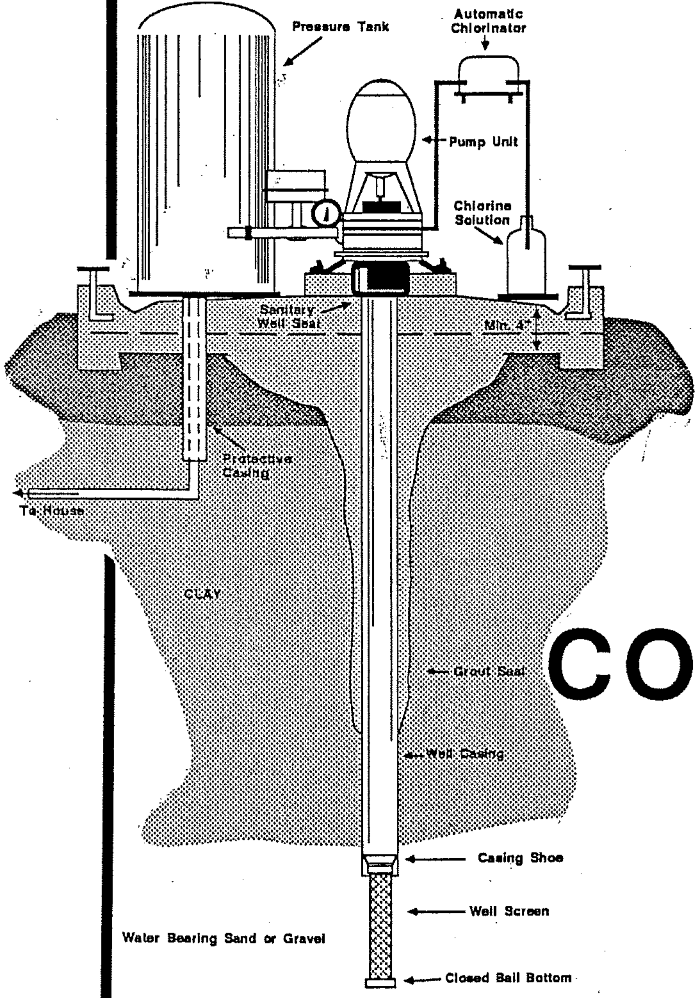
engineering bulletin no. 10



GUIDELINES FOR THE CONSTRUCTION OF WATER SYSTEMS

ARIZONA DEPARTMENT OF
ENVIRONMENTAL QUALITY

MAY 1978

ENGINEERING BULLETIN NO. 10

GUIDELINES
FOR THE
CONSTRUCTION OF WATER SYSTEMS

PREPARED BY

THE ARIZONA STATE DEPARTMENT OF HEALTH SERVICES

WITH TECHNICAL ASSISTANCE FROM

INTERNATIONAL ENGINEERING COMPANY, INC.
2966 West Clarendon Avenue
Phoenix, Arizona 85017

BLACK AND VEATCH CONSULTING ENGINEERS
12075 East 45th Avenue, Suite 333
Denver, Colorado 80239

MAY 1978

I N D E X

engineering bulletin no. 10

Chapter 1

PROJECT DEVELOPMENT CRITERIA

ARIZONA DEPARTMENT OF HEALTH SERVICES

MAY 1978

CHAPTER 1 - PROJECT DEVELOPMENT CRITERIA

CHAPTER 1 - PROJECT DEVELOPMENT CRITERIA

CHAPTER 1 - PROJECT DEVELOPMENT CRITERIA

A. PURPOSE OF BULLETINS

Engineering Bulletin No. 10 provides guidance and minimum design criteria for the modification and construction of water systems in Arizona. It is intended for use in the tasks of water system planning, design, plan development, specification writing, review, and construction.

Rules and Regulations covering water systems are published separately, and should also be referred to as necessary during project development.

B. PROJECT REVIEW AND APPROVAL REQUIREMENTS (Health Services)

1. APPLICATION FOR APPROVALS. The regulations of the Arizona Department of Health Services require that no person commence construction for installation, extension, or any material change which will affect capacity, quality, flow, or operational performance of a water system prior to receiving a Certificate of Approval to Construct from the Department.

   An application for approval to construct water systems should be submitted to:

   Technical Review and Planning Section
   Bureau of Water Quality Control
   Arizona Department of Health Services
   1740 West Adams
   Phoenix, Arizona 85007

   In some counties the approval function has been delegated to the County Health Department, and in such cases the application should be sent directly to the appropriate county.

   The content, scope and submittal order of information required in the Application Package varies with the size and complexity of the project. A summary of the items required in the Application Package is included on Figure I, with an X marking the requirements for each type of project. Also shown are the other submittal notification, inspection, and approval actions required for project completion.

   All application packages require the inclusion of a completed Form DHS/WQC-114, "Application for Approval to Construct Water and/or Wastewater Facilities".

FIGURE I - SUMMARY OF REQUIREMENTS

(A) PROJECT DEVELOPMENT STEPS	(D) TYPE OF PROJECT				
	1. 8" diameter well or smaller	2. 10" diameter well or larger, and other sources	3. Minor water line extensions	4. Major extensions, distribution transmission, pumping, storage, or hydropneumatic systems	5. Treatment facilities
(B) Form DHS/WQC-114, Application for Approval to Construct Water/Wastewater Facilities	X	X	X	X	X
(C) Design Report Components					
1. Land Department Well Forms	X	X			
2. Water Commission Adequacy Report		X		X	
3. Water Quality Analysis	X	X			X
4. Preliminary (Planning) Report		X		X	X
5. Final Report		X	X	X	X
(E) Construction Plans	X*	X	X	X	X
(F) Specifications	X*	X	X	X	X
(G) Certificate of Approval to Construct	X*	X	X	X	X
(H) Notification of Starting Construction	X*	X	X	X	X
(I) Changes During Construction	X*	X	X	X	X
(J) Notification of Completing Construction	X*	X	X	X	X
(K) Final Inspection	X	X	X	X	X
(L) As-built Plans		X	X	X	X
(M) Operation and Maintenance Manual					X
(N) Certified Operator Assigned	X	X	X	X	X
(O) Approval to Operate	X	X	X	X	X

* Required for well head construction and well connection to water system, but not for well drilling or casing installation.

2. REVIEW TIME. The Department reviews a large number of applications, and must process them in the order received. Each submittal must be made at least 30 days prior to the date upon which action is desired.

C. DESIGN REPORT COMPONENTS

Special Design Report procedures have been developed to simplify submittals for minor projects and to provide for consultation in the planning of larger projects. Several different Design Report Components can be assembled to fit the type of projects, as shown on Figure I. Duplication of effort is minimized by using information developed for other state agencies, where possible. Following is a description of the components.

1. ARIZONA LAND DEPARTMENT WELL DRILLING FORMS. Arizona law requires that a "Notice of Intention to Drill Well" be filed with the State Land Department before a well is drilled. This form includes a location and brief description of the proposed well.

   In the acknowledgement of receipt of the Notice of Intention, the Land Department will transmit back to the applicant a "Report of Well Driller" form and a "Equipment Installed" form. These forms contain much of the information required by the Department of Health Services in the review of wells. Additional information which should be added to the report form under remarks includes the depth, length, and type of seal used to exclude polluted zones.

   In proposed critical groundwater areas, the "Registration of Well" form may be substituted for the "Report of Well Driller Form".

2. ARIZONA WATER COMMISSION ADEQUACY OF WATER SUPPLY REPORT. This report is required for subdivisions (more than four (4) lots) planned for development within the State. It is submitted to the Arizona Water Commission for review of the adequacy or availability of proposed water supplies for subdivisions. Included in the report is a determination of current and projected future demands for water, and a quantification of supply characteristics.

   The water demand information is most useful in planning and sizing the elements of a water supply system. The supply characteristics portion of the study includes much of the information required to analyze surface and groundwater sources from a health standpoint.

3. WATER QUALITY ANALYSIS. Regulations of the Arizona Department of Health Services require that a chemical, physical, and radiological analysis of a proposed new source of water be included with the engineering report. This analysis must be performed by a laboratory certified by the Department. Tests are to be conducted in accordance with Part 1., Section 9-1-414 (amended) Laboratory Procedures Standards. The quality of water supplied to the users by water systems in the natural or treated state shall be in accordance with Part 6, R-8-220.

   A laboratory analysis may also be required for projects other than water sources, if requested by the department.

4. PRELIMINARY (PLANNING) REPORT. The preliminary report serves to determine project concepts, controls, and areas requiring special attention for the protection of public health. This provides for the establishment of design criteria prior to a large investment in final design plans and specifications.

   The Arizona Department of Health Services (ADHS) Regulations provide that designing or consulting engineers may confer with the Department before proceeding with detailed designs of major water works. An aid in this conference is the preliminary report. Frequently preliminary reports developed for alternative and cost analysis include the information required for ADHS review, or can be expanded to do so.

   Some detailed content of the Preliminary Report will vary depending upon the type of project (Refer to the following section, Design Report Components Required by Type of Project). However, the following information should be included in all preliminary reports.

   a. Identify the legal entity constructing and operating the water system.

   b. Describe the existing area served, and existing facilities including sources, pumps, treatment plants, distribution piping and storage.

   c. Discuss the area to be served, and the planning basis for improvements, including land use and population projections for at least 20 years in the future. Also include projected water consumption by category, and water demands used for design including design fire flow if fire protection is to be provided. (Not required if covered in Water Commission Adequacy of Water Supply Report).

   d. Existing and proposed topographic and planimetric features shall be presented in sufficient detail to determine physical controls.

e. Soil, groundwater, and foundation problems shall be outlined, including groundwater elevations and foundation conditions at proposed structures.

f. Describe existing sewage system and sewage treatment works, with reference to their impact on the quality of water supplied.

g. Note alternate sites and solutions for providing water service, construction and operating costs, and reason for recommendations.

h. Note consideration given to the impact of a 100-year return frequency flood on the features of the system. Show proposed methods of protection from the flooding condition. An alternative may be the isolation of the flooded element from the system, and subsequent disinfection.

5. FINAL REPORT. The final report serves to note any changes to the preliminary report and to supply necessary information concerning final design computations.

The final report normally serves as a transmittal of design computations, construction plans, and specifications. It may be as brief as a single page attached to the computations, or a separate report covering detailed design of a complex process.

The final report or documents shall include the basis of design computations, final construction plans, and specifications sufficient to review the project.

Pages of design computations should be numbered, and indexed to the plans and specifications. Explanation notes should be provided for computer printouts, if submitted as design computations.

D. DESIGN REPORT COMPONENTS REQUIRED BY TYPE OF PROJECT

Detailed information which should be addressed in the Design Reports includes compliance with or deviation from pertinent guidance included in this Bulletin. The following shall also be included, depending upon the type of project.

1. WELLS - 8" DIAMETER OR SMALLER. The Design Report for small wells shall consist of the documents required by the Arizona Land Department, and a laboratory analysis of the water.

If there is a possibility that a well may be a source of supply for a water system, an "Application for Approval" should be made to the ADHS before construction, and a "Notice of Intention to Drill Well" sent to both the ADHS and the State Land Department. If it is later determined that the well won't be used to supply a water system, no further action is required.

If it is determined that the well is to be used to supply a water system, the "Report of Well Driller", "Report of Equipment Installed", and water analysis shall be forwarded to ADHS, which will constitute the Design Report.

2. WELLS - 10" DIAMETER OR LARGER, SPRINGS, AND SURFACE WATER SOURCES. The Design Report for sources other than small wells shall consist of a Preliminary and Final Report.

   If the project is a well, the forms required by the Land Department shall be included.

   If the project is a subdivision, a "Water Supply Adequacy Report" must be submitted to the State Land Department, and a copy of this document shall also be included with the Design Report for the Arizona Department of Health Services.

   The preliminary report shall also include items under Section C-4, and the following:

   a. A sanitary site survey of existing or potential pollutant sources in the basin which could reach the water source, and proposed means of controlling such pollutants.

   b. Treatment types and levels proposed to meet water quality requirements.

   c. Wells for which disinfection is not proposed require a special submittal, including a plat of the property to be used for housing the groundwater development indicating the topography and the arrangement of present or planned well structures. It shall show the location, size and material of sewers, soil absorption systems and similar features within a 500-foot radius of the proposed well.

   A Water Quality Analysis and Final report in accordance with Section C-5 shall be included.

3. MINOR WATER LINE EXTENSIONS (Four or fewer service connections)

   This type of project shall require a brief Final Design Report. The Final Design Report shall identify the legal entity constructing and operating the water system to which the extension is connected. It should also discuss known proposals for future extensions to the line, and include items under Section C-5. More than one minor extension to a main will be considered a major extension.

4. MAJOR WATER LINE EXTENSIONS, DISTRIBUTION, TRANSMISSION, PUMPING, STORAGE, OR HYDROPNEUMATIC SYSTEMS. These type projects shall require a Preliminary and Final Design Report and Detailed Plans and Specifications. Any of the system elements in this section can effect minimum pressures, and therefore require analysis of expected pressures resulting from changes. A comprehensive analysis of the system should be made in cases where several changes have been made without consideration of the impact of the changes on pressure.

   The Preliminary Report shall include items under Section C-4, and the following:

   a. Schematic or preliminary plan of all elements of the system which affect pressure and flow. Show type and number of pumps, size and type of water lines, storage capacity, and flow regulators.

   b. An analysis of necessary water supply and demand flows required to assure minimum pressures under all operating conditions.

   c. Equipment for controlling flow in the system including pump cycles, liquid level, and valving. Describe automatic and manual functions.

   Final Reports shall be in accordance with Section C-5.

5. TREATMENT PROCESSES OR FACILITIES. The Preliminary Report shall include:

   a. Laboratory tests on raw water sources, with a sufficient number of samples to determine the quality of the water.

   b. Flow diagram of treatment process by steps, and with each step labeled by function and piping or flow alternatives shown. Describe process, and show approximate dimensions of each unit.

   c. Ranges of filtration or chemical dosage rates, reaction periods, detention or contact times.

   d. Estimations of expected compliance of treated water with the quality requirements of the Rules and Regulations.

e. Expected frequencies of requirements for backwash, and disposal procedures for sludge.

Final Reports shall be in accordance with Section C-5.

E. CONSTRUCTION PLANS

Guidance covering general layout and detailed construction plans is supplied to indicate minimum information requirements and is not intended to prohibit other plans which are standard engineering practice.

1. GENERAL LAYOUT. Layout sheets should be included which show the overall project. By using sequential plan generation techniques, the exhibits included in the Design Report may be used for this purpose. General layout sheets should show the following items.

   a. GENERAL. Suitable title and name of municipality, water district, or area served; scale in feet; the north point; date and name of the engineer and the imprint of his professional engineer's seal. The size of the plan should preferably be 12" x 18", 24" x 36" or such other size as will permit easy folding to these dimensions. Lettering and figures on the plans should be appropriate size. The datum which is utilized should be indicated. The border line of a municipality, water district or specified area to be served should be shown.

   b. EXISTING STRUCTURES. The location, size, and length of existing water mains and the location and nature of existing waterworks structures should be noted on one sheet.

   c. PROPOSED STRUCTURES. Indication of proposed water mains and waterworks structures, with size, length and identity.

   d. TOPOGRAPHY AND ELEVATIONS. Existing or proposed streets and all watercourses, ponds or lakes should be shown clearly. The elevation of water mains and other waterworks structures should be indicated, where pertinent. Contour lines at suitable intervals should be included on final plans.

2. DETAILED PLANS. All detailed plans should be prepared as black line or white prints and should be drawn to a suitable scale. Plans for modifications or extensions to existing distribution systems or waterworks structures should indicate clearly the relationship thereto, and plans for the existing systems or structures, if not already on file, must be filed. The detailed plans for water works systems should include:

   a. GENERAL. Show the scale to which the plans are drawn, the north point, the date, the name of the owner of the water supply system and the name of the engineer. (A suitable subtitle should be given on each sheet.)

b. DISTRIBUTION AND TRANSMISSION MAIN PROFILES. Profile views are required in hilly terrain so that the Department can assure that blowoff and drain valves are placed at appropriate locations, and to assist in other phases of plan review. The submission of profiles for distribution mains smaller than 12 inches in diameter shall be at the discretion of the Engineer. Profiles shall be submitted for transmission mains for 10 and 12 inch diameter pipe, and for all mains larger than 12 inch diameter. Profiles for stream crossings shall show elevations of the stream bed and the normal and extreme low and high water levels.

c. WASTEWATER FACILITIES. The exact locations of existing sewage works relating to the proposed water system construction shall be shown, including the sizes and types of sewers, appurtenances and treatment facilities.

d. APPURTENANCES. Show all appurtenances, specific structures or equipment, having any connection with plans for water mains and water works structures. Detailed plans should be drawn to a scale which will show clearly the nature or design of the proposed structures, with equipment and all dimensions, elevations and explanatory notes needed to make them readily intelligible for examination and construction.

e. SCHEMATIC DESIGNS. The schematic plumbing and lighting designs for all miscellaneous structures and equipment should be noted.

F. SPECIFICATIONS

Complete, detailed specifications shall be supplied for the construction of all facilities, including intakes, sources of groundwater supply, supply mains or conduits, pumping stations, treatment works, reservoirs, tanks, standpipes and all other construction work, material, equipment and appurtenances. An exception to this requirement will be made for drilling and casing installation for wells 8 inches in diameter or smaller.

References to standard specifications are acceptable if the specifications are on file with the Department, and if they were developed for the political subdivision encompassing the project area, or for the water company serving the area. Standard specifications used in other instances shall be included in the project documents.

G. CERTIFICATE OF APPROVAL TO CONSTRUCT

Documents submitted to the Department will be reviewed and if they demonstrate that the proposed water supply system can reasonably be expected to comply with these guidelines, including the water quality standards set forth in the Rules and Regulations, the Department will issue a "Certificate of Approval to Construct". If construction has not commenced within one year after the date of issue or there is a halt in construction of more than one year, the "Certificate of Approval to Construct" will be void unless an extension of time has been requested by the applicant and granted by the Department.

H. NOTIFICATION OF STARTING CONSTRUCTION

The Department shall be notified in advance of the beginning of construction on the site. Notification 7 days in advance of construction is necessary so that the Department may schedule inspection.

I. CHANGES DURING CONSTRUCTION

All work shall conform to approved plans and specifications. Should it be necessary or desirable to make any material change in the approved design which will affect water quality, capacity, sanitary features or performance, revised plans and specifications, together with a written statement of the reasons for such change, shall be submitted to the Department for review, and approval shall be obtained in writing before the work affected by the change is undertaken. Minor revisions not affecting water quality, capacity, flow, sanitary features or performance will be permitted during construction without further approval provided as-built plans documenting these changes are submitted to the Department as required.

J. NOTIFICATION OF CONSTRUCTION COMPLETION

The Department shall be notified when a public or semi-public water supply installation, change or addition, provided for by approved plans and specifications, is to be placed in service. Notification shall be given at least 15 days prior to the expected date of completion of the project to permit final inspection by the department.

K. FINAL INSPECTION

A final inspection must be completed for <u>all</u> projects, prior to issuance of an approval to operate. The final inspection must be completed by:

1. The Department, or

2. A Registered Engineer, with the approval of the Department.

L. AS-BUILT PLANS

As-built plans show the actual construction features of a project. They are essential because they show any changes made to the detailed plans during construction, and because they provide a permanent record of the construction. They must be based on field measurements. As-built plans must be submitted to the Department on all projects on which construction plans are required.

M. OPERATION AND MAINTENANCE MANUALS

These are essential for training new operators, and in providing continuity of operation between changes in assigned personnel. Operation and maintenance manuals must be developed for all treatment facilities. As a minimum, manufacturer's information as catalog cuts must be retained for other facilities such as pumps, or valves. Guidance documentation covering the development of operation and maintenance manuals is available from the Department.

N. ASSIGNMENT OF CERTIFIED OPERATOR

The State of Arizona has passed legislation for the purpose of classifying water supply facilities and assuring that operators of such facilities are suitably qualified to properly operate and maintain those facilities. Under the regulations promulgated, all water treatment facilities and water distribution systems are classified according to population and/or type of treatment. Four regular grades of classification, I through IV, were established with IV being the most complex. A special S grade was also established for plants and systems not in regular categories.

Each owner and surveyor of potable water is to employ the services of a certified operator of the required classification who will have direct responsibility for the operation of the treatment plant or system. The operator classification level required for each treatment plant or system classification is specified in the regulations.

A certified operator is required for all water systems, and must be assigned to the system before a "Certificate to Operate" is issued for the system.

O. CERTIFICATE TO OPERATE

A Certificate to Operate will be issued by the Arizona Department of Health Services upon completion of the applicable requirements.

P. OTHER APPROVAL REQUIREMENTS

As previously noted, the Arizona Department of Health Services requires approvals as noted herein. The State Land Department requires submittals on wells, and the Arizona Water Commission requires submittals on water sources developed for subdivisions. Additionally, the following submittals or approvals are required for water systems:

1. ARIZONA CORPORATION COMMISSION. Land areas including water systems serving the public in Arizona, except publicly owned systems, must be certified as Public Service Corporation by the Corporation Commission. Requirements include a description of the area by metes and bounds, and a County Franchise. The Corporation Commission will issue a "Certificate of Convenience and Necessity" for the area. Before a change is made to a water system, approval must be obtained from the Corporation Commission.

   Project development may be expedited by applying for the request for change to the Corporation Commission as soon as possible after issuance of the Approval to Construct by the Department of Health Services or County.

2. FEDERAL AID PROJECT. If federal funds are to be used on a project, the agency furnishing the funds shall be contacted directly to determine what specific submittals it requires. However, all Federal projects require Clearinghouse approval. Clearinghouse applications are made to the Arizona Office of Economic Planning and Development. Application should be made as early as possible in project development.

Q. DEVIATION FROM GUIDELINES AND NEW PROCESSES AND EQUIPMENT

The policy of the Department is to encourage, rather than obstruct new methods and equipment for water supply systems. For this reason, guidance documentation is included in the engineering bulletin to furnish the basis for the criteria. If it is proposed to deviate from the criteria, the exact nature of the proposed differences shall be noted in the Design Report. The scientific basis for the proposed change, including computations, and available practical experience on similar installations, shall be included. The justification and burden of proof for deviations from standards shall be the responsibility of the applicant.

At the discretion of the Department, before approval, any new developments should have been thoroughly tested in full scale comparable installation, under competent supervision before approval of plans can be issued for a plant utilizing a new process or equipment, unless the person owning the water supply in question is amply protected by a performance bond or other acceptable arrangement, so that any expenditure of money will be refunded in case of failure of any new process or equipment. The owner of the water supply involved should agree in writing to revisions or rebuilding of permanent plant structures necessary to accommodate other treatment processes or equipment, after the original installation has been rejected. The performance bond should include provisions to cover the cost of such alterations. Pending the development of satisfactory performance data, no new water treatment processes will be accepted by the Department unless the designing engineer can present conclusive evidence that his plans provide for effective use of the processes to treat the specific supply involved, in order to insure the delivery of safe drinking water without imposing undue problems of supervision, operation and control.

R. WATER SYSTEM PLANNING CRITERIA

Development of a water system should be based on sound planning information. A comprehensive water system plan should be developed for new systems prior to design. Comprehensive plans for existing systems should be periodically reviewed to assure that minimum pressures can be met under all demand conditions. Pressure problems can develop when several extensions are made to existing system without consideration to the impact on the system as a whole.

Planning information is used to determine the local and overall system water demand. The demand in turn is used to size and design the major elements of the system, including the sources, pumping equipment, treatment processes, storage, and the distribution network. Each element should be of the proper size in relation to other elements and the system as a whole, based on required flows, pressures, and water quality. A balanced system based on uniform planning criteria is usually the most cost effective.

1. WATER SYSTEM DEMAND. Water demand is a schedule of water requirements. For the purpose of these bulletins, the water demand for a system is discussed under General Service Requirements, and Fire Protection Requirements.

   When a water system is to serve fire protection requirements, the system demand shall be computed by adding the required fire flow in gallons per minute for the specified duration to the general service requirements.

Water demand varies considerably throughout Arizona, and not always in a predictable or logical manner. An analysis of the elements making up the total water demand of a community should be made including, but not limited to, the following items: location, climate, type and character of community, air conditioning, metering practice, sewerage, cost of water, water quality, pressure on mains, and fire protection. Water availability is not always an indicator of water uses, although lack of water may place a constraint on future demand.

Water use records are an excellent basis for determining water demand. A good historical record of water use can indicate present use and trends for a specific area. Consumer meter records can be most useful in supplying historical data, and extensive information can be gained from source, treatment, and storage metering, particularly if continuous recording devices are used. Good records are vital in the separation of fire protection from general service uses.

2. GENERAL SERVICE REQUIREMENTS. General service requirements includes all water uses except fire protection. Such uses encompass water for drinking, cooking, cleansing, toilet flushing, lawn and garden irrigation, air conditioning, and commercial and industrial uses.

   The minimum general service requirement shall be 100 gallons per capita per day, or the quantity (average daily flow) historically required in the past. An "Adequacy of Water Supply Report" may also be used as a basis for design flow.

   Greater than minimum water requirements can result from more extensive than normal irrigation practices. Evaporative coolers and air conditioning cooling towers can significantly increase general service water requirements. Large increases can also result from special commercial and industrial practices.

3. FIRE PROTECTION REQUIREMENTS. The Arizona office of the State Fire Marshal is available to assist in planning fire protection. Rating criteria currently recognized by this office is covered by the documents entitled Grading Schedule for Municipal Fire Protection and Guide for Determination of Required Fire Flow. The documents are published by the Insurance Services Office (ISO), 160 Water Street, New York, New York 10038.

   Fire protection requirements, when used to determine water system demand, shall be in accordance with current criteria of the insurance services office, or other method acceptable to the Department.

The ISO grading schedule notes that "In order to be recognized for grading purposes, a water supply shall be capable of delivering at least 250 gpm for a period of 2 hours, or 500 gpm for one hour, for fire protection plus consumption at the maximum daily rate. Any water supply which cannot meet this minimum requirement shall not be graded". For the high extreme, required fire flow may reach 10,000 gpm for 10 hours duration or more in unusual cases.

4. <u>FUTURE WATER SYSTEM DEMANDS</u>. Land use is the preferred basis for estimating water system demands. It offers a systematic method for projecting population by area in determining general service requirements. Unless specific structure types are known, it also offers a good method for estimating fire protection requirements. The level of accuracy of land use information could range from known occupancy and structure type to platted subdivisions to zoning to generalized planning. Each level would offer less certain information. Generalized land use planning offers the least certain information, but is occasionally the best available information for projecting use. Considerable land use planning is being accomplished in Arizona, much of which is coordinated by the State Office of Economic Planning and Development. Groups engaged in land use planning include:

    - The Federal Government
    - The State of Arizona
    - Councils of Governments
    - Counties
    - Cities and Towns
    - Special Districts

    Land use plans of the agency with jurisdiction over the project area should be considered.

    Projections of population growth may also be desired to determine overall water system demand. Methods which may correlate with historical growth include:

    - Uniform growth rate
    - Decreasing growth rate
    - Graphical extension
    - Comparison with similar areas

REFERENCES

American Water Works Association, "AWWA Standard for Filtering Material: AWWA B100-72". American Water Works Association, Denver, CO (1972).

American Water Works Association, "AWWA Standard for Deep Wells, (AWWA 100-66)", American Water Works Association, Denver CO.

American Water Works Association, Desalting Techniques for Water Supply Quality Improvement. American Water Works Assocation Research Foundation,

American Water Works Association, Ground Water, Manual of Water Supply Practices AWWA Manual M21, American Water Works Association, Denver, CO (1973).

American Water Works Association, Water Quality and Treatment (3rd Edition). McGraw-Hill Book Co., New York, NY (1971).

American Society of Civil Engineers, American Water Works Association, and Conference of State Sanitary Engineers, Water Treatment Plant Design. American Water Works Association, Denver, CO (1969).

Baylis, John R., Elimination of Taste and Odor in Water. McGraw-Hill Book Co., New York, NY (1935).

Bellack, Ervin, Fluoridation Engineering Manual. Environmental Protection Agency, Office of Water Programs, Water Supply Programs Division, Washington, DC (1972).

Calkins, Ronald J. and Novak, John T., "Characterization of Chemical Sludges". Journal American Water Works Assoication, 65:423 (1973).

Camp, Thomas R. and Meserve, R.L., Water and Its Impurities (2nd Edition). Dowden, Hutchinson & Ross, Inc., Strandsburg, PA (1974).

Clark, John W., Viessman, Warren, Jr., and Hammer, Mark J., Water Supply and Pollution Control. International Textbook, Scranton, PA (1971).

Cleasby, John L., "Filter Rate Control Without Rate Controllers". Journal American Water Works Association, 61:181 (1969).

Considine, Douglas M., editor, Encylopedia of Instrumentation and Control. McGraw-Hill Book Company, New York, NY (1971).

Considine, Douglas M., editor, Process Instruments and Controls Handbook. McGraw-Hill Book Company, New York, NY (1974).

Corrosion in Action. International Nickel Co., 67 Wall Street, New York, NY (1961).

Culp, Gordon L. and Culp, Russell L., New Concepts in Water Purification. Van Nostrand Reinhold Co., New York, NY (1974).

Culp, R.L. and Stoltenberg, H.A., "Fluoride Reduction at LaCrosse, Kansas". Journal American Water Works Association, 50:423 (1958).

Desalting Handbook for Planners. Bureau of Reclamation, Office of Saline Water, United States Department of the Interior (1972).

Dickey, George D., Filtration. Reinhold Publishing Co., New York, NY (1961).

Disposal of Wastes From Water Treatment Plants. American Water Works Association Research Foundation, Denver, CO (1969).

Dostal, Kenneth A., Pierson, Rex C., Hager, Donald G. and Robeck, Gordon G., "Carbon Bed Design Criteria Study at Nitro, W. Va.". Journal American Water Works Association, 57:663 (1965).

Engelbrecht, R.S., O'Connor, J.T. and Ghosh, M., "Iron Removal by Aeration and Filtration". Water & Sewage Works, p. 123 (April, 1967).

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

Fulton, George P., "Recover Alum to Reduce Waste Disposal Costs". Journal American Water Works Association, 66:312 (1974).

Glenn, R.W., Judkins, J.F., Jr. and Morgan, J.M., "Filtrability of Water Treatment Plant Sludge". Journal American Water Works Association, 65:414 (1973).

Granular Carbon Adsorption-Filtration System Purifies Water at Del City, Oklahoma. Calgon Corporation, Pittsburgh, PA (1967).

Hager, Donald G. and Flentje, Martin E., "Removal of Organic Contaminants by Granular-Carbon Filtration". Journal American Water Works Association, 57:1440 (1965).

Hammer, Mark J., Water & Wastewater Technology. John Wiley & Sons, Inc., New York, NY (1975).

Haney, Paul D., and Hamann, Carl L., "Recarbonation and Liquid Carbon Dioxide". Journal American Water Works Association, 61:512 (1969).

Hansen, Robert E., "Granular Carbon Filters for Taste and Odor Removal". Journal American Water Works Association, 64:176 (1972).

Harmon, J.A. and Kalichman, S.G., "Defluoridation of Drinking Water in Southern California". Journal American Water Works Association, 57:245 (1965).

Inhoffer, Wendell R. and Doe, Peter W., "Design of Wash-Water and Alum-Sludge Disposal Facilities". Journal American Water Works Association, 65:404 (1973).

Joyce, Roland S., "The Treatment of Process Water Using Granular Activated Carbon". The Brewer's Digest, (April, 1965).

Kleber, John P., "Use of Bimetallic Glassy Phosphates for Corrosion Control". Journal American Water Works Association, 57:783 (1965).

Koelzer, Victor A., Desalting. National Water Commission, Arlington, VA (May 1972).

Langelier, W.F., "The Analytical Control of Anti-Corrosion Water Treatment". Journal American Water Works Association, 28:1500 (1936).

Langelier, W.F., "Chemical Equilibria in Water Treatment". Journal American Water Works Association, 38:169 (1946).

Larson, T.E., "The Ideal Lime Softened Water". Journal American Water Works Association, 43:649 (1951).

Larson, T.E., "Chemical Control of Corrosion". Journal American Water Works Association, 58:354 (1966).

Larson, T.E., Corrosion by Domestic Waters (Bulletin 59). Illinois State Water Survey, Urbana, IL (1975).

Larson, T.E. and Buswell, A.M., "Calcium Carbonate Saturation Index and Alkalinity Interpretations". Journal American Water Works Association, 34:1667 (1942).

Larson, T.E. and Sollo, F.W., "Loss in Water Main Carrying Capacity". Journal American Water Works Association, 59:1565 (1967).

Larson, T.E. (et al), "Stabilization of Magnesium Hydroxide in the Solids Contact Process". Journal American Water Works Association, 51:1551 (1959).

Larson, T.E. and Skold, R.V., "Laboratory Studies Relating Mineral Quality of Water to Corrosion of Steel and Cast Iron". Corrosion, 14:43 (1958).

Magnesium Carbonate - A Recycled Coagulant for Water Treatment, EPA Technology Transfer Capsule Report. U.S. Environmental Protection Agency, Office of Technology Transfer, Washington, D.C.

Maier, F.J., "Defluoridation of Municipal Water Supplies". Journal American Water Works Association, 45:879 (1953).

Maier, F.J., Manual of Water Fluoridation Practice. McGraw-Hill Book Co., New York, NY (1963).

Manning, Alan W., "Computer Control of Chemical Addition at a Water-Treatment Plant". Journal American Water Works Association, 65:498 (1973).

Merten, Ulrich, editor, Desalination by Reverse Osmosis. The M.I.T. Press, Cambridge, MA (1966).

Moore, Edward W., "Calculation of Chemical Dosages Required for the Prevention of Corrosion". Journal New England Water Works Association, 52:311 (1938). (See also "Erratum", same volume, p. 466.)

More Water for Arid Lands - Promising Technologies and Research Opportunities. National Academy of Sciences, Washington, DC (1974).

National Association of Corrosion Engineers, NACE Basic Corrosion Course. National Association of Corrosion Engineers, Houston, TX (1970).

Nielsen, Hubert L., Carns, Keith E. and De Boice, John N., "Alum Sludge Thickening and Disposal". Journal American Water Works Association, 65:385 (1973).

Nordell, Eskel, Water Treatment for Industrial and Other Uses (2nd Edition). Reinhold Pub. Corp., New York, NY (1961).

Ockershausen, R.W., "Safe Handling of Water-Works Chemicals", Journal American Water Works Association, 63:336 (1971).

Popalisky, J. Robert, "Chemical and Physical Reactions in Water Heaters". Journal American Water Works Association, 47:359 (1955).

Quinn, Robert M. and Hendershaw, William K., "A Comparison of Current Membrane Systems Used In Ultrafiltration and Reverse Osmosis". Industrial Water Engineering, 13:12 (1976).

Riehl, Merrill L., Water Supply and Treatment (9th Edition), Bulletin 211. National Lime Association, Washington, DC (1962).

Robinson, J.H., (et al), "AWWA Standard for Granular Activated Carbon". Journal American Water Works Association, 66:672 (1974).

Rubin, Alan J., Aqueous - Environmental Chemistry of Metals. Ann Arbor Science Publishers, Inc., Ann Arbor, MI (1974).

Safety Practice for Water Utilities, (AWWA Manual M3). American Water Works Association, Denver, CO (1971).

Salotto, V.V., Farrell, J.B. and Dean, R.B., "The Effect of Water-Utility Sludge on the Activated Sludge Process", Journal American Water Works Association, 65:432 (1973).

Sawyer, Clair N. and McCarty, Perry L., Chemistry for Sanitary Engineers (2nd Edition). McGraw-Hill Book Co., New York, NY (1967).

Schwoyer, William L. and Luttinger, Lionel B., "Dewatering of Water Plant Sludges". Journal American Water Works Association, 65:399 (1973).

Sigworth, E.A., "Control of Odor and Taste in Water Supplies". Journal American Water Works Association, 49:1507 (1957).

Speller, Frank N., Corrosion Causes and Prevention (3rd Edition). McGraw-Hill Book Co., New York, NY (1951).

Spiegler, K.S., editor, Principles of Desalination. Academic Press, New York, NY (1966).

Standard Methods for the Examination of Water and Wastewater, (13th Edition). American Public Health Association, New York, NY (1971).

Stumm, W. and Lee, G. Fred, "Oxygenation of Ferrous Iron". Industrial & Engineering Chemistry, 53:143 (1961).

Stumm, W. and Morgan, J.J., Aquatic Chemistry. Wiley-Interscience, New York, NY (1970).

Uhlig, Herbert H., Corrosion and Corrosion Control. John Wiley & Sons, Inc., New York, NY (1971).

Water Chlorination Principles and Practices, (AWWA Manual M20). American Water Works Association, Denver, CO (1973).

Water Purification with Granular Activated Carbon at the Nitro Plant of West Virginia Water Co. Pittsburgh Activated Carbon Co., Pittsburgh, PA (1966).

Westerhoff, Garrett P. and Daly, Martin P., "Water Treatment Plant Disposal", Journal American Works Association, 66:319 (Part 1), 66:379 (Part 2) (1974).

Whipple, G.C., Fair, G.M., and Whipple, M.C., Microscopy of Drinking Water (4th Edition). John Wiley & Sons, Inc., New York, NY (1947).

Wolfe, Lowell, "Automatic Control of Level, Pressure, and Flow". Journal American Water Works Association, 65:654 (1973).

Woodward, Richard L., Dostal, Kenneth A. and Robeck, Gordon G., "Granular-Activated-Carbon Beds for Odor Removal". Journal American Water Works Association, 56:287 (1964).

engineering bulletin no. 10

Chapter 2

SOURCE DEVELOPMENT AND CONSTRUCTION

ARIZONA DEPARTMENT OF HEALTH SERVICES

MAY 1978

CHAPTER 2 - SOURCE DEVELOPMENT AND CONSTRUCTION

CHAPTER 2 - SOURCE DEVELOPMENT AND CONSTRUCTION

CHAPTER 2 - SOURCE DEVELOPMENT AND CONSTRUCTION

A. GENERAL

1. APPROVED WATER SOURCES. The regulations of the Arizona Department of Health Services (R9-8-210) require that all public and semi-public water systems shall obtain water from an approved source or sources and shall be located, constructed and operated in a manner to protect the water against entrance of any pollution, contamination or unclean substance. In the event water from a stream, lake or other source not protected against contamination is to be used, or if water from any source is subject to contamination, adequate purification, disinfection, or both, shall be carried out. In addition to the maximum contaminant levels contained in the regulations, the Department will maintain a list of recommended contaminant levels which gives consideration to aesthetics and public satisfaction.

   Procedures for water treatment are covered by Chapter 4 of this Bulletin. Disinfection is covered by Engineering Bulletin No. 8.

2. WATER TREATMENT. The treatment or disinfection level required of raw water from a water source can be an important consideration in whether or not to develop a source of water supply. In the selection of a water source, careful engineering analysis should consider all costs of the proposed treatment process, including costs of initial construction, operating staff, chemicals, facility maintenance, dependability and consistency of treatment, power requirements, potential for plant and process expansion, availability of operators skill levels, and environmental constraints such as methods of sludge disposal.

3. EMERGENCY DISINFECTION. Satisfactory means for emergency disinfection shall be constructed as a part of all water sources. The means shall be such that disinfectant can be immediately applied to the water system. The application of the disinfectant must be such that minimum required contact time is provided. As a minimum, piping and electrical connections for chlorination equipment are recommended.

B. SURFACE WATER SOURCE DEVELOPMENT

1. GENERAL. Surface waters shall include the waters of all sources flowing in streams, canyons, ravines, other natural channels, sheetflow and of lakes or ponds, whether perennial or intermittent, flood, waste or surplus water.

For the purpose of these standards, a surface water source (watershed) shall be considered to include all tributary streams and drainage basins above the point of water supply intake, including natural lakes and artifical reservoirs which may affect a specific water supply.

2. ADMINISTRATIVE AND PLANNING RESPONSIBILITY. It shall be the responsibility of the applicant to arrange for permits and clarify the legal status of waters to be developed.

In Arizona the quantity of surface water available for development is covered by the doctrine of prior appropriation. The salient feature of this doctrine is that he who is first in time has the better right - the senior in time prevails over the junior during periods of shortage. Hence, the maxim "first in time, first in right", illustrates the basic premise of this doctrine.

In 1919, the State Legislature enacted a rather comprehensive code governing the procedure to be followed in acquiring a surface water right. This appropriation procedure, outlined in the Arizona Water Code (ARS, Title 45, Chapter 1), has remained to this day substantially as established in 1919. Briefly, an application must be filed with the State Land Department for a permit to appropriate intrastate surface water. If the State Land Commissioner finds the application in order, he issues a permit which authorizes construction of the necessary works. After the water is applied to a beneficial use, proof of the fact is presented to the Department and a Certificate of Water Rights is issued to the applicant.

The Arizona Water Commission and the U.S. Bureau of Reclamation are authorized to plan for the development of interstate and intrastate waters, surface and groundwater, considering both water quality and water quantity.

Planning for water quality is also covered under the 1972 amended Federal Water Pollution Control Act in which the Federal Environmental Protection Agency proposed regulations which require each state to develop a state water quality management plan consistent with the Act. In January of 1973, the Governor of Arizona appointed the Arizona Water Quality Control Council as the official body responsible for the State's continuing water quality planning program. The State Department of Health Services and the Arizona Water Commission were directed to act as the Water Quality Control Council's staff in this planning activity.

Other agencies engaged in water planning and which have records available for use include the U.S. Geological Survey, the Corps of Engineers, the Bureau of Reclamation, the Soil Conservation Service and the Bureau of Land Management.

3. SANITARY SITE SURVEY. Careful consideration must be given to potential, present and future upstream contamination of surface water sources. Unexpected contamination may not be removed by the treatment process or may drastically increase the cost of treatment.

   A sanitary site survey shall be made of the factors, both natural and man made, which will affect the quality of water from surface sources of water supply. Such survey and study shall include, but not be limited to:

   a. Obtaining samples over a sufficient period of time to assess the microbiological, physical, chemical and radiological characteristics of the water.

   b. Determine possible future uses of impoundments or reservoirs.

   c. Assessing degree of hazard to the supply by accidental spillage of materials that may be toxic, harmful or detrimental to treatment processes.

4. SAFE YIELD. The safe yield of the water source shall be sufficient to supply the total water requirements (demands) of a community with due regard to all pertinent planning criteria within the region in which the supply must be developed.

   The safe yield of a surface water supply is defined as the quantity of water that can be provided on a continuous basis under the full range of hydrologic conditions that might reasonably be expected to occur during the life of the project. Yield considerations include climate, rainfall, runoff, evaporation, infiltration reservoir storage capacity, the area-versus-capacity relationship, drainage area size, sedimentation, minimum drawdown limitations, and various other considerations will affect a surface water source's performance and hydrologic effectiveness.

   Whenever possible, streamflow and weather records should be used in estimating the safe yield of the source. In using hydrologic records the conditions affecting their accuracy should be carefully evaluated. Hydrologic studies are complex and should be undertaken only by an engineer or hydrologist experienced in such work. Empirical formulas and ratios such as those involving the annual storage to annual demand, the annual storage to drainage area, the drainage area to reservoir area, etc. may vary widely for watersheds of the same size; therefore, they should not be considered satisfactory criteria for judging the adequacy of a source, unless supported by hydrologic data.

For surface water sources, special consideration should be critical drought conditions that are likely to affect safe yield. Drought conditions should be analyzed in terms of severity of runoff deficiency, and approximate duration. Potential critical drought conditions may be derived from past records, but, because of the uncertainty involved in projecting drought conditions on past records, a factor of safety should be included in source yield estimates. For reservoirs, this should be done by either assuming a storage capacity at the low point of a historical drought, leaving a reserve allowance, or by decreasing the estimated yield by a safe percentage of the average runoff experienced during the historical drought.

Operation studies should be used for analyzing reservoir yield capability. They are essential for large projects, and desirable for all.

5. FLOOD PROTECTION. All surface water reservoirs and structures shall be protected from a 100 year return frequency runoff condition, or be designed to either remain operational or isolated from the system during such a condition. For semi-public water systems, the requirement may be waived by the Department.

   Information on flood zones may be available from sources such as the U.S. Army Corps of Engineers, the Department of Housing and Urban Development, or county or local flood control districts, or may have to be developed for the specific project.

6. SOURCE PROTECTION.

   a. CONTROLLED CATCHMENT. A controlled catchment is a defined surface area such as a roof or paved area from which runoff is collected.

      It should only be used for small applications where groundwater is inaccessible or of such poor quality that it cannot be used for domestic use. A properly located and constructed controlled catchment and cistern, augmented by adequate filtration and disinfection facilities, can provide safe drinking water.

      The following precautions shall be taken to prevent contamination to any controlled catchment: (1) fencing to prevent unauthorized entrance by man or animals, and (2) an intercepting drainage ditch with a raised curb around the catchment area to prevent the mixture of undesirable surface drainage and controlled runoff.

A suitable location for a controlled catchment is on a hillside near the edge of a natural bench. The catchment area can be placed on a moderate slope above the receiving cistern. The cistern should be placed as close to the point of ultimate use as practical, but not closer than 50 feet to, and on higher ground than, any potential source of pollution. Cisterns can be placed underground to avoid freezing in colder climates and keep water temperatures low in warmer climates, but they should be protected from flooding.

The size of a cistern depends on the demand required and the length of time between periods of heavy rainfall. For adequate capacity, a catchment area shall be designed for at least two-thirds of the mean annual rainfall.

b. PONDS OR LAKES. The development of a lake or pond as a supply source depends on the following factors: (1) the selection of a watershed that permits only the highest quality water to enter the pond or lake, (2) use of the highest quality water in the pond, (3) treatment and disinfection of the water, (4) storage of treated water, and (5) proper maintenance of the entire system. A pond or lake should be capable of storing a minimum of one year's supply of water with allowances for seepage and evaporation losses.

To reduce the chance of contamination, the water shed shall be (1) free from barns, septic tanks, privies, and soil-absorption fields; (2) effectively protected against erosion and drainage from livestock areas; and (3) be fenced to exclude livestock. The pond or lake should be not less than 3 feet deep, and be kept free of weeds, algae and floating debris.

c. SURFACE STREAMS. Surface streams are fed from large uncontrolled watersheds and therefore possess varying water quality. The physical and bacteriological quality of stream water can impose heavy loads on treatment facilities. Stream intakes should be placed upstream from any known sources of contamination. The most favorable time to pump water from the stream is when the silt load is low. Ideal flow conditions vary for different streams and should be determined for each stream.

d. IRRIGATION CANALS. Water obtained from irrigation canals should be treated the same as water obtained from any other surface water source. Irrigation tailwater, because of its large concentrations of undesirable chemicals such as pesticides, herbicides, and fertilizer, should only be used as a last recourse.

C. SURFACE WATER SOURCE CONSTRUCTION

1. DAM CONSTRUCTION FOR WATER IMPOUNDMENT. The supervision of dam safety in Arizona is the responsibility of the Arizona Water Commission, and plans for review of the structural aspects of dam design should be sent to that office.

2. INTAKE STRUCTURE SYSTEM. Intake structures form the headworks of a conduit and pumping system which transports raw water from a surface water source to treatment facilities. Sources may be controlled catchments, ponds or lakes, running streams, or irrigation canals.

   The intake structure and system must have sufficient capacity to meet the maximum anticipated demand for water under all conditions during the period of its useful life. Also, it should be capable of supplying water of the best quality economically available from the source. Reliability is of major importance in intake design, because, unlike most parts of the water system, the intake is seldom constructed in duplicate. Functional failure of the intake, therefore, means failure of the water system. Intakes are subject to numerous hazards such as extreme low water, navigation or flood damage, clogging with fish, sand, gravel, silt, debris and ice. Unless these problems are considered during design, structural and operational failure of major components may result.

   A cribbing is usually constructed around the structure to protect it. Cribbing may range from concrete blocks for a small structure, to a rock filled timber cribbing for a large structure. Aggregate contained by a curb may be placed around the conduit end, or port as a stabilizing measure. Horizontal beams tied into the cribbing may also serve as stabilizing members. A screen shall be placed over the port to prevent debris from entering the system. (Refer also to Chapter 4, Pretreatment for screen criteria.)

   Ports shall be located above the bottom of the source, but at a sufficient depth to be kept submerged as the water level fluctuates.

   Provisions must be made for withdrawal of water from more than one level if water quality varies with depth. This may be accomplished with multiple inlet towers, which permit varying of depth of intake.

   In raw water intake conduits large enough to permit visual inspection, manholes or inspection ports shall be provided at adequate intervals.

D. GROUNDWATER SOURCE DEVELOPMENT

Groundwater is contained in beds of rock, gravel, and sand beneath the land surface. Underground formations that yield water readily are termed "aquifers". Groundwater aquifers can be replenished by seepage of water into the ground; the recharge area may be close to or distant from the main body of water. Water levels in many aquifers are dropping because the precipitation is not as great as the withdrawal rate, or because the paths to the aquifer are relatively impermeable and slow the recharge. Some aquifers can't be recharged because they are isolated, or too deep.

1. <u>ADMINISTRATIVE AND PLANNING RESPONSIBILITY</u>. It shall be the responsibility of the applicant to arrange for permits and clarify the legal status of waters to be developed.

   Dating from early territorial times, Arizona courts repeatedly stated that percolating water (groundwater) belong to the surface landowner and may not be appropriated and, furthermore, that groundwater is subject only to reasonable use by the landowner. Such opinions formed the foundation of Arizona's groundwater law which is still based on the permise that "waters percolating generally through the soil beneath the surface are the property of the owner of the soil, but subterranean streams, flowing in natural channels, between well-defined banks, are subject to appropriations under the same rule as surface streams". (8AZ 353)

   In 1945, legislation was passed which required owners and operators to report to the State Land Commissioner, data pertaining to their irrigation or drainage wells and to file a notice of intent with the Land Commissioner before drilling such wells. Notices of intent have been required on <u>all</u> wells since 1968. Later laws established "critical groundwater areas" in which the drilling of new wells for irrigation purposes is controlled and administered by the Arizona State Department.

2. <u>SANITARY SITE SURVEY</u>. A sanitary site survey shall be performed for all proposed wells and springs prior to drilling or excavation.

   The survey shall consider the various sites available and the advantages of the one to be recommended, including the proximity of residences, conduits and (where pertinent) the existence of sink holes, caves, test holes, abandoned wells, mine shafts, open pit mines, borings or developed areas to a radius of 1 mile from any well site, and shall discuss the relationship of maximum high water to the well site.

The location of sewers, tunnels, overflows, sewage pumping stations, sewage treatment plants, soil absorption systems, privies and other structures of public health significance, with relation to various portions of the groundwater development shall also be considered.

Where pertinent, all groundwater developments within a 1 mile radius of the proposed groundwater source, including protective casing depth, capacity and location shall be analyzed. A sufficient number of samples shall be obtained over a period of time adequate to assess the microbiological, physical, chemical, and radiological characteristics of the water.

3. CHARACTER OF LOCAL GEOLOGY. The character of local geology should be studied to assess the possibility of faults, crevices, and interstitial spaces which would allow contaminates to reach the source. The geology of the aquifer and recharge zones is also critical because they directly control the yield of the well or spring. The formations must be sufficiently porous to transmit water at an acceptable rate.

4. SAFE YIELD. The safe yield of a water source shall be sufficient to supply the total water requirements (demand) of a community with due regard to all pertinent planning criteria within the region in which the supply must be developed.

   A first step in determining the potential water yield of a well or spring is to review similar developments in the area. Well drilling reports must be filed with the State Land Department, and the reports from these operations may indicate the nature of the geology, depth to water and possibly pumping and drawdown rates. Analysis by a competent groundwater hydrologist can also be most useful.

   A well designed and conducted test drilling program is strongly recommended, especially for larger water supply projects. This drilling program can provide reliable information about the following matters: location of wells, depth of wells, well spacing, well design, probable productivity of completed wells, probable water quality, materials required for well construction, and pumping equipment.

   To select the proper pumping equipment, a pumping test is required after the well is developed to determine its yield and drawdown. The pumping test for yield and drawdown should include the determination of the volume of water pumped per minute or hour, the depth to the pumping level as determined over a period of time at one or more constant rates of pumpage, the recovery of the water level after pumping is stopped, and the length of time the well is pumped at each rate during the test procedure. The test for yield and drawdown should be done accurately by the use of approved measuring devices and accepted methods.

A test for yield and drawdown should be performed as close to the end of the dry season as possible. If this cannot be accomplished the additional seasonal decline in water levels should be determined from other wells tapping the same formations, and then added to the drawdown determined by the pumping test.

Individual wells shall be test pumped at a constant pumping rate that is not less than that planned for the final pump installation. The well shall be pumped at this rate for not less than four hours, and at least until a sustained yield is obtained with a static drawdown. Measurements of the water levels during recovery can then be made.

5. SOURCE PROTECTION. All groundwater sources require special protection to prevent the entry of contaminated or polluted water. This water may approach the source from the surface or from lower geological formations. The type, depth, or length of protection must be designed to fit specific conditions. For example, in many cases more than the minimum depth of 10 feet of grout encasement for surface protection will be required. Minimums are provided to allow cost effective application under good conditions.

   a. DRILLED WELLS. In the construction of a drilled well, the hole is excavated by the cutting action of a drill bit or tool operated by a drilling rig. The drill tool progresses downward by either a percussion, rotary, or hydraulic cutting action. A casing is placed within the hole to support the sidewalls and prevent collapse. A screen is set on the end of the casing when it reaches a water bearing formation yielding sufficient water. This screen retains fine material while allowing water to flow into the casing. A screen may not be necessary if the casing terminates in rock. A drilled well can be used for small or large supplies, with the maximum depth limited primarily by the distance necessary to reach an adequate supply of acceptable water.

      The minimum protective depth of drilled wells shall be such as to provide watertight construction to such depth as may be required to exclude contamination, but in no case less than 10 feet. The protection shall be designed to seal off formations that yield undesirable or contaminated water. There shall be an annular opening of at least 1.5 inches outside the protective casing filled with cement grout, cement and sand grout, or other approved material. Frequently an annular opening of at least 3 inches is constructed in order to facilitate placement of grout.

b. GRAVEL WALL WELLS. Gravel wall wells are also called gravel pack wells. In the construction of a gravel wall well, the zone excavated for the well is made larger than the well screen. Gravel of a selected gradation is placed between the outside of the well screen and the face of the well excavation. By special placement of graded gravel, it is unnecessary to remove the fine material from the natural formation by pumping it through the well, as is the case with a standard drilled well.

Gravel wall well construction can be useful in developing water from formations consisting of fine material of a uniform grain size. It allows the use of screens with larger openings or slot sizes than would be possible if the gravel pack were not provided. The result is an increase in the effective diameter of the well yielding lower entrance velocities and increased flow per unit of head loss. It should be emphasized that gravel wall wells must be specially designed.

In construction of gravel wall wells, the outer casing shall be of such diameter as to assure a minimum opening of 3 inches after placement of gravel refill pipes. The gravel pack shall consist of well rounded particles, 95 percent siliceous material, that are smooth and uniform, free of foreign material, properly sized, washed and then disinfected prior to or during placement. The gravel pack shall be placed in one uniform, continuous operation. The minimum depth of protective casing and grout shall be that required to exclude pollution, and in the special case of gravel wall wells the minimum depth shall be 20 feet, rather than 10 feet. Gravel refill pipes located in the grouted annular opening shall be surrounded by a minimum of 1-1/2 inches of grout. Grout shall be prevented from leaking into the gravel pack or screen.

c. DUG OR BORED WELLS. Dug or bored wells shall be considered only where geological conditions preclude the possibility of developing an acceptable drilled well.

A dug well may range to 30 feet in diameter, with depths ranging from 20 to 40 feet. Because it is capable of collecting water from all of the water bearing formations it passes through, it may furnish relatively large quantities of water from shallow sources. Dug wells are undesirable because it is difficult to protect the large opening and perimeter from the entrance of polluted surface water, airborne material, and objects or animals, and they are not dependable sources during times of drought.

A bored well is excavated with power or hand earth augers. An auger can be used only where the soil is relatively soft, but which will permit an unsupported hole to be bored to depths ranging from 25 to 60 feet without caving. Alluival deposits or glacial fill can be suitable formations. Augers may be used where speed of construction is important, and where water can be found at relatively shallow depths.

The minimum protective depth of lining and grouting of a dug or bored well shall be that required to exclude pollution, but in no case less than 10 feet. A watertight cover with openings curbed and protected from entrance of foreign matter shall be provided. Pump discharge piping shall not be placed through the well casing or wall, except in the application of a "pitless adapter".

d. <u>RADIAL WATER COLLECTOR</u>. A radial water collector consists of a central caisson (similar to a dug well) with horizontal driven wells projecting outward from near the bottom of its vertical walls. Water collected by the horizontal wells is concentrated in the central caisson. With careful location, design, and construction, a radial water collector can produce large quantities of water. Frequently they are located in the bank storage zone of a lake or river. In order to obtain desired infiltration, it is necessary that the horizontal wells be located in coarse material. It should be noted that water from this installation may require a relatively high level of treatment because of its close proximity to a surface water source.

Radial water collectors shall be constructed in areas and at depths approved by the Department. Provisions shall be made to assure that radial collectors are essentially horizontal. The location of all caisson construction joints and porthole assemblies shall be detailed. The caisson wall shall be able to withstand the forces to which it will be subjected, reinforced, and with no discharge piping placed through the wall. Provisions shall be made to insure the casing extends above a watertight floor a minimum of 6 inches. All openings in the floor shall be curbed and protected from the entrance of foreign matter.

The area around the collector shall be under the control of the water purveyor and flow in the lines shall be by gravity to the collecting well.

e. DRIVEN POINT WELLS. This type of source shall be specified only where geological conditions preclude the probability of developing a satisfactory drilled well source. A driven point well is constructed by forcing a series of lengths of pipe attached to a drive point into the soil. The pipe varies from 1-1/4 to 4 inches in diameter. Varieties of drive points include perforated pipe covered with woven wire mesh or with a tubular brass jacket, or drilled well screens adapted for driving. A steel tip on the end of the drive point serves to open passageways by breaking through pebbles or hard materials. A driven point well is normally only constructed to shallow depths of 30 to 40 feet.

When constructing a driven point well, an outer or protective casing shall be installed which protects the inner or suction casing to which the pump is attached, and on which a partial vacuum is placed that can draw contaminates at leaking joints. The outer casing should be 2 inches larger in diameter than the well casing. The outer casing shall extend a minimum of 20 feet below the ground surface, except in impermeable layers such as clay, in which case a 10 foot minimum depth shall be required.

f. INFILTRATION GALLERIES. This type of source shall be specified only where geological conditions preclude the probability of developing a satisfactory drilled well source.

An infiltration gallery is a chamber of lines with openings in the sides and bottom, and which extend horizontally into the water bearing formation.

Under favorable soil conditions, they can be effective in removing debris and high turbidity under high or flood flow conditions, when relatively small quantities of water are required.

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. 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 top of the tile to support the filtering material. 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 is terminated in watertight, concrete basin from where it is diverted or pumped to the distribution network following chlorination.

The area around the gallery shall be under the control of the water purveyor, and flow in the lines shall be by gravity to the collecting point.

g. SAND OR GRAVEL WELLS. This terminology applies to drilled or driven wells which are not gravel packed, and essentially constructed in sand or gravel formations. In such formations, the sand or gravel can slough in around the outside casing and close the space between the drill hole and the casing. In materials such as hardpan or clay which does not collapse, a gap may be left between the outside of the drill hole and the pipe. In this case, there is significant potential for contamination to pass through the gap and reach the well screens.

Where water quality problems are encountered, double casing or cement grout construction shall extend through the contributing formation. An outer casing may be permanently placed or withdrawn as grouting proceeds. Where permanently placed, the outer casing shall be withdrawn to an elevation at least 5 feet above the stable material. Exceptions may be approved by the Department.

h. LIMESTONE OR SANDSTONE WELLS. Wells constructed in limestone or sandstone formations present special problems. These formations are frequently creviced or channeled, which allows polluted water to reach the well screens. The probability of potential pollution can be lessened by the presence of an overlaying mantle of unconsolidated material.

Where the depth of mantle is more than 50 feet, the permanent casing shall be firmly seated in uncreviced or unbroken rock. Where the mantle material over an extnesive area is of a depth less than 50 feet, the limestone lying immediately below the mantle shall be sealed off and the well should be developed in underlying formations.

Special care shall be taken that there are no existing wells in the area which are below standard, and can cause polluted water to enter a channel or crevice in the formations. Such wells shall be sealed and capped.

i. FLOWING ARTESIAN WELLS. Such wells flow from natural pressure induced by the formations overlying the aquifer.

The construction of flowing artesian wells should be such that the flow from them can be controlled. The drill hole should extend into, but not through, the confining bed. A protective casing shall be set and the annular space should be grouted. Following the extension of the drill hole into the artesian formation, an inner casing shall be required where erosion of the confining bed by the flowing water will occur. This inner casing shall be joined in a watertight manner to the protective casing. Flow control should consist of valved pipe connections, watertight pump connections or receiving reservoirs, set at an altitude corresponding to that of the artesian head, and which is adjustable to match a fluctuating head.

E. WELL CONSTRUCTION REQUIREMENTS

1. NOTICE OF INTENTION AND IDENTIFICATION NUMBER. Before construction is begun on a well in Arizona, a "Notice of Intention to Drill Well" must be filed with, and receipted by, the Arizona State Land Department. A copy of this notice shall be included with the "Application for Approval to Construct Water/Wastewater Facilities" and sent to the Arizona Department of Health Services. (Refer to Chapter 1, Project Development Criteria, for specific submittal requirements.)

2. LOCATION. In the selection of a site, due regard shall be given to the type of well construction to be utilized, the depth to water bearing zones, the type of formations to be penetrated and the proximity of existing or possible future sources of pollution, such as sewers, seepage pits, soil absorption fields, privies, sink holes, dumping areas, caves, testholes, abandoned wells, borings, lagoons, private water supply developments and other underground construction. The site should have sufficient area to prevent adjacent structures and installations, present or future, from impairing the safety of the supply. Where practicable, every well shall be located at the highest point in the premises, insorfar as the general layout and the surroundings permit. The Department should be consulted as to required separation between sources of pollution and the groundwater development.

3. SAMPLES AND RECORDS. A copy of the "Report of Well Driller" developed for the State Land Department shall be included with the "Application to Construct" and sent to the Department of Health Services for wells which will serve a public or semi-public water supply. The forms shall be completed and shall include a log of the well at 10 feet intervals, an accurate record of the drill hole diameters, assembled order of size and length of casing and liners, grouting depths, water levels, location of blast shots, and pumping tests.

4. PRELIMINARY EXPLORATION. Where preliminary exploration is being conducted on a service which may serve a public or semi-public water supply, samples and records as noted in Item 3 shall be supplied. Geophysical surveys should be supported by test hole drilling.

5. AQUIFER PROTECTION. When a well shaft passes through formations such as limestone, sandstone or fractured rock, that do not provide good filtration or formations containing poor quality water contaminants may reach the aquifer. Pollution may enter the porous passages through excavations, outcrops, or old wells, and may travel great distances. When such formations are encountered, the well shall be protected from the entry of contaminants by grouting of these passages or formations. Exceptions may be approved by the Department in the case of driven point wells.

6. SITE PREPARATION. A properly constructed well should exclude surface water from a groundwater source to the same degree as does the undistrubed overlying geological formation. The top of the well must be constructed so that no foreign matter or surface water can enter during or after construction. The well site shall be properly drained and adequately protected against erosion, flooding, and damage or contamination from animals during and after construction. Surface drainage should be diverted away from the well.

7. BELOW GROUND PITS. A well pit to house the pumping equipment is prohibited because of the pollution hazards involved. The "pitless adapter" principle is available as an alternative to eliminate well pit construction. In unusual cases, special designs for below ground pits may be approved by the Department.

8. UPPER TERMINAL OF WELL. The casing pipe and the protective curbing of all groundwater sources shall project not less than 12 inches above the pumphouse floor, slab, or cover installed. In the case of pedestal construction, the top of the pedestal shall be not less than 12 inches above adjacent ground.

   In the case of the sites subject to flooding, the top of every well station floor, and the cover of every dug well, shall be at least 2 feet above a 100 year return frequency flood level, surrounded by an earth fill to a point 1 foot above the flood level and extending radially at the level 15 feet from the well casing. The well casing shall be surrounded with a reinforced concrete envelope having a minimum thickness of 6 inches from the upper terminal of the well to a point 10 feet below the original ground level. Exceptions may be approved by the Department in the case of semi-public water supplies, or for sources which can be isolated from the water system during flooding, and effectively disinfected.

9. SANITARY WELL SEAL AND SLAB. A sanitary well seal with an approved vent shall be installed at the top of the well casing to prevent contaminated water or other material from entering the well. A slab shall be provided around all wells. The slab should extend a minimum of 3 feet from the center of the well, be a minimum of 6 inches thick, and slope away from the well a minimum of 1/4" per

foot. For large diameter wells such as dug wells, a reinforced concrete slab, overlapping the casing and sealed to it with flexible sealant or rubber gasket, shall be installed. The annular space outside the casing should first be filled with suitable grouting or sealing materials.

10. METAL CASING AND LINER PIPE. Protective well casing should be constructed of wrought iron or steel having minimum weights as specified in Tables 1 and 2, and shall be adaptable both to stresses to which the pipe will be subjected during installation and to the corrosiveness of the water. Additionally, the following shall apply:

    a. DRIVE SHOE. Pipe that is to be driven shall be equipped with a drive shoe and starter joint.

    b. JOINTS. Casing and liner pipe joints shall be welded or threaded, and watertight.

    c. LIGHT WEIGHT PIPE. Temporary casings and liners installed without driving may be of lighter weight than specified by Tables 1 and 2. Light weight pipe shall have a minimum thickness of 0.25 inches. Casing pipe utilized for protection against contamination and having weights less than specified by Table 1 and 2 shall be surrounded by 6 inches of cement, sand and cement grout, or other approved material to a depth of 10 feet.

    d. HEAVY WEIGHT PIPE. When the minimum weight of casing and line pipe, as specified by Tables 1 and 2, is not sufficient to assure reasonable life expectancy of the well, the additional wall thickness and weight needed may be obtained by using extra strong or double extra strong pipe.

11. THERMOPLASTIC WELL CASING PIPE. Materials and requirements for thermoplastic well casing pipe shall be in accordance with the current addition of American Society for Testing and Materials (ASTM) F 480.

12. CONCRETE ELEMENTS. Portland cement concrete may be used for the construction of such well elements as protective slabs, curbs, pedestals, or walls.

    a. MATERIALS. Concrete materials and mixes should be such as to yield a 28 day strength at 3000 psi.

    b. CONSTRUCTION FEATURES. Slabs, walls, curbs, or pedestals should be at least 6 inches thick, with the concrete so placed as to be free of voids. Each element should be poured in one operation, if possible. For walls and curbs, vertical and horizontal reinforcing bars should be provided.

TABLE 1

Steel Pipe, Black or Galvanized *

Size *in.*	Diameter—*in.*		Thickness† *in.*	Weight per Foot—*lb*‡	
	External	Internal		Plain Ends (Calculated)	With Threads and Couplings§ (Nominal)
6	6.625	6.065	0.280	18.97	19.18
8	8.625	8.071	0.277	24.70	25.55
8	8.625	7.981	0.322	28.55	29.35
10	10.750	10.192	0.279	31.20	32.75
10	10.750	10.136	0.307	34.24	35.75
10	10.750	10.020	0.365#	40.48	41.85
12	12.750	12.090	0.330	43.77	45.45
12	12.750	12.000	0.375#	49.56	51.15
14	14.000	13.500	0.250	36.71	
14	14.000	13.250	0.375#	54.57	57.00
16	16.000	15.376	0.312	52.36	
16	16.000	15.250	0.375#	62.58	65.30
18	18.000	17.376	0.312	59.03	
18	18.000	17.250	0.375#	70.59	73.00
20	20.000	19.376	0.312	65.71	
20	20.000	19.250	0.375#	78.60	81.00
22	22.000	21.376	0.312	72.38	
22	22.000	21.250	0.375	86.61	
22	22.000	21.000	0.500#	114.81	
24	24.000	23.376	0.312	79.06	
24	24.000	23.250	0.375	94.62	
24	24.000	23.000	0.500#	125.49	
26	26.000	25.376	0.312	85.73	
26	26.000	25.000	0.500#	136.17	
28	28.000	27.376	0.312	92.41	
28	28.000	27.000	0.500#	146.85	
30	30.000	29.376	0.312	99.08	
30	30.000	29.000	0.500#	157.53	
32	32.000	31.376	0.312	105.76	
32	32.000	31.000	0.500#	168.21	
34	34.000	33.376	0.312	112.43	
34	34.000	33.000	0.500#	178.89	
36	36.000	35.376	0.312	119.11	
36	36.000	35.000	0.500#	189.57	

---

* Galvanized pipe in sizes 6-12 in. Inclusive may be purchased under ASTM A120. Larger sizes may be purchased galvanized by agreement with pipe manufacturer.

† Wall thickness to be selected to meet service conditions, heavier walls being indicated for permanence in severe service. Many other thicknesses of steel pipe are manufactured and marketed. Sizes over 20 in. are frequently electric fusion welded. Commonly used standards for black pipe are ASTM A53, A120, A134, A135, A139, A211; API (American Petroleum Institute) 5L, 5LX; Underwriters' Laboratories Standard 888; AWWA C201, C202.

‡ Manufacturing weight tolerance is 10 per cent over and 3.5 per cent under nominal weight for pipe 6-20 in. in size and ±10 per cent of nominal weight for larger sizes.

§ Nominal weights of pipe with threads and couplings (based on lengths of 20 ft, including coupling) are shown for purposes of specification. Thread data are contained in the various standards covering sizes which can be purchased with threads.

Thickness indicated is believed to be best practice. If soil and water conditions are unusually favora lighter pipe may be used *if permitted* in the purchaser's specifications.

Note: Welded joints advocated for pipe larger than 20 in. in diameter; also for smaller diameter pipe, where applicable, to obtain clearance and maintain uniform grout thickness.

Source: American Water Works Association Standard for Deep Wells (AWWA A100-66) page 34.

TABLE 2

Wrought-Iron Pipe, Black or Galvanized *

Size *in*	Diameter—*in.*		Thickness *in.*	Weight per Foot—*lb*†	
	External	Internal		Plain Ends (Calculated)	With Threads and Couplings‡ (Nominal)
6	6.625	6.053	0.286	18.97	19.45
8	8.625	7.967	0.329	28.55	29.35
10	10.750	10.005	0.372	40.48	41.85
12	12.750	11.985	0.383	49.56	51.15
14	14.000	13.234	0.383	54.56	57.00
16	16.000	15.234	0.383	62.58	65.30
18	18.000	17.165	0.417	76.84	81.20
20	20.000	19.125	0.438	89.63	94.38
20	20.000	19.000	0.500§	102.10	106.62
22	22.000	21.125	0.438	98.77	
22	22.000	21.000	0.500§	112.57	
24	24.000	23.125	0.438	107.96	
24	24.000	23.000	0.500§	123.04	
26	26.000	25.125	0.438	117.12	
26	26.000	25.000	0.500§	133.51	
28	28.000	27.125	0.438	126.27	
28	28.000	27.000	0.500§	143.99	
30	30.000	29.125	0.438	135.42	
30	30.000	29.000	0.500§	154.46	

* Dimensions for 6-12-in. sizes from ASTM A72, weights from manufacturer's specifications for wrought-iron line pipe; 14-20-in. pipe dimensions and weights from manufacturer's specifications for wrought-iron line pipe; 22-30 in. pipe dimensions and weights from manufacturer's specifications for wrought-iron large-diameter pipe. Sizes 14 in. and larger can be obtained in thicknesses other than those listed.

† Manufacturing weight tolerance is 10 per cent over and 3.5 per cent under nominal weight for pipe 6-20 in. in size and ±10 per cent of nominal weight for larger sizes.

‡ Based on length of 20 ft, including coupling. Threaded pipe has 8 threads per inch.

§ Thickness indicated is believed to be best practice. If soil and water conditions are unusually favorable, lighter pipe may be used *if permitted* in the purchaser's specifications.

Note: Welded joints advocated for pipe larger than 20 in. in diameter; also for smaller diameter pipe, where applicable, to obtain clearance and maintain uniform grout thickness

Source: American Water Works Association Standard for Deep Wells (AWWA A100-66) page 35.

13. GROUTING

a. NEAT CEMENT GROUT. Cement conforming to ASTM standard C150 and water, with not more than six gallons of water per sack of cement, should be used for 1-1/2 inch openings. Additives may be used to increase fluidity subject to approval by the Department.

b. CONCRETE GROUT. Equal parts of cement conforming to ASTM Standard C150, and sand, with not more than six gallons of water per sack of cement may be used for openings larger than 1-1/2 inches.

Where an annular opening larger than four inches is available, gravel not larger than one-half inch in size may be added.

c. APPLICATION. All grouting should be performed by adding the mixture, from the bottom of the space to be grouted towards the surface, in one continuous operation. Sufficient annular opening should be provided to permit a minimum of 1-1/2 inches of grout.

14. SCREENS. Generally, wells completed in unconsolidated formations such as sands and gravels are equipped with screens, devices that allow the maximum amount of water from the aquifer to enter the well with a minimum of resistance and without the passage of sand during pumping.

However, although one of the purposes of the screen is to prevent sand from entering the well during pumping, the screen actually permits the entrance of fine-formation particles into the well during the development process so they may be removed by pumping or bailing. At the same time, the large particles of sand are held back so that a graded natural-gravel screen is retained around the well screen itself. In this way, the permeability of the water-bearing formation around the screen is greatly increased and results in lowering of velocity head loss and higher capacity per foot of drawdown.

The size of screen openings, or slot number, is usually expressed in thousandths of an inch. The width of the slot, or slot size, as it is normally referred to, is best determined on the basis of a mechanical sieve analysis of a sample of the water-bearing formation. In gravel wall wells, the size of slot is directly dependent upon the gradation of the aggregate material.

Screen openings should provide the maximum amount of open area consistent with strength and the grading of the water bearing formation, should permit maximum transmitting ability without clogging or jamming and should be constructed of material which will not be damaged by the chemical action of the groundwater. The screen length and placement shall be as to prevent exposure above the pumping water level.

15. PLUMBNESS AND ALIGNMENT. Every well, before being officially accepted, should be tested for plumbness and alignment. The test method to be followed should be definitely stated in the specifications. A 40-foot dummy, having an outer diameter 1/2 inch smaller than the diameter of the casing or hole being tested, shall move freely throughout the length of casing or hole to the lowest anticipated pump setting. The well should not vary from the vertical in excess of two-thirds of the smallest inside diameter of that part of the well being tested, per 100 feet of depth.

16. WATER LEVEL MEASUREMENT. Provision for an acceptable method of measurement of water level shall be made on every well. The measurement method and equipment shall be such as to prevent contamination of the well.

17. CAPPING. A welded metal plate is the recommended method of capping a well until pumping equipment is installed. Other methods shall require the approval of the Department.

18. FENCING. If the well head is not enclosed by a building, security fencing at least 6 feet high shall be constructed. Other approved means of preventing potential contamination may be approved by the Department.

19. BLASTING AND CHEMICAL CONDITIONING. Specifications covering method, equipment and controls for the blasting or chemical conditioning of wells shall be submitted to the Department for approval.

20. DISINFECTION REQUIREMENTS. Every new, modified or reconditioned groundwater source shall be disinfected after placement of final pumping equipment. Information on disinfection procedures can be obtained from Engineering Bulletin No. 8, "Disinfection of Water Systems".

21. OBSERVATION WELLS. Any well designated as an observation well shall be constructed in accordance with these standards. Each observation well shall be protected at its upper terminal, to preclude the entrance of foreign material.

22. ABANDONED WELLS. Abandoned wells and test wells should be sealed by restoring the controlling geological conditions which existed before the wells were drilled. An acceptable alternative is to completely fill the well with concrete.

23. RECHARGE WELLS. The policy of the Department is to encourage, rather than to obstruct, the development of ways and means for economical use of the State's groundwaters; however, any proposal must be in accordance with, and have the complete approval of, the Department and any other authority having jurisdiction.

F. SPRING CONSTRUCTION REQUIREMENTS

An aquifer should be developed as a spring only when it is not feasible to develop an acceptable well.

1. LOCATION. Springs as potable supplies shall be located such as to protect them from contamination from both surface and groundwater origins, and surveys of potential contamination shall be conducted as required by these standards for both surface and groundwater sources. Springs shall not be located in low areas where water may accumulate nor in potential flood plains.

   The water yield from springs is generally relatively small. The approximate yield may be determined by constructing a small weir if conditions are such that water will flow, and periodically checking the height of flow over the weir. Because springs flow by gravity, water from only a small portion of the aquifer - perhaps only the top - is available for use. Consideration should be given to the possibility that they may dry up during periods of low precipitation, or drought.

2. SITE PREPARATION. Grading of the site shall provide for gravity drainage away from the spring of precipitation runoff, or waste water from the spring. Construction should be such as to minimize contamination or disturbance to the aquifer.

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

   A tank is usually constructed in place with reinforced concrete of such dimensions as to enclose or intercept as much of the spring as possible. When a spring is located on a hillside, the downhill wall and sides are extended to bedrock or to a depth that will insure maintenance of an adequate water level in the tank. Supplementary cutoff walls of concrete or impermeable clay extending laterally from the tank may be used to assist in controlling the water table in the locality of the tank. The lower portion of the uphill wall of the tank can be constructed of stone, brick, or other material so placed that water may move freely into the tank from the formation. Backfill of graded gravel and sand will aid in restricting movement of fine material from formation toward the tank.

The tank cover should be cast in place to insure a good fit. 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 at the lowest point in the bottom of the tank. The pipe should extend horizontally so as to clear the normal ground level at the point of discharge by at least 6 inches. The discharge of the pipe shall be covered with a #16 mesh screen.

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

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

4. <u>SPECIAL PROTECTION</u>. An interceptor ditch shall be located uphill from the site to divert surface drainage completely away from the spring area.

   Means shall be provided to prevent access to areas of the spring in which contamination could be introduced. The preferred method is a 6 foot high fence. It is also desirable to exclude livestock from the surface water drainage system at all points above the source.

5. <u>DISINFECTION</u>. Spring encasements shall be disinfected in accordance with the requirements of Engineering Bulletin No. 8.

   If the water pressure is not sufficient to raise the water to the top of the encasement, it may be possible to shut off the flow and thus keep the disinfectant in the encasement for 24 hours. If the flow cannot be shut off entirely, arrangements should be made to supply disinfectant continuously for as long a period as practicable.

engineering bulletin no. 10

Chapter 3

PUMPING FACILITIES

ARIZONA DEPARTMENT OF HEALTH SERVICES

MAY 1978

CHAPTER 3 - PUMPING FACILITIES

CHAPTER 3 - PUMPING FACILITIES

CHAPTER 3 - PUMPING FACILITIES

A. GENERAL

Pumps serving modern water systems range extensively in designation, classification, and application.

Pumps may be designated according to the types of water handled, as raw, semi-finished or potable water facilities; according to degree of lift, as low-lift, intermediate, high-lift and booster; according to type of operation, as manually controlled, automatic and remote-controlled; according to purpose, as individual water supply, treatment plant, main pumping and distribution system facilities; or as combinations of these.

Many different varieties of pumps are available, ranging from a fraction of one to several thousands of horsepower per pump. There are several possible pump classifications, but all pumps can be fitted into the categories adopted by the Hydraulic Institute Standards, which are: (1) Centrifugal, (2) rotary, (3) reciprocating, or (4) impulse pumps. Most pumps used in drinking water systems are centrifugal, although other types may occasionally be used.

1. PUMP SELECTION. In the selection of pumps it is necessary to investigate a number of different types of pumping arrangements and, in each instance, to tabulate the sanitary and water quality protection provided, initial cost, cost of operation and maintenance and expected life of equipment. From this tabulation, it is fairly simple to select the combination that offers minimum investment and operational costs and yet fulfills requirements of the system.

   Continuous pumping is preferable to stopping and starting. However, most pumps operate intermittently because of variations in water demand. The pumping rate should be such as to minimize the number of cycles of starting and stopping within a 24 hour period. A desirable maximum number of cycles is 6 times per hour. Every time a pump starts, it consumes power in lifting the water to the surface and developing the total dynamic head in the system before any water is actually discharged. Each time the pump stops, this work must be repeated, causing that much wasted power. Continuous operation obviously avoids this extra power cost.

   It is essential that the selected pump be able to produce the required flow against the system pressures. For centrifugal pumps, the discharge head increases as the rate of flow or capacity increases. Efficiency varies significantly throughout the operating range. Capacity-head curves, which show the relationship of these factors, are available for all sizes of pumps and should be used in the selection process. Most capacity-head curves also show net positive suction head required at the suction port.

2. PUMP INSTALLATION CONSIDERATIONS. Pumps should be located so that there is sufficient access and working space for inspection and maintenance. Provision should be made for use of a crane or hoist. Pumps must be mounted on a solid concrete foundation, and foundation bolts should be precisely placed according to dimensions furnished by the manufacturers.

   Frequently the base of equipment will be sprung to some extent during shipment, requiring that pump alignment be given careful attention during installation. The pump base should be leveled, and the pump and driving unit adjusted into exact alignment with shims.

   A flexible coupling can be installed on discharge piping to reduce the transference of vibration and stress. On unusually long discharge lines, a packed slip joint should be installed to compensate for elongation of pipe that might result from pressure or temperature changes. Piping should be supported independently to eliminate strain on the pump casing. It should line up naturally and not be forced into place by the flange bolts.

   The alignment of equipment and piping should be checked after piping installation. If stuffing boxes are adjusted properly and the pump and drives correctly aligned, small to medium size units can usually be operated by hand with ease.

B. PUMPING STATION LOCATION

It is essential that pumping stations be located such that the site meet the requirements for sanitary protection of water quality.

The station floor shall be elevated to a minimum of 1 foot above adjacent ground. In the case of sites subject to flooding, the station floor shall be a minimum of 1 foot above a 100 year return frequency flood level, or protected to such an elevation. Exceptions may be approved by the Department where the station can be isolated from the system during flooding without impairing system pressures, and effectively disinfected. The Department may also waive this requirement for semi-public water systems.

The station shall be readily accessible at all times unless permitted to be out of service for the period of inaccessibility. The topography shall be such as to not trap surface drainage, and the area around the site shall be graded to carry surface drainage away from the pumping facilities. It shall be protected from entrance by unauthorized persons or animals. Consideration should also be given to providing sufficient space on the site for future expansion.

The location of pumping stations must consider the hydraulic effect on the water supply system as a whole, including the source, the distribution system and storage facilities, and relative elevations of the system components.

The station shall be so located that its pumps can draw water from the source of supply down to the lowest practical level and, preferably, should discharge the water against the lowest average head which will provide the desired pressures. This requires, in general, that it should be designed to deliver water with due regard to its center of load and the hydraulics involved. The location should be chosen so that there will be adequate control over every external factor (such as usage of surrounding area) which might contribute to the impairment of the sanitary quality of the water.

C. PUMPIMG UNITS AND APPURTENANCES

1. TYPE AND NUMBER OF PUMPS. Pumps shall be of suitable type, have adequate capacity for the intended purpose, and shall be installed in accordance with the manufacturer's direction. A minimum of two complete pumping units shall be provided, each capable of delivering the required flow while maintaining minimum system pressures. Parallel facilities are considered to satisfy this requirement.

   Two pumps may not be required in the case of individual wells and pumps which do not pump from storage, where there will be ample time between pumping periods to overhaul completely and to repair or replace the pumping unit. The use of on pumping unit under these terms will be approved only if storage sufficient to serve one day's system demand is available. In the case of supplies dependent upon wells, two or more wells are desirable to insure continuity of service during repairs or other shutdowns. In small plants, when only one pumping unit is provided, sufficient spare parts and the tools for making all necessary repairs and other required servicing should be readily available.

2. SUCTION. Pump suction occurs when there is a negative pressure on the pump intake line. If possible, the pumping system should

be developed with a positive pressure on the intake. If lift installations are required, they shall be set at the practical suction limit for maximum temperatures and atmospheric pressures encountered at the site. This could result in a setting ranging from a maximum of 22 feet to less than one foot under some conditions. Required net positive suction head (NPSH) is the suction head necessary at the inlet of the pump impeller to ensure that the liquid will not boil under reduced pressure conditions, and the impeller will operate smoothly without cavitation. The available NPSH shall exceed the required NPSH by a minimum of three feet. Unless centrifugal pumps have a positive head on their suction lines, or are self priming, they shall have suitable foot valve, screened when necessary with a net valve area, at least 2-1/2 times that of the suction piping and shall have a positive means of priming.

3. PRIMING. Priming water shall not be of lesser sanitary quality than that of the water being pumped. Means shall be provided to prevent backsiphonage. When an air-operated ejector is used, the screened intake shall draw clean air from a point at least 10 feet above the ground or other source of possible contamination, unless the air is filtered by an apparatus approved by the reviewing authority. Vacuum priming may be used.

4. VALVES. Each pump shall have an easily accessible shut-off valve of appropriate type on its discharge line. Each pump, except well pumps, shall have a similar valve on its suction line. These valves are necessary to isolate the pump from the system for maintenance and repair purposes. Each pump shall also have a positive acting check valve on the discharge side between the pump and the valve. This valve prevents backflow through the pump when the pumps shuts off, maintaining system pressure and protecting the pump. When necessary, a by-pass or other means shall be provided around the pumps for use in draining the discharge line.

5. PRESSURE RELIEFS. Sudden changes in the velocity of water in a system cause pressure surges which can seriously damage system elements, and allow entry of pollutants. Surge can be caused by valve or automatic control system malfunction pipe line breaks, or any one of a number of system failures. Each discharge line and each suction line which is subject to surging flows shall be adequately protected against excessive pressures and vacuums, and provisions shall be made to remove entrained air by means of pressure and vacuum-relief valves, surge tanks, air-relief valves or other means which will be dependable under all probable conditions.

6. PIPING. It is essential that piping be constructed so that it will not be subject to contamination, and have watertight joints. It shall be designed to minimize friction losses, and be such that each pump has an individual suction line or that the lines shall be so manifolded that they will insure similar hydraulic and operating conditions.

7. GAGES AND METERS. It is important that pressures on both the suction and discharge side of pumps be determined to check compliance with pump operating and design criteria, and isolate pressure problems of failures in the system. Each pump shall have a standard bourdon-type gauge, or its equivalent, upon its discharge line. A similar gauge or means for pressure measurement should be provided, where necessary, upon its suction line. Satisfactory means should be provided for measuring the discharge of each pump, preferably by means of a calibrated meter. Wherever practicable, means should be provided for measuring the total water pumped by the station, preferably by an indicating, recording and integrating meter.

8. WATER SEALS. A water seal is a method of lubricating, cooling, and flushing the packing or bearing area of some pumps. Water seals shall not be supplied with water of a lesser sanitary quality than that of the water being pumped. Where pumps are sealed with potable water and are pumping water of lesser sanitary quality the seal shall be provided with a break tank open to atmospheric pressure, or have an air gap of at least six inches or two pipe diameters, whichever is greater, between the feeder line and the spill line of the tank.

9. CONTROLS. It is essential that the pumps, their prime movers and accessories, shall be positively and accurately controlled as to speed, pressures, quantities of discharge, operating temperatures, lubrication, voltages, and all other factors essential to proper operation, by apparatus which is appropriate to the intended service, and which has been proven satisfactory in actual service. The controls shall provide for proper alternation of the pumps and prime movers in service. Provision shall be made to prevent energizing the motor in the event of a backspin cycle. Electrical controls shall be located above grade, and housed in NEMA approved enclosures.

10. PRIME MOVER. The prime mover is the means of supplying energy to the pump. It is essential that each pump shall be driven by a prime mover able to operate against the maximum heads, discharge rates and temperatures which may be encountered. Whatever its type may be, the prime mover shall be of reputable manufacture and shall be installed in accordance with the instruction of its

manufacturer. All necessary tools and facilities for its proper operation and maintenance should be installed in the station in a convenient place. Where an air lift is used for pumping, the screened intake shall draw air from areas which are free from obnoxious fumes, oil mists, dust or gases, and from a point at least 10 feet above the ground or other source of contamination unless it is filtered by apparatus approved by the Department before entering the water.

11. POWER SUPPLY. Almost all of the prime movers of pumps in Arizona are presently powered by electrical motors. Pumping units are also powered by gas or diesel reciprocating engines. Solar powered units are under development which may generate steam as the motive force.

It is essential that a dependable source of power shall be provided for operating the pumping equipment and its accessories, preferably by means of two independent sources. Where power shut-downs can occur, of a duration longer than that during which the pumping station can be permitted to be out of service, a reliable, independent, emergency source of power should be available, of sufficient capacity to provide for at least the minimum essential services. Whatever the power supply may be, the prime movers and accessories, the equipment, its installation, and its operation shall conform to the relevant requirements of the recognized national, state, local or trade good-practices codes, whichever has jurisdiction.

a. ELECTRIC POWER. When the motive power is electrical, all electrical equipment and work shall conform to the relevant requirements of the national association of fire underwriters and to the relevant state or local codes. On three phase motors, protection from single phasing shall be provided. Protection from lightning shall be provided on all pump and pump control systems.

b. STEAM POWER. When steam is used, all steam-generating and steam-using equipment shall conform to the current requirements of the American Society of Mechanical Engineers for fire pressure containers and to other relevant provisions of that Society's code. Steam lines shall conform to the requirements of the current codes of the American National Standards Institute.

c. AIR OR GAS. When air or gas is used under pressure, equipment connected therewith shall conform to the current requirements for unfired pressure containers of the American Society of Mechanical Engineers Code, Section VIII, Division 1.

12. WATER PRE-LUBRICATION. When automatic pre-lubrication of pump bearings is necessary and an auxiliary power supply is provided, the pre-lubrication line shall be provided with a valved bypass around the automatic control so that the bearings can, if necessary, be lubricated manually before the pump is started.

D. BOOSTER PUMPS

Booster pumps are installed to increase pressure and quantity of water flow in a water system.

They shall be located or controlled so that they will not produce a negative pressure upon the suction lines. Intake pressure shall be at least 20 pounds per square inch, with automatic cutoff of pumps when the intake pressure falls to 10 pounds per square inch. Variations to this requirement may be approved by the Department.

Careful consideration should be given to the location of booster pumps within the system, the pressure effect of the pumps on the entire system, and the direction of flow through the pumps under all combinations of water demand.

A bypass of all booster pump station installations shall be available. This is required to minimize disruption to the system when the pump is out of service or not operating as designed.

E. PUMPING STATION STRUCTURES

An enclosing structure or building is most desirable for housing pumping facilities of a drinking water system. It provides protection from weather and damage by vandalism of pumps, appurtenances, automatic control and electrical equipment, and treatment facilities. It also affords more positive control over the sanitary protection of the system. Security shall be provided for pumping stations either by locked doors, or by 6 foot high security fencing with locked gates.

1. GENERAL CONSTRUCTION. These standards shall apply to all pumping station buildings, whether handling raw, semi-finished, or finished water.

   The building should be of durable construction and fire and weather resistant. The floor shall be at least 6 inches above finished grade. Floors shall slope a minimum of 1/4 inch per foot away from the pump(s) to a suitable drain. Floor drains shall discharge to the ground surface 20 feet or more from the structure. The end of the drain shall be fitted with a #16 mesh screen. Pump house floor drains must not, under any circumstance, be connected to storm or sanitary sewers. An outlet shall be provided for drainage from pump glands which doesn't discharge onto the floor. All doors shall be of adequate size and shall open outward. All portions of the structure below the ground surface, except footings and walls not forming part of a compartment, shall be of waterproofed concrete or other impervious materials.

2. SIZE OF BUILDINGS. Except in the case of small, readily removable buildings, or where servicing can be done wholly from the outside, the building should be large enough to house properly all the pumping equipment and accessories to be installed, with ample space around all moving and mechanical parts and electrical equipment both to insure the safety of personnel and to permit the ready removal or servicing of any equipment. Space should be provided for such additional equipment as may be needed within a reasonable time in the future. All piping should be so arranged that there is room to service all valves and other parts, and to permit their removal with minimum disturbance to the system.

3. SERVICING FACILITIES. Crane-ways, hoist beams, eye-bolts or other facilities should be provided for servicing or removing pumps, motors and other heavy equipment. Where necessary, openings should be provided in the station floors, roofs, or wherever else needed, for this purpose. A tool board and other facilities required for the proper operation and maintenance of the equipment should be provided, and placed in a convenient location.

4. STAIRWAYS AND LADDERS. Safe and adequate stairways, or (where these are impractical) ladders with handrails and non-skid treads, should be provided between all floors. Similar stairways, or well-anchored metal ladders, should be installed in all pits or compartments which can be entered. Stairs are preferred in areas where there is frequent traffic or where supplies are transported by hand.

5. HEATING AND VENTILATION. Heating facilities of a safe type should be provided in pump houses to provide personnel comfort, as well as for protection of the equipment. In some pump houses, only enough heat need be provided to prevent freezing of equipment or treatment processes.

   The building shall be well ventilated by means of windows and doors, roof ventilators or other means. All rooms, compartments, pits and other enclosures below the grade floor, which must be entered and in which an unsafe atmosphere may develop or where excessive heat may be built up by equipment, shall have adequate forced ventilation. The equipment shall be capable of producing at least six complete turnovers of air per hour. Rooms containing equipment or piping shall be adequately heated, ventilated and, if necessary, de-humidified to prevent injurious condensation. Where practicable, ventilation should be supplemented by insulation of the building, equipment and piping. Switches which control the forced ventilation shall be located outside of such compartments.

6. LIGHTING. The station shall be adequately lighted throughout by means of natural light or by artificial lighting facilities, or both. Control switches, where needed, shall be conveniently placed at the entrance to each room or compartment.

7. SANITARY AND OTHER CONVENIENCES. Except in the case of small automatic stations, each station should be provided with potable water and lavatory and toilet facilities. All wastes shall be safely disposed of so that there will be no danger of contaminating the water pumped by the station. At all large stations, shower baths, lockers and office facilities should be provided.

8. WET WELLS. All wet wells and other water-containing compartments shall be constructed of waterproofed masonry or other impervious material. They shall have floors with sufficient slope to permit the complete removal of the water and any entrained solids. They shall be so covered or otherwise protected as to prevent impairment of the quality of the water contained therein.

F. SURFACE WATER PUMPING FACILITIES

Raw water from such sources as controlled catchments, ponds or lakes, surface streams, or irrigation canals must usually be pumped from source. Refer to Chapter 2 - Source Development and Construction for additional information covering the planning and design of surface water facilities.

The intake system which draws water from the source shall be of a type appropriate to the pumping station and shall be protected so as to prevent deterioration of the sanitary quality of the water to be pumped.

1. INTAKE ENTRANCE STRUCTURES. Intake structures which draw water from surface water sources shall be protected by means of jetties racks, or other appropriate devices, against closing by sediment, trash or ice. Where the depth of water permits selection of the level from which the water can be drawn, in the case of raw water supplies, the intake structure should provide for such selection by suitable gates controlled from the operating floor of the intake, or some other readily accessible point and should be

constructed of such materials and of such design as will insure their free operation under all heads. Where practicable, an emergency intake is desirable.

2. SCREENS AND ICE CONTROL. The intake to the pumps drawing raw water should be protected by at least two sets of removable, stationary screens, or by a traveling screen with openings small enough to exclude all matter which will clog the suction line, injure the pumps, or interfere with subsequent treatment of the water. Suitable facilities for cleaning the screens also should be provided. Where ice formation can be anticipated, the intake should be designed to minimize this. Where necessary, provision shall be made to de-ice the screens and intake openings and to control frazil ice by means of steam lines or otherwise.

3. INTAKE CONDUITS. For surface water sources the water shall be conducted by a watertight conduit into a wet well, which is in or adjacent to the pump house. This conduit shall be capable of drawing water from the source when it is at the lowest stage for practical operation, at a rate equal to the maximum demand of the pumps, without producing a suction loss sufficient to reduce the rated discharge of the pumps.

4. COMBINED INTAKE - PUMPING STRUCTURES. In some cases raw water pumping facilities can be combined with and located adjacent to intake structures. Except in the case of submersible pumps, the pump suction port and the intake structure shall be separated by an impermeable wall with sluice gates to control or stop the flow. The depth and type of the structure is a function of the type and arrangement of the pumps used. Horizontal centrifugal pumps are often employed and will give satisfactory performance and good operating economy. However, if the supply is from a variable river and the pump suctions are to be under positive pressure under all operating conditions, a station of considerable depth probably will be required. Deep stations of the dry-pit type commonly used for horizontal centrifugal pumps shall be compartmented so that rupture of pump discharge piping within the station will not flood all other pumps and motors. The depth may be reduced, with some loss in reliability, by installing the pumps at an elevation such that suction lift prevails under some operating conditions. Use of vertical type-wet-pit pumps, which require less space in plan, permits a somewhat shallower station, and does not require priming, may prove an economical alternative. A variety of pump station arrangements is possible and those described briefly here are by no means all that may be conidered. Among other pumping arrangements that could be used are: vertical-type pumps or end- or side-suction centrifugals, with their shafts in a vertical position, located on a submerged suction header. The later permits location of the pump drive units at an elevation where they are protected from flooding and readily accessible.

G. GROUNDWATER PUMPING FACILITIES (WELLS)

In the selection of well pumps it is most important that the pumping level should have been determined to assure that the pumping element will be placed below the maximum drawdown with an adequate safety factor.

1. SPECIAL VALVES AND APPURTENANCES. Special provision must be made to protect the system if water can drain out of the column pipe when the pump stops. This will occur if there is no foot valve in the well. An air release valve shall be provided between the pump and check valve or, if applicable, on the pressure tank to expel air drawn into the line when the water drains out. An inverted check valve installed between the pump and main line check valve facilitates air being drawn into the line, which protects the column pipe from excessive pressures. This air may also be used to assist in charging hydropneumatic pressure tanks; however, it should be noted that air in water lines significantly increases friction loss.

   A hose bib type sampling tap shall be provided on the system side of the check valve to allow water samples to be taken. It is recommended that a coupling be provided between the discharge piping and the pump to allow easy removal of the pump for repair.

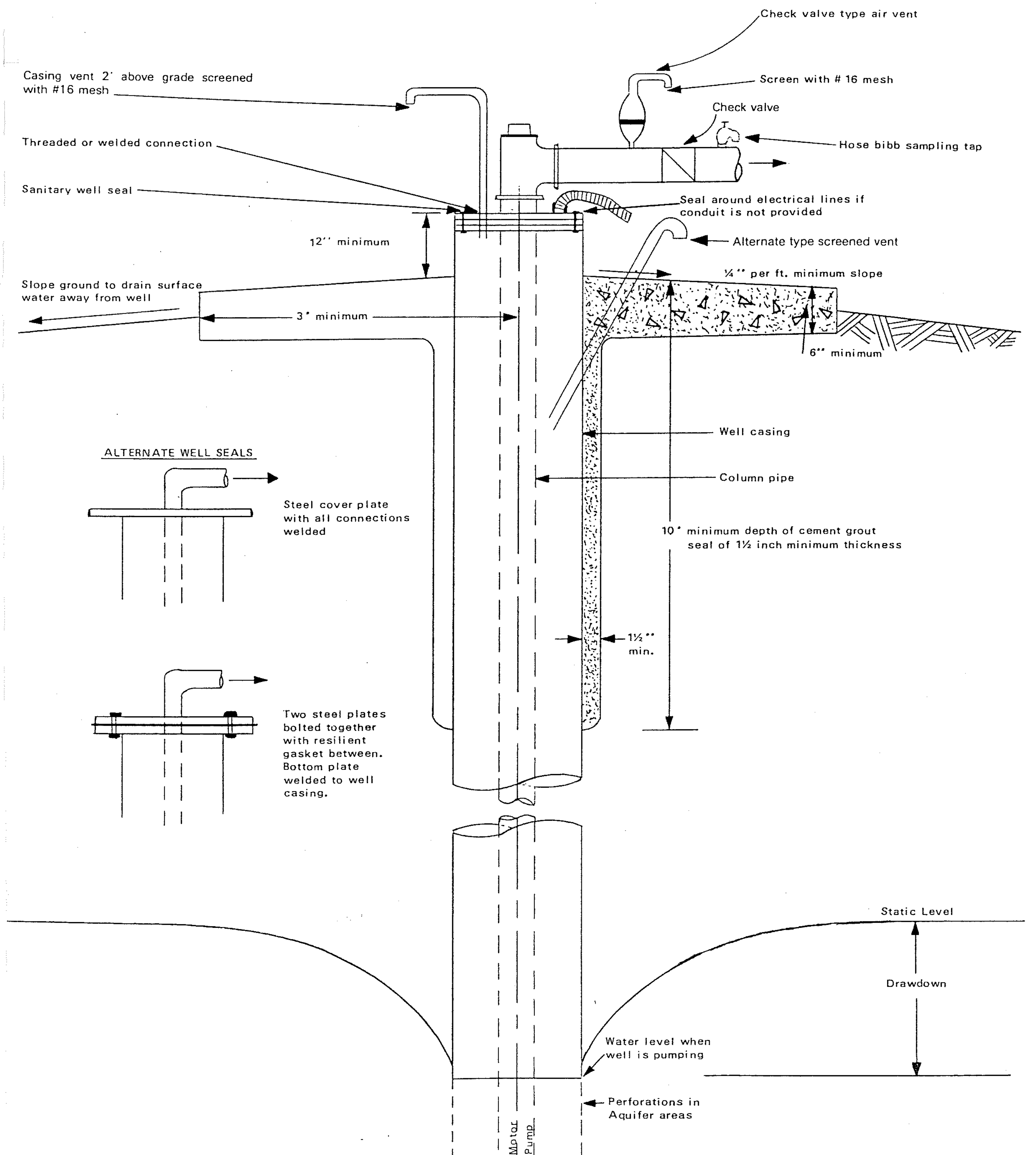
2. WELL VENTS. All wells shall be equipped with a vent which shall terminate at least 2 feet above the protective slab, and which shall be covered with a number 16 mesh screen. Alternative designs or locations are acceptable if approved by the Department. This vent releases fumes from the well, allows a direct transference of atmospheric pressure to the well, and expells air from the well when there is an increase in water level such as occurs when the column pipe drains.

3. DRILLED AND DRIVEN POINT WELLS. Recommended installations for turbine or line shaft and submersible pumps in drilled or driven wells are shown on the following pages. Discharge piping for turbine or line shaft pumps is normally located above ground. Discharge piping for submersible pumps may either be above ground, or under ground by means of a pitless well adapter. Casing requirements will vary for gravel packed drilled wells, driven point wells, or wells in special formations (See Chapter 4 - Source Construction).

   All installations require a protective slab and sanitary well seal to prevent contaminants from entering the well. The slab shall extend a minimum of 3 feet from the center of the well, be a minimum of 6 inches thick, and slope away from the well head a minimum of 1/4 inch per foot.

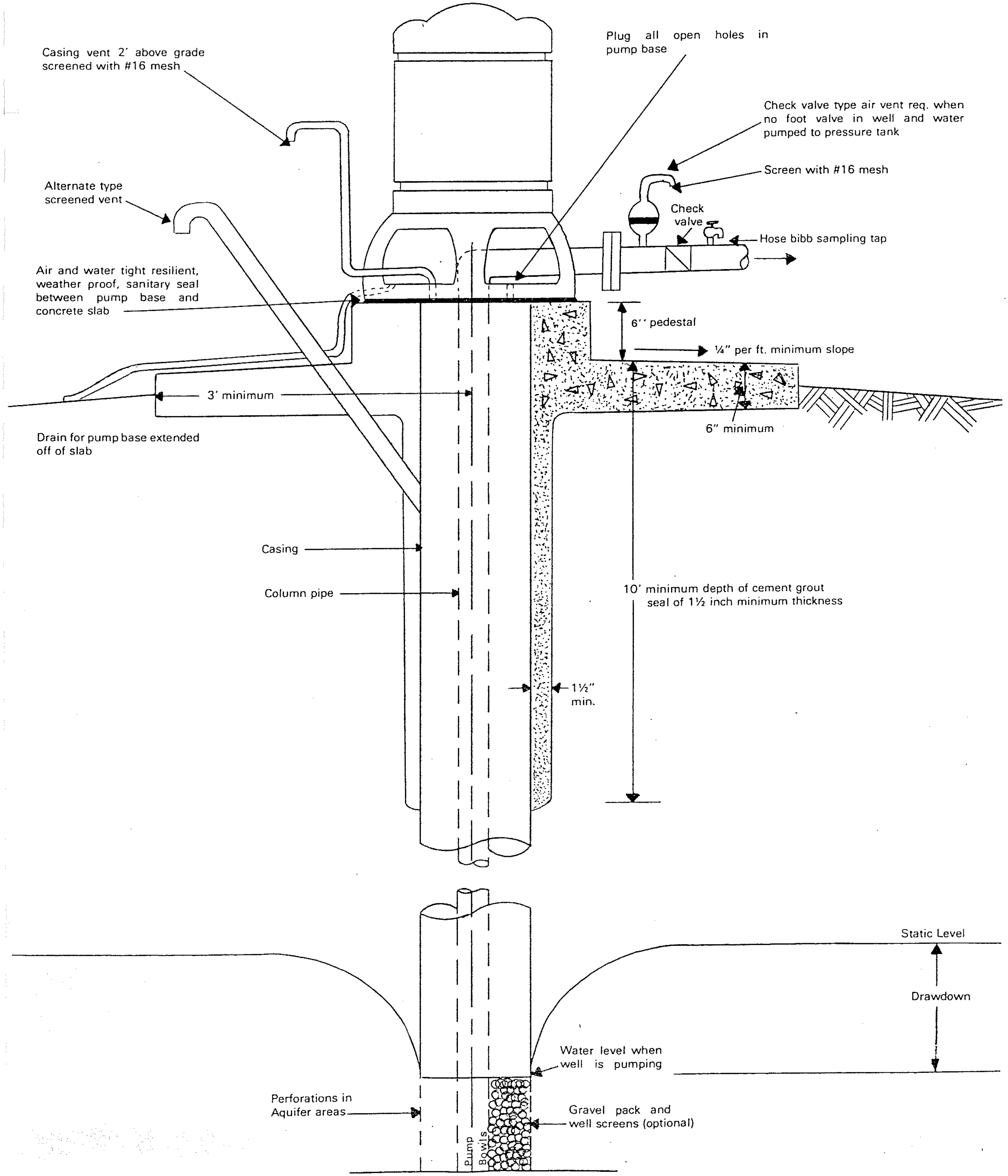
ARIZONA DEPARTMENT OF HEALTH SERVICES
Bureau of Water Quality Control

RECOMMENDED SUBMERSIBLE PUMP INSTALLATION



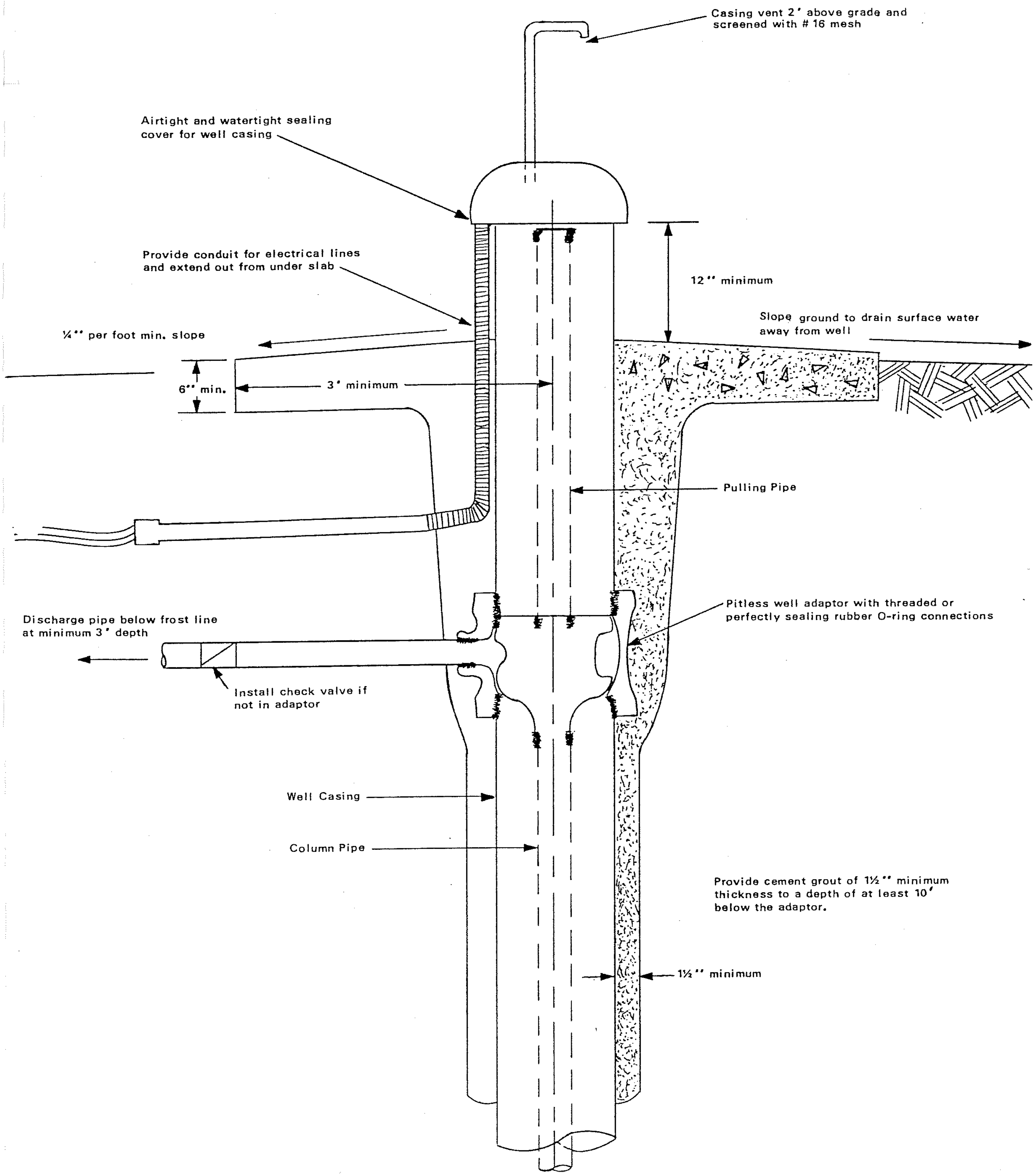
ARIZONA DEPARTMENT OF HEALTH SERVICES - Bureau of Water Quality Control

RECOMMENDED TURBINE PUMP INSTALLATION



RECOMMENDED PITLESS WELL ADAPTOR INSTALLATION

Arizona Department of Health Services



Turbine or line shaft pumps require a pedestal structure for pump mounting. The casing shall be firmly connected to the pump structure, or it shall be inserted into a recess extending at least 1/2 inch into the pump base.

Above ground discharge piping requires a sanitary well seal on the top of the casing, which shall be air and watertight under all conditions.

Discharge piping for submersible pumps may be underground by means of a pitless well adaptor. Discharge piping shall be at a minimum depth of 3 feet below the ground surface. Pitless well adaptors shall have threaded or perfectly sealing rubber O-ring connections with the column pipe. The top of the well casing shall have an airtight and watertight sealing cover.

Submersible pumps require an electrical power supply passing through the sanitary well seal or casing cover, which shall be effectively sealed against the entrance of water under all conditions of vibration or movement of conductors or cables. Additionally, the electrical cable shall be firmly connected to this column pipe at 20 foot intervals or less.

These installations shall also have discharge piping, appurtenances and vents in accordance with Sections 1 and 2.

4. <u>DUG OR BORED WELLS</u>, <u>SPRINGS</u>, <u>WATER COLLECTORS</u>, <u>AND INFILTRATION GALLERIES</u>. These methods of source development are normally shallow, have a relatively large diameter, and similar types of pumping installations.

Pumping installations located over the above sources shall have a watertight concrete floor, with an entrance hatch in the pump floor located adjacent to the inside of the well perimeter, with an elevated curb or coping at least 4 inches high and with a cover whose edge shall extend down over the curb at least 2 inches. The hatch cover shall have facilities for being locked in place and shall be kept locked at all times when not in actual use. All connections between the well and the pump, which are located above the floor, shall pass through the floor in such a way as to prevent any external drippage or other contaminating substance entering the well regardless of vibration or other factors. In general, the connection shall be made by means of a rigidly anchored riser pipe, or by extending the casing at least 6 inches above the floor and providing it with a flange, suitable stuffing box, or other device which will make a watertight connection between the riser pipe or casing and the base of the pump. Where a watertight connection is not provided, the casing shall be inserted into a recess extending at least 1/2 inch into the base of the pump. The base of the pump shall be at least 6 inches above the pump room floor. The design of the pump foundation and the pump base shall prevent water from coming into contact with the joint. Where a submersible pump is used, the top of the casing shall be effectively sealed against the entrance of water under all conditions of vibration or movement of conductors or cables.

Where applicable, provisions shall be made for lubricating the pump from a point at least 6 inches above the top of the well cover by means which will prevent contamination of the water supply.

H. PROTECTION OF SUCTION LINES

Where suction pipes are connected to individual wells, or to a series of wells they shall be protected against freezing, shall be valved to permit testing and control of each well, and shall form a watertight line from each well to the pump. If located outside a pump house structure all external valves shall be protected by curb boxes or other construction.

I. AUTOMATIC AND REMOTE-CONTROLLED STATIONS

Automatic and remote control equipment is used to operate such elements as pumps, valves, and treatment facilities in a water system. Control may be on an individual element basis, or there may be provision for interconnect and master control coordination of the system. Large systems usually require master control to maintain system pressures and uniform treatment under varying supply and demand conditions. All automatic stations should be provided, where practicable, with automatic signalling apparatus which will report when the stations are out of service. All remote-controlled pumping stations shall be effectively controlled. In addition to complying with all of the relevant foregoing standards, they shall have signalling apparatus of proven reliability, by means of which the condition and operation of the various pieces of equipment can be effectively determined at the central point, and their operation can be satisfactorily controlled.

J. CROSS CONNECTIONS

There shall not be, at any point in the pumping station, any cross connection between a potable water supply and any supply which is not of equal quality as determined by the Department. Steam-engine exhaust shall not be returned, nor shall the cooling water from engine jackets or other heat-exchange devices be returned, to a potable supply.

engineering bulletin no. 10

Chapter 4

TREATMENT

ARIZONA DEPARTMENT OF HEALTH SERVICES

MAY 1978

CHAPTER 4 TREATMENT

CHAPTER 4 TREATMENT

A. TREATMENT PLANT SYSTEMS

1. GENERAL DESIGN CRITERIA. The objective of water treatment is to produce high quality water sufficient in quantity for all intended purposes. As the water is to be used for human consumption, it must be free at all times of organisms or substances posing health hazards, and also essentially free of materials that make it esthetically unsatisfactory to the consumers. The overall water quality objective can be met if the water delivered to customer service meets the standards given in the Drinking Water Regulations. However, it is emphasized that these standards are minimum standards, and that a well-designed and operated water treatment plant should be able to produce water of a quality superior to that called for by the drinking water regulations.

   The quality of water obtained at the consumer's tap is not determined solely by water treatment operations. Raw water quality and conditions in treated water storage and water distribution systems affect the quality of water delivered to the consumer. Consequently, protection of raw water quality and finished water storage and delivery systems to the maximum practicable extent is essential. Excellence in water treatment is partially nullified unless other water system components are adequately designed, maintained, and operated.

   a. PLANT LAYOUT. Each plant is individualistic depending upon its present and potential size, treatment and waste disposal processes, and the site on which it is located.

      Design of the plant layout shall consider:

      (1) functional aspects of the plant,

      (2) provisions for future plant expansion,

      (3) provisions for expansion of plant waste treatment and disposal facilities,

      (4) access roads,

      (5) site grading,

      (6) site drainage,

(7) walks,

(8) driveways,

(9) chemical delivery, and

(10) adequate shop space and storage facilities.

Consideration must be given to the design requirements of federal, state and local regulatory agencies for items such as safety requirements, special designs for the handicapped, plumbing and electrical codes, etc.

The finished water supply serving the plant shall be from a source of finished water at a point where all chemicals have been thoroughly mixed.

Main switch gear electrical controls shall be located above grade.

An acceptable means of metering the finished water entering the distribution system shall be provided.

Consideration shall be given to providing extra wall castings built into the structures to facilitate passage of pipes through concrete walls in future expansion of the plant.

b. BUILDING LAYOUT. Design of the buildings of the plant shall provide for:

(1) adequate ventilation,

(2) adequate lighting,

(3) adequate heating,

(4) adequate drainage,

(5) dehumidification equipment, if necessary,

(6) accessibility of equipment for operation, servicing, and removal,

(7) flexibility of operation,

(8) operator safety,

(9) convenience of operation,

(10) chemical storage and feed equipment in a separate room to reduce hazards and dust problems, and

(11) adequate provisions to assure plant security.

Laboratory equipment and facilities shall be compatible with the raw water source, intended use of the treatment plant and the complexity of the treatment process involved. Sufficient bench space, adequate ventilation, adequate lighting, storage room, laboratory sink, and auxiliary facilities shall be provided. Air conditioning may be necessary. Testing equipment provided shall be adequate for the intended purposes. The State has a laboratory certification program by which public and private laboratories are inspected and certified. Use of certified laboratories is recommended.

Sample taps should be provided so that water samples can be obtained from each water source and from appropriate locations in each unit operation of treatment. Taps shall be consistent with sampling needs, and those used for obtaining samples for bacteriological analysis shall be of the smooth-nosed type without interior threads, shall not be of the mixing type, and shall not have a screen, aerator, or other such appurtenance.

To facilitate identification of piping in the plant and pumping stations, it is recommended that the following color scheme be utilized:

WATER LINES

Raw	Olive Green
Settled or Clarified	Aqua
Finished or Potable	Dark Blue

CHEMICAL LINES

Alum or Coagulant	Orange
Ammonia	White
Carbon Slurry	Black
Chlorine (Gas or Solution)	Yellow
Fluoride	Light Blue with Red Band
Lime Slurry	Light Green
Potassium Permanganate	Violet
Sulfur Dioxide	Light Green with Yellow Band

WASTE LINES

Backwash Waste	Light Brown
Sludge	Dark Brown
Sewer (Sanitary or Other)	Dark Gray

OTHER

Compressed Air	Dark Green
Gas	Red
Other Lines	Light Gray

In situations where two colors do not have sufficient contrast to easily differentiate between them, a 6-inch band of contrasting color should be painted on one of the pipes at approximately 30-inch intervals. The name of the liquid or gas should also be painted on the pipe. In some cases, it may be advantageous to paint arrows indicating the direction of flow.

2. SITING. Many problems relating to water treatment operation can be avoided by careful selection of the plant location and construction on the site. The following considerations may aid in choosing the plant site.

   a. PROXIMITY TO RAW WATER SOURCE. It is desirable to have the water treatment plant near the source of raw water to minimize the cost of conveying the water to the plant.

   b. PROXIMITY TO AREA TO BE SERVED. The plant should be built reasonably close to the area it is to serve. In this regard, an accurate estimation of the future direction of growth within the service area is especially important.

   c. POTENTIAL FOR FLOODING OF THE SITE. If the water treatment plant is flooded, it will be out of service during the high water period and for several days thereafter for clean-up and repair. Obviously, flood protection is a high priority consideration in plant location. Offices of the U.S. Geological Survey, U.S. Federal Insurance Administration, U.S. Army Corps of Engineers, state water resources agency or local flood control district may provide guidance of the expected limits of flooding in a particular area.

      New plants shall not be located in a flood prone area or where it will impede normal or flood stream flows. If location within a flood prone area is necessary for good reasons, the plant must either be built up above the 100-year flood level or protected from inundation by the 100-year flood.

d. GEOLOGY AND TOPOGRAPHY. Locations which require extensive site preparation because of irregular terrain or inadequate foundation conditions should be avoided.

e. AVAILABILITY OF TRANSPORTATION FACILITIES. If possible, the plant should be located near a major highway or railroad facilities to permit easy delivery of materials and equipment during construction and of chemicals and supplies during operation.

f. SIZE OF SITE. Sufficient space should be provided on the site for the plant, reasonable plant expansion, changes in the treatment processes, access roads, and expansion of the plant waste treatment and disposal facilities.

g. LEGAL CONSIDERATIONS. Local, state, and federal laws and ordinances should be examined to assure there are no prohibitions to use of the site. Easements for pipelines to or from the site may need to be obtained, and no laws or ordinances should prevent securing such easements.

h. ENVIRONMENTAL CONSIDERATIONS. The environmental effects of any proposed plant construction on the site should be examined and weighed. If federal land is involved either with the site itself or with pipe easements to or from the site, the required environmental assessment or environmental impact statement as required by federal law must be prepared and approved prior to construction.

i. OTHER CONSIDERATIONS. A water treatment plant should not be located where it is subject to a significant risk from earthquakes, fires, or other disasters which could cause a breakdown of the plant or any treatment unit thereof.

3. PROCESS SELECTION AND DESIGN. The selection and design of the water treatment processes to be used at a particular facility is dictated by raw water quality, practicability, reliability, flexibility, and overall economics. Engineers

experienced in water treatment plant design should be consulted to determine the best treatment system for any particular situation.

These guidelines and standards are offered to aid in the process selection and design. Consultation with Department engineers is suggested to secure information relative to plant design and water treatment experience in the State.

4. RELIABILITY. Unless the treatment plant can be taken out of service for a period of time for maintenance and repair work, two or more of all essential treatment units or items shall be provided. With one unit or item out of service, the remaining units or items shall meet the design capacity of the plant. When deciding whether or not to install more than one unit, the consequences of failure of that unit should be considered. For example, a standby chlorinator should always be provided but a spare feeder for fluoridation is not required. The degree of importance of each unit should be evaluated on a case-by-case basis, with the knowledge that the water treatment plant should be capable of continually supplying safe water.

   If delivery of crucial chemical supplies is uncertain, larger than normal stores of these chemicals must be maintained on hand at the plant. This may necessitate larger than normal chemical storage areas.

   A plant preferably should have dual power sources and electrical switchgear which will automatically switch from one source to the other in case of failure of one source. Standby power may be required by the Department so that water can be treated and/or pumped to the distribution system during power outages.

5. OPERATING CONSIDERATIONS. The simpler the operation of a water treatment plant, the less likely the occurrence of human or mechanical malfunctions. This does not mean less effective, simple operations are to be preferred over more effective, complex operations, but every effort should be expended during the design stage to insure that unnecessary equipment and operations are eliminated.

   Operations requiring frequent attention from the plant operators should be located reasonable close together. The most attention is generally required for operation of the filters, flocculators, and chemical feeding equipment.

Chemical handling and feeding should be simplified as much as possible. Unloading and storage areas for chemicals should be easily maintained and readily accessible and be close to the point of application of the chemicals. This will lead to short, direct chemical feed lines which are much easier to maintain and repair than long, circuitous feed lines.

Plants treating a river water should be arranged to provide the flexibility of treatment needed to cope with the raw water quality changes.

Operation and maintenance manuals or instructions, including a parts list and parts order form for equipment and proprietary unit elements, shall be available at the plant.

Provisions shall be made for operator instruction at the start-up of a plant or pumping station.

6. CAPACITY. The rated or nominal capacity of the treatment plant should equal or exceed the estimated maximum daily water demand of the system to the design year. For filtration plants, rated or nominal capacity is based on the filtering rate established for design purposes.

   Expansion of the plant is indicated when the maximum daily demands of the system approach the rated capacity of the existing plant. As a general rule, steps to provide additional treatment capacity should be taken at least 5 years before present capacity is reached to allow sufficient time for engineering investigations, design, financing, and construction.

7. STAFFING. The operation of the water treatment plant must rest in the hands of qualified persons. The number of such personnel depends principally upon the plant size and to some extent upon the quality of the raw water and the type of treatment processes used.

   A qualified operator or operators should be on-duty or available while the plant is in operation.

   Each member of the operating staff should be instructed of his responsibilities and the relationship of his duties to the health and welfare of the community being served.

   All operators shall be certified as required by state law.

8. SAFETY. It shall be the responsibility of the Engineer to follow all pertinent federal, state, and local regulations pertaining to safety requirements in the design of the plant facilities.

B. PRETREATMENT

1. PURPOSE OF PRETREATMENT. Raw surface water supplies often contain significant amounts of floating debris and/or algae which could damage pumps, clog pipes, or seriously disrupt subsequent treatment units. Rivers are likely, at times, to contain large concentrations of suspended matter that could overload clarification basins. Pretreatment processes may be employed for removal of debris, algae, and part of the sediment load.

   Subsurface raw water supplies seldom have this problem although some well discharges contain objectionable quantities of sand. In those cases, pretreatment to remove the sand may be desirable.

2. INTAKE SCREENS. All raw water intakes located in surface waters (lakes, reservoirs, rivers, streams, etc.) should be screened to prevent entry of large suspended or floating material. The clear space opening of the screen and the method of cleaning, if any, depends upon the location of the intake and the type and quantity of debris anticipated.

   a. BAR SCREENS. All intakes shall have a bar or coarse screen in front of the pipe or entry to the wet pit of a pumping station. The function of the coarse screen is to prevent entry of large objects into the raw water pipe or wet pit. The screen can be constructed of any durable material but for most intakes is made of steel circular or rectangular bars. The bars are usually placed upright and supported at top, bottom, and necessary intermediate points on the down-stream edge of the bars. The bar screen can be hand or mechanically cleaned. If hand cleaned, the bar screen should have an approximate slope of 2 to 4 inches horizontal to 12 inches vertical (70^{o} to 80^{o}), and a suitable raking platform above high water.

      Mechanically-cleaned screens can be vertical or inclined. The opening between bars is determined by the debris to be intercepted but shall not be less than 1 inch.

   b. TRAVELING SCREENS. If the raw water supply contains a significant amount of material too small to be intercepted by bar screens but larger than 1/4 inch, traveling screens should be utilized. These screens have openings of 3/8-inch square or less. The screen is formed by a series of screening baskets or panels which are revolved by a motor driven chain. Trapped refuse is removed from each basket by a powerful spray of water. The washwater is usually obtained from the screened water and may constitute about one per cent or more of the total amount of water passing through the screen.

All traveling screens shall be protected from large debris by a bar screen. Refuse washed from the traveling screen shall be disposed of as specified in Section R.

3. PRESEDIMENTATION. Waters containing high turbidity, which can be reduced by gravitational settling, may require plain sedimentation, either with or without the use of coagulation chemicals. Settling tests using raw water will assist in determining the probable value of presedimentation. If very little of the suspended matter in the raw water can be removed by plain sedimentation, this treatment step can be omitted. The primary function of presedimentation is to remove the bulk of the readily settleable solids that are present in the raw water. The effluent from a presedimentation basin may remain very turbid but this remaining turbidity will be of a colloidal or very fine nature requiring chemical coagulation, flocculation, and sedimentation to remove.

   a. BASIN DESIGN. Presedimentation basins may be any shape but shall be designed so that the flow through the basin is smooth, even, slow, and as free from turbulence as possible. Basins should have hopper bottoms to ease solids removal or be equipped with continuous mechanical solids removal apparatus. Arrangements for dewatering of the basin shall be provided.

   b. INLET. Incoming water shall be disposed across the full width of the line of travel as quickly as possible. Baffles shall be provided as necessary to prevent short-circuiting. For a circular basin, entry into the center of the basin is the usual configuration.

   c. DETENTION TIME. The detention time required to accomplish the purpose of presedimentation varies with the raw water quality, its variance, cost, and space limitations. A minimum detention time of three hours is recommended. Longer detention may be required in some instances.

   d. BYPASS. Provisions for bypassing presedimentation basins shall be provided to permit periods for cleaning or when use of the basins is unnecessary.

e. SOLIDS DISPOSAL. The disposal of solids collected and removed by presedimentation, either on a periodic or continuous basis, shall meet the provisions of Section R.

4. MICROSCREENING. A microscreen is essentially a circular drum consisting of a metal skeleton frame covered by cloth constructed of micro-fabric stainless steel threads. The drum is enclosed such that raw water enters the drum at one end, passes through the microscreen, and is discharged. The drum is submerged for about three-fifths of its diameter. At the top just above the drum is a continuous wash where high velocity water jets wash the collected material from the drum interior into a waste hopper and outlet for disposal. The cloth or screen around the drum has very small openings, varying from 20 to 60 microns, so many solids and algae in the raw water are collected and removed from the water.

a. USES OF MICROSCREENS. A microscreen is a mechanical supplement of treatment capable of removing some suspended matter from the water by straining. It may be used to reduce suspended matter, nuisance organisms like algae which cause tastes and odor, and organic loadings.

Microscreens shall not be used in place of filtration, when filtration is necessary to provide a satisfactory water. The water shall not have a chlorine residual when passing through the microscreen.

b. DESIGN. Design of a microscreening installation shall provide:

(1) a durable, corrosion-resistant screen,

(2) by-pass arrangements,

(3) protection against back-siphonage when potable water is used for washing,

(4) proper disposal of wash waters as covered in Section R, and

(5) due consideration to the nature of the suspended matter to be removed, and the corrosiveness of the water.

C. AERATION

In this manual, the term "aeration" refers to the processes in which water is brought into contact with air for the purpose of transferring volatile substances to or from the water. These volatile substances include oxygen, carbon dioxide, nitrogen, hydrogen sulfide, methane, and unidentified organic compounds responsible for tastes and odors.

The transfer, by aeration, of a volatile substance to or from water is dependent upon a number of factors, including characteristics of the volatile material to be removed or added, temperature, gas transfer resistance, partial pressure of gases in the aerator atmosphere, turbulence in gaseous and liquid phases, area-volume ratio, and time of exposure. All should be considered in determining the need for and the type of aeration.

Ventilation is an important consideration in aeration design as the saturation value of a gas in water is influenced by its partial pressure in the air in contact with the water. Thorough ventilation is also important from a safety standpoint when gases such as carbon dioxide, methane, and hydrogen sulfide are being removed. Carbon dioxide is an asphyxiant, methane may create an explosion hazard, and hydrogen sulfide is highly poisonous.

Aeration is not needed at all water treatment plants, and a decision whether to aerate or not requires careful assessment of the economic and water quality benefits achieved by its use.

1. PURPOSE OF AERATION. The principal objectives of aeration are:

   a. Reduction of the concentration of taste and odor producing substances such as hydrogen sulfide, and to a limited extent volatile organic compounds.

   b. Partial removal of substances that may interfere with or add to the cost of water treatment. Examples: removal of hydrogen sulfide prior to chlorination and removal of carbon dioxide prior to lime softening.

   c. Addition of oxygen to water for the oxidation of iron, manganese, and hydrogen sulfide and to a limited extent, organic matter.

2. LIMITATIONS OF AERATION. Aeration is effective in the absorption and release of gases, principally oxygen and carbon dioxide. An efficient aerator will result in near oxygen

saturation and 90 per cent reduction of the carbon dioxide content of ground water.

At lime-soda water softening plants, any carbon dioxide dissolved at the point of lime application will consume lime without accompanying softening. For high (> 50 mg/l) carbon dioxide concentrations, as encountered in some ground waters, aeration for its removal is probably justified. For concentrations on the order of 10 mg/l or less, aeration is probably not economically valid. Before a decision to aerate for carbon dioxide removal, the cost of aeration should be compared to the chemical savings.

Ground waters are usually deficient in oxygen, and aeration is an effective means of adding it. Oxygen addition is desirable if iron and manganese removal is a treatment objective.

Aeration is effective for the removal of hydrogen sulfide if the concentration is not more than about 1.0 to 2.0 mg/l. Higher concentrations may require special provisions, such as prolonged aeration with diffused air.

Aeration is but one form of gas exchange. Degasification is another form that can remove undesirable gases to very small concentrations. Degasification occurs when the gas-carrying liquid is sprayed or introduced into a vacuum chamber at ordinary temperatures or at elevated temperatures. By refining droplet atomization, using steam scrubbing action, and venting released gases, thermal degasification can remove dissolved oxygen, for example, to below 0.007 mg/l concentration. Degasification is normally not used at water treatment plants as removal of gases to such low concentrations is not justified.

Surface waters usually exhibit low concentrations of carbon dioxide, no hydrogen sulfide and fairly high dissolved oxygen. As a consequence, aeration is not required for the removal or addition of these gases. Aeration of surface waters for taste and odor removal is of little value. Many of the substances causing taste and odor do not have sufficient volatility to respond to conventional aeration systems.

3. TYPES OF AERATION

a. NATURAL DRAFT AERATION. Aeration units of this type include spray nozzles, cascade, and multiple trays, with or without media.

(1) Spray Nozzles. The size, number and spacing of the nozzles depend upon the head and the area available for aeration. Pressure should be about 10 pounds per square inch at the throat. Output per nozzle should be from 75 to 175 gallons per minute, depending upon the type of nozzle. Nozzles should vary from 1 to 1-1/2 inches in diameter. Spacing of nozzles should be from 2 to 12 feet. The trajectory of the spray may be vertical or inclined with the vertical giving the longest exposure time for a given head.

(2) Cascades. In cascade aerators, exposure time and increased area-volume ratio are obtained by allowing the water to flow downward over a series of steps or baffles. The design should give as thin a film of water as possible. Exposure time can be increased by increasing the number of steps, and the area-volume ratio improved by adding baffles to produce turbulence. Total fall should be as long a distance as possible, and normally varies from 3 to 10 feet. In cold climates, these aerators should be housed to prevent freezing and when housed, adequate provisions should be made for ventilation.

(3) Multiple Tray Aerators. A multiple tray aerator consists of a series of trays equipped with slat, perforated, or wire-mesh bottoms over which water is distributed and allowed to fall to a collection basin at the base. Coarse media, such as coke, stone, crushed limestone, or ceramic balls, may be placed in the trays to improve the efficiency of gas exchange, distribution, and to take advantage of catalytic effects of deposited manganese oxides.

The design of multiple tray aerators shall provide that:

(a) the water is distributed uniformly over the top tray,

(b) the water is discharged through a series of three or more trays with separation of trays of 12 to 20 inches,

(c) the trays be loaded at a rate of 1 gallon per minute to 5 gallons per minute for each square foot of total tray area,

(d) the trays have slotted, heavy wire (1/2 inch opening) mesh or perforated bottoms,

(e) where used, the perforations be 3/16 to 1/2 inches in diameter and spaced 1 to 3 inches on centers, and

(f) where used, the media be inert, 8 to 12 inches in depth, 1-1/2 to 6 inches in size, structurally sound, and resistant to disintegration.

Multiple tray aerators should be housed if freezing is a factor; if housed, adequate ventilation should be provided.

b. FORCED OR INDUCED DRAFT AERATION. The forced or induced draft aerator is a closed structure containing multiple trays, a fan to either blow air into or out of the structure, and an adequate air outlet or inlet. In a forced-air aerator, the fan is located near the bottom and blows air into the structure with the air outlet at the top of the structure. In an induced draft aerator, the fan is located at the top of the structure and blows air out of the structure with the air inlet at the bottom. In both cases, air passes upward countercurrent to the downward flow of the water.

The forced or induced draft aerator shall:

(1) be of durable material resistant to the agressiveness of the water and dissolved gases,

(2) provide a uniform distribution of water over the top tray,

(3) discharge through a series of five or more trays with separation of trays not less than 6 inches,

(4) provide a loading rate of 1 to 5 gallons per minute for each square foot of total tray area,

(5) insure that the water outlet is adequately sealed to prevent unwarranted loss of air,

(6) insure adequate counter current of air through the enclosed aerator column,

(7) exhaust air directly to the outside atmosphere,

(8) include a down-turned air outlet and inlet covered with a 16-mesh screen,

(9) insure that air introducted into the column be as free from obnoxious fumes, dust, and dirt as possible,

(10) include a blower with a weatherproof or explosion-proof motor in a tight housing and screened enclosure, and

(11) permit sections of the aerator to be easily reached or removed for interior maintenance or be installed in a separate room.

c. DIFFUSION AERATION. Diffusion aerators generally consist of rectangular tanks in which perforated pipes, porous diffuser tubes, or various patented impingement or sparger devices are located near the bottom of the basin. Compressed air is injected into the water, and the air bubbles, on rising, cause turbulence. This provides opportunity for exchange of volatile gases between the air bubbles and the water, and between water and the air at the water's surface.

The design of a diffusion aerator shall provide:

(1) a basin depth of 9 to 15 feet and a width of 10 to 30 feet,

(2) a ratio of width to depth not to exceed 2:1 to achieve effective mixing,

(3) a detention time of 10 to 30 minutes,

(4) air compressor capacity equal to 0.01 to 0.20 cubic feet of air per gallon of water treated,

(5) an air inlet to the compressor located free from obnoxious fumes, dust, dirt, and other contaminants,

(6) if porous diffusers are used, an adequate air filter to minimize clogging, and

(7) lateral baffles, if necessary, to prevent short circuiting through the basin.

d. PRESSURE AERATION. Pressure aerators or saturators are occasionally employed for iron and manganese removal, where open aerators and double pumping is undesirable. Air is injected into the water in a closed container at pressures greater than atmospheric. Since the solubility of air in water increases in direct proportion to the absolute pressure, more air is dissolved. Upon release from the higher pressures, the air will be released from the water very quickly.

Pressure aeration may be used for oxidation purposes if laboratory or pilot plant studies indicate the method is applicable and if approved by the Department.

Pressure aerators are not acceptable for removal of dissolved gases.

Filters following pressure aeration must have adequate exhaust devices for release of air.

Design of pressure aerators shall:

(1) give thorough mixing of compressed air with the water being treated, and

(2) provide screened and filtered air, free of obnoxious fumes, dust, dirt, and other contaminants.

e. OTHER METHODS OF AERATION. Other methods of aeration may be used if applicable to the treatment needs and are approved by the Department.

4. <u>PROTECTION FROM WIND</u>. Cascade and multiple tray aerators shall be protected by being placed in a louvered enclosure. The louvers shall slope to the outside at an angle of approximately 45 degrees. The enclosure shall be screened on the inside with not less than 16-mesh, noncorrosive wire, and on the outside with a 1/4-inch mesh hardware cloth. Easy access to the interior of the enclosure shall be provided.

5. <u>PROTECTION FROM CONTAMINATION</u>. Aerators that are used for oxidation or removal of dissolved gases from waters that will be given no further treatment other than disinfection shall be protected from contamination from insects, birds, dust, dirt, and obnoxious fumes.

6. <u>BYPASS</u>. A bypass shall be provided for all aeration units to permit taking each unit out of service for maintenance and repair.

D. COAGULATION AND FLOCCULATION

1. PURPOSE OF COAGULATION AND FLOCCULATION. Raw water supplies, especially surface water supplies, often contain suspended substances causing unacceptable levels of turbidity. These substances include mineral and organic substances and microscopic organisms ranging in size from 0.001 to one micrometer. Particles in this size range are often referred to as "colloidal" particles. Larger particles, such as sand and silt, readily settle out of water, but the settling rate of colloidal particles is so low that removal of colloidal particles by plain sedimentation is not practicable. An important characteristic of particles suspended in water is the ratio of particle surface area to mass. For large particles, this ratio is relatively low and mass effects, such as sedimentation under the influence of gravity, dominate. On the other hand, particles in the colloidal size range have a relatively large surface area-to-mass ratio and these particles exhibit characteristics dominated by surface phenomena, such as electric charge.

   Colloidal particles in suspension in water have electrical charges at their surface. These charges are usually negative. The charge at the surface of the particle causes the particle to attract oppositely charged ions present in the water. The oppositely-charged ions are bound to the outer surface of the particle and form a "layer" around the particle. Thus, if most of the suspended particles in a naturally-occurring water have a layer of positively-charged ions around them, the particles cannot approach each other because of the repulsion between the positively-charged layers of each. The electrical strength at the outer surface of the layer of bound ions is frequently referred to as the "zeta potential". The magnitude of the zeta potential provides an indication of the repulsive forces between suspended particles. There are also forces of attraction between the colloidal particles present in water. The primary of these forces is the Van der Waals force, which is a cohesive force in existence between all atoms. If the repulsive forces between particles, as described above, can be sufficiently reduced to allow Van der Waals forces to predominate, the particles will stick together and form larger particles which settle out of the water more readily.

   The terms "coagulation" and "flocculation" are often used interchangeable to describe the overall process of conditioning suspended matter in water so that it can be readily removed by subsequent treatment processes. The coagulation and flocculation processes, though closely related, are distinct and separable and are defined as follows: The term "coagulation" means a reduction in the forces which tend to keep suspended particles apart. The reduction of these repulsive forces allows small particles to join together to form larger particles which settle readily. The joining together of the small particles into larger, settleable and filterable particles is called "flocculation". Thus, coagulation is the precursor of flocculation and the two processes must be considered conjunctively.

Negation of the repulsive forces between particles is generally achieved by adding salts of trivalent aluminum or iron to the water containing the particles. The aluminum or iron salts cause a series of reactions to occur in the water, the net result of which is reduction of the electrical charges on the particle. The attractive forces between particles are then sufficient to overcome the reduced repulsive forces, and any particles which collide are joined together into larger particles which readily settle. The likelihood of collisions between particles is often enhanced by slow mechanical mixing or agitation ("flocculation") of the water. As more and more particles are joined together, they form flocculent masses which settle out of the water. Any particles which are struck by the flocculent material as it settles to the bottom are ensnared in the flocculent mass.

2. COAGULANTS. Probably the most frequently used coagulant is aluminum sulfate, averaging about 17 per cent Al_2O_3, also called "alum" or "filter alum". Other aluminum compounds used as coagulants are potash alum and sodium aluminate, principally the latter. Salts of iron, such as ferric sulfate, ferrous sulfate (copperas), chlorinated copperas, and ferric chloride are also used as coagulants. Magnesium hydroxide, produced by lime softening of waters high in magnesium, is another effective coagulant. Organic polyelectrolyte compounds have also proven effective as primary coagulants. Certain polyelectrolytes, at a low dosage, have been found to significantly enhance the efficiency of turbidity removal in presedimentation basins.

   Determination of type and dosage of coagulant is approximated through a series of "jar tests". These tests are performed in a laboratory stirrer by applying varying dosages of different coagulants to representative raw water samples. The coagulant is rapidly mixed in the water, and the mixture is then stirred slowly to allow flocculation to take place for a period of time and then allowed to settle quiescently. Comparison of turbidity removal efficiencies for each of the various coagulants and dosages yields an evaluation of the best coagulant and dosage to be utilized. Adjustment of the dosage is usually required in actual plant operation.

3. AIDS TO COAGULATION AND FLOCCULATION. In some cases, coagulation can be improved by the use of coagulant aids in addition to the usual aluminum or iron coagulant. The most widely used coagulant aids are activated silica, polyelectrolytes, and bentonite clays.

   a. ACTIVATED SILICA. A partially neutralized sodium silicate solution is known as "activated silica". It is often used as an aid to coagulation because it may lower the required coagulant dose, increase the rate of coagulation, broaden the pH range of effective coagulation, and cause the floc particles to be tougher, which may result in longer filter runs. However, preparation of the sodium silicate solution may be difficult, and, unless carefully applied, activated silica may actually hinder coagulation and shorten filter runs. Activated silica dosages must be determined for each water. Usual dosages are from 7 to 11 per cent of the coagulant dosage.

   b. POLYELECTROLYTES. Polyelectrolytes are long-chain organic compounds which contain repeating units of small molecular weight. Each of the units has an electrical charge associated with it, which gives the long-chain molecule a large number of similar electrical charges. Polyelectrolytes with negative charges are termed "anionic", while those with positive charges are termed "cationic". Those having essentially no charge are termed "nonionic". Polyelectrolytes act as bridging mechanisms between particles in water and cause small floc particles to agglomerate into large floc particles with greatly reduced settling times. Anionic and nonionic polyelectrolytes are often used as coagulant aids in conjunction with metal coagulants. Cationic and nonionic polyelectrolytes, used without metal coagulants, have been effective in reducing turbidity in the first stage of treatment of high turbidity waters.

      There are a large number of commercial polyelectrolytes currently available. Optimum dosages of polyelectrolytes are usually quite low (about 1 mg/l) and must be determined for each raw water. All polyelectrolytes used in water treatment plants shall have the approval of the Department and the U.S. Environmental Protection Agency (EPA) for use in potable waters and must be used within the specified maximum dosages.

   c. BENTONITIC CLAYS. In waters containing high color and low turbidity, the floc produced by aluminum or iron coagulants is often too light to settle rapidly. Since clays similar to bentonitic clay particles cause the floc to have a higher specific gravity, it settles more readily. Dosages of bentonitic clays generally range from 10 to 50 mg/l.

4. FACTORS AFFECTING COAGULATION AND FLOCCULATION.

a. pH. The pH of the water to be treated often has a significant effect on coagulation. Aluminum salts are most effective as coagulants at pH values from 6.0 to 7.8. For iron salts, the range of pH values at which effective coagulation may occur is broader. It is important that coagulation be carried out within the optimal range of pH values, and, if the pH is not within this range, it may be necessary to adjust the pH with an acid or an alkali.

b. NATURE OF TURBIDITY. There are very few definitive rules to follow with respect to coagulation and flocculation but the following are useful approximations:

(1) Organic turbidity particles are usually more difficult to coagulate than inorganic turbidity particles.

(2) The required dosage of coagulant does not increase linearly with an increase in turbidity. In fact, very high turbidities often coagulate more easily than low turbidities because of the increased likelihood of particle collisions.

(3) If the suspended particles in water are of a wide range of sizes, they are usually much easier to coagulate than if all the particles are of similar size.

c. DISSOLVED SALTS. Some ions of dissolved salts exert influences on the coagulation processes. Anions exert a much greater effect than cations and of the common anions found in nature, the sulfate and phosphate ions have the greatest effect on coagulation. Sulfate ions tend to broaden the pH range in which effective coagulation takes place, whereas phosphate ions move the pH range for effective coagulation to the more acid side. The generalizations of dissolved solids effects are:

(1) Coagulation with aluminum or iron salts is subject to greater interference from anions than from cations. Thus, ions such as sodium, calcium, and magnesium have relatively little effect on coagulation.

(2) Anions extend the optimum pH range for coagulation to the acid side to an extent dependent on their valency. Monovalent anions such as chloride and nitrate have relatively little effect, while sulfate and phosphate cause marked shifts in pH optima.

d. COAGULANT. One factor which is within the control of a water plant's designer and operator is the choice of coagulant. While alum is by far the most commonly used coagulant, iron salts can be used as well and, in some instances, have advantages over alum. A significant advantage of iron salts over aluminum is the broader pH range for good coagulation. Thus, in the treatment of soft colored waters where color removal is best obtained at acid pH values, the use of iron salts is preferable. Also, the greater insolubility of ferric hydroxide at high pH values, such as occur in some softening plants, suggests that iron salts should be considered under these conditions.

The choice of coagulant for any particular water should be based on experimental comparison of performance and economics.

5. COAGULATION (RAPID MIXING). In the water treatment plant, coagulation and flocculation are usually effected in two separate mechanical operations. The first operation involves rapid mixing of the coagulant and other chemicals, if needed, including those for pH adjustment and flocculation aid, in a small rapid-mix chamber. The purpose of rapid mixing is to uniformly distribute the applied chemicals in the water and promote collisions of chemical particles with turbidity particles. The interaction between chemical coagulants and turbidity particles occurs very quickly, so it is essential that the chemical coagulant be rapidly mixed into the water to insure that the coagulation process proceeds uniformly. Generally, rapid mixing is accomplished by creating turbulence and energy dissipation in the basin. As approximate guidelines, the water flowing into a rapid mix chamber equipped with

mechanical mixers usually requires from 30 seconds to two minutes to flow through the chamber, and mechanical mixing units usually need 1 to 2 horsepower for each cubic foot per second of water. Where possible, the rapid mix should be a two-compartment unit to enable sequential application and dispersion of each chemical, and to prevent short-circuiting.

Rapid mixing facilities should be located as close as possible to the chemical feeders to minimize the length of chemical feed lines. They should also be located as close as feasible to the flocculation basins.

a. TYPES. Various methods are employed for rapid mixing of chemicals with the water to be treated. The most common methods are: mechanical mixing devices, hydraulic jumps, baffled chambers, pumps, and air agitation. Of these methods, the mechanical mixing devices are the most effective.

(1) Mechanical Mixer. Mechanical mixers consist of two general types: rotary units and reciprocating units, with the former being more common having either an impeller or a propeller. Either vertical mixers in a basin or in-line mixers are acceptable. The drive is an electric motor, operating through a gear-type speed reducer. The power input into the water is usually measured by the velocity gradient G. This parameter is calculated from the following equation:

$$G = [P/\mu V]^{0.5}$$

where

G = velocity gradient, fps/foot or sec $^{-1}$
P = power dissipated in the water, ft-lb/sec
μ = water viscosity, lb-sec/sq ft
V = volume of basin, cu ft

Rapid mixing is best achieved at G values of 500 sec $^{-1}$ to 1,000 sec $^{-1}$ and detention times of about two minutes, although shorter detention times are often used effectively. Longer detention times for these values of G result in negligible mixing improvement. If high G values (> 10,000 sec $^{-1}$) are maintained for as long as two minutes, subsequent floc formation processes are significantly retarded.

Since the best velocity gradient may vary from time to time, variable speed drive equipment is desirable. A 3:1 speed range is usually adequate.

Mechanical mixers are very effective, are not affected by flow variance, and cause little head loss.

(2) Baffled Basins. Basins baffled for rapid mix purposes may be either horizontally or vertically baffled. In the horizontally baffled basin, the water travels back and forth around the ends of the baffles. In the vertically baffled basin, the water travels over and under the baffles.

The velocity gradient G can be calculated for baffled basins by the following equation:

$$G = [62.4H/\mu T]^{0.5}$$

where

G = velocity gradient, fps/foot or sec^{-1}
H = head loss due to friction, ft
μ = water viscosity, lb-sec/sq ft
T = detention time, seconds

The G values for optimum rapid mixing are the same as given above for mechanical mixer-equipped basins.

The violence of agitation in a baffled basin is dependent upon the flow rate through the basin. Therefore, baffled basins are not suitable where flow rates vary widely unless provisions are built in the basin design permitting adjustment of the baffles to maintain optimum velocities.

(3) Hydraulic Jump. The hydraulic jump is a method of providing a rapid mix without the use of mechanical devices. The hydraulic jump is formed by passing water down a steep slope and allowing the water to acquire a high velocity, 10 to 12 fps. On reaching the bottom, the water enters a slowly moving pool where the jump occurs. In the jump, some of the kinetic energy of the water is dissipated, resulting

in considerable turbulence and creating a rapid mix. Head loss can be 1-foot or more. In selecting a hydraulic jump as a rapid mix, care must be exercised to assure that the turbulence produced and energy dissipated is great enough for quick and complete mixing. Most Parshall flumes, for example, are not effective mixing devices as there is little energy dissipated. The chemicals shall be applied across the width and just ahead of the jump to assure complete mixing. Use of a hydraulic jump as a rapid mix must be approved by the Department.

(4) Air Agitation. Diffused air agitation is used occasionally as a rapid mix, especially where aeration of the water may be required or desired. Very little head loss occurs in use of air agitation mixing. The requirements for diffusion aeration as given in Section C must be met but the injection of chemicals into the aeration basin shall be near the effluent end so as to give a chemical mixing time not to exceed 2 minutes. Use of air agitation as a rapid mixing device must be approved by the Department.

(5) Pumps. A centrifugal pump may serve as a rapid mixing device when the chemicals are injected in the suction line just ahead of the pump. The cost of such an installation is often low, and no head loss by rapid mixing occurs. The disadvantages of using a pump is that the mixing time is very brief and the pump may become clogged if a chemical like lime is injected.

Use of a pump as a rapid mixing device must be approved by the Department.

(6) Other Devices. Other devices may be developed for rapid mixing. These new devices may be used if approved by the Department.

b. CHEMICAL APPLICATION. The point of chemical application in a rapid mix basin depends upon the type of mixer.

For basins equipped with mechanical mixer equipment, the chemical(s) should be injected adjacent to the impeller(s) or propeller(s) of the mixing device.

For baffled basins, the chemical(s) should be injected at mid-water depth at the upstream end of a pass. Sequential chemical addition is possible if the basin has two or more baffled passes.

In hydraulic jump rapid mixers, the chemicals should be injected just above the point of the jump and distributed across the width of the jump.

With air agitation, the chemicals should be injected just above the point where the air is injected into the water. Care should be exercised in chemical injection to assure a uniform distribution of chemical.

Chemicals should be injected into the suction piping of a pump just upstream of the pump.

c. NUMBER. A minimum of 2 rapid mix units shall be provided.

d. DETENTION TIME. Total detention time for rapid mixing shall not be greater than 2 minutes.

6. FLOCCULATION (SLOW MIXING). Flocculation, which follows coagulation, is usually accomplished by agitating the water at low velocities for long periods of time. Mixing in flocculation basins is intended to promote collisions and growth of the coagulated particles into settleable floc particles. The motion imparted to the water in the flocculation basins is much gentler than the motion in the rapid mix basins; otherwise, the shear forces in the turbulent water would break up the agglomerated floc particles.

a. BASIN DESIGN. The flocculation basin should be located as close to the preceeding rapid mix basin and the following sedimentation basin as possible. Inlet and outlet design shall prevent short-circuiting and destruction of the floc particles. A drain or pump shall be provided to permit dewatering and sludge removal.

As in the case for rapid mixing, the value of the velocity gradient G is useful in estimating the effectiveness of mechanical agitation in flocculation basins. The optimal range in values of G appears to be between 20 sec^{-1} and 70 sec^{-1}. If the velocity gradient is multiplied by the detention time in seconds, an additional parameter GT is obtained. Conventional values of this nondimensional parameter range from 30,000 to 150,000 for flocculation basins.

The use of baffled flocculation basins is discouraged. To prevent short-circuiting in mechanical flocculators, at least 3 successive compartments should be provided. Special attention should be given to the ports between compartments to further suppress short-circuiting.

b. DETENTION TIME. Detention time in a flocculation basin shall not be less than 20 minutes at maximum flow through the basin nor greater than 60 minutes at minimum flow through the basin. The flow-through velocity should not permit settling of the floc particles in the flocculation basin.

c. EQUIPMENT. Flocculation equipment should provide a gentle conditioning mix. Mixing is generally accomplished by a series of paddles rotating either parallel or perpendicular to the direction of flow through the basin. Other acceptable devices are the walking beam and vertical axial-flow flocculators.

Agitators shall be driven by variable speed drives with the peripheral speed of paddles ranging from 0.5 to 2.0 feet per second. Tapered flocculation is permissible, with the G value decreasing in successive compartments through the basin. Baffles shall be provided between each set of paddles to minimize short-circuiting.

d. PIPING. Floc may be broken up at points of increased agitation such as bends and flow through pipe or conduits. To minimize floc break-up, flocculation and sedimentation basins should be as close together as possible. Allowances shall be made to minimize turbulence at bends, pipe entrances and exits, and changes in direction to prevent breakup of the floc. The velocity of flocculated water through pipes or conduits should not be less than 0.5 nor greater than 1.5 feet per second.

e. OTHER DESIGNS. Baffling may be used to provide flocculation in small plants only after consultation with the Department. The design should be such that the velocities and flows noted above will be maintained. A superstructure over the flocculation basins may be required.

E. SEDIMENTATION

1. <u>SEDIMENTATION BASINS</u>. Sedimentation or clarification is the separation of suspended solids from water by gravity. To accomplish this, the flocculated water passes through relatively large basins at low velocity to allow the suspended or floc particles to settle to the bottom.

   a. TYPES. The most common types of sedimentation basins are the rectangular horizontal flow and the center-feed radial flow. The basin configuration of the latter type may be either circular or square.

      (1) <u>Rectangular Basins</u>. In all types of sedimentation basins, the design objective is to obtain, as nearly as possible, the condition of ideal flow through the basin. For a rectangular basin, all the water enters at one end of the basin and should flow in parallel paths of equal velocity to the effluent end of the basin. This ideal flow cannot be attained under actual operating conditions because of imperfect inlet and outlet arrangements, friction, turbulence, etc. Generally, a length to width ratio between 3:1 to 5:1 is used. Basin depths generally range from 7 to 16 feet. Under comparable conditions, deeper basins usually perform better than shallow ones. Effluent weirs are located near the effluent end of the basin.

      Bottoms of rectangular basins are usually designed to slope from the effluent end of the tank to a sludge hopper or hoppers located at the tank inlet. A scraper mechanism will move the settled solids along the bottom to the hopper. Movement of the sludge scraper should be slow enough not to disrupt the settling process or to resuspend the settled sludge. Sludge is drawn off the hopper bottom.

      (2) <u>Circular Basins</u>. Circular basins employ a radial flow design and may vary in diameter from 10 to as much as 250 feet. The basin may be square for the advantage of common wall construction rather than circular. Square tanks seldom exceed a side length of 70 feet. Basin depths vary from 8 to 16 feet.

      Water containing the suspended particles is usually introduced through a central influent well, where it flows radially outward toward outlet troughs along the perimeter of the basin. As in the case of rectangular basins, the water inlet should be designed to minimize turbulence in the influent flow. A cylindrical baffle around the influent well is commonly used in an attempt to achieve uniform radial flow.

The settled solids in a circular basin are collected in a sludge hopper at the center of the bottom of the basin. The bottom slopes downward from the outer edge of the basin toward the hopper. Mechanical sludge collectors consist of radial arms along the bottom of the tank equipped with blades which plow the sludge toward the central hopper. Arm drive units are located either at the tank center or at the outer end of arms along the wall of the basins.

Peripheral-feed, circular tanks are also employed. Water is distributed around the tank perimeter and flows radially toward effluent collection facilities located in the center or at the periphery.

b. NUMBER. A minimum of two basins shall be provided to allow one basin to be out of service for maintenance or repair while the other remains in service. The plant design shall provide appropriate piping or conduits to permit removal from service of one or more basins when necessary. The design shall also provide for equal flow distribution among two or more basins operating in parallel configuration and among the remaining basin(s) when one or more basins are out of service.

c. BASIN OVERFLOW RATE. An important parameter in the sizing of sedimentation basins is the "overflow rate", which is defined as the flow rate divided by the surface area of the basin. The overflow rate is usually expressed in terms of gallons per day per square foot (gpd/sq ft) or gallons per minute per square foot (gpm/sq ft). In theory, if the settling velocity of a particle is greater than the overflow rate of the basin, the particle will settle out before the water leaves the basin. Settling rates for various sizes and kinds of particles have been determined in the laboratory under ideal condition. However, the suspended floc particles in most sedimentation basins do not have the same specific gravity or configuration of those tested in the laboratory, so their settling rates are not the same. In addition, actual sedimentation basins have currents which hinder settling. These currents may be the result of inlet or outlet induced turbulence, wind action, density differences, etc. The net result is that the settling rates of particles in an actual sedimentation basin are considerably less than those determined in the laboratory, and the overflow rate must be adjusted to allow for this difference.

The following equations express convenient relationships between basin water depth in feet (D), overflow rate in gpd/sq ft (O_r), and detention time in hours (T):

$$D = [O_r T/180]$$

$$T = [180D/O_r]$$

$$O_r = [180D/T]$$

Temperature of the water has a significant effect on particle settling rates. As the temperature of water increases, the viscosity of the water decreases. Thus, particle settling rates increase as water temperature increases, and the basin overflow rate can increase.

Overflow rates for gravity-type sedimentation basins are dependent upon the type of water, the type of floc, and the water temperature. Overflow rates at the design flow rate generally range as follows:

Type of Water	Treatment	Overflow Rate	
		gpm/sq ft	gpd/sq ft
Surface water	Alum, iron, or polyelectrolyte floc	0.25-0.38	360-550
Surface or ground water	Lime softening	0.38-0.75	550-1080

Basins treating cold water should use the lower overflow rates; for warm water the higher overflow rates. If new coagulation-flocculation chemicals are used, laboratory or pilot plant studies or other documentation must be presented to the Department to justify any radical departure from the above overflow rates.

d. DETENTION TIME. The theoretical time for a unit volume of water to flow through a sedimentation basin is called the "detention time". It can be computed by dividing the basin volume by the rate of flow through the basin. The detention time for effective clarification is dependent upon a number of factors relating to basin design, nature of the raw water, and basin purpose.

In a properly designed settling basin which handles well-coagulated and flocculated water, a detention time of 2-4 hours at the design rate should be provided. A water containing alum floc should have the longer settling time whereas a lime-soda ash softened water the shorter time. A longer detention time is permissible if shown to be necessary for effective clarification of the water.

e. INLET DEVICES. Inlets shall be designed to distribute the water equally and uniformly, to minimize turbulence or inertial currents, and to produce uniform velocities. A baffle should be constructed across the basin near the inlet or around the inlet and should project several feet below the water surface to dissipate inlet velocities and provide uniform flows across the basin.

f. OUTLET DEVICES. The outlet device shall be designed to maintain velocities suitable for basin settling and to minimize short-circuiting through the basin. Weirs, V-notch weirs, and submerged orifices are often used for basin outlets, and these should be installed with provisions for vertical adjustment.

The rates of flow over an outlet weir generally vary from 8 to 20 gallons per minute per foot of weir length. Where submerged orifices are used, they should not be lower than three feet below the flow line with flow rates equivalent to weir loadings.

g. COVERS. A superstructure over the sedimentation basin may be required. If there is no mechanical equipment in the basin and if provisions are included for adequate monitoring under all expected weather conditions, a cover may be provided in lieu of a superstructure.

h. VELOCITY. The velocity of flow through a settling basin will not be uniform over the cross section perpendicular to the flow even though the inlets and outlets are designed for uniform distribution. The velocity will not be stable because of density currents, eddy currents, and operation of sludge removal mechanism. To minimize these disturbances, the velocity through a sedimentation basin should be kept between 0.5 and 3.0 feet per minute. Short-circuiting should be minimized and baffles provided as necessary.

i. OVERFLOW. An overflow weir or pipe should be installed which will establish the maximum water level on the filters. The overflow shall discharge with a free fall where the discharge will be noted. The water passing through the overflow should be reclaimed, if possible, and returned to the plant influent.

j. DRAINAGE. All sedimentation basins shall be provided with a means for dewatering the basin. If mechanical sludge collection equipment is not utilized, the basin bottoms should slope toward the drain not less than one foot in twelve feet.

k. SLUDGE COLLECTION. The use of mechanical sludge collection equipment in all sedimentation basins is encouraged for continuous sludge removal to maintain volumetric efficiency and to reduce the need to shut the basin down for cleaning.

Unless sludge is removed continuously, an allowance shall be made in the basin volume for sludge accumulation between cleanings. The Department must approve the basin volume allocated for sludge accumulation in basins not equipped with mechanical sludge removal equipment. The volume allowance is dependent upon the nature of chemical treatment, quantity of suspended particles in the raw water, the density of the settled solids, and the frequency of basin cleaning.

Flushing lines or hydrants shall be provided to aid in removing the accumulated sludge from a basin. These lines or hydrants shall be equipped with backflow prevention devices acceptable to the Department.

Provisions shall be made for the operator to observe or sample sludge being withdrawn from a settling basin. Sludge removed from settling basins shall be disposed of as directed in Section R.

1. SAFETY. Safety facilities should be provided to prevent personnel from falling into basins and injury from equipment. A handrail should be included around a basin and along walkways on top of a basin. Permanent ladders or handholds should be provided on the inside walls of basins above the water level. Equipment above the water line should be enclosed or adequately covered to prevent personal injury.

2. <u>TUBE SETTLERS</u>. The theory of solids sedimentation indicates that the removal of settleable material is a function of the overflow rate and basin depth. Tube settlers utilize this theory to provide a shallow depth to permit more rapid removal of settleable solids.

Tube settlers are rectangular or chevron shaped tubes with common wall construction to form a readily handled module. Tubes in the modules are about two feet long, and the modules can be stacked one upon the other. Two general configurations of tube settlers are currently being utilized: (a) parallel 2-inch square tubes inclined at 60° from the horizontal, and (b) paralled 1-inch hexagonal tubes inclined at 5° from the horizontal. Other commercial configurations are appearing on the market with varying degrees of inclination. Water usually enters the tube settlers from the bottom and in passing upward through the tubes permits the settleable material to settle to the bottom of the tube. In the 60° inclined tubes, the sludge slides down the tubes and is collected below the tubes. The 5° inclined tubes must be cleaned by backwashing. Generally, the distance between the basin inlet and the tube settlers should be at least one-third of the total basin length in order to minimize the turbulence of water entering the tubes.

It has been claimed that tube settlers may increase the capacities of sedimentation basins by 50 per cent or more. Tube settlers can be installed in new sedimentation basins thereby reducing the size of the basins or in existing basins thereby increasing the capacity of the basins. Depending on the temperature of the water and the raw water turbidity, overflow rates recommended by the manufacturers for tube settlers in horizontal flow basins with cold water vary from 2.5 to 4.0 gpm/sq ft, or 3,600 to 5,760 gpd/sq ft, for that portion of the basin covered by tubes. The overflow rates, based on total basin area under the same conditions, vary from 2.0 to 3.0 gpm/sq ft or 2,880 to 4,320 gpd/sq ft. The probable basin effluent turbidity with these overflow rates is claimed to be 1-10 JTU for cold waters and 1-7 JTU for warm waters.

Although recognized as an alternative method of clarification, sufficient experience on tube settlers is not yet available in the water treatment field to establish design standards. Therefore, design calculations and plans for use of tube settlers in either new or existing sedimentation basins shall be submitted to the Department for approval.

3. <u>SUSPENDED SOLIDS CONTACT CLARIFIERS</u>. A solids contact clarifier is defined as a unit which incorporates in a single unified structure the processes of mixing, coagulation, flocculation, sedimentation, and sludge removal. The unit may be either rectangular or circular. Coagulation and flocculation take place in the presence of floc which has been formed previously and cycled back to the primary mixing and reaction zone. Flow in the sedimentation section is generally upward through a layer (blanket) of flocculated, suspended matter. The units are also known as upward-flow solids contact units and upward-flow sludge blanket type clarification basins. In addition, these units have facilities for automatically controlled removal of solids so that the basin-retained solids can be maintained at a desired concentration. Several companies make proprietary equipment for these units with each having some distinctive feature.

Solids contact clarifiers are more widely used in connection with lime-soda softening than for conventional chemical coagulation-flocculation-sedimentation.

Units of this nature are more suitable for waters with a uniform quality and where flow rates do not vary greatly. Maintenance of the sludge blanket is important for adequate results, and, with waters having a varying quality and varying flow rates, maintenance of this sludge blanket can be very difficult. These units are also more suitable for lime-soda softening as the sludge blanket is composed of heavier solids and thus less likely to be drawn over into the effluent. Also improved precipitation of the calcium and magnesium occurs by passage through the solids blanket.

Suspended solids contact clarifiers are acceptable for combined softening and clarification where water characteristics are not variable and flow rates are uniform. Approval of the Department must be secured before such units are considered as clarifiers without softening. A minimum of two units are required for surface water treatment. The units should be designed for the maximum uniform rate and should be adjustable to changes in flow which are less than the design rate and for changes in water characteristics.

a. MIXING. Mixing devices employed in the unit shall be so constructed as (1) to provide good mixing of the chemicals and water with previously formed sludge particles, and (2) to prevent deposition of solids in the mixing zone. Upon review, the Department may require installation of a rapid mix device or chamber ahead of the solids contact unit.

Flocculation equipment shall be adjustable as to speed and/or pitch and must provide for flocculation in a separate chamber or baffled zone within the unit. The mixing and flocculation period should not be less than 30 minutes.

b. CHEMICAL FEED. The chemicals shall be applied by such means and at such points in the mixing zone to insure satisfactory mixing of the chemicals with the water.

c. DETENTION PERIOD. The detention time shall be established on the basis of the raw water characteristics and other local conditions that affect the operation of the unit. Based on the design flow rates, the detention time should not be less than:

(1) 4 hours for suspended solids contact clarifiers and softeners treating surface water, or

(2) 1 hour for the suspended solids contact softeners treating only groundwater.

d. BASIN OVERFLOW RATE. Unless supporting data is submitted to the Department justifying overflow rates exceeding the following, the basin overflow rates shall not exceed:

(1) 1.0 gallon per minute per square foot of area at the sludge separation line for units used for clarification, or

(2) 1.75 gallons per minute per square foot of area at the slurry separation line for units used for softening.

e. OUTLET DEVICES. The units should be equipped with either overflow weirs or submerged orifices constructed so that water at the surface of the unit does not travel over 10 feet horizontally to the collection trough. Weirs shall be adjustable, and at least equivalent in length to the perimeter of the unit. Weir loadings shall not exceed:

(1) 10 gallons per minute per foot of weir length for units used for clarification, or

(2) 20 gallons per minute per foot of weir length for units used for softening.

Where orifices are used, the loading per foot of launder should be equivalent to weir loadings. The type of outlet device shall produce uniform rising rates over the entire area of unit.

f. SLUDGE CONCENTRATORS. The optimum solids concentration should be maintained by automatic collection and discharge of excess solids, after proper thickening in concentrators.

The unit's equipment should provide either internal or external concentrators in order to obtain a concentrated sludge with a minimum of waste water.

Softening units should be designed so that continuous slurry concentrates of one per cent or more, by weight, can be satisfactorily maintained.

g. SLUDGE REMOVAL. Excess solids are usually automatically discharged from the sludge concentrator. The sludge discharge is controlled by adjustable timer-controlled hydraulic or pneumatic actuators, or by proportionate sludge blow off.

Each unit shall be provided with suitable controls for sludge withdrawal. Solids concentrations of waste sludge should be (1) approximately three per cent by weight for clarifiers and (2) five per cent by weight for softeners. Total water losses from a unit should not exceed (1) approximately five per cent for clarifiers and (2) three per cent for softeners.

Sludge removal design shall provide that:

(1) sludge pipe be not less than four inches in diameter and arranged to facilitate cleaning,

(2) the entrance to sludge withdrawal piping prevent clogging,

(3) valves be located outside the unit for accessibility, and

(4) the operator be able to observe and sample sludge being withdrawn from the unit.

Sludge withdrawn shall be disposed of in accordance with the requirements of Section R.

h. INSTALLATION OF EQUIPMENT. Supervision by a representative of the manufacturer shall be provided with regard to all mechanical equipment at the time of installation and initial operation.

i. OPERATION OF EQUIPMENT. To assure correct operation of the equipment, the following shall be provided for plant operation:

(1) manufacturer's operating and maintenance instructions,

(2) a complete set of tools, accessories, and spare parts,

(3) necessary laboratory equipment, and

(4) adequate piping and suitable sampling taps located to permit the collection of samples from critical portions of the unit.

j. CROSS CONNECTIONS. An acceptable means of cross-connection control shall be included on all potable water lines used to backflush sludge lines or for other basin purposes.

k. DRAINAGE. Each unit shall be provided with a means for dewatering. Blow-off outlets and drains shall terminate and discharge freely at places satisfactory to the Department.

4. FLOCCULATION-SEDIMENTATION BASINS. Units of this type, usually circular or square in plan, combine the functions of flocculation and sedimentation. Flocculation is normally accomplished in a circular center well. Sedimentation occurs in the space between the flocculation section and the outer walls of the basin. Chemical addition, rapid mixing and coagulation take place outside the basin, with the coagulated water being introduced into the flocculation zone. There is no attempt to maintain a sludge blanket. The flocculated water passes from the flocculation zone into the settling zone. Mechanical sludge collection equipment moves the settled solids to a hopper located in the center of the basin. Several manufacturers produce equipment for these units.

a. MIXING. Mixing of the chemicals with the raw water occurs outside the flocculation-sedimentation basin. The requirements for coagulation, as given in Section D, shall be followed.

b. CHEMICAL FEED. The locations of chemical application as presented in Section D should be followed.

c. DETENTION TIME. The detention times for flocculation basins as given in Section D and as given heretofore in this section under sedimentation basins shall be provided.

d. BASIN OVERFLOW RATES. The overflow rates as presented heretofore in this section under sedimentation basins should be provided.

e. INLET DEVICE. The raw coagulated water shall be introduced into the center of the flocculation zone near the water surface. Open ports, submerged ports and similar inlet arrangements should be constructed to dissipate inlet velocities and assure uniform flows in the flocculation zone.

f. OUTLET DEVICE. The requirements for outlet devices as specified heretofore in this section under sedimentation basins shall be followed.

g. SLUDGE REMOVAL. Mechanical sludge collection equipment shall be provided for each unit. Sludge withdrawal from the unit will be determined by the raw water characteristics and shall be at intervals frequent enough to assure acceptable operation of the unit and an acceptable basin effluent. Provisions shall be made for the operator to observe or sample sludge being withdrawn from the unit.

   Sludge withdrawn from the unit shall be disposed of as required by the provisions of Section R.

h. INSTALLATION OF EQUIPMENT. Supervision by a representative of the equipment manufacturer shall be provided at the time of installation and initial operation of the unit.

i. DRAINAGE. Units shall be provided with drains or a means for dewatering. Basin bottoms should slope toward the drain not less than 1 foot in 12 feet or as required by the mechanical sludge collection equipment.

j. CROSS CONNECTIONS. Flushing lines or hydrants containing potable water and used during operation and/or maintenance functions shall be equipped with backflow prevention devices acceptable to the Department.

F. FILTRATION

Filtration of water is defined as the separation of colloidal and larger particles from water by passage through a porous medium. As water passes through the medium, the suspended particles are either left in the interstices between the grains of the medium or left on the medium itself. Sand filtration will remove particles much smaller than the void spaces between the sand grains. This phenomenon is probably due to the particles in the water being attracted to the surface of the granular medium and being held there by relatively strong surface forces. Suspended solids removed during filtration range in diameter from about 0.001 to 50 micrometers and larger.

1. <u>QUALITY OF RAW WATER</u>. The need for filtration is dependent upon the quality of the raw water and the treatment processes required to convert the water to a quality meeting the drinking water regulations.

   Some well waters may be of a chemical and physical quality that treatment of the waters, other than disinfection, may not be necessary to permit the waters to meet the drinking water regulations. Other well waters may contain chemical substances, such as iron and manganese, that require treatment including filtration for removal. Surface waters almost always contain substances that require removal by treatment processes including filtration.

   In determining the need for filtration, the following shall be considered:

   a. All surface waters shall be filtered.

   b. All ground waters, if treated for iron and manganese removal or softened by the lime-soda ash process, shall be filtered.

   c. Filtration is not required for a ground water whose quality meets the drinking water regulations at all times but which is softened by the ion exchange process (see Section G).

   d. Filtration is not required for a ground water whose quality meets the drinking water regulations at all times and which is adequately protected.

   e. Slow-rate gravity filtration shall be limited to waters having maximum turbidities of 50 units, average turbidities less than 20 units, and maximum color of 30 units; such turbidity must not be attributable to colloidal clay; raw water quality data must include examination for algae content.

2. TYPES OF FILTRATION. Several different types of filters, medium arrangements, and rates of flow can be used. Acceptable filters shall include, at the discretion of the Department, the following types:

   a. rapid-rate gravity filters,

   b. rapid-rate pressure filters,

   c. slow-rate gravity filters, and

   d. diatomite filters,

   The application of any one type must be supported by water quality data representing a reasonable length of time to characterize the variations in water quality. Experimental treatment studies may be required to demonstrate the applicability of the treatment method proposed.

3. RAPID-RATE GRAVITY FILTERS. Rapid-rate gravity filters have a water surface exposed to atmospheric pressure and commonly operate at rates between approximately 2 and 6 gallons per minute per square foot of filter area. If the higher rates are used in design, great care must be taken to insure that all prefiltration treatment processes, including coagulation, flocculation, and sedimentation, will operate satisfactorily and consistently. High-rate filter operation requires excellence in prefiltration treatment.

   The filter medium is generally supported on a gravel bed. Beneath the gravel bed lies an underdrain system which collects the filtered water. Head loss through a clean filter is about one foot, and the filter is cleaned by backwashing when the head loss reaches about 8 feet.

   a. PRETREATMENT. Pretreatment shall be required prior to use of a rapid-rate gravity filter.

   b. NUMBER. All water treatment plants should have a minimum of two filter units so that one filter may be operating when the other is shutdown. Three or four small filter units are preferable to two large units because of added system reliability and flexibility.

Filter units are usually arranged in a side-by-side manner to facilitate the interconnection of water collection lines and wash water lines.

In the design of filtration plants, the following shall apply:

(1) At least two filter units shall be provided.

(2) Where two or more filter units are provided, the filters shall be capable of meeting the plant design capacity at the approved filtration rate with the largest filter out of service.

c. RATE OF FILTRATION. The rate of filtration shall be determined through consideration of such factors as raw water quality, degree of pretreatment provided, filter media, water quality control parameters, competency of operating personnel, and other factors as required by the Department. The filtration rate shall be proposed and justified by the designing Engineer to the satisfaction of the Department prior to the preparation of final plans and specifications.

d. FILTER MEDIA. Various media are presently used in filtering water for potable uses. The traditional medium has been a clean fine sand having a specific gravity of not less than 2.5, an effective size of 0.35 to 0.50 millimeters (mm), and a uniformity coefficient of 1.3 to 1.7. (The "effective size" of a sample of sand is a grain diameter such that 10 per cent by weight of the sample has smaller diameters. The "uniformity coefficient" is the ratio of the grain diameter with 60 per cent of the sample smaller to the grain diameter with 10 per cent of the sample smaller). Sand finer than about 0.3 mm stratifies at, or near, the surface of the filter, thereby shortening the filter runs. Sand coarser than 1.2 mm is generally too large to effect good removal of suspended matter.

The gravel bed beneath the filter is designed to keep the sand from passing into the underdrains and to distribute the wash water uniformly during backwashing. Ideally, the gravel bed should be composed of well-rounded gravel, with a uniform variation in diameter from the top to the bottom. It is important for the gravel to have few irregularly shaped (thin, flat, jagged) stones and to be essentially free of soil, sand, or organic residue of any kind.

In recent years, the use of other media and configurations has come into general usage. The most common of the alternative media is anthracite coal, which can be used in place of the sand layer or can be used in conjunction with sand by being installed in a layer above the sand. When used in place of the sand, the layer of anthracite coal should be approximately 24 to 30 inches deep. Special care should be taken to ensure that the anthracite medium is generally free from irregularly shaped pieces. Also, the specific gravity of the grains of coal should be greater than 1.5, since coal particles with smaller specific gravities will often be carried away in the backwash water, even at minimal rates of backwash flow. The effective size of the grains of coal may be as high as 1.2 mm. If the anthracite coal is to be used in a separate layer above a layer of filter sand, the coal layer should be about 18 inches thick and the sand layer about 8 inches thick. The coal particles should be about one mm in diameter, and the sand grains about 0.5 mm. This arrangement, often called a dual media filter, has the advantage of having the larger particles on top of finer particles, which greatly increases the effective depth of the filter bed and increases the length of filter runs.

In a conventional rapid sand filter with a single sand layer that has been hydraulically classified by backwashing, the smallest sand grains will be near the top of the bed. Any suspended matter that passes through the top few inches of sand may pass through the entire filter bed. Thus, the effective depth of a traditional rapid sand filter is only a few inches. However, when a coarse medium is placed over a fine medium, the filtration ability of the unit is increased, since the larger particles in the water will be removed in the coarse medium and the smaller particles will be removed in the fine medium. This is the advantage of coarse-to fine filters such as the coal-sand filter just described.

An alternative to the coal-sand filter configuration outlined above is "capping" of existing rapid sand filters with anthracite coal. This involves replacement of approximately the upper 6-10 inches of filter sand with 6-10 inches of anthracite coal. The primary benefits of this coarse-to-fine filter arrangement are usually longer filter runs and improved finished water quality.

Other coarse-to-fine filters can be constructed by using three or more materials of different grain size and specific gravity, selected so as to form a filter with the large particles at the top and the small particles at the bottom. The grain size decreases uniformly from the top to the bottom of the filter. In order to achieve this configuration, the particles in the filter bed must also vary uniformly in specific gravity, with the coarse upper particles having the lowest specific gravity and the fine lower particles having the highest specific gravity. Filters with this coarse-to-fine arrangement and three or more different materials in the filter are called "mixed-media" filters. Mixed-media filters have several advantages over conventional rapid sand filters, including: generally higher capacity, capability to adequately filter poorer quality influent, and longer filter runs. However, they are more costly than rapid sand filters.

If the raw water contains an excessive amount of dissolved organic impurities, it may be necessary to use granular activated carbon as a filter medium, probably in a separate filter following filtration for turbidity removal. The configuration of activated carbon filters is given in Section K.

Filter media shall be clean silica sand or other natural or synthetic media approved by the Department and having the following characteristics:

(1) a total depth of not less than 24 inches,

(2) an effective size range of the smallest material not greater than 0.45 mm to 0.55 mm,

(3) a uniformity coefficient of the smallest material not greater than 1.65,

(4) a minimum of 6 inches of media in the bottom layer or layers with an effective size range not greater than 0.45 mm to 0.55 mm and a minimum specific gravity of 2.5, and

(5) filter media and supporting gravel bed shall be installed in the filter in conformance with the American Water Works Association standard for filtering material, AWWA B100.

e. ANTHRACITE. Clean crushed anthracite, or a combination of anthracite and other media may be considered on the basis of data specific to the project. The anthracite shall be visibly free of clay, shale, and extraneous dirt, and shall have:

(1) an effective size of 0.45-1.2 mm depending on the intended use (anthracite used alone must meet the requirements of subsection d above), and

(2) a uniformity coefficient not greater than 1.85 (not greater than 1.65 if used alone).

f. SAND. Filter sand shall consist of hard durable grains of siliceous material and shall be visibly free from dirt, loam, clay, and micaceous and organic matter. Filter sand shall have:

(1) an effective size of 0.45-0.55 mm depending on the intended use (sand used alone or with anthracite must meet the specifications of subsection d above), and

(2) a uniformity coefficient not greater than 1.65.

g. GARNET. A high density garnet, with a specific gravity of not less than 4.2, shall have:

(1) an effective size of 0.20 to 0.30 mm, and

(2) a uniformity coefficient not greater than 1.65.

h. GRANULAR ACTIVATED CARBON. Use of granular activated carbon may be considered only with approval of the Department, and shall meet the basic specifications for filter material as given in subsection d above.

The granular activated carbon shall:

(1) be composed of hard, durable grains,

(2) have a specific gravity between 1.4 and 1.65, and

(3) be visibly free of foreign materials such as clay, dirt, etc.

There must be provision for a free chlorine residual in the water following the filters and prior to distribution, and a means for periodic treatment of filter material for control of bacteria and other growths.

i. DIATOMACEOUS EARTH. The filter medium used in diatomite filters is manufactured from diatomaceous earth deposits which consist of the siliceous fossil remains of dead diatoms. At present, there is no standard specification for diatomaceous filter media. Commercial grades of filter media have mean particle sizes varying from 9 to 50 microns.

In filter plant design, laboratory or pilot plant studies shall be conducted to determine the diatomaceous earth filter grade or grades that will produce the desired permeability-filtrate clarity relationship for the water being treated. Results of these studies shall be submitted to the Department for approval of the diatomaceous earth filter media.

j. OTHER MEDIA. Other media will be considered by the Department based on available experimental data and operating experience.

k. COARSE SAND. A layer of coarse sand or high density gravel (garnet or ilmenite) is placed between the fine filter medium and the supporting gravel bed. This coarse layer prevents disruption of the gravel and prevents the fine filter medium from migrating down into the gravel bed.

The coarse sand or high density gravel shall have:

(1) a minimum thickness of 3 inches,

(2) an effective size of 0.8 mm to 2.0 mm, and

(3) a uniformity coefficient not greater than 1.7.

l. GRAVEL. Gravel, when used as the supporting media, shall:

(1) consist of hard rounded particles with a specific gravity not less than 2.5,

(2) not include thin, flat, or elongated particles,

(3) be visually free of shale, mica, sand, silt, clay, dirt, and organic impurities,

(4) be 2-1/2 inches in size when the gravel rests directly on the strainer system and must extend above the top of the perforated laterals, and

(5) have not less than four layers in accordance with the following sizes and depth distribution when used with perforated laterals:

Size	Depth
2-1/2 to 1-1/2 inches	5 to 8 inches
1-1/2 to 3/4 inches	3 to 5 inches
3/4 to 1/2 inches	3 to 5 inches
1/2 to 3/16 inches	2 to 3 inches
3/16 to 3/32 inches	2 to 3 inches

Reduction of gravel depths will be considered by the Department when proprietary filter bottoms are specified.

m. FILTER BOTTOMS AND UNDERDRAIN SYSTEMS. The filter underdrains are placed at the bottom of the gravel bed and serve a dual purpose: (1) to collect the filtered water, and (2) to distribute backwash water uniformly beneath the filter media and gravel bed. Type of underdrains in common use include (1) perforated pipe-grids, and (2) false bottom systems of various types.

Cast iron and asbestos-cement pipes are often used for the construction of perforated-pipe type underdrains. These underdrains consist of a header running lengthwise along the center of the filter bottom, with several pipe laterals on both sides. The laterals have orifices on the underside through which filtered water is collected and backwash water is applied.

Porous plate or porous block false bottoms are suitable where deposition within the pores of the plates or blocks is not a problem. If deposition occurs, there will be a progressive, undesirable increase in head loss across the plates. Structural failure may occur during backwashing if clogging is severe. Some false-bottom systems employ vitrified clay blocks containing orifices; other are constructed of concrete and contain orifices terminating in inverted square pyramids filled with large and small earthware spheres.

Departures from these standards may be acceptable for high-rate filters and for proprietary bottoms. Porous plate bottoms shall not be used where iron or manganese may clog them or with waters softened by lime.

Design of perforated-type collection systems shall:

(1) minimize loss of head in the header and laterals,

(2) assure even distribution of the wash water and an even rate of filtration over the entire area of the filter,

(3) provide a ratio of the area of the final openings of the collection system to the area of the filter at about 0.003,

(4) provide a total cross-sectional area of the laterals at about twice the total area of the final openings, and

(5) provide a cross-sectional area of the main header (or manifold) at 1-1/2 to 2 times the total area of the laterals.

n. BACKWASH. Filters must be backwashed periodically to wash away particles trapped in the pore spaces of the filter and on the surface of the media. Filter runs between backwashes will usually range from 12 to 24 hours.

Short filter runs are often an indication of inadequate coagulation, flocculation, and sedimentation. Backwash water is applied to the underside of the filter bed through the underdrains, which should be designed to provide an even application of wash water to the filter. The wash water containing the material removed from the filter media is carried away in wash water troughs located above the surface of the filter media. Backwashing is necessary whenever the head loss through the filter exceeds the acceptable value, usually about eight feet, or when effluent turbidities are unacceptably high. The backwash water is filtered water applied to the filter at a rate of 10 to 20 gpm per square foot for a period of approximately 10 to 15 minutes. The filter bed should be expanded by 20 to 50 per cent in order to effect complete washing. The rate at which wash water is applied to the filters is highly dependent on the temperature of the water. Inasmuch as the viscosity of water becomes lower at high temperatures, more water is needed for bed expansion as the water temperature increases. For example, about 80 per cent more water is needed to achieve a 30 per cent bed expansion with 70° F water than when the water temperature is 32° F.

If the backwash water is applied in surges or if large air bubbles are present in the wash water being applied to the filter bed, the gravel and fine media may be overturned. When this occurs in enough of the bed to affect the efficiency of the filter, the entire unit must be taken out of service, and all of the media removed, regraded, and replaced. Air may collect in the backwash pump or in high places in the piping between backwashings, and should be removed from these locations through air release valves prior to backwashing. Consequently, the provision of air release valves at high points in the wash water system is a necessity.

The water used for washing the filters should be obtained from protected storage. As a minimum, sufficient wash water should be available to allow backwashing of any filter at 15 gpm per square foot for 15 minutes. If pumps are used to supply backwash water, they should have sufficient capacity to provide a minimum of 15 gpm per square foot backwash rate to any filter. Installation of standby backwash pumps should be considered to insure reliability. The need for backwash pumps can be eliminated by construction of an adequately sized wash water tank at an elevation sufficient to provide the required flow. The choice between an elevated storage tank and backwash pumps must be made on a case-to-case basis. Wash water tanks are usually filled by small pumps automatically controlled by the water level in the wash water tank.

Means of controlling and measuring the rate of flow of wash water from the pump or tank to the filters should be provided. The amount of wash water required will generally average about one per cent of the water filtered and should not exceed five per cent. Wash water use greater than five per cent is considered excessive and probably a sign of inadequate pretreatment.

During backwashing, if the wash water is not evenly distributed beneath the filter bed or if there are irregularities in the filter medium, the wash water may flow up through the filter in the areas of least resistance and form "jets" through the filter. These localized high-velocity flows may cause overturning of the filter media and gravel bed, with the resultant loss of media through the underdrains. Evidence of this occurrence is unusual "boiling" which may be visually apparent during backwashing. Also, media may appear in a leakage detector built into the effluent water line from the filter. A leakage detector consists of a small glass bowl connected by a small pipe to the underside of the effluent water line. Media settle out of the effluent water line into the glass bowl, where it can easily be seen.

Provisions for washing filters shall be as follows:

(1) A minimum rate of 15 gallons per minute per square foot shall be provided.

(2) Filtered water shall be provided at the required rate by a wash water tank, a wash water pump, from a high service main, or a combination of these.

(3) Wash water pumps in duplicate shall be provided unless an alternate means of obtaining wash water is available.

(4) Water sufficient for not less than a 15-minute wash of one filter at the design rate of wash shall be provided.

(5) A wash water regulator or valve on the main wash water line to obtain the desired rate of flow with the wash water valve on the filter wide open shall be provided.

(6) A rate-of-flow indicator, preferably with a totalizer, shall be provided on the main wash water line, located so that it can be easily seen by the operator during the washing process.

(7) The design shall provide an initial slow flow rate and shall prevent rapid changes in the backwash water flow.

o. WASH WATER TROUGHS. To equalize the static head on the underdrain system during backwashing and thus to aid in uniform distribution of the wash water, a system of troughs is used to collect the backwash water after it emerges from the filter media and to conduct it to the wash water gullet or drain. The bottom of the trough should be above the top of the expanded filter media to prevent loss of media during backwashing. The system should be designed so each trough serves an equal area of the filter. Troughs may be made of concrete, fiberglass reinforced plastic, or other structurally adequate and corrosion-resistant materials. A freeboard is allowed to prevent flooding of the trough and uneven distribution of wash water.

Wash water troughs shall be designed to provide:

(1) a bottom elevation above the maximum level of expanded media during washing,

(2) a 2-inch freeboard in the trough at the maximum rate of wash,

(3) the top edge of the trough to be level and all trough edges within the filter to be at the same elevation,

(4) spacing so that each trough serves the same number of square feet of filter area, and

(5) the maximum horizontal travel of suspended particles to reach the trough not to exceed 3 feet.

p. SURFACE WASH. In some treatment plants, the backwash process does not wash away all waste material, and "mud balls" form from agglomerated waste material on the surface of the filter media. As time passes, the mud balls can become large enough to settle into the filter media during backwashing, with the result that portions of the filter become clogged. To help avoid the formation of these mud balls, a surface or subsurface wash system is often installed. The surface wash system, which may be either fixed or rotating, usually consists of horizontal pipes containing a series of nozzles. These horizontal pipes are connected by vertical pipes to water lines above the filters. These nozzles have small orifices through which water is forced down onto the filter surface. The surface wash is routinely used during backwashing. Surface wash systems are generally needed with coal-sand filters to obtain adequate cleaning deep within the bed.

Another method of enhancing filter backwashing is through the use of auxiliary air scour. This is used often in European water treatment plants, but rarely in the United States. Air is applied to the filter bed through a pipe grid laid just above the supporting gravel or through air channels or nozzles included in the underdrain system. The rate of application is 3 to 5 cubic feet per minute per square foot of filter, maintained for 3 or 4 minutes prior to, or during, filter backwashing.

If auxiliary air scour is to be provided for filter washing, the rate of air application, location of application, and time of application shall be included in the design calculations and shall be submitted to the Department for approval.

Surface or subsurface wash facilities are required for filters except for filters used exclusively for iron and manganese removal, and may be accomplished by a system of fixed or a revolving-type apparatus.

All surface wash devices shall be designed with:

(1) provisions for a minimum water pressure of 45 psi,

(2) a minimum rate of flow of 2.0 gallons per minute per square foot of filter area with fixed nozzles or 0.5 gallons per minute per square foot for revolving arms, and

(3) a properly installed vacuum breaker or other approved device to prevent back siphonage if connected to the treated water system.

q. STRUCTURAL DETAILS AND HYDRAULICS. The filter structure and filter piping shall be designed to provide the following:

(1) vertical walls within the filter,

(2) no protrusion of the filter walls into the filter media,

(3) a superstructure cover as determined necessary under local climatic conditions,

(4) head room to permit normal inspection and operation,

(5) a minimum water depth of 3 feet over the surface of the filter media,

(6) a trapped effluent to prevent backflow of air to the filter bottoms,

(7) wash water drain capacity to carry the maximum flow,

(8) cleanouts and straight alignment for influent pipes and conduits where solids loading is heavy, or following lime-soda softening,

(9) prevention of flooding by providing an overflow somewhere in the plant,

(10) prevention of floor drainage to the filter with a minimum 3-inch curb around the filters,

(11) prevention of roof drains from discharging into the filters or into the basins or conduits preceding the filters,

(12) walkways around the filters to be not less than 24 inches wide, and

(13) safety handrails or walls around filter areas adjacent to normal walkways.

r. CONTROL APPURTENANCES. Three types of filter operation controls are commonly utilized: local manual, remote manual, and fully automatic. Local manual control involves the operation of valves at the filter, usually from a filter console, to control flow rate, effluent flow rate, backwash flow rate, and sometimes filtering-to-waste. Various means may be employed for actual operation of the valves--manual, pneumatic, hydraulic, and electric are the common methods.

With remote manual control, the valve positions controlling the pertinent flows are controlled from a central control panel removed from the filter location.

Fully automatic control involves the use of devices to detect maximum head losses or filter effluent turbidities. These devices initiate the backwash cycle by the closing of filter influent and effluent valves and the opening of wash water supply and wash water drain valves. After backwashing has continued for a specified period of time or until a specified volume of wash water has been used, the wash water supply and wash water drain valves are automatically closed, and the filter influent and effluent valves opened, thus commencing normal filtration. If filtration operation is under full automatic control, provisions shall be included for manual overriding of the automatic controls.

No matter what type of control system is used, sufficient alarms should be incorporated in the system to insure that malfunctions are promptly noticed and corrected. Alarms are particularly necessary to indicate the failure of valves to perform as desired or to indicate water levels which are too high or too low, particularly in the wash water storage tank.

Several methods of controlling the rate of filtration are available. The three most commonly used are: (1) control of the effluent, (2) splitting of influent flow, and (3) variable declining rate.

The traditional rate-of-flow control in most rapid-rate gravity filters is by an automated valve on the filter effluent line. This valve is interconnected to a pressure-differential sensing device so that water is filtered at the set rate until the loss of head through the filter approaches the total available head. With this method, there is a constant total pressure drop across the filter including the piping and automated valve. With the automatic controls currently available, the plant operator only has to select the desired flow rate; filter operation and backwashing are controlled automatically.

Plants have been constructed to split the flow nearly equally (influent flow splitting) to all the operating filters, usually by means of an influent weir box or siphon to each filter. The filtered water leaves the filter over a weir to assure that the effluent has a relatively constant head. The inlet water level will rise as the filter becomes dirty until the inlet weir level is reached. The filter is then backwashed. Constant rate filtration is achieved by this method if the total plant inflow remains constant. Changes in filtering rate occur slowly and smoothly without any automatic or manual control equipment. The effluent weir must be located above the filter media to prevent accidental dewatering of the filter bed. A disadvantage of the system is the additional 5 to 6 feet depth of filter box required to provide a reasonable available head loss.

The variable declining rate method involves the connection of either all the filter influent lines or all the effluent lines to a common water line, called a header. The pressure in this line is varied as needed to control the total rate of filtered water flow. The header and valves are large so that the head loss is small. This makes the water level essentially the same in all filters. As the filters get dirty, the dirtiest filters decrease their production most rapidly, automatically causing the cleaner filters to pick up the capacity lost by the dirtier filters. This method of operation causes a gradually declining rate of filtration as the filter gets dirty. Rate changes, both upward and downward, in all the filters, clean or dirty, occur gradually and smoothly without any automatic control equipment. Fixed restraints, such as orifices or weirs, must be incorporated into the individual filter effluent line so that no filter will operate at an excessively high rate immediately after being washed.

As a minimum, the following shall be provided:

(1) a loss-of-head indicator for each filter,

(2) a rate of flow indicator for each filter,

(3) a rate of flow indicator for the wash water line,

(4) a water level indicator for the wash water tank,

(5) influent and effluent sampling taps for each filter, and

(6) a manual override if full automatic filtration controls are provided.

A pump in each filter effluent line may be used as the limiting device for the rate of filtration only after consultation with and approval by the Department.

The following should be provided for each filter: provisions for draining the filter to waste with appropriate measures for backflow prevention; a 1 to 1-1/2 inch pressure hose and storage rack at the operating floor for washing filter walls; and wall sleeves providing access to the filter interior at several locations for sampling or pressure sensing.

s. OPERATION MONITORING DEVICES. Inasmuch as a filter is intended to provide the best possible removal of particulate matter from water, the parameter most easily measured to provide an immediate indication of filter performance is turbidity. The turbidity of the filter effluent should be measured by a laboratory light-scattering microphotometer or a continuous-flow, light-scattering microphotometer, accurate to within ±0.005 turbidity units. It is desirable to have continuous recording equipment connected to the turbidimeter so that trends can be easily determined.

If a water treatment plant has several filters, the turbidity of water from each of the filters can be measured by a single turbidimeter by connecting sampling taps from each filter into a header leading to the turbidimeter. The lines from these sampling taps are opened and closed by solenoid valves automatically controlled by a sequencing switch. Thus, the source of water passing through the turbidimeter automatically rotates between filters. Special care is necessary to prevent the entry of air bubbles, which give false turbidity readings, to the sampling lines.

t. EFFICIENCY. The efficiency of the filtration process is dependent on a number of factors, such as filtrability (size, shear strength, and adhesive properties) of the floc, grain size and depth of filter media, and water temperature.

The effectiveness of a filtration process in removing suspended particles from water is usually gaged by the turbidities of the influent and effluent water. If the pretreatment and filtration units of a water treatment plant are operated properly, the effluent from the filter units should have 0.5 turbidity units or less.

u. FILTER AIDS. It is sometimes advantageous to add a polyelectrolyte, called a "filter aid", to the settled water prior to its passage through the filter. A filter aid can cause further coalescence of particles while the water is passing through the filter media and may increase the shear strength of the floc. Use of a filter aid is warranted only for coarse-to-fine filters such as mixed-media filters and dual-media filters. Conventional fine-to-coarse rapid sand filters are rapidly sealed off at the surface when filter aids are used.

There are many polyelectrolytes available for use as filter aids, and experimental usage can only determine the most effective one and the dosage for a particular plant and water. The dosage of polyelectrolyte as a filter aid is very low, usually less than 0.1 mg/l. For best results, the filter aid should be applied to the water just ahead of the filters.

For dual-media and mixed-media filters designed to operate at rates of 4 gpm per square foot or greater, provisions shall be provided for addition of a filter aid to the filter influent.

v. WASTE WATER DISPOSAL. All waste waters from filter backwashing and operation shall be disposed of as specified in Section R.

4. RAPID-RATE PRESSURE FILTERS. Pressure filters are similar in filter bed construction to rapid-rate gravity filters; however, in a pressure filter, the entire filter apparatus, including filter media, gravel bed, and underdrains, is enclosed in a steel shell. An advantage of a pressure filter is that any pressure in the water lines leading to the filter is not lost but can be used for distribution of the water once it has passed through the pressure filter. Between 3 and 10 feet of pressure head is lost in friction through the filter bed, but any pressure in excess of this can be utilized for water distribution. The primary disadvantage of pressure filters is that, due to the steel enclosure, access to the filter bed for normal observation and maintenance is restricted. Also, the steel shells require careful periodic maintenance to prevent both internal and external corrosion.

Pressure filters will be considered for raw ground waters and surface waters adequately pretreated, and for iron and manganese removal. Pressure filters shall not be used in the filtration of polluted waters or following lime-soda softening.

Minimum criteria relative to number, filter media, wastewater disposal, etc. given herefore for rapid-rate gravity filters also apply to pressure filters where appropriate.

a. RATE OF FILTRATION. The rate of filtration for pressure filters shall conform to that specified for rapid-rate gravity filters.

b. DETAILS OF DESIGN. Pressure filters shall be designed to provide for:

(1) loss of head gauges on the inlet and outlet pipes of each filters,

(2) an easily readable meter or flow indicator on each battery of filters; a flow indicator is recommended for each filtering unit,

(3) filtration and backwashing of each filter individually with a piping arrangement as simple as possible,

(4) top of the wash water collectors to be at least 18 inches above the surface of the media,

(5) an underdrain system to efficiently collect the filtered water and to uniformly distribute the backwash water at a rate not less than 15 gallons per minute per square foot of filter area,

(6) backwash flow indicators and controls that are easily readable while operating the control valves,

(7) an air release valve on the highest point of each filter,

(8) an accessible manhole to facilitate inspections and repairs,

(9) means to observe the wastewater during backwashing, and

(10) construction to prevent cross-connections.

5. SLOW-RATE GRAVITY FILTERS. The configuration of a slow sand filter is similar to that of a rapid-rate filter, but the modes of operation are different. Operation of a slow sand filter depends on the formation of a layer of trapped solids and impurities in the upper few inches of the filter medium (usually sand). The filtration rate through slow sand filters is usually about 3 to 4 million gallons per acre per day, which is about 1/30 the loading rate of rapid-rate filters. The sand bed is 24 to 42 inches deep, and is supported by about 10 inches of gravel. The filter sand has an effective size of about 0.3 mm and a coefficient of uniformity between 2 and 3. Slow-rate filters must be cleaned when the head loss through the filter reaches 4 feet, which usually occurs after 20 to 60 days of filter operation. Cleaning is achieved by scraping off the upper few inches of sand, washing this sand in special machines, and storing the sand until the filter bed is resanded.

Advantages of slow-rate filters are: no prior treatment processes, except plain sedimentation, are used; operation is relatively simple; and less skilled supervision is required. Disadvantages are: large land areas are required; high capital and maintenance costs; less flexibility in operation; water applied to filter must consistently have less than 20 units of turbidity; lower efficiencies in removing color; and poor results with waters having high algae content.

The trend is to select rapid-rate filters, even for waters with low turbidity, because of their flexibility in operation and moderate labor requirements.

Slow-rate filters will be approved by the Department when engineering studies indicate the adequacy and suitability of this method of filtration for a specific water supply.

a. NUMBER. The number of filters shall conform to that specified for rapid-rate gravity filters.

b. RATE OF FILTRATION. The permissible rates of filtration shall be determined by the quality of the raw water and shall be on the basis of experimental data specific to the water to be treated. The nominal rate may be 2 to 6 million gallons per acre per day, with 10 million gallons per acre per day acceptable when justified to the satisfaction of the Department.

c. FILTER MEDIA. The filter medium used in a slow-rate gravity filter shall be a clean, hard, durable, siliceous sand having the following characteristics:

(1) a total depth of not less than 30 inches,

(2) an effective size between 0.2 mm and 0.40 mm, and selected with due regard to the proposed rate of filtration and character of the raw water,

(3) a uniformity coefficient not greater than 2.5, and

(4) visibly free from dirt, loam, clay, and micaceous and organic matter.

d. FILTER GRAVEL. The supporting gravel shall conform to the size and depth distribution provided for rapid-rate gravity filters in Section F-3-1. The gravel layer shall be held at least 3 feet away from the filter's side wall to permit the filter sand to rest on the concrete bottom within 2 feet of the side walls.

e. UNDERDRAINS. The underdrain system for a slow-rate gravity filter can consist of vitrified clay tile with open joints, half tile with open joints and laid with curved side upward, or hollow blocks with perforations. Laterals discharge to a large central drain which carries the finished water from the filter. The laterals and main drain are sized to minimize the head loss in the underdrain system.

Each filter shall be equipped with a main drain and an adequate number of lateral underdrains to collect the filtered water. The underdrains shall be spaced so that the maximum velocity of water flow in the lateral underdrains will not exceed 0.75 feet per second. Maximum spacing of the laterals shall not exceed 10 feet.

f. DEPTH OF WATER ON FILTER BED. Slow-rate sand filters are filled by introducing water through the underdrain system up through the sand to drive all air from the filter bed. When the sand is covered, raw water is run onto the bed and filtration begins. Depth of water on the filter is kept fairly constant by regulating the effluent as head loss builds up in the filter bed.

The design shall provide a minimum depth of 3 feet of water over the filter sand. Influent water shall not scour the sand surface. The filter shall not be operated under a negative head.

g. CONTROL APPURTENANCES. Practically the only control necessary for a slow-rate sand filter is the rate of filtration. Control of the water entering the filter is desirable, but not necessary. Control of the filtration rate is usually accomplished by an orifice, venturi meter, or other similar metering device and a valve on the effluent line. Head loss through a clean slow-rate filter is very small and increases very slowly with time as the filter becomes dirty. Automatic effluent control devices are not necessary.

Each slow-rate gravity filter shall be equipped with:

(1) a loss of head gauge,

(2) an orifice, venturi meter, or other suitable metering device installed on each filter to indicate the rate of filtration, and

(3) a valve on the effluent line of each filter to control the rate of filtration.

h. STRUCTURAL DETAILS. Slow-rate gravity filters shall be designed to provide:

(1) a cover as determined necessary by climatic conditions,

(2) headroom of at least 7 feet 6 inches above the sand to permit normal operation by personnel for scraping and sand removal,

(3) adequate manholes and access ports for handling of sand, and

(4) filtration to waste and an overflow at the maximum water level.

i. SAND CLEANING EQUIPMENT. When the head loss in a slow-rate gravity filter reaches about 4 feet, the filter is taken out of service for cleaning. After the water is drawn down below the sand level, a thin layer of sand, about 3/4 to 1-1/2 inches, is removed from the top of the filter bed, and the filter returned to service. The sand removed is cleaned by washing and then stored. When the sand remaining on the bed after repeated cleaning reaches about 15 inches, the filter is resanded to its original sand depth by using the stored, cleaned sand.

All slow-rate gravity filtration plants, except very small plants, shall have the following sand removal and cleaning equipment:

(1) portable sand ejectors, operated by water under pressure, for removing dirty sand scraped from the filter surface, and

(2) a sand-washing unit to clean the dirty sand removed from the filter.

6. <u>DIATOMITE FILTERS</u>. The diatomite filter was developed during World War II when the military needed compact, light-weight equipment for water purification. The process consists of passing raw water through a layer of diatomaceous earth supported by a porous filter element called a septum. This layer of diatomaceous earth is about 1/8-inch thick at the beginning of filtration and must be maintained during filtration by a constant body feed of diatomite filter medium to the influent unfiltered water. At the conclusion of a filter run, the layer of diatomaceous earth will have increased in thickness to about 1/2-inch. The filter is backwashed by removing all the diatomaceous earth from the septum and flushing to waste. The filtration process is started after precoating the septum with diatomaceous earth. Filtration rates generally vary from 0.5 to 2.0 gallons per minute per square foot.

a. QUALITY OF RAW WATER. The chief difficulty in using diatomite filters is in maintaining the diatomaceous earth film of uniform permeability and filtering capability to produce an acceptable effluent. If the raw water contains substances that can adversely affect the permeability and filtering capability, diatomite filters should not be used. Gross quantities of turbidity, turbidity with poor filterability characteristics, and grossly or moderately polluted waters are examples of undesirable substances. Municipal experience to date has been principally with waters of low turbidity and good bacteriological quality.

Diatomite filters may be considered for application to surface waters with low turbidity and low bacterial contamination, and may be used for iron removal from ground waters providing the removal is effective and the water is of satisfactory sanitary quality before treatment.

Diatomite filters are expressly excluded for the following conditions:

(1) bacterial removal,

(2) color removal,

(3) turbidity removal where either the gross quantity of turbidity is high or the turbidity exhibits poor filterability characteristics, and

(4) waters with high algae counts.

b. PILOT PLANT STUDIES. Commercial diatomite filter media come in a variety of grades with mean particle sizes ranging from 10 to 50 microns. The filter medium selected must provide a filtered water of satisfactory suspended solids quality and also cake characteristics that will result in economical operation. Medium selection can only be made for each raw water by pilot plant tests, and then that medium, or equal, specified in the filter plant design.

Installation of diatomite filters shall be preceded by a pilot plant study on the water to be treated. The following conditions shall govern:

(1) Conditions of the pilot plant study such as filter rates, head loss accumulation, slurry feed rates, turbidity removal, duration of testing, etc. must be submitted to and approved by the Department prior to the study.

(2) Satisfactory pilot plant results must be obtained prior to preparation of final construction plans and specifications.

(3) The pilot plant study must demonstrate the ability of the system to meet applicable drinking water regulations at all times.

c. TYPES OF FILTERS. Diatomite filtration can be accomplished using either pressure or vacuum filters. In the pressure filter, the septum and its layer of filter media are located in a pressure housing on the discharge side of the filter pump. Accordingly, the filter cake is always maintained at a pressure greater than atmospheric. The total pressure drop or terminal head loss permitted across the filter is unlimited but in practice is usually limited to 50 to 200 feet of water.

In the vacuum filter, the septum and its layer of filter media are located in a filter housing open to the atmosphere on the suction side of the filter pump. As a result, the total pressure drop through the filter cake is limited to the total positive head of water above the filter plus the normal suction lift of the service pump. Although the theoretical suction lift of a pump is about 34 feet of water, the practical terminal head loss in a vacuum filter is only 18 to 22 feet of water.

If dissolved gases (CO_2, O_2) are present in the raw water, these gases will come out of solution in the filter cake in a vacuum filter. If the gas bubbles remain intact, they will serve to block the filter area and increase the cake thickness, resulting in a more rapid buildup of pressure drop. If the bubbles collapse, they may disrupt the uniformity of the filter cake and allow unfiltered water to pass through the cracks or openings formed.

The pressure filter has a housing which makes it difficult to observe the effectiveness of the various filter operations, and increases the cost of maintenance in repairing or replacing filter elements. The vacuum filter is much easier to operate and maintain. Vacuum filters are normally used with clearer waters, pressure filters with more turbid waters.

Pressure or vacuum diatomite filters will be considered for approval by the Department. The vacuum type is preferred for its ability to accommodate a design which permits observation of the filter surfaces to determine proper cleaning, damage to a filter element, and adequate coating over the entire filter area.

d. NUMBER. The number of filters shall conform to that specified for rapid-rate gravity filters.

e. RATE OF FILTRATION. The recommended nominal rate of filtration is 1.0 gallon per minute per square foot of filter area with a maximum rate of 1.5 gallons per minute per square foot. Each filter shall be provided with equipment to indicate and maintain a constant rate of flow through the filter.

f. HEAD LOSS. The head loss through a filter shall not exceed 30 psi for a pressure diatomite filter, or a vacuum of 15 inches of mercury for a vacuum filter.

g. RECIRCULATION. The filter media is retained on the septum by either pressure or vacuum. If this pressure or vacuum is removed by taking the filter out of service, the filter media drops off the septum. Where the possibility of interrupted operation of the filter cycle exists, the filter cake should not be allowed to slip or fall off the septum. Each installation should provide positive filter cake control during such periods. A pump recirculation system should be provided to circulate water from the filtered water side of the septum to the raw water side at a flow rate sufficient to keep the filter cake in place. This system should automatically start when filtering is interrupted.

A recirculation or holding pump shall be employed to maintain differential pressure across the filter unit when the unit is not in operation. A minimum recirculation rate of 0.1 gallon per minute per square foot of filter area shall be provided.

h. PRECOAT. A uniform precoat shall be applied hydraulically to each septum by introducing a slurry to the tank influent line and employing a filter-to-waste or recirculation system.

Diatomaceous earth in the amount of 0.1 pound per square foot of filter area or an amount to apply a minimum 1/16-inch coating should be used with recirculation. When precoating is accomplished with a filter-to-waste system, 0.15 to 0.20 pound per square foot of filter area is recommended. Only filtered water shall be used during precoating operations. The filter influent shall be designed to prevent scour of the diatomaceous earth from the filter element.

i. BODY FEED. For proper operation, each diatomite filtration installation should be provided with a body feed apparatus with an adjustable feed range adequate to cover the anticipated variation of body feed. Since dry diatomaceous earth is dusty and individual particles are fragile, dust-free handling equipment should be provided, and feeders should be designed to reduce or prevent the degradation of particles. Only slow-speed mixers should be used in slurry mix tanks. Preferably, the slurry should be fed into the discharge side of the filter service pumps.

For diatomite filtration installations, the following shall apply:

(1) A body feed system to apply additional amounts of diatomaceous earth slurry during the filter run shall be provided.

(2) The rate of body feed is dependent on raw water quality and characteristics and must be determined in the pilot plant study.

(3) Continuous mixing of the body feed slurry is required.

(4) Accessibility to the feed system and feed lines shall be provided.

j. SEPTUM. The septum or filter element shall be structurally capable of withstanding maximum pressure and velocity variations during filtration and backwash cycles, and shall be spaced such that not less than 1 inch is provided between elements or between any element and a wall.

The septum design shall be such as to facilitate uniform precoating and rapid and effective cleaning.

k. BACKWASH. Once the filter run has been terminated, the backwash or cleaning cycle is initiated to wash the accumulated filter cake (precoat plus body feed plus suspended particles) from the septum and filter housing. Many methods of cleaning are used: air-bump, reverse-flow, jetting, high-velocity sluicing, and air-gurgle. Care must be taken to assure that all the filter media is removed from the septum and filter housing.

In backwashing of diatomite filters, the following shall apply:

(1) Only filtered water shall be used during cleaning operations.

(2) No direct connection shall exist between the potable water supply and the filter cleaning system.

(3) The cleaning method shall be designed to assure adequate distribution of water to all parts of the filter area to free the filter area of filter cake and to dislodge the cake so it will be flushed completely from the filter housing.

(4) Waste waters from the cleaning operation shall be disposed of as specified in Section R.

l. TREATED WATER STORAGE. Treated water storage capacity in excess of normal requirements shall be provided to:

(1) allow operation of the filters at a uniform rate during all conditions of system demands at or below the approved filtration rate, and

(2) guarantee continuity of service during adverse raw water conditions without bypassing the system.

m. APPURTENANCES. For proper operation and control of the process, the following shall be provided for each filter:

(1) sampling taps for raw and filtered water,

(2) loss of head or differential pressure gauge,

(3) rate of flow indicator, preferably with totalizer,

(4) a throttling valve to reduce rates below normal during adverse raw water conditions, and

(5) a continuous monitoring turbidimeter with recorder on the filter effluent for plants treating surface water.

n. DISINFECTION. All waters which are filtered through diatomite filter units shall be disinfected as specified in Engineering Bulletin No. 8.

G. SOFTENING

1. HARDNESS. Water softening is the process of removing hardness. Hardness is caused principally by calcium and magnesium ions in the water. Other ions that can cause hardness include aluminum, iron, manganese, strontium, and zinc. However, the concentrations of the latter are usually too low to be of practical significance insofar as hardness is concerned. In general, the sum of calcium and magnesium ions, expressed in terms of equivalent calcium carbonate, indicate the hardness of a water.

   Hardness of water is invariably expressed in terms of calcium carbonate ($CaCO_3$). Factors for converting calcium, magnesium and other ions to equivalent calcium carbonate are as follows:

Ion	Factor
Calcium (Ca^{+2})	2.497
Magnesium (Mg^{+2})	4.116
Aluminum (Al^{+3})	5.564
Iron (Fe^{+2})	1.792
Manganese (Mn^{+2})	1.822
Strontium (Sr^{+2})	1.142
Zinc (Zn^{+2})	1.531

   Multiplication of the ion concentrations in mg/l by the above factors converts to equivalent calcium carbonate ($CaCO_3$) in mg/l.

   Two types of hardness are recognized, carbonate hardness and noncarbonate hardness. Carbonate hardness is derived from limestone through the solvent action of water containing free carbon dioxide. Noncarbonate hardness is derived principally from gypsum (calcium sulfate) and related soluble calcium and magnesium salts; e.g. calcium chloride, magnesium sulfate, magnesium chloride.

   Carbonate and noncarbonate hardness are calculated as follows:

When the total hardness is numerically greater than the sum of the carbonate and bicarbonate alkalinity (expressed as calcium carbonate), that amount of hardness equivalent to the total alkalinity is termed carbonate hardness; the remainder of the hardness is termed noncarbonate hardness.

When the total hardness is numerically equal to or less than the sum of the carbonate and bicarbonate alkalinity (expressed as calcium carbonate), all of the hardness is carbonate hardness, and the noncarbonate hardness is zero.

Natural waters exhibit a wide variation in hardness from region to region in the United States. The softest waters, surface and ground, are found in New England, the Pacific Northwest, and in most of the Southeastern region. The hardest waters are found in the Midwest and Southwest. A rough classification of hardness is as follows:

Total Hardness mg/l	Classification
0-100	Very Soft to Soft
100-200	Soft to Moderately Hard
200-300	Hard to Very Hard
over 300	Extremely Hard

2. ADVERSE EFFECTS OF HARD WATER. The reasons for water softening are principally economic. Hard water consumes soaps and detergents and reduces their cleansing power. It also has an adverse effect on clothing and other articles being washed as a result of precipitates formed by interaction of the hardness constituents and the cleansing agent. Hard water may reduce the hydraulic capacity of pipes through incrustation on the pipe walls, produce scale when heated which seriously impedes heat transfer, and in general, shorten the life of pipes, fixtures, heating systems, water heaters, and boilers. Hard water is unsuitable for many industrial operations.

Softening of the entire supply can usually be justified when total hardness exceeds about 300 mg/l and may prove economically advantageous at hardness levels above 200 mg/l. Each situation requires careful analysis before a decision regarding softening the entire supply is made. However, it is generally more cost-effective to soften the entire supply than to provide a multiplicity of individual home softeners.

3. SOFTENING PROCESSES. Two general types of processes are used for softening. These are the "lime-soda ash" process and the "cation ion exchange" or "zeolite" process. The lime-soda ash process is used principally at central water treatment plants serving fairly large numbers of domestic users and/or large industries. The ion exchange process can be similarly applied and, in addition, is adaptable to small installations at homes, heating plants, laundries, etc. If the noncarbonate hardness is high, a combination of the two processes may be economically advantageous.

The selected softening process should be based upon the mineral qualities of the raw water and the desired finished water quality. Disposal of sludge or brine waste, cost of plant, cost of chemicals, and plant location should be considered in arriving at the process selection. Applicability of the softening process chosen shall be demonstrated.

a. LIME-SODA ASH PROCESS. The name of this process is derived from the principal chemicals used to effect softening. These are lime, either hydrated lime ($CaOH_2$) or quicklime (CaO) and soda ash (Na_2CO_3). If quicklime is used, it is usually converted to a slurry of hydrated lime by slaking with water prior to application. The lime is added to neutralize the free carbon dioxide in the water and to reduce the calcium and magnesium carbonate hardness. Soda ash is added to reduce the calcium noncarbonate hardness and, in conjunction with lime, to reduce the magnesium noncarbonate hardness. Some carbonate hardness invariably remains in the water because calcium carbonate and magnesium hydroxide, although considered insoluble, are slightly soluble, and thus concentration in the finished water is never reduced to zero. In most lime softened waters, it is desirable that the magnesium hardness be reduced to 40 mg/l or less. The calcium hardness could be approximately 50 mg/l and the alkalinity also about 50 mg/l.

Some ground water supplies contain no noncarbonate hardness. For such waters, lime treatment alone will suffice to reduce the hardness to the desired level.

The softening process may be carried out in conventional rapid mix, flocculation, and sedimentation basins or in suspended solids contact units. The design standards for these units are given in Sections D and E.

For most municipal supplies, a lime-soda ash softened water should have a total hardness of 75-100 mg/l (as calcium carbonate); the optimum range being 75-85 mg/l. The magnesium hardness should not be more than 40 mg/l to minimize the possibility of magnesium hydroxide scale in domestic hot water heaters. The softened water is usually stabilized to prevent corrosive or scale-forming characteristics.

Lime-soda softening yields other significant water quality benefits. Excess lime provides excellent bactericidal treatment, especially at pH values above 10.5. Lime treatment, while not a substitute for chlorination, is an effective supplement.

Removal of carbonate hardness by lime treatment results in reduction of the total dissolved solids content of the water. Lime softening is also highly effective as a means of iron and manganese removal. The high pH achieved insures essentially complete precipitation of any iron and manganese present in the raw water. Lime softening provides excellent coagulation and clarification as a result of the precipitation of magnesium hydroxide and calcium carbonate.

(1) Aeration. Aeration may be employed to remove excessive amounts of carbon dioxide from the raw water prior to softening. Carbon dioxide will be removed by lime but it may be more economical to remove the carbon dioxide by aeration. See Section C for the limitations of aeration and the requirements if aeration is employed.

(2) Sludge Removal Equipment. Mechanical sludge removal equipment shall be provided in the primary sedimentation basin. In two-stage softening, the secondary sedimentation basin need not be equipped with mechanical sludge removal equipment. If not so equipped, adequate provisions must be made for periodic removal of sludge from the secondary basin.

(3) Stabilization. The term "recarbonation" is used to designate the process of introducing carbon dioxide and/or bicarbonate ion into softened water for the purpose of neutralizing excess hydroxide alkalinity and relieving calcium carbonate and magnesium hydroxide supersaturation. Carbon dioxide is the more common compound used to stabilize a softened water.

Equipment for stabilization of water softened by the lime or lime-soda process shall be provided. See Section H for standards pertaining to calcium carbonate saturation and pH adjustment.

(4) Sludge Disposal. Since softening plants produce large quantities of sludge, means of proper disposal of waste solids must receive careful consideration at an early stage of treatment plant design. See Section R for requirements of sludge disposal.

(5) Split Treatment. Split treatment is accomplished by treating a part of the raw water with excess lime, removing by sedimentation most of the precipitated magnesium hydroxide and calcium carbonate, adding the balance of the raw water to the sedimentation basin effluent, and again mixing and settling. Employment of excess lime treatment in the first stage insures magnesium removal. The excess lime is neutralized in the second stage by carbon dioxide and bicarbonate in the unsoftened, raw bypassed water. Split treatment is often applicable to well waters containing carbon dioxide and where taste, odor, turbidity, and color are not a problem. While the process can be employed with surface waters, it is generally preferable to follow conventional procedures in which all the water receives two-stage treatment.

Split treatment is an acceptable softening treatment practice. Selection of the process will depend upon the character of the raw water and should meet specific local conditions as determined by engineering investigations, including chemical analyses of an adequate number of representative samples of water to be treated. Approval of the Department must be received.

(6) Disinfection. The use of excess lime to produce high pH values shall not be considered an acceptable substitute for disinfection.

(7) Softening Plant Design. The equipment, basins, and filters required for lime, lime-soda ash, or split treatment softening are similar to the facilities used in conventional coagulation-flocculation-filtration plants. Sections D, E, and F present

the standards for these treatment units. Filtration plants can be converted to softening plants by installation of the required treatment units and equipment.

Lime feeders and slakers are key items of equipment at a softening plant. Chemical storage facilities should be given careful consideration. Depending on the size of plant, bulk or bag unloading facilities for lime and soda ash should be provided. Standards for chemicals and chemical handling are given in Section N.

Mixing and flocculation equipment are important units of softening plants. One problem encountered at softening plants is the calcium carbonate scale that forms on rapid mixing equipment. This is particularly troublesome on high speed rapid mixers because the non-uniform scale deposits adversely affect the balance of the mixing device, causing serious vibration problems. Frequent cleaning of the mixer may be required.

Sludge recirculation is generally desirable except during occurrences of severe taste and odor problems. Recycling a portion of the settled sludge, high in calcium carbonate, to the rapid mix chamber is effective in promoting the softening reactions, especially carbonate precipitation. Sludge recycling also helps prevent excessive calcium carbonate deposition on the rotating parts of the rapid mixer. Where presedimentation is employed, recycling sludge to the presedimentation basin influent will enhance the performance of that basin. Some magnesium hydroxide from the recycled sludge will redissolve at the lower pH value prevailing in the presedimentation basin but this will be removed in the softening stages without the use of lime in excess of normal requirements. Magnesium hydroxide precipitated during softening is an excellent coagulant.

Many softening plants, particularly those treating ground water, use solids contact type basins. Basins of this type, if properly sized, will provide effective softening and clarification treatment. Section E gives the standards for these units.

A disadvantage of the lime-soda ash softening process is the production of a large mass of sludge of high water content. Provision for disposal of the softening sludges in an acceptable manner shall be made, and this problem must be carefully considered. Section R presents the standards for disposal of these sludges.

b. ION EXCHANGE. Hardness is caused principally by the calcium and magnesium cations, and ion exchange softening is accomplished by exchanging these cations for a cation, usually sodium, which does not contribute to hardness. This exchange is achieved by passage of the raw water through a bed of a granular sodium cation exchange resin. The calcium and magnesium in the water react with and are held by the cation exchanger which simultaneously replaces these ions with an equivalent amount of sodium. This reaction is reversible. After most of the sodium content of the bed has replaced the calcium and magnesium in the water, the exchanger can be regenerated with a strong solution of sodium chloride (common salt). Sodium ions from the salt solution then reenter the exchanger displacing the previously accumulated calcium and magnesium. The latter are washed out of the bed as calcium and magnesium chlorides.

Several different substances have been used as media materials including natural greensand, processed greensand, synthetic silicates, sulfonated coal, phenolic resins, and polystyrene resins. The term "zeolite" has been applied to any material used as an ion exchange softening medium, but, strictly speaking, it includes only greensands or synthetic silicates. The ability of an ion exchange softening medium to remove hardness is termed its exchange capacity and is given in terms of grains of hardness per cubic foot. The exchange capacities of some media materials are:

	Hardness Exchange Capacity grains/cubic foot
Greensand	2,800
Processed greensand	5,500
Synthetic silicates	11,000
Sulfonated coal	8,200
Phenolic resin	12,500
Polystyrene resin	28,000

Polystyrene resins are the most popular ion exchange softening materials in current use.

(1) Factors Affecting Ion Exchange Softening. Factors having a significant influence on ion exchange softening include: rate of flow through the softener; turbidity; bacterial slimes; temperature; iron, manganese, and aluminum; total hardness; sodium salt concentration in the raw water; and the salt dosage, brining time, and brine concentrations used in regeneration.

The exchange of ions within a bed occurs very rapidly, and operating capacities are little affected if the service rates do not become excessive. Severe reductions in exchange capacity are experienced if the softener operates at flow rates exceeding 10 gallons per minute per cubic foot for sustained periods of time.

Turbidity particles present in the water influent are deposited on the softening media and may cause losses of exchange capacity and excessive head losses. If turbidity levels are excessive, the particles must be removed from the water prior to softening or special backwashing procedures must be implemented.

Unless proper disinfection is practiced, bacterial slimes can form in the softening medium. These slimes coat the surface of the ion exchange material and cause excessive head losses and loss of exchange capacity. These slimes can be prevented or removed through chlorination of feedwater or regeneration water.

Loss of head through a water softener is strongly affected by water temperature, with lower head losses occurring at higher water temperature. For example, at similar flow rates the head loss through a softener at 50° C is only about 35 per cent of what it would be at 2° C. The water temperature also affects the exchange capacity of the softener, with a 10 to 15 per cent increase at high operating temperatures (> 30° C) over the exchange capacity at low temperatures (0-10° C).

If iron, manganese, and aluminum are present in the influent water, precipitates may be formed which coat the medium particles and cause a loss of exchange capacity. This problem can be avoided through treatment to remove the iron, manganese, and aluminium from the water prior to softening. If iron fouling occurs, it may be possible to remove it by periodic applications of sodium bisulfite, sodium hydrosulfite, hydrochloric acid or sulfuric acid.

Composition of the influent water may have a marked effect upon the capacity and hardness leakage of the medium. Hardness alone in the influent water has little effect on the medium. However, as the sodium content increases, competition develops between the sodium and hardness ions for the active sites on the medium. When the sodium-hardness ratio approaches or exceeds 2:1, there will be a lowering of exchange capacity. In conjunction with this capacity reduction, there will be an increase in the hardness leakage of the softener. In most water supplies, the sodium-hardness ratio is low, and the effect upon capacity and leakage is hardly noticeable.

The regeneration process generally involves three steps: (1) backwashing, (2) application of salt brine, and (3) rinsing. The purposes of backwashing are to remove any turbidity or other particles trapped in the medium. Bed expansions of 50 to 100 per cent are generally required. Backflow rates of 4 to 8 gallons per minute per square foot of bed area are employed. Backwash periods usually range from two to five minutes.

After the unit has been backwashed, a salt solution is applied to the medium to regenerate its softening capabilities. Regeneration brines are usually 10 to 15 per cent solutions of salt. The more salt used, the more complete the regeneration will be, and the greater the exchange capacity of the regenerated medium. Costs of the extra salt required to obtain the added exchange capacity must be weighed against the advantages of the higher exchange capacity. Salt consumption commonly ranges from about 0.3 to 0.5 pound of salt per 1,000 grains of hardness removed.

The contact time of the brine with the softening medium also has a direct effect on the exchange capacity of the regenerated medium. Exchange capacity increases with increasing contact time. Contact times of 20 to 30 minutes are common. Optimum regenerations are obtained if the brine concentration is between about 10 and 15 per cent.

After regeneration, the brine must be rinsed from the unit before softening is resumed. About 20 to 90 gallons of rinse water are required for each cubic foot of softening material. The total time needed for backwashing, brining, and rinsing usually varies from about 35 to 70 minutes.

(2) Design. Design of an exchange softening system is based upon the flow, influent water quality, effluent water quality requirements, resin exchange capacity, resin hydraulic characteristics, period of time between regenerations, type of operation, and number of units to be installed.

Ion exchange units may be of pressure or gravity type, of either an upflow or downflow design. Automatic regeneration based on volume of water softened or hardness sensing shall be used unless manual regeneration is justified and approved by the Department. A manual override shall be provided on all automatic controls.

Waters having five units or more of turbidity should not be applied directly to the cation exchange softener. Silica gels should not be used for waters having a pH above 8.4 or containing less than 6 mg/l silica and should not be used when iron is present. Phenolic resin should not be used. When the applied water contains a chlorine residual, the exchange resin shall be a type that is not damaged by residual chlorine. Backwash, rinse and air relief discharge piping should be installed to prevent any possibility of back-siphonage.

(3) Exchange Capacity. The design capacity for hardness removal should not exceed 20,000 grains per cubic foot when the resin is regenerated with 0.3 pounds of salt per 1,000 grains of hardness removed.

(4) Depth of Media. The depth of the exchange media should not be less than three feet.

(5) Flow Rates. The rate of softening should not exceed 10 gallons per minute per cubic foot of medium, and the backwash rate should be six to eight gallons per minute per square foot of bed area.

(6) Freeboard. The freeboard will depend upon the specific gravity of the resin and the direction of water flow. The softener should be designed to provide adequate freeboard for at least 75 per cent bed expansion without loss of resin to waste.

(7) Underdrains and Supporting Gravel. The bottoms, strainer systems, and support for the exchange resin shall conform to criteria provided for rapid-rate gravity filters as given in Section F.

(8) Regeneration. The backwash water shall be virtually free of suspended matter, and the backwash period shall not be less than two minutes. Contact time of the brine solution with the exchange resin shall not be less than 20 minutes.

The regeneration brines should be 10 to 15 per cent solutions of salt. During regeneration, the brine should be evenly distributed over the entire surface of the medium for both upflow and downflow units. After regeneration, the brine should be thoroughly rinsed from the softening unit.

(9) Blending or Bypass. Since an exchange softener will produce an effluent with practically zero hardness, the softened water is usually blended with raw water to produce a blended water with a desired final hardness. A blending bypass shall be provided around softening units to produce a blended water of desired hardness. Totalizing meters shall be installed on the bypass line and on each softener unit. An automatic proportioning or regulating device and shut-off valve should be provided on the bypass line. In some installations, it may be necessary to treat the bypassed water to obtain acceptable levels of some constituents in the finished water.

(10) Sampling Taps. Sampling taps shall be provided for the collection of representative samples of the influent, effluent, and blended water. The sampling taps for the blended water shall be at least 20 feet downstream from the blending point.

(11) Brine and Wet-Salt Storage Tanks. Tanks or basins are provided for dissolving of salt and storage of the brine. In domestic and small installations, the brine tank serves both as salt storage and concentrated-brine storage tank. During the brining cycle, the concentrated brine is withdrawn from the bottom of the tank while freshwater is introduced at the top. An excess of undissolved salt assures an ample supply of concentrated brine. Saturated brine is an approximate 26 per cent solution.

In large installations, the salt is dissolved in a wet-storage basin or tank, and the brine is transferred to a holding tank from which it is introduced into the softener.

Brine measuring or salt dissolving tanks and wet-salt storage facilities shall be covered and shall be constructed of corrosion-resistant material. The make-up water inlet shall have a free fall discharge of two pipe diameters above the maximum liquid level of the unit or be otherwise protected from back-siphonage. Water for filling the tank should be distributed over the entire surface by pipes above the maximum brine level in the tank. The salt shall be supported on graduated layers of gravel under which is a suitable means of collecting the brine.

Wet-salt storage basins shall be equipped with manhole or hatchway openings having raised curbs and watertight covers having overhanging edges. The overflow, where provided, shall be turned down, have a proper free fall discharge, and be protected with corrosion-resistant screens or self-closing flap valves.

(12) Dry Salt Storage Capacity. Salt storage should have sufficient capacity for at least 30 days of operation.

(13) Stabilization. Stabilization of the blended water for corrosion control shall be provided. See Section H.

(14) Construction Material. The softener interior shall be constructed of or coated with a material resistant to salt corrosion. All internal and external pipes, valves, and fittings shall be constructed of corrosion-resistant materials.

(15) Waste Disposal. Suitable disposal shall be provided for the brine waste and the overflow from the wet-salt storage basins. See Section R.

(16) Housing. Salt storage shall be enclosed and separated from other operating areas in order to prevent damage to equipment.

H. CORROSION AND SCALE CONTROL

"Corrosion" can be defined as the deterioration of metal by direct chemical or electrochemical reaction with its environment. "Scale" refers to an accumulation of solids precipitated out of the water. Scale, which may be hard or soft, loose or adherent, is often found on the interior surfaces of pipelines, tanks, boilers, etc. Scale usually accompanies corrosion and vice versa. The scope of this section is limited principally to the control of internal corrosion and scale in pipe systems used to distribute potable water.

Corrosion and scale in a water distribution system adversely affects the system's hydraulic capacity resulting in a significant economic loss. Corrosion products, such as hydroxides and oxides of iron, often produce a serious deterioration in water quality. When flushed out of the system, these iron compounds cause numerous "red water" complaints and stains on laundry and plumbing fixtures. Loose deposits of manganese scale cause generally similar problems.

In water treatment, corrosion and scale are closely associated. Both must be considered in connection with the design and operation of treatment works. Thin scale may be desirable because it can provide a measure of protection against corrosion. However, thick layers of scale are detrimental in both hot and cold water systems. It is essential to produce a "balanced" water that is neither highly corrosive nor excessively scale forming.

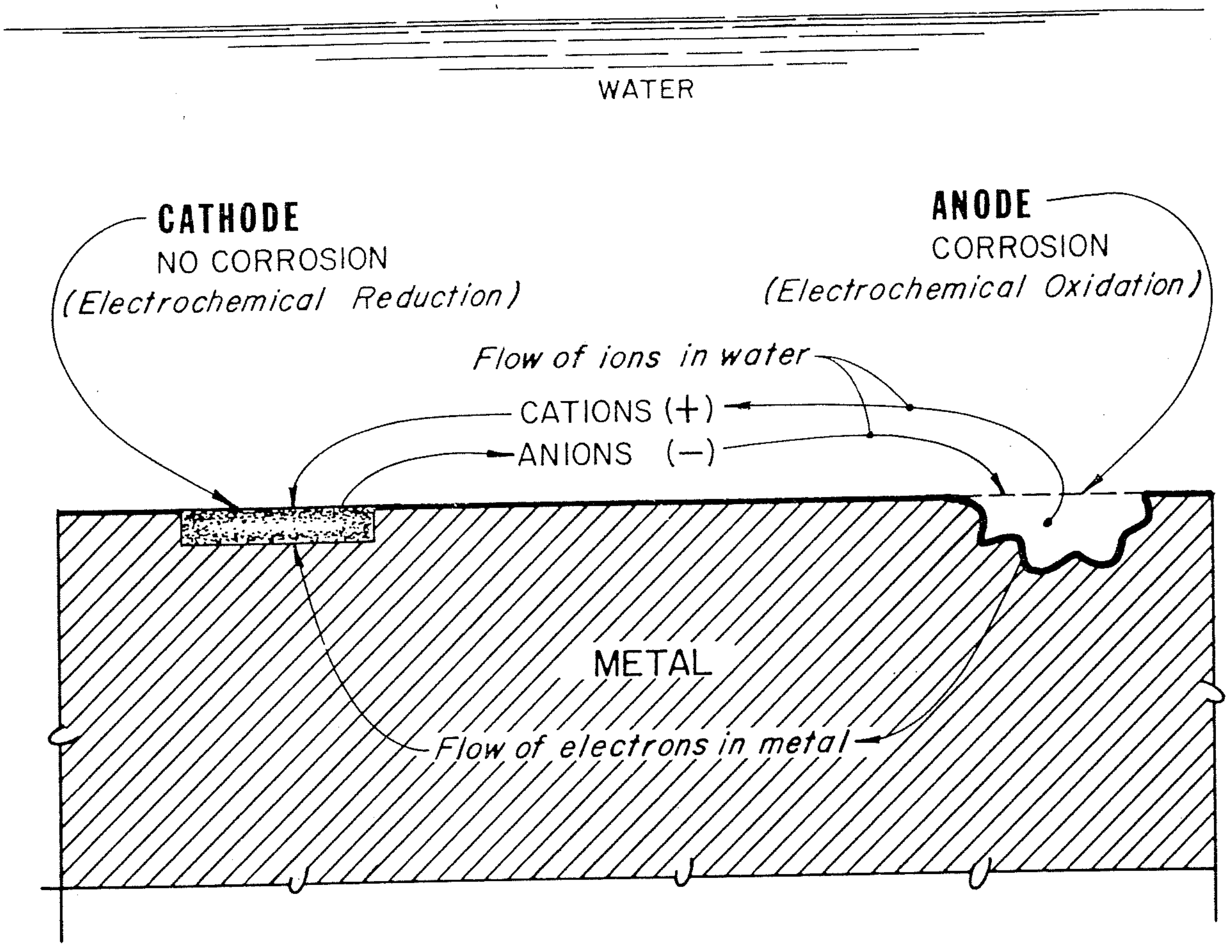
1. CORROSION. Corrosion occurs because metallic elements, with the exception of the noble metals, gold and platinum, are not inherently stable as metals. Offered the opportunity, most metals, notably iron, will revert to more stable forms chemically similar to metallic ores encountered in mining operations. In the case of iron, stable forms of this element are exemplified by various oxides such as hematite (Fe_2O_3) and magnetite (Fe_3O_4). These and other oxides are the familiar iron rust, which in low concentrations in water can cause turbidity and staining. Corrosion of metals, such as iron, can never be entirely eliminated, but can, through practical control measures, be reduced to a tolerable level.

   Distribution systems constructed of iron pipe present a large iron-water interface, and there is ample opportunity for corrosion reactions between the pipe and water. These reactions, unless controlled, can produce large amounts of familiar iron rust which can cause loss of hydraulic capacity and serious water quality problems. The extent and nature of these corrosion reactions depend upon a multiplicity of factors. Among the most important are the chemical and physical nature of the water, its velocity, pipe metallurgy, dissolved oxygen in the water, and pipe coating. In existing systems, where corrosion is a problem, most of these factors, with the exception of the chemical nature of the water, are not readily susceptible to change. Consequently, for these situations, emphasis must be placed on adjustment of the water's chemical quality as the only practical means of corrosion control. Controllable factors are principally calcium content, alkalinity, and pH. Certain corrosion inhibitors can also be used, but relatively few are suitable for potable water systems.

Corrosion of iron in contact with water is an electrochemical reaction; i.e., one that is accompanied by a flow of electrons. The electrode at which electrochemical oxidation occurs (loss of electrons) is termed the "anode". The electrode at which chemical reduction occurs (gain of electrons) is termed the "cathode". The circuit is completed via the metal and the water. Iron is corroded (oxidized) at the anode. There is little or no corrosion at the cathode. A corrosion "circuit" is shown in schematic form on Figure H-1.

The process of corrosion of iron involves formation of a solution of the metal in the water. This is the "anodic" or oxidizing reaction. For corrosion to take place, there must be exposed anodic areas at which chemical oxidation can occur and similar cathodic areas at which an exactly equivalent amount of reduction can proceed. These areas are invariably present in iron pipe. In addition, the electrical circuit must be completed via the pipe and water in contact with the anodic and cathodic areas. All of these requirements are met by unlined iron water pipes.

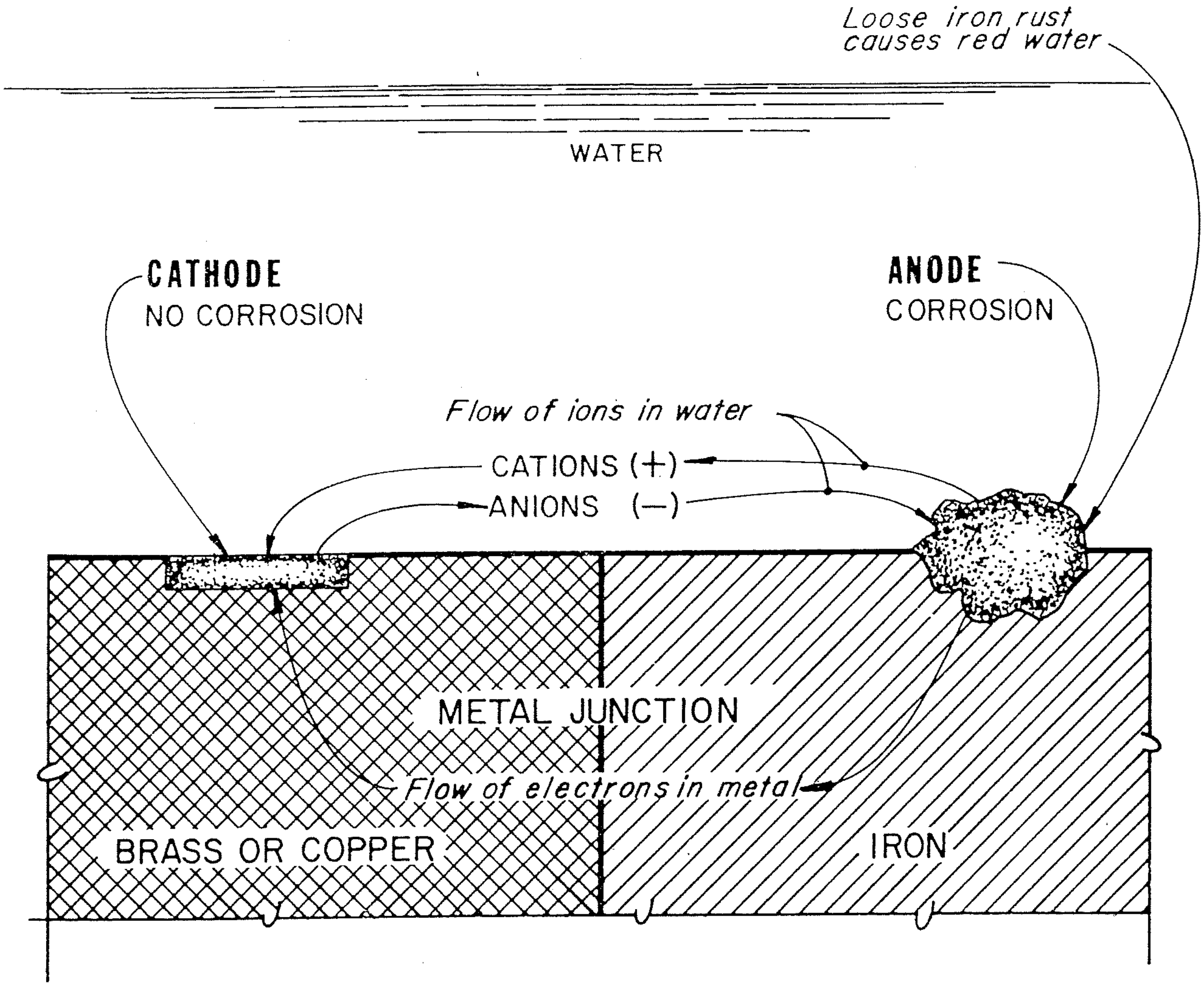
Rapid corrosion of iron also occurs when it is in contact with brass or copper in water. This is an example of "galvanic" corrosion and is characteristic of the interaction of dissimilar metals in contact with each other and water. Galvanic corrosion is shown schematically on Figure H-2. In this reaction, the anodic or least noble metal corrodes; the cathodic or more noble metal does not corrode. The relative behavior of different metals may be gaged from the electromotive force series or from a galvanic series that takes into account the environmental conditions normally encountered in water. In this galvanic series, magnesium, zinc, and aluminum are anodic or less noble than steel or iron, whereas the brasses, bronzes, copper, and tin are cathodic or more noble than steel or iron.



Electric current is carried by electrons through the metal and by ions through the water.

SCHEMATIC DIAGRAM ILLUSTRATING ELECTROCHEMICAL PROCESS OF CORROSION OF METAL

FIGURE H-1



SCHEMATIC DIAGRAM ILLUSTRATING ELECTROCHEMICAL PROCESS OF CORROSION OF IRON IN CONTACT WITH BRASS OR COPPER

FIGURE H-2

The speed at which corrosion occurs depends upon the rate of the anodic reactions. This rate is matched at the cathode and is indicated by the corrosion current in amperes. The total corrosion current, hence the rate of corrosion, is dependent on the resistance of the corrosion circuit. This resistance is influenced by temperature, coatings on the pipe such as mortar or coatings derived from the water as a result of treatment, and by mineral substances dissolved in the water. A key factor in corrosion control is the suppression of the corrosion reaction by blocking the anodic and/or cathodic areas in the pipe. This can be accomplished by pipe coatings and by water treatment designed to produce and maintain an effective coating. Treatment to insure deposition and maintenance of a thin layer of calcium carbonate on the pipe interior is one widely used means of corrosion control. This control method, while not infallible, has been fairly successful in minimizing the corrosion rate of iron pipe.

Corrosion rates may also be reduced by the use of certain inhibitors. For potable water systems, the most practical inhibitors are certain polyphosphate compounds and silicates. Sodium silicate has been used to a limited extent in very soft waters. Polyphosphates have been applied for scale as well as corrosion control. They are considered most effective for corrosion control in the pH range 5.0 to 8.0, and their effectiveness is greatly influenced by velocity. Low velocity, such as encountered in dead-end mains, reduces the effectiveness of this corrosion control method.

Dissolved gases have a significant effect on corrosion rates. Carbon dioxide can be removed chemically but it is generally not feasible to attempt chemical removal of oxygen from potable water supplies. Most surface waters are normally saturated with oxygen. Ground waters, initially free of oxygen, usually absorb some during treatment and distribution. When considering the removal of carbon dioxide by aeration, it should be kept in mind that while efficient aeration will remove most of the carbon dioxide, it will, in doing this, practically saturate the water with oxygen.

Dissolved oxygen is a major factor in the corrosion of iron. Ferrous (Fe^{2+}) ions are formed at the anode of the corrosion cell and in the presence of dissolved oxygen, the iron is oxidized to the ferric (Fe^{3+}) state and hydrolyzed. The net result is the formation of iron rust [$Fe(OH)_3$] and hydrogen ions which maintain a condition of acidity at the anode. This increases the rate at which iron goes into solution; i.e., the corrosion rate. However, this rate is limited by the

supply of oxygen to the anode. Oxygen must diffuse through the water to reach the anode, and the greater the concentration of oxygen in the water, the more rapid is its diffusion. Also, the greater the water velocity, the more oxygen is carried to the anode. On the other hand, the precipitated iron rust at the anode tends to limit the diffusion of oxygen to the anode. If the rust is removed by flushing or cleaning, the oxygen barrier is eliminated and accelerated corrosion results.

At the cathode, in the presence of dissolved oxygen, the principal reaction is that of water and oxygen to form hydroxyl (OH^-) ions. As at the anode, the oxygen supply is regulated by oxygen concentration and water velocity. Important side reactions at the cathode involve bicarbonate alkalinity (HCO_3^-) and calcium (Ca^{2+}). Bicarbonate reacts with hydroxyl to form carbonate (CO_3^{2-}). The carbonate formed then reacts with calcium ions, and calcium carbonate ($CaCO_3$) is precipitated if the water contains sufficient calcium. The result is the formation of a calcium carbonate barrier at the cathode which reduces oxygen diffusion to the cathode and hence reduces the corrosion rate. The rate of formation of calcium carbonate is favored by high concentrations of calcium and bicarbonate and carbonate alkalinity. Protection of this type cannot be attained in waters containing very low concentrations of calcium and alkalinity. To obtain appreciable benefit from alkalinity and calcium, the total alkalinity, expressed as calcium carbonate, should be at least 50 mg/l, preferably in the range of 50 to 100 mg/l. The calcium concentration, calculated as calcium carbonate, should also be at least 50 mg/l. In general, the higher the concentrations of alkalinity and calcium, the greater is the water's capacity for corrosion retardation. On the other hand, excessive calcium and alkalinity will often result in objectionable scale formation. It is, therefore, necessary to seek a compromise between corrosion on the one hand and scale formation on the other.

Chloride and sulfate accelerate corrosion whereas calcium and alkalinity inhibit it. A qualitative judgment regarding the corrosion action of a water can be made on the basis of the concentrations of chloride, sulfate and alkalinity in relation to one another. This finds expression in the following ratio termed the "Corrosion Index".

$$\text{Corrosion Index} = \frac{(.02821)\quad(Cl^-) + (.02083)\quad(SO_4^{2-})}{(.01639)\quad(HCO_3^-)}$$

(Cl^-) = mg/l chloride ion as Cl^-
(SO_4^{2-}) = mg/l sulfate ion as SO_4^{2-}
(HCO_3^-) = mg/l bicarbonate ion as HCO_3^-

For a pH range of about 7 to 8, and in the presence of dissolved oxygen, an index below about 0.1 indicates probable general freedom from corrosion. An index higher than 0.1 is indicative of corrosion tendencies. The higher the index, the greater the probability of corrosion.

In general, temperature increases will accelerate corrosion. However, temperature exerts its effect in a complex manner. Solubilities of scale forming substances such as calcium carbonate are generally reduced as the temperature increases. On the other hand, the ionization of water is greater at elevated temperatures. The result is increased conductivity and lower pH with consequent effects on solubility and corrosion rates. An additional important effect of temperature may be reversal of the polarity of the corrosion cell. Zinc is normally anodic to iron and, therefore, offers protection to the iron. However, at elevated temperatures (170° F), iron may become the anode. The result is loss of protection afforded by the zinc and rapid corrosion of the iron.

2. SCALE. Scale problems in distribution systems are caused principally by calcium carbonate, magnesium hydroxide, aluminum hydroxide and the oxides and hydroxides of manganese and iron. Zinc carbonate and hydroxide may also be encountered occasionally as a result of internal corrosion of galvanized pipe. Hydrous oxide deposits of iron and manganese are inevitable in distribution systems handling water containing more than about 0.3 mg/l of iron and 0.05 mg/l of manganese. The severity of the problem is directly related to the concentration of iron and manganese, and the best solution is to remove them at the source. See Section L. A less satisfactory procedure is to attempt to prevent their precipitation by polyphosphate treatment at the source. Iron deposits may also be caused by corrosion reactions which form loose scale or tubercles. In severe cases, cleaning and lining of the pipe may be required. Tubercle formation can be minimized through corrosion control.

   a. ALUMINUM. Aluminum hydroxide deposits can result from excessive alum use for coagulation and/or improper coagulation pH. See Section D. Aluminum hydroxide can create a soft, white deposit having a rippled surface which will produce surprising reductions in pipe carrying capacity as measured by the Hazen-Williams "C" value. The problem is one of "after precipitation" of aluminum hydroxide; i.e., aluminum remains in solution until after filtration. Chlorination, which often follows filtration, will reduce the pH slightly, and the chemical nature of aluminum is such that a slight reduction in pH will result in a significant reduction in solubility.

Temperature as well as pH also plays a role in aluminum precipitation. A temperature increase will reduce its solubility. This solubility reduction with temperature rise is characteristic of other scale forming substances, such as calcium carbonate and magnesium hydroxide.

b. MAGNESIUM. Magnesium hydroxide deposits have caused serious difficulties in distribution systems and hot water heaters. Magnesium solubility is highly sensitive to pH and temperature, and failure to exercise careful control over its stabilization following softening will usually lead to deposition problems. A softened water should not be supersaturated with magnesium hydroxide at the water temperature prevailing in the distribution system because such water is quite likely to form a soft scale in distribution piping. This scale usually has a rippled surface, and a relatively thin layer will produce a large reduction in the hydraulic capacity of the system. A warning of potential magnesium problems is the accumulation of soft, white deposits in hot water tanks and hot water pipes. Magnesium silicate as well as magnesium hydroxide may be involved. All such deposits have an insulating effect that greatly reduces heat transfer efficiency in hot water heaters.

Experimental work conducted by one large water utility led to the following criteria for pH and magnesium hardness. These criteria are based on protection of domestic hot water heaters operated at water temperatures up to 140° F.

pH of Water at 25° C (77° F)	Maximum Allowable Magnesium Hardness ($CaCO_3$) mg/l
9.0	65
9.2	57
9.4	51
9.6	45
9.8	40

These data on magnesium hardness and pH should be viewed as approximations and are presented merely for guidance. Each situation should be independently investigated. In the absence of detailed information regarding the scaling tendencies of a given water, it is advisable to maintain magnesium hardness below 40 mg/l and the pH below 9.8. Hot water heaters should be operated so that water temperatures will not exceed 140° F.

c. CALCIUM. Calcium carbonate deposits have caused serious problems in distribution systems. In some cases, the scale has built up to such an extent that flow through the pipe has practically been stopped. Careful control of pH, calcium concentration, and alkalinity following softening is necessary to prevent excessive calcium carbonate deposition. A thin layer of calcium carbonate on the interior surface of distribution system piping can be beneficial in helping to control corrosion. The calcium carbonate insulates the pipe surface, thereby preventing the formation of active anodic or cathodic areas. A method of estimating calcium carbonate saturation so that deposition is minimized is presented later in this section.

3. CONTROL OF CORROSION. Corrosion protection of water pipe can be achieved through the use of corrosion-resistant pipe materials, such as copper, concrete, and cement-asbestos; use of galvanized pipe; and cement or coal tar or calcite lined pipe. Chemical control by water treatment is a useful supplement to these measures but not a substitute for them. Chemical control can be expected to allevaite corrosion problems resulting from distribution system deficiencies but not eliminate them entirely.

a. CALCIUM CARBONATE SATURATION. One means of corrosion control that has been reasonably successful is treatment of the water to ensure deposition and maintenance of a coating of calcium carbonate. Various procedures are available to predict the tendency of a water to precipitate or dissolve a protective coating of calcium carbonate. A widely used method is based on computation of what is termed the "Saturation Index" (SI). This index is calculated as follows:

$$SI = pH - pH_s$$

where

SI = Saturation Index
pH = Actual pH of the water
pH_s = Calculated pH of water corresponding to saturation with calcium carbonate

The value of pH_s is calculated on the basis of no change in the water's alkalinity, calcium content, dissolved solids, or temperature. If the computed pH_s is less than the actual pH, the SI will be positive, indicative of a calcium carbonate deposition tendency. If pH_s is greater than the actual pH, the SI will be negative, indicating undersaturation or a tendency toward dissolving calcium carbonate. A SI value of 0 indicates exact saturation with calcium carbonate and no tendency toward deposition or solution.

The complete equation for the exact calculation of pH_s is quite complex and a simplified form, covering the pH range of 6.5 to 9.5, is as follows:

$$pH_s = K - [\log_{10} Ca^{2+} + \log 10 \ Alk]$$

where

pH_s = pH of calcium carbonate saturation

K = a numerical value whose magnitude depends on temperature and total dissolved solids concentration (TDS)

$\log_{10}Ca^{2+}$ = logarithm to the base 10 of the Ca^{2+} concentration in mg/l

$\log_{10}Alk$ = logarithm to the base 10 of the total alkalinity expressed as $CaCO_3$, in mg/l

Values of Ca^{2+} and Alk are obtained from analytical data. The value of K is obtained from the following table.

K VALUES

TDS mg/l	0°C	10°C	20°C	25°C	50°C	60°C	70°C	80°C	90°C
0	11.75	11.53	11.32	11.24	10.82	10.66	10.53	10.38	10.25
20	11.84	11.62	11.41	11.33	10.91	10.75	10.62	10.47	10.34
40	11.88	11.66	11.45	11.37	10.95	10.79	10.66	10.51	10.38
80	11.92	11.70	11.49	11.41	10.99	10.83	10.70	10.55	10.42
120	11.96	11.74	11.53	11.45	11.03	10.87	10.74	10.59	10.46
200	12.01	11.79	11.58	11.50	11.08	10.92	10.79	10.64	10.51
280	12.06	11.84	11.63	11.55	11.13	10.97	10.84	10.69	10.56
400	12.11	11.89	11.68	11.60	11.18	11.02	10.89	10.74	10.61
520	12.16	11.94	11.73	11.65	11.23	11.07	10.94	10.79	10.66
680	12.21	11.99	11.78	11.70	11.28	11.12	10.99	10.84	10.71
800	12.23	12.01	11.80	11.72	11.30	11.14	11.01	10.86	10.73

Column at left gives total dissolved solids (TDS) in mg/l. Other column headings show water temperature in °C. Values of "K" are given in the body of table.

The saturation index is not a quantitative index in the sense of providing a numerical measure of the amount of calcium carbonate that will be precipitated or dissolved. Rather, it merely indicates a tendency in the direction of precipitating or dissolving calcium carbonate. If the water is extremely soft (deficient in calcium ions) and has a low alkalinity, the water's capacity for protection will be minimal even though a high pH and a positive SI are consistently maintained. A water should contain at least 50 mg/l of alkalinity and at least 50 mg/l of calcium hardness in order to take advantage of calcium carbonate protection. For softened waters, it is usually best to maintain a SI of about +1.0, and, in addition, apply about 0.5 mg/l of polyphosphate to the filtered water in order to prevent excessive deposition in pumps and mains near the treatment plant.

Maintenance of a positive saturation index does not preclude the possibility of corrosion. Conditions may be such that only a partial coating of calcium carbonate is deposited, resulting in a type of corrosion at the uncoated areas known as "pitting". The pits develop at anodic points of limited area on the pipe surface. Other large areas, including those coated with calcium carbonate, serve as cathodes. The overall result is high intensity corrosion at the relatively small anodic areas. Pitting corrosion results in loss of metal from relatively small areas of the pipe rather than uniformly over the entire surface. As a consequence, the pipe may fail rather quickly because of corrosion penetration of the pipe wall.

b. PH ADJUSTMENT. At water softening plants, pH adjustment to provide a satisfactory saturation index can usually be accomplished by control of recarbonation and finished water alkalinity. For natural waters, the pH can be adjusted upwards by the use of alkaline agents such as lime, soda ash, or caustic soda at some stage in the treatment process, usually immediately following filtration. For a downward pH adjustment, an acid, such as hydrochloric or sulfuric, can be used.

Inasmuch as the value of pH_s is dependent on both the alkalinity and calcium concentrations in the treated water, either quicklime or hydrated lime are somewhat more effective than soda ash or caustic soda. Lime treatment increases both alkalinity and calcium concentration, whereas soda ash or caustic soda affects only alkalinity. A disadvantage of lime is that it increases the hardness of the water.

Under some conditions, a lime softening water treatment plant may use "split treatment" in which raw water is blended with lime-softened water to partially stabilize the water. Treatment plants designed for "split treatment" should also contain facilities for further stabilization by other methods.

Unstable water created by ion exchange softening shall be stabilized by an alkali feed. An alkali feeder shall be provided for all ion exchange water softening plants except when exempted by the Department.

If an acid is used for pH adjustment, the feed equipment shall conform to Section N, and adequate precautions shall be taken for safety.

c. PHOSPHATES. The feeding of polyphosphates and bimetallic polyphosphate (sodium-zinc glassy phosphate) may be applicable for sequestering calcium in lime-softened water, corrosion control, and in conjunction with alkali feeding following ion exchange softening. The effectivness of the phosphates is related to pH and flow conditions.

Dosages are usually in the range of about 0.5 mg/l to 5 mg/l. The sodium-zinc polyphosphate compound apparently is more effective for corrosion control than sodium polyphosphate although neither is very effective as a corrosion inhibitor at pH values above 8.0. Maximum effectiveness for iron and steel is achieved in the pH range 6.0 to 7.5. Both compounds give the best results when the calcium hardness of the water is 20 mg/l or greater.

When using phosphates, the following shall apply:

(1) Feed equipment shall conform to Section N.

(2) Phosphate shall be food grade.

(3) Stock phosphate solution shall be kept covered and disinfected by carrying approximately 10 mg/l free chlorine residual.

(4) Satisfactory chlorine residuals shall be maintained in the distribution system.

d. SILICATE TREATMENT. Sodium silicate has been used for corrosion control especially in waters of low hardness and alkalinity. To be effective, treatment must be continuous. The required dosage will vary considerably depending on water quality and flow conditions and may be in the range of 1 to 30 mg/l. Higher than normal dosages are desirable for the first few months of treatment. Silicates should not be employed in high magnesium waters because of the probability of magnesium silicate scale formation in water heaters. Chemical feeders shall be as required in Section N.

e. CATHODIC PROTECTION. Since solution of metal ions from pipe is, in effect, a passage of current from pipe to water or soil, a potential applied to reverse this current flow would stop corrosion of the pipe.

This is the theory of cathodic protection. Cathodic protection is the application of a countercurrent sufficiently large to neutralize the currents responsible for corrosion. Under these conditions, the surface which was previously corroding is now the cathode, and the anodic (corroding) process occurs on an auxiliary anode. Cathodic protection can be provided (1) by using direct-current electricity to feed electrons into a metal and render it cathodic or (2) by introducing into the system a metal higher in the electromotive series, or less noble, to become the anode and be corroded or sacrificed. Protection of steel water storage tanks and distribution mains are examples of the first method. The insertion of magnesium plugs into hot water heaters is an example of the second.

Cathodic protection is a specialized field, and experts should be consulted whenever the use of cathodic protection is contemplated.

I. FLUORIDE

Fluorine is the thirteenth most prevalent element in the earth's crust and is present as fluoride in all natural waters to some extent. The concentration of fluoride in natural waters may be more or less than what public health authorities consider to be optimal. Consequently, health departments often recommend adjustment of the fluoride level in the finished water.

1. <u>HEALTH EFFECTS OF FLUORIDE IN WATER</u>. In the 1920's and 1930's, the incidence of mottling of teeth (dental fluorosis) was definitively linked to the ingestion of waters that contained high concentrations of fluoride, generally in excess of 2 mg/l. It was also observed that persons suffering from dental fluorosis had very few dental caries, and that concentrations of fluoride near 1.0 mg/l greatly reduced the occurrence of dental caries in children without producing mottling of the teeth.

Inasmuch as fluoridation effects a marked decrease in the number of dental caries suffered by children but high concentrations of fluoride cause dental fluorosis, the objective of fluoride adjustment in water treatment is to add or remove fluoride to reach an optimum concentration to reduce dental caries and to prevent dental fluorosis.

Maximum concentrations of fluoride in water which can be tolerated without the occurrence of dental fluorosis are dependent on the average daily intake of water by children in any particular location. The average daily intake of water is related to the annual average maximum daily air temperature, hence maximum fluoride concentrations are related to this temperature parameter. These maximum concentrations are as follows:

Temperature °F	Maximum Concentration 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

For those water utilities practicing fluoride removal, the above maximum concentrations shall govern.

For water utilities practicing fluoride addition, the recommended control limits are as follows:

Annual Average Maximum Daily Air Temperature* °F	Control Limits Lower mg/l	Upper mg/l
50.0 - 53.7	1.0	1.4
53.8 - 58.3	0.9	1.3
58.4 - 63.8	0.8	1.2
63.9 - 70.6	0.7	1.1
70.7 - 79.2	0.6	1.0
79.3 - 90.5	0.5	0.9

*Minimum record: five years

The average fluoride concentration in the water delivered to the distribution system shall fall between the above control limits when fluoride addition is practiced.

2. <u>OTHER EFFECTS OF FLUORIDE IN WATER</u>. The small amount of fluoride normally in or added to drinking water does not cause taste or odor nor does it increase the corrosive properties of the water or cause encrustation in the distribution system or household plumbing.

3. <u>FLUORIDE REMOVAL</u>. Although fluoride is beneficial in the prevention of dental caries, excessive concentrations of fluoride cause permanent mottling of tooth enamel and, in severe instances, pitting of the enamel and loss of teeth.

Fluoride can be removed from water by percolating the water through an insoluble, granular medium composed of activated alumina, bone meal, bone char, or tri-calcium phosphate. The fluoride is removed by a combination of ion exchange and adsorption. When activated alumina or bone char beds become saturated with fluoride, they are regenerated with a caustic soda solution. Excess caustic soda is removed by rinsing and neutralization with an acid.

Mixed-bed demineralization can also be used to reduce the fluoride concentration. A mixed-bed demineralizer will remove other minerals along with the fluoride. When exhausted, the beds must be regenerated, usually with an acid and a base. See Section J for requirements on demineralization units.

Additional methods of fluoride removal include sorption on precipitates of aluminum or magnesium and saline water conversion methods. In the magnesium process, fluoride removal is proportional to the square root of magnesium removal. Precipitation of substantial concentrations of aluminum or magnesium are required to effect major reduction in fluoride concentrations.

Saline water conversion methods, such as electrodialysis and reverse osmosis, will remove a part of the fluorides in the raw water. These methods are not selective to fluoride removal but will partially remove all ions in water as well as fluoride. See Section J for requirements on desalination units.

The predicted removal rates for the defluoridation processes are as follows:

Unit Process	Per Cent Removal
Reverse Osmosis	90 - 97
Electrodialysis	90
Ion Exchange/Adsorption	95
Excess Lime Softening	30 - 70

The method most commonly used for fluoride removal is the ion exchange/adsorption process using either bone char or activated alumina as the exchange resin. Bone char removes both fluoride and arsenic; however, arsenic can interfere with fluoride removal when bone char is used. Investigations showed that bone char which had absorbed arsenic could not be regenerated. Activated alumina, however, is readily regenerated when both fluoride and arsenic are removed. Therefore, activated alumina is the preferred medium to use for this method of fluoride removal if the raw water contains both fluoride and arsenic.

Activated alumina and bone char for defluoridation have a mesh size between 30 and 50. The filtration rate is about 4 gallons per minute per square foot of filter area. Either gravity or pressure filters can be used. Regeneration of the activated alumina and bone char media consists of backwashing to remove the accumulated solids strained from the water, use of a 0.5 to 5.0 per cent caustic solution to remove the fluorides absorbed by the medium, and neutralization of the residual caustic with an acetic, carbonic, or 0.05 normal sulfuric acid, and water rinses. The caustic solution can be applied countercurrently so that one operation combines the backwashing step and the caustic application. The acid is applied until the alkalinity of the wastewater approaches the usual alkalinity or pH of the plant effluent. Equipment required for these fluoride removal processes is a collection of standard ion exchange units, and their cost and complexity are identical to those for ion exchange plants.

Determination of the defluoridation media or processes to be used shall be based on experience at operating plants, on engineering studies, or on laboratory or pilot plant studies of their relative effectiveness and fluoride removal capacity, using samples of the actual water to be treated. Approval by the Department shall be secured of the media and processes selected. Fluoride concentrations in the finished water shall be removed to at least the maximum concentration allowable by the drinking water regulations.

4. FLUORIDE CONCENTRATION CONTROL SYSTEMS. Several alternatives exist for control of fluoride concentration with the selection being dependent upon cost, dependability and practicality. Any alternative must be approved by the Department.

   a. INDIVIDUAL UNITS. Individual fluoride removal units may be installed at each service connection in the public utility easement to treat only the water used for drinking and culinary purposes. The remainder of the water supply need not be treated for fluoride removal. This method would only be economical and practical if the number of service connections is small. To insure each unit is functioning properly, a replacement schedule should be established so that each unit is replaced at periodic intervals with a regenerated unit, and all exhausted units regenerated at a single plant. The fluoride content of the unit's effluent should be tested at intervals frequent enough to establish the replacement schedule.

   b. DUAL WATER SYSTEMS. A dual water system could be established in which one system would carry nonpotable water with objectionable fluoride concentrations and the other system potable water from a centralized fluoride removal plant. Water through both systems would have an acceptable physical and bacterial quality. Potable water, with the acceptable fluoride concentration, would be used only for drinking and culinary purposes. Under this arrangement, the capacity of the centralized fluoride removal plant would be reduced. The requirements necessary for a dual water system as given in Chapter 7 shall apply.

   c. PARTIAL TREATMENT AND BLENDING. The fluoride in a raw water may be of such a concentration that fluoride removal from only a part of the water and blending may produce a finished water with a fluoride concentration within the maximum allowable limit. Partial treatment and blending shall assure a constant acceptable fluoride content in the finished water delivered to the distribution system.

   d. BLENDING OF TWO SUPPLIES. Blending of two or more supply sources, one or more with a high fluoride content and one or more with a low fluoride content, is acceptable if the blended finished water delivered to the distribution system has a fluoride content within the maximum allowable limit.

5. FLUORIDE ADDITION.

a. FORMS OF FLUORIDE. The most common compounds used in fluoride addition are sodium fluoride, fluosilicic acid (hydrofluosilicic acid), and sodium silicofluoride. The choice of which form is best for an individual water treatment plant is dependent largely on cost, availability, and the mode of fluoride application selected. Other compounds used successfully by some water utilities are ammonium silicofluoride and hydrofluoric acid. However, neither of these compounds are recommended for routine application. The use of ammonium silicofluoride results in an increase in the ammonia content which may be objectionable because of its effect on chlorination practice. Hydrofluoric acid presents such extreme safety and corrosion problems that it is not acceptable for general use.

All chemicals used for addition of fluoride to water shall conform to the applicable American Water Works Association (AWWA) standards. Other chemicals which may become available must be approved by the Department.

All fluoride compounds shall be stored in covered or unopened shipping containers inside a building and so segregated as to prevent any confusion with other chemicals. Unsealed storage units for fluosilicic acid shall be vented to the atmosphere at a point outside any building.

(1) Sodium Fluoride. Sodium fluoride is a white, odorless, free-flowing material available as a powder or as a mixture of various-sized crystals. The crystalline form is preferred to minimize fluoride dust. The chemically pure compound contains 45.2 per cent fluoride. The solubility of sodium fluoride is about 4.0 grams per 100 ml at 25° C, which is equivalent to a fluoride concentration of about 18,000 mg/1. If the sodium fluoride being applied to the water is weighed accurately, the resulting concentration of fluoride in water can be precisely controlled. Current AWWA standards indicate that commercial sodium fluoride to be used in water treatment plants should be of at least 95 per cent purity.

Sodium fluoride is usually obtainable from distributors in 100 lb. sacks or in 400 lb. drums.

(2) Fluosilicic Acid. Fluosilicic acid (hydrofluosilicic acid) is a colorless, transparent, fuming, corrosive liquid having a pungent odor and an irritating action on the skin. The liquid solution contains 20 to 30 per cent fluosilicic acid, corresponding to about 16 to 24 per cent fluoride.

There are several undesirable effects of fluosilicic acid which should be avoided. Inhalation of air containing fluosilicic acid vapor can cause irritation of the nose and throat, and contact of fluosilicic acid with the eyes and skin can cause itching and burning. For these reasons, protective clothing should be worn when handling fluosilicic acid, and any acid coming into contact with hands, arms, etc. should be immediately washed off with water.

The pH of a 1 per cent solution of fluosilicic acid is 1.2. If fluosilicic acid is added to poorly buffered water, the pH of the water may be lowered significantly. It should not be used with a water having a very low alkalinity unless the alkalinity of the water is adjusted to compensate for the acidity derived from the fluosilicic acid.

(3) Sodium Silicofluoride. Sodium silicofluoride is a white, free-flowing, odorless, crystalline powder, containing about 60 per cent fluoride by weight. It is used for fluoride addition more than any other compound primarily because of its relatively low cost, widespread availability, and ease of handling. Sodium silicofluoride is derived from fluosilicic acid and is commercially available through producers of phosphate fertilizers.

Sodium silicofluoride is prepared as a white powder in either of two forms: regular or fluffy. The regular form has a density of about 85 pounds per cubic foot and the fluffy form a density of about 65 pounds per cubic foot. Most commercial sodium silicofluoride has a purity of 98-99 per cent. At a water temperature of 25° C, its solubility is about 0.76 gram per 100 ml. The pH of a saturated solution is 3.5.

The principal criteria in selecting the brand of sodium silicofluoride to purchase are the moisture content of the powder and the size distribution of the powder crystals. A low moisture content and a relatively narrow size distribution are best for uniform, efficient feeding of the powder in the fluoridation equipment.

b. APPLICATION OF FLUORIDES

(1) Points of Application. All water shall pass the point of fluoride injection. If no such common point exists, more than one application point shall be used. If ground water is used as a source of water without treatment other than disinfection, the fluoride should be injected beyond the well head. Multiple well installations may require a feeder at each well.

The application of fluoride in a water treatment plant should be after filtration, if possible. When fluoride is applied during the coagulation process, some fluoride will be lost. Lime softening will also remove some fluoride, especially if the concentration of magnesium in the raw water is high.

(2) Automatic Control of Fluoridation. In many cases, it is desirable to have the rate of feed of fluoride controlled automatically by a meter measuring the rate of flow of water to be treated. Automatic control of fluoride feed is acceptable if the flow meter installed is reliable and if the equipment for feeding fluoride can operate at various speeds. If automatic control is used, provisions shall be made for manual control in case the automatic control fails.

(3) Feed Equipment. Dry feeders or solution feeds can be used in feeding fluoride, depending upon the fluoride compound being used. The dry feeders can be either of the gravimetric or volumetric type.

Gravimetric dry feeders apply a dry, powdered compound, such as sodium fluoride or sodium silicofluoride, to water at a predetermined rate on a weight basis. They can deliver large quantities of the chemical in short periods of time, are extremely accurate, and can easily be controlled automatically; however, they are more expensive than volumetric dry feeders. Volumetric dry feeders apply the chemical powder at a predetermined rate on a volume basis. Due to settling, agitation, irregularly shaped particles, etc., a constant volume of a dry fluoride compound does not always have a constant weight, so volumetric dry feeders, while acceptable, are not as accurate as gravimetric dry feeders. The choice between the two types of feeds must be made on the basis of feed rates, accuracy requirements, and overall cost.

Solution feeders consist of several types of positive-displacement pumps if pressure feed is used, or a paddle-wheel or bucket apparatus if gravity feed is used. Solution feeders are required for application of fluosilicic acid and may be used for feeding solutions of the dry fluoride compounds. If solution feeders are used, the type should be selected on the basis of capacity, accuracy, durability, and corrosion resistance.

Chemical feed installations shall:

(a) conform to the general requirements of Section N,

(b) provide scales or loss-of-weight recorders for dry chemical feeders,

(c) have an accuracy that actual feed will be within 5 per cent of that intended,

(d) inject fluosilicic acid into the lower half of the pipe if the pipe is horizontal, and

(e) provide adequate anti-siphon devices for all fluoride feed lines.

c. FLUORIDE CHEMICAL STORAGE. Fluoride chemical storage and handling shall conform to the requirements as given in Section N.

d. SAFETY. Waterworks operators who handle fluoride compound should be instructed of the toxic nature of the compounds and to avoid accidental exposure. Inhalation of fluoride vapors or dust can cause severe irritations of the respiratory tract. Ingestion of fluoride can result in vomiting, diarrhea, stomach cramps, weakness, and poor vision. Accidental spills of fluoride solutions on the hands or in the eyes cause a severe burning sensation. Full advantage should be taken of the procedures and equipment available to protect workmen from possible hazardous exposures. Safety margins can be obtained by choosing less hazardous fluoride compounds, by equipping feeders and hoppers with safety appurtenances, and by providing personal safety equipment.

Personnel handling fluoride should wear protective clothing, including gloves, masks, and goggles. Thorough hand washing should be routinely practiced after each handling or loading, and showers should be taken if the loadings are prolonged.

If powdered fluoride compounds are used, hoppers shall be equipped with dust exhaust systems. Air exhausted shall discharge through a dust filter to the outside atmosphere of the building. Rooms in which acid equipment is housed shall be continuously ventilated, and the spent air exhausted to the outdoors. All vents on acid storage tanks shall terminate outdoors. All spills should be immediately hosed down and mopped. Acid spills can be neutralized with lime water.

When repairing pipelines and pumps containing fluosilicic acid, personnel should protect the hands and eyes by wearing goggles, face masks, rubber gloves, and boots. A copius amount of flowing water should be immediately available for flushing the eyes and for rinsing the hands and other parts of the skin, if necessary.

6. MONITORING FOR FLUORIDES. Equipment shall be provided for measuring the concentration of fluoride in the water. Field testing equipment shall be calibrated against more precise laboratory testing equipment. All such testing equipment shall be subject to the approval of the Department. Sampling taps shall be located to permit collection of representative samples of the raw water and of the finished water delivered to the consumer or distribution system.

J. REMOVAL OF DISSOLVED SUBSTANCES

1. REMOVAL OF DISSOLVED INORGANIC SUBSTANCES. In some cases, it may be necessary to use raw water supplies containing unacceptable concentrations of constituents that cannot be removed by conventional treatment processes. The most common of these objectionable substances are dissolved inorganic salts and trace organics.

   The presence of excessively high concentrations of dissolved inorganic minerals is most often indicated by high chloride, sulfate, and total dissolved solids. The recommended water criteria for these substances are 250 mg/l for chloride, 250 mg/l for sulfate, and 500 mg/l for total dissolved solids. Considerably higher concentrations, while not desirable, can be tolerated.

   Removal of dissolved inorganic substances is termed "demineralization" or sometimes "desalination", or "desalting". Common means of demineralization include electrodialysis, reverse osmosis, distillation, and ion exchange. Freeze crystallization can also be used, but it is not used as widely as the other four methods. These methods remove all ions whether present in the raw water in large concentrations or in trace concentrations.

   a. ELECTRODIALYSIS. Electrodialysis is the demineralization of water by the removal of ions through special membranes under the influence of a direct-current electrical field. Metal electrodes are placed at opposite ends of a stack of ion-selective membranes and a direct-current potential is applied to the electrodes. Since the minerals in water dissociate into cations and anions, the positively charged electrode, called the anode, attracts anions (ions with minus charge) present in the water, and the negatively-charged electrode, called the cathode, attracts the cations (ions with a plus charge).

      Two types of special membranes are used in electrodialysis. One can be permeated by cations only; the second by anions only. These membranes are arranged in a stack with cation-permeable membranes alternating with anion-permeable membranes. Feed water enters the space between the membranes. The direct-current electric field is applied to the stack, causing the ions to migrate toward the electrodes. This results in a concentration of ions in alternate spaces between membranes while the water in the other spaces becomes depleted in ions, or demineralized.

Water is drawn off from between the membranes in two separate streams, one containing most of the ions (brine) and the other relatively free of ions.

An electrodialysis stack can remove about 50 per cent of the dissolved solids in the feed water. Higher degrees of removal are obtained, if necessary, by arranging stacks in series which are called stages. Product water recovery (demineralized water effluent) rates generally range from 75 to 90 per cent for each stack. Total product water recovery is dependent upon the number of stacks in series or number of stages.

If the feed water is not properly prepared, the efficiency of the membranes may be greatly reduced by scaling and fouling deposits. These deposits may include suspended matter in the feed water, including iron and manganese; calcium carbonate or magnesium hydroxide scale; or calcium sulfate scale. Formation of these deposits can be avoided by pretreating the influent water as follows:

> Removal of suspended particles larger than 5 to 25 micrometers in diameter from the feed water by filters.
>
> Removal of iron and manganese.
>
> Addition of acid to lower the pH to 5.5-6.5 to prevent formation of calcium carbonate and magnesium hydroxide deposits.
>
> Addition of a sequestering agent to prevent calcium sulfate deposits.

The economics of electrodialysis is dependent upon the size of the facility, characteristics of the feed water, and the cost of power. Hardness, TDS concentration, temperature, and suspended solids are the most important feed water characteristics. Electric power is required for pumping the water through the stacks and for energizing the anodes and cathodes. The membranes have a life of about 5 years before replacement is necessary.

Electrodialysis presently is most suitable for demineralization of waters containing less than 5,000 mg/l TDS.

The following criteria shall apply to the design of an electrodialysis plant:

(1) At least two electrodialysis units shall be provided with each unit capable of meeting the plant design capacity. Where more than two units are provided, the units shall be capable of meeting the plant design capacity with the largest unit removed from service.

(2) If the feed water contains 5 units or more of turbidity, pretreatment of the feed water shall be provided to remove the suspended matter prior to pumping into the electrodialysis unit.

(3) If the feed water contains 0.3 mg/1 or more of iron and manganese, the feed water shall be treated for iron and manganese removal prior to the electrodialysis unit.

(4) If the calcium concentration in the feed water is 600 mg/1 or greater, pretreatment of the feed water shall be considered to prevent fouling of the electrodialysis membranes.

(5) A blending bypass shall be provided around the electrodialysis plant to permit production of a blended water of desired mineral concentration.

b. REVERSE OSMOSIS. When two solutions containing different concentrations of dissolved minerals are separated by a semipermeable membrane, relatively pure water will migrate through the membrane from the dilute solution to the more concentrated solution. This phenomenon, called osmosis, continues until the buildup of pressure on the more concentrated solution is sufficient to stop the flow. The amount of pressure which must be applied to the more concentrated solution to stop the flow is known as the osmotic pressure. If a pressure in excess of the osmotic pressure is applied to the more heavily mineralized water, relatively pure water will flow through the membrane in the opposite direction in a process called "reverse osmosis".

The essential element in the reverse osmosis method of demineralization is the semipermeable membrane. Several types and configurations of membranes are currently available, with the most widely used being various forms of cellulose acetate or polyamide membranes. The most common configurations are tubular, spiral wound, and hollow fine fiber. Much progress has been made in recent years on development of improved membranes, and this progress will probably continue.

The most important properties of a reverse osmosis facility are the product water recovery percentage and the salt rejection capability. Both vary with the type of membrane used, configuration of the membrane, characteristics of the feed water, and the operating pressure used. For commercial units, common operating pressures are 200 to 800 psi and water recovery rates range from 50 to 90 per cent, with an average of about 80 per cent. Salt rejection varies from about 70 per cent to near 99 per cent, with an average of 90 to 95 per cent.

The main problems causing reduction in capacity of reverse osmosis units are compression of the membranes because of the high pressures used, formation of calcium carbonate or calcium sulfate scale on the membrane, and bacterial attack on cellulose acetate membranes if water is left stagnant. Suspended matter in the feed water will also blind the membrane. The problems of suspended matter, scale formation, and bacterial attack can be eliminated by proper pretreatment of the feed water. This pretreatment is the same as that recommended for electrodialysis, except that chlorine may also be added to control bacterial attack of chlorine-tolerant membranes. If bacterial attacks are eliminated, most reverse osmosis membranes should last about three years before requiring replacement.

The principal power requirements for reverse osmosis are for pumping the feed water into the treatment modules.

The following criteria shall apply to the design of a reverse osmosis plant:

(1) At least two reverse osmosis units shall be provided with each unit capable of meeting the plant design capacity. Where more than two units are provided, the units shall be capable of meeting the plant design capacity with the largest unit removed from service.

(2) Pretreatment of the feed water shall be provided to remove suspended matter or iron and manganese if the feed water contains 5 units or more turbidity or 0.3 mg/l or more iron and manganese.

(3) If the feed water contains 600 mg/l or more of calcium, pretreatment of the feed water shall be considered to prevent fouling of the membranes.

(4) A blending bypass shall be provided around the reverse osmosis plant to produce a blended water of desired mineral concentration.

c. DISTILLATION. Distillation is the oldest method of demineralizing water. It involves the evaporation of a saline solution and condensation of the water vapor. Since the dissolved salts remain in the liquid water, the quality of condensed water will approach purity.

Inasmuch as the boiling temperature of water is directly dependent on water pressure, it is possible to heat water to a high temperature under pressure without boiling. If pressure is reduced, boiling commences. The liquid may then be passed to a second chamber under a still lower pressure where further boiling occurs. Water vapor from the first chamber is used to heat the water in the second chamber, thus conserving energy. This sequence of events can be continued until the remaining water is at the lowest feasible temperature and pressure. This is multiple-effect distillation and is one general technique of utilizing heat energy to the maximum possible extent. The three principal types of distillation processes currently used on new construction are: (1) long-tube vertical, (2) multistage flash, and (3) vapor compression.

The major problems encountered in distillation processes are scale formation, corrosion, heat transfer, and post-treatment. Scales of calcium sulfate, magnesium hydroxide, and calcium carbonate are all readily deposited in distillation units. Pretreatment of the feed water through decarbonation and pH adjustment can prevent the formation of magnesium hydroxide and calcium carbonate scale, but calcium sulfate scale formation must generally be controlled by limiting the temperature used or by limiting the concentration of calcium and sulfate ions in waste brine streams. Corrosion of pumps, pipes, pressure vessels, etc., in a distillation plant can be severe because of the high concentrations of chloride and sulfate ions generally present. This corrosion may be alleviated by pH adjustment, oxygen removal, and care in materials selection. The third problem of heat transfer is important as the distillation process is dependent on the transfer of vast quantities of thermal energy from one medium to another. The surfaces across which heat is transferred must have the highest practicable heat transfer coefficients to avoid serious losses of heat energy. The need for post-treatment is caused by the extreme purity of product waters, which makes these waters very corrosive to most metallic surfaces. Adjustment of pH or addition of inhibitors is sometimes required.

The following criteria shall apply to the design of a distillation plant:

(1) A blending bypass shall be provided around the distillation plant to produce a blended water of desired mineral concentration. Totalizing meters shall be installed on the bypass line and on the plant effluent line. An automatic proportioning or regulating device and shut-off valve shall be provided on the bypass line.

(2) At least two distillation units shall be provided with each unit capable of meeting the plant design capacity. Where more than two units are provided, the units shall be capable of meeting the plant design capacity with the largest unit removed from service.

(3) The plant product water or the blended water shall be stabilized before discharge into the distribution system. See Section H for stabilization procedures.

d. ION EXCHANGE. In ion exchange demineralization, the mineralized water is successively passed through two separate beds containing ion-exchange resins. The first resin exchanges hydrogen ions (H^+) for any cations present in the water, resulting in a highly acidic solution. This solution then passes through an anion-exchange bed in which the anions present in the water are replaced with hydroxide ions (OH^-). The hydrogen and hydroxide ions combine to form water, resulting in a demineralized product.

When the exchange capacities of the ion-exchange resins are substantially depleted, the resins are regenerated.

Cation-exchange resins are regenerated by solutions of strong acids, and anion-exchange resins are regenerated by strong basic solutions. The equipment used in ion-exchange demineralization is similar to that described in Section G for ion-exchange softening.

If waters to be demineralized by ion exchange processes contain dissolved organic materials, strong oxidizing agents, or suspended matter, pretreatment may be necessary. This pretreatment usually involves sand filtration if suspended particles are present or activated carbon filtration if dissolved organics or strong oxidizing agents are present. Iron and manganese removal may be necessary if concentrations exceed 0.3 mg/l.

Some of the water produced in an ion-exchange demineralization unit must be used for rinsing of the regenerated media and for preparation of the regeneration solutions. For a mineral reduction of 1,500 mg/l, about 20 per cent of the product water must be used for these purposes. If the mineral reduction is increased to 4,000 mg/l, about 50 per cent of the product water is used for regeneration and rinsing.

The following criteria shall apply to design of an ion exchange demineralization plant:

(1) The units may be of pressure or gravity type, of either an upflow or downflow design. Automatic regeneration based on volume of water regenerated shall be used unless manual regeneration is justified and is approved by the Department. A manual override shall be provided on all automatic controls.

(2) The freeboard will depend upon the specific gravity of the resin and the direction of water flow.

(3) The bottoms, strainer systems and support of the resin shall conform to criteria provided for rapid rate gravity filters in Section F.

(4) Facilities shall be provided for even distribution of regeneration chemicals over the entire surface of both upflow and downflow units.

(5) Backwash, rinse and air relief discharge pipes shall be installed as to prevent any possibility of back-siphonage.

(6) A blending bypass shall be provided around the demineralization units to produce a blended water of desired mineral content. Totalizing meters shall be installed on the bypass line and on each demineralization unit. An automatic proportioning or regulating device and shut-off valve shall be provided on the bypass line.

(7) Waters having 5 units or more turbidity or 0.3 mg/1 or more iron and manganese shall not be applied directly to the exchange unit but shall be pretreated. When the applied water contains a chlorine residual, the exchange resin shall be a type not damaged by residual chlorine.

(8) At least two ion exchange units shall be provided with each unit capable of meeting the plant design capacity. Where more than two units are provided, the units shall be capable of meeting the plant design capacity with the largest unit removed from service.

(9) Sampling taps shall be provided for the collection of representative samples. The taps shall be located for sampling of the unit influent, effluent and blended water. The sampling taps for the blended water shall be at least 20 feet downstream from the point of blending.

(10) Regeneration chemical storage shall have sufficient capacity for at least 30 days of operation. Chemical storage shall be enclosed and separated from other operating areas in order to prevent damage to equipment.

(11) Pipes and contact materials shall be resistant to the corrosiveness of the chemicals used.

(12) Product water stabilization for corrosion control shall be provided. See Section H.

e. OTHER METHODS. Freezing and solar distillation are two other demineralization methods on which much development work is being done. If a mineralized water is frozen so that the salt crystals are not trapped, the resulting ice will be essentially free of minerals and the brine constituents are concentrated. The mineral-free ice is separated from the brine and melted to produce a mineral-free water. This process is not practical for a water supply source.

The ion exchange/adsorption process using either bone char or activated alumina as the exchange resin is effective for removal of arsenic in water. See Section I. Other methods for removal of either dissolved organic or inorganic substances may be developed. These methods shall be approved by the Department prior to use for production of a potable water.

Solar distillation offers some promise in hot, arid regions. In solar distillation, sunlight passes through a transparent cover onto the mineralized water. The temperature of the water is raised and the water evaporates. The vapor condenses on the transparent cover and runs off into collection troughs. Solar distillation requires large surface areas and usually has a high capital cost. Much work is being done on use of solar energy, and ways may be developed to make solar distillation for potable water sources more feasible.

f. PROCESS SELECTION. Several factors should be considered in determining the most suitable demineralization process or processes.

(1) <u>Salt Concentration and Composition of Feed Water</u>. The most favorable feed water dissolved solids concentrations for each of the four common demineralization processes are:

Electrodialysis	1,000 - 5,000 mg/l
Reverse Osmosis	1,000 -10,000 mg/l
Distillation	10,000 -50,000 mg/l
Ion Exchange	1,000 - 2,000 mg/l

In some instances, it may be advantageous to achieve partial demineralization by one process and further demineralization by another.

Softer waters are more amenable to demineralization because calcium sulfate and calcium carbonate scales are less likely to form. If the feed water contains more than 600 mg/l calcium, softening is usually justified prior to demineralization. Calcium concentrations as high as 900 mg/l can be tolerated in waste streams if polyphosphates are added.

(2) <u>Feed Water Temperature</u>. Warmer feed water temperatures enhance the electrodialysis, reverse osmosis, and ion exchange processes. For distillation, high feed water temperatures reduce power requirements. However, some membranes used in the electrodialysis and reverse osmosis processes will have a shorter life as the feed water temperature approaches and

exceeds 85° F. The manufacturer's requirements or restrictions, relative to feed water temperature, should be followed whenever demineralization processes are employed.

(3) Desired Product Water Quality. In general, the concentrations of minerals (total dissolved solids) in product waters of the various processes are as follows:

Electrodialysis	350-500 mg/l
Reverse Osmosis	100-500 mg/l
Distillation	5- 50 mg/l
Ion Exchange	0-200 mg/l

If the demineralization process produces a water lower in dissolved solids than necessary, blending of feed water with product water can produce a water of desired dissolved solids while reducing the average cost of treatment.

(4) Availability of Heat and Energy. All demineralization processes require the use of energy in one or more forms. Ion exchange processes use the least energy, only enough to meet pumping requirements for feed water, rinse water, and regeneration solutions. However, chemicals, whose manufacture involves energy expenditure, are required for regeneration. In reverse osmosis, most of the total energy requirements goes to applying sufficient pressure (200-800 psi) to the feed water. Energy is required to pump water through an electrodialysis unit and to activate the electric field across the unit. Distillation processes use the most energy per gallon of product water, due primarily to the heat requirements to convert water to a vapor.

2. REMOVAL OF DISSOLVED ORGANIC SUBSTANCES. The presence of dissolved organics in almost all natural waters may be attributed to a variety of sources, including decay of plant and animal wastes or residues, industrial discharges, wastewater treatment plant discharges, and agricultural runoffs containing herbicides and pesticides as well as numerous other organic substances.

An excessive level of dissolved organic substances will usually cause objectionable tastes and odors. Treatment for control of the tastes and odors, generally attributable to dissolved organic substances, is outlined in Section K. However, many dissolved organics do not cause tastes and odors, and a water may have high concentrations of organic substances without undesirable esthetic effects. The organic content of a given water can be estimated by measuring the total organic carbon (TOC), the chemical oxygen demand (COD), or the carbon-chloroform extract (CCE). These tests are subject to various limitations and can only be used as general indications of water quality. Inasmuch as certain organic compounds are harmless and other organic compounds pose serious health hazards, and tests for estimating concentrations of organics do not differentiate between the two, it is helpful to have representative water samples tested for individual organic compounds.

Among the dissolved organic substances causing concern are: insecticides, herbicides, phenolic compounds, foaming agents, polychlorinated byphenyls, and short-chain halogenated organics, such as chloroform ($CHCl_3$) or carbon tetrachloride (CCl_4). Some of these substances are partially removed during conventional treatment processes, but the degree of removal is largely unknown. Halogenated organics, such as chloroform, can be formed as a result of chlorination of water containing certain dissolved organics.

Maximum contaminant levels for specific dissolved organic substances have been promulgated and are given in the Drinking Water Regulations.

The most common means of effecting dissolved organic removal is through the use of activated carbon, either in powdered or granular form. Powdered activated carbon is usually applied as a slurry at the head end of a treatment plant and removed along with the adsorbed organic substances in the coagulation, flocculation, sedimentation, and filtration processes. Granular activated carbon is used as a filter medium in either conventional gravity flow filters or in pressure filters. Due to the variety of organic contaminants discovered in water supplies in recent years, granular activated carbon filters are being used with increasing frequency.

a. ACTIVATED CARBON. Organic pollutants are removed from water by activated carbon through the process of adsorption, which is the adhesion of molecules to a solid surface. Activated carbon is especially effective as an adsorbing agent because of its large surface area to mass ratio, ranging from 500 to 1,400 square meters per gram (150,000-430,000 square feet per ounce). The large surface areas are the result of the structure of the activated carbon granule. Each granule contains a tremendous number of pores and crevices into which organic molecules enter and are adsorbed to the activated carbon surface.

Activated carbon has a particularly strong attraction for organic molecules and, hence, is especially suited for removal of organic impurities. A variety of materials have been used as the parent material of activated carbon.

Regulations pertaining to the application of powdered activated carbon are presented in Section K.

b. ACTIVATED CARBON FILTERS. Filters utilizing granular activated carbon media may be used after conventional filters, or in place of conventional filters with approval of the Department. If activated carbon filters are permitted in place of conventional filters, special care must be taken in the design and operation of filter cleansing facilities and in the selection of carbon granule characteristics so that the filters can be effectively washed without loss of the carbon in the backwash troughs.

The standards for granular activated carbon filters as given in this Section and in Section F shall be followed.

(1) Removal Efficiencies. Available data indicate that activated carbon filters can remove 80 to 90 per cent of dissolved organic substances.

(2) Cleansing and Regeneration of Activated Carbon Media. Activated carbon filters are backwashed in the same manner as conventional rapid rate filters. Treated water is applied to the underside of the bed through the underdrains, and the wash water is carried away in wash water troughs above the filters. Since the carbon has a particle density less than sand, the wash rates are lower for carbon than for sand.

Expansion of the granular activated carbon filter bed shall not be less than 30 per cent or greater than 50 per cent.

Provisions shall be made to provide a minimum wash rate of 5 gallons per minute per square foot.

Other provisions for filter backwashing as given in Section F shall be followed.

After a period of operation, the activated carbon media must be replaced with new or regenerated activated carbon granules. Regeneration involves (1) removing the spent carbon as a slurry, (2) dewatering the slurry, (3) feeding the carbon into a special furnace where regeneration occurs, (4) water quenching the carbon, and (5) returning the carbon to use. From 5 to 10 per cent of the carbon is lost during this process. The choice between on-site regeneration, shipment of spent carbon to a regeneration center, or purchase of new activated carbon is usually governed by economic considerations for each specific plant.

Adequate testing of each activated carbon filter effluent must be performed to ascertain when the carbon is spent and needs regeneration.

c. OTHER METHODS. Other processes are available for the removal of certain dissolved organics, including aeration, application of oxidizing agents, reverse osmosis, ultrafiltration and distillation.

The applicability of aeration techniques is covered in Section C. In general, aeration effects partial removal of highly volatile substances but practically no removal of less volatile compounds.

The suitability of using oxidizing agents to convert organic substances to innocuous oxidation products is covered in Section K. The oxidizing agents most commonly used are chlorine, chlorine dioxide, ozone, and potassium permanganate. If the objectionable organics are readily oxidized to innocuous products, this form of treatment may be advantageous.

Distillation, as discussed heretofore in this section, can be used only if the organic substances are nonvolatile. If volatile, they will evaporate and condense with the water. It is generally not feasible to use distillation for removal of organics.

Another process by which dissolved organics may be removed is reverse osmosis, also discussed earlier in this section. Although this process has been rarely used specifically for the removal of organics, operating experience for existing reverse osmosis desalination facilities indicates that a large percentage of organic substances is retained in the waste brine. It is probably not feasible to use reverse osmosis exclusively for excessive dissolved organic levels, but if dissolved minerals and dissolved organics are present in the same water, the concentration of both can be reduced.

Ultrafiltration (UF) is a low pressure membrane process which permits separation of organics and colloids from a liquid stream. The degree and quantity of separation is a function of (1) pore size of the membrane and (2) size and shape of the colloids and organic molecules. Some UF membranes have pore sizes in the 0.0015 micron range. Soluble substances smaller than the pore size pass through the membrane. The UF membrane will normally reject all colloidal material as well as organics having a molecular weight of about 1,000 and larger. Dissolved inorganic salts are not rejected by the membrane. Ultrafiltration requires low pressures, namely 25-150 psi, in contrast to the high pressures required by reverse osmosis.

3. DISPOSAL OF WASTES. In all demineralization processes, the minerals removed from the produce water are concentrated into waste brines that require disposal. Finding a suitable method of disposal may be difficult. Wastes from backwashing of a granular activated carbon filter are similar to those from a conventional rapid rate filter. Requirements for disposing of the brine wastes and the filter wash wastes are given in Section R.

K. TASTE AND ODOR CONTROL

Water for public consumption is expected to be virtually free from tastes and odors. Tastes and odors can be a problem in both ground and surface water sources but are more intense and more frequent in the latter as surface waters are subject to taste and odor problems from a variety of sources. Removal of tastes and odors, although frequently difficult, can be achieved by several means.

Quantification of the intensity of tastes and odors in water is necessarily difficult, due to the variable reaction of different individuals to the same taste or odor. The most commonly accepted means of testing for odors in water is through the Threshold Odor Test. This test involves presentation of solutions containing odor-causing substances to observers who smell each solution and note whether or not an odor is detected. The minimum concentration at which an observer detects on odor is the threshold concentration, and the "Threshold Odor Number" is the number of times the odor-bearing substance has been diluted with odor-free water.

Waters which have, or which develop, objectionable tastes and/or odors require methods to prevent them or special treatment to eliminate them.

1. CAUSES OF TASTES AND ODORS. The causes of tastes and odors in water are often complex and difficult to define. Although some problems may be caused by inorganic substances, such as metal ions, most tastes and odors are caused by organic substances. The following are the major types of objectionable materials:

   a. ODOROUS DISSOLVED GASES. Notably, these gases are hydrogen sulfide and related organic compounds containing sulfur.

   b. ORGANIC MATTER FROM MICROORGANISMS. This source of taste and odor difficulties is probably the most common. Algae contain metabolic compounds which are released upon their death and which impart a distinct taste and odor to water. Actinomycetes (a type of rod-shaped bacteria) in small numbers can cause persistent earthy or musty odors. Nematodes (microscopic parasitic worms), although not implicated as frequently as algae or actinomycetes, are another source of tastes and odors.

   c. DECOMPOSING ORGANIC MATTER. When weeds, tree leaves, or grasses decay in water, musty or swampy odors are given off. This problem is encountered when a raw water reservoir is not properly cleared of vegetation before it is filled. Sewage pollution of a water supply can also cause objectionable tastes and odors.

d. INDUSTRIAL WASTES. Industrial wastes are another source of taste and odor. Constituents of industrial wastes which are the most troublesome and persistent include formaldehyde, picolines, phenolics, xylenes, phenyl-ether, cresols, and numerous other compounds.

e. CHLORINE. Chlorine alone is rarely encountered in water supplies in sufficient concentrations to cause distinctive tastes and odors, even if free residual chlorination is practiced. However, if chlorine combines with some organic compounds, particularly phenolics, very noticeable tastes and odors may be produced. Most complaints of "chlorine" tastes in drinking water are the result of the formation of taste producing compounds formed by the reaction of chlorine with organic substances in the water.

f. PESTICIDES AND FERTILIZERS. Some pesticides and fertilizers, even in minute concentrations, are known to cause or contribute to tastes and odors.

Treatment for taste and odor problems generally involves either destruction of the odor causing materials or removal of these substances.

2. DESTRUCTION OF TASTE AND ODOR SUBSTANCES. Treatment of odorous substances by destruction usually involves oxidation of the objectionable compounds to unobjectionable forms. Chemical oxidation may be accomplished through the addition of several substances to the water, including chlorine, chlorine dioxide, potassium permanganate, or ozone.

a. CHLORINATION. Chlorination for taste and odor control is usually practiced in one of the following modes: combined residual chlorination (chlorine-ammonia treatment), free residual chlorination (breakpoint process), and superchlorination and dechlorination. See Engineering Bulletin No. 8 for chart and definitions of these chlorination processes.

(1) Combined Residual Chlorination. Combined residual chlorination has been used to prevent the formation of taste-producing chlorophenols. If a sufficient amount of ammonia is added to the water prior to chlorination, the chlorine is unable to react readily

with phenols and related compounds. The reason for this is that the chlorine reacts with the ammonia forming chloramines whose reactivity is of a much lower order than free chlorine. A serious consequence of this reduction in activity is substantial loss of the chlorine's disinfection power. Use of the ammonia-chlorine process is not always completely successful in preventing chlorophenolic tastes. Given sufficient time, the chloramines will react with phenol. Thus, while water leaving the treatment plant may be free of tastes and odors, these may develop in remote parts of the distribution system after additional contact time.

In special cases, combined residual chlorination may be indicated for taste and odor removal but shall be used only with the approval of the Department.

(2) Free Residual Chlorination. Free residual (breakpoint) chlorination can be used to oxidize some taste and odor producing compounds to non-taste and odor producing end-products. Adequate contact time is necessary to complete the chemical reactions involved.

Theoretically, when the breakpoint is reached, all ammonia present has been removed and all oxidizable material has been destroyed. In practicing breakpoint chlorination, the variations in chlorine feed required to reach the breakpoint should be known by the plant operator. The primary disadvantage of using breakpoint chlorination for taste and odor control is that some organic substances are oxidized very slowly by chlorine, and the time required to reach breakpoint can be several hours or days long, far in excess of the plant's detention time. Also, some odorous organic compounds are not destroyed by breakpoint chlorination. In such cases, alternative means of taste and odor control should be used.

(3) Superchlorination and Dechlorination. In order to decrease the long detention periods sometimes required for breakpoint chlorination and to increase the potential for oxidation of organic compounds to innocuous end products, superchlorination followed by dechlorination is sometimes practiced.

Superchlorination is the application of chlorine to water in amounts greatly in excess of that needed to produce a free chlorine residual and usually results in an unpalatable chlorinous taste. As the high residual chlorine values are unpleasant, it is necessary to dechlorinate the water to acceptable residual chlorine levels.

If superchlorination is utilized, the chlorine should be applied at the earliest feasible point in the water treatment system. Often it is applied at or near the raw water intake. Where dechlorination is necessary, equipment should be provided for adding sulfur dioxide, sodium bisulfite, sodium sulfite, or activated carbon. Water discharged into the distribution system following superchlorination shall have the free chlorine residual reduced to 0.2 to 1.0 mg/l.

b. CHLORINE DIOXIDE. Chlorine dioxide, an unstable, unpleasant smelling, irritating gas at ordinary temperatures and pressures, has a total oxidation capacity of some two and a half times that of chlorine. It is generally recognized as a treatment for tastes caused by industrial wastes, such as phenols, but can be used in the treatment of any taste and odor treatable by an oxidizing agent. Chlorine dioxide is generated as needed at the water treatment plant by the addition of a sodium chlorite solution to a chlorine solution at a pH of 4.0 or less. Normal practice is to use an excess of chlorine, since it is cheaper, and the surplus acts as a disinfectant. Chlorine dioxide is used when the available detention time is brief or when chlorine alone is unable to completely oxidize odorous substances. Chlorine dioxide dosages are usually in the 0.2 to 1.0 mg/l range. Since chlorine dioxide is considerably more expensive than elemental chlorine, its use is generally limited to those plants having severe taste and odor problems.

If chlorine dioxide is used, proper provisions shall be made for storing and handling sodium chlorite so as to eliminate any danger of explosion. Storage and handling requirements shall conform to those given in Section N.

c. POTASSIUM PERMANGANATE.. Potassium permanganate acts effectively as an oxidizing agent in destroying tastes and odors. It is important to add the permanganate to the water prior to chlorination if organic compounds are present which may combine with chlorine to form odorous compounds more resistant to chemical oxidation. Common practice is to add 1 to 5 mg/l to the raw water entering the plant. The application of potassium permanganate should be carefully controlled. If an excess of potassium permanganate is applied, the characteristic pink permanganate color will be evident in water leaving the plant. In addition, the excess permanganate will be converted to insoluble manganese dioxide in the distribution system, and this will cause staining of laundry and plumbing fixtures.

The quantity and application point of potassium permanganate shall be so designed that the products of the reaction and unused permanganate will not be present in the finished water.

d. OZONE. Ozone is another powerful oxidant used in the control of tastes and odors. The ozonation process may be a viable alternative in the treatment of waters having a high threshold odor number, but when threshold odor numbers are small, ozonation is not generally as economical or efficient as other methods.

Ozone is produced by the passage of dry air or oxygen between two high-voltage electrodes. Electric discharges through the air between the electrodes result in the formation of ozone. Like chlorine, ozone is a toxic substance. Ozone molecules contain three atoms of oxygen and are highly reactive. Ozone cannot be stored as a compressed gas; it must be generated at the point of use and used as soon as generated. Ozone is a rapid and effective disinfectant, can eliminate or reduce taste, odor, and color problems, and is little affected by temperature and pH in its disinfection capability. Typical dosages are 1 to 6 mg/l or 8 to 50 lb of ozone per million gallons of water. The disadvantages of ozone are: large quantities of electric energy are required; production facilities must be designed to meet the maximum rate of use as ozone cannot be stored; and equipment required to generate and inject the large volume of ozonized air into the water is expensive.

Because of the high energy requirements, the complexity of ozonation equipment, and the cost of the equipment, ozone has not been used extensively in this country.

3. REMOVAL OF TASTE AND ODOR SUBSTANCES. Particulate materials causing tastes and odors are usually removed in the coagulation, flocculation, sedimentation, and filtration processes. However, tastes and odors caused by dissolved substances in water are not removed by conventional treatment. Other methods of removal have to be employed.

   a. AERATION. Aeration is not notably effective as a means of taste and odor reduction unless the taste and odor producing substances are highly volatile. Even in those cases, all the volatile matter may not be removed by aeration. Aeration may be advantageous as a partial solution but will seldom completely solve the problem. See Section C.

   b. ACTIVATED CARBON. Adsorption of soluble odor producing materials from water is an effective method of taste and odor control. The adsorbent that has proven to be most reliable, efficient, and economical for this purpose is activated carbon. Activated carbon is made from a variety of source materials and through a variety of processes. All the processes basically consist of destructive distillation of the source material to obtain the highest possible percentage of pure carbon, followed by heat treatment while an oxidizing gas, such as steam or air, is being blown through the carbon. The final product is then ground into granular or powder-sized particles. The granular particles are used in the construction of filters through which the odorous water passes and the powdered activated carbon is added directly to waters containing odorous substances.

      (1) Powdered Carbon. Powdered activated carbon can be applied to the water at any treatment point prior to filtration. The application site(s) should be selected to accord with other treatment processes. Since the efficiency of taste and odor control is influenced by the length of contact time between the activated carbon and the taste and odor producing substances, it is advisable to apply it early in the treatment process.

      The efficiency of carbon adsorption is best at lower pH values, long contact times when the carbon remains in suspension and in circulation, and when the active surface is preserved from sealing or coating by other chemicals. If possible, carbon should be applied to the raw water and allowed to act prior to the addition of other chemicals, such as chlorine, potassium permanganate, lime, alum, etc. Sometimes, a "split feed" is used with part of the carbon applied to the raw water and the remainder just before filtration. Care must be exercised to avoid too large a carbon dose to the filter influent as this may cause a rapid increase in head loss and possibly a carbon break-through to the filtered water.

Use of powdered activated carbon for taste and odor removal has the advantage that application rates can be varied with the severity of the problem. The following rates of application may serve as very rough guidelines:

Continuous application - 2 to 8 mg/l
Sporadic severe odor problems - 5 to 20 mg/l
Emergency treatment (chemical spills) - 20 to 100 mg/l

Powdered activated carbon can be applied to water either in slurry form or in powdered form through dry feed machines as long as the carbon is properly "wetted." Agitation is necessary to keep the carbon from despositing in the mixing chamber. Specifications for powdered activated carbon should conform to AWWA Standard B600.

Adequate forced draft ventilation of activated carbon feed equipment shall be provided to ensure that carbon dust does not become a nuisance or potentially explosive. Storage and handling of powdered activated carbon shall conform to the requirements of Section N. The required dosage of carbon in a water treatment plant depends on the tastes and odors in the water but provisions shall be made for feeder capacity of not less than 50 mg/l of activated carbon.

(2) *Granular Activated Carbon Beds*. A granular activated carbon bed may be used after a conventional filter or as part of a conventional filter, offering adsorptive capabilities in addition to the ability to filter the water. Many of the standards given for conventional filters are also applicable to activated carbon filters. See Sections F and J. Specifications for granular activated carbon should conform to AWWA Standard B604.

When exhausted, the activated carbon media must be replaced with new or regenerated activated carbon granules. The choice among the alternatives of on-site regeneration, shipment of spent carbon to a regeneration center, or purchase of new activated carbon is usually governed by economic considerations.

4. OTHER METHODS. The decision to use other methods of taste and odor control should be made only after careful engineering study and laboratory tests, and after consultation with and approval by the Department.

5. PREVENTIVE MEASURES. The first step in producing an odor free water should be development of the best feasible source of raw water. Minimizing the tastes and odors associated with the raw water source minimizes the taste and odor control measures required at the treatment plant. Many common taste and odor problems are associated with growths of algae and aquatic plants in raw water storage reservoirs, so any effort to eliminate or reduce their growth will help alleviate tastes and odors. The use of herbicides to control aquatic plants is hazardous because of potential fish kills and the fact that the herbicides may import additional tastes and odors to the water. Algae growths may be controlled through the application of copper sulfate or potassium permanganate to the reservoir water. Copper sulfate is the most frequently used algacide.

   Continuous or periodic use of copper sulfate to kill algae or other growths shall be controlled to prevent copper in excess of 1.0 mg/l as copper appearing in the plant effluent or distribution system.

6. FLEXIBILITY. Where tastes and odors are known to be a problem, treatment plant design should provide for maximum practical flexibility in application of treatment chemicals, especially those involved in taste and odor removal. During severe taste and odor episodes, treatment procedures may have to be drastically altered to cope with the problem.

L. IRON AND MANGANESE CONTROL

Iron and manganese control, as used herein, refers solely to treatment processes designed specifically for that purpose. The treatment process used will depend upon the character of the raw water.

The selection of one or more treatment processes shall meet specific local conditions as determined by engineering investigations, including chemical analyses of representative samples of water to be treated. It may be necessary to operate a pilot plant in order to gather all information pertinent to the design.

Some of the processes involve the use of patented equipment which may be of recent development. In all cases, the engineering report should give sound reasons for the selection of specific treatment processes.

1. <u>OCCURRENCE OF IRON AND MANGANESE</u>. Dissolved iron and manganese are encountered principally in ground waters devoid of dissolved oxygen. Normal surface waters rarely contain significant concentrations of dissolved iron and manganese. When found in surface waters, iron and manganese are usually associated with suspended matter or industrial wastes. However, the lowest levels of thermally stratified reservoirs often contain soluble forms of both iron and manganese. Their presence in solution is associated with anaerobic conditions prevailing in the bottom waters of these reservoirs.

2. <u>EFFECTS OF IRON AND MANGANESE</u>. The presence of iron and manganese in water is objectionable primarily because the precipitation of these metals alters the appearance of the water, turning it a turbid yellow-brown to black.

   Iron concentrations in excess of 1 or 2 mg/l can impart a taste to water and concentrations greater than 0.3 mg/l will cause red stains on plumbing fixtures and laundry. Concentrations of manganese above 0.05 mg/l will cause black stains on plumbing fixtures and clothing. Certain types of bacteria use iron or manganese in their metabolic processes, and, if sufficient concentrations of either element are present, deposits of these bacteria may build up in water distribution piping. These growths periodically slough off the pipe walls, creating odor and turbidity in the water. Finally, the precipitation of these metals may cause clogging problems and loss of capacity in ion exchange units.

3. REMOVAL TECHNIQUES. Methods of achieving iron and manganese removal fall into two categories: (1) oxidation of soluble iron and manganese to insoluble forms and removal of the precipitates by filtration; and (2) ion exchange.

   a. REMOVAL BY OXIDATION, DETENTION AND FILTRATION. Oxidation may be accomplished by aeration or by the addition of oxidizing agents such as chlorine, chlorine dioxide, or potassium permanganate. The removal of manganese by oxidation is usually more difficult than the removal of iron.

      If the manganese concentration is sufficiently low but high levels of iron are present, aeration followed by filtration may achieve the necessary removal. To use this procedure, the pH of the raw water should be at least 6.5; if lower, pH adjustment may be required. The efficiency of the aeration-filtration process in removing iron is enhanced by a high pH and a high water temperature. The floc particles formed by aeration of iron-bearing water are generally small and light and difficult to remove by sedimentation. Most of the precipitated iron must be removed by filtration. However, iron concentrations in excess of about 5 mg/l in the raw water usually respond fairly well to flocculation and sedimentation of the aerated water.

      Manganese removal cannot generally be effected by simple aeration and filtration processes alone, unless the pH is first raised to about 9.5. It is often more economical to use stronger oxidants such as chlorine or potassium permanganate instead of raising the pH. Complete oxidation of soluble manganese can be achieved in 1 to 2 hours at pH values in excess of 6.8 in the presence of 0.50 to 1.00 mg/l of free chlorine. The precipitates formed by the oxidation of manganese are even smaller and lighter than those resulting from the oxidation of iron. Consequently, coagulation and flocculation are often necessary to make the manganese floc large enough to be readily filtered. The presence of organic matter in water adversely affects the removal of both iron and manganese.

      (1) Aeration. Aerators may be used to oxidize iron and manganese. Aerators shall conform to Section C. Tray aerators with coarse media are especially efficient as the media becomes coated with previously oxidized iron and manganese which aids in and speeds up the oxidizing reactions. Their use may make pH

adjustment unnecessary, especially for iron removal. When multiple tray aerators are used, positive means should be provided for removing surplus precipitated iron and manganese from the units.

Pressure aerators are acceptable provided that pilot plant tests indicate their applicability.

(2) Oxidants. Iron and manganese can be oxidized by chlorine, chlorine dioxide, or potassium permanganate without the need for aeration. These oxidants will destroy or alter complex organic compounds of iron and manganese so precipitation may be obtained in the absence of catalytic action or without pH adjustment.

Theoretically it takes 0.64 mg/l of chlorine to oxidize 1.0 mg/l of iron and 1.3 mg/l to oxidize 1.0 mg/l of manganese. In practice slightly higher values are used. For potassium permanganate, it requires 0.94 mg/l to oxidize 1.0 mg/l of iron and 1.92 mg/l per 1.0 mg/l of manganese. In practice slightly lesser values are used. Required dosages of chlorine dioxide are usually given in the quantities of technical grade (80 per cent) sodium chlorite. Chlorine and sodium chlorite are mixed in a 1:1 proportion to make chlorine dioxide. It requires 2.02 mg/l of sodium chlorite to oxidize 1.0 mg/l of iron and 4.12 mg/l per 1.0 mg/l of manganese.

(3) Detention Basins. A minimum detention of 20 minutes shall be provided following oxidation to assure the oxidation reactions are as complete as possible. The detention basin shall be designed as a holding tank with no provisions for sludge collection but with sufficient baffling to prevent short circuits. This minimum detention shall be omitted only where a pilot plant study indicates no need for detention.

Flocculation and sedimentation basins prior to filtration shall be provided when treating water with a high iron and/or manganese content or where chemical coagulation is used to effectively remove the iron and/or manganese precipitates. Flocculation and sedimentation basins shall conform to Sections D and E.

(4) Filtration. Filters shall conform to Section F.

b. REMOVAL BY LIME-SODA SOFTENING PROCESS. Lime-soda ash softening will readily remove iron and manganese eliminating the need for further treatment for iron and manganese removal. See Section G on Softening.

c. REMOVAL BY ION EXCHANGE. Soluble iron and manganese may be removed by the ion exchange process in pressure tanks similar to those described in Section G. The cation exchange medium used may be either a sodium resin or a hydrogen exchange resin. In the use of both resins, removal of the soluble iron and manganese is accomplished in concert with removal of other cations. The sodium resin also removes calcium and manganese whereas the hydrogen resin removes calcium, manganese, and sodium. Soluble iron and manganese removal by these resins is usually a secondary effect in the ion exchange softening process.

In the removal of soluble iron and manganese by the ion exchange process, the raw water can not be exposed to oxygen, and can not be treated with any oxidizing chemical prior to passage through the ion exchange unit. If either occurs, the iron will be converted to a precipitate which will be removed by and retained in the resin bed, eventually fouling the bed to such an extent as to render the unit useless. A significant problem in the use of ion exchangers for iron and manganese removal is the fouling of the resin with ferric iron. Periodic cleansing of the resin to remove the ferric iron may be necessary.

Design of the ion exchange process for soluable iron and manganese removal shall conform to the following:

(1) The process is not acceptable where either the raw water or wash water contains dissolved oxygen or where oxidizing chemicals are introduced prior to the ion exchange unit.

(2) The process is not acceptable for raw waters containing more than 1.0 mg/l of soluble iron, manganese, or combination thereof.

(3) The requirements pertaining to pressure ion exchange units given in Section G shall be followed.

(4) A blending bypass is permitted if the blended water meets the drinking water regulations for iron and manganese concentrations.

d. REMOVAL BY UNITS USING CONTINUOUS POTASSIUM PERMANGANATE REGENERATION. This process consists of a continuous application of potassium permanganate to the raw water and filtration through manganese dioxide greensand. Greensands are naturally occurring silicates of sodium and aluminum. Manganese dioxide, an oxidizing agent, is affixed to the greensand. Potassium permanganate is continuously fed to the water entering the filter. The iron and manganese are oxidized by the potassium permanganate and precipitated on the filter resin. If too little potassium permanganate is added, the iron and manganese are oxidized by the manganese dioxide affixed to the greensand; if too much potassium permanganate is added, the manganese dioxide greensand is regenerated. Thus, uniform amounts of potassium permanganate may be added to a water containing varying concentrations of iron and manganese. The normal dosage of permanganate is about 1.0 mg/l per 1.0 mg/l of total iron and manganese to be removed.

A variation of the continuous regeneration process is the periodic regeneration process wherein potassium permanganate is added to the influent periodically in concentrations large enough to regenerate the bed. Eventually, the greensand must be cleaned of the precipitated iron and manganese.

Design of this process shall provide:

(1) an anthracite media cap of at least 6 inches over the manganese greensand,

(2) application of the permanganate to a point before the filters,

(3) normal filtration rate of 3 gallons per minute per square foot,

(4) normal wash rate of 8 to 10 gallons per minute per square foot,

(5) air wash, and

(6) sample taps prior to permanganate application, immediately ahead of filtration, at a point between anthracite media and the manganese greensand, half-way down the manganese greensand, and at filter effluent.

Other oxidizing agents or processes, such as chlorination or aeration, may be used prior to the permanganate feed to reduce the cost of the chemical.

e. WASTE DISPOSAL. Disposal of filter waste waters shall conform to requirements of Section R.

4. STABILIZATION OF IRON AND MANGANESE. Under some circumstances, stabilization of iron and manganese by application of a polyphosphate compound may be acceptable. As used in connection with iron and manganese, "stabilization" means that the soluble iron and manganese in the water are maintained in the soluble state through the complexing action of a polyphosphate compound. Stabilization will not persist if the water is heated because heating rapidly converts polyphosphates to orthophosphates which have no stabilizing power. Stabilization, although helpful, is not a substitute for iron and manganese removal, and, in general, should be viewed as a temporary expedient to be used pending installation of removal facilities.

The process shall not be used for water containing more than 1.0 mg/l iron and manganese.

Where the process is applicable, the following shall be followed:

a. The polyphosphate dosage shall not exceed 10 mg/l,

b. The point of polyphosphate application shall precede any aeration or oxidation process if no iron or manganese removal treatment is provided,

c. Stock phosphate solution shall be kept covered and disinfected by carrying approximately 10 mg/l chlorine residual,

d. Phosphate chemicals shall be food grade,

e. Phosphate feed equipment shall conform to requirements of Section N.

5. SAMPLING EQUIPMENT. Sampling taps shall be provided for control purposes. Taps shall be located on each raw water source, each treatment unit influent, and each treatment unit effluent.

6. TESTING EQUIPMENT. Testing equipment shall be provided for all plants. The equipment shall have the capacity to accurately measure the iron content to a minimum of 0.1 mg/l and the manganese content to 0.05 mg/l. Where polyphosphate stabilization is practiced, appropriate phosphate testing equipment shall be provided.

M. DISINFECTION

The provisions in Engineering Bulletin No. 8, "Disinfection of Water Systems", issued by the Department in October 1977, shall be followed.

N. CHEMICALS AND CHEMICAL HANDLING

1. COMMON WATER TREATMENT CHEMICALS. Chemicals are used for a variety of purposes in conventional water treatment purposes, including coagulation and flocculation, disinfection, fluoridation, taste and odor control, and pH adjustment. The most common chemicals and some of their characteristics are listed in a following table.

No chemicals shall be applied to treat drinking waters unless specifically permitted by the Department. All chemical shipping containers shall be fully labeled to include (a) the chemical name, purity, and concentration, and (2) the supplier's name and address. All chemicals shall meet the current American Water Works Association Standards, where applicable.

The AWWA publication number for some of these standards are:

Chemical Name	AWWA Publication Number
Aluminum sulfate (lump, ground, or liquid)	B403
Sodium aluminate	B405
Ferrous sulfate	B402
Ferric chloride	None published
Ferric sulfate	B406
Sodium silicate (Activated silica)	B404
Chlorine	B301
Calcium hypochlorite	B300
Sodium fluoride	B701
Hydro-fluosilicic acid (Fluosilicic acid)	B703
Sodium silicofluoride	B702
Potassium permanganate	B603
Activated carbon (Powdered)	B600
Activated carbon (Granular)	B604
Copper sulfate	B602
Calcium hydroxide (Hydrated lime)	B202
Calcium oxide (Quicklime)	B202
Sodium carbonate (Soda ash)	B201
Sodium hydroxide (Caustic soda)	B501
Carbon dioxide	None published
Sodium chloride (Salt)	B200
Sodium hexametaphosphate	B502

Principal Chemicals Used in Water Treatment

Chemical Name and Formula	Common or Trade Name	Shipping Containers	Suitable Handling Materials	Available Forms	Bulk Density lb/cu ft	Solubility lb/gal	Commercial Strength	Characteristics
Aluminum sulfate solution	Liquid alum	Tank trucks or tank cars	Lead or rubber-lined steel, 316 stainless steel, plastic	Off-white to yellow-brown liquid	(11.047 lbs/gal)	-	5.36 lbs dry alum per gallon	pH of 1% solution is 3.4
Aluminum sulfate (dry) $Al_2(SO_4)_3 \cdot 14.3H_2O$	Alum, filter alum, sulfate of alumina	100-200 lb. bags, 300-400 lb. barrels, bulk (carloads).	Dry-iron, steel. Solution - lead-lined rubber, silicon, asphalt, 316 stainless steel	Ivory-colored: Powder Granule Lump	 38-45 60-63 62-67	4.2 at 60°F	15-22% Al_2O_3	pH of 1% solution is 3.4
Sodium aluminate $Na_2OAl_2O_3$	Soda alum	100-150 lb. bags; 250-440 lb. drums; solution.	Iron, plastics, rubber, steel	Brown powder, liquid	50-80	Highly souble	70-80% $Na_2Al_3O_4$, 32% $Na_2Al_3O_4$ minimum	Hopper agitation required for dry feed
Farrous sulfate $FeSO_4 \cdot 7 H_2O$	Copperas, green vitriol	Bags, barrels, bulk	Asphalt, concrete, lead, tin, wood	Green crystal granule, lump	63-66	0.5 at 32°F 1.0 at 68°F 1.4 at 86°F	55% $FeSO_4$ 20% Fe	Hygroscopic; cakes in storage; optimum pH is 8.5-11.0
Ferric chloride $FeCl_3$ (37-47% solution)	Ferrichlor, chloride of iron	5-13 gal. carboys, trucks, tankcars	Glass, stoneware, synthetic resins	Dark brown syrupy liquid	(11.2-12.4 lbs/gal)	-	37-47% $FeCl_3$ 13-16% Fe	Very corrosive
Ferric sulfate $Fe_2(SO_4)_3 \cdot 9 H_2O$	Ferrifloc, Ferrisul	50-175 lb. bags, 200-425 lb. drums	Ceramics, lead, plastic, rubber, 18-8 stainless steel	Red-brown powder or granules	55-72	Soluble in 2-4 parts water	66% Fe_2SO_4 20% Fe	Mildly hygroscopic. Coagulant at pH 3.5-11.0
Sodium silicate Na_2OSiO_2	Water glass	Drums, bulk (tank trucks, tank cars)	Cast iron, rubber, steel	Opaque, viscous liquid	(11.6 lbs/gal)	Highly souble	28.7% SiO_2	Variable ratio of Na_2O to SiO_2. pH of 1% solution is 12.3
Chlorine	Chlorine gas, liquid chlorine	100-150 lb. cylinders, 1 ton containers, 16-30-55-85 and 90 ton tank cars, tank trucks (about 15-16 tons)	Dry - black iron, copper, steel. Wet gas - glass, hard rubber, silver, earthenware	Liquefied gas under pressure	91.7 (liquid at 32°F)	0.083 at 50°F 0.047 at 86 F	99.8% Cl_2	Toxic gas. Solutions in water highly acidic and corrosive
Calcium hypochlorite Approx. $Ca(OCl)_2 \cdot 4 H_2O$	"HTH", "Perchloron", "Pittchlor"	5 lb. cans, 100-300-800 lb. drums	Glass, rubber, stoneware, wood	White powder	48	Approx. one	70% "available" chlorine	
Sodium fluoride NaF	Fluoride	Bags, barrels, fiber drums, kegs	Iron, lead, steel	Nile blue or white powder; Light Dense	60 90	0.35 at most temperatures	90-98% NaF	pH of 4% solution is 6.6
Hydro-fluosilicic acid H_2SiF_6	Fluosilicic acid	Rubber lined drums, trucks, or tank cars	Rubber lined steel, PVC	Liquid	(10.5 lbs/gal)	Approx. 1.2 at 68°F	20-35% H_2SiF_6	pH of 1% solution is 1.2
Sodium silicofluoride Na_2SiF_6	Sodium silicofluoride	Bags, barrels, fiber drums	Iron, lead, steel	Nile blue or yellowish-white powder: Regular Fluffy	 85 65	0.03 at 32°F 0.06 at 72 F 0.12 at 140°F	99% Na_2SiF_6	pH of 1% solution is 5.3

Principal Chemicals Used in Water Treatment

Chemical Name and Formula	Common or Trade Name	Shipping Containers	Suitable Handling Materials	Available Forms	Bulk Density lb/cu ft	Solubility lb/gal	Commercial Strength	Characteristics
Potassium permanganate $KMnO_4$	Purple salt	Bulk, barrels, drums	Iron, steel, plastics	Purple crystals	90-100	0.5 at 70°F	98%	Danger of explosion on contact with organic matter
Activated carbon (powdered)	Powdered activated carbon	Bags, bulk	Dry-iron, steel, Wet-rubber, silicon iron, stainless steel	Fine Powder	8-28	Insoluble (used as a 1 lb/gal slurry)	..	..
Activated carbon (granular)	Granular activated carbon	Bags, bulk	Dry-iron steel. Wet-rubber, silicon iron, stainless steel	Granular: Effective size 0.5-0.9	22-36	Insoluble	..	..
Copper sulfate $CuSO_4 \cdot 5\ H_2O$	Blue vitriol, blue stone	100 lb. bags, 450 lb. barrels, drums	Asphalt, silicon, iron, stainless steel, plastics	Crystal Lump Powder	75-90 73-80 60-64	1.6 at 32°F 2.2 at 68°F 2.6 at 86°F	63% $CuSO_4$	pH of 1% solution is 4.7
Calcium hydroxide $Ca(OH)_2$	Hydrated lime, slaked lime	50 lb. bags, 100 lb. barrels, bulk (carloads or trucks).	Asphalt, cement, iron, rubber, steel	White powder	25-35	0.01 at 70°F	85-99% as $Ca(OH)_2$ 63-73% CaO	Hopper agitation required for dry feed of light form
Calcium oxide CaO	Quicklime, burnt lime, chemical lime, unslaked lime	80 lb. bags; 100 lb. barrels, bulk (carloads or trucks)	Asphalt, cement. Iron, rubber, steel	Lump, pebble, granule	55-60	Slakes to form hydrated lime	75-99% CaO	pH of saturated solution is 12.4
Sodium carbonate Na_2CO_3	Soda ash	Bags, barrels, bulk (trucks, carloads)	Iron, rubber, steel	White powder: Extra light Light Dense	 Approx. 30 " 35 " 65	0.6 at 32°F 1.7 at 68°F 3.2 at 86°F	99.4% as Na_2CO_3	Hopper agitation required for dry feed of light and extra-light forms. pH of 1% solution is 11.3
Sodium hydroxide NaOH (50% solution)	Caustic soda, soda, lye. (50%)	Trucks, tankcars	Cast iron, rubber, steel	Liquid	(12.76 lbs/gal) 50%	-	50% NaOH	50% solution freezes at 60°F pH of 1% solution is 12.9
Carbon dioxide CO_2	Carbon dioxide	20-50 lb. cylinders, 10-20 or 18-20 ton tank trucks, 30-43 ton tank cars	Dry-iron, steel. Wet-rubber, ceramics	Dry ice, liquefied gas under pressure	63.7 at 0°F (liquid)	0.03 at 32°F 0.014 at 68°F 0.008 at 104°F	99.9% CO_2	pH of saturated solution at 68°F is approx. 4.0
Sodium chloride NaCl	Common salt, salt	Bags, barrels, bulk (carloads)	Bronze, cement, rubber	Rock Powder Crystal Granules	Rock 50-60 Fine 58-70	2.9 at 32°F 3.0 at 68°F 3.0 at 86°F	98% NaCl	Corrosive when moist.
Sodium hexametaphosphate	Polyphosphate, glassy phosphate, vitreous phosphate	100 lb. bags, 100-320 drums	Hard rubber, plastics, stainless steel	Crystal Flake Powder	78 81 64	Highly soluble	67% P_2O_5	pH of 1% solution is 6.7-7.2

a. ALUMINUM SULFATE. Aluminum sulfate (alum) is available in lump, ground, or liquid form. The dry forms of alum are usually available in 100-200 pound bags, 300-400 pound barrels, and carloads. The 100-pound bags are the most widely used shipping form. These may be unloaded or moved by hand-carts, fork lifts, etc. Handling of the bags can be expedited by receiving the bags in palletized shipments or by palletizing at the unloading site. The loaded pallets can be readily moved by motorized or manually operated fork lifts. The bags may be stored by stacking them in layers in an interlocking fashion. Although the dry alum is in the form of granules or lumps, some dust may be generated when the bags are emptied. Mechanical dust collectors may partially alleviate the problem, and respirators and protective clothing should be worn if the dust levels are excessive. Protective clothing includes loose, denim-quality, dust-proof, long-sleeved garments with a bandana and a cap. A protective cream should be applied to exposed skin surfaces, and trousers should be tied at the ankles. Dry alum has a slight tendency to absorb moisture, which often causes it to stick to the sides of hoppers or unloader mechanisms.

Vibrators are often necessary to free this caked material. Bins and hoppers for storage of dry alum should not be cleaned by compressed air; rather, use of an industrial, water-chamber vacuum is safer. Mixtures of dry alum and quicklime can generate heat and explode if confined, so contact between these chemicals must be avoided.

Liquid alum is a solution containing about 50 per cent dry alum $[Al\ (SO_4)_3 \cdot 14.3\ H_2O]$ by weight. Many plants use liquid alum because of its ease of handling and ease of application. It is usually shipped in tank trucks or railroad tank cars. Unloading can be effected by silicon-iron or other corrosion resistant pumps and rubber or plastic hoses. Storage tanks must be lead, rubber, or plastic lined because of the acidity of the liquid (the pH of the 50 per cent solution is 2.4). Provisions should be made for periodic flushing of lines carrying liquid alum. Persons handling this solution should wear protective clothing, aprons, gloves, goggles, and face masks.

b. FERRIC SULFATE. Ferric sulfate $[Fe_2(SO_4)_3 \cdot 9H_2O]$ is available as a reddish-brown deliquescent solid. It is shipped in asphalt-impregnated paper bags and has sometimes been shipped in ordinary steel railroad hopper cars in bulk. Ferric sulfate is soluble in water producing an acidic solution which is very corrosive. Corrosion-resistant materials must be used for solution handling and application. Because of the extremely acidic nature of this material, greater care must be taken to protect the operator than that necessary for alum.

c. FERRIC CHLORIDE. Ferric chloride [$FeCl_3 \cdot 6H_2O$] is used more for wastewater treatment than for water treatment. It is an orange-yellow, very deliquescent crystalline solid. It is also available in liquid form in some areas. The dry chemical is highly soluble in water and in the presence of moist air or light decomposes to yield hydrochloric acid. It must be shipped, stored, and fed in equipment and devices that are corrosion-resistant. The hazards and operator protection are those required for a highly acidic chemical compound.

d. FERROUS SULFATE. Ferrous sulfate [$FeSO_4 \cdot 7H_2O$] is a greenish-white crystalline solid that is obtained as a by-product of other chemical processes, principally the pickling of steel wire or plate. It is also available in the liquid form. The handling and storage of ferrous sulfate and the associated hazards are identical to those for alum. Ferrous sulfate often contains small concentrations of heavy metals. The heavy metals content of any ferrous sulfate used in water treatment should not exceed 0.031 per cent expressed as lead.

e. SODIUM SILICATE. Sodium silicate [Na_2SiO_3] is known as "water glass". When activated by one of several chemicals, it becomes a coagulant aid called "activated silica". Sodium silicate is an opaque viscous liquid available as 40° Be' containing approximately 30 per cent SiO_2. It is shipped in ordinary tank cars, trucks, or drums and may be stored in ordinary steel tanks.

f. CHLORINE. Chlorine comes in 100-150 pound cylinders and one ton containers, as well as tank cars and tank trucks. The shipping containers can be handled with skids, troughs, and up-ending cradles. If chlorine containers must be lifted, approved lifting clamps or cradles should be used rather than ropes, cables, or chain clings. Cylinders may be moved with a hand truck equipped with a clamp support or safety chain at least two-thirds of the way up the cylinder. Chlorine cylinders should never be dropped or allowed to collide roughly with another.

Cylinders should be stored in an upright position in a cool, well-ventilated room. As filled by the supplier, most chlorine containers are completely full of liquid chlorine at 154° F; higher temperatures may cause pressures which could burst the container. Chlorine containers shall be stored away from external heat sources such as radiators, heat ducts, hot-water pipes, etc. One-ton containers should be stored on their sides on a level rack or platform with safety blocks to prevent rolling. Storage areas should be selected so that containers will be shielded from mechanical disturbances such as falling objects or moving vehicles.

Any chlorine gas which might leak out of a container will readily react with many substances, so it should be stored away from other compressed gases, turpentine, ether, finely divided metals, and hydrocarbons. The protective caps on the containers shall be kept in place when the containers are not in use, because the discharge valves and fusible plugs cannot withstand shocks.

Chlorine gas irritates the respiratory system and mucous membrane of persons exposed to it. However, this irritating effect insures that persons exposed to excessive concentrations of chlorine gas will immediately seek uncontaminated atmospheres. Extreme chlorine gas exposures can lead to severe eye, nose, and throat irritation, unconsciousness, and possibly death. For these reasons, approved gas masks with self-contained air supplies shall be available near chlorine storage and application areas. Chlorine leaks can be detected by holding a swab soaked in ammonia water near the leak. A white cloud of ammonium chloride will form if chlorine is present. Leaks in chlorine containers can be repaired by using a chlorine leak repair kit consisting of suitable clamps, drift pins, hammers, wrenches, and other appropriate tools. These kits are available commercially and should be supplied to all installations using chlorine.

g. CALCIUM HYPOCHLORITE. Commercial high-test calcium hypochlorite $[Ca(OCl)_2 \cdot 4H_2O]$ is an off-white granular (free-flowing or compressed tablet) material containing at least 70 percent available chlorine. It is a highly active oxidizer but is relatively stable throughout production, packaging, distribution, and storage. The granular form is essentially nonhydroscopic and resists moist caking tendencies when properly stored. Granular forms are usually shipped in 35- or 100-lb drums or cases containing 5-lb resealable cans. Tablet forms are shipped in 35- and 100-lb drums and in cases containing 4-lb resealable plastic containers. Because of its strong oxidizing powers and reactivity with organic materials, calcium hypochlorite should preferably be segregated or stored in a dry, dark, cool location separate from other chemicals or material with which it can react. Stored containers should be so arranged that they can be easily moved in the event of leaks.

All hypochlorite solutions are corrosive to some degree and affect the skin, eyes, and other body tissues that they contact. Rubber gloves, aprons, goggles, and similar suitable protective apparel should be provided for preparing and handling hypochlorite solutions. Areas of skin contact should be promptly flushed with water.

h. SODIUM FLUORIDE. This chemical (NaF) is usually obtained as crystals or a white powder in bags, drums, or barrels. It is relatively noncorrossive. The handling of either of these forms, particularly the powder, can lead to the evolution of considerable sodium fluoride dust, which is poisonous. Consequently, dust-abatement handling techniques and dust-collection machinery should be used in sodium fluoride handling and storage areas. Personnel handling or exposed to sodium fluoride dust should wear respirators, chemical goggles, and protective clothing, including rubber gloves. If sodium fluoride dust falls on the skin or in the eyes, the affected areas should be washed with warm water. In storage, it should be segregated to prevent confusion with other chemicals.

i. FLUOSILICIC ACID. Because of the corrosiveness of this liquid chemical (H_2SiF_6), great care should be exercised while handling it. All materials for handling and storage of fluosilicic acid should be constructed of corrosion resistant materials such as plastics or rubber-lined steel. Storage areas should be well ventilated. Persons handling fluosilicic acid should wear garments designed for protection from acidic solutions, such as chemical goggles or face shields, rubber gloves, rubber boots, and acidproof aprons. Oil diaphragm pumps should be used for handling this chemical, because metal pistons are rapidly abraded by the decomposition products of fluosilicic acid. Any unsealed storage units should be vented to the atmosphere at a point outside the building to avoid inhalation of the acid fumes. Spills should be washed away promptly.

j. SODIUM SILICOFLUORIDE. The handling, storage, and safety precautions associated with the use of sodium silicofluoride (Na_2SiF_6) are the same as those for sodium fluoride.

k. POTASSIUM PERMANGANATE. Potassium permanganate ($KMnO_4$) poses few problems during ordinary handling and storage, but, inasmuch as it is a strong oxidizing agent, it should be stored away from oils, organic solvents, and combustible materials. Concrete floors are preferable to wooden decks for storage areas. It should not be stored near radiators, heat ducts, hot water pipes, etc. Spills should be swept up or washed away promptly to avoid contact with organic materials. If such contact occurs, explosions are likely. When handling this chemical, workers should wear cotton masks to prevent inhalation of dust, safety glasses to prevent eye injury, and rubber gloves to avoid skin irritation.

l. ACTIVATED CARBON. Most large plants using powdered activated carbon store it in a slurry form in special tanks. If the powdered activated carbon is delivered in bulk, railroad cars or trucks equipped with airslide hoppers are often used. The powdered activated carbon is discharged directly or conveyed to the carbon slurry tank either by vacuum, pneumatic, or mechanical conveyance devices. The carbon slurry tank contains propeller or turbine mixers which agitate the carbon-water mixture until the carbon is thoroughly wetted. The usual concentration of powdered activated carbon in the contents of the tank is one pound per gallon of slurry. If powdered activated carbon is received in bags, the bags may be taken to the slurry tank by handcarts and manually emptied into the tank. A special dust-reducing cover should be used on the tank if manual unloading is used.

At small plants, activated carbon is commonly received and stored in bags and fed by special dry-feed machines equipped with carbon storage hoppers.

Bulk granular activated carbon is usually stored in dry storage bins. Bags of granular activated carbon may be stored in any convenient storage area away from extreme heat.

Persons handling activated carbon should wear dust masks to avoid inhalation of the activated carbon dust. The most serious hazard posed by dry activated carbon is the possibility of fire in the storage areas. These fires are especially difficult to control because the pores of the activated carbon contain enough oxygen to support combustion without an outside air supply. In order to prevent fires, storage areas or bins should be of fire proof construction, smoking should be prohibited near activated carbon, and carbon should not be stored where an accidental spark or flame could start a fire. Small fires can be dealt with by removing the burning material from the storage area. Larger fires will probably require a fine water spray directed at the activated carbon. Personnel fighting an activated carbon fire should wear gas masks provided with oxygen or air to avoid carbon dioxide and carbon monoxide inhalation.

m. COPPER SULFATE. Bags or drums of copper sulfate ($CuSO_4$) may be moved by handcarts, conveyor belts, etc. Storage spaces should be dry, since copper sulfate in solution is poisonous and corrosive. In some cases, a copper sulfate solution, rather than the solid form, is used for application to reservoirs. If such a solution is to be stored, the containers should be constructed of non-corrosive materials such as plastics, rubber, or silicon-iron.

n. CALCIUM HYDROXIDE. Calcium hydroxide, or "hydrated lime" [$Ca(OH)_2$], is a white powder available both in bags and bulk. Bags can be unloaded by bag lifts, fork lifts, handcarts, etc., and can be stored in most storage areas for considerable lengths of time without deterioration. Bulk shipments are unloaded and conveyed to storage bins by pneumatic devices and/or screw conveyors and bucket lifts. Hydrated lime absorbs carbon dioxide from the atmosphere, so exposure to the outside air should be controlled as carefully as possible. If the hydrated lime stands in bins for a long time, it may cake and stick to the sides of the bin. Mechanical agitation or vibration is needed to alleviate this situation. Hydrated lime is often applied as a slurry, which can be prepared by mixing the powder with water in a special tank equipped with a turbine mixer. The mixing process is often enhanced by pneumatically fluidizing the hydrated lime powder as it leaves the bulk truck and discharging the fluidized stream into a receiving line containing water jets. The wetted lime is then discharged into the mixing tank. The hydrated lime may comprise as much as 42 per cent of the lime slurry.

Workers handling hydrated lime should wear denim-quality clothing, dust masks, and chemical goggles. Hydrated lime can cause serious injury to eyes, and any contacting the eyes should be immediately washed away with water.

o. CALCIUM OXIDE. The handling of calcium oxide, or "quicklime" (CaO), is similar to that for hydrated lime. Quicklime readily absorbs moisture from the air, so exposure to the atmosphere should be minimized. In order to form a calcium hydroxide slurry, quicklime is slaked, which involves the application of heat and water to the quicklime. The slaking apparatus is a large tank equipped with a mixing device, a tight-fitting cover, and a dust and vapor removal unit. One of the major problems of the slaking process can be the removal of "grit", which are particles of impurities in the quicklime, from the slaker. The slaked lime slurry may contain as much as 35 per cent calcium hydroxide. Lines for conveying lime slurries should be made of flexible hose or open troughs so that caked deposits can be worked loose.

Quicklime can cause severe irritation of eyes, mucous membranes, and respiratory tracts. Continued contact of quicklime dust with the skin can cause dermatitis or skin burns. Personnel exposed to quicklime should wear denim clothing with long sleeves, bandanas, and trousers tied around the ankles. Exposed skin areas should be covered with a protective cream. Wherever dust is generated, efficient dust-collecting equipment should be installed. After handling quicklime, a shower should always be taken, even if dust was not apparent. Dust masks and chemical goggles are also a necessity. Persons working in areas where lime slurries may be spattered, such as around slakers, should wear face shields.

Dry quicklime should never be mixed with dry alum or similar substances, because the lime has an affinity for water and will rapidly react with the water of hydration in the alum. This reaction generates considerable heat and may cause explosions.

p. SODIUM CARBONATE. Sodium carbonate, or "soda ash" (Na_2CO_3), is available as a white powder in bags, barrels, or bulk. Conventional solids handling techniques can be used for unloading and moving this substance. It is noncorrosive and can be stored in steel or concrete bins or silos. Soda ash dust irritates the eyes, skin, mucous membranes, and respiratory tract, so dust-abatement procedures, including installation of ventilation and dust-collection systems, must be implemented. Persons exposed to the dust should wear chemical safety goggles, a dust respirator, and protective clothing. Protective cream should also be applied to exposed skin surfaces. If soda ash solutions are used, goggles or face shields, rubber aprons, rubber gloves, and rubber boots should be worn. Soda ash dust or solutions coming into contact with the body should be washed away with large amounts of water.

q. SODIUM HYDROXIDE. The usual form of sodium hydroxide, or "caustic soda" ($NaOH$), used in water treatment practice is a 50 per cent solution. The solution is usually unloaded and transferred to storage tanks by pumps and pipelines. Caustic soda can cause severe burns to the skin and eyes; therefore, manufacturers' instructions for unloading should be carefully followed. Inasmuch as a 50 per cent $NaOH$ solution begins to crystallize at 54°F, all storage tanks should be equipped with some heating device if air temperatures of less than about 60° F around the tanks are possible. An alternative is to dilute the solution to a $NaOH$ concentration which will not crystallize, but extreme caution should be used during the dilution because considerable heat is generated, and boiling or spattering of the solution can occur.

Workmen handling caustic soda should wear head covers, respirators with goggles, cotton clothing, rubber aprons, rubber gloves, and rubber boots.

r. CARBON DIOXIDE. If the carbon dioxide (CO_2) is received in cylinders, care should be exercised in the unloading and handling of the cylinders to avoid damage to the cylinders or the safety devices on the cylinders. Cylinders may be moved with a hand truck or other mechanical means.

Carbon dioxide cylinders contain frangible disc safety devices which will rupture and release the contents of the cylinder if the internal pressure exceeds 2,200 psig. This corresponds to a temperature of approximately 130° F. Consequently, cylinders should not be stored in areas near sources of heat such as radiators, nor exposed to direct sunlight. Additionally, storage areas should be dry, well ventilated, and fire resistant.

If the carbon dioxide is received in bulk (tank cars or tank trucks), it should be stored in low-pressure bulk storage tanks, ranging in size from 5 to 100 tons of CO_2 capacity. Most bulk storage tanks are self-contained units, including a freon refrigeration system and steam or electric vaporizers designed to maintain the liquid CO_2 at a temperature of near 0° F and a pressure of 300 psig. These bulk tanks are equipped with safety relief valves and frangible discs. The tanks should be located outdoors in a location relatively free of dust and oil and where they are unlikely to be struck by vehicles or falling objects. Construction of a protective fence around the tanks is desirable. Carbon dioxide gas is an asphyxiant and is heavier than air. Consequently, a gas leak in an enclosed space can produce a deadly atmosphere simply as a result of air displacement. Automatic alarms, indicative of high CO_2 concentration or oxygen deficiency, should be provided where there is danger of carbon dioxide accumulation.

s. SODIUM CHLORIDE. This chemical (NaCl) is available as a solid in rock, powder, crystal, and granular forms. It can be shipped and stored in bags or bulk. Storage spaces should be relatively moisture-free, since sodium chloride (common salt) has a tendency to absorb moisture and to cake.

t. SODIUM HEXAMETAPHOSPHATE. This chemical ($Na_{16}P_{14}O_{43}$) is one of several forms of what is known as "glassy" phosphates and is available in both the powdered and granular form. It is available in 100-lb multiwall paper and net burlap bags. Solutions are usually prepared in a mixing tank to a definite concentration and fed through either hard rubber, plastic, or stainless steel lines.

u. HYDROCHLORIC ACID. Hydrochloric acid (HCl) is a clear-colored or slightly yellow fuming, pungent liquid. It is poisonous and if used in water treatment must be of the purified form (U.S.P.). It can be shipped in glass bottles, carboys, rubber-lined steel drums, rubber-lined tank cars or trucks. It should be diluted before use by adding the acid to water. After dilution, it may be fed in any reasonably accurate corrosion-resistant liquid-chemical feeding device. Extreme care should be taken in handling as it can cause severe burns. Contact with the skin should be avoided and protective equipment for the eyes, face, and hands should be worn when handling the acid.

v. SULFURIC ACID. Sulfuric acid (H_2SO_4) is a strongly corrosive, dense, oily liquid, either clear or dark brown depending on purity. For water treatment, it should be of the U.S.P. grade, free of heavy metals. In the 94% grade, it is noncorrosive to steel drums, tank cars, or tanks. Once diluted, it is highly corrosive and should be contained in rubber-, glass-, or plastic-lined equipment. Care should be taken in handling as for hydrochloric acid. It may be fed with any corrosion-resistant (rubber covered) liquid-chemical feeder.

2. CHEMICAL HANDLING AND STORAGE. Methods of handling and storing of water treatment chemicals should be selected primarily on the basis of ease of operation, operating flexibility, and safety considerations.

If chemicals are to be received in shipping containers such as bags, boxes, drums, or canisters, equipment for handling may include carts, dollies, fork lifts, cranes, etc. If chemicals are shipped in bulk quantities, the mode of unloading depends on the physical characteristics of the chemical. Bulk liquids are usually unloaded by pumping from the tank truck or railroad car to the storage tanks at the treatment plant. Bulk dry chemicals can be unloaded by pneumatic unloading and conveyance devices, or, if the chemical is to be mixed or dissolved in water, it can be unloaded directly into a water eductor in which the chemical and water are mixed as the water flows to the storage tank. Crystalline or granular chemicals are usually unloaded by mechanical devices. All three forms of bulk chemicals can be unloaded by gravity if the chemical storage tanks or bins are located below ground near the railroad tracks or roadway.

Chemicals shipped in bags, drums, barrels, or other shipping containers can usually be stored by placing these containers in a specified storage area.

Bulk chemicals are stored in tanks or bins. In general, the supply of chemicals in storage at a water treatment plant should always be greater than projected 30-day requirements. It may be desirable to maintain larger supplies of essential chemicals, such as chlorine or coagulants, and smaller supplies of nonessential chemicals, such as fluoridation agents. Hazardous chemicals must be stored in separate rooms.

a. STORAGE. Storage space for chemicals shall provide for:

(1) at least 30 days of chemical supply at the projected use,

(2) convenient and efficient handling of chemicals,

(3) dry storage conditions,

(4) adequate separation of chemicals, and

(5) liquid chemical storage tanks with (a) a liquid level indicator and (b) an overflow and a receiving basin or drain capable of receiving accidental spills or overflows.

Chemicals shall be stored in covered or unopened shipping containers, unless the chemical is transferred into an approved covered storage unit.

Storage tanks and pipelines for liquid chemicals shall be specific to the chemicals and not for alternates.

b. HANDLING. For unloading of chemicals to storage and for loading of feed machines, elevators, conveyors, carts, fork lifts, and other appropriate means shall be provided for lifting the chemicals and chemical containers to minimize excessive lifting by operators.

Provisions shall be made for disposal of empty bags, drums, or barrels by an approved procedure which will minimize exposure to dust and dangerous conditions.

Provisions shall be made for the proper transfer of dry chemicals from shipping containers to storage bins or hoppers as to minimize the quantity of dust entering the equipment room.

Control should be provided by use of vacuum pneumatic equipment or closed conveyor systems, facilities for emptying shipping containers in special enclosures, and/or exhaust fans and dust filters which put hoppers or bins under negative pressure.

Provision shall be made for measuring quantities of chemicals used to prepare feed solutions.

c. HOUSING. Chemicals shall be stored in weatherproof housing except for bulk storage tanks or bins which may be outdoors. Bulk storage tanks or bins shall be designed to prevent water from entering the storage unit.

Floor surfaces shall be impervious, slip-proof, and well-drained.

Vents from feeders, storage facilities, and equipment exhaust shall discharge to the outside atmosphere above grade and remote from air intakes.

d. OPERATOR SAFETY. Each operator should be fully instructed of the dangers of the chemicals being used, the protective measures and equipment to be employed, and the first-aid and emergency procedures to be followed in case of an accident.

Protective equipment, consisting of at least one pair of rubber gloves, a dust respirator of a type certified by the National Institute for Occupational Safety and Health (NIOSH) for toxic dusts, an apron or other protective clothing, and goggles or face mask, shall be provided for each operator as required by the Department. Other protective equipment should be provided as necessitated by the chemicals being employed in the water treatment plant.

Approved gas masks with a self-contained air supply shall be available where chlorine gas is handled, and shall be stored at a convenient location but not inside any room where chlorine is used or stored.

A bottle of strong ammonia water (10% NH_3) shall be available for chlorine leak detection. Where ton containers are used, a leak repair kit approved by the Chlorine Institute shall be provided.

Adequate ventilation of chlorine feed and storage room shall be provided as specified in Engineering Bulletin No. 8.

3. CHEMICAL APPLICATION. Chemicals utilized in water treatment plants are applied in solid, liquid, or gaseous forms by means of special chemical measuring and application devices. Application rates are determined on the basis of either chemical volumes (volumetric feed) or chemical weights (gravimetric feed).

a. GENERAL. In general, all chemicals shall be applied to the water at such points and by such means as to:

(1) assure maximum efficiency of treatment,

(2) assure maximum safety to consumer,

(3) provide maximum safety to operators,

(4) assure satisfactory mixing of the chemicals with the water,

(5) provide maximum flexibility of operation through various points of application, when appropriate, and

(6) prevent backflow or back-siphonage between multiple points of feed through common manifolds.

b. CHEMICAL FEEDERS. Chemical feeders are generally divided into categories on the basis of the mode of application, i.e., either gravimetric or volumetric, and physical form of chemical, i.e., solid (dry), liquid, or gaseous. Hence, the types of chemical feeders are: gravimetric dry feeders, volumetric dry feeders, volumetric liquid feeders, and volumetric gas feeders. Liquids and gases cannot be readily applied on a weight basis so there is no "gravimetric liquid" or "gravimetric gas" category. There are many kinds of chemical feeders available, mostly proprietary in nature.

(1) Gravimetric Dry Feeders. Gravimetric dry feeders operate by applying a chemical at a set rate on the basis of weight. An example of a gravimetric feed rate is 10 pounds per hour. The two major types of gravimetric dry feeders are belt feeders and loss-in-weight feeders.

In a belt feeder, operation is based on the principle of maintaining a constant weight of chemical on a moving belt by actuation of a feed gate. The dry chemical enters the feeder inlet from a hopper and is continuously fed onto the weigh belt. The chemical is conveyed over a weight sensing section and on to a discharge point. The rate at which the chemical is weighed and discharged is usually dictated by a manual rate setter or automatically regulated from a flow meter.

In a loss-in-weight feeder, the chemical, chemical hopper, and feed mechanism are mounted on a beam balance scale. The scale has a counterpoise which is mechanically moved to set the desired weight of chemical feed. The speed of the device controlling the rate of flow of the chemical from the hopper is regulated by the position of the beam. If the beam moves upward, the speed of the feed mechanism (usually a helical screw or a vibrating plate) is increased so that more chemical is discharged and the beam moves downward, and vice versa. If the scale beam becomes excessively unbalanced, an alarm is usually tripped.

(2) Volumetric Dry Feeders. Volumetric dry feeders consist of chemical bins or hoppers with openings at the bottom through which the chemical is measured and discharged. A variety of devices are used to govern the rate of chemical discharge, including rotating discs, vibrating feeding trays, helical screws, and revolving gears, paddles, or buckets.

Dry chemicals can be applied directly to the water being treated by allowing them to fall into an open channel carrying the water, or they can be mixed with water to form a chemical solution or slurry which is then discharged into the water. If dry chemicals are applied directly to the water to be treated, they must be adequately mixed with the water to ensure uniform chemical distribution.

(3) Volumetric Liquid Feeders. Liquid chemicals, chemical solutions, and chemical slurries are applied to water by volumetric liquid feeders. Three particular types of volumetric liquid feeders are in common use: diaphragm pumps, plunger or piston pumps, and rotating wheel feeders.

Diaphragm pumps use a flexible diaphragm to alternately apply a suction and a direct pressure to a chamber through which the liquid flows. As the diaphragm flexes away from the chamber, the chamber is effectively enlarged and an inlet valve opens to allow the liquid to flow into the chamber. Then the diaphragm is flexed toward the chamber creating a pressure on the liquid which forces the inlet valve closed and forces the outlet valve open. The liquid is discharged through the outlet valve at a rate proportional to both the rate of diaphragm flexure and the distance through which the diaphragm flexes. Flexure of the diaphragm can be controlled by a reciprocating push rod attached to the diaphragm or by the variation of hydraulic pressure in a fluid contained in a chamber on the reverse side of the diaphragm.

A plunger or piston pump differs from a diaphragm pump in that the alternate suction and pressure are applied to the enclosed liquid through the movement of a plunger or piston. The volume of liquid pumped depends both on the rate at which the plunger reciprocates and the length of stroke of the plunger. A piston pump shall not be used to feed chemical slurries.

Several types of rotating wheel feeders are available. Probably the most common is one which has several narrow, seimcircularly-shaped buckets attached to a central rod. As the rod turns, the buckets are dipped into a chemical solution in a tank below the rod, filling the buckets. When the buckets are turned by the rotation of the rod, the liquid runs out of the buckets near the juncture between the buckets and the rod. The buckets are so constructed that the liquid flows out in a uniform manner and can be collected in a special trough located adjacent to the rotating wheel. The amount of chemical solution placed in the trough is proportional to the number of revolutions of the wheel feeder. If the contents of the trough are allowed to drain to the water being treated, the rate of application of the chemical solution is controlled through regulation of the speed of the rotating wheel feeder.

(4) Volumetric Gas Feeders. Two chemical gases are in widespread use at water treatment plants: chlorine and carbon dioxide.

For feeding of chlorine gas for water treatment purposes, see Engineering Bulletin No. 8.

Carbon dioxide may be fed in devices similar to solution-feed chlorinators. These solution-type feeders have carbon dioxide feed capacities approximately three-fourths as great as their chlorine feed capacities. For example, a chlorinator rated at 8,000 lb per day for chlorine feed would be rated at 6,000 lb per day for carbon dioxide feed. If it is more desirable to apply carbon dioxide gas rather than a carbon dioxide solution to the water to be treated, the carbon dioxide feed line should include a pressure reducing valve, a rate indicator, and a rate controller. Carbon dioxide in either the gaseous or solution form may be applied through perforated pipes at the bottom of a recarbonation basin.

(5) Chemical Feed Equipment. Chemical feed equipment shall be such that:

(a) Feeders shall be able to supply, at all times, the necessary amounts of chemicals at an accurate rate, throughout the range of feed.

(b) Chemical-contact materials and surfaces are resistant to the aggressiveness of the chemical solution.

(c) Corrosive chemicals are introduced in such a manner as to minimize potential for corrosion.

(d) Incompatible chemicals are not fed, stored, or handled together.

(e) No direct connection exists between any sewer and a drain or overflow from the feeder, solution chamber, or tank by providing that all drains terminate at least six inches, or two pipe diameters, whichever is greater, above the overflow rim of a receiving sump, conduit or waste receptacle.

(f) Dry chemical feeders measure chemicals either volumetrically or gravimetrically.

(g) Dry chemical feeders provide solution water and agitation of the chemical in the solution pot.

(h) Dry chemical feeders provide gravity feed from solution pots, if possible.

(i) Dry chemical feeders prevent emission of dust to the operating room.

c. NUMBER OF FEEDERS. A separate feeder shall be used for each chemical applied. Where chemical feed is essential for protection of the water, such as chlorination, a minimum of two feeders shall be provided, and a standby unit or a combination of units of sufficient capacity shall be available to replace the largest unit during shut-downs. Where a booster pump is required, duplicate equipment shall be provided and, when necessary, standby power. Spare parts shall be available for all feeders to replace parts subject to wear and damage.

d. CAPACITY OF FEEDERS. Chemical feeds shall be able to supply, at all times, the necessary amounts of chemicals at an accurate rate, throughout the range of feed. Activated carbon feeders, if used in a treatment plant, shall have a carbon-dosage capacity of not less than 50 mg/l.

e. LOCATION OF FEEDERS. Chemical feed equipment shall:

(1) be located as near as possible to points of application to minimize length of feed lines,

(2) be located in a separate room, if feasible, to reduce hazards and dust problems, and

(3) be readily accessible for servicing, repair, and observation of operation.

f. CONTROL OF FEEDERS. Chemical feeders may be manually or automatically controlled, with automatic controls designed to permit override by manual controls. Chemical feed rates shall be proportional to flow, which will necessitate an automatic or manual change in chemical feed rate whenever the flow rate through the plant is changed. Provisions shall be made for measuring the quantities of chemicals used and the rate of flow through the plant, so that the chemical dosage rates can be determined.

g. SOLUTION TANKS. Chemicals are often received as solids but are more conveniently applied as solutions. In such cases, chemical solutions must be prepared at the water treatment plant. The amount of chemical and water used to make a solution must be accurately measured so that the strength of the solution is known. One method of preparing a solution involves a volumetric dry feeder, a solution chamber with a mechanical agitator for mixing, and a water supply. The specified volume of dry chemical is measured by the feeder, dropped through a pre-wetter, which applies a water spray to the chemical, and falls into the solution chamber. The proper amount of water is added, and the mechanical mixer, of which several types are available, thoroughly mixes the chemical and water in the chamber.

Another common method is for the operator to empty one or more sacks of known weight of chemical into a mixing chamber, add a specified amount of water, and mix thoroughly with a mechanical device. In making up a solution, caution should be exercised to insure that the proposed solution strength is within the range of solubility of that particular chemical. Two solution tanks of adequate volume may be required for a chemical to assure continuity of chemical supply.

When utilizing solution tanks, the following shall apply:

(1) A mixing device appropriate to the nature of the chemical solution shall be provided in the solution tank to maintain a uniform strength of solution.

(2) Continuous agitation shall be provided to maintain slurries in suspension.

(3) Means shall be provided to measure the solution level in the tank.

(4) Chemical solutions shall be kept covered.

(5) Large tanks with access openings shall have such openings curbed and fitted with tight overhanging covers.

(6) Subsurface locations for solution tanks shall be free from sources of possible contamination and assure positive drainage of ground waters, accumulated water, chemical spills, and overflows.

(7) Overflow pipes, when provided, shall be turned downward with the end screened, have a free discharge, and be located where noticeable.

(8) Acid storage tanks shall be vented to the outside atmosphere, but not through vents in common with day tanks.

(9) Each tank shall be provided with a valved drain and protected against backflow.

(10) Solution tanks shall be located and protective curbings provided so that chemicals from equipment

failure, spillage, or accidental drainage shall not enter the water in conduits, treatment or storage basins.

h. DAY TANKS. There may be instances where feeding of a liquid chemical solution directly from the solution or storage tank is not advisable or possible. For those cases, a "day tank" is provided which receives the liquid from the solution tank and from which the liquid feeders take suction. The "day tank" is so called because is usually holds only enough liquid chemical for about one day's supply.

When "day tanks" are utilized, the following shall apply:

(1) Day tanks shall meet the requirements above for solution tanks.

(2) Day tanks shall hold no more than a 30-hour supply.

(3) Day tanks shall have some device that will permit an accurate measurement of the quantity of chemical used daily.

(4) Hand pumps may be provided for transfer from a carboy or drum. A tip rack may be used to permit withdrawal into a bucket from a spigot. Where motor-driven transfer pumps are provided, a liquid level limit switch and an overflow from the day tank, draining by gravity back into the bulk storage tank, shall be provided.

(5) A mixing device consistent with the nature of the chemical solution shall be provided to maintain uniform strength of the day tank solution. Continuous agitation shall be provided to maintain chemical slurries in suspension.

(6) Day tanks shall be properly labeled to designate the chemical contained.

i. WEIGHING SCALES. Weighing scales shall be provided for weighing cylinders containing chlorine gas except for installations where automatic switchover from an empty to a full cylinder is provided. Scales shall be of corrosion-resistant material and shall be accurate enough to permit measuring increments of 0.5 per cent of load.

j. FEED LINES. Many of the chemicals used in a water treatment plant are either corrosive or scale-forming. All chemical feed lines shall be maintained in a condition permitting full flow of chemical to the feed point. Maintenance of feed lines can be minimized by proper design and feeder placement.

Chemical feed lines should be as short as possible in length of run, of durable, corrosion resistant material, easily accessible throughout the entire length, protected against freezing, and readily cleanable.

Feed lines should slope upward from the chemical source to the feeder when conveying gases, should be color coded, and should be designed consistent with scale forming or solids depositing properties of the water, chemical, solution, or mixture conveyed.

k. SERVICE WATER SUPPLY. Many chemical feeders require a water supply to carry the chemical to the point of discharge or to prepare solutions or slurries of the chemical. This water service supply is usually the finished water produced by the treatment plant and may have to be pumped to provide the required pressure.

The service water supply shall be:

(1) ample in supply and adequate in pressure,

(2) provided with a measuring device when used in preparing specific solution concentrations by dilution,

(3) properly treated for hardness, when necessary, and

(4) properly protected against backflow.

The connection between the service water supply and the feeders shall prevent any of the chemicals from entering the potable water supply system. Cross connection control shall be provided to assure that the service water lines discharging to solution tanks are properly protected from backflow as required by the Department, and liquid chemical solutions cannot be siphoned through solution feeders into the water supply by providing a vacuum relief, or providing a suitable air gap, or providing other suitable means or combinations as necessary.

O. MEASUREMENT, INSTRUMENTATION, AND CONTROL

The mechanisms used for control of plant operation can be divided into three groups: (1) devices for measuring items related to water treatment, (2) instruments for indicating these measurements, and (3) mechanisms for control of the treatment processes. Control can be exerted manually, semiautomatically, or automatically, depending on the degree of interaction between the measuring devices and the control mechanisms.

There is no "standard" design for a measurement, instrumentation, or control system for a water treatment plant. Only the necessary measurement, instrumentation and controls for efficient operation should be provided at any plant.

1. MEASUREMENT. Process variables commonly measured in a water treatment plant include water flow rates, temperatures, liquid levels, pressures, turbidities, chemical feed rates, and chemical concentrations. Most of these variables, especially the physical characteristics, are measured by placing the appropriate measuring device at the desired points within the plant. Chemical concentrations are frequently measured by taking water samples and analyzing them in the laboratory. Laboratory tests are covered more fully in Section P. New techniques are presently available, such as potentiometric or polarographic analyses, gas chromatography, infra-red spectrophotometry, and atomic absorption spectrophotometry, which greatly expedite testing for many chemicals. This section deals only with those treatment variables which can be measured at the necessary points within the plant and not requiring laboratory analyses.

   There are certain basic measurements that should be made in a plant regardless of plant capacity, water quality, or manpower factors. These variables can be measured electrically, mechanically, hydraulically, or pneumatically. Many important dissolved elements or ions in water can be measured electrically using potentiometric or polarographic analyses. Among these elements or ions are chloride, fluoride, and oxygen. Measurement of the pH of water can be done with a special glass electrode apparatus.

2. INSTRUMENTATION. Measurements should be indicated on some type of instrument if they are to be used in water treatment plant operation. Thus, the measurement is sent from the point of measurement to a dial, gauge, etc. that can be observed by

a plant operator, or, alternatively, the measurement is sent to an automatic control mechanism which will alter some aspect of the water treatment process. For example, if increased turbidity would be measured in the raw water influent to the treatment plant, that measurement could be sent to an indicating instrument in the control area of the water treatment plant. The plant operator would observe the indication of higher raw water turbidity and make an appropriate modification in the treatment process, such as an increase in the rate of feed of chemical coagulant to the rapid mix basin. However, it is possible for the turbidity measurements to be sent directly to devices which will adjust the coagulant feed rate automatically, without any manual adjustments by the plant operator.

When water treatment variables are measured, the measurement signals can result from a variety of mechanical, electrical, hydraulic, or pneumatic stimuli, such as mechanical motion, liquid displacement, motion of light or electron beam, total force, pressure, voltage, or current. These measurement signals may be transmitted to the appropriate instrument indicating the measurement in the same form of energy; for example, a water level indicator may consist merely of an open glass tube hydraulically connected to a basin and rising outside the basin to a point above the maximum water level in the basin. The water in the tube will be at the same level as the water in the basin. On the other hand, it might be desirable for a plant operator in a central control room to know the water level in a basin remote from the control room. In this case, the measurement device would receive the water level signal probably as a pressure, and an ancillary device, called a transducer, would convert the pressure signal to an electronic signal which would be sent to an instrument in the control room. A transducer is a device that converts energy from one form to another, such as mechanical or radiant energy to electrical energy.

A plant operator should know the value of many different variables to run the water treatment plant efficiently. Some of these may be determined in the plant laboratory from samples collected throughout the plant.

Instruments to indicate the following variables, as required by the Department, shall be installed in each water treatment plant:

Raw Water	Rate of flow
Filtration	Head loss Effluent flow rate Wash water flow rate Water level (wash water tank)
Finished water	Water level (clearwell) Rate of flow to distribution system

Instruments to measure and indicate other variables would be desirable but are not necessary for plant operation. Some of these are:

Raw Water	pH Turbidity Temperature Individual chemicals
Rapid Mixing	Water level Mixer operation
Flocculation	Water level Flocculator operation
Sedimentation	Water level Sludge removal equipment operation
Filtration	Water level (filter) Effluent turbidity
Finished Water	pH Fluoride Residual chlorine Turbidity
Chemical Feed	Rate of feed Weight of chemicals in tanks, bins, or hoppers

The above is only an example of the variables which might be measured in a conventional water treatment plant using coagulation, flocculation, sedimentation, filtration and chlorination. Softening plants would also require measurement of calcium, magnesium, carbon dioxide, alkalinity, pH, and total dissolved solids concentrations in the plant influent and effluent as well as possible intermediate locations. Many other measurements can be used as individual conditions dictate.

It is often desirable to maintain records of various instrument readings so that various trends can be discerned. This can be done by manually recording observed values at various intervals, but it can also be performed by automatic recorders. Almost any variable that can be measured can be automatically recorded in one fashion or another. It is possible to obtain automatic recorders which record measured values only at preset intervals, but most automatic recorders operate continuously. Continuous records are kept on either bar charts or circular charts. Bar charts may be recorded on paper wrapped around a drum or cylinder, on paper rolled tight between two drums, or on paper which is emitted from the recorder as a continuous sheet. Circular charts are recorded on special discs of paper which revolve at a predetermined rate. All automatic recorders use special paper to fit the particular paper holders or drive mechanisms, and all of these special papers have grids printed on them to indicate the magnitude of the measurement being recorded.

3. CONTROL. Water treatment plant processes are most commonly controlled by manual, semiautomatic or automatic methods.

Manual control involves total operator control of the various water treatment processes. The personnel at the water treatment plant observe the values of the different variables associated with the treatment processes, and make suitable adjustments to the processes.

Semiautomatic control utilizes instruments to automatically control a function or series of functions within control points that are set manually after a button is pushed to begin the automatic sequence of operations. An example of semiautomatic control is the automatic backwashing of a filter after a button is pushed to initiate the program.

Automatic control involves the use of instruments to control a process, with necessary changes in the process made automatically by the controlling mechanisms. When a process variable changes, the change is measured and transmitted to a control device which adjusts the mechanisms controlling the process. An example of automatic control is the maintaining of a uniform rate of flow through a filter even though the head loss varies. This is usually done by measuring the rate of flow and automatically opening or closing a valve on the filter effluent line as the rate of flow varies from the set point. Another example of automatic control is chlorination, where the rate of chlorine application can be controlled by either the water flow rate, or, if the flow of water is fairly uniform, by a chlorine residual analyzer. An advancement on these chlorination systems is the combination of both automatic flow control and automatic residual control into a single system in which flow is the primary means of control and the residual reading is used to trim the feed rate. Automatic control systems have been developed which are very reliable, but no system is failure-proof and provisions for emergency manual control should be included.

Many large modern water treatment plants have incorporated computers into their automatic control systems. These computers receive measurement signals, calculate the amount by which the process must be changed, and send the appropriate message to the control device.

In the design of water treatment plants, any type of control can be utilized. If automatic controls are used, provisions shall be included for manual control in case of an emergency or malfunction.

4. DESIGN OF INSTRUMENTS AND CONTROLS. Modern instruments and control devices can greatly aid water treatment plant personnel in producing a water adequate in both quality and quantity, so long as the proper instruments are provided in the proper locations. Prior to installation, the instruments and controls should be carefully selected so that the plant does not contain too many nor too few instruments. If too few instruments are installed, the plant operator will have great difficulty in properly controlling the treatment processes; if too many are installed, superfluous instruments probably will be ignored.

The designing engineer should carefully evaluate the extent of instrumentation and controls necessary for efficient operation of the plant. All factors should be considered in this evaluation including size of plant, difficulty of treatment, number of control points, location of various process steps, number and caliber of operating personnel, possible operating problems, cost, frequency of response, and process time delay.

All instruments and control devices shall be placed in readily accessible locations in order to facilitate observation, maintenance, repair, and replacement. Instruments shall not be located in environments which might lead to premature failure of the instruments.

5. MAINTENANCE OF INSTRUMENTS AND CONTROLS. The most modern and reliable instruments and control systems will eventually fail if proper maintenance is not practiced. Maintenance is the responsibility of both the manufacturer and the plant operator.

The following maintenance guidelines shall be observed as far as possible:

a. Follow the manufacturer's recommendations concerning maintenance and operation of instruments and controls.

b. Have trained personnel regularly inspect and calibrate instruments and controls, especially the more complex items.

c. Keep essential spare parts and repair tools on hand at all times. At least one member of the water treatment plant staff shall be acquainted with emergency repair procedures for essential instruments and controls.

d. Personnel assigned to such activities shall be thoroughly versed in proper maintenance procedures.

e. Emergency procedures for manual control of various processes shall be developed in case an automatic system fails.

P. WATER QUALITY ASSURANCE

1. SAMPLING AND MONITORING. Water supplies may contain a variety of substances or organisms which pose potential hazards to human health or render the water esthetically unsatisfactory. The purpose of water treatment is to remove all or part of these substances and organisms so that the treated water is safe for human consumption and essentially free from objectionable taste, odor, color, and turbidity. The suitability of various sources of water for human consumption should be gaged by measuring the concentrations of objectionable substances or organisms in the water and comparing these with predetermined guides or regulations.

   Samples collected to comply with the minimum testing regulations of the Department shall be analyzed in a laboratory approved by the Department. Testing of samples for plant process control can be performed in any laboratory.

   a. WATER QUALITY PARAMETERS. The constituents or characteristics of water most commonly tested for are as follows:

Raw Water	Finished Water
Physical Quality	
Temperature	Turbidity
Turbidity	Color
Color	Threshold Odor Number
Threshold Odor Number	
Chemical Quality	
pH	pH
Iron	Iron
Manganese	Manganese
Hardness (calcium and magnesium)	Hardness (calcium and magnesium)
Alkalinity	Alkalinity
Carbon Dioxide	Total dissolved solids
Total dissolved solids	Chlorine residual
Nitrogen (NH_3, NO_2^-, NO_3^-)	
Chloride	

Raw Water	Finished Water
Bacteriological Quality	
Total coliform bacteria	Total coliform bacteria
Fecal coliform bacteria	Fecal coliform bacteria
Bacterial plate count	Bacterial plate count

The above listing gives only the parameters most commonly checked in raw and finished water supplies. Each water supply has its own characteristics and may have other constituents more critical than some of the above. For example, a water may be deficient in fluoride or contain excessive fluoride, in which case, the implementation of fluoride addition or removal procedures may be required. The concentrations of fluoride in both the raw and finished water should then be regularly monitored.

A list of parameters to be checked routinely in the raw and finished water shall be submitted to the Department for approval.

In all cases, the sampling and monitoring of finished water parameters must, as a minimum requirement, follow that specified by the Drinking Water Regulations.

b. FREQUENCY OF TESTING. The frequency of testing for critical components or characteristics of a water supply should be dictated by (1) variability of the raw water supply, (2) variability of treatment processes leading to possible finished water quality variations, and (3) size of the population served by the water treatment facility.

If a raw water supply is subject to possible rapid variations in quality, samples must be taken at frequent intervals and tested. Conversely, slow changes in quality require less frequent testing. For example, if the source of raw water is a deep aquifer which exhibits very little historical variation in water quality, it may be possible to test for constituents as infrequently as monthly or even seasonally; but if the source is a river flowing through upstream urban areas, more frequent testing, i.e. daily or hourly, is desirable.

The two elements determining the quality of water leaving a water treatment plant are (1) the characteristics of the raw water entering the plant and (2) the type and extent of treatment given the water in the plant. Changes in raw water quality should be observed and quantified, so that the water treatment processes can be modified accordingly. If water treatment processes in a plant are changed rapidly, water samples from various points in the plant will have to be tested frequently in order to determine the effects of treatment variations on water quality.

An additional consideration in determining frequency of sampling and testing is the population served by the treatment plant. The larger the population served, the more serious the consequences of unsafe water. Thus, increased sampling is justified due to the increased magnitude of responsibility involved.

In all cases, the frequency of testing shall be that required to assure deliverance of a safe finished water regardless of the number of persons served.

The frequency of sampling and testing shall be submitted to and approved by the Department. Minimum frequency of sampling shall be that specified by the Drinking Water Regulations.

c. COLLECTION OF SAMPLES. Samples of water obtained from flowing sources may be taken as either grab samples or as composite samples. Grab samples are taken nearly instantaneously. Most water samples analyzed are grab samples. Inasmuch as a grab sample is used to determine water quality only for one particular moment, the entire range of water quality variation at that location can be determined only by examination of a large number of grab samples.

A composite sample is made up of several grab samples pooled into one large sample over a period of time. The grab samples are collected at regular intervals and added to the composite sample in proportion to the rate of flow at the time. Probably the most common type of composite sample is the 24-hour variety, for which grab samples are taken every one or two hours. Composite samples reflect water quality averages over the composite time period. The major disadvantage in the use of composite samples is that short-term fluctuations in water quality go unnoticed because compositing masks quality variations within the composite period. In addition, composite samples cannot be used to obtain average values of parameters which would change during storage in the sample container. Examples of such parameters are dissolved gases, temperature, turbidity, and bacterial numbers.

Whenever samples are taken, they must be truly representative of existing conditions. In order for the sample to be representative, the container must be free of contaminants. If sampling taps are used, the water should be allowed to flow through the tap for a time sufficient to flush out any stagnant water in the supply piping before collecting the sample. Samples collected from sedimentation basins or flocculation basins should not be taken in corners of the basin where the water moves slowly or forms eddies and currents.

Collection of representative samples is equally as important for raw water sources. Samples should be taken from wells only after the well has been pumped for a period of time, at least several hours. Stream samples can vary with depth and distance from shore, so it is usually best to take a grab sample at mid-depth in the center of the stream, or at mid-depth quarter points across the stream. Lakes and reservoirs can vary widely in water quality from one location to another and from one depth to another, so care should be taken to obtain samples at the point(s) which best serves the purposes of the investigation.

In some cases, the material used for the sample container can affect the concentrations of certain substances in the sample. For this reason, the use of pyrex glassware is recommended. Certain cations, such as aluminum, cadmium, chromium, copper, iron, lead, manganese, silver, and zinc, can be lost through adsorption on or ion exchange with the walls of glass containers. Samples to be tested for these cations are best collected in separate clean bottles and acidified with concentrated hydrochloric or nitric acid to a pH of 3.5 or less to minimize adverse influences of the containers.

For some water quality parameters, samples cannot be collected and taken to a laboratory for analysis; determinations must be made on site. Among these parameters are temperature, pH, and dissolved gases such as oxygen, carbon dioxide, hydrogen sulfide, and chlorine. Other water quality parameters require preservation of the sample by addition of chemicals or control of the sample temperature. These preservations allow the sample to be stored for a short time prior to laboratory analyses. Recommended preservatives and maximum holding periods for several constituents or characteristics of water are listed below.

Parameter	Preservative	Maximum Holding Period
Acidity-Alkalinity	Cool, 4°C	24 hours
Bacteria	Cool, 4°	<6 hours
Biochemical Oxygen Demand	Cool, 4°C	6 hours
Calcium	None required	Indefinite
Chloride	None required	7 days
Color	Cool, 4°C	24 hours
Fluoride	Cool, 4°C	7 days
Hardness	Cool, 4°C	7 days
Metals, Total	HNO_3 to pH<2	6 months
Sulfate	Cool, 4°C	7 days
Threshold Odor	Cool, 4°C	24 hours

More specific directions for the preservation and storage of samples are given in the latest edition of the "Standard Methods for the Examination of Water and Wastewater," published jointly by the American Public Health Association, the American Water Works Association, and the Water Pollution Control Federation and the latest edition of the "Manual of Methods for Chemical Analysis of Water and Wastewater" published by the EPA.

All samples collected shall be identified as to location, time, date, and sample collector.

2. CERTIFICATION. The State of Arizona has passed legislation which purpose is to classify water supply facilities and to assure that operators of such facilities are suitably qualified to properly operate and maintain those facilities. Under the regulations promulgated, all water treatment facilities and water distribution systems are classified according to population and/or type of treatment. Four regular grades of classification, I through IV, were established with IV being the most complex. A special S grade was also established for plants and systems not in regular categories.

Each owner and purveyor of potable water is to employ the services of a certified operator of the required classification who will have direct responsibility for the operation of the treatment plant or system. Grade IV is the highest operator classification level and Grade I is the lowest. The operator classification level required for each treatment plant or system classification is given in the regulations.

Reference is made to the appropriate regulations on classification of treatment plants and certification of operators for more complete details.

Q. PLANT FINISHED WATER STORAGE

Finished water storage at the plant is the clearwell holding the finished water from the filters and the wash water tank holding the finished water for backwashing the filters. Clearwell storage is normally either aboveground, steel or reinforced concrete tanks or reinforced concrete subsurface reservoirs, located under the filters or as separate structures. Wash water storage can be a steel elevated tank or standpipe or an above ground steel or reinforced concrete tank. In some instances, wash water is taken from the clearwell storage by pumps.

In all cases, care should be taken to assure that unsafe water cannot enter the finished water storage unit through overflows, walls, pipe connections, etc. and contaminate the finished water.

The design standards as given in Chapter 6, where applicable, shall be followed for all plant storage.

1. CLEARWELL. The primary function of clearwell storage is to permit a uniform production rate of the treatment plant while meeting the water demands of the distribution system. A secondary function is to provide adequate contact time for the disinfectant to act.

   Clearwell storage should be sized, in conjunction with distribution system storage, to relieve the filters and other plant processes from having to follow fluctuations in water use.

   When clearwell storage is used to provide the contact time for chlorine, special attention shall be given to size and baffling to prevent short-circuiting through the storage unit.

   Overflows, access manholes, and vents for finished water storage tanks shall be designed to prevent unsafe water, insects, birds, dirt, etc. from entering the clearwell.

2. WASH WATER TANKS. Wash water storage tanks shall be sized, in conjunction with available pumping units and clearwell storage, to provide the backwash water required by Section F. Consideration shall be given to the backwashing of several filters in rapid succession.

3. ADJACENT COMPARTMENTS. The structural and wall configuration in a water treatment plant may bring a finished water and unsafe water in adjacent compartments or flumes that are separated by a common wall. This is a potential source of contamination of the finished water.

To prevent contamination, finished water shall not be stored or conveyed in a compartment adjacent to unsafe water when the two compartments are separated by a single (common) wall.

Pipes carrying unsafe water shall not pass through any finished water storage.

4. BASINS AND WET WELLS. Finished water from filters may be discharged into small receiving basins located under the filters. These receiving basins may supply a small wet pit from which the finished water is pumped into the larger clearwell storage.

   Receiving basins and pump wet pits for finished water shall be designed as finished water storage units and in accordance with the requirements of this section and Chapter 6.

R. TREATMENT PLANT WASTES

Provisions should be made for proper disposal of water treatment plant wastes such as sanitary, coagulation and/or softening sludge, filter backwash water, spent regenerant and rinse water from ion exchange softeners, diatomite filter sludge, and mineral wastes from desalination facilities. The requirements contained herein should be considered minimum requirements as the Department's water pollution control regulations may be more stringent. Alternative methods of water treatment and chemical use should be considered as means of reducing waste handling and disposal problems.

All waste discharges shall be governed by regulatory agency requirements. In locating waste disposal facilities, due consideration shall be given to preventing potential contamination of water supplies.

1. QUANTITIES AND CHARACTERISTICS OF WASTES. The different types of water treatment plant wastes vary widely in characteristics, with some, such as alum sludge and softening sludge, having a significant suspended solids content. Others, such as ion exchange regeneration wastes, have virtually no suspended solids but very high concentrations of dissolved solids.

    a. PRESEDIMENTATION BASIN SLUDGE. Very little information as to the approximate characteristics of presedimentation sludge is available. The settled material generally consists of sands, silts, clays, and organic debris of vegetable origin. Presedimentation basins are designed on an empirical basis to serve a varying suspended solids loading, and the properties of the sludge reflect the nature of the solids present in the raw water. If the particles in the raw water are large and settle out readily, the sludge will probably be of fairly high solids content. Slowly settling particles will produce a thin sludge of low solids content.

       In some cases, chemicals or recycled sludge are added to the water entering a presedimentation basin in order to promote suspended matter removal.

    b. COAGULATION SLUDGE. Since aluminum and iron salts are generally used to accomplish coagulation, aluminum and ferric hydroxides are the chief constituents of sludges from water treatment plants practicing chemical coagulation. In addition, the residues contain entrained particulate matter, both organic and inorganic. In the absence of gross pollution of the raw water source, the amount of entrained material is usually small and consists mainly of fine sands, silts, and clays.

Normally the sludge has a pH range of 6 to 8, although the range may be slightly greater if iron salts are used as coagulants. The settled sludge will range in suspended solids content from about 1,000 mg/1 (0.1%) to about 20,000 mg/1 (2.0%). The sludges are gelatinous, especially those resulting from aluminum salts, and are difficult to dewater. The quantity of sludge will vary widely being dependent upon the amount of aluminum or iron salt added to the water and the amount of particulate material in the raw water. Dry weight of the sludges is typically 75 to 95 pounds per cubic foot.

c. LIME SOFTENING SLUDGES. The solids produced from the lime-soda ash softening process are primarily calcium carbonate and magnesium hydroxide.

Also included are suspended particles initially present in the raw water but removed in the softening process. Softening sludges vary widely in characteristics depending upon the relative amounts of calcium carbonate and magnesium hydroxide in the sludge, the nature and amount of suspended matter in the raw water, and whether or not a coagulant, such as alum, was used. Generally the sludges from softening are more readily dewatered than those from coagulation. The solids content of softening sludges may vary from 2 to 33 per cent, and the total sludge volume may range from 0.3 to 6 per cent of the water treated. Chemical solids (calcium carbonate and magnesium hydroxide) derived from lime softening are roughly 2.5 times the weight of quicklime applied.

d. FILTER WASH WATER. A variety of suspended substances may be present in the waste filter wash water, including clay, organic matter, activated carbon, hydroxides of iron and aluminum, calcium carbonate, oxides of iron and manganese, etc. The relative prevalence of various substances is largely dependent on the chemicals used for water treatment. Waste filter wash waters invariably are very dilute, having average suspended solids concentrations of approximately 200 mg/1 (0.02%) or less for coagulation plants and approximately 1,500 mg/1 (0.15%) or less for iron and manganese removal plants.

e. DIATOMITE SLUDGE. In cleaning a diatomaceous earth filter, the precoat plus body feed plus suspended matter removed during filtration are removed from the filter housing for disposal. Approximately two-thirds of the sludge is diatomaceous earth and one-third is the impurities removed from the water. About 300 to 600 pounds of diatomite sludge are produced per million gallons of water treated. The dry bulk density of the sludge is about 10 pounds per cubic foot.

f. REGENERATION WASTES FROM ION EXCHANGE. The principal waste products in the brine wastes from ion exchange regeneration are dissolved chlorides of calcium, magnesium, and sodium. In addition, small quantities of iron, manganese, and aluminum may be present. Total dissolved solids (TDS) concentrations in these wastes commonly range from 35,000 to 45,000 mg/l (3.5-4.5%), with maximums of about 95,000 to 120,000 mg/l (9.5-12.0%). The total waste flow may be between 2 to 8 per cent of the amount of water softened.

g. DEMINERALIZATION WASTE BRINES. The purpose of desalination processes is to obtain a product water with a lower concentration of dissolved salts than is present in the raw water. To do this, salts are removed from a portion of the raw water and transferred to the water wasted from the process. The waste products most often found in desalination waste brines are chloride and sulfate salts of calcium, magnesium, and sodium. Raw waters treated by various desalination techniques may range in TDS concentrations from less than 1,000 mg/l (0.1%) to 35,000 mg/l (3.5%). TDS concentrations in the waste brines may range from 2,000 mg/l (0.2%) to 100,000 mg/l (10%). Depending on the desalination method used and the characteristics of the raw water, the volume of the waste brine flow may be as little as 1 per cent or as much as 50 per cent of the raw water processed, with an average of 15 to 20 per cent. Inasmuch as suspended particles are detrimental to most desalination processes, raw waters intended for desalination are usually pretreated for turbidity, iron removal, etc.

2. DISPOSAL METHODS. Various methods of waste disposal have been used by the water utility industry. Inasmuch as the properties of different types of wastes vary considerably, no specific method of waste disposal can be considered most suitable for all wastes.

In some cases, it is possible to recover chemicals from water treatment sludges. For example, lime can be recovered from softening sludge and alum from alum sludge. Chemical recovery permits reuse of some chemicals while reducing the quantity of wastes for disposal. Unfortunately, recovery is only economical for large plants with large chemical usage and large quantities of sludge.

The fundamental problem in disposal of water treatment plant wastes is to concentrate them and render them innocuous so they are suitable for disposal at sites other than in a water supply.

a. DIRECT DISCHARGE TO WATER COURSE. The predominant method of disposal of filter backwash wastes and waste solids from water treatment plants has been direct discharge to surface waters. This method is now being abandoned due to regulations for discharges to water courses set by the State of Arizona and the U.S. Environmental Protection Agency. In these regulations, water treatment plant wastes are considered pollutants and are restricted from discharge to a water course unless the waste stream has specified quality characteristics.

A discharge permit, called the National Pollutant Discharge Elimination System (NPDES) Permit, is required before direct discharge of water treatment plant wastes to a water course can be made. This permit sets restrictions on the concentration of parameters, such as mineral content, suspended solids and pH, in the waste stream that can be discharged to a stream or lake. If the water treatment plant wastes are not discharged to a waterway, the permit is not required. The permit is required, however, if the plant employs some treatment method for its wastes and discharges an effluent from those waste treatment facilities to a water course.

All wastes from a water treatment plant discharged to a water course, either directly or as an effluent from a waste treatment facility, shall conform to the requirements as set forth in the National Pollutant Discharge Elimination System Permit.

b. LAGOONS. The most common treatment method presently utilized at water treatment plants for handling water treatment plant wastes is lagooning. Operating costs of this method are low, but land requirements are high.

Lagoons are generally built by enclosing a land area by dikes or excavation with no attempt to maximize drainage with underdrains or by a sand layer. Sludge is added until the lagoon is filled with solids at which time the lagoon is removed from service until the solids have dried for removal for ultimate disposal. Lagoons take advantage of natural temperatures for evaporation and freezing to aid in dewatering of the waste solids. Lagooning is not so much a disposal method as one for dewatering, thickening, and temporary storage.

Lagoons can be either a nonevaporative or an evaporative type. A nonevaporative lagoon has a discharge; an evaporative lagoon does not. Water is removed from a nonevaporative lagoon by decantation.

Evaporation may provide a hard crust at the surface, but the remaining depth can turn into a viscous liquid upon agitation, depending upon the concentration of solids. In cold climates, freezing aids in dewatering by separating attached water from the solids. After thawing, the solids are in the form of small granular particles that settle readily, and additional water can be decanted.

When sufficient land is available, filled lagoons can be abandoned, thereby eliminating an ultimate disposal problem. This is called a permanent lagoon. A temporary lagoon is one that is cleaned periodically of the accumulated solids and reused. If possible, permanent lagoon areas should be reclaimed to remove any unsightly land areas.

Serious consideration should be given to the disposal of the decantate and underdrainage from a lagoon. Discharge to a surface water is recommended if the discharge can meet the quality requirements of the NPDES permit. Alternative methods are return to the water treatment plant influent, discharge to a sanitary sewer, and land application.

All wastes from water treatment processes can be discharged to a lagoon. Sludges from the coagulation and sedimentation processes have proven difficult to dewater in lagoons. These sludges may only dewater to about 10 per cent solids concentration which is too thin for landfill disposal without further thickening. Lime sludges are more easily dewatered in lagoons. A solids content of 50 per cent may be achieved with lime sludges, which is adequate for handling and disposal in a sanitary landfill operation. The concentration of magnesium in the lime sludge affects the final solids concentration as magnesium sludges are difficult to dewater.

Lagooning of wastes from diatomite filtration plants has been effective. Inasmuch as diatomite sludges are relatively innocuous, it may be possible to construct a lagoon, use it until it is filled with sludge, and abandon it. This can be done only if land is available. Otherwise, the lagoon must be filled, dried, and cleaned of sludge, with the sludge disposed of on land or in a landfill.

Lagoons receiving highly mineralized wastes from ion exchange and desalination plants shall be of the evaporative type and shall be lined to prevent seepage of the wastes into the ground. The solids in these wastes are dissolved and can only be concentrated by evaporation of water in the wastes.

The design of both temporary and permanent lagoons shall provide for:

(1) a location free from flooding,

(2) when necessary, dikes, deflecting gutters or other means of diverting surface water,

(3) a minimum usable depth of 5 feet,

(4) a minimum embankment top width of 8 feet to permit access of maintenance vehicles, a lesser top width may be used for very small installations,

(5) maximum inner and outer embankment slopes not steeper than 3:1, horizontal to vertical, and a minimum inner embankment slope not less than 4:1, horizontal to vertical,

(6) additional protection for embankments by riprap when dikes are subject to wind action or severe flooding of an adjacent water course,

(7) fencing to prevent access by unauthorized persons,

(8) adequate freeboard,

(9) a minimum of 2 cells and preferably more to give flexibility of operation,

(10) cell and piping arrangement to permit parallel and series operation,

(11) adjustable decanting device,

(12) width of lagoon adequate to allow removal of solids by dragline, clamshell, scraper, tugger hoist, or any other mechanical equipment that might be employed,

(13) effluent sampling point,

(14) adequate safety provisions,

(15) 3 to 5 years solids storage volume,

(16) if receiving a lime softening sludge, a permanent lagoon having a volume at least 4 times that for a temporary lagoon,

(17) an acceptable means of final sludge disposal,

(18) an acceptable means of final effluent disposal, and

(19) if receiving the wastes from an ion exchange or desalination plant, an impervious lining of either natural or man-made materials to prevent seepage.

If receiving lime softening sludge in a temporary lagoon, the design should be based on about 0.7 acres per million gallons per day per 100 mg/l of hardness removed with a usable depth of 5 feet. This should provide about 2.5 years storage.

c. DRYING BEDS. Sand drying beds for water treatment waste solids are basically similar to those employed in drying of sewage sludges. These beds usually consist of 6-9 inches of sand over a 12-inch deep gravel underdrain system overlying drain tiles with open joints. Sand sizes of about 0.35-0.50 mm are typically used with a uniformity coefficient of less than 5. Gravels are usually 1/8-1/4 inch in size. The beds are subdivided to meet plant-operating conditions.

An underdrained sand bed may include a decanting device depending upon the depth of waste sludge on the bed, but basically water is removed by drainage and air drying. A sufficiently shallow waste-solids depth to allow cracking of the solids down to the sand-solids interface will accelerate drying and yield drier cakes.

Both the drainage and decantate from a drying bed can be discharged to a sanitary sewer or to a surface water if the discharge meets the NPDES Permit requirements. The dried solids can be removed from the drying beds by hand or mechanical equipment but shall be disposed of in a satisfactory manner.

Sand drying beds have the disadvantage of (1) requiring extensive space and long dewatering times, (2) poor to inadequate performance during cold or wet periods, (3) having high capital costs, (4) requiring more operation and maintenance, and (5) being dependent upon the weather for successful operation.

Drying beds for lime sludges are not recommended as the filtrate may adhere to and eventually clog the filter media and underdrain system.

Drying beds are not applicable for wastes from ion exchange or desalination plants as the solids are dissolved and will pass through the bed media.

d. WASTEWATER TREATMENT FACILITY. An increasingly popular method of disposal of water treatment plant wastes is discharge to the sewage treatment facility via sanitary sewers. This would be particularly true for a small community served by sewage lagoons. If the sewage lagoons are of sufficient size to handle the water treatment wastes, then construction of separate facilities may not be justified.

Sludges from the coagulation-sedimentation process, such as alum sludge, wastes from ion exchange and desalination plants, and filter wash wastes may be discharged to the sanitary sewer. Discharge of lime sludge to sanitary sewers should be avoided since it may cause both liquid volume and sludge volume problems at the sewage treatment plant. This method should be used only when the sewerage system has the capability to adequately handle the lime sludge. Surge storage at the water plant may be needed so that the volume of the water plant wastes may be released at a controlled rate to ease the load on both the sewerage system and the sewage treatment facilities.

Evaluation of the following considerations shall be made before the discharge of water treatment plant wastes to a sewage treatment plant via sanitary sewers can be made:

(1) possible damage to the sewer system due to clogging,

(2) amenability of the wastes to the existing sewage treatment processes, principally in mechanical treatment plants,

(3) hydraulic capacity of sewers, pumping stations, and sewage treatment facilities,

(4) effect of the wastes on the final effluent of the sewage treatment plant,

(5) a direct connection between the water treatment plant waste disposal line and the sanitary sewer must be prevented, and

(6) discharge of the waste solids over a time period compatible with operation of the wastewater treatment plant.

Approval of this method shall be secured from the Owner of the sanitary sewer system and sewage treatment facilities as well as from the Department before final designs are made.

e. LAND APPLICATION. Direct land application of water treatment plant wastes is not common. Indirect land application has been common in the western states where irrigation is extensively practiced. The water plant wastes were discharged directly to a water course whose waters were subsequently utilized for land irrigation purposes. This indirect use of these wastes for land application has been stopped or curtailed by the restrictive regulations pertaining to discharge of those wastes to a water course. Most water treatment plants now try to recycle much of their wastes with only the dewatered solids being disposed of on land or in a sanitary landfill.

Land application has been investigated as it applies to treated sewage and sewage sludges. These liquids and sludges have nutrient value for crop production as well as water value. Wastes from a water treatment plant have a water value but the solids have little value for the land or crops. The high concentrations of aluminum or iron in some sludges and the brine wastes from ion exchange or desalination plants may actually be detrimental to crop production. In isolated instances, an acid soil may be able to beneficially use a lime sludge or an alum or iron hydroxide sludge to neutralize the acidity.

Direct land application of water treatment plant wastes will be approved after the designing engineer has demonstrated to the Department the feasibility of such a plan.

f. SANITARY LANDFILL. Sanitary landfills have been used more extensively in recent years as the final disposal site of both liquid and solid wastes from water treatment plants. Generally, for economic reasons, the solids are separated from the liquid by various means with the solids being transported by truck to the landfill and the liquid being returned to the plant influent or disposed of elsewhere. In some instances, the total wastes, liquid and solid, can be pumped through a pipeline to the landfill site. Each case has to be investigated and the disposal methods determined by economics and the regulations pertaining to sanitary landfill operations.

Disposal of water treatment plant wastes, liquid or solid, at a sanitary landfill will be approved by the Department if the landfill can and will accept such wastes under the permit issued for the landfill.

g. DEWATERING. Several mechanical devices have been used for dewatering of sludges with varying degrees of success. Those presently used are vacuum filters, pressure filters, centrifuges, and dual-cell gravity solids concentrators. Two or more of these processes can be used within the same system to obtain a higher degree of solids concentration than would be attainable using only one process.

Alum waste solids have proven difficult to dewater by all of these processes. The gelatinous nature of these solids almost precludes the use of vacuum filters without precoating the filter with diatomaceous earth. With precoating, vacuum filters will produce a cake containing 20-30 per cent solids. Vacuum filtration of lime sludges has been more successful but usually the waste solids are thickened prior to being vacuum filtered. Solids concentrations of 45-65 per cent have been achieved by vacuum filtration of thickened lime sludges.

Centrifuges are widely applied to dewatering of water softening sludges with a 40-65 per cent solids concentration being achieved. However, centrifugation for alum sludges has not been successful with maximum solids concentrations of only 12-15 per cent being obtained.

Pressure filters are not used extensively in this country, although they have been used in Europe for alum sludges. Sludge cake with 15-20 per cent solids has been reported without chemical preconditioning and 25-50 per cent solids with chemical preconditioning. Pressing time has been as long as 8 hours. Lime sludges have been reported to dewater to 65 per cent solids in about 1 hour of pressing time.

The dual cell gravity concentrator, although not widely used for water treatment plant wastes, is reported to be able to produce a dewatered sludge with approximately the same per cent solids as the other mechanical dewatering devices.

The above mechanical processes could be used effectively with wastes from diatomite filters, with the dewatered solids being disposed of on land or in a landfill.

All of the above mechanical dewatering units are not applicable to brine wastes from ion exchange and desalination plants. Also, the high costs for equipment, operation and maintenance, and disposal of dewatered waste solids make use of these mechanical dewatering devices impractical for small installations.

Mechanical dewatering of water treatment plant wastes will be considered by the Department only after Engineering or pilot plant studies on the particular plant wastes have demonstrated the feasibility of the process.

h. MATERIALS RECOVERY. Alum, lime, and magnesium carbonate recovery is possible by treatment of specific sludges. Alum recovery from alum sludges is possible by treatment of the sludge with sulfuric acid followed by sedimentation or filtration to remove raw water sediment. The recovered alum solution is contained in the sedimentation basin effluent or the filtrate. If a settling basin is used, alum recoveries of 60 to 80 per cent can be expected. With filters, recoveries of about 90 per cent are likely. Recovered alum can be recycled many times, so long as inert material, iron and manganese, soluble color, or impurities from the sulfuric acid do not become unacceptably concentrated.

Lime can be recovered from lime sludges of a softening plant by recalcination. The process involves recarbonation of the sludge to convert the magnesium to soluble magnesium bicarbonate which is then removed with the excess water, dewatering, drying of the dewatered sludge, and recalcination to produce calcium oxide and carbon dioxide. The magnesium must be removed or the recovered lime is useless. Because heat energy is required, most of the water has to be removed from the sludge before recalcining for economic reasons. At high temperatures, calcium carbonate is broken down into calcium oxide and carbon dioxide. The lime is reused in the softening process and the carbon dioxide is captured and used to recarbonate the softened water and/or the lime sludge prior to dewatering. A recalcination plant will realize a larger production of lime than needed for softening. The excess lime can be sold to help defray operating expenses. Present evidence indicates that the minimum economic size for recalcining plants is roughly 20 tons of dry sludge solids per day. There are some waste solids from a lime recovery plant, and provision must be made for their disposal.

A recent development is the use of recycled magnesium carbonate as a coagulant. As indicated above, prior to recalcination, magnesium must be removed from the softening sludge by recarbonation to convert insoluble magnesium hydroxide to soluble magnesium bicarbonate. The soluble magnesium bicarbonate solution, after separation from the calcium carbonate, can be applied to the raw water as a coagulant. Magnesium bicarbonate solution not required for coagulation can be heated and aerated to precipitate magnesium carbonate. The resulting magnesium carbonate sludge is dewatered, dried, and sold or otherwise disposed of.

In all of the above recovery processes, the quantity of solids requiring disposal is reduced, and a resource is reused.

Product recovery processes will be considered by the Department after engineering or pilot plant studies done on a particular plant waste demonstrate the feasibility of the processes.

i. FILTER WASH WATER RECOVERY. Disposal of waste filter wash waters has generally been to natural receiving waters. However, this waste flow is now regarded as a pollutant and alternative means of disposal should be found.

Recovery and reuse of the wash water is the most frequently used alternative. The reuse is accomplished by mixing the filter wash water with the plant influent before or at the rapid mix basin. In most cases, the wash water is collected in a recovery basin from which it is pumped into the plant influent. Suspended solids in the wash water settle with other solids in the sedimentation basins, and the only wastewater discharged from the plant is that associated with basin sludge removal. The recycling of waste filter wash water serves as a water conservation technique and may have advantages over other means of disposal. If desired, the waste wash water can be allowed to settle in the recovery basin with the decantate being returned to the plant influent and the settled solids combined with the basin sludge for disposal.

Lagooning is an acceptable means of managing waste filter wash water flows. If a separate lagoon is used for the waste wash water, the supernatant from the lagoon may be recycled to the plant influent. Algae growing in the lagoon may present a problem if recycling to the plant influent is practiced.

Waste filter wash water may also be discharged to a sanitary sewer, although a rate of flow regulation may be required to avoid sewer surcharge. This mode of disposal may be most applicable if the waste wash water characteristics make it unsuitable for recycling.

Design of disposal facilities for waste filter wash waters shall consider the following:

(1) For direct discharge to a water course, waste filter wash water shall have a parameter content less than that specified in the NPDES Permit.

(2) If a recovery basin is provided, the basin shall have a capacity to contain the anticipated volume of waste wash water produced by the plant when operating at design capacity. A plant with 2 filters shall have a recovery tank capacity equal to the total waste wash water from both filters calculated by using a 15 minute wash at 15 gallons per minute per square foot. In plants with more than 2 filters, the size of the recovery basin will depend on the anticipated hours of operation. It is recommended that waste filter wash water be returned to the plant influent at a rate less than 10 per cent of the raw water entering the plant.

j. OTHER METHODS. Other methods of treating plant sludges are heat treatment, freezing of alum sludges, and lime sludge pelletization. Deep-well injection of brine wastes from ion exchange and desalination plants may be feasible under some circumstances. Application of this method requires extensive knowledge of ground water resources and subsurface geology.

When colloidal gel solids are heated under pressure, the gelatinous flocs break down, allowing bound water to escape which improves the dewaterability of the sludge. Although heat treatment appears to offer an alternative means of alum sludge conditioning, there is little data presently available on the process.

The process of freezing a sludge removes water from a gelatinous floc such as alum sludge. When thawed, the sludge remains as small granular particles resembling brown sand with the volume reduced by a factor of about 6. Thickening of the sludge prior to freezing appears desirable to reduce the volume of material to be frozen. A refrigeration plant is required unless natural freezing can take place.

A technique has been developed to pelletize lime sludge prior to disposal where recalcining or dewatering is not feasible nor attractive. Water and the lime sludge are introduced into a cone-shaped, bottom apex vertical tank tangentially at the apex. Sand which serves as a nucleus for formation of calcium carbonate pellets is introduced at the top of the tank. The resulting sand-sludge mixture is maintained in suspension by the upward spiraling flow of the water. Calcium carbonate plates out on the sand, forming hard pellets which grow and eventually fall to the apex. The pellets are periodically discharged to a sump for dewatering. This process works if the magnesium content and turbidity in the sludge is not too high. The resulting pellets may be disposed of in a landfill.

Brine wastes from ion exchange or desalination plants are sometimes disposed of by injection into deep wells. Deep injection wells, 400 to 1,500 feet, have been used primarily for the disposal of oil field brines. Great care should be exercised to prevent contamination of freshwater aquifers when this method is used.

Heat treatment and freezing of alum sludges, pelletization of lime sludges, and other methods will be considered by the Department if it is demonstrated that the process is feasible for a particular waste. Deep-well injection of spent brine wastes will be approved by the Department when it is demonstrated that the method will not contaminate any ground water aquifers.

3. SANITARY WASTES. The sanitary wastes from water treatment plants, pumping stations, etc. shall be discharged directly to a sanitary sewer system, when feasible, or to an adequate on-site waste treatment facility.

engineering bulletin no. 10

Chapter 5

HYDROPNEUMATIC TANKS

ARIZONA DEPARTMENT OF HEALTH SERVICES

MAY 1978

CHAPTER 5 - HYDROPNEUMATIC PRESSURE TANKS

CHAPTER 5 - HYDROPNEUMATIC PRESSURE TANKS

A. GENERAL

Hydropneumatic pressure tanks are used to develop and maintain pressure in a water system by means of compressed air.

1. APPLICATIONS. The hydropneumatic tank is an alternative to developing and maintaining water system pressure by elevated tanks. Selection of the optimum means of developing water system pressure should be based on a comprehensive engineering analysis.

   Example applications for hydropneumatic tanks include small communities, housing developments, private homes, camps, restaurants, hotels, resorts, country clubs, factories, institutions, and booster installations.

   A hydropneumatic pressure tank can be used to increase distribution system pressure, to stabilize a variable pressure supply to within acceptable limits, and to minimize the frequency of on-off cycles from water supply pumps. They also provide an excellent cushion against water hammer. Since water generally only occupies 10 to 50 percent of the effective volume of a hydropneumatic tank, they should not be considered as water storage, and provide no emergency reserve capacity.

2. PRINCIPLE OF OPERATION. The hydropneumatic tank uses compressed air chambers to maintain system pressure. Water is pumped from the source to the tank, compressing entrapped air within the tank. The air and water pressure are in equilibrium and can be controlled within desired limits.

3. ESSENTIAL COMPONENTS OF A HYDROPNEUMATIC PRESSURE SYSTEM. The essential components of a hydropneumatic pressure system include a pump, pressure tank, an air supply, and necessary controls and inlet and outlet piping.

B. TYPES OF HYDROPNEUMATIC TANKS

1. TANK WITH AIR-CHARGER. In a tank equipped with an air-charger, the amount of air in the tank can be varied so that the minimum and maximum water levels can be set at a predetermined height. Tanks may be of either a horizontal or vertical configuration, with the horizontal more common.

2. CAPTIVE AIR TANKS. The amount of air contained in the tank or cell in this system is equal to the amount contained in the

tank at atmospheric pressure. Water, which is non-compressible, is pumped into a closed tank, compressing the air into a smaller volume. The water level in the tank at the lowest pressure is fixed by this pressure. Air loss in the tank (due to leakage and absorption into the water) is replaced by emptying and refilling the tank. Small hydropneumatic tanks are sometimes equipped with a diaphragm inside that separates air contact, reducing air loss through absorption. Another alternative is for the water to be totally contained by a flexible membrane in the tank. Captive-air systems are normally used for small applications because only a minimum amount of water can be handled by the tank.

C. DESIGN OF HYDROPENUMATIC TANKS

1. CRITERIA. All hydropneumatic tanks shall be designed and constructed in accordance with the current requirements of the American Society of Mechanical Engineer's (ASME) Code for Unfired Pressure Vessels, Section VIII, Division 1.

2. TANK SIZING. Correct sizing of a hydropneumatic tank is important because the size of the tank directly determines the frequency of pump cycling. If the tank is too small in relation to system demands, the pump must cycle excessively, prematurely wearing out the pump motor. Normal pump cycling is in the range of 2 to 6 times per hour. A tank that is too large in relation to system requirements does not take the best advantage of the hydropneumatic concept. Because hydropneumatic tanks do not effectively provide storage, the pumps serving the system must be able to supply the peak demand within the required pressure range.

   Hydropneumatic tanks shall be sized such that the system can supply instantaneous demand for a minimum of 20 minutes. Consideration may be given to the inflow pumping rate in the system design.

   Instantaneous demand shall be determined from Table 3, "Tabulated Maximum Instantaneous Flows", or from historical records covering the system. The demand and pumping rate are in units of gallons per minute (gpm). If the well or other water supply cannot provide enough water for maximum use, ground level storage shall make up the difference.

   A minimum of 2 pumps shall be provided above a maximum instantaneous demand rate of 105 gpm.

TABLE 3

TABULATED MAXIMUM INSTANTANEOUS FLOWS

Number of Connections vs. Maximum Instantaneous Demand Flows
for
Residential Use *

No.	Flow	No.	Flow	No.	Flow	No.	Flow
1	20.0	45	98.9	89	151.9	133	195.1
2	22.1	46	100.3	90	152.9	134	196.0
3	24.2	47	101.7	91	153.9	135	196.9
4	26.3	48	103.1	92	154.9	136	197.8
5	28.4	49	104.5	93	155.9	137	198.7
6	30.5	50	105.9	94	156.9	138	199.6
7	32.6	51	107.2	95	157.9	139	200.5
8	34.7	52	108.5	96	158.9	140	201.4
9	36.8	53	109.8	97	159.9	141	202.3
10	38.9	54	111.1	98	160.9	142	203.2
11	41.0	55	112.4	99	161.9	143	204.1
12	43.1	56	113.7	100	162.9	144	205.0
13	45.2	57	115.0	101	163.9	145	205.9
14	47.3	58	116.3	102	164.9	146	206.8
15	49.4	59	117.6	103	165.9	147	207.7
16	51.5	60	118.9	104	166.9	148	208.6
17	53.6	61	120.1	105	167.9	149	209.5
18	55.7	62	121.3	106	168.9	150	210.4
19	57.8	63	122.5	107	169.9	151	211.2
20	59.9	64	123.7	108	170.9	152	212.0
21	61.6	65	124.9	109	171.9	153	212.8
22	63.3	66	126.1	110	172.9	154	213.6
23	65.0	67	127.3	111	173.9	155	214.4
24	66.7	68	128.5	112	174.9	156	215.2
25	68.4	69	129.7	113	175.9	157	216.0
26	70.1	70	130.9	114	176.9	158	216.8
27	71.8	71	132.0	115	177.9	159	217.6
28	73.5	72	133.1	116	178.9	160	218.4
29	75.2	73	134.2	117	179.9	161	219.2
30	76.9	74	135.3	118	180.9	162	220.0
31	78.4	75	136.4	119	181.9	163	220.8
32	79.9	76	137.5	120	182.9	164	221.6
33	81.4	77	138.6	121	183.9	165	222.4
34	82.9	78	139.7	122	184.9	166	223.2
35	84.4	79	140.8	123	185.9	167	224.0
36	85.9	80	141.9	124	186.9	168	224.8
37	87.4	81	143.0	125	187.9	169	225.6
38	88.9	82	144.1	126	188.8	170	226.4
39	90.4	83	145.2	127	189.7	171	227.2
40	91.9	84	146.3	128	190.6	172	228.0
41	93.3	85	147.4	129	191.5	173	228.8
42	94.7	86	148.5	130	192.4	174	229.6
43	96.1	87	149.6	131	193.3	175	230.4
44	97.5	88	150.7	132	194.2	176	231.1

For each connection in excess of 176, add an additional 0.7 gpm.

* Add fire flow, where applicable.

3. WATER SEAL. A water seal is the water layer which is left in the bottom of the tank to prevent the compressed air from escaping into the distribution system, resulting in the loss of system pressure. Normally approximately 10 percent of the tank volume is required for a water seal, but the water seal volume is a function of tank configuration. Regardless of tank configuration the tank outlet should be at the lowest possible elevation in the tank to minimize the volume required for a water seal.

4. PRESSURE SETTINGS. The air to water ratio in hydropneumatic tanks should be that which permits the maximum withdrawal between the high and low pressure settings. The low pressure setting is established by the distribution requirements. The low pressure is the pressure necessary to deliver water to any part of the distribution system at minimum system pressure of 20 psi (the difference between dynamic head and the minimum tank pressure setting). The high pressure setting should be determined by system design and service requirements.

5. AIR SUPPLIES. Air must be supplied to hydropneumatic tanks to replace air loss in the tank due to leakage and air absorbed into the water. Compressed air is generally supplied to hydropneumatic tanks in one of the following ways:

   a. For most applications, an air charger with either automatic or manual controls is used.

   b. Tanks for very small applications are drained and refilled to replenish lost air.

   c. Air can be supplied to a system through a valve in the discharge pipe of a well pump. When the pump stops and water drains from the discharge pipe, air is drawn into the pipe. When the pump restarts, the air is forced through the discharge pipe to the hydropneumatic tanks.

   d. Elevated static air charger system.

D. APPURTENANCES

1. PRESSURE GAGES. The hydropneumatic tank shall be equipped with easily visible pressure gages showing instantaneous pressure in the tank.

2. PRESSURE RELIEF VALVE. A pressure relief valve shall be provided on all hydropneumatic tanks, the valves shall be set to open at

the greater of the maximum allowable pressure rating for the equipment, or 80 percent of the rated working pressure of the tank. The orifice opening of the valve should be large enough to discharge all or most of the capacity of the pumps.

3. AIR RELIEF VALVE. An air relief valve should be provided in all air-charging pneumatic systems. The air relief valve shall be located at the low water level setting of the tank, unless alternative design concepts are provided. This function prevents excessive air from entering the distribution system in the event the water seal is lost.

4. LEVEL GAGE AND CONTROLS. All hydropneumatic tanks shall have a water level indicator. The system shall be equipped with liquid level controls that will not allow the tank to be drawn down below 10 percent capacity. Hydropneumatic tanks designed to serve any public water system shall have controls necessary to maintain the minimum pressure in the distribution system.

5. DRAIN VALVE. All hydropneumatic tanks shall be equipped with a drain valve.

engineering bulletin no. 10

Chapter 6

STORAGE

ARIZONA DEPARTMENT OF HEALTH SERVICES

MAY 1978

CHAPTER 6 WATER STORAGE

CHAPTER 6 WATER STORAGE

A. OBJECTIVES OF WATER STORAGE

Water demands within a distribution system vary yearly, monthly, daily, and hourly, and the water supply system must supply water in sufficient quantity to meet all these demands. To do so, the following criteria are met: (1) the sources produce the required quantity and quality of water; (2) the transmission and distribution mains be large enough to carry these flows; and (3) the pressure levels within the distribution system be high enough. It is usually inefficient and uneconomical to construct the treatment plant and pumping stations sufficiently large to meet the largest anticipated water demands. Also, a water treatment plant may become less effective and much more difficult to operate if flow rates through the plant are rapidly varied. Consequently, water storage facilities are often constructed within a distribution network to aid in meeting the peak flow requirements exerted on the system.

The objectives of finished water storage are: (1) to help meet peak flow requirements, (2) to equalize system pressures, and (3) to provide emergency water supply.

Water supply systems are designed to satisfy the maximum anticipated water demands. These maximum demands usually occur during certain hours of the day of maximum usage, usually during a hot, dry summer. If enough storage is provided to handle the hour-to-hour variations in water use, the treatment plant can operate at a relatively uniform rate throughout the day.

Water supply to and through the distribution system during periods of peak demands should result in adequate pressures at the consumer's tap. Desirable pressures are given in Chapter 7. Storage located within the distribution system can contribute water to the system during peak demand periods, thus reducing the friction loss through the distribution system and maintaining a higher system pressure. Also, storage contribution to meet peak water demands permits high service pumps at the treatment plant to operate at relatively uniform rates.

A large water demand, which can occur at any time, is that required for firefighting purposes. It may coincide with other large demands on the system. Water in storage within the system is available to meet the demand imposed by a fire. Another function of water storage is to provide an emergency supply of water in the event the water treatment plant, pumping stations, or a principal transmission main is out of service. One concern in designing the elements of a water supply system, principally the storage and distribution facilities, should be provision for the necessary water to meet fire flows, if provided, and emergency conditions.

B. TYPES OF STORAGE

Storage capacity is met by use of elevated storage or ground storage. Elevated storage feeds the distribution system by gravity, whereas ground storage is normally pumped into the system. Clearwell storage, which is usually part of a water treatment plant, is not included in computing storage requirements unless sufficient firm pumping capacity is provided to assure clearwell storage usage during emergency conditions. Clearwell storage is used to supply peak demand rates in excess of the production rate, and to provide water for plant use, filter backwashing, and water supply to the distribution system for short periods when plant production is stopped because of failure or replacement of some component or unit of treatment.

1. GROUND STORAGE. Ground storage may be tanks on the ground surface or below natural ground elevation. A ground storage tank can be classified as one whose diameter is greater than its height. Steel or reinforced concrete are the usual construction materials. If the tank is below natural ground surface and covered by soil, it is also called a subsurface tank. The usual construction material for a subsurface tank is reinforced concrete. Sizes of the most common steel ground storage tanks vary from 50,000 to 10,000,000 gallons. Common water depths are 15 to 40 feet. Reinforced concrete tanks can be of any size but are generally built no deeper than 20-25 feet below ground surface. Concrete tanks built above ground have the same general capacity and depths as steel tanks.

   Ground storage is usually located remote from the treatment plant but within the distribution system. It is used to equalize flows from the treatment plant, to be a source of emergency water supply, and to be a source of supply for repumping to a higher service level. Such storage for repumping is common in distribution systems of large areal extent because the outlying service areas are usually beyond the range of the primary pumping facilities.

2. ELEVATED STORAGE. Elevated storage tanks "float" on the distribution system. That is, the elevated tank is hydraulically connected to the distribution system and tends to maintain system pressures at a uniform level. When water use is high and

pumping facilities cannot maintain pressures, water is discharged from the elevated tanks to meet the water use demands and maintain system pressures. Conversely, when water use is low, the pumps supply excess water to the system and the elevated storage is replenished.

Any storage facility is considered to be elevated storage if it is at an elevation above the minimum hydraulic gradient elevation of the distribution system. Thus, ground or subsurface tanks or basins built on high ground may be elevated storage.

The most common types of elevated storage are elevated steel tanks and standpipes. An elevated steel tank is a steel water container mounted on columns. Capacities of individual elevated tanks normally range from 25,000 to 1,500,000 gallons. Three million gallons may be viewed as a practical maximum. Concrete elevated tanks are also used to a limited extent.

A standpipe is a tall cylindrical tank, normally constructed of steel or reinforced concrete, whose height is greater than its diameter. Only the upper portion of the storage volume of a standpipe is considered useful storage for pressure equalization purposes. The lower portion of the storage acts to support the useful storage and to provide a source of emergency water storage.

Elevated storage is generally located at some distance from pumping station(s) serving the distribution system level but not outside the boundaries of the service area, unless the facility can be placed on a nearby hill. Additional considerations for siting of elevated tanks are conditions of terrain, suitability of subsurface soil and/or rock for foundation purposes, and hazards to low-flying aircraft, especially near airports. Elevated tanks are normally built on the highest available ground to minimize the required construction heights.

C. CONSTRUCTION MATERIALS

The materials and designs used for finished water storage units shall provide stability and durability as well as protect the quality of the finished water. Steel structures shall follow the current AWWA Standard D100 concerning steel tanks, standpipes, reservoirs, and elevated tanks wherever applicable. Other materials of construction are acceptable when properly designed to meet the requirements of this chapter.

D. CAPACITY

Storage facilities should have sufficient capacity, as determined from engineering studies, to help meet domestic demands, and where fire protection is provided, fire flow demands.

The minimum storage capacity for systems not providing fire protection should approximate the annual average daily consumption. This capacity may be reduced when the source and treatment facilities have sufficient capacity, with standby power capability, to supplement peak demands of the system.

E. GENERAL DESIGN CONSIDERATIONS

1. LOCATION. The location and type of treated water storage for any water works system should be integrated with the distribution system, ground elevations and system pressures, type and capacity of supply and treatment plant, economics of pumping and construction, and water demand rates. All finished water storage facilities should be located to protect the quality of the finished water.

   Specific requirements for finished water storage units are as follows:

   a. The bottom of ground storage units shall be placed at the normal ground surface and shall be either above the 100-year flood level or protected from the 100-year flood. If such location or protection cannot be provided, provisions shall be made permitting isolation of the storage unit and protection of the other waterworks facilities from contamination during flood periods.

   b. When the bottom of a storage unit must be below normal ground surface, it shall be placed above the high ground water table.

   c. When the bottom of a storage unit is below normal ground surface, sewers, drains, standing water, and other sources of possible contamination shall be kept at least 50 feet from the unit. Water main pipe, pressure tested in place to 50 psi without leakage, may be used for gravity sewers at distances greater than 20 feet and less than 50 feet from the storage unit.

   d. The top of a storage unit shall not be less than 2 feet above normal ground surface. Clearwells constructed under filters may be excepted from this requirement when the total design gives the same protection.

2. COVERS. All finished water storage units shall have a substantially watertight roof which excludes birds, animals, insects, and excessive dust to prevent contamination and quality deterioration of the finished water. All existing open finished water storage units shall be eliminated or covered.

3. PROTECTION FROM TRESPASSERS. A six-foot fence, locks on access manholes, or other necessary precautions shall be provided to prevent trespassing, vandalism, and sabotage.

4. DRAINS. All finished water storage units have to be taken out of service at periodic intervals for cleaning, repair, or maintenance. Provisions shall be made in the design to permit complete isolation and drainage of each storage unit while maintaining service to the system.

   Storage units which float on the distribution system shall be designed so they can be isolated and drained without causing an adverse loss of pressure in the distribution system.

   No drain on a water storage unit shall have a direct connection to a sanitary sewer, storm sewer, or irrigation facility. A drain may discharge to a storm sewer through a suitable air break which requires at the drain pipe discharge a space of at least 2 drain pipe diameters above the maximum water surface elevation.

5. FOUNDATION. All storage units shall have adequate bedding or foundation commensurate with the soil bearing properties.

6. OVERFLOW. All water storage units shall have an overflow which extends down to an elevation between 12 and 24 inches above the ground surface and discharges freely. No overflow shall be connected directly to a sanitary sewer or storm sewer. An overflow pipe may discharge to a storm sewer through a suitable air break which requires at the overflow pipe discharge a space of at least 2 overflow pipe diameters above the maximum water surface elevation. All overflow pipes should be located so the discharge is visible.

   When an internal overflow pipe is used on an elevated tank, it should be located in the access tube. For vertical drops on other types of storage units, the overflow pipe should be located on the outside of the unit.

   The overflow of an above-ground storage unit shall open downward and be screened with 16-mesh noncorrodible screen installed within the pipe at a location least susceptible to damage by vandalism.

The overflow pipe shall be of a diameter sufficient to permit waste equal to or in excess of the filling rate.

7. LEVEL CONTROLS. A water level indicating device shall be provided for each finished water storage unit. Installation of a water level recording device is recommended. Installation of these devices will permit more efficient operation of the system and a more accurate record of water usage.

   Adequate controls shall be provided to maintain levels in storage units providing pressure to the distribution system.

   Pumps should be controlled from water levels in storage units with the signal transmitted by telemetering equipment when any appreciable head loss occurs in the distribution system between the source and the storage unit.

   Overflow and low-level warnings or alarms should be located at a place(s) where they will be under responsible surveillance 24 hours a day.

   When two or more elevated tanks are located within the same pressure level of a distribution system, each finished water storage unit should have an altitude valve or equivalent control to prevent overflows. These altitude valves are usually located in a concrete pit adjacent to the storage unit. Provisions for draining valve or control pits by gravity or pumping shall be provided, but the drains shall not be directly connected to a sanitary or storm sewer.

8. ACCESS. Finished water storage units shall be designed with reasonable convenient access to the interior for cleaning and maintenance. Manholes or roof hatches above the waterline:

   a. shall be framed at least 4 inches, and preferably 6 inches, above the surface of the roof at the opening; on subsurface units, manholes shall be elevated 24 to 36 inches above the top or covering sod,

   b. shall be fitted with a solid watertight cover which overlaps the framed opening and extends down around the frame at least 2 inches,

   c. should be hinged at one side, and

   d. shall have a locking device.

9. VENTS. Finished water storage units shall be vented. Overflows shall not be considered as vents. Open construction between the sidewall and roof is not permissible.

Vents on all storage units:

a. shall prevent the entrance of surface water and rainwater,

b. shall exclude birds and animals,

c. shall exclude insects and dust, as much as this function can be made compatible with effective venting; for elevated tanks and standpipes, 16-mesh noncorrodible screen may be used, and

d. shall, on subsurface storage units, terminate in an inverted U construction with the opening 24 to 36 inches above the roof or sod, and covered with 16-mesh noncorrodible screen installed within the pipe at a location least susceptible to vandalism.

10. ROOF AND SIDEWALL. The roof and sidewalls of all finished water storage units shall be watertight with no openings except properly constructed vents, manholes, overflows, risers, drains, pump mountings, control parts, or piping for inflow and outflow. Other provisions are:

a. Any pipes running through the roof or sidewall of a finished water storage structure shall be welded or properly gasketed in metal tanks. In concrete tanks, these pipes shall be connected to standard wall castings which were imbedded in place during the forming of the concrete. These wall castings shall have seepage rings imbedded in the concrete.

b. Openings in the roof or top, designed to accommodate control apparatus or pump columns, shall be curbed and sleeved with proper additional shielding to prevent the access of surface or floor drainage into the storage unit.

c. Valves and controls shall be located outside the storage unit so that the valve stems and similar projections will not pass through the roof or top of the unit.

11. DRAINAGE OF ROOF. The roof of the storage unit shall be well-drained. Downspout pipes shall not enter or pass through the unit. Parapets, or similar construction which would tend to

hold water and snow on the roof, will not be approved unless adequate waterproofing or drainage are provided.

12. SAFETY. The safety of employees shall be considered in the design of the storage units. As a minimum, such safety matters shall conform to pertinent local, state, and federal laws and regulations.

    As a minimum, the following safety features shall be provided:

    a. Interior and exterior ladders, ladder guards, balcony railings, and safely located entrance hatches shall be provided where applicable.

    b. Elevated tanks with riser pipes over 8 inches in diameter shall have protective bars over the riser openings inside the tank.

    c. Railings or handholds shall be provided on elevated tanks where persons must transfer from the access tube to the water compartment.

13. FREEZING. All finished water storage units and their appurtenances, especially the riser pipes, overflows, and vents, shall be designed to prevent freezing which will interfere with proper functioning.

14. GRADING. The area surrounding a ground-level storage unit shall be graded in a manner to prevent surface water from ponding within 100 feet of the unit.

15. INTERNAL CATWALK. Every catwalk over finished water in a storage unit shall have a solid floor with raised edges so designed to prevent shoe scrapings and dirt from falling into the water.

16. SILT STOP. Discharge pipes from all storage units shall be located to prevent the flow of sediment into the distribution system. Removable silt stops or traps should be provided where feasible.

17. PAINTING AND/OR CATHODIC PROTECTION. Because waters are corrosive to metal surfaces, proper protection of metal surfaces of storage units shall be given by paints or other protective coatings, by cathodic protection devices, or by both.

    Paint systems as given in the current AWWA Standard D102 are acceptable. All other paint systems must receive the approval of the Department. After proper curing, the paint coatings shall not transfer any substance to the water which will be toxic or cause tastes or odors.

Cathodic protection equipment shall be in accordance with the current AWWA Standard D102.

18. DISINFECTION. Finished water storage units shall be disinfected in accordance with Engineering Bulletin No. 8 or with the current AWWA Standard D102 before being put into service for the first time and after it has been entered for cleaning, repair, or painting. Two or more successive sets of samples, taken at 24-hour intervals, shall indicate microbiologically satisfactory water before the unit is placed in service. A sampling tap or other means shall be provided for collection of a representative sample from the storage unit.

19. PRESSURE. The maximum variation between high and low levels in storage units providing pressure to the distribution system should not exceed 30 feet. The minimum and maximum working pressures in a distribution are given in Chapter 7.

engineering bulletin no. 10

Chapter 7

DISTRIBUTION SYSTEMS

ARIZONA DEPARTMENT OF HEALTH SERVICES

MAY 1978

CHAPTER 7 – DISTRIBUTION SYSTEMS

SECTION G. SURFACE WATER CROSSING

SECTION H. CROSS CONNECTIONS

CHAPTER 7 - DISTRIBUTION SYSTEMS

CHAPTER 7 - DISTRIBUTION SYSTEMS

A. GENERAL

Distribution systems consist of the piping and appurtenances necessary to transmit water to the consumer. Pressure and flow requirements dictate that distribution systems must be designed in conjunction with all other elements of the water supply system, including sources, treatment, pumping and water storage.

In most existing Arizona communities, water for all uses in the community is supplied by the same system (a combined or single system). The standards and guidelines in this chapter through Section N cover combined systems. Special considerations for dual systems, which are expected to be used more where water of a good quality is becoming scarce, are covered in Section M.

All distribution systems shall be capable of delivering required flow while maintaining minimum allowable system pressures.

B. MATERIALS

Water distribution pipes are available in a variety of materials. Those most commonly used are asbestos-cement, cast iron, reinforced concrete, steel, and plastic. Appurtenances for distribution systems are manufactured primarily from steel, cast or ductile iron, copper, bronze, or plastic. In selecting the material to be used for a particular application, the following items should be considered:

1. Ability to withstand maximum anticipated internal pressures and external loads or the most severe combination thereof.

2. Flow resistance of the pipe and appurtenances, both in new condition and after several years of service.

3. Ease of installation. This involves the unit weight, type of joints used, type of bedding required, and whether or not thrust blocking is required.

4. Resistance to external and internal corrosion.

5. Joint tightness. Considerable quantities of water are lost from most water systems due to leaks around joints and connections. Minimizing the potential for leaks can save water and operating expenses later.

6. Durability. Due to a variety of factors, distribution lines lose strength and carrying capacity with time, and appurtenances may fail by locking in position. Those that can continue in service for long periods of time, without a significant number of breaks or serious loss of flow capacity and require less maintenance, are sometimes better choices even if they are more expensive or difficult to install.

7. Compatibility with soils, backfill and bedding materials.

8. Ease of tapping pipes for service connections.

Pipe, fittings, valves, fire hydrants, and other appurtenances shall conform to the current standards of the American Water Works Association, the American Standards Association, or the Federal Government. In addition, plastic pipe and fittings must bear the seal of the National Sanitation Foundation.

C. WATER MAIN AND SYSTEM DESIGN

1. DISTRIBUTION SYSTEM CONFIGURATION. The configuration of the distribution system is determined primarily by size and location of water demands, street patterns, location of treatment and storage facilities and topography. Wherever possible, water mains shall be of looped or circulating configuration. This provides for equalization of pressure and flow and considerably improves operational flexibility under varying operating conditions.

   The alternative to the looping pattern is the branching or dead end pattern. Dead ends in a distribution system are undesirable for several reasons. If dead ends are present, the water flows in only one direction, which allows water to sometimes stand in the main and become stagnant. The chlorine residual in stagnant water may become depleted, thus allowing bacterial growths and the occurrence of taste and odor problems. Taste and odor problems may have to be alleviated by periodically opening a fire hydrant or valve near the dead end of the main to flush out the stagnant water and refill the main with fresh water.

2. SYSTEM PRESSURES. Pressure extremes in water systems result in potential for contamination to enter the network. Low pressures in the water system may allow polluted fluids to be forced into the system. High pressures may cause ruptures or breaks in some elements of the network. The normal working pressure in the distribution system should be approximately 75 pounds per square inch (psi), and not less than 40 psi.

   The system shall be designed to maintain a minimum pressure of 20 psi at ground level at all points in the distribution system under all conditions of flow.

Maximum pressures of as much as 100 pounds per square inch can be allowed in small, low-lying areas not subject to high flow rates and surge pressures. Areas of excessively high or low pressures require that the system be divided into multiple pressure levels, or that pressure reducing and pressure relief valves be installed. Where multiple-level systems are required, it is desirable to establish the lines of separation so that the pressures in each system will approach the optimum range of 40 to 75 pounds per square inch.

All water mains and service lines should be designed for a minimum normal internal working pressure of 150 pounds per square inch plus appropriate allowances for water hammer.

In cases where greater than the above noted maximum pressures are required for effective operation, all elements of the system shall be designed accordingly. Responsibility for pressure reduction, if necessary, shall be specifically defined to be either the responsibility of the supplier of water or the customer.

3. SIZE OF PIPE MAINS. Pipe sizes shall be designed to provide a minimum system pressure of 20 psi, as noted above. The Arizona Corporation Commission requires that water mains serving fire hydrants be a minimum of 6 inches in diameter, or larger, as necessary to serve general service and fire flow requirements. The minimum size of water main shall be 4 inches in diameter, except for the following reasons:

a. Temporary services to be replaced later with large mains.

b. For secondary parallel mains.

c. In wide or paved streets to avoid long and expensive service connections or pavement cuts to the principal mains.

d. Short mains, not for fire service, in courts or cul-de-sacs.

The length of run of mains smaller than 6" should be determined by local conditions but in no case should they exceed the following:

I.D. Size	Dead-ended	Circulating
2 inch	300 feet	600 feet
3 inch	500 feet	1000 feet
4 inch	1300 feet	2600 feet

e. As justified by the Engineer.

4. DEPTH OF PIPES. Minimum cover over water pipes is essential to provide a distribution of stress from superimposed loads, and to provide protection from frost action. External stress and required cover due to external loadings (static and dynamic superimposed forces and earthfill) can be determined in accordance with the applicable standards of the American Water Works Association for each kind of pipe, or by other acceptable criteria. In no case shall the depth of cover to the top of pipe be less than 3 feet, unless adequate structural protection is provided and justified by the Engineer. Where frost depths are greater than the above minimum, the cover should be equal to the frost depth, particularly for small lines which may not be flowing continuously.

5. WATER HAMMER. Water hammer is the phenomenon of oscillations in the pressure of water about its normal pressure in a closed conduit, flowing full, that results from too rapid acceleration or retardation of flow. Water hammer may produce momentary pressures greatly in excess of normal static pressures, thus increasing the probability of water main failure. Suitable provisions shall be made to protect the system from water hammer pressures. The occurrence and severity of water hammer can be reduced through the use of slow-closing valves, pressure-release valves, surge tanks, and air chambers.

   Pumps are particularly susceptable to surge damage during rapid shut-off. Pumps shall be protected from dynamic head by a spring loaded check valve or other safety valve.

6. DEAD ENDS. Blowoff valves, fire hydrants, or other suitable means shall be installed at the ends of dead-end mains to allow periodic flushing of the lines. The minimum size of blowoff valves shall be 2" I.D. Primary feeder mains and larger distribution mains shall have a blowoff valve in each valved section which should be installed at low points in the mains where the flushing water can be readily discharged to natural drainage channels. Blowoff valves must be designed so that operation which will result in erosion or destruction of wildlife is not permitted. Special care must be taken to eliminate the possibility of contaminated water entering the distribution system through blowoff valves which have not been tightly closed.

7. THRUST BLOCKING. Thrusts on pipelines with unrestrained joints occur wherever a bend or branch outlet exists. Thrust forces can be large and may cause the movement and rupture of an inadequately anchored distribution main with unrestrained joints. If the lengths of pipe are joined by tension joints, such as welded joints in a steel pipeline and lugged joints in concrete and cast-iron pipelines, other forms of anchorage are not usually required. The determination of whether or not a given section of

pipeline needs thrust blocks or other means of anchorage shall be made by a qualified engineer. All thrust anchorages shall be designed for a safety factor of not less than 1.50 under maximum pressure loading.

D. VALVING

1. SHUTOFF VALVES. Shutoff isolation valves installed in water mains at various locations within the distribution system allow sections of the system to be taken out of service for repairs or maintenance without significantly curtailing service in other areas. Sufficient valves shall be provided on water mains so that inconvenience and sanitary hazards will be minimized during repairs. Valves should be located at not more than 500 foot intervals in commercial districts and at not more than one block or 800 foot intervals, whichever is the lesser distance, in other districts. Variations in this spacing may be required for transmission mains, or special applications.

   All mains branching from feeder mains or loops should be valved as closely adjacent to the feeders as practicable so that the branch mains can be taken out of service without interrupting the supply to other locations. At intersections of distribution mains, the number of valves required will normally be one less than the number of radiating mains; the one valve will be omitted from the line which principally supplies flow to the intersection. As far as practicable, shutoff valves should be installed in standardized locations so they can easily be found in emergencies. For large shutoff valves (approximately 30 inch diameter and larger), it may be necessary to surround the valve operator or entire valve with a manhole to allow for repair or replacement. In important installations and for deep pipe cover, pipe entrance access manholes should be provided so that valve internal parts can be serviced.

   Sufficient valves shall be provided to allow shut-off of lines crossing streams, railroads, major highways, and airports. A valve shall also be provided on each hydrant branch.

2. PRESSURE-REDUCING VALVES. Pressure-reducing valves will normally be required in areas of the distribution system which have pressures in excess of 100 pounds per square inch, or local ordinances or plumbing codes may make pressure reductions the responsibility of the customer. The pressure reducing valves may be installed on the mains serving these areas, or on individual service lines. In some cases, it may be necessary for customers to install pressure-reducing valves only on lines to certain plumbing or heating units which are adversely affected by excessive pressures.

3. AIR RELEASE AND VACUUM RELIEF VALVES. Air release valves are needed to allow air to leave the main when it is filled with water and to allow the discharge of air accumulated under pressure at high points in the line. This unwanted air, if allowed to accumulate at high points, can cause a resistance to flow and an increase in pumping power requirements. Vacuum relief valves are needed to permit air to enter a line when it is being emptied of water or subjected to vacuum. Special valves are available to perform either or both of these functions.

   Air release valves, vacuum release valves, fire hydrants, or other suitable means of air control shall be installed at high points in a line, or where a long line changes slope. Automatic air relief valves shall not be used in situations where flooding of the manhole or chamber may occur. The open end of an air relief pipe from automatic valves shall be extended to at least one foot above grade and provided with a screened, downward-facing elbow. The pipe from a manually operated valve should be extended to the top of the pit.

4. PRESSURE-RELIEF VALVES. Pressure-relief valves should be installed in all systems which might be subjected to greater than allowable pressures. The setting for valve discharge will depend upon design conditions for each system. Generally, in systems with 100 pounds-per-square inch pumps, the pressure-relief valves should be set to discharge at 120 pounds per square inch; pressures greater than 120 pounds per square inch may be experienced for brief periods during testing or operation of these pumps. All pumps driven by variable speed motors or engines will be provided with relief valves. (See also Pumping Facilities, Chapter 3.)

5. CHECK VALVES. Check valves may be installed at locations where it is necessary to prevent reversal of flow, such as at pump discharge piping, instrumentation, or water storage facilities.

6. VALVE, METER, AND BLOW-OFF CHAMBER DRAINAGE. All valves shall be located or housed in such a manner that they are quickly accessible during an emergency.

   Chambers, pits or manholes containing valves, blow-offs, meters, or other such appurtenances to a distribution system, shall not be connected directly to any storm drain or sanitary sewer, nor shall blow-offs or air relief valves be connected directly to any sewer. Suitable drainage shall be provided for such chambers.

E. FIRE PROTECTION AND HYDRANTS

Most single or combined water systems are designed to provide water for fire protection as well as supplying water for potable needs. Information concerning the design of water systems to provide fire flows can be obtained from the Office of the State Fire Marshal, or from local authorities.

1. <u>HYDRANT INSTALLATION</u>. All fire hydrants should be installed on firm footings such as stone slabs or concrete bases to prevent settling and strains on line joints. Separation of the pipe joints in the elbow beneath the hydrant is sometimes a problem because of forces created by the water pressure across the joint through the elbow. This problem can be alleviated by placing thrust blocks between the elbow and supporting undisturbed soil, or by tying the joint.

2. <u>HYDRANT DRAINS</u>. Drains from hydrant barrels on distribution systems shall not be connected to sanitary sewers or storm drains. Where practicable, hydrant barrels should be drained to the ground surface, or to dry wells provided exclusively for that purpose.

F. PROTECTION OF WATER MAINS NEAR SEWERS

1. <u>GENERAL</u>. Water lines located near sewers present conditions for serious potential cross connections. Protection from cross contamination can be provided by separation of the facilities and special piping. The following factors should be considered in providing adequate protection:

   a. Materials and type of joints for water and sewer pipes.

   b. Service and branch connections into the water main and sewer line.

   c. Compensating variations in the horizontal and vertical separations.

   d. Space for repair and alterations of water and sewer pipes.

   e. Off-setting of pipes around manholes.

2. <u>HORIZONTAL SEPARATION</u>. When water pipe and sewers are laid parallel to each other, the horizontal distance between the water pipe and sewer shall not be less than 6 feet. Each line shall be laid in a separate trench or the space in between filled with compacted fill.

3. VERTICAL SEPARATION. When a sewer crosses a water pipe at a point at which the sewer is 2 feet or more below the water pipe, no extra protection is required. At all other crossings the sewer shall be constructed of ductile iron pipe with mechanical joints, or approved equal, for a distance of at least 6 feet in each direction measured perpendicular to the water line. As an alternate, the sewer shall be encased in concrete of 6 inch minimum thickness for the same distance.

4. UNUSUAL CONDITIONS. Where conditions prevent the minimum horizontal and vertical separation set forth above, both the water main and sewer should be constructed of mechanical joint cast iron pipe, or approved equal, and pressure tested to assure water tightness before backfilling. Where a water main must cross under a sewer, a vertical separation of at least 18 inches between the bottom of the sewer and the top of the water main shall be maintained, under all conditions, with adequate support provided for the sewer lines to prevent them from settling on and breaking the water main.

5. SEWER-MANHOLES. No water pipe shall pass through, or come into contact with, any part of a sewer manhole. Special care should be taken to make sewer manholes as nearly watertight as practicable.

G. SURFACE WATER CROSSING

Surface water crossings present special problems which should be discussed in a preliminary way before final plans are prepared.

1. ABOVE WATER CROSSINGS. The pipe shall be adequately supported and anchored, protected from damage and freezing, and accessible for repair or replacement.

2. UNDERWATER CROSSINGS. Special consideration shall be given to the protection of the pipe from scour action, and in no event shall the minimum cover over the pipe be less than 2 feet below the scour level. The pipe shall be of special construction, having flexible watertight joints. Mechanical joints with rubber gaskets are satisfactory and acceptable. Valves shall be provided at both ends of water crossings so that the section can be isolated for test or repair. The valves shall be easily accessible and not subject to flooding. Sampling taps shall be available at each end of a crossing to facilitate the sanitary control on water crossings. Permanent taps shall be made for installing pressure gauges and applying compressed air for testing and locating leaks.

H. CROSS CONNECTIONS

1. GENERAL. Any physical connection which provides an opportunity for nonpotable water to contaminate potable water is considered a cross connection. To eliminate any possibility of contamination, there shall be no physical tie between potable and nonpotable water supplies. There shall be no connection between the potable distribution system and any pipes, pumps, hydrants, or tanks whereby unsafe water or other contaminating materials may be discharged or drawn into the system. Exceptions to this requirement may be approved by the Department where local codes provide a policy on backflow prevention.

   Existing cross connections should be sought out and eliminated and all possible precautions should be taken to ensure that there is no backflow or back-siphonage from the nonpotable supply to the potable supply.

2. PREVENTION OF BACKFLOW. Devices for the prevention of backflow include air gaps, atmospheric-type vacuum breakers, or pressure-type vacuum breakers. Backflow and back-siphonage prevention devices other than air gaps must regularly be maintained, inspected, and tested. Air gap distances shall be at least twice the diameter of the water supply line, and reduced-pressure-principle backflow prevention devices should meet the criteria of AWWA C506. Double check valves sometimes used for backflow prevention are not desirable. Their use may be approved by the Department if local codes provide a policy on backflow prevention which positively controls application and operation. Records of the types and locations of all devices must be kept by the agencies responsible for potable water supply.

3. AVOIDANCE OF CROSS CONNECTIONS. Standby water reservoirs serving fire protection systems are sometimes filled from both potable and nonpotable supplies. If this is the case, the potable water should be discharged to the reservoir through an air break a suitable distance above the maximum water level of the reservoir. In a similar manner, where potable water is to be used as gland seal on a pump handling nonpotable water, the potable water must be stored in a tank with an air gap between the end of the water supply line and the top of the tank. Special care must also be taken of such items as valve pits and water storage facilities to ensure that surface water runoff cannot enter potable water systems. Other situations that can result in back-siphonage are flexible hose having one end immersed in nonpotable water and the other end connected to a potable water hose bib, potable water lines entering swimming pools without air gaps, lawn irrigation with sprinkler heads flush with the ground, and improper connections at vehicle wash racks.

I. WATER MAINS CROSSING UTILITIES OR TRANSPORTATION FACILITIES

Many public and private agencies require that water mains crossing their facilities be placed inside sleeves or casing. This allows water main construction or removal for maintenance purposes without disruption of the overlying facility. It also reduces the effect of vibration, and provides drainage in case of leakage or rupture of the pipe. Water mains placed inside sleeves or casing shall be adequately supported, and shall be easily removable for repair purposes.

Whether sleeves are used or not, mains crossing facilities which generate vibration such as railroads or highways shall be constructed such that all joints lying within 8 feet of the railroad tracks or highway shoulders be either mechanical joints with rubber gaskets, or an alternative approved by the Department.

J. WATER SERVICE

Service connections to the distribution system should be closely controlled and inspected. Normal practice is for the operator of the water company to supply service taps to the main, and the connection to the water meter, which is located immediately adjacent to the property line. Each connection should be individually metered. Service connections from the property line to building are frequently constructed by the plumbing trades. Water services and plumbing shall conform to relevant local and/or State Plumbing Codes, or to the National Plumbing Code. The customers should install and maintain their own shutoff valves.

K. WATER LOADING STATIONS

Water dispensing facilities, such as those used to load water trucks, present special problems when the fill line may be used for filling both potable water vessels and other tanks or contaminated vessels. To prevent contamination of the potable supply, special precautions must be taken. A device shall be installed on the fill line to provide an air break and prevent a submerged discharge line. The fill hose and cross connection control device must be constructed so that when hanging freely it will terminate at least two feet above the ground surface. The discharge end of the fill line must be unthreaded and constructed to prevent the attachment of additional hose, piping or other appurtenances.

L. <u>INSTALLATION OF MAINS</u>

1. <u>GENERAL</u>. Installation requirements for water distribution system piping and appurtenances vary considerably depending upon pipe material and construction, local soil conditions, pipe bedding, static and dynamic surcharge loads, compaction methods and other

facilities which may influence construction. Project specifications shall cover specific distribution system installation and construction requirements, and inspection methods and procedures. Specifications may incorporate the provisions of the AWWA Standards and manufacturers recommended installation procedures.

2. PRESSURE AND LEAKAGE TESTING. Pressure and leakage testing of water systems is an essential element of installation inspection. The project specifications shall address pressure tests, and allowable leakage as a function of test pressure and pipe diameter. Test specifications for several types of pipe are included in AWWA Standard C600.

3. DISINFECTION. All new, cleaned, or repaired elements of a distribution system shall be disinfected in accordance with Engineering Bulletin No. 8, Disinfection of Water Systems.

M. DUAL DISTRIBUTION SYSTEMS

Dual water systems as defined herein cover the use of separate piping networks for "potable" and "domestic" water. Potable water is drinking water which meets all of the water quality criteria of the Rules and Regulations of the Arizona Department of Health Services. Domestic water meets all of the criteria of the Rules and Regulations, except certain chemical parameters. Development of such a dual system should be based upon a careful economic analysis to determine if construction and operation of a second system is less expensive than treating all of the water.

1. DESIGN CRITERIA. Because water from a domestic system may be inadvertently consumed by humans, the sanitary quality of the water in both systems must be preserved. All planning, design and construction standards in this bulletin shall apply to both potable and domestic systems. Each system should be independently designed to satisfy pressure and flow requirements. The combined design demand for both systems shall not be less than 100 gpcd plus fire flow requirements.

2. SEPARATION OF SYSTEMS. Separation shall be maintained between potable and domestic systems, by developing totally independent networks. Potable systems shall be protected from cross-connections with domestic systems in the same manner as protection from other sources of pollution.

   Before dual water systems will be approved, local plumbing codes must be adopted which assure separation of the separate systems within the structure.

3. IDENTIFICATION OF NONPOTABLE SYSTEMS. Various methods are available for the identification of nonpotable portions of dual water systems, including color coding of pipes, adhesive tape on pipes, ground markers near fire hydrants, valve boxes, and faucets, markers in backfill around pipes, and signs in all locations. Nonpotable water systems shall be identified by a sign on the piping. The sign shall state that both potable and nonpotable systems service the structure and shall identify each.

engineering bulletin no. 10

Guidance
Documentation

⇨DEVELOPMENT OF OPERATIONS AND MAINTENANCE MANUALS

⇨SAMPLING COLLECTION TECHNIQUES

ARIZONA DEPARTMENT OF HEALTH SERVICES

MAY 1978

GUIDANCE DOCUMENTATION
DEVELOPMENT
OF
OPERATION AND MAINTENANCE MANUALS

GUIDANCE DOCUMENTATION
DEVELOPMENT
OF
OPERATION AND MAINTENANCE MANUALS

A. GENERAL.

Operation and maintenance manuals are an essential part of the construction of water systems. Equipment and materials of the best manufacturers and installed with the greatest care will not serve their purpose if not operated properly. Nor can they be operated properly if not systematically maintained by trained personnel. Experience has shown that one of the most important elements in an effective training program for operation and maintenance personnel is the manuals which contain the information essential to run the system. Information not contained in the manuals must be learned by trial and error at a significant expense to public health and the system owners.

Sufficient copies of the manuals must be supplied to assure that the personnel on the job can get access to a manual when needed. Experience has shown that if only a minimum number of manuals are supplied, these will be kept at the management level, and the people who need them won't have them. A minimum of three maintenance and operation manuals shall be supplied. Up to 10 or more may be required for a large system.

B. APPROACH.

Manuals must be read by people of varying levels of background and education. To be useable by all, they must be written for a minimum educational level. The format should make it easy to find things in a hurry. Readibility can be increased by use of subtitles, short sentences and paragraphs, simple vocabulary and wide spacing. Use of illustrations is encouraged, especially where they can supplement or replace involved instructions. Tables are better than graphs or equations. Loose leaf binding should be used to allow easy addition and replacement of pages.

Following is recommended content for operation and maintenance manuals:

C. INTRODUCTION.

1. Operation and Managerial Responsibility.
2. Description of distribution system and plant type.
3. Percent efficiency expected and how plant should operate.
4. Principle design criteria.

D. DISTRIBUTION SYSTEM DESCRIPTION.
(Purpose, schematic diagrams, interrelationship of unit.)

1. Minimum pressures.
2. Maximum pressures.
3. Sources.
4. Intake systems.
5. Mains.
6. Pumps.
7. Pressure tanks.
8. Valves.
9. Storage.
10. Meters
11. Drains and hydrants.
12. Control systems.

E. TREATMENT PROCESS DESCRIPTION.
(Function, relation to other plant units, schematic diagrams.)

1. Pumping.
2. Pretreatment.
3. Aeration.
4. Coagulation and Flocculation.
5. Sedimentation.
6. Filtration.
7. Softening.
8. Corrosion and scale control.
9. Fluoride.

10. Trace element removal.

11. Taste and odor control.

12. Iron and manganese control.

13. Disinfection.

14. Waste disposal.

15. Instrumentation and controls.

F. DETAILED OPERATION AND CONTROLS.
(Routine, alternate, emergency, description of various controls, recommended settings, reference to schematic diagrams, failsafe features.)

1. Manual.

2. Automatic.

3. Physical.

4. Chemical.

5. Energy consumption.

6. Safety features.

7. Problems, causes, and cures.

G. LABORATORY CONTROLS.
(What and why tests are made, interpretation of results, and how samples are obtained.)

1. For each process description given above.

   a. Sampling.

   b. Flow controls.

   c. Analysis.

2. Monitoring of treated water.

3. Water quality standards.

H. RECORDS.
(Importance of records, graphing test results, example and sample forms.)

1. Process operations.
2. Laboratory.
3. Reports to be submitted to state agencies.
4. Maintenance.
5. Operating costs.

I. MAINTENANCE.
(Schedule--daily, weekly, monthly, etc., reference to pages in manufacturers' manuals.)

1. Manufacturers' recommendations.
2. Preventative maintenance summary schedule.
3. Special tools and equipment.
4. Housekeeping schedule.

J. SAFETY.

1. Mains.
2. Electrical equipment.
3. Mechanical equipment.
4. Explosion and fire hazards.
5. Health hazards.
6. Chlorine handling.
7. Chemical handling.
8. Recommended safety equipment.

K. UTILITIES.
(Source, reliability, cost.)

1. Electrical.

2. Gas.

3. Water.

4. Heat.

L. PERSONNEL.
(Detail of job requirements, task plan estimating man-hours per month and year.)

1. Manpower requirements.

2. Qualifications and Background.

3. Certifications.

4. Administration and supervision.

5. Laboratory.

M. APPENDIX.

1. Schematics.

2. Valve Indices.

3. Sample Forms.

4. Chemicals used in plant.

5. Chemicals used in laboratory.

6. Water quality standards.

7. Detailed design criteria.

8. Equipment suppliers.

9. Suppliers' manuals.
(May be bound separately.)

hours is the recommended time limit, however, samples will be accepted up to 24 hours after collection. It is recommended that the laboratory be contacted before submission of samples for these tests.

G. RADIONUCLIDE SAMPLES

Radioactive samples should be submitted in the plastic one half gallon bottle. They should be submitted to a specially authorized laboratory for radiological analysis. A list of these may be obtained from the State laboratory or the Water Quality Control Bureau. There is no time limit between taking and submitting samples of natural radionuclides, but man-made nuclides, such as from fallout, should be forwarded as soon as possible.

H. SPECIAL PROBLEMS

For further information, contact either the State laboratory in Phoenix or one of the following Bureau of Water Quality Control offices:

Bureau of Water
Quality Control
1740 W. Adams
Phoenix, Arizona 85007
271-5453

Dept. of Health Service
Caldera Professional Bldg.
2501 N. 4th Street
Flagstaff, Arizona 86001
779-0313

Dept.of Health Services
5055 E. Broadway
Suite C209
Tucson, Arizona 85711
882-5321

D. BACTERIOLOGICAL SAMPLES

Bacteriological sampling kits are self-contained in a small cylinder, including a 100 ml plastic bottle, specimen submitting and report form, mailing label and instruction. It is most important that the bottle be filled exactly to the line marked on the neck. If the bottle is filled below the fill line, there will not be a sufficient quantity of water for the test. If filled above, the sample will be contaminated when pouring during the test.

Where continuous chlorination is applied to the water system, a chlorine residual reading must be taken and recorded when the water sample is collected.

The sample must be tested within 30 hours of the time sampled. If possible, refrigerate the sample and ship in iced containers. This will significantly reduce potential failures due to confluent growth.

Routine bacteriological samples may be tested at the State laboratories and several State authorized commercial laboratories as noted in Section B. Special samples are tested at the State laboratory in Phoenix.

E. CHEMICAL SAMPLES (ROUTINE)

The sampling kit for routine chemical analysis consists of 3 plastic bottles, including (1), a one half-gallon bottle with HNO_3 preservative for metals, (2), a one quart bottle with H_2SO_4 preservative for nutrients such as nitrate, and (3), a one quart bottle with no preservatives for other chemical tests. A Form 17 - Water Quality Analysis is also included in the kit and must be returned with the samples. Sample kits are available as noted in Section B with the following exception. Sample kits are not available at the State laboratories in Flagstaff and Tucson.

Samples must be submitted directly to a State authorized laboratory for analysis within 72 hours. Samples received without a collection time, well or source identification, and client identification on the form will be rejected without examination. Those samples arriving after 72 hours of collection or improperly preserved will also be rejected.

F. CHEMICAL SAMPLES (ORGANICS)

The sampling kit for grease, N.B.A.S., chlorinated hydrocarbons, and chlorophenoxys is a one gallon glass bottle and Form 17. The sample must be cooled to 4°C, and should be delivered directly to the State laboratory in Phoenix or State authorized laboratories. Six (6)

GUIDANCE DOCUMENTATION
SAMPLE COLLECTION TECHNIQUES

A. SAMPLING REQUIREMENTS

All semi-public and public water systems are required to sample and test the supplies to assure conformance with water quality standards. The specific number and type of samples and test required are covered in Chapter 2. In addition, it is necessary to sample raw water from sources to determine treatment requirements.

B. SAMPLING CONTAINERS

Sample collection kits and forms are available at State authorized commercial laboratories for all water systems. A list of these may be obtained from the State laboratory or Water Quality Control Bureau. Sampling kits and forms are also available at the following locations for some municipalities, school districts, and State and County agencies by mutual arrangement:

State Laboratory
1520 West Adams
Phoenix, Arizona 85007
271-4551

State Laboratory
415 W. Congress, Rm. 119
Tucson, Arizona 85701
882-5381

State Laboratory
Courthouse Basement
Flagstaff, Arizonz 86001
774-6581

C. GENERAL SAMPLING PROCEDURES

1. Use only the sterilized bottle provided by the State authorized laboratories. Do not use any bottles which have loose lids. Return them to the laboratory for replacement.

2. Select a faucet or hose bib which has been in use and does not leak. Do not take a sample from a drinking fountain, gate valve or other large appurtenance. Do not sample outside faucets whenever there is a strong wind or rain.

3. Remove any spray attachment or strainer from faucet.

4. Allow water to run at least five (5) minutes before collecting sample. Then carefully remove the cap from the bottle without touching either the inside of the cap or the lip of the bottle. Do not rinse the bottle. Quickly remove the bottle from the water stream and recap.

GUIDANCE DOCUMENTATION
SAMPLE COLLECTION TECHNIQUES