundwater contamination by petroleum products causes objectionable taste and odor at extremely small concentrations. Petroleum products are quite stable and thus not readily decomposed by bacteria in water or soil. These products may travel great distancesover a long period of time. The adsorption potential of soil particles (particularly clay and organic matter) traps petroleum products, releasing them gradually and contributing contamination to a water aquifer over a prolonged period of time.

The water purveyor should be alert for potential situations which may result in the contamination of the water system with petroleum products. Over lubrication of pumps, particularly vertical turbine and other over-the-well pumps, should be avoided. Furthermore, well casings in pump rooms should extend above the floor and should be sealed to prevent the entry of accidently spilled petroleums or other potentially harmful materials. It is preferable that these materials not be stored in well houses. As a matter of safety, they should not be stored on the ground in the vicinity of wells. Oil storage tanks used to heat pump rooms have on many occasions contaminated the ground water in the vicinity of water wells, from hardly noticeable leaks.

If the well should become contaminated with small quantities of petroleum products, it may be helpful to add a household type detergent directly to the well casing. The well should then be pumped, returning the discharge back into the casing and washing the inside of the casing. The recycling will enhance emulsification. Then pump to waste until the detergent is completely removed. Do not pump the waste in such a way as to recontaminate the well. If the taste or odor persists, the State agency should be consulted for advice.

CONTAMINATION WITH OTHER CHEMICALS

Most insecticides, pesticides and herbicides are highly toxic. All industrial chemicals and radioactive substances must also be considered toxic. If it is suspected that any foreign substance has inadvertently (or intentionally) contaminated the system, notify the State agency immediately by the swiftest form of communication for advice. In the meantime, notify consumers immediately and, if necessary, shut down the water system.

Rock salt and other salts used extensively for road de-icing, are a potential source of groundwater contamination, particularly when stored on the surface of the ground in the vicinity of water wells. The salts are readily dissolved by rain and runoff and percolate with the water to penetrate water aquifers for considerable distances. The water purveyor should be alert for open storage of salts near the water source. If the salt storage poses a significant threat and the owner cannot be persuaded to correct the situation, or the groundwater aquifer becomes contaminated with these salts, the State agency should be called for advise.

PART III

APPENDICES

APPENDIX A

GLOSSARY | Selected Water Related Terms

Selected from <u>Glossary of Water and Wastewater Control Engineering</u>, 1969 Edition, Prepared by Joint Committee representing:

- American Public Health Association
- American Society of Civil Engineers
- American Water Works Association
- Water Pollution Control Federation

acid - (1) A substance that tends to lose a proton. (2) A substance that dissolves in water with the formation of hydrogen ions. (3) A substance containing hydrogen which may be replaced by metals to form salts.

acre-foot - A volume of water 1 foot deep and 1 acre in area, or 43,560 cubic feet.

air and vacuum valve - An air valve which permits entrance of air into an empty pipe to counteract a vacuum and escape of accumulated air. Also called vacuum valve.

air-gap separation - The unobstructed vertical distance through the free atmosphere between the lowest opening from any pipe or outlet supplying water to a tank, plumbing fixture or other device, and the flood level rim of the receptacle.

air relief valve - An air valve placed at the summit of a pipeline to release the air automatically and prevent the pipeline from becoming air bound with a resultant increase of pressure.

algae - Primitive plants, one or many celled, usually aquatic, and capable of elaborating their foodstuffs by photosynthesis.

alkali - Any of certain soluble salts, principally of sodium, potassium, mangesium, and calcium, that have the property of combining with acids to form neutral salts and may be used in chemical processes such as water or wastewater treatment.

alkalinity - The capacity of water to neutralize acids, a property imparted by the water's content of carbonates, bicarbonates, hydroxides, and occasionally borates, silicates and phosphates. It is expressed in milligrams per liter of equivalent calcium carbonate.

altitude-control valve - A valve that automatically shuts off the flow when the water level in a water storage tank reaches a predetermined elevation and opens when the pressure on the system side is less than that on the tank side.

aquifer - A porous, water bearing geologic formation. Generally restricted to materials capable of yielding an appreciable supply of water.

artesian aquifer - An aquifer confined between less permeable materials from which water will rise above the bottom of the overlying confining bed if afforded an opportunity to do so. Also called confined aquifer.

artesian flowing well - A flowing well in which water is lifted above the land surface by hydrostatic pressure.

artesian spring - A spring in which water issues under pressure through some fissure or other opening in the confining formation above the aquifer. The spring is due to a permeable water bearing bed between relatively impermeable confining beds.

available chlorine - A measure of the total oxidizing power of chlorinated lime and hypochlorites.

backflow - (1) A flow condition, induced by a differential in pressure, that causes the flow of water or other liquid into the distribution pipes of a potable water supply from any source or sources other than its intended source. (2) The backing up of water through a conduit or channel in the direction opposite to normal flow.

backflow preventer - A device for a water supply pipe to prevent the backflow of water into the water supply system from the connections on the outlet end.

backsiphonage - A form of backflow caused by a negative or subatmospheric pressure within a water system. See backflow.

bacteria - A group of universally distributed, rigid, essentially unicellular microscopic organisms lacking chlorophyll. Bacteria usually appear as spheroid, rod like, or curved entities, but occasionally appear as sheets, chains, or branched filaments. Bacteria are usually regarded as plants.

booster pump - A pump installed on a pipeline to raise the pressure of the water on the discharge side of the pump.

breakpoint chlorination - Addition of chlorine to water or wastewater until the chlorine demand has been satisfied and further additions result in a residual that is directly proportional to the amount added beyond the breakpoint.

carbonate hardness - Hardness caused by the presence of carbonates and bicarbonates of calcium and magnesium in water. Such hardness may be removed to the limit solubility by boiling the water. When the hardness is numerically greater than the sum of the carbonate alkalinity and the bicarbonate alkalinity, that amount of hardness which is equivalent to the total alkalinity is called carbonate hardness.

casing shoe - A rigid annular fitting placed at the lower end of a metal well casing, commonly with a cutting edge on the bottom.

chlorine contact chamber - A detention basin provided primarily to secure the diffusion of chlorine through the liquid. Also called chlorination chamber.

coagulation - In water and wastewater treatment, the destabilization and initial aggregation of colloidal and finely divided suspended matter by the addition of a floc-forming chemical or by biological processes.

coliform-group bacteria - A group of bacteria predominantly inhabiting the intestines of man or animal, but also occasionally found elsewhere.

combined available chlorine - The concentration of chlorine which is combined with ammonia as chloramine or as other chloro derivitives, yet is still available to oxidize organic matter.

corrosion control - (1) In water treatment, any method that keeps the discharge of the metallic ions of a conduit from going into solution, such as increasing the pH of the water, removing free oxygen from the water, or controlling the carbonate balance of the water. (2) The sequestration of metallic ions and the formation of protective films on metal surfaces by chemical treatment.

cross connection - (1) A physical connection through which a supply of potable water could be contaminated or polluted. (2) A connection between a supervised potable water supply and an unsupervised supply of unknown potability.

cement grout - A fluid mixture of cement and water, sometimes including additives such as sand, bentonite and hydrated lime, which can be forced through a pipe, as in forming a seal in the annular space of a well casing. Neat cement is a mixture of 1 bag of cement (94 lbs.) to not more than 6 gallons of water and may include up to 5% additives to improve fluidity. Sand cement and concrete grouts are also used in sealing a well casing.

diatomaceous-earth filter - A filter used in water treatment, in which a built up layer of diatomaceous earth serves as the filtering medium.

disinfection - The art of killing the larger portion of micro-organisms in or on a substance with the probability that all pathogenic bacteria are killed by the agent used.

distribution reservoir - A reservoir connected with the distribution system of a water supply, used primarily to accommodate fluctuations in demand which occur over short periods (several hours to several days) and also to provide local storage in case of emergency such as break in a main supply line or failure of a pumping plant.

distribution system - (1) A system of conduits and their appurtenances by which a water supply is distributed to consumers. The term applies particularly to the network or pipelines in the streets in a domestic water system and or to pipes and canals other than the main canal in an irrigation system. (2) The network used for distributing electrical power to consumers.

drawdown - (1) The magnitude of the change in surface elevation of a body of water as a result of the withdrawal of water therefrom. (2) The magnitude of the lowering of the water surface in a well, and of the water table or piezometric surface adjacent to the well, resulting from the withdrawal of water from the well by pumping.

fire demand -The required fire flow and the duration for which it is needed, usually expressed in gallons per minute for a certain number of hours. Also used to denote the total quantity of water needed to deliver the required fire flow for the specified number of hours.

free available residual chlorine - That portion of the total residual chlorine remaining in water or wastewater at the end of a specified contact period which will react chemically and biologically as hypochlorous acid or hypochlorite ion.

groundwater - (1) Subsurface water occupying the saturation zone, from which wells and springs are fed. In a strict sense the term applies only to water below the water table. Also called phreatic water, plerotic water.

hardness - A characteristic of water, imparted by salts of calcium, magnesium and iron such as bicarbonates, carbonates, sulfates, chlorides and nitrates, that causes curdling of soap and increased consumption of soap, deposition of scale in boilers, damage in some industrial processes, and sometimes objectionable taste.

ion exchange - (1) A chemical process involving reversible interchange of ions between a liquid and a solid but no radical change in structure of the solid. (2) A chemical process in which ions from two different molecules are exchanged.

pressure filter - A rapid sand filter of the closed type, having a vertical or horizontal cylinder of iron, steel, wood or other material inserted in a pressure line.

red water - Rust colored water. Such color is usually due to the presence of precipitated ferric iron salts or to dead organisms the life processes of which depended on iron and manganese.

safe yield - The maximum dependable draft that can be made continuously on a source of water supply (surface or groundwater) during a period of years during which the probable driest period or period of greatest deficiency in water supply is likely to occur. Dependability is relative and is a function of storage provided and drought probability.

wastewater - The spent water of a community. From the standpoint of source, it may be a combination of the liquid and water carried wastes from residences, commercial building, industrial plants, and institutions, together with any groundwater, surface water, and storm water that may be present. In recent years, the word wastewater has taken precedence over the word sewage.

water borne disease - A disease caused by organisms or toxic substances carried by water. The most common water-borne diseases are typhoid fever, Asiatic cholera, dysentery, and other intestinal disturbances.

water conditioning - Treatments, exclusive of disinfection, intended to produce a water free of taste, odor, and other undesirable qualities.

water consumption - The quantity or quantity per capita, of water supplied in a municipality or district for a variety of uses or purposes during a given period. It is usually taken to mean all uses included within the term municipal use of water and quantity wasted, lost or otherwise unaccounted for.

water hammer - The phenomenon of oscillations in the pressure of water about its normal pressure in a closed conduit, flowing full, that results from a too-rapid acceleration or retardation of flow. Momentary pressures greatly in excess of the normal static pressure may be produced in a closed conduit by this phenomenon.

water quality - The chemical, physical, and biological characteristics of water with respect to its suitability for a particular purpose. The same water may be of good quality for one purpose or use, and bad for another, depending on its characteristics and the requirements for the particular use.

water treatment - The filtration or conditioning of water to render it acceptable for a specific use.

well cone of influence - The depression, roughly conical in shape, produced in a water table or other piezometric surface by the extraction of water from a well at a given rate. The volume of the cone will vary with the rate and duration of withdrawal of water. Also called cone of depression.

well log - A chronological record of the soil and rock formations encountered in the operation of sinking a well, with either their thickness or the elevation of the top and bottom of each formation given. It also usually includes statements about the lithologic composition and water bearing characteristics of each formation, static and pumping water levels, and well yield.

APPENDIX B

STATE WATER SUPPLY AGENCIES

Alabama
Division of Public Water Supplies
Environmental Health Administration
State Office Building
Montgomery, AL 36130

Alaska
Division of Air & Water Quality Control
Dept. of Environmental Conservation
Pouch O
Juneau, AK 99801

Arkansas
Bureau of Consumer Protection Services
State Department of Health
4815 W. Markham Street
Little Rock, AR 72201

Arizona
Bureau of Water Quality Control
1740 West Adams Street
Phoenix, AZ 85007

California
State Department of Health
2151 Berkeley Way
Berkeley, CA 94704

Colorado
Engineering & Sanitation
Department of Health
4210 E. 11th Avenue
Denber, CO 80220

Connecticut
Water Supply Division
CT Department of Health
Elm Street
Hartford, CT 06115

Delaware
Bureau of Environmental Health
Dept. of Health & Social Services
Jesses. Cooper Building
Capitol Square
Dover, DE 19901

District of Columbia
Water Resources Administration
415 12th Street N.W.
Washington, D.C. 20001

Florida
Bureau of Drinking Water & Special Programs
FL Dept. of Environmental Reg.
2562 Executive Center Circle, E.
Tallahassee, FL 32301

Georgia
Water Protection Branch
GA Dept. of Natural Resources
270 Washington Street, S.W.
Room 822
Atlanta, GA 30334

Hawaii
HI State Department of Health
Environmental Protection Div.
Pollution Technical Review Bureau
P.O. Box 3378
Honolulu, HI 96801

Idaho
Department of Health & Welfare
Statehouse
Boise, ID 83720

Illinois
Division of Public Water Supply
IL Environmental Protection Agency
4500 South 6th Street
Springfield, IL 62706

Indiana
Division of Sanitary Engineering
State Board of Health
1330 West Michigan Street
Indianapolis, IN 46206

Iowa
Water Quality Management Division
Department of Environmental Quality
P.O. Box 3326
Des Moines, IA 50316

Kansas
Water Supply Section
Division of Environment
Dept. of Health & Environment
Topeka, KS 66620

Kentucky
Division of Sanitary Engineering
KY Dept. for Natural Resources & Environmental Protection
Century Plaza-U.S. 127 South
Frankfort, KY 40601

Louisiana
Bureau of Environmental Health
LA Health & Human Resources Adm.
Division of Health
P.O. Box 60630
New Orleans, LA 70160

Maine
Division of Environmental Engineering
ME Department of Human Services
State House
Augusta, ME 04330

Maryland
Water Supply
Division of Water & Sewerage
State Dept. of Health & Mental Hygiene
201 W. Preston Street
Baltimore, MD 21201

Massachusetts
Division of Water Supply
MA Dept. of Environmental Quality Eng.
600 Washnngton Street
Boston, MA 02111

Michigan
Department of Public Health
Division of Water Supply
3500 North Logan Street
Box 30035
Lansing, MI 48919

Minnesota
Water Supply & General Engineering
MN Department of Health
715 Delaware St., S.E.
Minneapolis, MN 55440

Mississippi
Division of Water Supply
State Board of Health
P.O. Box 1700
Jackson, MS 39205

Missouri
Water Supply Program
Division of Environmental Quality
P.O. Box 1368
Jefferson City, MO 65101

Montana
Water Quality Bureau
Dept. of Health & Env. Sciences
Cogswell Building
Helena, MT 59601

Nebraska
Division of Environmental Eng.
Department of Health
Lincoln Building
10th and O Streets
Lincoln, NB 68509

Nevada
Department of Human Resources
201 South Fall Street
Carson City, NV 89710

New Hampshire
NH Water Supply & Pollution Control Commission
105 Loudon Road
Concord, NH 03301

New Jersey
Bureau of Potable Water
Dept. of Environmental Protection
P.O. Box 2809
Trenton, NJ 08625

New Mexico
Water Supply Section
Environmental Improvement Agency
P.O. Box 2348
Santa Fe, NM 87501

New York
Bureau of Public Water Supply
NY Department of Health
Empire State Plaza
Albany, NY 12237

North Carolina
Sanitary Engineering Section
Division of Health Services
Department of Human Resources
Bath Bldg., P.O. Box 2091
Raleigh, NC 27602

North Dakota
Division of Water Supply & Pollution Control
Department of Health
State Capitol
Bismarck, ND 58501

Ohio
Office of Public Water Supply
OH Environmental Protection Agency
P.O. Box 1049
Columbus, OH 43216

Oklahoma
Water Quality Service
Department of Health
N.E. 10th & Stonewall
Oklahoma City, OK 73117

Oregon
Office of Sanitation Services
Dept. of Human Resources
1400 S.W. Fifth Avenue
Portland, OR 97201

Pennsylvania
Division of Water Supply & Sewage
Pennsylvania Dept. of Env. Resources
P.O. Box 2063
Harrisburg, PA 17120

Rhode Island
RI Department of Health
Health Bldg., Room 209
75 Davis Street
Providence, RI 02908

South Carolina
Division of Water Supply
SC Dept. of Health & Env. Resources
2600 Bull Street
Columbia, SC 29201

South Dakota

Water Hygiene Program
Dept. of Environmental Protection
Joe Foss Building
Pierre, SD 57501

Tennessee
Division of Environmental Sanitation
TN Dept. of Public Health
320 Capitol Hill Building
Nashville, TN 37219

Texas
Environmental & Consumer Health Protection
TX Dept. of Health Resources
1100 West 49th Street
Austin, TX 78756

Utah
Bureau of Water Quality
Environmental Health Branch
44 Medical Drive
Salt Lake City, UT 84113

Vermont
Division of Environmental Health
VT Department of Health
60 Main Street
Burlington, VT 05401

Virginia
Bureau of Sanitary Engineering
State Department of Health
James Madison Building
109 Governor Street
Richmond, VA 23219

Washington
Water Supply & Waste Unit
Dept. of Social & Health Services
P.O. Box 1788
Olympia, WA 98504

West Virginia
Drinking Water Program
Environmental Health Services
State Department of Health
1800 E. Washington Street
Charleston, WV 25305

Wisconsin
Public Water Supply Section
Dept. of Natural Resources
P.O. Box 450
Madison, WI 53701

Wyoming
Water Quality Division
Dept. of Environmental Quality
Hathaway Bldg.
Cheyenne, WY 82002

Samoa
Department of Public Works
Government of American Samoa
Pago Pago, American Samoa 96920

Guam
Environmental Protection Agency
Government of Guam
P.O. Box 2999
Agana, Guam 96910

Mariana Islands
Chief of Environmental Health
Dept. of Health Services
Trust Territory of the Pacific Islands
Saipan, Mariana Islands 96950

Puerto Rico
Water Supply Program
PR Health Department
P.O. Box 9342
Hayto Rey, Puerto Rico 00927

Virgin Islands
Department of Conservation
Division of Natural Resource Mgmt.
Building 15-F
Watergut Homes
Christiansted, St. Croix
U.S. Virgin Islands 00820

U.S.ENVIRONMENTAL PROTECTION AGENCY REGIONAL OFFICES

EPA REGIONAL OFFICES	STATES COVERED
EPA Region 1 Room 2303 JFK Federal Building Boston, MA 02203	Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island Vermont
EPA, Region 2 Room 1005 26 Federal Plaza New York, NY 10007	New Jersey, New York, Puerto Rico, Virgin Islands
EPA Region 3 Curtis Building 6th and Walnut Streets Philadelphia, PA 19106	Delaware, Maryland, Pennsylvania, Virginia, West Virginia, District of Columbia
EPA Region 4 345 Courtland St., NE Atlanta, GA 30308	Alabama, Georgia, Florida, Mississippi, North Carolina, South Carolina, Tennessee, Kentucky
EPA Region 5 230 South Dearborn Street Chicago, IL 60604	Illinois, Indiana, Ohio Michigan, Wisconsin, Minnesota
EPA Region 6 1201 Elm St Dallas, TX 75270	Arkansas, Louisiana Oklahoma, Texas, New Mexico
EPA Region 7 1735 Baltimore Street Kansas City, MO 64108	Iowa, Kansas, Missouri Nebraska
EPA Region 8 Suite 900 1860 Lincoln Street Denver, CO 80203	Colorado, Utah, Wyoming Montana, North Dakota, South Dakota
EPA Region 9 215 Freemont Street San Francisco, CA 94111	Arizona, California, Nevada, Hawaii
EPA Region 10 1200 Sixth Avenue Seattle, WA 98101	Alaska, Idaho, Oregon Washington

APPENDIX C

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3. Water Systems Handbook, Water Systems Council, 221 N. LaSalle St., Chicago, Ill., 60601. A rather complete handbook on well systems.

4. National Standard Plumbing Code. National Association of Plumbing, Heating, Cooling Contractors (1971).

5. Fire Protection Handbook. National Fire Protection Association, Thirteenth Edition (1969)

6. Standards for the Installation of Standpipe and Hose Systems, NFPA No. 14, 1974 National Fire Portection Association.

7. Standards for the Installation of Sprinkler Systems, NFPA No. 13, 1974. National Fire Protection Association.

8. Guide to Water Systems Construction - Recommended Industry Practices, 2nd Printing, Water Systems Council, 221 LaSalle St., Chicago, Illinois 60601.
Booklet written in layman's terms describing location and construction, head and friction losses in supply lines and basic pump design.

9. Minimum Design Standards for Community Water Supply Systems, U.S. Dept of Housing and Urban Development Handbook, FHA 4517.1, May, 1968.

10. Practical Engineering Information, Red Jacket Manufacturing Co., P.O. Box 3888, Davenport, Iowa 52808.
Includes information about water systems, selection of pumping equipment, water requirements and storage tanks. Many charts of engineering information

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A technical journal published by NWWA's Technical Division

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19. Water Well Handbook, Keith Anderson, Missouri Water Well Drillers Association, Box 250, Rolla, MO., 65401

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PUMP SYSTEMS*

21. Application Manual for Large Submersible Pumps, Red Jacket Manufacturing Co., P.O. Box 3888, Davenport, Iowa 52808.
Information on the proper application of large submersible water pumps with a discussion of the effects of well conditions, abrasives, corrosives and temperatures.

22. Compact Service Manual, Goulds Pumps, Inc., Advertising Dept. Seneca Falls, N.Y. 13148.
Summarizes installation, operation and maintenance procedures covering nearly all jet, centrifugal and submersible pumps made by Goulds.

* Consult local pump suppliers for additional bulletins.

23. Installation of Submersible Pumps, Red Jacket Mfg. Co., P.O. Box 3888, Davenport, Iowa 52808.
Describes a "Drain-back" System to eliminate aeration of iron bearing water.

24. Pump Fundamentals Workbook, Goulds Pumps, Inc. Advertising Dept., Seneca Falls, New York, NY 13148.
A basic introduction and summary of pumps.

25. Water Systems Pump Fundamentals. Goulds Pumps, Inc. Advertising Dept., Seneca Falls, New York, NY 13148.
A basic introduction and summary of water system operations.

WATER QUALITY

26. Standard Methods for the Examination of Water and Waste Water. American Public Health Association, Inc.
Approved sampling, testing and interpretation information.

27. National Interim Primary Drinking Water Regulations. U.S. Environmental Protection Agency, Federal Register, December 24, 1975.

WATER TREATMENT

28. A Guide to Trouble-Free Water Conditioning Systems, Red Jacket Manufacturing Co., P.O. Box 38888, Davenport, Iowa 52808.
Lists fourteen primary water problems and explains how to specify the right equipment to correct them.

29. Water Quality and Treatment, Prepared by American Water Works Association, 6666 W. Quincy Ave., Denver, Colorado, 80235.

30. Basic Water Treatment Operator's Manual. American Water Works Association (AWWA No. M18), 6666 W. Quincy Ave., Denver, Colorado, 80235.

31. Disposal of Wastes from Water Treatment Plants. AWWA Research Foundation Report, Journal AWWA, October, November and December 1969.

32. State of the Art of Small Water Treatment Systems, U.S. EPA, Government Printing Office, Washington, D.C. 20402.

SAFETY PRACTICES

33. Safety Practices for Water Utilities (M3), American Water Works Association, 6666 W. Quincy Ave., Denver, Colorado, 80235.

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16 ABSTRACT

The Manual is prepared as a guide for the planning, design, development, maintenance, operation and evaluation of small water systems serving the public, particularly the non-community system, but also including small community type systems of 50 services or less. It is coorelated with the National Drinking Water Regulations. The Manual is designed to serve the particular needs of:

- Owners and operators of small water systems serving the public
- The design engineer
- State and local enforcing agencies as a tool to assist in inspection and evaluation responsibilities

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