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WATER SUPPLY, WATER TREATMENT

DEPARTMENTS OF THE ARMY AND THE AIR FORCE

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CHAPTER 1

GENERAL

1-1. Purpose and scope.

This manual, intended for planners and design engineers, presents information on water quality standards and design criteria for water treatment processes. This manual also establishes criteria to be followed in determining the necessity for and the extent of treatment, and on procedures applicable to the planning of water treatment projects. This manual is applicable to all elements of the Army and Air Force responsible for the planning and design of military construction,

1-2. Water treatment proiects.

State health department, State water resource, and U.S. Environmental Protection Agency personnel, as appropriate, should be consulted in the early stages of project planning regarding supply sources and associated water treatment needs. In addition to the usual treatment that may be required to insure delivery of potable water, consideration will be given to the need for special treatment to protect pipelines, water heaters, plumbing fixtures, and other equipment against scaling, corrosion, and staining, Because of the widely varying conditions and the many types of water, it is not possible to establish criteria for all cases of special water treatment. Treatment for prevention of scaling and corrosion may not be entirely effective; and in many cases a decision as to the necessity of special treatment cannot be reached prior to actual operating experiences. In general, special treatment will be provided only in cases where a study of water analyses and experience with the water definitely show that there will be severe corrosion of the water system or that severe scaling of hot-water heaters, storage tanks, and other parts of the plumbing system will occur. Marginal cases will be deferred and treatment provided only after operating experience determines treatment to be necessary.

1-3. Water quality criteria and standards.

Information on current criteria and standards for raw and potable water are presented in appendix A.

CHAPTER 2

WATER TREATMENT PROCESS

2-1. Process selection factors.

The design of treatment facilities will be determined by feasibility studies, considering all engineering, economic, energy and environmental factors. All legitimate alternatives will be identified and evaluated by life cycle cost analyses. Additionally, energy use between candidate processes will be considered. For the purpose of energy consumption, only the energy purchased or procured will be included in the usage evaluation. All treatment process systems will be compared with a basic treatment process system, which is that treatment process system accomplishing the required treatment at the lowest first cost. Pilot or laboratory analysis will be used in conjunction with published design data of similar existing plants to assure the optimal treatment. It is the responsibility of the designer to insure that the selected water treatment plant process complies with Federal Environmental Agency, State or local regulations, whichever is more stringent.

2-2. Preliminary treatment.

Surface waters contain fish and debris which can clog or damage pumps, clog pipes and cause problems in water treatment. Streams can contain high concentrations of suspended sediment. Preliminary treatment processes are employed for removal of debris and part of the sediment load.

a. Screens.

(1) *Coarse screens or racks.* Coarse screens, often termed bar screens or racks, must be provided to intercept large, suspended or floating material. Such screens or racks are made of l/2-inch to 3/4-inch metal bars spaced to provide 1- to 3-inch openings.

(2) *Fine screens.* Surface waters require screens or strainers for removal of material too small to be intercepted by the coarse rack, These may be basket-type, in-line strainers, manually or hydraulically cleaned by backwashing, or of the traveling type, which are cleaned by water jets. Fine-screen, clear openings should be approximately 3/8 inch. The velocity of the water in the screen openings should be less than 2 feet per second at maximum design flow through the screen and minimum screen submergence.

(3) *Ice clogging.* In northern areas screens maybe clogged by frazil or anchor ice. Exposure of racks or screens to cold air favors ice formation on submerged parts and should be avoided to the maximum practicable extent. Steam or electric heating, diffusion aeration and flow reversal have been used to overcome ice problems.

(4) *Disposal of screenings.* Project planning must include provision for the disposal of debris removed by coarse and fine screens.

b. Flow measurement. Water treatment processes, e.g., chemical application, are related to the rate of flow of raw water, Therefore, it is essential that accurate flow-rate measurement equipment is provided. Pressure differential producers of the Venturi type are commonly used for measurement of flow in pressure conduits. An alternative selection for pressure conduits is a magnetic flow meter if the minimum velocity through the meter will be 5 feet per second or more. A Parshall flume can be used for metering in open channels. Flow signals from the metering device selected should be transmitted to the treatment plant control center.

c. Flow division. While not a treatment process, flow division (flow splitting) is an important treatment plant feature that must be considered at an early stage of design. To insure continuity of operation during major maintenance, plants are frequently designed with parallel, identical, chemical mixing and sedimentation facilities. No rigid rules can be given for the extent of duplication required because a multiplicity of factors influence the decision. Normally, aerators are not provided in duplicate. Presedimentation basins may not require duplication if maintenance can be scheduled during periods of relatively low raw water sediment load or if the following plant units can tolerate a temporary sediment overload. If it is determined that presedimentation at all times is essential for reliable plant operation, then the flow division should be made ahead of the presedimentation basins by means of ldentical splitting weirs arranged so that flow over either weir may be stopped when necessary, During normal operation, the weirs would accomplish a precise equal division of raw water, regardless of flow rate, to parallel subsequent units; rapid-mix, slow-mix and sedimentation. The water would then be combined and distributed to the filters. If presedimentation units are not provided, then the flow is commonly split ahead of the rapid-mix units. If a single treatment train is to be provided initially with the expectation of adding parallel units in the future, then the flow-splitting facilities should be provided as part of the original design, with provision for Mocking flow over the weir which is to serve future units.

d. *Sand traps.* Sand traps are not normally required at surface water treatment plants. Their principal application is for the removal of fine sand from well water, The presence of sand in well water is usually a sign of improper well construction or development. If sand pumping cannot be stopped by reworking the well, the sand must be removed. Otherwise, it will create serious problems in the distribution system by clogging service pipes, meters, and plumbing. Centrifugal sand separators are an effective means of sand removal. These cyclone-separator devices are available assembled from manufacturers and require no power other than that supplied by the flowing water. They operate under system pressure; therefore, repumping is not necessary. Water from the well pump enters tangentially into the upper section of the cone and centrifugal force moves the sand particles to the wall of the cone. They then pass downwater into the outlet chamber. Sand is periodically drained to waste from this chamber through a valve that can be manually or automatically operated. The clarified water is discharged from the top of the cone, These units are available in diameters of 6, 12, 18, 24, and 30 inches. providing a capacity range from 15 to 4500 gallons per minute (gpm) and are suitable for operation up to 150 pounds per square inch (psi). Pressure drop through the unit ranges from 3 to 25 psi, depending on unit size and flow rate. These separators will remove up to 99 percent of plus 150 mesh sand and about 90 percent of plus 200 mesh. The units are rubber lined for protection against sand erosion.

e. Plain sedimentation. Plain sedimentation, also termed “presedimentation” is accomplished without the use of coagulating chemicals. Whether plain sedimentation is essential is a judgment decision influenced by the experience of plants treating water from the same source. Water derived from lakes or impounding reservoirs rarely requires presedimentation treatment. On the other hand, water obtained from notably sediment-laden streams, such as those found in parts of the Middle West, requires presedimentation facilities for removal of gross sediment load prior to additional treatment. Presedimentation treatment should receive serious consideration for water obtained from rivers whose turbidity value frequently exceeds 1,000 units. Turbidity values of well over 10,000 units have been observed at times on some central U.S. rivers.

(1) *Plain sedimentation basins.* Plain sedimentation or presedimentation basins may be square, circular, or rectangular and are invariably equipped with sludge removal mechanisms.

(2) *Design criteria.* Detention time should be approximately 3 hours. Basin depth should be in the approximate range of 10 to 15 feet, corresponding to upflow rates of 600 to 900 gallons per day (gpd) per square foot for a detention period of 3 hours. Short-circuiting can be minimized by careful attention to design of inlet and outlet arrangements. Weir loading rates should not exceed approximately 20,000 gpd per foot. Where presedimentation treatment is continuously required, duplicate basins should be provided. Basin bypasses and overflows should also be included.

2-3. Aeration.

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 water. These volatile substances include oxygen, carbon dioxide, hydrogen sulfide, methane and volatile organic compounds responsible for tastes and odor. Aeration is frequently employed at plants treating ground water for iron and manganese removal.

a. Purpose of aeration. The principle objectives of aeration are:

(1) Addition of oxygen to ground water for the oxidation of iron and manganese. Ground waters are normally devoid of dissolved oxygen. The oxygen added by aeration oxidizes dissolved iron and manganese to insoluble forms which can then be removed by sedimentation and filtration.

(2) Partial removal of carbon dioxide to reduce the cost of water softening by precipitation with lime and to increase pH.

(3) Reduction of the concentration of taste-and-odor producing substances, such as hydrogen sulfides and volatile organic compounds.

(4) Removal of volatile organic compounds which are suspected carcinogens, (see para 2-13b.).

b. Types of aerators. Three types of aerators are commonly employed. These are: waterfall aerators exemplified by spray nozzle, cascade, and multiple-tray units; diffusion or bubble aerators which involve passage of bubbles of compressed air through the water; and mechanical aerators employing motor-driven impellers alone or in combination with air injection devices. Of the three types, waterfall aerators, employing multiply trays, are the most frequently used in water treatment. The efficiency of multiple-tray aerators can be increased by the use of enclosures and blowers to provide counterflow ventilation.

c. Design criteria.

(1) *Multiple-tray, tower aerators.*

(a) Multiple-tray aerators. Multiple-tray aerators are constructed of a series of trays, usually three to nine, with perforated, slot or mesh bottoms. The water first enters a distributor tray and then falls from tray to tray, finally entering a collection basin at the base. The vertical opening between trays usually

ranges from 12 inches to 30 inches. Good distribution of the water over the entire area of each tray is essential. Perforated distributors should be designed to provide a small amount of head, approximately 2 inches on all holes, in order to insure uniform flow. In aerators with no provision for forced ventilation, the trays are usually filled with 2- to 6-inch media, such as coke, stone, or ceramic balls to improve water distribution and gas transfer and to take advantage of the catalytic oxidation effect of manganese oxide deposits in the media. The water loading on aerator trays should be in the range of 10 to 20 gpm per square foot. Good, natural ventilation is a requirement for high efficiency. For multiple tray aerators designed for natural ventilation, the following empirical equation can be used to estimate carbon dioxide (CO_2) removal:

$C_r = C_o(10^{-kn})$

C_r = mg/l CO_2 remaining after aeration

C_o = mg/l CO_2 present in water in distribution tray

n = number of trays, including distribution tray

k = 0.11 to 0.16 depending on temperature, turbulence, ventilation, etc.

Where icing is a problem and the aerator must be housed, artificial ventilation by fans or blowers is necessary. An enclosed induced- or positive-draft aerator requires approximately 3.5 to 6 standard cubic feet of ventilating air per gallon of water aerated. Thus, for an enclosed aerator operating at a rate of 1.5 million gallons per day (mgd), air requirements will be in the range of 3600 to 6200 standard cubic feet of air per minute. Positive-draft aerators employing the higher air-flow rates exhibit the highest efficiency for the addition and removal of dissolved gases and oxidation of iron, manganese, and sulfide. Power requirements for a natural draft, multiple-tray aerator having an overall height of 10 feet will be approximately 1.7 kilowatts per mgd of aeration capacity. Power demands for forced draft units will be greater.

(b) Counter-current packed column aeration. A counter-current parked column aerator tower is similar to operation to counter-current multiple tray aerators, but are particularly efficient at the removal of volatile organic compounds (VOCs) through air-stripping. Packed column aerators consist typically of a long thin tower filled with either a random dumped media (Rasching rings, Ber) saddles, Pall rings) or corrugated sheet media, held by a packing support plate. Water is pumped to the top of the tower over a distribution plate and allowed to fall through the media. Air is blown up through the tower by a fan counter to the falling water. Redistributor plates are used throughout the column to prevent channeling of the water or air stream. Efficiency of the tower is dependent on the extent of contact between the air and water. Detailed design can be found in various chemical engineering literatures and handbooks or AWWA, EPA publications.

(2) *Diffusion aerators.* Compressed air is injected into the water as it flows through a rectangular basin. A variety of air injection devices may be employed including perforated pipes, porous plates or tubes and various patented sparger devices. Basin size is determined by desired detention time, which commonly ranges from 10 to 30 minutes. Tank depth is usually from 10 to 15 feet. Air requirements, supplied by a compressor, generally range from 0.1 to 0.2 standard cubic foot per gallon of water aerated. Major advantages of a diffusion aeration system include practically no head loss and freedom from cold-weather operating problems. An additional advantage is that a diffusion aerator may also be used to provide chemical mixing. Power requirements are those associated with air compression and range from 1.0 to 2.0 kilowatts per mgd of aerator capacity. Aeration efficiency in terms of addition of oxygen or removal of carbon dioxide is generally similar to that provided by multiple-tray aerators employing natural ventilation.

(3) *Mechanical aerators.* Mechanical aerators typically consist of an open impellar operating on the waters surface. Basin size is determined by detention time required. Basin depth can vary from 5 to 17 feet with the average depth being 10 feet. Major advantages of mechanical aerators are practically no head loss and the ability to provide mixing. Mechanical aerators are generally not as efficient as aeration towers or diffused aerators and longer detention times are required.

d. Criteria for installation of aerators. Aeration is a gas transfer process which is not needed at all water treatment plants. A decision as to whether to aerate or not requires assessment of the economic and water quality benefits achieved by its use.

(1) *Addition of oxygen.* Aeration processes are commonly used in adding oxygen to groundwaters and to oxidize iron, manganese, hydrogen sulfide and to a limited extent, organic matter. Groundwaters are usually deficient in oxygen and acration is an effective means of adding it. Oxygen addition is normally required if iron and manganese removal is a treatment objective. Aeration will also help oxidize hydrogen sulfide and some organic matter.

(2) *Partial removal of volatile substances.* Aeration is a useful method of removing volatile substances from water. Groundwaters while being deficient in oxygen can contain objectionable levels of carbon dioxide. An efficient aerator will result in near saturation with oxygen and about 90 percent reduction of the carbon dioxide content of groundwater. At lime-soda water softening plants, any carbon dioxide dissolved in the water at the point of lime application will consume lime without accompanying softening. For high (>50

mg/L) carbon dioxide concentrations, as encountered in some groundwaters, 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 deciding to aerate for carbon dioxide removal, the cost of purchasing, maintaining and operating the aerator should be compared to the value of the lime saved. At softening plants, each mg/L of carbon dioxide removed will effect a saving of about 1.3 mg/L quicklime (95 percent calcium oxide). It will also reduce the quantity of softening sludge produced proportionately.

(3) *Reduction of hydrogen sulfide.* Aeration is also used for removing hydrogen sulfide from well water. It may be sufficient in itself if the hydrogen sulfide concentration is not more than about 1.0 or 2,0 mg/L. Otherwise, it maybe used in conjunction with chlorine to oxidize the hydrogen sulfide not removed by aeration.

(4) *Reduction of Volatile Organic Compounds (VOCs).* Recent studies have shown that aeration can be successfully employed to reduce volatile organic compounds (VOCs) such as total Trihalomethane (TTHM) concentration in chlorinated water to meet current US EPA regulations limiting TTHM concentrations. Aeration by diffused air or multiple-tray aerators can reduce TTHM concentration at low cost, with cost increasing with higher concentrations of Trihalomethane (THM). Counter-current packed tower aeration is most efficient in achieving mass transfer of VOC.

e. Aeration summary. Where icing is a problem and the aerator must be housed, artificial ventilation by fans or blowers is necessary. An enclosed induced- or positive-draft aerator requires approximately 3.5 to 6 standard cubic feet of ventilating air per gallon of water aerated. Thus, for an enclosed aerator operating at a rate of 1.5 mgd, air requirements will be in the range of 3600-6200 standard cubic feet of air per minute. Positive-draft aerators employing the higher air-flow rates exhibit the highest efficiency for the addition and removal of dissolved gases and oxidation of iron, manganese, and sulfide. Counter-current packed column aeration is particularly efficient to remove volatile organic compounds, Requirements for a natural draft, multiple-tray aerator having an overall height of 10 feet will be approximately 1,7 kilowatts per mgd of aeration capacity, Power demands for forced draft units will be greater. In general, aeration is worthy of consideration in connection with the treatment of groundwater supplies in conjunction with lime softening and for the removal of some VOCs. 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. However, surfaces waters contain higher levels of THM precursors than groundwaters and therefore a need for aeration may arise to reduce TTHM following chlorination. Water high in the bromine-containing THMs are difficult to treat by aeration and other methods of removal should be used, such as coagulation and flocculation or contact with granular activated carbon.

2-4. Coagulation and flocculation.

Coagulation and flocculation processes are defined as follows: "Coagulation" means a reduction in the forces which tend to keep suspended particles apart. The joining together of small particles into larger, settleable and filterable particles is "flocculation." Thus, coagulation precedes flocculation and the two processes must be considered conjunctively.

a. Purposes of coagulation and flocculation. Raw water supplies especially surface water supplies, often contain a wide range of suspended matter, including suspended minerals, clay, silt, organic debris and microscopic organisms ranging in size from about 0.001 to 1.0 micrometer. Small particles in this size range are often referred to as "colloidal" particles. Larger particles, such as sand and silt, readily settle out of water during plain sedimentation, but the settling rate of colloidal particles is so low that removal of colloidal particles by plain sedimentation is not practicable. Chemical coagulation and flocculation processes are required to aggregate these smaller particles to form larger particles which will readily settle in sedimentation basins. The coagulation-flocculation processes are accomplished step-wise by short-time rapid mixing to disperse the chemical coagulant followed by a longer period of slow mixing (flocculation) to promote particle growth.

b. Chemical coagulant. The most frequently used chemical coagulant is aluminum sulfate ($Al_2(SO_4)_3 14H_2O$). This aluminum coagulant is also called "alum" or "filter alum," and dissociates in water for form $S0_4=$, Al^{3+} ions and various aluminum hydroxide complexes. Other aluminum compounds used as coagulants are potash alum ($AlK(SO_4)_2 \cdot 12H_2O$) and sodium aluminate ($Na_2Al_2O_4$), principally the latter. Iron coagulants include ferric sulfate ($Fe_2(SO_4)_3 \cdot 9H_2O$), ferrous sulfate ($FeSO_4 \cdot 7H_2O$), also available as $FeSO_4 \cdot 5\ H_2O$ and ferric chloride ($FeCl_3 \cdot 6H_2O$). Magnesium hydroxide ($Mg(OH)_2$), is also an effective coagulant, Organic polyelectrolyte compounds, applied in low dosages alone or in combination with the metal coagulant, are also employed, Polyelectrolytes are high-molecular-weight polymers that dissociate in water to give large highly charged ions, The polyelectrolytes and dissociated ions destabilize the colloids and promote their settling, These polymers can be classified an anionic, cationic or nonionic according to their dissociated polymeric ions being negatively charged, positively charged or both negatively and positively charged,

c. Coagulation for Removal of Trihalomethane Precursors. Recent US EPA regulations limit allowable TTHM concentrations in finished potable water (see para 2-13). To help meet the current maximum contaminant level (MCL) of 0.10 mg/L for TTHM, trivalent metal ion coagulant, such as aluminum sulfate or ferrous sulfate, and a variety of organic polyelectrolytes have been used to remove THM precursors before chlorination. Naturally-occurring THM precursors, such as humic and fulvic compounds, are only partially removed by coagulation and filtration. For coagulation with alum, a pH of between 5 and 6 is the optimum for the removal of fulvic and humic acid compounds. Ferrous sulfate exhibits an optimum pH for removing organic compounds of between 3 and 5. Fulvic acids require twice the dosages of alum needed for humic acids, The addition of anionic polymers at doses from 1 to 10 mg/L can also provide some removal of humic compounds. The efficiency of removal depends upon the type and concentration of organic compounds present in the water supply, pH, coagulant dose, and solids-liquid separation step. Optimum precursor removal can only be estimated using laboratory simulation techniques, such as simple jar testing, followed by settling or removal of precipitated colloids with membrane filters. This procedure can provide the information necessary to determine the optimum conditions for the removal of trihalomethane precursor compounds. Monitoring of the removal of organic precursor compounds by coagulation and filtration can be facilitated by the measurement of total organic carbon.

d. Design criteria for mixing. Criteria for rapid- and slow-mix processes have been developed on the basis of detention time, power input, velocity gradient (G) and the product (Gt) of velocity gradient and detention time. The values of G and Gt are computed from:

$$G = \left(\frac{P}{\mu V}\right)^{1/2}$$

and

Gt = product of G and t, a dimensionless number

where

G = velocity gradient (fps/foot: or sec^{-1})

P = the power dissipated in the water (ft-lb/see)

u = water viscosity (lb_f-sec/ft^2) ($\mu = 2.73 \times 10^{-5}$ @ 50°F)

V = volume of mixing basin (cubic feet)

t = mixer detention time (seconds)

e. *Rapid mixing.* For rapid-mix units, detention periods usually range from 10 to 30 seconds with installed mixer power approximately 0,25 to 1.0 hp per mgd. Power and detention time should be matched so that values of G will be in the approximate range: 500-1000 see^{-1}. A wire-to-water efficiency of 80 percent, a water temperature of 50 'F, a power input of 1.0 hp per mgd and a detention time of 10 seconds, yield a G value of about 1000 see^{-1} and a Gt value of 10,000. Similarly, a 30-second detention time gives a G value of about 600 and a Gt value of 18,000. Long detention period for rapid-mix basins should be avoided because of higher power requirements and inferior coagulation results. The rapid-mix basin should be designed to minimize short circuiting.

f. Slow mix, For slow-mix (flocculating) units, detention periods should range from 30 minutes to 60 minutes, with installed mixer power of approximately 0.1 to 3.5 hp per mgd. G values in the range of 20 see^{-1} to 100 see-1 are commonly employed, Corresponding Gt values will, therefore, be in the range of 36,000 to 360,000. Tapered, slow mixing with G decreasing from a maximum of about 90 see^{-1} down to 50 see^{-1} and then to 30 sec^{-1} can be used and will generally produce some improvement in flocculation. Somewhat higher G values, up to 200 see^{-1}, are employed in some water softening plants. For normal flocculation, using alum or iron salts, the maximum peripheral speed of the mixing units should not exceed about 2.0 fps and provision should be made for speed variation. To control short circuiting, two to three compartments are usually provided. Compartmentation can be achieved by the use of baffles. Turbulence following flocculation must be avoided, Conduits carrying flocculated water to sedimentation basins should be designed to provide velocities of not less than 0.5 fps and not more than 1.5 fps, Weirs produce considerable turbulence and should not be used immediately following flocculation.

2-5. Sedimentation basins.

Sedimentation follows flocculation, The most common types of sedimentation basins in general use are shown in figures 2-1 and 2-2. A recent innovation in clarifiers is a helicai-flow solids contact reactor, consisting of a above ground steel conical basin as shown in figure 2-3. However, these above ground basins require a high head and additional pumps may be required. A minimum of two basins should be provided to allow one unit to be out of service for repair or maintenance. The design must include arrangements that permit use of a single basin when necessary.

a. Design criteria. The design of a sedimentation tank is based on the criterion as listed in table 2-1, The sedimentation basins should have adequate capacity to handle peak flow conditions and to prevent excessive deteriorated effluent water qualities. The above design data represent common conditions, higher overflow rates may be used at lime softening plants and at some plants employing upflow clarification units as indicated in the tables of Water Treatment Plant Design by ASCE, AWWA, CSSE (see app E). Unusual conditions may dictate deviation from these general criteria. Detention time in the range of 8 to 12 hours, or more provided in several stages, maybe

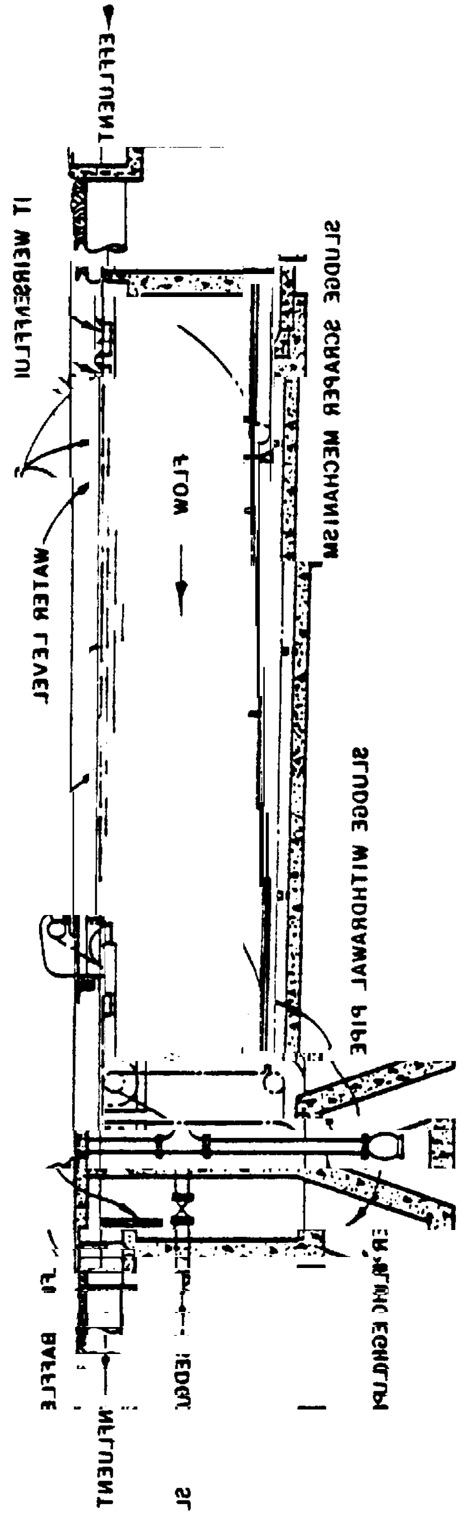

Figure 2-1. Rectangular sedimentation basin.

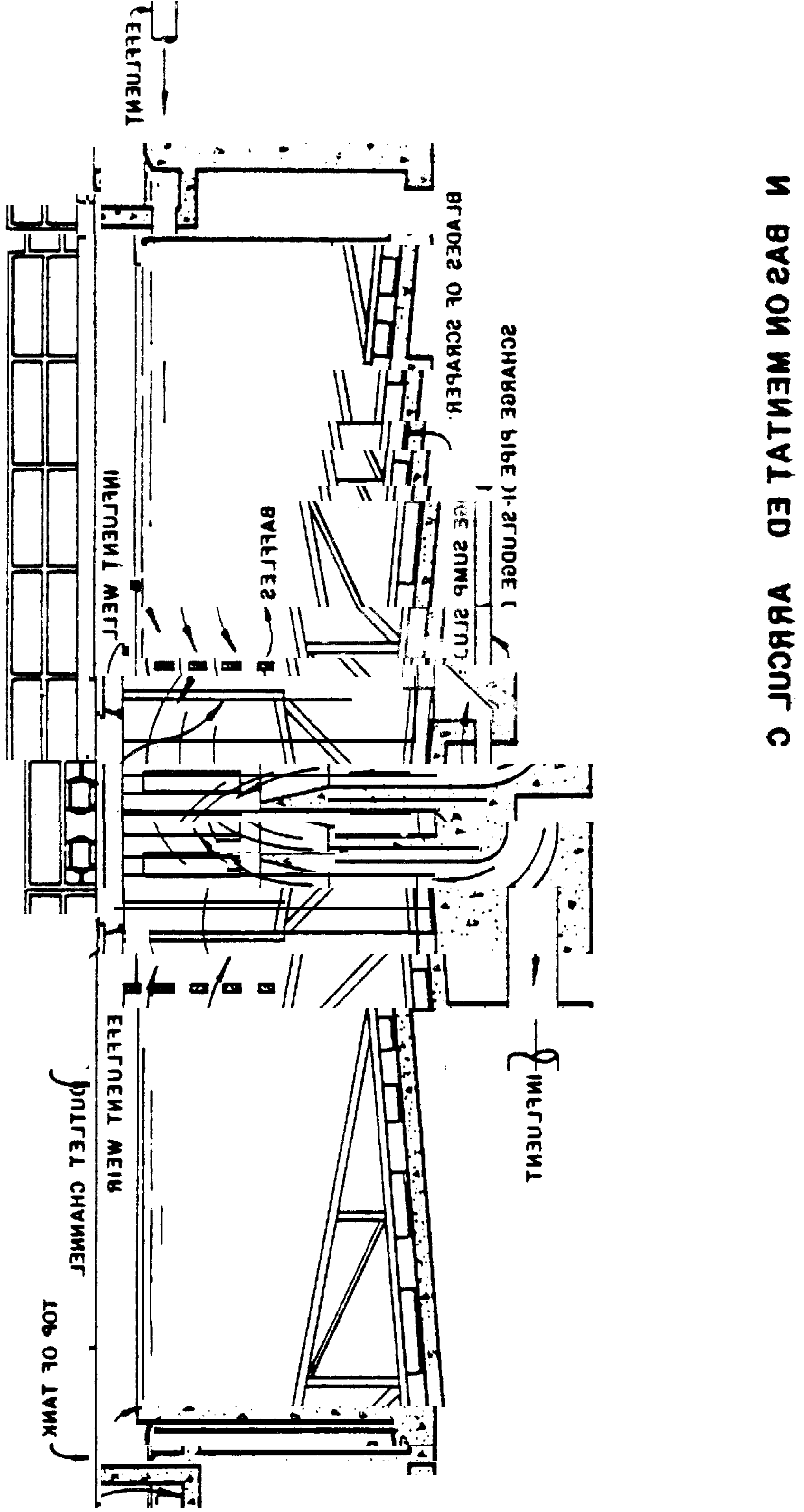

Figure 2-5. Circular sedimentation basin.

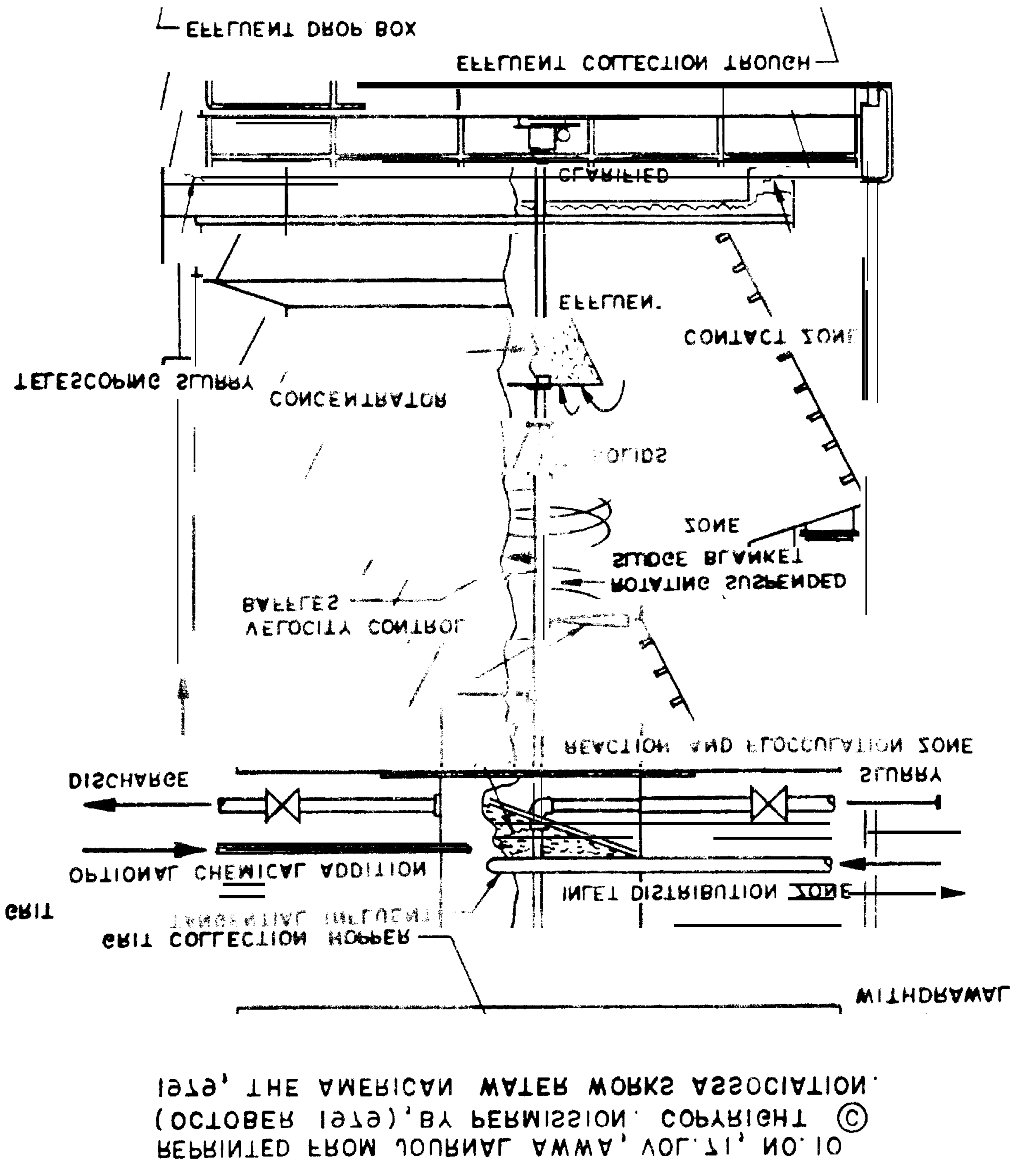

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Figure 2-3. Conical sedimentation basin

necessary for treating highly turbid waters. On the other hand, conical clarifiers are more efficient in softening and/or turbidity removal and require a detention time of one hour or less. The design data shall be examined by laboratory analysis or pilot plant studies especially for larger plants. Jar test of coagulant dosage in conjunction with settling column analysis to determine the optimal design criteria will be beneficial for design. If the space available for sedimentation basins is limited, multiple-story basins, in which the water flows horizontally along one level and then passes upward and then flows horizontally along another level, may be utilized. A newer commercial development in sedimentation, the "tube" settler, may be used if the capacity of existing sedimentation basins must be increased or if little space is available for the construction of new sedimentation basins. Detailed information relative to the size, capacity, and configuration of tube settlers may be obtained from the manufacturers. Steel basin conical clarifiers may also be used to expand sedimentation plants when space available is limited. Conical clarifiers as shown in figure 2-3 stand on a pedestal base and require less space than conventional sedimentation basins. Sedimentation basin inlets, outlets, and baffles must be carefully designed to minimize short circuiting. The solids (sludge) which settles to the bottom of the basin must be removed before the depth of the sludge becomes great enough to interfere with effective sedimentation. In general, mechanical sludge removal equipment is a requirement. All basins must be provided with drains and overflows. Basin covers, usually in the form of a superstructure, will be required in northern localities where ice is a problem.

Table 2-1: Design Criteria for Sedimentation Tank

Design Element	0.35 - 1.5
Tank Depth (ft)	< 15
Length\width Ratio (Rectangular)	
Diameter (circular) (ft)	Criteria
Flow-Through Velocity (fpm)	10-16
Entrance Velocity of Inlet Ports (fps)	3:1 to 5:1
Detention Time (hour)	10-100
Surface Overflow Rate (conventional	0.5-3
coagulation Plant) (gpm\ft^2)	0.5-2
Weir Overflow Rate (gpm\ft^2)	2-4

b. Flocculation-sedimentation basins. Units of this type, usually circular, combine the functions of flocculation, sedimentation and sludge removal, Flocculation is accomplished in a circular center well, Sedimentation occurs in the annular space between the flocculation section and the perimeter effluent weir. Design criteria are generally similar to those applicable to separate units.

c. *Suspended solids contact basins,* Basins of this type combine rapid-mixing, flocculation, sedimentation, and sludge removal in a single unit. Coagulation and flocculation take place in the presence of a slurry of previously formed precipitates which are cycled back to the mixing and reaction zone. Upflow rates at the point of slurry separation should not exceed about 1.0 gpm per square foot for units used as clarifiers following coagulation and approximately 1.5-1.75 gpm per square foot for units used in conjunction with lime softening.

2-6. Filtration.

Filtration of water is defined as the separation of colloidal and larger particles from water by passage through a porous medium, usually sand, granular coal, or granular activated carbon. The suspended particles removed during filtration range in diameter from about 0.001 to 50 microns and larger. Several different types of medium arrangements and rates of flow through filters can be used. The filtration process most commonly used is gravity filtration, but pressure filters and diatomite filters are used at smaller installations. Recently high-rate filters have been developed which require less space and have higher solids-loading capacity than conventional filters.

a. *Rapid sand filters.*

(1) *Filtration rate.* Rapid sand filters are those filters which commonly operate at rates between approximately 2 and 8 gpm per square foot. The usual rate is about 3 to 5 gpm per square foot. The rate of filtration to be employed at a specific plant can be determined only after careful consideration, by the designer, or raw water quality and the probable efficiency of pretreatment that will be consistently provided. Good quality water is not ensured by low filtration rates. Adequate pretreatment and filter design will allow application rates of up to 6 gpm per square foot with little difference in water quality. It is emphasized that if high rates are to be used in design, great care must be taken to insure that all prefiltration treatment processes including coagulation, flocculation, and sedimentation will perform satisfactorily and consistently. High-rate filter operation definitely requires excellence in pre-filtration treatment, especially in the case of surface waters. It is recommended that data from laboratory or pilot studies be utilized whenever possible rather than an arbitrary selection of criteria.

(2) *Filter medium.*

(a) *Sand.* Silica sand is the most commonly used filter medium and its depth should be at least 24 inches and not more than 30 inches. When sand is employed, its "effective size" should fall in the range 0.35 to 0.5 millimeter (mm) with a uniformity coefficient of 1.3 to 1.7. Filter sand usually ranges in size from that passing a 16-mesh (U.S. Series) sieve to that retained on a 50-mesh (U.S. Series) sieve. Approximately 100 percent by weight, of the sand should pass the 16-mesh sieve and 90 to 100 percent be retained on a 50-mesh sieve. Filter sand should be clean silica sand having a specific gravity of not less than 2.5. The hydrochloric acid volubility of the sand should be less than 5 percent.

(b) Anthracite. Anthracite is an alternative medium consisting of hard anthracite coal particles. The effective size commonly ranges from about 0.45 mm to 0.6 mm with a uniformity coefficient not to exceed 1.7. The hardness should not be less than 2.7 on the Moh scale and the specific gravity not below 1.4. Also, the anthracite should be visibly free of clay, shale, and dirt.

(c) Multimedia. Multimedia filters employ two or three layers of media of different size and specific gravity. A common arrangement, the dual media filter, is 20 inches of anthracite overlaying a sand layer of approximately 8 to 12 inches. The anthracite layer has size range of about 0.8 to 2.0 mm; the sand layer, about 0.4 to 1.0 mm. Tri-media filters employ an 18-inch anthracite layer, an 8-inch sand layer, and an underlying 4-inch layer of garnet or ilmenite having a size range of 0.2 to 0.4 mm. Garnet has a specific gravit y of about 4, and ilmenite about 4.5.

(3) *Filter gravel and underdrains,* The filter media is commonly supported by a 10- to 18-inch layer of coarse sand and graded gravel. The gravel depth may range from 6 inches to 24 inches, depending on the filter underdrain system chosen. The gravel should consist of hard, rounded stones having a specific gravity of at least 2.5 and an acid volubility of less than 5 percent. A 3- to 4-inch transition layer of coarse (torpedo) sand, having a size range of about 1.2 to 2.4 mm, is placed on top of the filter gravel. Gravel size usually ranges from about 0.1 inch to about 2.5 inches. Filter underdrains may be constructed of perforated pipe grids or various proprietary underdrain systems. A variety of the latter are available. Design details for pipe underdrains are given in numerous texts and handbooks. Manufacturers will furnish design and installation criteria for proprietary systems.

(4) *Sand, anthracite, gravel specifications.* Detailed specifications for filter sand, anthracite and gravel are contained in AWWA B100.

(5) *Number of filters.* Not less than two filters should be installed regardless of plant size. For large plants, rough guidance as to the number of filters to be provided may be obtained from:

—$N = 2.7\sqrt{Q}$

—N = number of filter units

–Q = design capacity in mgd

Thus, a 9 mgd plant would require eight filters.

(6) Size of filter units. The maximum filter size is related to wash water flow rate and distribution. Normally, individual filters sizes do not exceed about 2100 square feet corresponding to a capacity of about 6 mgd at a flow rate of 2.0 gpm per square foot. A unit of this size would require a maximum backwash water rate of about 60 mgd, which is excessive. Consequently, it should be divided into two parts of equal size arranged for separate backwashing. Total filter depth should be at least 9 feet.

(7) *Filter backwash.* Backwash facilities should be capable of expanding the filter media 50 percent. This will require wash rates in the range of 10 to 20 gpm per square foot. Backwash water can be supplied by a backwash pump or from elevated storage provided specifically for this purpose. Filter down-time during wash periods commonly average 10 to 20 minutes including a 5- to 15-minute wash period. For a 15-minute backwash of a single unit, at maximum rate, the wash water volume will be 300 gallons per square foot of filtration area in that unit. In addition to backwashing, auxiliary scour is commonly provided. This aids in cleaning the filter and is commonly accomplished by rotary or fixed surface-wash equipment located near the top of the bed. It is operated for a time period equal to that of the backwash, Water pressures of 40-100 psi are required for surface-wash operation at a rate of 0.5 gpm per square foot. Air scour may also be employed but is not generally used. If an independent washwater storage tank is used, it must refill between washes. Tank capacity should be at least 1.5 times the volume required for a single wash.

(8) *Wash water troughs.* Wash water troughs equalize the flow of wash water and provide a conduit for removal of used water. Two or more troughs are usually provided. The elevation of the trough bottoms should be above that of the expended bed. The clear horizontal distance between troughs should not exceed 5 to 6 feet, and the top of the troughs not more than 30 inches above the top of the bed.

(9) *Filter piping and equipment.* Essential filter control valves, etc., are shown schematically in figure 2-4. Each filter should be equipped with a rate-of-flow controller plus associated equipment for automatic filter water-level control. The latter senses the water level in the main influent conduit and transmits a signal to the flow controllers. The controllers, in response to this signal, adjust filtration rates to match the inflow from the sedimentation basins. Thus, within practical limits, total filter outflow always equals total inflow and the filter water level remains virtually constant. A device that will sense maximum permissible clearwell level should also be provided. This should be arranged so that at maximum allowable clearwell water level, a shut-off signal will be transmitted to all filter controllers and also to an audible alarm. Other designs, not involving rate controllers, such as "influent flow splitting" and "variable declining rate"

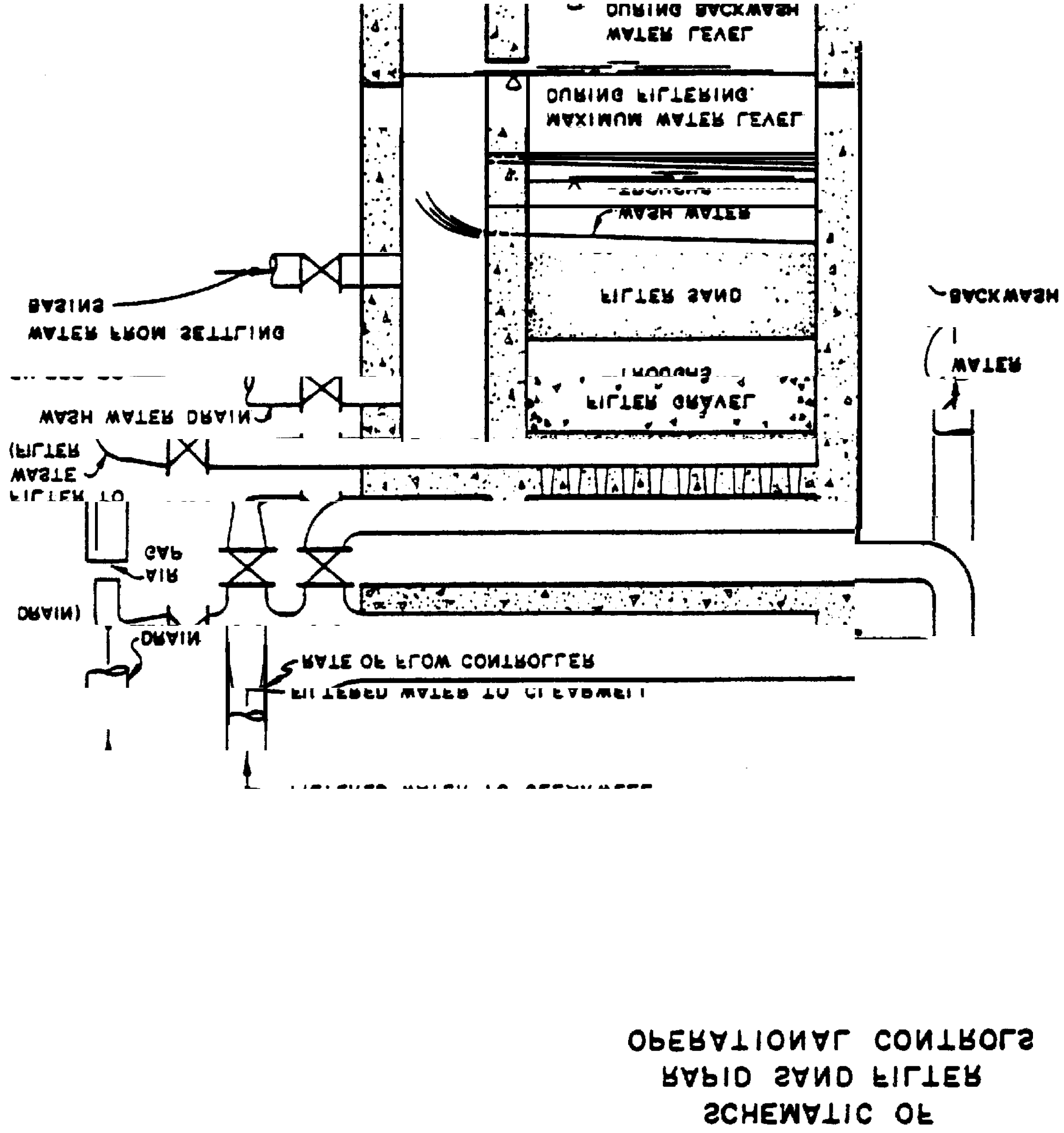

Figure 2-4. Schematic of rapid sand filter operational controls.

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have been developed and may be employed at the discretion of the designer. In general, each filter must have five operating valves: influent, wash water, drain, surface wash, and filter-to-waste. It is emphasized that the filter-to-waste piping must not be directly connected to a plant drain or sewer. An effluent sampling tap must be provided for each filter. Valves can be manually, electrically, hydraulically, or pneumatically operated. Butterfly type valves are recommended for filter service. Design velocities commonly employed for major filter conduits are as follows:

Conduit	Design Velocity ft/sec
Influent	1-4
Effluent	3-6
Wash water	5-10
Drain	3-8
Filter-to-waste	6-12

The effluent conduit must be trapped to present backflow of air and provide a seal for the rate controllers. The filter pipe gallery should have ample room and good drainage, ventilation, and lighting. Dehumidification equipment for the gallery should receive careful consideration. Filters should be covered by a superstructure except under favorable climatic conditions. Drainage from the operating floor into the filter should be prevented by a curb. Access to the entire bed should be provided by a walkway at operating floor level around the filter. Filters may be manually or automatically controlled from local or remote locations. Facilities permitting local, manual control are recommended irrespective of other control features. Used backwash water should be discharged to a wash water recovery basin or to a waste disposal facility. Regulatory agencies generally view filter wash water as a pollutant and forbid its direct discharge to the natural drainage.

(10) *Essential instrumentation.* Minimum essential instrumentation for each filter will be provided as follows: rate=of-flow indicator; loss-of-head indicator; effluent turbidity indicator; wash water rate-of-flow indicating and totalizing meter. If a wash water storage tank is provided, it must be equipped with a water-level indicator. While not absolutely required, a turbidity indicator on the main filter influent is desirable.

b. Diatomite filters. Filtration is accomplished by a layer of diatomaceous earth supported by a filter element termed a septum, This layer of diatomaceous earth is about l/8-inch thick at the beginning of filtration and must be maintained during filtration by a constant feed of diatomaceous earth (body feed) to the influent water. At the conclusion of a filter run, the layer of diatomaceous earth will have increased in thickness to about 1/2 inch. Filtration rates generally vary from 0.5 to 2.0 gpm per square foot. The principal use of diatomite filters has been for swimming pool waters, but some have been installed for the treatment of potable water.

c. Pressure filters. Pressure filters are similar in construction and operating characteristics to rapid sand filters. However, in a pressure filter the media, gravel bed, and underdrains are enclosed in a steel shell. There are a variety of new pressure filters in use today. The most common of these are the conventional downflow filter, the high-rate downflow filter and the up flow filter. An advantage of any pressure filter is that any pressure in waterlines leading to the filter is not lost, as in the case of gravity filters, but can be used for distribution of the filter effluent. Between 3 and 10 feet of pressure head are lost through the filter. The primary disadvantage of a pressure filter is that, due to the filter being enclosed in a steel shell, 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. The use of pressure filters is not advantageous in most systems. However, if the pressure requirements and conditions in a particular system are such that repumping of filtered water can be eliminated, cost savings will be realized,

(1) *Conventional downflow filters.* Conventional downflow pressure filters consist of a bed of granular media or multi-media and are good in removing suspended solids comprised of floe. The advantages over gravity filters include lower installation cost and adaptability y to different piping systems. Hydraulic loadings range from 1 to 4 gpm/sq. ft.

(2) *High-rate downflow filters.* High-rate downflow filters have filtration rates of 10-20 gpm/sq. ft. The higher downflow velocities require coarser media which allow suspended solids to penetrate deeper into the medium. As a result, more solids can be stored in the filter bed before backwashing is required, Many units exhibit a 1-4 lbs/sq. ft. solids-loading capacity, The higher filtration rates also allow smaller or fewer filters to be used over conventional filters. However, the high solids-loading capacity of this filter requires higher backwashing flow rates and hence larger backwashing water storage tanks.

(3) *Upflow filters.* Upflow multi-media filters allow filtration of high solids-loaded liquids in concentration up to 1,000 mg/L. The advantage of upflow multi-media filters is that the coarser material at the inlet collects the heavier particles, while the finer material collects the smaller particles, thus efficiency of the filter is increased.

(4) *Upflow continuous backwash sand filters.* Upflow continuous backwash sand filters continuously clean the filter medial by recycling the sand internally through an air lift pipe and sand washer. The regenerated sand is then redistributed to the top of the sand bed. Once the sand migrates down to the bottom of the

bed it is again airlifted and repeats the cycle. Upflow continuous backwash sand filters require no backwash valves, storage tanks, or backwash pumps, therefore their operation is greatly simplified.

2-7. Disinfection.

Disinfection involves destruction or inactivation of organisms which may be objectionable from the standpoint of either health or esthetics. Inasmuch as the health of water consumers is of principal concern to those responsible for supplying water, design of facilities for disinfection must necessarily be carefully executed.

a. *Chlorination.* The application of chlorine to water is the preferred method of disinfecting water supplies at military installations.

(1) *Definitions.* Terms frequently used in connection with chlorination practice are defined as follows:

(a) *Chlorine demand.* The difference between the concentration of chlorine added to the water and the concentration of chlorine remaining at the end of a specified contact period. Chlorine demand varies with the concentration of chlorine applied, time of contact, temperature, and water quality.

(b) *Chlorine residual.* The total concentration of chlorine remaining in the water at the end of a specified contact period,

(c) *Combined available residual chlorine.* Any chlorine in water which has combined with nitrogen. The most common source of nitrogen is ammonia, and compounds formed by the reactions between chlorine and ammonia are known as chloramines. The disinfecting power of combined available chlorine is about 25 to 100 times less than that of free available chlorine.

(d) *Free available residual chlorine.* That part of the chlorine residual which has not combined with nitrogen.

(2) *Chlorination practice.*

(a) *Combined residual chlorination,* Combined residual chlorination entails the application of sufficient quantities of chlorine and ammonia, if ammonia is not present in the raw water, to produce the desired amount of combined available chlorine (chloramine) in a water. If enough ammonia is present in raw water to form a combined chlorine residual, only chlorine need be added to the water. Combined residual chlorination is generally used only when maintaining an adequate free chlorine residual in the distribution system is difficult or when objectionably high levels of TTHMs would be formed as a result of free residual chlorination. Due consideration of other TTHM control alternatives should be made before using chloramines, (see para 2-13).

(b) Breakpoint chlorination. If a water contains ammonia or certain nitrogenous organic matter which reacts with chlorine, the addition of chlorine causes the formation of chloramines until the ratio of elemental chlorine to ammonia compounds is about 5 to 1. Further addition of chlorine results in the oxidation of chloramines to gaseous nitrogen and nitrogen oxides, which decreases the quantity of chloramines present. After all of the chloramines have been oxidized, additional chlorine added to the water forms only free available chlorine. The point at which all of the chloramines have been oxidized and only free chlorine is formed is called the "breakpoint ." If no ammonia is present in the water, there will be no breakpoint. The chlorine required to reach the breakpoint is usually about 10 times the ammonia nitrogen content of the water. However, in certain waters, because of the presence of other chlorine consuming substances, as much as 25 times the ammonia nitrogen concentration may be required. Enough chlorine should be added past the breakpoint to ensure an adequate free chlorine residual.

(c) *Marginal chlorination.* Marginal chlorination involves the application of chlorine to produce a desired level of total chlorine residual regardless of the relative concentrations of free or combined chlorine present. In marginal chlorination the initial chlorine demand has been satisfied but some oxidizable substances remain.

(d) Chlorine dosages. Figure 2-4 provides minimum cysticidal and bactericidal free chlorine residuals and minimum bactericidal combined chlorine residuals for various pH and temperature levels. Since waterborne bacteria are the major concern at fixed installations, minimum bactericidal levels will be maintained in treated water in all parts of the distribution system under constant circulation. Even at lower pH levels, free chlorine residuals should not fall below 0.2 mg/L and combined chlorine residuals should not fall below 2.0 mg/L. If marginal chlorination is practiced, the total chlorine residual must not be less than 2.0 mg/l. Whenever epidemological evidence indicates an outbreak of a nonbacterial waterborne disease such as amebiasis, infectious hepatitis, or schistosomiasis in the area of a fixed military installation, cysticidal free chlorine residuals shall be maintained in the water supply. Further guidance on disinfection requirements may be obtained from the Surgeon General's office. Air Force policy on minimum chlorine levels is established in AFR 161-44.

(3) *Other effects of chlorination.* In addition to the disinfection achieved with chlorination, other beneficial effects should be noted. Since the oxidizing power of chlorine is high, in the presence of free chlorine, hydrogen sulfide is oxidized, nitrites are oxidized to nitrates, and soluble iron and manganese are oxidized to their insoluble oxides. Free chlorine also reacts with naturally occurring taste, odor and color-producing organic substances to form chloro-organic

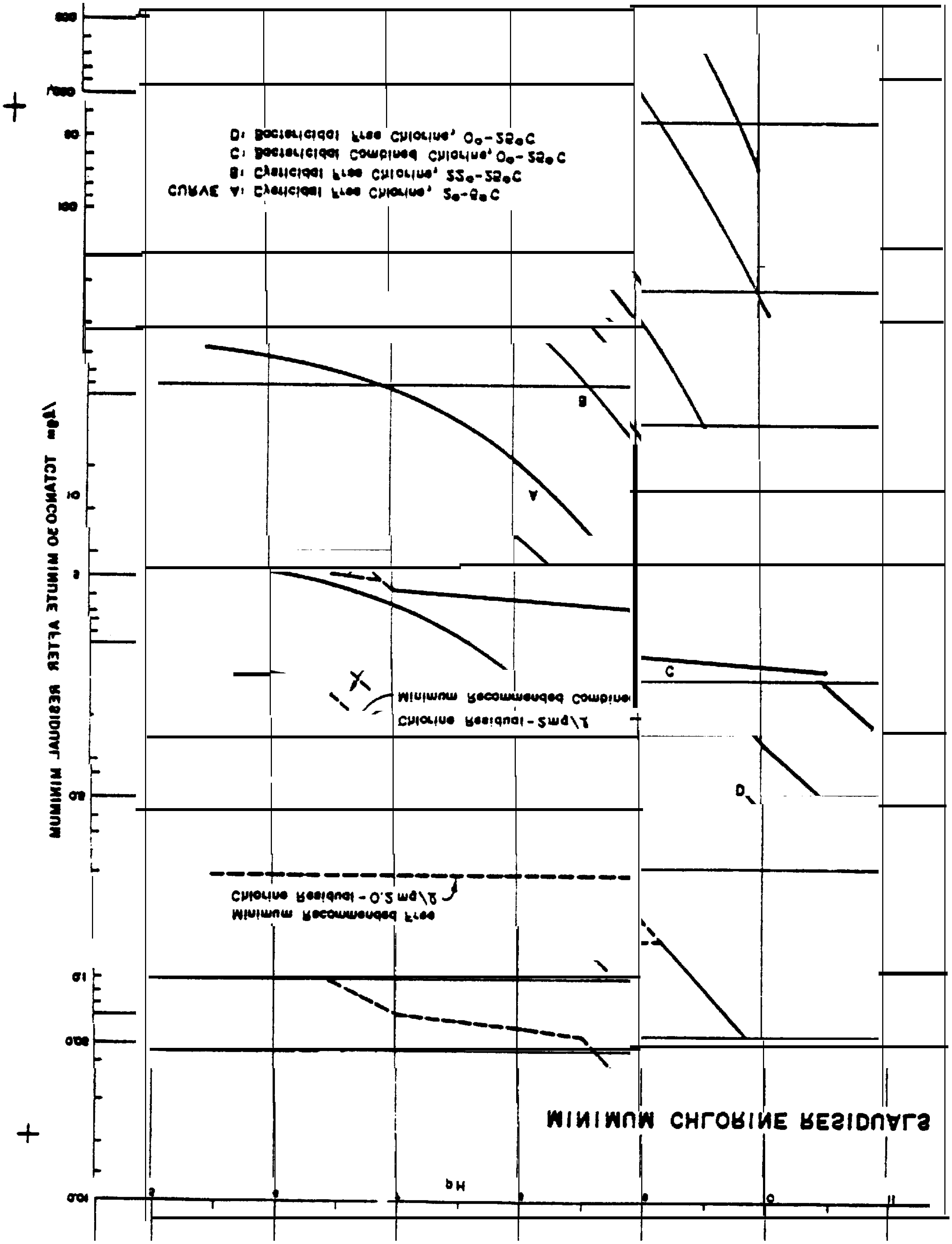

Figure 2-5. Minimum chlorine residuals.

compounds, e.g., trihalomethanes (see para 2- 13.b.). The US EPA, after much discussion over costs/benefits, has chosen a maximum contaminant level for TTHM's of 100 micrograms per liter (µg/L) for plants serving above 10,000 persons and has indicated a future goal of 10-25 µg/L. The present maximum contaminant level of 100 µg/L was a compromise with the water treatment industry to avoid costly modifications to existing plants. To reach the US EPA's future maximum contaminant level for TTHM's, more significant changes in disinfection practices will be required.

(4) *Application of chlorine.* Chlorine may be applied to water of two forms: As gaseous elemental chlorine or as hypochlorite salts. Gaseous elemental chlorine shall be used for water disinfection at all fixed installations. The cost of hypochlorite salts is prohibitive in all plants larger than 0.5 mgd. For remote sites at fixed installations, some well sources require 5 gpm or less. These sources with small demands can use hypochlorite for disinfection.

(a) Point of application. Chlorine may be applied to water in a variety of locations in the water treatment plant, storage facilities, or distribution system. It is absolutely essential that the chlorine applied to the water be quickly and thoroughly mixed with the water undergoing treatment. If required, special chlorine mixing facilities should be provided. In conventional water treatment plants, chlorine may be applied prior to any other treatment process (prechlorination), following one or more of the unit treatment process (postchlorination), and again in the more distant points of the distribution system (dechlorination).

1 Prechlorination., Prechlorination has often been used so the water would maintain a chlorine residual for the entire treatment period, thus lengthening the contact time. The coagulation, flocculation, and filtration processes were thought to be improved by prechlorination of the water, and nuisance algae growths in settling basins were reduced. In prechlorination, the chlorine was usually injected into the raw water at or near the raw water intake. Prechlorination was the most accepted practice of disinfection in the past. However, since many surface waters contain THM precursors that will combine with the free chlorine during prechlorination and form potentially carcinogenic THMs, such as chloroform, the point of application has been shifted further down the treatment process to take advantage of precursor removal during treatment.

2 Postchlorination. Postchlorination generally involves the application of chlorine immediately after filtration and ahead of the clear well. The design and construction of water treatment plants for military installations will include the necessary provisions for changing the locations of chlorine applications as may later be desirable for improving treatment or disinfection processes.

3 Dechlorination. Dechlorination is the practice of adding chlorine to water in the distribution system to maintain a minimum chlorine residual throughout the system.

(b) Chlorination equipment. Hypochlorite salts must be applied to the water in solution form. Hypochlorite solutions are pumped by a diaphragm pump through an injection system into the water to be chlorinated. If elemental chlorine is used for disinfection, it shall be injected by solution-type chlorinators. Since chlorine solutions are acidic, many components of a chlorination system must be constructed of corrosion resistant materials such as glass, silver, rubber, or plastics. Maintaining the chlorination apparatus in a trouble-free state is essential, Key spare parts and repair kits for chlorination systems must be kept on hand. Critical components of the chlorination system shall be installed in duplicate.

(c) *Automatic control.* If automatic chlorination control is utilized, the chlorine feed rate should be controlled primarily by the rate of flow of water, with a signal from a downstream residual chlorine analyzer used to trim the feed rate. Provision for manual control during emergency situations must be included.

(5) *Superchlorination and dechlorination.* Superchlorination may be necessary if there are large variations in chlorine demand or if available contact time is brief. Water which has been superchlorinated generally requires dechlorination before discharge to the distribution system. Dechlorination may be achieved through the application of sulfur dioxide, sodium bisulfite, or sodium sulfite, or by passing the water through granular activated carbon filters. The dechlorination process (and subsequent dechlorination, if necessary) shall be controlled so that the free residual chlorine remaining in the water is at least 0.2 mg/L. Careful monitoring must be practiced to assure that potentially harmful levels of TTHMs are not exceeded. A summary of TTHM regulations are presented in table 2-2.

Table 2-2: Summary of TTHM Regulations

Maximum Contaminant Level (MCL):	0.10 mg/l (100 micrograms per liter) Total Trihalomethanes
Applicability:	Community water systems that add disinfectant to the treatment process (ground and surface)
Effective:	Systems >75,000: November 29, 1981 Systems 10-75,000: November 29, 1983 Systems <10,000: State discretion
Monitoring requirements:	Running annual average of a minimum of 4 samples per quarter per plant taken on same day. Systems using multiple wells drawing raw water from a single aquifer may, with State approval, be considered one treatment plant for de-

Table 2-2: Summary of TTHM Regulations (Cont'd)

termining the required number of samples.

Effective: Systems >75,000: November 29, 1980
Systems 10-75,000: November 29, 1982
Systems <10,000: State discretion

Sample Locations: 25% at extreme of distribution system; 75% at locations representative of population distribution.

Frequency:
For ground water systems, reduced monitoring may be appropriate for certain systems; States may reduce the requirements through consideration of appropriate data including demonstration by the system that the maximum total trihalomethane potential (MTP) is less than 0.10 mg/l; the minimum frequency would be one sample per year for MTP.
For ground water systems not meeting the above MTP and for surface water systems, States may reduce the monitoring requirements if after one year of data collection, TTHM levels are consistently below 0.10 mg/l; the minimum frequency would be one sample per quarter for TTHM.
The original frequency would be reinstated if the levels exceed 0.10 mg/l or if the treatment or source is modified.

Reporting Requirements:
To State: Average of each quarterly analysis, within 30 days; until States have adopted the regulations, reporting will be to EPA unless State requests receipt of data from the public water systems.
To Public and State: Running annual average of each quarterly sample if it exceeds MCL as prescribed by the public notification provisions.

Other Requirements:
To ensure microbiological quality: State approval of significant modifications in the treatment process for the purpose of meeting the TTHM MCL.

Analytical requirements: In accordance with specified methods (purge and trap or liquid/liquid extraction) conducted by certified laboratories.

Other Issues of Interest: Guidance on alternative disinfectants
- Conduct monitoring when chlorine dioxide is used and residual oxidants should not exceed 0.5 mg/l.
- The decision of using chloramines is best made on a case-by-case basis by the State
- Standard plate count should be a condition for State approval of systems where process modifications are contemplated

Laboratory Availability (interim certification):
- To qualify for interim certification, laboratories will be required to demonstrate their abilities to analyze the performance evaluation samples provided to them by EPA's Environmental Monitoring and Support Laboratory (EMSL) to within 20% of the “true value” for each THM as well as the total.
- A quality assurance program will be established to ensure a laboratory's ability to perform quality analyses.

(6) *Safety precautions for chlorination. The* AWWA manual “Safety Practice for Water Utilities” contains safety recommendations regarding the use of chlorine. These recommendations shall be followed at all military water treatment facilities. Further discussion on safe operation of chlorination facilities for Army installations are contained in TB MED 576, appendix L.

b. Alternate Disinfectants. If the use of chlorine as a disinfectant causes unacceptably large concentrations of chlorinated organic compounds, and if all other methods for reducing TTHM's have been exhausted, such as moving the point of chlorination, aeration, and special coagulant (as shown in table 2-3 for chloroform which is the main constituent of TTHMs in many cases) and if an alternate raw water source, such as a ground water source, is not available, an alternative disinfectant must be considered. Any alternate disinfectant system installed as the primary means of water disinfection shall have chlorination facilities available and operative for stand-by use. Five alternative disinfectants are discussed below; ozone, chlorine dioxide, chloramines, ultraviolet (UV) radiation, and UV and Ozone combined. While chlorine is the least costly disinfectant, considering dosage and energy consumption basis. However alternate disinfectants are not significantly more expensive.

Table 2-3: Effectiveness of Various Unit Processes
for Reducing Chloroform Formation Potential

Process	Chloroform Formation Potential µg/l	Chloroform Formed µg/l	Remarks
Ozone followed by chlorination			
Chlorine Dioxide only			
Coagulation, Sedimentation and Filtration followed by:	48	48	at PAC dosage = 8 mg/l
		<1	at PAC dosage = 8 mg/l
	48		PAC contact time = 2-20 min.
Ozone only	74	None Found	O_3 neither forms trihalomethanes, nor removes precursors at disinfection doses
Filtration/Adsorption by Granular Activated Carbon (5 min. contact time) followed by chlorination		20[a]	Disinfection doses (≤ 1 mg/l)
	27[a]	6	ClO_2 does not form trihalomethanes
Powdered Activated Carbon added after Coagulation and Settling followed by chlorination	48	≤1	GAC would be effective for 3 weeks
Coagulation, Sedimentation and Dual-Media Filtration followed by Chlorination		≤10	GAC would be effective for 8 weeks
Coagulation, Sedimentation	66[a]	66[a]	
Aeration followed by chlorination	48[b]	13[b]	Diffused-air aeration with air to water ratios up to 20:1 did not reduce chloroform formation potential (10 min. Contact Time)

Table 2-3: Effectiveness of Various Unit Processes for Reducing Chloroform Formation Potential (Cent 'd)

Process	Chloroform Formation Potential µg/l	Chloroform Formed µg/l	Remarks
1. Chlorination	—	17c	1.3 mg/l ClO_2 and 1.5 mg/l Cl_2
2. Chlorine dioxide	—	3d	Trihalomethane with chlorine formation decreases as the ratio of ClO_2 to Cl_2 increases

All tests performed on Ohio River water. Chloroform Formation Potential is the amount of chloroform formed when raw water is chlorinated past break-point and stored at 25°C for a specified contact time.

a—chlorine contact time = 48 hours

b—chlorine contact time = 96 hours

c—chlorine contact time = 22 hours

d—contact time for combination of chlorine dioxide with chlorine —22 hours

(1) *Ozone.* Ozone is an extremely powerful disinfectant that has been used in Europe either as a sole disinfectant, or in conjunction with postchlorination to impart a persistent chlorine residual in the water distribution system. United States potable water plants have in the past used ozone to control taste and odor. Today ozonation is being increasingly used as a primary disinfectant prior to rapid mixing, flocculation and filtration. Ozonation does not produce THMs. It is reduced to oxygen and does not leave any residual disinfectant. Hence, the need for postchlorination. Ozone is generated electrically, as needed using the electric discharge gap (corona) technique. Air or oxygen stream, a cooling water stream and alternating electric current are required. Efficient cooling is essential to reduce thermal decomposition of ozone. Bubble diffusers appear to be the most economic ozone contractors available.

(2) *Chlorine Dioxide,* Chlorine dioxide is a highly effective disinfectant producing minimal THMs in the presence of their precursors. Chlorine dioxide uses in the United States have been limited to taste and odor control although it has been used elsewhere as a primary disinfectant and is presently receiving more attention in the United States. The common method of chlorine dioxide production is to react chlorine gas from a conventional chlorinator with a sodium chlorite solution. Following the mixing of the chlorine and sodium chlorite streams and prior to introduction into the main stream the mixed stream is passed through a packed column contactor to maximize chlorine dioxide production. A major disadvantage of chlorine dioxide is the formation of chlorate and chlorite which are potentially toxic.

(3) *Chloramines,* The use of chloramines as a disinfectant fell into disuse after the introduction of breakpoint chlorination. To achieve the same disinfection ability of chlorine, 10 to 15 times the amount of chloramines are needed or longer contact time is required. More chloramines are needed if high concentrations of organic material are found in the influent water, Chloramines are easy to generate, feed, and produce a persistant residual that will remain through the water distribution system. Chloramines may be produced by introducing ammonia to the water stream prior to the addition of free chlorine. This process can be optimized for minimum THM production and maximum disinfection. Recently however there has been some concern over chloramine toxicity.

(4) *Ultraviolet Radiation.* Ultraviolet (UV) radiation has undergone development, but has not been used on a large scale for drinking water supply disinfection. Most of its uses include product or process water disinfection where high purity, sterile water is needed. UV radiation has been used to disinfect drinking water at remotely located hotels and on cruise ships. Few large scale water processing plants use UV disinfection, although its application is feasible. UV disinfection does not leave a disinfectant residual and should be accompanied by postchlorination. Ultraviolet irradiation is also effective in oxidizing organic compounds in water, Water turbidity will inhibit the effectiveness of UV disinfection.

(5) *UV and Ozone,* Recently there has been some experimentation in a combined UV and ozone contactor. Results from these tests show promise. However, there is no known water treatment plant operating with this method of disinfection.

2-8. Fluoride adjustment.

a. Health effects. An excessive fluoride concentration will damage the teeth of children using the water for extended periods. On the other hand, moderate concentrations, 0.7- 1.2 mg/L, are beneficial to children's teeth. Most natural waters contain less than the optimum concentration of fluoride. Upward adjustment of the fluoride concentration can be achieved by application of a measured amount of a fluoride chemical to the water. For installations where it is desirable and feasible to add fluoride, control limits and optimum concentrations are as follows:

Annual Average* of Maximum Daily Air Temperatures °F	Control Limits Fluoride Concentration mg/l Lower	Optimum	Upper
50.0—53.7	0.9	1.2	1.7
53.8—58.3	0.8	1.1	1.5
58.4—63.8	0.8	1.0	1.3
63.9—70.6	0.7	0.9	1.2
70.7—79.2	0.7	0.8	1.0
79.3—90.5	0.6	0.7	0.8

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*Minimum record: 5 years

b. Fluoridation chemicals. Chemicals most frequently used for fluoridation are: Sodium silicofluoride (Na_2SiF_6), sodium fluoride (NaF), and fluosilicic acid (H_2SiF_6). For a particular installation, the choice of chemical will depend principally on delivered cost and availability.

(1) Sodium fluoride. This chemical is commercially available as a white crystalline powder having a purity of 95 to 98 percent. (Sometimes it is artificially colored nile blue.) Volubility is approximately 4 percent at 770 F. The pH of a saturated solution is 6.6. The 100 percent pure material contains 45.25 percent fluoride. It is available in 100-pound bags, 125 to 400 pound drums, and bulk.

(2) Sodium silicofluoride. This compound is commercially available as a white powder with a purity of 98 to 99 percent. Volubility is only about 0.76 percent at 770 F. The pH of a saturated solution is 3.5. The 100 percent material contains 60.7 percent fluoride. It is available in 100 pound bags, 125 to 400 pound drums, and bulk.

(3) Fluosilicic acid. This chemical is commercially available as a liquid containing 22 to 30 percent by weight of fluosilicic acid. It is sold in 13 gallon carboys, 55 gallon drums, and in bulk. The 100 percent pure acid contains 79.2 percent fluoride. The pH of a 1 percent solution is 1.2, and the use of fluosilicic acid as a fluoridation agent in a water of low alkalinity will significantly reduce the pH of the water. It should not be used for fluoride adjustment of waters of this type unless pH adjustment is also provided.

c. *Point of application.* It is essential that all water pass the point of injection of the fluoridation chemical and that the flow rate past this point be known with reasonable accuracy. At a water treatment plant, the preferred application point is usually the combined effluent of all filters. The fluoride chemical can be fed at an earlier stage of treatment, for example, the combined filter influent, but part of the fluoride applied will be removed by the filtration process. Coagulation and lime softening will also remove a small amount of the applied fluoride. A larger dose is required to offset treatment process losses. If ground water is the supply source, the fluoride chemical should be injected into the discharge pipe of the well pump. Where the supply is from several wells, each pumping independently to the distribution system, it will be necessary to provide an injection point at each well. If flow past the injection point is variable, automatic equipment that will feed fluoride chemical at a rate proportional to flow is a requirement.

d. Fluoride feeders. Volumetric or gravimetric dry feeders equipped with dissolvers are suitable for sodium fluoride or sodium silicofluoride. Feeders should be equipped with weighing devices that will accurately measure the weight of chemical fed each day and the feed equipment should be designed to minimize the possibility of free flow (flooding) of chemical through the feeder. Normally, the feed machine's supply hopper should hold no more than 100 to 200 pounds of chemical. Large extension hoppers holding much greater quantities of dry fluoride chemical increase the danger of flooding and overfeeding and are not recommended for most installations. Solutions of sodium silicofluoride are acidic and corrosion-resistant dissolvers and solution piping must be provided where this chemical is employed. If fluosilicic acid is used, it can be applied by means of a small metering pump into an open channel or a pressure pipe. Storage tanks, feeders, and piping for fluosilicic acid must be made of corrosion-resistant material. The acid is slightly volatile and the feed system should be enclosed. If not enclosed, special exhaust ventilation should be provided to protect personnel from fluoride fumes.

e. Fluoride removal. Fluoride removal can be accomplished by passage of the water through beds of activated alumina, bone char, or tricalcium phosphate. When the capacity of the bed to remove fluoride is exhausted, it can be regenerated by treatment with a caustic soda solution followed by rinsing and acid neutralization of the residual caustic soda. Other methods of fluoride removal include electrodialysis, reverse osmosis and ion exchange. Some fluoride reduction can be obtained by water softening using excess lime treatment. Fluoride reduction by this method is associated with magnesium precipitation and the extent of fluoride removal is a function of the amount of magnesium precipitated from the water. All removal processes produce liquid wastes and suitable provision must be made for their disposal. Guidance as to the fluoride removal process to be employed can be obtained from laboratory studies of process effectiveness and fluoride removal capacity, using samples of the water that is to be treated.

2-9. Taste and odor control.

Most taste and odors in surface water are caused by low concentrations of organic substances derived from decomposing vegetation, microscopic organisms, sewage and industrial waste pollution, etc. Treatment for taste and odor removal involves destruction of the odorous substance by chemical oxidation or its removal by aeration or adsorption or activated carbon.

a. Chemical oxidation. Chemical oxidizing agents which have been found effective and which can be used in the treatment of potable water are chlorine, chlorine dioxide, potassium permanganate, and ozone. No single chemical is completely effective under all operating conditions.

b. Aeration. Aeration is helpful in eliminating odor caused by hydrogen sulfide, but is ineffective in significantly reducing odor associated with dissolved organics.

c. Absorption. Powdered activated carbon is commonly used for removal of tastes, odor and color by adsorption. The carbon can be applied to the water at any point in the treatment plant prior to filtration, but it is usually advisable to apply it early in the treatment process to prolong contact. For maximum effectiveness, carbon should be applied well ahead of chlorine, and preferably in advance of lime softening, The influent to a presedimentation basin is normally an effective carbon application point. Powdered carbon dosages usually range from 5 to 10 mg/L, but as much as 50 mg/L may be required. The use of powdered activated carbon adds more suspended solids and increases the amount of sludge, thereby creating a sludge disposal problem. Powder activated carbon is marginally effective in reducing TTHMs. Granular activated carbon (GAG) has also been used for taste and odor removal. It has been employed as a separate treatment step in the form of carbon columns and as a substitute for sand in the filtration process. Used in this way, the granular carbon serves in a dual capacity as a filtration medium and for taste and odor removal. Granular activated carbon is also excellent at reducing TTHMs. Granular activated carbon must be reactivated on a regular basis to keep its absorptive abilities. Because of the cost of reactivation of GAC, other methods of taste-and-odor control and reduction of TTHMs should be considered. Aeration is generally more cost-effective than GAC contractors.

2-10. Softening.

Whether water softening is provided will depend entirely on the type of project and the uses to be made of the water. Two general types of processes are used for softening: The "lime-soda ash" process and the "cation ion exchange" or "zeolite" process.

a. *Applications.*

(1) *Permanent posts or bases.* Softening of the entire supply for a permanent post or base may be considered if the hardness exceeds 200 mg/l, with hardness expressed as equivalent $CaCO_3$. Softening of a post water supply to a total hardness of less than 100 mg/L is not required, however, softening to less than this amount is justified for the special purposes and services given in paragraphs (3), (4), (5), and(6) below.

(2) *Nonpermanent bases.* For Army temporary construction and for Air Force bases not in the permanent category, the entire supply will not be softened unless the total hardness exceeds 300 mg/L. However, when a treatment plant is constructed for the removal of turbidity or iron, the plant may also be designed to accomplish partial softening.

(3) *Laundries.* Water for laundries shall have a hardness of 50 mg/l or less. Installation of cation ion exchange water softeners to reduce the hardness to zero is recommended.

(4) *Boiler water.* Boiler water for power plants and heating plants may require softening, but satisfactory results can often be obtained by application of corrosion and scale inhibitors. Depending on the pressure at which the boiler is to operate, partial water-demineralization may also be necessary, See paragraph 2-13a. for additional information on demineralization.

(5) *Dining facilities.* The installation of softeners for small dining facilities, latrines and bathhouses is not recommended. However, water softeners to reduce hardness to 50 mg/L maybe justified for large central dining facilities to protect equipment and to insure satisfactory washing of dishes. Each such instance will be justified separately.

(6) *Hospitals.* When the water supplied to a hospital has a hardness of 170 mg/L or more, the water will be softened to approximately 50 mg/L. Where critical equipment requires water having a hardness of less than 50 mg/L, as special study will be made to determine the most feasible means of obtaining water of the necessary hardness. Zero hardness water may be piped from the main softener or maybe supplied from small individual softeners, whichever is the more feasible. The sodium content of the treated water must be taken into account when selecting a softening method for hospitals.

b. Lime-soda ash process,

(1) Softening chemicals and reactions. The principal chemicals used to effect softening are lime, either hydrated lime ($Ca(OH)_2$) or quicklime (CaO), and soda ash (Na_2CO_3). These chemicals are added to the water to be softened and react with the calcium carbonate and magnesium in the ater to form insoluble compounds of calcium carbonate and magnesium hydroxide. If quicklime is used, it is usually converted to a slurry of hydrated lime by slaking with water prior to application. The chemistry of the process can be illustrated by the following equations:

Lime Treatment

1. $CaO + H_2O \rightarrow Ca(OH)_2$ (lime slaking)
(quicklime) (hydrated lime)

2. $CO_2 + Ca(OH)_2 \rightarrow CaCO_3\downarrow + H_2O$
(free carbon dioxide)

3. $Ca(HCO_3)_2 + Ca(OH)_2 \rightarrow 2CaCO_3\downarrow + 2H_2O$
(carbonate hardness)

4. $Mg(HCO_3)_2 + Ca(OH)_2 \rightarrow CaCO_3\downarrow + MgCO_3 +$ $2H_2O$
(carbonate hardness)

5. $MgCO_3 + Ca(OH)_2 \rightarrow CaCO_3\downarrow + Mg(OH)_2\downarrow$
(carbonate hardness)

7. $MgSO_4 + Ca(OH)_2 \rightarrow Mg(OH)_2 + CaSO_4$
(noncarbonate hardness)

Soda Ash Treatment

6. $CaSO_4 + Na_2CO_3 \rightarrow CaCO_3\downarrow + Na_2SO_4$

All of the above reactions can be accomplished in a single stage of treatment. Lime and soda ash can be added at the same point and will react with each other;

however, the net effect will be as illustrated by reactions 2 through 7.

(2) *Chemical requirements.*

(a) *Lime.* A reasonably accurate estimate of lime requirements for softening can be computed from a water analysis which gives free CO_2, bicarbonate alkalinity and, magnesium. Requirements of quicklime or hydrated lime can be computed as follows:

lbs quicklime per million gallons =

$$\frac{[10.6][CO_2] + [4.68][Alk + MgH] + [35][8.34]}{\%\ CaO\ in\ quicklime}$$

CaO)

(Quicklime purity usually ranges from 90 to 95%

100

lbs hydrated lime per million gallons =

$$\frac{[14.0][CO_2] + [6.18][Alk + MgH] + [46][8.34]}{100}$$

% $Ca(OH)_2$ in hydrated lime

— MgH = Magnesium hardness expressed as $CaCO_3$

— Alk = mg/l bicarbonate alkalinity expressed as

— CO_2 = mg/l carbon dioxide expressed as CO_2

98% ($Ca(OH)_2$) where

(Hydrated lime purity usually ranges from 95 to

sure effective precipitation of magnesium.

— 35 = excess of pure quicklime required to in-

$CaCO_3$, mg/L

insure effective precipitation of magnesium.

— 46 = excess of pure hydrated lime required to

mg/L

ments it is only necessary to know the noncarbonate

(b) Soda ash. To estimate soda ash require-

mg/L

hardness of the raw water and to establish the amount of noncarbonated hardness to be left in the finished water. The latter is termed residual noncarbonated hardness. Inasmuch as most commercial soda ash is 990/0+ Na_2CO_3, it is normally not necessary to correct for the purity of this chemical.

lbs soda ash per million gallons = [8.34] [NCH-R]
where

— NCH = mg/L of noncarbonated hardness

— R = mg/L of residual noncarbonated hardness

– (The term [NCH-R] is the mg/L of noncarbonated hardness removed)

(3) *Characteristics of lime-softened water.* The carbonate hardness of the water, after application and reaction of the softening chemicals plus sedimentation and filtration, should be approximately 50 mg/L. The total hardness will consist of the carbonate hardness, 50 mg/L, plus the residual noncarbonated hardness that was intentionally allowed to remain in the water. It is not advisable to reduce the carbonate hardness to the lowest possible value because such water will be corrosive. In lime softened wasters, it is desirable that the magnesium hardness be reduced to 40 mg/L or less. The residual calcium hardness should be approximately 50 mg/L and the alkalinity also about 50 mg/L. Some ground water supplies contain no noncarbonated hardness. For such waters, lime treatment alone will suffice for softening.

(4) *Sludge production.* The lime-soda ash softening process produces chemical sludge composed principally of calcium carbonate and magnesium hydroxide. As withdrawn from sedimentation basins equipped for mechanical sludge removal, the proportion of dry solids in the sludge will generally fall within the range of 2 to 10 percent. The weight of dry solids produced by softening reactions will average approximately 2.5 times the weight of commercial quicklime used. For hydrated lime, softening solids produced will be roughly twice the weight of commercial hydrated lime employed. Fairly accurate values of total solids production at an operating plant can be developed utilizing a mass balance which takes into consideration the suspended solids in the raw water, the quantity of dissolved calcium and magnesium in the raw and finished water, the quantity and purity of lime applied, the quantity of coagulant used, and the stoichiometry of the softening and coagulation reactions. Means of disposal of waste solids from softening plants must receive careful consideration at an early stage of treatment plant design. See chapter 6.

(5) *Lime-caustic soda process.* An alternative softening process, sometimes used, is the lime-caustic soda process. The process is worth consideration when considerable reduction in noncarbonated hardness is required. Application of the process involves substitution of caustic soda (sodium hydroxide) for soda ash and part of the lime. The remaining lime reacts with carbonate hardness constituents as previously indicated. The caustic soda also reacts with carbonate hardness as follows:

$$Ca(HCO_3)_2 + 2NaOH \longrightarrow CaCO_3\downarrow + Na_2CO_3 + 2H_2O$$

$$Mg(HCO_3)_2 + 4NaOH \longrightarrow Mg(OH)_2\downarrow + 2Na_2CO_3 + 2H_2O$$

The above reactions generate soda ash (Na_2CO_3) which will reduce the noncarbonated hardness as previously indicated. All of the reaction products are chemically identical to those obtained by the use of lime and soda ash. The amount of caustic soda required can be calculated from the theoretical quantities of pure lime and soda ash required. Less calcium carbonate sludge is formed with the lime-caustic soda process. This may be an advantage if softening sludge disposal is a problem. For water softening purposes, caustic soda should be purchased as a 50 percent solution containing 6.38 pounds of pure NaOH per gallon. A 50 percent solution must be stored at temperatures above about 600 F. to prevent freezing. As a storage alternative, the 50 percent solution may be diluted to 25 to 30 percent strength which has a freezing point in the approximate range of 0° to 30° F. Caustic soda in any form must be viewed as a hazardous substance, capable of causing serious burns. Personnel responsible for handling and feeding the chemical must understand its potentially dangerous nature, know what precautions should be taken and be supplied with appropriate protective clothing, safety showers, etc.

(6) *Recarbonation.* Recarbonation involves the introduction of 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 should either be purchased as liquefied carbon dioxide, which must be stored at the plant in a refrigerated storage tank, or generated at the water treatment plant by the combustion of coke, oil, or gas. Recarbonation can also be achieved by utilizing carbon dioxide and bicarbonate available in the raw water. This is the "split" treatment process.

(a) *Chemical reactions.* The following reactions illustrate the chemistry of the recarbonation process:

Neutralization of excess lime.

— $CO_2 + Ca(OH)_2 \rightarrow CaCO_3\downarrow + H_2O$

Conversion of magnesium hydroxide to magnesium carbonate.

— $2HCO_3^- + Ca(OH)_2 \rightarrow CaCO_3\downarrow + CO_3^{2-}$

Use of bicarbonate derived from raw water.

— $2CO_2 + MgCO_3 + H_2O \rightarrow Mg(HCO_3)_2$

— $2CO_2 + CaCO_3 + H_2O \rightarrow Ca(HCO_3)_2$

Conversion of carbonates to bicarbonates.

— $CO_2 + Mg(OH)_2 \rightarrow MgCO_3 + H_2O \qquad + 2H_2O$

The above reactions are accompanied by important changes in the pH of the softened water, and the pH value is used as a recarbonation control parameter. Recarbonation can be practiced in a single-stage or two-stage configuration. If recarbonation is accomplished in two stages, the first stage is devoted to neutralization of most of the excess lime. This involves conversion of excess lime to calcium carbonate and a pH change from about 11 to approximately the 9.5-10 range. Following the first stage of recarbonation, the water must be flocculated and settled to remove excess calcium carbonate. Coagulant such as silica, starch, polymer or ferric sulfate may be employed to assist in coagulation and settling of the calcium carbonate particles. The second stage of recarbonation, usually just ahead of filtration, serves principally as a "trim" stage in which final pH adjustments are made, as necessary. Guidance as to the correct pH can be obtained through calculation of the saturation index (see para 2-12c). For softened waters of low alkalinity, a plus index is generally advisable. Carbon dioxide added in the second stage converts carbonates to bicarbonates. If only a single stage of recarbonation is employed, the carbon dioxide feed must be adjusted so that the previously described reactions take place to the extent necessary at the single point of recarbonation. Single stage recarbonation should be followed by facilities for removal of precipitated calcium carbonate. A single stage of recarbonation provides no opportunity for further pH adjustment prior to filtration. Application of polyphosphate compound, such as sodium hexametaphosphate, may be desirable following recarbonation. Approximately 0.5 mg/L of a polyphosphate will inhibit scale formation and prevent incrustation of the filter media with hard, crystalline deposits of calcium carbonate.

(b) *Carbon dioxide requirements.* Carbon dioxide requirements are established by the amount of hydroxide alkalinity converted to carbonate and the amount of bicarbonate formed. For plant control purposes, alkalinity values are generally expressed in terms of calcium carbonate ($CaCO_3$). Total carbon dioxide requirements are calculated as follows, where (OH^-) is the hydroxide alkalinity in mg/L, as $CaCO_3$; and (HCO_3^-) is the desired bicarbonate alkalinity in mg/L as $CaCO_3$ in the finished water:

— Total mg/L $CO_2 = (.44)[(OH^-) + (HCO_3^-)]$

— lbs CO_2 per million gallons $= 3.67[(OH^-) + (HCO_3^-)]$

— The approximate CO_2 yields of common fuels are:

Fuel	Basis	CO_2 Yield lbs
Natural gas	1000 cu ft	115
Coke	1 lb	3
Kerosene	1 gal	20
Fuel Oil (No. 2)	1 gal	23
Propane	1000 cu ft	141
Butane	1000 cu ft	142

Carbon dioxide injection equipment must be carefully designed to insure maximum absorption efficiency. This is especially important if pure (99.5 percent and) carbon dioxide is used. Equipment is available which will give essentially 100 percent absorption of pure CO_2 when injected as a gas. An alternative feed method for pure CO_2 is use of a chlorinator as a feeding device. With this feeding arrangement, the CO_2 is in solution at the feed point and the problems associated with interphase gas transfer are avoided.

(7) *Split treatment.* Split treatment is accomplished by excess lime treatment of part of the raw water and then, after removal of most of the precipitated magnesium hydroxide and calcium carbonate by sedimentation, adding the balance of the raw water and again mixing and settling. Employment of excess lime treatment in the first stage insures efficient magnesium removal. The excess lime is neutralized in the second stage by carbon dioxide and bicarbonate in the unsoftened, bypassed water. Conventional recarbonation facilities are not normally required when split treatment is used. Split treatment is often applicable to well waters 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 of the water receives two-stage treatment. The principal operating problems associated with split treatment are correct ad-

justment of chemical feeds and bypass flow. The calcium carbonate equivalent of the HCO_3 and CO_2 content of the bypassed water must equal the calcium carbonate equivalent of the OH^- content of the first stage softened water plus the desired bicarbonate alkalinity in the finished water, all expressed in consistent units. This is shown in the following equation:

$$Q_B(A + 2.2C) + (Q_R - Q_B)(H) + (Q_R)(F)$$

where

Q_R = rate of flow of raw water

Q_B = rate of flow of bypass raw water

P = % of raw water bypassed = $\frac{100Q_B}{Q_R}$

$Q_R - Q_B$ = rate of flow of softened water

H = hydroxide alkalinity of the first stage softened water, mg/L as $CaCO_3$

C = carbon dioxide in raw water, mg/L as CO_2 ($2.2C$ = CO_2 expressed as $CaCO_3$)

A = bicarbonate alkalinity of raw water, mg/L as $CaCO_3$

F = bicarbonate alkalinity desired in finished water, mg/L as $CaCO_3$

Solving this equation and recalling that P, the percentage of total raw water bypassed = $\frac{100Q_B}{Q_R}$ gives the following:

$$P = \frac{100(H + F)}{H + A + 2.2C}$$

The magnesium hardness of the finished water can be estimated from the following:

$$MgH = \frac{(P)(MgR) + (100 - P)(MgS)}{100}$$

MgH = magnesium hardness of finished water in mg/L

MgS = magnesium hardness of the first stage softened water in mg/L

MgR = magnesium hardness of the raw water in mg/L

P = ‘/o bypass water

(8) *Incidental benefits of lime softening.*

(a) Disinfection. 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,

(b) Reduction of dissolved solids. Removal of carbonate hardness by lime treatment results in reduction in the total dissolved solids content of the water. All reaction products of lime softening are relatively insoluble. The lime added to the water, as well as the carbonate hardness constituents in the water, are largely precipitated.

(c) *Iron and manganese removal.* Lime softening is also highly effective as a means of iron and manganese removal. The high pH achieved insured essentially complete precipitation of any iron and manganese present in the raw water.

(d) Clarification. Lime softening provides excellent coagulation and clarification as a result of the precipitation of magnesium hydroxide plus a large amount of calcium carbonate.

(9) *Softening plant design.* The equipment, basins, and filters required for lime, lime-soda ash, lime-caustic, or split treatment softening are generally similar to the facilities used in conventional coagulation-filtration plants. Two stages of treatment are usually advisable. The design of a lime-soda ash or similar softening plant is a complex and difficult task requiring the services of engineers experienced in projects of this kind. Their assistance should be sought in early stages of project planning.

(a) Mixing equipment, One problem encountered at softening plants is vibration of rapid mixing devices due to nonuniform deposits of calcium carbonate scale._ Frequent cleaning of the mixer may be required. The frequency of such cleaning can be reduced by recirculation of previously precipitated calcium carbonate sludge from the settling basin to the rapid-mix chamber. Parshall flumes can serve as mixing devices.

(b) Flocculation and clarification. Each separate stage of flocculation and clarification should have a total detention time at design flow of about 2.5 hours, 30 minutes for flocculation and 2 hours for clarification. Average depths of both flocculation and clarification units should be 8 to 15 feet. The overflow rate in clarifiers at design flow should be about 0.75 gpm per square foot.

(c) Sludge removal and recirculation. First-stage settling basins shall have mechanical sludge removal equipment. Such equipment is also desirable in the second-stage basins which follow recarbonation. Sludge recirculation is generally desirable except during occurrences of severe taste and odor problems. Recycling of a portion of the settled sludge, which is high in calcium carbonate, to the rapid-mix chamber is effective in promoting the softening reactions, especially carbonate precipitation. Where_ presedimentation is employed, recycling sludge to the presedimentation basin influent will enhance the performance of the presedimentation basin.

(d) Solids contact units. Solids contact type basins may be used at many softening plants, particularly those treating ground water, These basins provide the functions of mixing, sludge recirculation, sedimentation and sludge collection in a simple compact unit. Basins of this type, if properly sized, will provide effective softening and clarification treatment. Overall basin depths of 10 to 15 feet should be used, and the unit should be designed so that the softening slurry is recirculated through the center chamber at a rate of

flow 3 to 5 times as great as the rate of flow through the entire unit. The upflow rate at the slurry separation level in the clarification zone should not exceed approximately 1.5 gpm per square foot.

(e) Chemical application and storage. Lime feeders and slakers are key items of equipment at a softening plant and must be selected on the basis of reliability. Another important item requiring careful consideration by the designer is chemical storage. Depending on the size of the plant, bulk or bag unloading and storage for lime and soda ash must be provided. Storage equivalent to at least 30 days average use shall be provided. Caustic soda, if used, will generally be purchased as a 50 percent solution and appropriately sized storage tanks must be provided for this chemical.

(f) Sludge disposal. A disadvantage of any lime softening process is the production of a large mass of sludge of high water content. Provision for its disposal in an environmentally acceptable manner must be made and this problem must be carefully considered in connection with softening plant location and design.

c. *Cation exchange softening.* Hardness is caused principally by the cations calcium and magnesium, and cation exchange softening is accomplished by exchanging these ions for a cation, usually sodium, which does not contribute to hardness. This exchange is achieved by passage of the water through the bed of a granular sodium cation exchanger. This reaction is reversible and the exchanger can be regenerated with a strong solution of sodium chloride (common salt).

(1) *Media used for ion exchange softening.* Ion exchange water softeners at fixed military installation shall use polystyrene resins as the softening media. Such resins must have a hardness exchange capacity of at least 25,000 grains of hardness per cubic foot of resin.

(2) *Regeneration of ion exchange softeners.* The regeneration process generally involves three steps: (1) backwashing, (2) application of regeneration solutions, and (3) rinsing.

(a) *Back washing.* The purposes of water softener backwashing are generally the same as the purposes of filter backwashing. Any turbidity particles filtered out of the water during softening are removed by the backwashing process. For polystyrene resin media, bed expansions of from 50 to 100 percent are normally required, which involves backflow rates of 4 to 10 gallons per minute per square foot of bed area. Backwash periods generally range from 2 to 5 minutes. Ion exchange water softeners which operate upflow rather than downflow will not require backwashing, but the water to be softened must be virtually free of suspended matter.

(b) Application of salt brine. After the unit has been backwashes, a salt solution is applied to the medium in order to regenerate its softening capabilities. Regeneration brines should be 10 to 15 percent solutions of salt. The more salt used in the regeneration of a softener, the more complete the regeneration will be, and the greater the exchange capacity of the regenerated medium will be. The costs of the extra salt required to obtain the added exchange capacity must be weighed against the advantages of the higher exchange capacity in order to determine which salt dosage to use. 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. Contact times of 20 to 35 minutes will generally be used.

(c) *Rinsing.* After regeneration, the brine must be rinsed from the unit before softening is resumed. Disposal of backwash water, spent regenerant, and rinse water must be carefully considered.

(3) *Ion exchange water softeners.* Although most ion exchange softeners at military installations will be downflow pressure softeners, softening can also be achieved upflow. Larger ion exchange softening facilities are often operated upflow in order to avoid the necessity of backwashing. In general, ion exchange softeners are of two types; open gravity softeners and pressure softeners.

(a) Open gravity softeners. Open gravity softeners are constructed in much the same manner as rapid sand filters, and the modes of operation are very similar. However, the ion exchange medium used in open gravity softeners is much lighter than the sand used in filters, so backwash rates for open gravity softeners may also be operated upflow, but the softener will not achieve any filtering effects so the influent water must be virtually free of suspended matter.

(b) Pressure softeners. A polystyrene *resin* medium used for pressure softening shall have a minimum bed depth of 24 inches and physical properties approximately the same as the following:

Shipping weight	45-52 lb./cu. ft. net
Density	48-53 lb./cu. ft.
Fines through 50 mesh screen	<1%
Uniformity coefficient	<1.70
Effective size	0.45-0.55 mm
Screen grading	16-50 mesh
Void volume	40%
Moisture content	45-48%

If downflow softening is used, the flow rate through the softening medium may vary from 2 to 8 gpm per square foot but must not exceed 10 gpm per square foot under the most severe loadings. Severe reductions in exchange capacity are experienced if the softener operates at rates of flow in excess of 10 gpm per cubic foot for sustained periods of time. With upflow softening, the rate of flow should be adjusted to maintain a bed expansion of from 40 to 60 percent. The degree of bed expansion is a function of both the flow rate and the temperature of the influent water, so the flow rate must be decreased as water temperature decreases if a constant bed expansion is to be maintained,

(4) *Blending,* An ion exchange softener operating properly will produce a water having a hardness approaching zero. Inasmuch as it is not generally economical nor desirable to soften all water to this low hardness level, provisions, for blending the softened water with the unsoftened water are desirable.

(5) *Other factors affecting ion exchange softening,*

(a) Turbidity, Turbidity particles present in the water influent to the softener are deposited on the softening medium and may cause losses of exchange capacity and excessive head losses through the softener. If turbidity levels are excessive, the particles must be removed from the water prior to softening or special backwashing procedures must be implemented.

(b) Bacterial slimes. Unless proper disinfection is practiced, bacterial slimes can form in the softening medium and cause excessive head losses and loss of exchange capacity. These slimes can be prevented or removed through chlorination of' feedwater or regeneration water.

(c) *Temperature.* The loss of head through a water softener is strongly affected by water temperature, with lower head losses occurring at higher temperatures. For example, at similar flow rates the head loss through a softener at 1220 F. is only about 35 percent of what it would be at 32° F. Also, the water temperature affects the exchange capacity of the softener, with a 10 to 15 percent increase at high operating temperatures (>860 F.) over the exchange capacity at low temperatures (32 to 50° F.)

(d) Iron, manganese and aluminum. 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 aluminum from the water prior to softening. If iron fouling occurs it may be possible to overcome it by periodic applications of sodium bisulfite, sodium hydrosulfite, hydrochloric acid, or sulfuric acid to the softening media. However, these treatments should be implemented only after a thorough study of the problem by someone experienced in this area.

(e) Total hardness and sodium concentration. If the total hardness exceeds 400 mg/L or the sodium salts, expressed as mg/L $CaCO_3$, exceeds 100 mg/L, the softener should be sized on the basis of the "compensated total hardness" rather than the total hardness. Compensated hardness is calculated as follows:

$$TH_c = \frac{(TH)(9000)}{9000 - TC}$$

where

TH_c = compensated hardness in mg/L as $CaC0_3$

TH = total hardness in mg/L as $CaC0_3$

TC = total cations in mg/L, all expressed as $CaC0_3$

Compensated hardness (TH_c) in mg/L is converted to grains per gallon by multiplying by 0.0584 or dividing by 17.1.

(6) Removal of noncarbonated hardness following lime softening. In some cases, it is more economical to remove noncarbonated hardness in cation exchanges than by application of soda ash. This method involves the use of lime for reduction of carbonate hardness. Following recarbonation, the water is filtered. Then all or part of the water, depending on the final hardness desired, is treated in cation exchange softeners for the removal of noncarbonated hardness. The technique is most suitable to those areas where regeneration salt can be obtained at a low cost.

(7) Comparison on lime-soda ash and cation exchange processes. Although the purpose of both the lime-soda ash process and the cation exchange process is to achieve removal of calcium and magnesium ions, the modes of operation and the quality of the resultant water are somewhat different.

(a) Turbidity, iron, and manganese. Lime-soda softening also effects removal of turbidity and iron and manganese, whereas cation exchange softening may have to be preceded by conventional treatment for removal of suspended matter and iron and manganese.

(b) Bacteria. The lime-soda ash process will also result in the removal or destruction of most bacteria in the water. In contrast, the water entering a cation exchange softener must be disinfected in order to prevent the growth of bacterial slimes within the softening resin.

(c) *Total dissolved solids.* Total dissolved solids concentrations of water are usually lowered by lime-soda ash softening, especially if most of the hardness initially present is carbonate hardness. However, application of soda ash to remove noncarbonated hardness results in a slight increase of TDS concentrations. Softening of water by cation exchange processes always results in an increase in TDS levels, because the sodium required to replace calcium and magnesium in the water has a mass 1.15 times as large as the calcium replaced and 1.89 times as large as the magnesium replaced.

2-11. Iron and manganese control.

a. Occurrence of iron and manganese. Dissolved iron and manganese are encountered principally in ground waters devoid of dissolved oxygen, Normal, oxygenated surface waters do not contain significant concentrations of these metals; however, stagnant water, found in the bottom of thermally-stratified reservoirs, sometimes contain dissolved iron and manganese. Their presence in solution is associated with anaerobic conditions near the bottom of the reservoir.

b. Effects of iron and manganese. Dissolved iron in excess of 1 or 2 mg/L will cause an unpleasant taste, and on standing, the water will develop a cloudy appearance. Iron concentrations appreciably greater than 0.3 mg/L will cause red stains on plumbing fixtures and laundry. Similarly, manganese will cause black stains if present to the extent of more than about 0.05 mg/L. Deposits of iron and manganese can build up in water distribution systems and periodic "flushouts" of these deposits result in objectionable color and turbidity at the consumer's tap.

c. Removal by oxidation and filtration. Oxidation can be accomplished with dissolved oxygen, added by aeration, and by the addition of an oxidizing chemical, such as chlorine, chlorine dioxide, potassium permanganate, or ozone. Manganese is more difficult than iron to oxidize and precipitate. In the absence of manganese, iron can often be removed with minimum treatment, consisting of aeration followed by direct filtration. In general, aeration alone will not oxidize manganese unless the pH is raised to about **9,5.** Strong oxidants, such as chlorine or potassium permanganate, are effective at lower pH values. To insure oxidation, precipitation and agglomeration of iron and manganese and their essentially complete removal, at least three treatment steps are usually necessary: aeration, contact time, and filtration. An aerator containing trays of coke, limestone, etc., as mentioned in paragraph 2-3c is commonly used. Reaction time is provided by a contact or contact-sedimentation basin having a detention period of at least 30 minutes. Filtration is accomplished by conventional single or multimedia filters designed for a filtration rate of at least 3.0 gpm per square foot. The aeration step is frequently supplemented by a chemical oxidant, such as chlorine or permanganate. Flocculation is advantageous in the contact basin, particularly if iron exceeds about 2 mg/L.

d. Removal by ion exchange. The cation exchange (sodium zeolite) softening process, under proper conditions, is capable of removing limited amounts of dissolved (unoxidized) iron and manganese. For application of this process, it is essential that the raw water and wash water contain no dissolved oxygen and that the sum of the iron and manganese concentrations not exceed about 0.5 mg/L. The presence of oxygen or higher concentrations of iron and manganese will cause rapid fouling of the exchange resin with consequent loss of removal capacity. If fouling occurs, treatment of the resin with sodium bisulfite solution and dilute hydrochloric or sulfuric acid will be required to restore capacity.

e. *Removal by lime-soda softening.* Lime-soda softening is an effective means of removing both iron and manganese.

f. Stabilization of iron and manganese. Under some circumstances, stabilization of iron and manganese by application of a polyphosphate compound may be acceptable. The iron and manganese in the water are maintained in a dispersed state through the completing action of a polyphosphate compound. Dosages of about **5** mg/L of sodium hexametaphosphate for each mg/L of iron and manganese are reasonably effective however, the total polyphosphate dosage should not exceed 10 mg/L, expressed as PO_4^{3-}. The polyphosphate stabilizing compound *must be* added to the water prior to chlorination. If the chlorine is applied first, it will oxidize the iron and manganese to insoluble forms rendering the stabilizing agent ineffective. Stabilization of concentrations of iron and manganese in excess of approximately 1.0 mg/L is generally not satisfactory. Also, stabilization will not persist if the water is heated because heating coverts 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.

2-12. 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. In water treatment, corrosion and scale are closely associated. Both must be considered in connection with the design and operation of treatment works. This 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.

a. Corrosion.

(1) The extent and nature of corrosion reactions depend upon many factors. Among the most important are the chemical and physical nature of the water, its velocity, pipe metallurgy 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 in an existing system. 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.

(2) 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. 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.

(3) Corrosion rates may also be reduced by the use of certain inhibitors. For potable water systems, the most practical inhibitors are silicates and certain polyphosphate compounds. Sodium silicate can be used to a limited extent in very soft water. Polyphosphates can be 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 all corrosion control methods.

(4) Dissolved oxygen and carbon dioxide have a significant effect on corrosion rates. Carbon dioxide lowers the pH and makes the water more aggressive. 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 while 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.

(5) Corrosion rates are influenced to some extent by all mineral substances found in water, but corrosion effects are so interrelated that it is not possible to isolate the quantitative influence of individual ions. It is known that high concentrations of chloride and sulfate ions will produce increased corrosion rates. However, their adverse effects are somewhat mitigated by alkalinity (carbonate, bicarbonate) and calcium ions. To obtain appreciable benefit from alkalinity and calcium, the total alkalinity, expressed as calcium carbonate, should be at least 50 mg/L, preferable 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.

(6) Based on the corrosion accelerating effects of chloride and sulfate and the corrosion inhibiting effects of alkalinity, the following ration, termed the "Corrosion Index," has been developed.

$$\text{Corrosion Index} = \frac{[.01639]\,[HCO^{3-}]}{[.02821]\,[Cl^{-}] + [.02083]\,[SO_4^{2-}]}$$

$[HCO^{3-}]$ = mg/L bicarbonate ion as HCO^{3-}

$[SO_4^{2-}]$ = mg/L sulfate ion SO_4^{2-}

$[Cl^{-}]$ = mg/L chloride ion as Cl^{-}

The higher the index, the greater the probability of corrosion. For a pH range of about 7 to 8, and in the presence of dissolved oxygen, an index below about 0.1 indicated probable general freedom from corrosion. An index higher than 0.1 is indicative of corrosion tendencies.

b. 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.

(1) Aluminum. Aluminum hydroxide deposits can result from excessive alum use for coagulation and/or improper coagulation practice, such as poor mixing and flocculation and incorrect coagulation pH. Aluminum hydroxide can create a soft, white deposit having a rippled surface which will produce 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 insolubility.

(2) Magnesium. Magnesium hydroxide deposits have caused serious difficulties in distribution systems and hot water heaters. Magnesium volubility is highly sensitive to pH and temperature and failure to exercise careful control over its stabilization following softening will usually lead to deposition problems. 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 pH below 9.8. Hot water heaters should be operated so that water temperatures will not exceed 140° F.

(3) Iron and manganese. 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. 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.

c. Chemical Control of corrosion.

(1) Calcium carbonate saturation,

(a) One means of chemical control that has been reasonably successful is treatment of the water to ensure deposition and maintenance of a coating of calcium carbonate. Prediction of the tendency of a water to precipitate or dissolve a protective coating of calcium carbonate can be based on computation of what is termed the "Langlier Index" (LI). This index is calculated as follows:

$$LI = pH - pH_s \qquad \text{(eq 2-1)}$$

where:

LI = Langlier 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 LI will be positive, indicative of a calcium carbonate deposition tendency. If pH_s is greater than the actual pH, the LI will be negative and this indicates under saturation or a tendency toward dissolving calcium carbonate, and corrosivity. An LI value of O indicates exact saturation with calcium carbonate and no tendency toward deposition or solution.

(b) The complete equation for the exact calculation of pH_s is quite complex and a simplified form, covering the pH range 6.5 to 9.5, may be used. The simplified equation is as follows:

$$pH_s = A + B - \log(Ca^{2+}) - \log(\text{alkalinity})^{*} \qquad \text{(eq 2-2)}$$

where:

pH_s = pH of calcium carbonate saturation

A = constant which is a function of water temperature

B = constant which is a' function of total dissolved solids concentration (TDS, mg/L)

$\log(Ca^{2+})$ = logarithm to the base 10 of the Ca^{2+} concentration in mg/L

log (Alkalinity) = logarithm to the base 10 of the total alkalinity expressed as $CaCo_3$, in mg/L.

Values of Ca^{2+} and Alkalinity are obtained from analytical data.

The values of A and B are obtained from the tables 2-4 and 2-5.

Table 2-4 Constant A as a Function of Water Temperature

Water Temperature °F	*A*
32	*2,60*
39	*2,50*
46	*2.40*
54	*2.30*
61	*2.20*
68	*2,10*

Table 2-5 Constant B as a Function of Total Dissolved Solids

TDS mg/L	*B*
0	*9.70*
100	9.77
200	9.83
400	9.86
800	9.89
1,000	9.90

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(c) Examples of the calculation procedure to be followed in determining the LI are as follows:

Water No. 1

Temperature, °F.	65
pH	8.6
Alkalinity, mg/L as $CaCO_3$	80
Calcium (Ca^{2+}), mg/L	72
TDS, mg/L	340

LI = pH − pH_s

$pH_s = A + B - \log(Ca^{2+}) - \log(\text{alkalinity})$

$pH_s = 2.10 + 9.86 - 1.86 - 1.90 = 8.20$

$LI = 8.6 - 8.2 = +0.3$

Water No. 2

Temperature, °F.	76
pH	7.5
Alkalinity, mg/L as $CaCO_3$	20
Calcium (Ca^{2+}), mg/L	32
TDS, mg/L	490

LI = pH − pH_s

$pH_s = 2.00 + 9.87 - 1.51 - 1.30 = 9.07$

$LI = 7.5 - 9.1 = -1.6$

(d) The LI 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 LI are consistently maintained. The 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, maintain an LI 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.

(e) The maintenance of a positive Langlier 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." Pitting corrosion results in loss of metal from relatively small areas of the pipe rather than informly over the entire surface. As a consequence, the pipe may fail fairly quickly because of corrosion penetration of the pipe wall.

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2-13. Special Processes.

In some cases it will be necessary to use raw water supplies containing unacceptably large concentrations of constituents that cannot be removed by conventional treatment processes. The most common of these objectionable constituents are mineral salts, such as sulfates and chlorides, and volatile organic compounds, (VOCs). Special treatment processes are necessary to remove these materials,

a. Demineralization. The presence of excessively high concentrations of dissolved minerals in water is indicated by high chloride (Cl-), sulfate ($S04^{2-}$), and total dissolved solids (TDS) levels. The recommended limits for these substances are 250 mg/L, 250 mg/L, and 500 mg/L, respectively. These limits are based on esthetic considerations and considerably higher concentrations, while not desirable, can be tolerated. Where demineralization is required, processes commonly employed are electrodialysis, reverse osmosis, distillation, and ion exchange. Disposal of waste brine solutions derived from these processes often poses a serious problem and must be carefully considered at an early stage in project development. All demineralization processes are energy intensive, and alternative water sources should be thoroughly investigated before a commitment to a demineralization project is made. If the demineralization process selected requires large inputs of electricity, consideration should be given to its operation principally during "off-peak" hours with storage of desalted water until needed,

b. Removal of Volatile Organic Compounds. VOCs can be either halgonated naturally occurring organic substances (trihalomethanes), or synthetic organic compounds (SOCs).

(1) Trihalomethanes. Naturally occurring organic substances (precursors), such as humic and fulvic acids are derived from leaf and soil extract and are not themselves volatile. When the precursors (usually found in surface waters) enter the treatment facility in the raw water they react with the free available chlorine injected for purposes of disinfection. These halgonated organic compounds are known as trihalomethanes (THMs). Other THMs can be produced by exposing precursors to other halogens, such as bromine or iodine. This grouping of total trihalomethanes (TTHMs) is generally comprised of four primary constituents: trichloromethane (chloroform), bromodichlormethane, chlorodibromomethane, and tribromomethane (bromoform), Monitoring and analytical requirements imposed by the EPA for THMs are to be found in Title 40 CFR 141 Subpart C, sections 141.12 (c), 141.30 and Appendix C. These sections of Title 40 include MCL's, monitoring frequencies and the approved method for measuring TTHM's. THMs are difficult to remove, hence the need for special processes to assist in their removal. Three basic approaches to control THMs are:

(a) Use of a disinfectant that does not generate THMs in water. (Ozone, chlorine dioxide)

(b) Treatment to reduce the concentrations of precursor material prior to chlorination (coagulation, flocculation, filtration),

(c) Treatment to reduce THM concentrations subsequent to their formation (aeration, carbon adsorption).

These three methods have been presented throughout this technical manual.

(2) Synthetic Organic Compounds (SOCs), are VOCs some of which have been found in many groundwater sources used for potable water supplies. SOCs are found in groundwater due to improper disposal of spent industrial-type solvents, paint thinners, cleaning agents and some household chemicals, Two common SOCs are trichloroethylene (TCE) and tetrachlorethylene. Some VOCs are rather soluable and have little affinity for soil materials, and therefore can travel great distances to an aquifier from an industrial waste lagoon, industrial, commercial on domestic septic system, landfill, accidental spill or illegal disposal.

(3) Removal Technologies for VOCs. Three different technologies are available for the removal of VOCs: aeration, carbon adsorption, or resin absorption. All of these methods have been presented in previous sections of this technical manual, with the exception of resin absorption. Resin absorption involves the physical separation of the organic compounds from water by using a polymeric absorbent or resin filled unit. The resin is specific to the VOC it will remove, therefore great care must be taken in the selection of the resin. The resin-filled units also require frequent regeneration with a low pressure backwash and an alcohol-wash. The waste from the backwash will contain high concentrations of VOCs and may be classified as hazardous waste.

(4) Selection of a removal technology. Important parameters for removing VOCs are the concentrations concerned, the type of VOC, and the cost of the removal method.

(a) The higher the concentration of VOCs the more expensive removal will become, Higher concentrations of VOCs will normally require larger equipment, e.g. counter-current packed column aeration towers must increase in either volume or blower and pump horse power for increased removal of VOCs, Low TTHM concentrations may be handled by simply changing the point of chlorination and allowing coagulation and flocculation to remove THM precursors. High TTHM concentrations may require the addition of an aeration tower or a GAC contactor and at the extreme an alternate disinfectant such as ozone.

(b) The type of VOC to be removed may dictate

the method of removal. Most VOCs can be reduced to meet Federal maximum contaminant levels through airstripping by an aeration tower. However, some VOCs, such as bromoform cannot be easily removed through airstripping and a more expensive method of removal such as carbon adsorption must be used.

(c) Airstripping through counter-current packed column aeration towers appear to be a cost-effective method for reducing VOCs. Preliminary analyses suggests that it may be more economical than GAC or resin absorption treatment. Predicted capital costs and overhead and maintenance expenditures for aeration towers are less than other treatment technologies. However, pilot testing must be performed to prove the feasibility of any solution to the removal of VOCs. Pilot testing will allow enhancement of a selected method, once that method has been proven feasible, allowing a maximum removal of VOCs for a minimum of cost.

c. Industrial water treatment.

(1) Water quantity and quality requirements for industrial uses can vary greatly from industry to industry, and even from plant to plant within the same industry. Also, quality requirements within a large industrial plant can vary depending on the purpose for which the water is to be used (e.g., process needs, cooling, sanitary requirements, boiler makeup). Consequently, the first step in designing a water treatment plant for an industrial facility is to define the water quantity and quality requirements.

(2) The water system serving an industrial facility will be sized to supply the maximum anticipated quantity of water required during a single day of operation. If hourly water usage rates exceed the average rate for the day of maximum use, storage tanks will be necessary to equalize the rate of flow of water through the treatment plant (see TM 5-813-4/AFM 88-10, Chap. 4).

(3) After the water quality requirements have been determined, treatment works will be designed using the appropriate treatment processes to meet these quality requirements. Most water quality requirements can be met through the use of treatment processes previously described. Approval for the use of treatment processes not described in this manual must be obtained from HQDA (DAEN-ECE-G), WASH DC, 20314 or HQ USAF/LEEEU, Washington, D.C. 20332.

CHAPTER 3

WATER TREATMENTSYSTEMS

3-1. General design criteria.

a. Water treatment plants. Water treatment plants at military installations must produce high quality water sufficient in quantity for all intended purposes. If 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 would make it esthetically unsatisfactory to the consumers. The overall water quality objective can be met if the water delivered to service meets the drinking water standards given in appendix A.

b. Water storage and distribution. The quality of water obtained at the user's tap is not determined solely by water treatment operations. Raw water quality and conditions in treated water storage and water distribution systems also affect the quality of the water. 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.

3-2. Plant siting.

The following items will be considered in choosing a plant site,

a. Proximity to the source of raw water.

b. Proximity to the area to be served.

c. Potential for flooding of the site.

d. Availability and reliability of electric power.

e. Geology and topography of the site.

f. Availability of transportation facilities.

g. Size of the site, both for original and for anticipated expansions.

h. Legal obligations or restrictions.

i. Environmental effects.

3-3. process selection and design.

a. The selection and design of the water treatment processes to be used at a particular facility are dictated by practicability, reliability, flexibility, and overall economics. Engineers experienced in water treatment plant design are needed to determine the best treatment system for any particular situation, and their advice should be obtained in early stages of project planning. Detailed information about major treatment processes is given in chapter 2,

b. State agencies have established design guidelines based on local conditions and experiences. Information regarding these guidelines is available from the division of engineering within the state agency responsible for environmental protection. Consultation with State engineers will provide valuable information relative to plant design and water treatment experience in the State or region. It is also advisable to confer with management and operating personnel of nearby water supply utilities.

3-4. Reliability.

a. 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 items, such as pumps, settling basins, flocculators, filters, and chemical feeders must be provided. The degree of importance of each item must be evaluated on a case-by-case basis, considering that safe water has to be supplied at all times.

b. If there is a definite possibility that lengthy power outages will occur, installation of emergency generating facilities at the water treatment plant should be contemplated. Likewise, if the delivery of crucial chemical supplies is uncertain, larger than normal stores of these chemicals must be kept on hand, which would necessitate larger than normal chemical storage areas.

3-5. Operating considerations.

To simplify plant operations, the following guidelines should be observed during the design stage.

a. Unnecessary equipment and operations should be eliminated.

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

c. Chemical handling and feeding should also 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 chemicals.

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

3-6. Plant capacity.

The water treatment plant will be sized to treat enough water to meet the requirements given in TM 5-813-1/AFM 88-10, Vol. 1. Care should be taken not to underestimate special water demands.

CHAPTER 4

MEASUREMENT AND CONTROL

4-1. Measurement of process variables.

In order to determine the degree of effectiveness of the different treatment processes, several physical and chemical parameters associated with water treatment must be measured. After they are measured, the information must be evaluated so that necessary adjustments can be made in the treatment processes.

a. Minimum analyses. The minimum type, number, and frequency of analyses for military water treatment plants will conform to paragraph C-1 of appendix C.

b. Laboratories. Laboratories at military water treatment plants must have the minimum amounts of laboratory furniture, laboratory equipment, and laboratory chemicals prescribed in paragraphs C-2, C-3, and C-4 of appendix C.

c. Records *of analyses.* Results of laboratory analyses will be recorded and maintained in an orderly filing arrangement.

4-2. Control.

Water treatment plant processes may be controlled by manual, semiautomatic or automatic methods, which are defined as follows.

a. *Manual control.* 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.

b. Semiautomatic control. Semiautomatic control utilizes instruments to automatically control a function or series of functions within control points that are set manually. The operator manually starts the automatic sequence of operations. An example of semiautomatic control is the automatic backwashing of a filter after operator initiation of the program,

c. Automatic control. 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. Automatic control systems have been developed which are reliable, but provision for emergency manual control must be included.

4-3. Design of instruments and controls.

All instruments and control devices should be placed in readily accessible locations in order to facilitate observation, maintenance, repair, and replacement. Instruments should not be located in environments which might lead to premature failure of the instruments. Examples of such environments are areas subject to high temperatures or corrosive vapors. Provisions should be made for many of the instruments to actuate alarms if critical process variables exceed or fall below predetermined tolerable levels. Such alarms should include both audio and visual signals.

CHAPTER 5

WATER TREATMENT CHEMICALS

5-1. Chemical properties.

Chemicals are used for a variety of purposes in conventional water treatment practice, 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 table 5-1.

5-2. Chemical standards.

Chemicals used at military water treatment plants will meet the applicable standards of the AWWA. The AWWA publication number for these standards are:

	B-701	
Softening	B-604	Sodium aluminate
Category	B-603	Sodium silicate (activated silica)
	B-602	Aluminum sulfate
	B-601	Ferrous sulfate
	B-600	Sodium chlorite
	B-503	Ammonium sulfate
	B-502	Chlorine
Disinfection	B-501	chlorites)
	B-407	Calcium hypochlorite (hyp-
	B-406	Calcium oxide (quicklime)
	B-405	lime)
	B-404	Calcium hydroxide (hydrated
Coagulants	B-403	Sodium carbonate (soda ash)
	B-402	Sodium chloride (salt)
	B-303	Chemical Name
	B-302	Sodium fluoride
	B-301	Granular activated carbon
Corrosion		Potassium permanganate
	B-300	Copper sulfate
	B-202	Sodium metabisulfite
Control		Powdered activated carbon
Taste and Odor	B-202	Sodium tripolyphosphate
	B-201	Sodium hexametaphosphate
	B-200	Caustic soda
	Standard	Liquid ferric chloride
Prophylaxis	AWWA	Ferric sulfate
	B-703	Fluosilicic acid
	B-702	Sodium silicofluoride

5-3. Chemical handling and storage.

In the design of water treatment facilities, the selection of methods of chemical handling and storage must be based primarily on 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 required for chemical 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 powders can be unloaded by pneumatic unloading and conveyance devices, or if the powder is to be mixed or dissolved in water, it can be unloaded directly into a water eductor in which the powdered chemical and the water are mixed as the water is flowing to the storage tank, Chemical crystals or granules are usually unloaded by mechanical devices, such as bucket elevators and conveyor belts. 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, Hazardous chemicals must be stored in separate rooms to avoid reaction of chemical vapors. The supply of chemicals in storage at a water treatment plant should always be at least equal to the projected 30-day requirements. Under some circumstances, it may be desirable to maintain larger supplies of essential chemicals, such as chlorine or coagulant, and smaller supplies of nonessential chemicals, such as fluoridation agents.

5-4. Chemical application.

a. Dry chemicals. Dry chemicals are usually converted to a solution or slurry prior to application to the water. Measurement of the chemical application rate is accomplished by the dry-feed machine. The measured quantity of chemical is then dissolved or slurried in a small amount of water for transport to the feed point, where the solution or slurry must be rapidly and thoroughly mixed with water being treated. Before quicklime can be applied to water, it must be hydrated in a slaker. Either retention-type or paste-type slakers may be used at military water treatment plants. If a retention-type slaker is used, a temperature of 160° F or greater will be maintained in the slaker. All slakers must be equipped with grit removal mechanisms.

b. Liquid chemicals. Chemical solutions or slurries are applied directly, or after dilution, to the water being treated by volumetric liquid feeders such as metering pumps or rotating wheel feeders. Rapid, thorough mixing of the chemical solution or slurry with the water is essential,

Table 5-1. 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 (dry) Aluminum sulfate	Alum, filter alum, Liquid alum	100-200 lb. bags, 300- Tank trucks or	Dry-iron, steel. Lead or rubber-lined	Ivory-colored: Off-white	(11.047 lbs/gal)	4.2 at 60°F -	15-22% Al_2O_3 5.36 lbs	pH of 1% solution is 3.4 pH of 1% solution is 3.4
$Al_2(SO_4)_3 \cdot 14.3H_2O$	sulfate of alumina	400 lb. barrels, bulk	Solution - lead-lined steel, plastic	Powder liquid	38-45		dry alum per gallon	
Sodium aluminate	Soda alum	100-150 lb. bags; (carloads).	Iron, plastics, rubber, silicon, asphalt, 316 stainless steel	Brown powder. Granule Lump	50-60 60-63 62-67	Highly soluble	70-80% $Na_2Al_2O_4$	
$Na_2Al_2O_3$		250-440 lb. drums;	rubber, steel	liquid			32% $Na_2Al_3O_4$	for dry feed
Ferrous sulfate	Copperas, green	Bags, barrels, solution.	Asphalt, concrete,	Green crystal	63-66	0.5 at 32°F	55% $FeSO_4$ minimum	Hygroscopic; cakes in
$FeCl_3$ (37-47% solution)	chloride of iron	trucks, tank cars	glass, stoneware, synthetic resins	liquid		- 1.4 at 86°F	13-16% Fe	very corrosive 8.5-11.0
Ferric sulfate $Fe_2(SO_4)_3 \cdot 9H_2O$	Ferrifloc, Ferrisul	50-175 lb. bags, 200-425 lb. drums	Ceramics, lead, plastic, rubber, 18-8 stainless steel	Red-brown powder or granules	56-72	Soluble in 2-4 parts water	68% Fe_2SO_4 20% Fe	Mildly hygroscopic. Coagulant at pH 3.5-11.0
Na_2SiO_2		trucks, tank cars)	steel	liquid				SiO_2. pH of 1% solution is 12.3
Chlorine	Chlorine gas, liquid	30-55-85 and 90 ton 100-150 lb. cylinders,	Wet gas - glass, Dry - black iron,	Liquefied gas under	91.7	0.083 at 50°F	99.8% Cl_2	corrosive Toxic gas. Solutions in
		tank cars, tank trucks (about 15-16 tons)	hard rubber, silver, earthenware					
Calcium hypochlorite	"HTH", "Perchloron"	5 lb. cans, 100-300-	Glass, rubber,	White powder	48	Approx. one	70% "available"	
4 H_2O								
				Dense	90			
Sodium fluoride	Fluoride	Bags, barrels, fiber	Iron, lead, steel	Nile blue or white		0.35 at most	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	Sodium silico- fluoride	Bags, barrels, fiber drums	Iron, lead, steel	White powder: Regular Fluffy Nile blue or yellowish-	85 65	0.12 at 140°F 0.03 at 32°F	99% Na_2SiF_6	pH of 1% solution is 5.3

Table 5-1. Principal chemicals used in water treatment—Continued.

Activated carbon (powdered)	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
Chemical Name and Formula	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 $CuSO_4 \cdot 5\ H_2O$	Soda ash	Bags, barrels, bulk (trucks, carloads)	Iron, rubber, steel	White powder	25-35	0.01 at 70°F	63% $CuSO_4$	pH of 1% solution is 4.7
Calcium hydroxide $Ca(OH)_2$	Quicklime, burnt lime, chemical lime, unslak~~ed lime~~	80 lb. bags; 100 lb. barrels, bulk (car~~loads or trucks)~~	Asphalt, cement, iron, rubber, steel	Crystal Lump Powder	75-90 73-80 60-64	1.6 at 32°F 2.2 at 68°F 2.6 at 86°F	85-98% as $Ca(OH)_2$ 63-73% CaO	Hopper agitation required for dry feed of light form
Calcium oxide CaO	Hydrated lime, slaked lime	50 lb. bags, 100 lb. barrels, bulk (car~~loads or trucks).~~	Asphalt, cement, iron, rubber, steel	Lump, pebble, granule	55-60	Slakes to form hydrated lime	75-99% CaO	~~Hopper agitation required for~~ pH of saturated solution is 12.4
Sodium carbonate Na_2CO_3	Blue vitriol, blue stone	100 lb. bags, 450 lb. barrels, drums	Asphalt, silicon, iron, stainless steel, ~~plastics~~	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	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, tank cars	Cast iron, rubber, ste	Liquid	(12.76 lbs/gal) 50%	-	50% NaOH	50% solution freezes at 60°F pH of 1% solution is 12.9
Carbon dioxide	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 CO_2	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 hexameta-phosphate NaCl	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

c. Chlorine application. At military water treatment plants, chlorine will be fed through solution-type vacuum feeders. If the concentrated solution from the feeders is introduced to the water supply in an open channel, the point of discharge of the chlorine solution must beat least 2 feet below the surface.

d. Corrosion. Special attention should be directed to the materials used for the critical parts of chemical feeders. Many chemicals form corrosive environments for common metals.

CHAPTER 6

WATER TREATMENT PLANT WASTES

6-1. Quantities and characteristics of wastes.

In connection with water treatment plant location and design, the disposal of the wastes generated during the various treatment processes must receive careful consideration. Among these wastes are sludge from presedimentation basins, coagulation and/or softening sludge, filter wash water, spent regenerant and rinse water from ion-exchange softeners, diatomite filter sludge, and mineral wastes from desalination facilities.

a. Presedimentation sludge. Presedimentation basin sludges reflect the nature of the solids present in the raw water. If the particles in the raw water settle out readily, the sludge will be of fairly high solids content. Slowly settling particles will produce a thin sludge of low solids content.

b. Coagulation sludge. The settled residues resulting from coagulation with alum range in suspended solids content from about 1,000 mg/L (0.1%) to about 17,000 mg/L (1.70/0). The bulk density of dry alum sludge is usually between 75 and 99 pounds per cubic foot. In order for alum sludge to be placed in a landfill, it must have a solids content of about 20 percent or more. Waste sludges produced by coagulation with iron salts are similar to those produced with aluminum salts.

c. *Lime softening sludge.* Softening sludges can vary widely in characteristics depending on the relative amounts of calcium carbonate and magnesium hydroxide in the sludge, the nature and amount of suspended particles present in the raw water, and whether or not a coagulant, such as alum, was used. The solids content of softening sludges may vary from 2 to 33 percent, and the total sludge volume may range in volume from 0.3 to 6 percent 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. Diatomite sludge. About 300 to 600 pounds of diatomite sludge are produced per million gallons of water treated. Approximately two-thirds of the sludge is the diatomaceous earth used for filtration and one-third is the impurities removed from the water. The dry bulk density of the sludge is about 10 pounds per cubic foot.

e. Filter wash water. A variety of suspended sub stances may be present in filter wash water, including clay, hydroxides of iron and aluminum, calcium carbonate, activated carbon, etc. The characteristics of filter wash water at plants using alum for coagulation will differ considerably from those of wash water derived from plants practicing softening or iron and manganese removal. Filter wash waters invariably are quite diluted, exhibiting average suspended solids concentrations of less than 200 mg/L (0.020/0).

f. Regeneration brines for ion-exchange softeners. The principal waste products in the waste brines from ion-exchange regeneration are chlorides of calcium, magnesium, and sodium. In addition, small quantities of iron, manganese, and aluminum maybe present. Total dissolved solids (TDS) concentrations in these waste flows 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%). The total wastewater flow will be between 2 to 8 percent of the amount of water softened.

g. Desalination waste brines. The waste products most often found in desalination waste brines are chloride and sulfate salts of calcium, magnesium and sodium. TDS concentrations in the waste brines may range from 2,000 (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 one percent or as much as 50 percent of the raw water processed, with an average of 15 to 20 percent. Inasmuch as suspended particles are detrimental to most desalination processes, raw waters intended for desalination are usually treated for turbidity, iron removal, etc., prior to desalination.

6-2. Waste management.

a. Water treatment sludges.

(1) Presedimentation sludge. Presedimentation sludge may be disposed of by returning it to the stream from which the raw water was taken, if the appropriate regulatory agencies will grant their approval. Otherwise, the sludge should first be dewatered in lagoons or sludge drying beds and then hauled to landfills or spread on land.

(2) Coagulation sludge,

(a) Lagoons. If land is available near the treatment plant, alum sludge can be placed in lagoons to effect further concentration of solids. Depending on the local climate and the properties of the sludge, the final solids content in the lagoon may be as low as one percent or as high as 17.5 percent. A liner of impervious material may be required within the lagoon by state authorities if ground water contamination is a concern. Water should be removed from the lagoon by recantation. The decanted water may be returned to natural watercourses if state authorities permit, and is sometimes returned to the treatment plant for recycling. At least two lagoons must be provided so that fresh alum sludge can be placed in one while the alum sludge in the other is allowed to concentrate. After sufficient drying, the sludge should be removed from the lagoon and placed in a landfill or spread on suitable ground. The minimum solids content which should be attained before alum sludge can be removed from lagoons is generally about 10 percent. In colder climates, the freeze-thaw cycles to which the liquid in the lagoon is subjected will aid materially in concentrating the solids. Sludge lagoons should be enclosed by fencing adequate to exclude children and animals.

(b) Discharge to sanitary sewers. Alum sludges may also be discharged to sanitary sewers if disruption of wastewater treatment processed is not anticipated. If this procedure is chosen, precautions must be taken to insure that the sludge does not create a hydraulic overload in the sewers or form significant deposits in the sanitary sewer. Inasmuch as a large portion of alum sludge is not biodegradable, the addition of alum sludge to wastewater will increase the sludge production at the wastewater treatment plant. Disposal of alum sludge to storm sewers is equivalent to disposal in natural water courses and should not be attempted.

(c) Sludge beds. Another method of dewatering is application of the sludge to special sludge beds. These beds are usually composed of 6 to 12 inches of sand ranging in size up to 0.5 mm, with an underdrain system of graded gravel 6 to 12 inches deep. Drain pipes 6 to 8 inches in diameter are placed in the gravel to carry away the water from the beds. Sand beds can usually achieve a 20 percent solids concentration in alum sludge within 100 hours at a loading rate of 0.8 pounds per square foot. However, the results are highly dependent on the characteristics of the sludge and local climatic conditions. Warm, dry climates are best suited to the use of sand drying beds. The water passing into the drain pipes should be suitable for disposal into natural watercourses, The dewatered sludge is usually removed from the sand bed by mechanical means, but a minimum solids content of approximately 20 percent must be attained before mechanical handling is practical. After removal, the dewatered sludge is usually hauled to a landfill.

(d) Mechanical dewatering devices. Several mechanical devices have been used for dewatering of alum sludge, including pressure filters, centrifuges, freeze-thaw devices, vacuum filters, 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. In order to enchance the performance of some dewatering devices, the sludge can be "conditioned" prior to dewatering. Among the methods of conditioning which have been used are: application of heat and pressure, freezing, lime treatment, and application of organic polymers.

(e) Alum recovery. Recovery of alum from alum sludge is possible by treatment of the sludge with sulfuric acid followed by sedimentation or filtration to remove raw water sediment. Recovered alum can be recycled, so long as inert material, iron and manganese, toxic metals, and color, do not become unacceptably concentrated in the recycled alum solutions. Of these materials, iron and manganese usually pose the greatest problem.

(3) Lime-soda softening sludge. In most cases, lime-soda softening sludge will be managed by lagooning. In order to use this method, large areas of land must be available within a reasonable distance from the treatment plant. Lagoon capacity should be at least 3.5 acre-feet per million gallons daily per 100 mg/L of hardness removed. Sized on this basis, the storage capacity will be sufficient for 2-1/2 to 3 years, after which the accumulated sludge must be removed for disposal on farm land or in a landfill. If the sludge must settle through ponded water, a solids concentration of 20 to 40 percent can be anticipated. If the ponded water is regularly decanted, the solids content of the sludge will be about 50 percent. As in the case of alum sludge lagoons, softening sludge lagoons should be constructed in groups of at least two or three to allow for alternate filling, drying, and removal of the dried sludge. Lagoon depths will vary from 3 to 10 feet. Lagoons will be fenced. The area dimensions of sludge lagoons should be such that the settled sludge can easily be removed by cranes or draglines. The sludge removed from lagoons can be placed in landfills" or used as soil conditioner, although in some cases the applied sludge has plugged the upper soil layer until broken down by winter freezing. The sludge maybe recalcined for lime recovery, usually after removal of most of the magnesium hydroxide by recarbonation and centrifuging. Other methods of dewatering softening sludge prior to recalcining or landfilling include vacuum filtration and centrifugation. Vacuum filters and centrifuges produce sludge cake having solids content of 50 to 60 percent. Lime-soda softening sludge will not be discharged to sanitary sewers, and drying beds are not recommended because of clogging difficulties and potential dust nuisance.

(4) Diatomite sludge. Diatomite sludge dewaters rather easily, so any of several techniques, particularly vacuum filtration and lagooning, may be used to in-

crease the solids content prior to placement in a landfill. Inasmuch as diatomite sludges are usually relatively innocuous, it may be possible to construct alagoon, use it until it is filled with sludge, and abandon it. This can be done only if land is readily available for lagoons. If land is not available, lagoons must be alternatively filled, dried, and cleaned of settled diatomite sludge, with the removed sludge taken to a landfill.

b. Filter wash water. Wash water volumes range from about one to three percent of the raw water processed. Disposal of filter wash water may be by discharge to natural receiving waters, by recovery and reuse of the wash water, by lagooning, or by discharge to a sanitary sewer,

(1) Discharge to natural receiving waters. This means of disposal may be practiced only with the approval of the appropriate State and Federal regulatory agencies.

(2) Recovery and reuse. Recovery and reuse are accomplished by mixing the filter wash water with the influent raw water 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 raw water inflow. Suspended solids in the wash water settle along with other solids in the plant basins and the only wastewater discharged from the plant is that associated with basin sludge removal. The recycling of filter wash water serves as a water conservation technique and may have economic advantages over other means of disposal. In some instances, the suspended particles in the filter wash water may not settle out easily, and recycling may, under some circumstances, cause abbreviated filter runs. Another potential drawback of wash water recycling, particularly if the raw water has a high plankton count, is a build-up of algae in the recycled suspended matter and consequent increase of taste and odor in the water.

(3) Lagooning. Lagooning is an accepted means of managing filter wash water flows. If a separate lagoon is used for the wash water, the supernatant from the lagoon may be recycled through the water treatment plant.

(4) Discharge to sanitary sewer. Filter wash water may also be discharged to a sanitary sewer. Rate of flow regulation generally will be required to avoid sewer surcharge. This mode of disposal is most applicable if the characteristics of the wash water make it unsuitable for recycling.

c. *Waste brines.* Two types of brine flows can be generated at water treatment plants, regeneration brines from cation-exchange softeners and waste brines from desalination processes. These brines are very similar as far as disposal techniques are concerned. Methods of brine disposal include regulated discharge to surface waters, deep well injection, “evaporation” pond disposal, and discharge to a sanitary sewer. If pond disposal is utilized, the ponds must be lined to prevent seepage of brine into the ground water, Depending on the location of the water treatment plant and the volume of brine generated, these methods may vary widely in cost, reliability, and environmental acceptability.

(1) Discharge to surface waters. Unregulated discharge to surface waters is usually unacceptable. An exception is that waste brines from a desalting plant near the ocean can probably be discharged to the ocean if precautions are taken in the design of the outfall to ensure that the brine is adequately diluted. On large rivers, it maybe possible to store wastes in watertight ponds during low-flow periods and release them at a controlled rate during high flows. This may be an acceptable procedure if it can be shown that the wastes do not significantly affect water quality when released during the high-flow period.

(2) Deep well injection. In order to determine the feasibility of using deep well injection for brine disposal, it must first be ascertained whether or not a suitable subsurface formation is present. Such a formation must be porous, of large extent, and completely sealed off from any potential fresh-water aquifiers. The wastes may require treatment prior to injection to avoid clogging the receiving formation. The costs of deep well injection are dependent chiefly on disposal volumes, treatment requirements, well depths, and injection pressures. All deep well injection projects must meet appropriate State and Federal regulations.

(3) Evaporation ponds. Evaporation ponds can be used for disposal of waste brines if evaporation rates are high, precipitation is minimal, and land costs are low. This method usually involves large capital expenditures because of the large surface areas required and also because of the pond linings required to retard seepage. In most localities, precautions must be taken to insure that brine ponds do not overflow or leak into the ground water. Watertight ponds are required for most situations.

(4) Discharge to a sanitary sewer. Disposal by regulated discharge to a sanitary sewer may be practiced if wastewater treatment plant operating personnel and regulatory authorities approve. Conventional wastewater treatment processes do nothing to remove dissolved minerals from water. Hence, all of the dissolved salts discharged to the sanitary sewer will eventually be present in the effluent from the wastewater treatment plant.

APPENDIX A

WATER QUALITY CRITERIA AND STANDARDS

A-1. General.

In order to evaluate the suitability of water for public supply purposes, it is necessary to have numerical quality guidelines by which the water maybe judged. Drinking water standards are of primary concern but it is also valuable to have criteria for assessing the suitability of a source of raw water for providing water of drinking water quality after receiving conventional treatment. Accordingly, data for evaluating both raw water and drinking water are given. The raw water criteria are those recommended by the National Academy of Sciences-National Academy of Engineering, WASH, DC, and published in "Water Quality Criteria." The Drinking Water Standards are those developed by the U.S. Environmental Protection Agency (EPA) under the provisions of the Safe Drinking Water Act of 1974. (P. L. 93-523, 93rd Congress). Additional Army guidance and critera are contained in TBMED 576, Sanitary Control and Surveillance of Water Supplies at Fixed Installations and in TBMED 229, Sanitary Control and Surveillance of Water Supplies for Fixed and Field Installations (currently used only for field installations). Additional Air Force guidance and criteria are contained in AFR 161-144, Management of the Drinking Water Surveillance Program.

A-2. Raw water quality criteria.

Present-day, advanced water treatment processes have developed to the point that a raw water supply of almost any quality, theoretically, could be used to produce finished water that meets the current standards for potable water. However, many of the advanced treatment processes required to treat a poor quality water are complex and costly and should not be installed unless absolutely necessary; i.e., when the sole available water source is of inferior quality. Raw water criteria have been developed by the National Academy of Sciences and National Academy of Engineering and published in "Water Quality Criteria." It is important to note that these criteria were developed on the basis that relatively simple, conventional treatment would be given to raw water prior to human consumption. The criteria are not intended to be definitive bases for acceptance or rejection of a raw water supply. They are meant to serve as guidelines in determining the adequacy of the supply for producing an acceptable finished water supply with conventional treatment -practices.

a. Recommended raw water quality criteria. Table A-1 contains a list of recommended criteria from "Water Quality Control," except as otherwise noted. .

Table A-1. Raw water quality criteria

Substance or Characteristic	Recommended Limit
Alkalinity	(†)
Ammonia	0.5 mg/l as ammonia nitrogen
Arsenic*	0.1 mg/l total arsenic
Bacteria	
Fecal coliform	2,000/100 ml, geometric mean
Total coliform	20,000/100 ml, geometric mean
Barium*	1 mg/l
Boron*	1.0 mg/l (§)
Cadium*	0.010 mg/l
Chloride*	250 mg/l
Chromium*	0.05 mg/l total chromium
Color	75 platinum—cobalt color units
Copper*	1 mg/l
Cyanide	0.2 mg/l
Foaming agents*	0.5 mg/l as methylene blue active substances
Hardness*	(†)
Iron	0.3 mg/l soluble iron
Lead*	0.05 mg/l
Manganese	0.05 mg/l soluble manganese
Mercury*	0.002 mg/l
Nitrate*	10 mg/l nitrate nitrogen
Nitrite*	1 mg/l nitrite nitrogen
Nitrilotriacetate (NTA)	(†)
Odor	Water should be essentially free of odor
Oil and grease	Water should be essentially free of oil & grease
Organics—Carbon Adsorbable Carbon—Chloroform extract (CCE)	0.3 mg/l
Pesticides	
Chlorinated Hydrocarbon Insecticides	
Aldrin*	0.001 mg/l
Chlordane*	0.003 mg/l
DDT*	0.05 mg/l
Dieldrin*	0.001 mg/l
Endrin*	0.0005 mg/l
Heptachlor*	0.0001 mg/l
Heptachlor epoxide*	0.0001 mg/l
Lindane*	0.005 mg/l
Methoxychlor*	1.0 mg/l
Toxaphene*	0.005 mg/l
Organophosphorous and carbamate insecticides*	0.1 mg/l
Chlorophenoxy herbicides	
2,4-D*	0.02 mg/l

Table A-1. Raw water quality criteria (cont'd)

Substance or Characteristic	Recommended Limit
	0.03 mg/l
2,4,5-TP (Silvex)*	0.002 mg/l
2,4,5-T*	5.0-9.0
pH	0.001 mg/l
Phenolic compounds	(†)
Phosphate*	(†)
Phthalate esters*	(†)
Plankton	
Polychlorinated biphenyls (PCB)*	(†) 0.01 mg/l
Selenium*	0.05 mg/l (§)
Silver*	(†)
Sodium*	250 mg/l
Sulfate*	(†)
Temperature*	500 mg/l (§)
Total dissolved solids*	(†)
Turbidity	(†)
Uranyl ion*	(†)
Viruses*	5 mg/l
Zinc*	

* Conventional treatment has little known effect on this constituent.

(†) No specific criteria recommended; however, these substances or characteristics are important from a water quality standpoint and are treated narratively in "Water Quality Criteria, 1972."

(§) These criteria are given in "Water Quality Criteria, 1968."

b. Fluoride. Normally, conventional treatment has little effect on high fluoride concentrations. Therefore, the criterion for the fluoride concentration in a raw water supply is practically identical to that for drinking water. The drinking water criteria is given in Table A-2.

c. *Radioactivity.* Table A-3 contains the recommended criteria for maximum concentrations of radioactive substances in raw water supplies. Gross alpha radioactivity limits are based on maximum allowable concentrations of radium-226 (the alpha emitter with the most critical intake limit).

Table A-2. Maximum contaminant levels for fluoride.

Annual avg. of max. daily air temp. at system location Temp (°F)	*Max. contaminant levels for fluoride* MCL (mg/L)
53.7 and below	2.4
53.8 to 58.3	2.2
58.4 to 63.8	2.0
63.9 to 70.6	1.8
70.7 to 79.2	1.6
79.3 to 90.5	1.4

Table A-3. Radioactivity limits

Gross Alpha Concentration (pCi/l)*	Recommended Action
Not exceeding 0.5 pCi/l	None
Greater than 0.5, but not exceeding 5 pCi/l	Radiochemical analysis for radium-226
Greater than 5 pCi/l	Comprehensive radiochemical analysis

Table A-3. Radioactivity Limits (cont'd)

Gross Beta Concentration excluding Potassium-40†	Required Action
Not greater than 5 pCi/l	None (with knowledge that lead-210 and radium-228 are essentially absent).
Greater than 5, but less than 50 pCi/l	Analyses for strontium-90, iodine-129, and iodine-131.
Greater than 50 pCi/l	Comprehensive radiochemical analysis.

* picocurie/liter

† Gross beta radioactivity limits are keyed to strontium-90 and isotopes of radioiodine.

A-3. Drinking water standards.

a. Interpretation. It is the responsibility of the Surgeons General of the Army and Air Force to interpret drinking water standards established by the USEPA.

b. Bacteriological standards. These standards are based upon bacteriological tests for oganisms of the coliform group of bacteria, as specified by the EPA.

(1) Membrane filter technique. When the membrane filter technique is used, the number of coliform bacteria will not exceed any of the following:

(a) One per 100 mm as the arithmetic mean of all samples examined per month; or

(b) Four per 100 mm in more than one sample when less than 20 are examined per month; or

(c) Four per 100 mm in more than 5 percent of the samples when 20 or more are examined per month.

(2) Fermentation tube method–10 mL portions. When the fermentation tube method using five 10 mL portions per sample is employed, coliform bacteria will not be present in any of the following:

(a) More than 10 percent of the 10 mL portions examined in any month; or

(b) Three or more portions in more than one sample when less than 20 samples are examined per month; or

(c) Three or more portions in more than 5 percent of the samples when 20 or more samples are examined per month.

(3) Fermentation tube method–100 mL portions. When the fermentation tube method using five 100 mL portions per sample is employed, coliform bacteria shall not be present in any of the following:

(a) More than 60 percent of the 100 mL portions examined in any month; or

(b) Five portions in more than one sample when less than five samples are examined per month; or

(c) Five portions in more than 20 percent of the samples when five or more samples are examined per month.

(4) Bacteriological samples. The standards also specify the *minimum* number of samples that must be examined each month. This is based upon the population served and ranges from one sample per month for a population of 1,000 or less up to 500 per month for

the largest systems. The standards provide a table setting forth the minimum number of samples per month as a function of population served, The samples must be collected at points that are representative of conditions in the distribution system.

c. Chemical and physical standards. Tables A-4 and A-5 give standards applicable to all water supplies at fixed facilities used for drinking purposes. Except as denoted otherwise, these are the standards and criteria established by the EPA.

Table A-4. National interim primary drinking water regulations (NIPDWR)

Inorganic Chemicals Contaminant	Maximum Contaminant Level (MCL) mg/l
Arsenic	0.05
Barium	1.00
Cadmium	0.01
Chromium	0.05
Lead	0.05
Mercury	0.002
Nitrate (as N)	10.00
Selenium	0.01
Silver	0.05
Fluoride*	

(°F)	(°C)	
53.7 and below	12.0 and below	2.4
53.8 to 58.3	12.1 to 14.6	2.2
58.4 to 63.8	14.7 to 17.6	2.0
63.9 to 70.6	17.7 to 21.4	1.8
70.7 to 79.2	21.5 to 26.2	1.6
79.3 to 90.5	26.3 to 32.5	1.4

Organic Chemicals	
Endrin	0.0002
Lindane	0.004
Methoxychlor	0.1
Toxaphene	0.005
2,4-D	0.1
2,4,5-TP Silvex	0.01
Trihalomethanes**	0.10

Turbidity—The MCL for turbidity is applicable to both community water systems and noncommunity water systems using surface water sources in whole or in part. The MCL for turbidity in drinking water, measured at a representative entry point(s) to the distribution system, are:

(1) One turbidity unit for monthly average (5 turbidity units monthly average may apply at Station option).

(2) Five turbidity units (maximum) average for 2 consecutive days.

* The MCL for fluoride is based upon the annual average of the maximum daily air temperature for the location of the installation.

** The MCL of 0.10 mg/l is based on population and is effective on 29 November 1983 for installations serving 10,000-75,000 persons. For installations serving 10,000 or less persons, the individual States may, at their discretion, adopt an effective date for the MCL.

Table A-5. National secondary drinking water regulations (NSDWR)

Contaminant	Maximum Contaminant Level (MCL) mg/l
Chloride	250
Color	15 color units

Table A-5. National secondary drinking water regulations (NSDWR) (cont'd)

Contaminant	Maximum Contaminant Level (MCL) mg/l
Copper	5
Corrosivity	1
Foaming Agents	Noncorrosive
Iron	0.5
Manganese	0.3
Odor	0.05
pH	3 threshold odor number
Sulfate	6.5-8.5
TDS	250
Zinc	500

NOTE:
The contaminants covered by this regulation are those that may adversely affect the aesthetic quality of the drinking water. These secondary levels represent reasonable goals for drinking water quality, but are not federally enforceable. The individual States may establish higher, lower or no levels for these contaminants as appropriate to their particular circumstances.

d. Radioactivity standards.

(1) The maximum allowable levels for radium-226, radium-228, and gross alpha particle radioactivity are:

(a) Combined radium-226 and radium-228–5 picocuries (pCi)/liter.

(b) Gross alpha particle activity (including radium-226 but excluding radon and uranium)–15 pCi/liter.

(2) Maximum levels for beta particles and photon radioactivity from man-made radionuclides are:

(a) The average annual concentration of beta particle and photon radioactivity from man-made radionuclides in drinking water shall not produce an annual dose equivalent to the total body or any internal organ greater than 4 mrem/year.

(b) Except for the radionuclides listed in table A-6, the concentration of man-made radionuclides causing 4 mrem total body or organ dose equivalents shall be calculated on the basis of a 2 liter per day drinking water intake using the 168 hour data listed in "Maximum Permissible Body Burdens and Maximum Permissible Concentration of Radionuclides in Air and in Water for Occupational Exposures," NCRP Pub. No. 22-59. If two or more radionuclides are present, the sum of their annual dose equivalent to the total body or to any organ shall not exceed 4 mrem/year.

Table A-6. Average annual concentrations assumed to produce a total body or organ dose of 4 mrem/yr

Radionuclide	Critical Organ	pCi Per Liter
Tritium	Total body	20,000
Strontium-90	Bone marrow	8

APPENDIX B

DESIGN EXAMPLES

B-1. Clarification.

This design example is based on the following conditions: river water source; no softening required; turbidity of raw water is variable, but rarely exceeds 1000 units. See plant flow schematic, figure B-1, showing two-stage clarification treatment.

a. Facility to be served. The water treatment plant will serve a permanent installation.

b. Population served.

- Resident 6000
- Nonresident 1800
- Effective population $= \frac{1800}{3} = 6000 = 6600$

c. System design capacity,

- Capacity factor: 1.42 (based on effective population)
- Design population = (1.42)(6600) = 9372
- System design capacity, based on population = (9372)(150) = 1,405,800 gpd. Use 1,41 mgd
- Special design capacity for industrial processes, independently determined: 0,79 mgd
- Total system design capacity = 1.41 + 0.79 = 2.20 mgd

= 1530 gpm
= 3.40 cfs

Intake structure will be difficult to enlarge at a later date, therefore its hydraulic design should be based on at least 4.4 mgd, twice plant capacity.

d. Preliminary treatment.

(1) Rack and strainers. Provide coarse rack with 3-inch clear opening followed by hydraulically cleaned basket strainers with 3/8-inch clear openings ahead of each pump. Strainers sized to provide velocity of less than 2 feet per second through 3/8-inch openings.

(2) Pumps. Provide three pumps rated at 1.10 mgd each. This gives firm pumping capacity of 2.20 mgd. Maximum capacity is 3.30 mgd. Raw water pumping station design should provide space and piping arrangements that will permit future installation of larger and additional pumps without major structural or piping changes.

(3) Meter. Provide Venturi-type flow meter in pipeline from intake works to treatment plant. Meter should be sized to cover expected flow range, minimum to maximum. Flow meter should be equipped with flushing lines and bayonet cleaning rods.

(4) Presedimentation basins. Not required.

(5) Aeration, Not required.

(6) Flow division, Normally, flow division is to be maintained through the second stage of treatment. Provide first-stage flow division structure with two identical rectangular weirs which will split flow into two equal parts. Hydraulic design of division structure should be such that flow, corresponding to maximum pumping capacity (3.3 mgd), can be carried through either half. Provide plates or gates so that either half of flow from division structure can be stopped. Structure should be designed to permit easy expansion in the event plant enlargement is required at a future date,

e. *First-stage mixing and sedimentation.*

(1) Rapid mix. Provide two identical rapid-mix basins, each providing a detention time of 20 seconds at 50 percent of design flow. Volume each basin is (20)(0.5)(3.4) or 34 cubic feet. Provide one electric motor-driven, rapid-mix unit, each basin, powered to yield a G value of approximately 700 sec^{-1} at a water temperature of 50°F.

(2) Flocculation-sedimentation. Provide two mechanically-equipped, circular flocculator-clarifiers, each sized for 50 percent of design flow. These units will normally operate in parallel.

- Detention time in flocculation zone: 30 minutes.
- Flocculator volume = (30)(60)(0.5)(3.4) = 3060 cu. ft.
- Flocculator depth: 10 ft.
- Flocculator area = 3060/10 = 306 sq. ft.
- Flocculator diameter: 19.7 ft.
- Detention time in peripheral sedimentation zone: 3 hours.
- Volume of sedimentation zone: (3)(60)(60)(0.5)(3.4) = 18,360 cu. ft.
- Basin side-water depth: 12 ft.
- For 12 foot basin depth, sedimentation area = 1530 sq. ft.
- Total basin area = 306 + 1530 = 1836 sq. ft.
- Upflow rate in sedimentation zone = $\frac{(.5)(2.2)(10^6)}{1530} = 719$ gpd/ft^2 or 0.5 gpm/ft^2, a satisfactory value.
- Basin diameter $= \sqrt{\frac{1836}{\pi/4}} = 48.3$ ft.

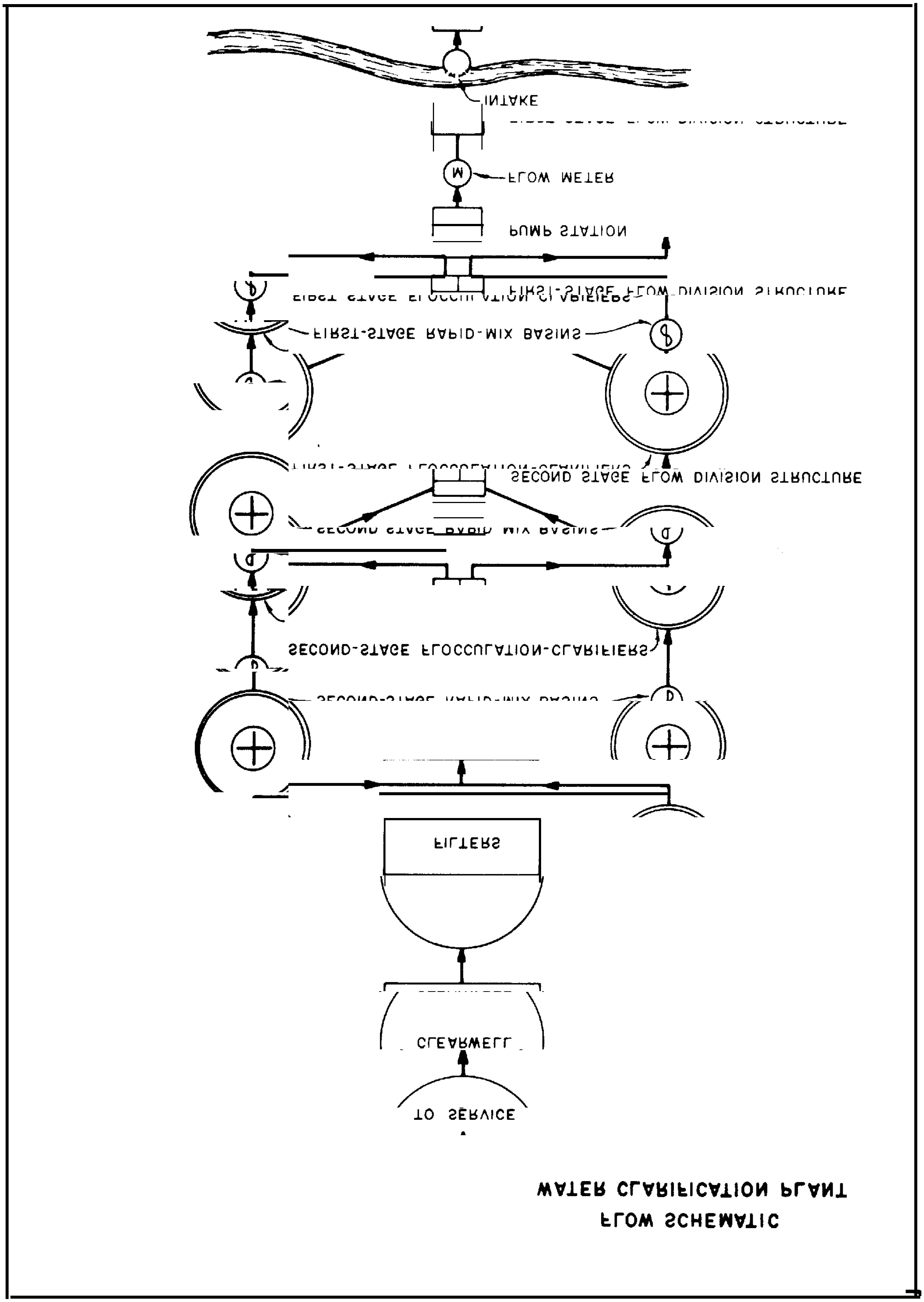

Figure B-1. Flow schematic—water clarification plant.

- Use double, V-notch, effluent weirs with inboard, effluent launder.
- Approximate total weir length, each basin: 225 ft. Weir loading $= \frac{(.5)(2.2)(10^6)}{225} = 4890$ gpd/ft.

Flocculator units should have variable speed drives and be powered to yield a G value of approximately 50 see-l at mid-speed and a water temperature of 50°F. Provide piping and valves so that either basin can be bypassed while maintaining following secondary units in service. Provide basin overflow and basin cover structure if climatic conditions require. Provide basin sludge withdrawal piping to point of sludge disposal. Sludge pumps will be required if gravity sludge flow is not feasible.

f. Second-stage flow division structure. Provide second-stage flow division structure identical to first-stage. This structure allows combining the flows from the two, parallel-operating, first-stage sedimentation units followed by their division into two equal flows, which are then directed to the second-stage rapid-mix basins. Use of this flow division structure provides maximum flexibility and optimum use of plant facilities when one first- or second-stage rapid mix or flocculator-clarifier is out of service for repair or maintenance.

g. Second-stage mixing and sedimentation.

(1) Rapid mix. Provide two second-stage rapid-mix units identical to those used for first-stage rapid mixing.

(2) Flocculation-sedimentation. Provide two mechanically equipped, circular, flocculator-clarifiers identical in size to those used in the first-stage. These units will provide 30 minutes flocculation time and 3 hours sedimentation time. Total time for flocculation, both stages, is 60 minutes. Total sedimentation time, both stages, is 6 hours.

h. Filtration. Determine number of filter units.

— $N = 2.7\sqrt{Q}$
— $Q = 2.2$ mgd
— $N = 2.7\sqrt{2.2} = 4$ units

Filter configuration will consist of two filters, side by side, along both sides of a gallery sized to accommodate filter piping, valves controls, etc. Main influent header pipe will be sized for a velocity not to exceed 1.5 feet per second. Calculated pipe diameter is 20.4 inches. Use 24-inch pipe giving actual velocity of 1.08 feet per second. Use 12-inch pipes to supply individual filters. At a rate of 2 gmp per square foot, total filtration area required will be 1530/2 or 765 square feet or 191 square feet of medium area per filter. Provide 14 feet by 14 feet medium area. Use dual-media filters with 8 inches of filter-grade sand, 4 inches of coarse sand, and 20 inches of filter-grade anthracite, equipped with rotary surface wash. Actual filter cells, including gullet, will be approximately 14 feet by 18 feet, Use vitrified clay tile or similar underdrains and gravel layer as recommended by manufacturer. Provide rate controllers and filter level control equipment. Establish overall depth of filter cell at 15 feet. Assume an arbitrary operating floor elevation of 15 feet. Significant filter elevations and related depths will be approximately as follows:

	Elevation, ft.
– Filter cell bottom	0.00
– Top of underdrains (+ 10”)	0.83
– Top of gravel (+ 10”)	1.67
– Top of coarse sand (+ 4”)	2.00
– Top of filter sand (+ 8”)	2.67
– Top of anthracite (+20”)	4.33
– Bottom of surface wash equip ment(+2”)	4.50
– Bottom of troughs (+ 14”)	5.67
– Operating water level (7’ above anthracite)	11.33

Depth of water above bottom of filter cell = 11.33-0.0000 = 11.33 ft.

Freeboard = 15.00-11.33 = 3,67 ft.

All four filters, each operated at 2 gpm per square foot, theoretically will produce $\frac{(4)(14)(14)(2)(1440)}{10^6}$ or 2.25792 million gallons of water in 24 hours. Assuming two filters washed at 15 gpm per square foot for 15 minutes each in each 24-hour period, wash water requirements will be $\frac{(2)(14)(14)(15)(15)}{10^6}$ or 0.0882 million gallons for normal backwash, or about 4 percent of production. Surface washing will require an additional $\frac{(2)(14)(14)(0,5)(15)}{10^6}$ or 0.00294 million gallons. Total down-time, each filter, is assumed to be 20 minutes. The theoretical net water production for delivery to service will be as follows:

— Theoretical total production	2.25792 mgd
– Less due to filter down-time	0.01568
– Less wash water required	0.09114
– Net theoretical production available for service	2,1511 mgd

Under actual operating conditions, with the filter-rate and level control equipment specified, the filters remaining in service will automatically compensate for production lost as a result of a filter being out of service for washing or repair, Level control insures that filter outflow will always match inflow. In addition to flow and level control equipment, provide automatic filter shut-off and alarm equipment, to be activated at maximum allowable clearwell level, and also provide filter high-level alarm. Provide all essential piping, valves, surface and backwash facilities, and operating consoles. provide essential instrumentation for each filter. Provide sampling taps for each filter. Plant layout and hydraulic design should be such that additional filters can be readily added as required.

i. Clearwell. Clearwell (filtered water storage) capacity should be related to the available or proposed distribution system storage (ground and elevated). As an approximation for this design example, clearwell capacity of at least 0.6 million gallons could be provided. This is about 25 percent of the plant's daily production when operating at 2.2 mgd (design capacity). Greater clearwell capacity may prove advantageous depending on water demand patterns and plant operating schedule. The clearwell is commonly located adjacent to the filters and at an elevation permitting gravity flow to it. This usually requires an underground structure. An alternative arrangement consists of a sump following the filters, equipped with automatically controlled transfer pumps, which discharge to an above-ground tank or basin. Underground clearwells are commonly constructed or reinforced concrete. For above-ground installations, steel tanks can be used. Regardless of the arrangement, the clearwell should be an independent structure, watertight, and protected against birds, animals and insects. Vents must be installed and protected against surface and rainwater entry, birds, insects and animals. A protected, free-discharge, overflow should also be provided. The overflow must not be connected to any sewer or drain. Access to the interior of the clearwell is required.

The access opening should be curbed at least 6 inches above the roof surface and be equipped with a hinged, overlapping, watertight, locking cover. As a general rule, the clearwell should be located at least 50 feet from sewers or drains. The area around the clearwell should be fenced and the site graded so that surface drainage is away from the structure. Where winters are severe, special consideration must be given to the design of vents and overflows to prevent freeze-up as a result of vapor condensation. A water level sensing instrument with readout in the plant control center should be provided. This can operate in conjunction with the previously described maximum level control-alarm circulation and lengthened chlorine contact time.

j. Hydraulic profile. The hydraulic interrelationship of major plant units must be carefully considered. In general, the hydraulic design of the plant should be on the side of ample flow capacity so that, under emergency conditions, water can be treated and filtered at considerably more than the normal rate with all filters in service. The approximate elevation data, given in the following tabulation, establish the emergency-operation hydraulic profile:

Location	82.76
Water level upstream, first-stage flow division weir	10.00)
Water level downstream, first-stage flow division weir	81.43 1.37)
(Loss: raw water pipe friction + velocity head in pipe	96.43
Water level in first-stage rapid-mix basin	85.76
(Loss: rapid-mix to first-stage flocculator-clarifier	92.76 1.80)
Water level in first-stage flocculator basin	
(Loss: flocculator to sedimentation basin	95.06
Water level in first-stage sedimentation basin	94.56
First-stage sedimentation basin overflow level	0.01)
(Loss: sedimentation basin weirs, launder and piping to second-stage division structure	94.47 0.50)
(Loss: second-stage division structure	95.07
Water level in second-stage rapid-mix basin	1.00)
(Loss: rapid-mix to second-stage flocculator clarifier	1.50)
Water level in second-stage flocculator	
(Loss: flocculator to sedimentation basin	98.57
Water level in second-stage sedimentation basin	98.07
Second-stage sedimentation basin overflow level	0.01)
(Loss: sedimentation basin weirs, launder and filter influent piping	98.08 0.50)
Water level in filters	
Top of anthracite (- 7.00)	98.58
Filter operating floor level (+3.67)	0.42)
(Filter freeboard at second-stage basin overflow level	99.00
Bottom of filter cells (- 15.00)	
(Maximum loss through filter media, gravel underdrains, effluent piping and controls	100.00
Maximum water level in clearwell	(feet) Elevation
(Overall head loss during emergency operation: first-stage division structure—maximum clearwell level	17.24)

By utilizing higher-than-normal chemical dosages, the plant can be operated under emergency overload conditions and still produce water meeting drinking water standards. In deriving the above data, the following emergency conditions were assumed:

(1) All raw water pumps are operated, giving a raw water flow of 3.3 mgd, which is 1.5 times nominal design rate.

(2) Both first- and second-stage rapid mix, flocculation, and sedimentation units on one side of plant are out of service.

(3) Reference elevation of water in first-stage flow

division structure upstream from flow division weirs is arbitrarily established at the 100 footmark.

(4) Raw water transmission pipe is assumed to be a flow division structure to first-stage rapid mix with a 44.5 foot, 16-inch pipe having a C value of 100.

(5) Plant units in service:

—Half of first-stage flow division structure.

–First-stage rapid mixer and first-stage flocculater-clarifier.

—Half of second-stage flow division structure.

–Second-stage rapid mixer and second-stage flocculator-clarifier.

–All (4) filters, with filter level control equipment, etc., operating normally.

(6) Filters are to be washed when head loss exceeds approximately 8 feet.

k. Wash water. Water supply for filter backwash can be supplied by a special pump, sized to provide the required flow. If used, backwash pumps should be provided in duplicate. An alternative is an elevated wash water storage tank providing gravity flow. The capacity of this tank should be at least 1.5 times maximum wash water requirement for a single filter. For this example, it is assumed that two filters will be washed in succession, each for 15 minutes, at maximum rate. A water tank having a capacity of three times the wash requirement for a single filter is recommended. Its capacity will be (3)(15)(14)(14)(15) or 132,000 gallons. The wash water storage tank is refilled by pumping filtered water from the clearwell. Duplicate, automatically-controlled, refill pumps should be provided. A single pump should be capable of refilling the wash water tank in approximately 4 hours. A wash water rate-of-flow controller should be provided on the main wash water line serving the filters. Rate of wash water flow and totalizing instrumentation with readout visible during the washing process should also be provided.

l. Wash water recovery. Filter wash water can be recovered and recirculated through the plant. Solids contained in the wash water are removed in the plant sedimentation basins. Wash water recovery requires the construction of a basin into which the wash water is discharged. The basin bottom should slope steeply toward the suction pipe of the recycling pump. The capacity of the basin should be approximately equal to the value of two, maximum rate, 15-minute filter washes, or about 90,000 gallons. For an assumed schedule of two filter washes every 12 hours, the recycle pump should have a capacity of about 125 gpm so that the recovery tank will be emptied in about 12 hours. The recycle pumps should be provided in duplicate. The recovery tank should be equipped with an overflow and a drain connection, both discharging to the plant waste disposal system. Under unusual circumstances, associated with raw water quality, it may be undesirable to recycle wash water. For such a situation, the wash water can be discharged to the recovery basin and then drained slowly to the plant waste disposal system.

m. Chemical application. Chemicals required for plant operation and the purpose of each are shown in table B-1. Table B-2 summarizes major features of chemical application and related factors.

Table B-1. Chemicals for plant operation

Chemical	Purpose
Activated carbon	Taste-odor control
Potassium permanganate	Taste-odor control
Chlorine	Disinfection
Lime, hydrated	pH adjustment
Polyelectrolyte	Coagulation
Alum or ferric sulfate	Coagulation

n. Chemical storage space. Chemical storage space requirements must be analyzed in terms of required application rates, shipping schedules and quantities. In general, a 30-day supply of a given chemical, based on estimated average feed rate, is the minimum storage volume that should be provided. If chemicals are purchased in bulk, the minimum storage volume available should be 150 percent of the volume of one bulk shipment, or about 30 days of storage at average feet rate, whichever is greater. For example, if the chemical purchase contract is for liquid alum, depending on local conditions, the manufacturer may elect to ship as follows: rail tank cars, 7,000 to 10,000 gallons; tank trucks, 3,600,4,000 or 5,000 gallons. For rail delivery, minimum storage should be 1.5 x 10,000 or 15,000 gallons. For tank-truck delivery, minimum storage should be 1.5 x 5,000 or 7,500 gallons. If the estimated average alum feed rate is 30 mg/1 and the plant is operated at design rate, 2.2 mgd, daily requirements, in terms of dry alum, are (30)(8.34)(2.2) or 550 pounds per day. Liquid alum, as furnished by the manufacturer, normally contains 5.4 pounds of dry alum per gallon of solution. The daily alum solution requirement will, therefore, be about 102 gallons. A storage volume of 15,000 gallons provides about 150 days of storage at average feed rate and design flow rate; a storage volume of 7,500 gallons, about 75 days. In this example, standard shipping volumes determine storage capacity. If the alum supply is to be purchased and stored in 100 pound bags, minimum bag storage space equivalent to (30)(550) or 16,500 lbs. of alum should be provided. Loosely-packed, dry alum has a bulk density of about 50 pounds per cubic foot. The minimum bag storage volume should, therefore, be about 330 cubic feet arranged so that bags can be handled and stored on pallets. Suppliers should be consulted in advance of design regarding shipping quantities, schedules and costs. It maybe possible to reduce overall shipping and handling costs by providing plant storage capacity that will permit the manufacturer to ship in larger quantities.

B-2. Water softening.

a. Facility to be served. The water treatment plant will serve a permanent installation.

Source of raw water—River water requiring lime-soda softening; wide variation in suspended matter concentration in raw water, with turbidity frequently exceeding 1,000 turbidity units. Maximum anticipated concentrations of the following chemical constituents are:

Constituent	mg/L
Calcium as Ca^{+2}	65
Magnesium as Mg^{+2}	20
Bicarbonate as HCO_3^-	220
Carbon dioxide as CO_2	5
Total hardness ($CaCO_3$)	320
Carbonate hardness ($CaCO_3$)	180
Noncarbonate hardness ($CaCO_3$)	140

Treatment objective is water with a total hardness of approximately 150 mg/L; made up of 50 mg/L carbonate hardness and 100 mg/L noncarbonate hardness; magnesium (Mg^{2+}) concentration, approximately 5 mg/L.

b. Population served.

– Resident 12,600

– Nonresident 1,200

— Effective population $= \dfrac{1{,}200}{3} + 12{,}600 = 13{,}000$

c. System, design capacity.

– Capacity factor: 1.22

– Design population = (1.22)(13,000) = 15,860

– System design capacity, based on population = (15,860)(150) = 2,379,000 gpd. Use 2.38 mgd

— Special design capacity for industrial processes and landscape irrigation: 0.44 mgd

– Total system design capacity = 2.38 + 0.44 = 2.82 mgd

2.82 mgd = 1,960 gpm = 4.36 cfs

d. Treatment system. Figure B-2 illustrates principally the design of facilities for presedimentation, followed by lime-soda softening. Intake, pumping, metering, hydraulic profile, filters, chemical feeding, etc., were discussed in the preceding example and discussion and calculations pertaining to them are not repeated here.

e. Pretreatment. Provide a circular presedimentation basin equipped for mechanical sludge removal with a detention time of 3 hours at design flow. With a side-water depth of 12 feet, the basin overflow rate will be about 720 gpd per square foot, a satisfactory value. Basin area will be approximately 3920 square feet and diameter about 70 feet. Basin effluent should be collected by a peripheral weir and launder. The weir's length will be approximately 220 feet, corresponding to a weir loading of about 12,700 gpd per foot, a satisfactory value. A presedimentation basin bypass should be provided so that plant operation can be maintained when the presedimentation basin is out of service.

f. Flow-division structures. Refer to figure B-2. Flow division structures, generally similar to those described in the preceding design example, are required following the presedimentation basin. These division structures insure continuity and efficiency of plant operation under emergency conditions; i.e., when a major unit, such as a solids contact or flocculator-clarifier basin, is out of service for repair or maintenance. Hydraulic design of the division structures shall be such that with all raw water pumps in operation, the full flow can be carried through either half of the structures.

Table B-2: Chemical Application

Chemical	Purchased	Storage	Feed Equipment	Feed Points
Alum	Dry, bags	Chemical storage area [1]	Dry [1]	First- and second-stage rapid-mix basins
	Dry, bulk	Elevated hopper in chemical feed room [1]	Dry [1]	
	Liquid, bulk	Tanks in bldg. [1]	Solution [1]	
Ferric sulfate	Dry, bags	Chemical storage area [1]	Dry [1]	First- and second-stage rapid-mix basins
	Dry, bulk	Elevated hopper in chemical feed room [1]	Dry	

Table B-2: Chemical Application (cont'd)

Chemical	Purchased	Storage	Feed Equipment	Feed Points
Polyelectrolyte	Liquid, drums Dry, bags	Chemical storage area	Solution	First-stage rapid-mix basins [2] or Combined filter influent [2]
Potassium permanganate	Dry, drums	Chemical storage area	Solution	First-stage rapid-mix basins
Lime, hydrated	Dry, bags	Chemical storage area	Dry	First-stage rapid-mix basins [3] and/or
	Dry, bulk	Elevated hopper in chemical feed	Dry	Second-stage rapid-mix basins [3]
Chlorine	One-ton cylinders	Separate ventilated room in chemical feed area [3]	Solution [4]	Rapid-mix basins [5] and/or Combined filter influent [5] and/or Combined filter effluent [5]
Activated carbon	Dry, bags	Chemical storage room	Dry	First-stage rapid-mix basins [6] and Combined filter influent [6]

Notes:

[1] Alum (or ferric sulfate), the principal coagulant, and associated feed systems are critical to plant performance and water safety. Therefore standby feeding facilities and ample reserve coagulant storage must be provided.

[2] Alternative feed points are provided in the interest of treatment flexibility. Normally, polyelectrolyte will be applied at the first-stage rapid-mix basins; but under some raw water quality conditions, it may prove advantageous to feed an additional small quantity, 0.1 mg/l or less, of polyelectrolyte to the combined filter influent. Polyelectrolyte, so applied, acts as a filter aid and improves turbidity removal by the filtration process.

[3] Alternative feed points are provided in the interest of treatment flexibility. Coagulation efficiency under all possible raw water quality conditions cannot be predicted with certainty. Under some circumstances, lime slurry applied in the first-stage rapid-mix basins may reduce the effectiveness of the primary coagulant.

[4] Chlorine and the chlorine feed systems are critical to the production of safe water. Standby chlorination equipment and ample reserve chlorine storage space must be provided.

[5] Alternative feed points are provided in the interest of treatment flexibility. Normally, sufficient chlorine will be fed at the second-stage rapid-mix basins to provide a free chlorine residual in the effluent from the filters. The residual is then adjusted upward as necessary by application of a small amount of chlorine to the combined filter effluent. Chlorine will be applied to the combined filter influent only when little or no chlorine residual is present in the sedimentation basin effluents.

[6] Alternative feed points are provided in the interest of treatment flexibility. Activated carbon will be used on an intermittent basis, as required, for taste-and-odor reduction. When it is necessary to apply large quantities of carbon, it should be applied to the first-stage rapid-mix basins. For some taste-and-odor conditions, the effectiveness of the carbon may be increased by splitting the carbon dosage between the first-stage rapid-mix basins and the combined filter influent. When using a split carbon feed, the bulk of the carbon should be applied to the rapid-mix basins with no more than about 10% of the total carbon application going to the combined filter influent. Under these conditions, it probably will be necessary to increase the chlorine dosage to the combined filter effluent in order to provide disinfection and an adequate residual in the water delivered to service.

g. Solids-contact basins. Provide two identical circular, solids-contact units, equipped for mechanical sludge removal. Units of this type are available from several manufacturers. While they may differ in certain details, all are generally similar in function and design. They combine mixing and flocculation, in contact with previously precipitated chemical solids, with clarification and sludge removal in a single basin. Solids-contact basins commonly consist of a central chamber for mixing, flocculation and slurry recirculation. Clarification and sludge removal take place in a peripheral slurry separation basin. Overall basin depth is about 15 feet. Mixing, flocculation and slurry cycling equipment should be capable of recirculating the slurry in the center chamber at a rate of 3 to 5 times the unit's design throughout. For this example, each unit will handle one-half of the plant design flow (980 gpm). The internal recirculation capacity should,

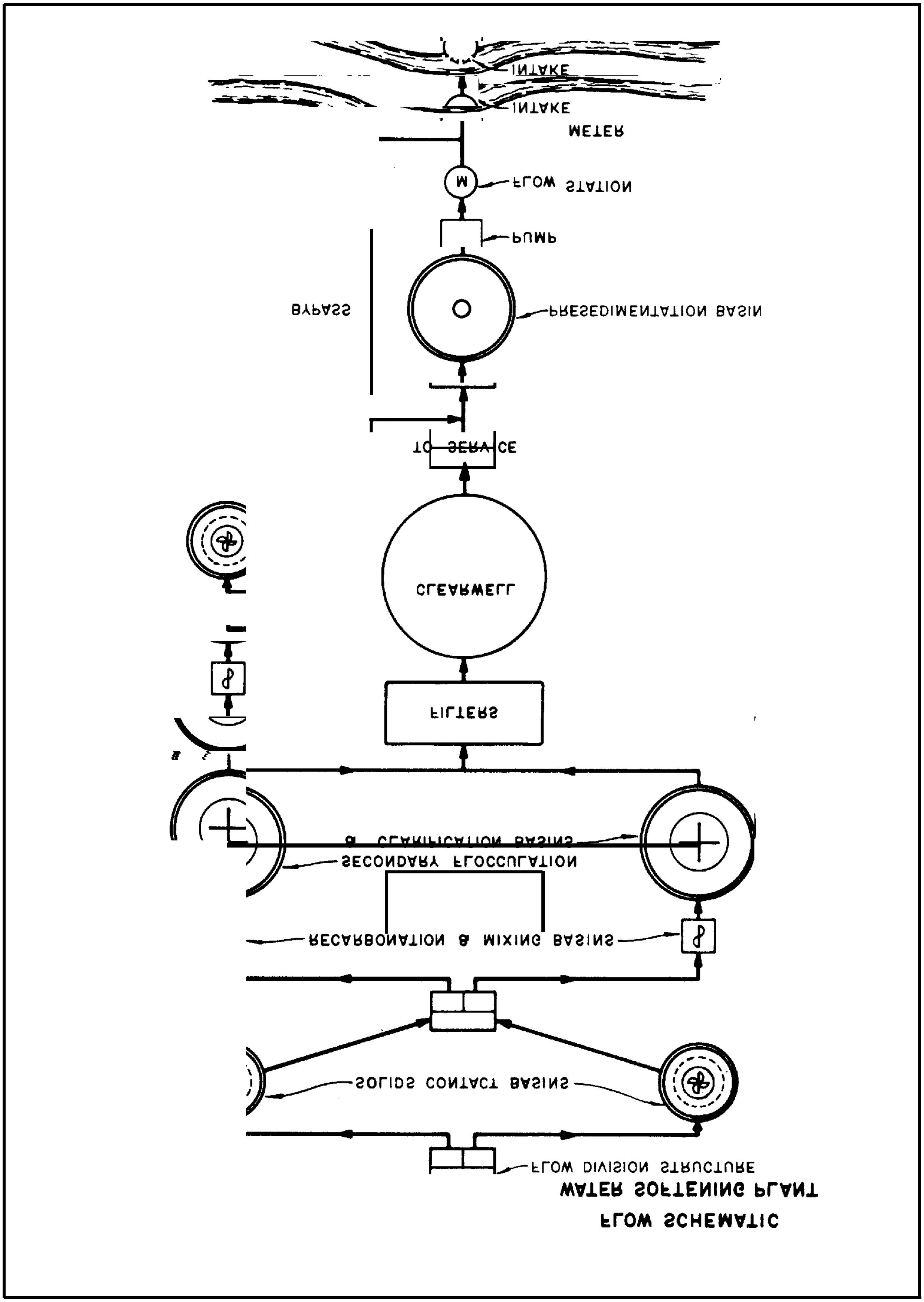

Figure B-2. Flow schematic—water softening plant.

therefore, be in the range of approximately 3000 to 4900 gpm. A critical design factor is the upflow rate at the slurry separation level in the clarification zone. This should not exceed approximately 1.5 gpm per square foot (2160 gpd per square foot) for lime-soda softening plants treating turbid surface water. For this example, basin area at the slurry separation level should be at least 980/1.5 or 653 square feet. Radial launders with submerged orifices are commonly provided to collect the clarified water. Lime and soda ash for coagulation and softening are added to the mixing section of each solids-contact basin.

h. First-stage recarbonation. Provide two identical 5 feet by 5 feet recarbonation-mixing basins, having a water depth of 5 feet, and located as shown on figure B-2. Flow from the division structure should enter near bottom of each basin where it will be mixed with carbon dioxide (CO_2) solution, supplied by a CO_2 solution feeder. The combined flow of softened water and CO_2 solution flows upward through the basin, which is mechanically mixed. For a G value of 500 sec^{-1} at 50°F, mixer horsepower will be approximately 2.0. In addition to the CO_2 solution, secondary coagulants (ferric sulfate and polymer) are applied in these mixing basins. Means for recycling of ferric sulfate-calcium carbonate sludge to these mixing basins should be provided. This sludge is pumped from the underflow of tack of the secondary flocculator-clarifiers and discharged to the corresponding recarbonation-mixing basin at a maximum rate of approximately 200 gpm. Sludge pumps should be equipped with timers so that Pump operation can be started and stopped at the intervals found to be best during plant operation.

i. Secondary flocculation and clarification. Provide two identical circular center-feed basins with an inner flocculation zone, an outer clarification zone, and mechanical sludge removal equipment. Each basin should Provide at 50 percent of design flow a total detention time of 2-1/2 hours, 30 minutes for flocculation and 2 hours for sedimentation. Value flocculation zone is (30)(60)(0.5)(4.36) or 3,920 cubic feet. Volume clarification zone is (120)(60)(0.5)(4.36) or 15,700 cubic feet. For an average depth of 10 feet in the flocculation zone and 12 feet in the sedimentation zone, the required construction diameters are 22 feet for the flocculation zone and 47 feet for the entire basin. Overflow rate in clarification zone is $\frac{\pi(23.5)^2 - \pi(11)^2}{(0.5)(2.82)(10^6)}$ or 1040 gpd per square foot, (0.72 gpm per square foot), The flocculator should have a variable speed drive and should provide a G value of approximately 50 sec^{-1} at mid-speed and a water temperature of 50°F.

j. Second-stage recarbonation. Prior to filtration, provide an additional stage of recarbonation. Use solution-type CO_2 feeder and apply CO_2 solution in conduit carrying the combined effluents from the secondary flocculator-clarifier basins.

k. Carbon dioxide. In developing this example, it was assumed that carbon dioxide would be purchased in liquid form, stored in a refrigerated storage tank, equipped with a vaporizer, and applied by means of solution-feed equipment generally similar to that employed for the measurement and application of chlorine. Other sources of carbon dioxide could be used. Carbon dioxide may be generated on-site by combustion of oil, gas, or coke. A compressor and recarbonation basin containing a diffusion system are required to apply the CO_2 thus generated to the water.

l. Chemical requirements for softening process.

(1) *Lime.*

–Lbs. 95%quicklime (CaO)per million gallons

$$= \frac{(10.6)(CO_2) + (4.68)(Alk + MgH) + (35)(8.34)}{0.95}$$

$$(10.6)(5) + (4.68)[(0.82)(220) + (4.12)(20)] + 291.9$$

= 8.84 (NCH-R)

—Lbs. soda ash (Na_2CO_3) per million gallons

(2) *Soda ash.*

—Lbs/day = (1660)(2.82) = 4680

= 1660

0.95

(3) *Ferric sulfate.*

—Lbs/day = (354)(2.82) = 998

= 8.84 (140-100) = 354

gallons = (20)(8.34) = 168 lbs/day = (168)(2.82)

fate = 20 mg/l lbs. ferric sulfate per million

—Estimated maximum requirement of ferric sulfate

(c) Estimated maximum requirement of polyelec-

(4) *Polyelectrolyte.*

= 474

gallons = (20)(8.34) = 168 lbs/day = (168)(2.82)

lion gallons = (1)(8.34) = 8.34 lbs/day = (8.34)

trolyte = 1 mg/L lbs. polyelectrolyte per mil-

—Estimated maximum requirement of polyelec-

(a) First-stage recarbonation (CO_2) converts ex-

(5) *Carbon dioxide.*

(2.82) = 24

= 291.9

—Lbs. excess lime per million gallons = (35)(8.34)

cess lime to calcium carbonate.

(b) Second-stage recarbonation (CO_2) adjusts

—Lbs. first stage CO_2 per day = (231)(2.82) = 651

(0.79)(291.9) = 231

—Lbs. first-stage CO_2 per million gallons =

—1 lb. excess lime requires $\frac{(1)(44)}{56}$ = 0.79 lb. CO_2

approximately 50 mg/L of carbonate alkalinity to the

mum second-stage CO_2 required is needed to convert alkalinity and pH of filter influent. Estimated maxi-

(b) Second-stage recarbonation (CO_2) adjusts

will normally be less than this maximum because not bicarbonate. Actual second-stage CO_2 requirements approximately 50 mg/L of carbonate alkalinity to the all of the carbonate alkalinity is converted to bicarbonate.

—Maximum CO_2 required for alkalinity conversion = $\frac{(50)(44)}{100}$ = 22 mg/L.

—Maximum lbs. CO_2 per million gallons = (22)(8.34) = 183

—Maximum lbs. CO_2 per day = (183)(2.82) = 517

—Total CO_2 (first- and second-stages) = 231 + 183 = 414 lbs/million gallons: (414)(2.82) = 1170 lbs/day

m. Additional chemicals. In addition to the chemicals required for the softening process, chlorine must be applied for disinfection. Taste-and-odor control chemicals, potassium permanganate and activated carbon will also be required at times. Discussion of the storage and application of these and other chemicals is given in the preceding example.

n. Sludge production. The raw water contains suspended matter which is removed by treatment. Additional solids are precipitated as a result of the water softening process. Most of these solids are found in basin drainage with a much smaller amount in filter wash water. If wash water recovery is practiced, all solids removed appear in basin drainage. Daily solids production can be estimated from data on suspended matter concentration in the raw water and by mass balance calculations based on water softening and coagulation reactions. An estimate of daily solids production is developed as follows: (Note that the following calculations of daily solids production are based on operation of the treatment plant at the design rate; lower average rates of operation would reduce solids production proportionately.)

(1) Rw water solids, If information on suspended solids is available this should be used to estimate solids derived from the raw water. In the absence of such information, turbidity values can be substituted as a rough approximation. Raw water turbidity is assumed to be 1000 units. Raw water solids to sludge is (1000)(8.34)(2,82) or 23,500 pounds per day.

(2) Process solids. Chemical solids produced by softening and coagulation are principally calcium carbonate ($CaCO_3$), magnesium hydroxide ($Mg(OH)_2$), and ferric hydroxide ($Fe(OH)_3$).

(a) Calcium balance in terms of $CaCO_3$.

Lbs/day as $CaCO_3$

— Calcium in raw water = (95)(2.497)(8.34)(2.82) = 5,579

— Calcium from lime = $\frac{(4680)(.95)(100)}{56}$ = 7,939

Total 13,518

— Less calcium in product water [150 − (5)(4.12)](8.34)(2.82) = 3,043

Calcium carbonate in sludge = 10,475

(b) Magnesium balance in terms of $Mg(OH)_2$.

lbs/day

— Magnesium hydroxide in sludge = $\frac{(20-5)(8.34)(2.82)(58.3)}{24.3}$ = 846

(c) Miscellaneous chemicals.

Lbs/day

— Ferric sulfate contains 21.8% Fe

Ferric hydroxide in sludge = $\frac{(20)(.218)(8.34)(2.82)(106.9)}{55.8}$ = 196

— Polyelectrolyte in sludge = (1)(8.34)(2.82) = 24

— Lime inerts in sludge = (.05)(4680) = 234

— Activated carbon in sludge = (5)(8.34)(2.82) = 118

(Assumed dosage: 5 mg/l)

Total 572

(3) Total solids in sludge.

Lbs/day

— From raw water 23,500

— From softening-coagulation process

Calcium carbonate	10,475	
Magnesium hydroxide	846	
Miscellaneous	572	
Total process		11,893
Total solids in sludge		35,393
Use		35,000

(4) Sludge weight and volume. If sludge drawn from the various basins averages 2 percent solids, the weight withdrawn per day will be approximately $\frac{35,000}{0.02}$ or 1,750,000 lbs. The specific gravity of 2 percent sludge will be approximately 1.01. The volume of the wet sludge will, therefore, be $\frac{1,750,000}{(1.01)(62.4)}$ or 27800 cubic feet per day, or about 0.64 acre-foot per day. Lagoons are commonly used for sludge storage and dewatering.

(5) Lagoon capacity. Lagoon capacity will be required for storage and partial dewatering of suspended solids removed from the raw water and the solids generated by the softening-coagulation reactions. Assuming all solids dewater to an average of 25 percent

tray, with the coke and collector trays spaced to

c. System design capacity.

— Capacity factor: 1.43

— Design population = (1.43)(6,400) = 9,152

— System design capacity, based on population = (9,152)(150) = 1,372,800 gal/day. Use 1.37 mgd

— Special design capacity for industrial processes and landscape irrigation: 0.30 mgd

— Total system design capacity: 1.37 + 0.30 = 1.67 mgd = 1,160 gal/min = 2.58 cfs

d. Aeration. Provide flow-division structure followed by two natural-draft, multiple-tray aerators. Flow is divided equally between aerators. Each aerator has a distributor tray, three coke trays, and a collector

— Effective population = $5{,}200 + \frac{3{,}600}{3} = 6{,}400$

will serve a permanent installation.

b. Population served.

— Resident	5,200
— Nonresident	3,600

prior to the design of the treatment plant.)

a. Facility to be served. The water treatment plant

formance of an iron-manganese removal treatment plant, based only on the chemical characteristics of the raw water, is difficult due to the variety of factors that can influence the removal processes. For this reason, laboratory and possibly pilot plant tests are desirable

B-3. Iron and manganese removal.

Source of raw water—Ground water, containing approximately 3.0 mg/l of iron and 0.25 mg/l of manganese. No sulfide present. The pH of the raw well water is 7.5. Laboratory studies have indicated that iron and manganese oxidation and precipitation can be readily accomplished by aeration and chlorination, followed by a short period of flocculation. (Prediction of the per-

For a usable lagoon depth of 5.0 feet, net lagoon area must be 7.8 acres.

— $\frac{(2.5)(365)(1870)}{43{,}560} = 39.$ acre-feet

For a storage period of 2-1/2 years, usable lagoon volume must be:

$$\frac{140{,}000}{(1.2)(62.4)} = 1870 \text{ ft}^3/\text{d}$$

— Approximate specific gravity of 25% sludge = 1.2

— Approximate volume of 25% sludge =

— Sludge @ 25% solids = $\frac{35{,}000}{.25} = 140{,}000$ lb/d

solids, the weight and volume of the partially dewatered sludge will be as follows:

each filter is $\frac{(1{,}160)}{(4)(3)}$ or 97 square feet. Depth of me-

each sized for 1/4 of the design flow at a loading of 3 gallons per minute per square foot. Medium area of

conditions are anticipated.

g. Filtration. Provide 4 identical, dual-media filters,

in service while only one aerator is operating. Provide basin overflow piping and sludge withdrawal piping.

launder along the periphery of the basin. Aerator effluent division structure allows either basin to be out of service while utilizing both aerators. or both basins

culator-clarifier basin with an overall diameter of 36 feet and a side water depth of 12 feet. Clarifier effluent should be collected by means of a weir and

time of approximately 2 hours, and an upflow rate of approximately 0.75 gpm per square foot (1080 gpd per square foot). These requirements can be met by a flocculator-

center of the basin, should have a detention time of approximately 30 minutes at 50 percent of design flow. Peripheral sedimentation zone should have a detention

structure for aerated water and two identical, circular, flocculator-clarifiers equipped for mechanical flocculation and sludge removal. Flocculator zone, located in

or 50.0 pounds of chlorine per day. Apply chlorine to effluents from aerators.

f. Flocculation-sedimentation. Provide flow division

chlorine to the aerated water. For a 5 mg/l dosage, the total daily chlorine requirement will be (5)(8.34)(1.67)

See figure B-3.

e. Chlorination. Provide two identical solution-type

structure ahead of aerators must be designed so that either aerator can be taken out of service for maintenance while plant continues to operate at full capacity

good, natural ventilation will be obtained. If severe freezing conditions are likely, aerators must be housed and mechanical ventilation provided. Flow-division

inches apart. Dimensions of trays are 7.5 feet by 7.5 feet. Hydraulic loading is 10 gpm per square foot. Each tray is filled to a depth of 6 inches with 2 inch pieces of coke. The distributor tray orifices are sized and spaced to insure 2 inches of head on the orifices. In a mild climate, aerators can be located outdoors where

dium is 32 inches, consisting of 8 inches of filter-grade sand, 4 inches of coarse sand, and 20 inches of filter-grade anthracite.

h. Postchlorination, Provide two solution-type chlorinators for application of chlorine to the filtered water, as required, to supply a suitable residual in the water delivered to service, Normally, one chlorinator will be in use with the other serving as a standby. Maximum dosage capacity of each chlorinator should be approximately 5 mg/L for the total plant flow rate.

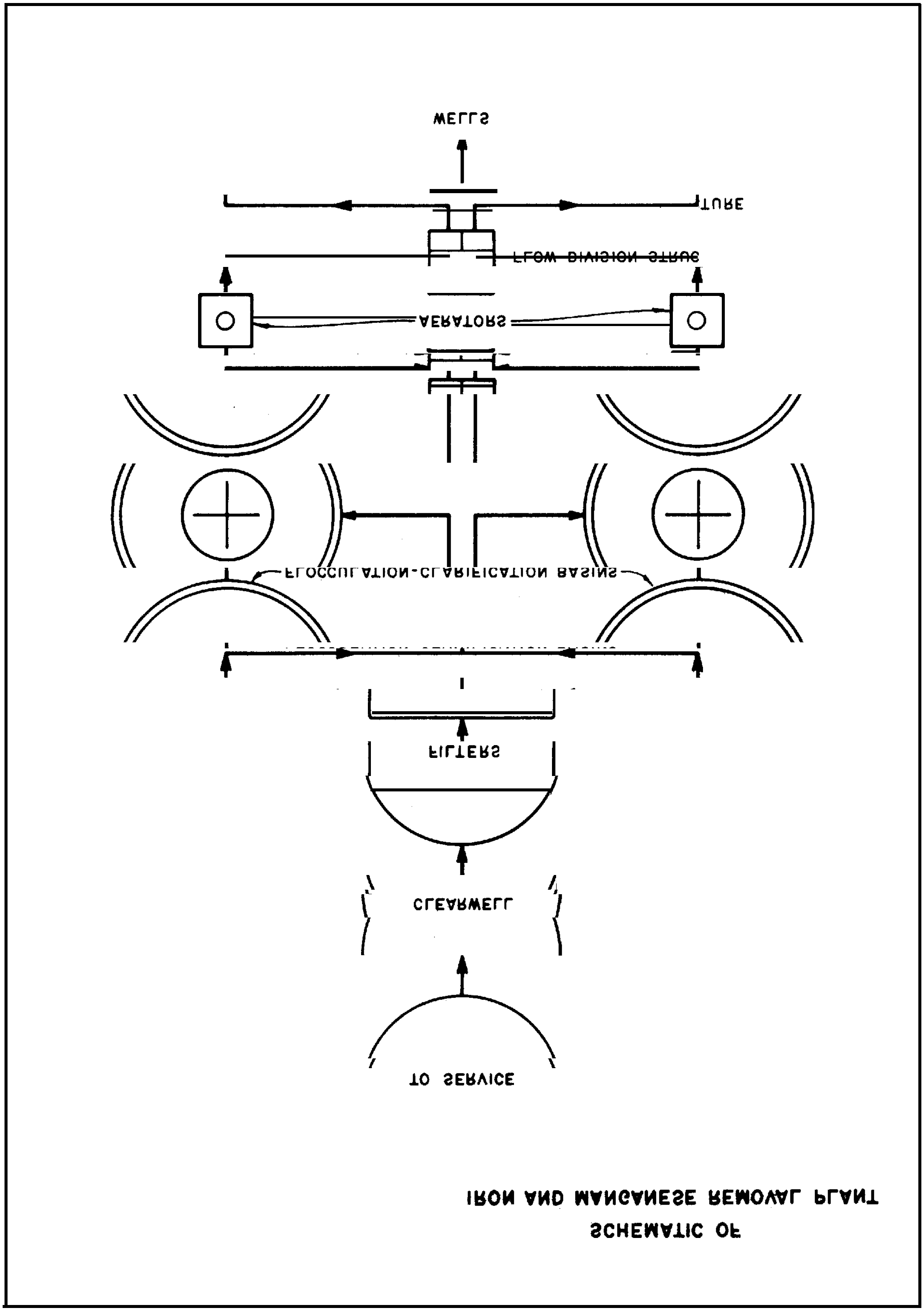

Figure B-3. Schematic of iron and manganese removal plant.

APPENDIX C

LABORATORIES AND LABORATORY ANALYSES

C-1. Minimum analyses for military water treatment plants.

The minimum number and frequency of analyses to insure drinking water of acceptable quality are determined by the size of the system and the treatment required. The frequency of analyses must also be adjusted locally to meet changing raw water characteristics. For purposes of establishing the required analytical frequency, water treatment plants have been divided into two classes, Class A and Class B. A Class A plant is any plant employing treatment beyond chlorination and fluoride control. A Class B plant is any plant which provides only chlorination and/or fluoride addition or control. Minimum analysis frequencies are listed in table C- 1.

Table C-1. Minimum Analysis Frequencies

PLANT CLASS A	B	MINIMUM ANALYTICAL FREQUENCY	CONSTITUENT/ANALYSES
X[7]	X[7]	as needed[8]	16. Manganese[1]
X		1/day to 2/month	4. Coagulation Test (where chemical addition is employed)
X		1/day[5,6]	5. Color
X		1/day	6. Odor
X	X	2/day	7. Total Plate Count[2]
X		2/month	8. Turbidity (surface waters)
X		2/month	9. Hardness[1]
X		2/month	10. Alkalinity[1,3]
X		1/week	11. pH[3]
X		1/week	12. Temperature[3]
X	X	2/day	13. Calcium[3]
X	X	2/day-plant, 2/week-system	14. Total Filtrable Residue[3]
X[4]	X	8/month for first 1000 (6,700 for Air Force Projects) population. One additional sample/month for each 1000 (900 for Air Force Projects) additional population.	15. Iron[1]
X	X	2/month	1. Chlorine residual
X	X	1/day	2. Fluoride[1]
X		1/day	3. Total Coliform[2]

[1] Where controlled.

[2] The installation medical authority is responsible for bacteriological sampling of the potable water supply. However, in some instances (e.g., due to the remoteness of medical laboratory support), it may be desirable to have bacteriological surveillance capability available at the water treatment plant. Facilities engineering personnel should coordinate such instances with the installation medical authority to prevent needless duplication of equipment.

[3] Required to calculate Langelier Index.

[4] Surface supplies only.

[5] For raw water measuring 75 or more Jackson Units on the turbidity scale.

[6] For treated water measuring 15 or more Jackson Units on the turbidity scale. AWWA establishes 3 Jackson Units on the turbidity scale as a desirable goal.

[7] Not routinely required.

[8] Required only when odor is a problem.

The procedure for the Coagulation Test is given in TM 5-660, Operation of Water Supply and Treatment Facilities at Fixed Army Installations, November 1952. The Langelier Index is calculated to given an indication of the corrosiveness of the water or its tendency to produce a scale.

C-2. Minimum laboratory furniture for military water treatment plants.

Minimum laboratory furniture requirements are as follows:

a. Class A plants. All Class A plants will be furnished with:

(1) One metal laboratory bench assembly, 108 inches long, 30 inches wide, 38 inches high, equipped for 4 cupboards; not less than 24 drawers; a bottle rack, 104 inches long, 12 inches wide, and 18 inches

high; a lead-lined or chemical composition trough, 100 inches long, 6 inches wide, and 3 to 6 inches deep; a stone or chemical composition sink, 24 inches long, 16 inches wide, and 12 inches deep with hot and cold running water; 4 double power outlets (115V). The table top should be scored to drain to the drain trough. The bottle rack should be constructed of material resistant to water, chemicals and wear.

(2) One balance table, 36 inches wide, 30 inches high, and 24 inches deep, constructed of marble.

(3) One metal supply case, 72 inches high, 48 inches wide, 16 inches deep, constructed of marble.

b. Class A plants practicing both softening and iron/manganese removal. Those Class A plants practicing both softening and iron/manganese removal will have the furniture listed above; and one metal chemistry laboratory well bench assembly, 72 inches long, 38 inches high, 30 inches wide; with one sink, 24 inches long, 16 inches wide, and 12 inches deep with hot and cold running water; 4 double power outlets (115 V); with at least 16 drawers. The table top will be of stone or chemical composition.

c. class B plants. All Class B plants will be furnished with:

(1) One metal chemistry laboratory well bench assembly, 72 inches long, 38 inches high, 30 inches wide; with one sink, 24 inches long, 16 inches wide, and 12 inches deep with hot and cold running water; 4 double power outlets (115V); with at least 16 drawers. Table top will be of stone or chemical composition.

(2) One metal supply case, 36 inches high, 36 inches wide, 16 inches deep, two adjustable shelves.

C-3. Minimum laboratory equipment for military water treatment plants.

Military water treatment plants will have the items of equipment listed in table C-2.

Table C-2. Minimum laboratory equipment for military treatment plants

Treatment Class A	B	Unit	Item Description													
C-2	4	ea	Beads, Boiling, Glass 1 mm		x			x				x				
		ea	beam graduated in 0.1 g													
	2		Balance, Triple Beam, Capacity 1500 g, Smallest													
4	2	ea	±0.05 mg, Readability 0.1 mg													
6	2	ea	Balance, Analytical, 160-200 g Capacity, Precision	x												
		ea	Autoclave, Portable, Electrically Heated, 115 V	x												
2	6		Apron, Rubberized Cloth, acid/caustic resistant													
2	6	ea	Alcohol Lamp	x												
2		ea	Gauges	x										x		
	2		Air Pump, Pressure Vacuum, Motor Driven, with	x				x								
12	2	ea	Bottle, Amber, ground glass stopper, 500 ml		—		—				—		—	—	—	
12		ea	50 ml	x												
			150 ml	x									x			
			250 ml										x			
2	6		400 ml	x												
2	4	ea	600 ml	x												x
		ea	1000 ml													
	6	ea	2000 ml					x								x
12	12	ea	Beakers, Griffin, Low Form, Graduated with Spout													
8	6	ea	1000 ml, Pouring, Glass, 1 mm	x	—	x	x	x			x					x
4	6	ea	Bottle, Washing, Polyethylene													
6	6	ea	with Screw Cap	x				x								12 to
12	4	ea	Bottle, Milk Dilution, Pyrex, Graduated at 99 ml,	x												
12		ea	Bottle, Dropping, 30 ml	x												
12		ea	Bulb, Rubber (for pipetting)	x												
12			Buret, 25 ml	x												
4		lb	Test Tube, Medium													
	1		Erlenmeyer Flask, 500 ml													
1	1	ea	Brushes, For													
	1	ea	32 oz													
1	3	ea	4 oz													
	1	ea	Bottle, Wide Mouth, Flint Glass, with Caps	x												
1		ea	500 ml													
1	1		250 ml	x												
3	—	ea	4 oz	x												
1																
1																

Table C-2. Minimum laboratory equipment for military treatment plants (Cont'd)

Treatment Class A	B	Unit	Item Description	General Lab Equipment	Alkalinity			total			ness	n Ir	r Test	Mgn anese	pH	Count		m		DO
	2		Cork, Rubber, Assorted Sizes, 5-15, 100/box																	
8		ea	Cork Borer, Brass, 5 mm to 15 mm, Set 8	x					x											
	2		Clamp, Pinch, 1 inch																	
4		ea	Plastic coated jaws	x			x									total				
3			Clamp, Buret, Double, Spring Closing, Rubber or																	
5		ea	Cells, Spectrophotometric, Glass, 1 cm, 4/set											x						
			Buret Support																	
6		ea	with dust cap						x											
2		ea	Buret, 25 ml in 0.1 ml graduation, Teflon Plug,	x																
4		ea	File, Triangular, Tapered, 4-inch	x			Residual									x				
12		Ro	Dish, Weighing, Aluminum, pk/144	x																
1			15 mm, 500/case																	
1		ea	Dish, Petri, Disposable, Sterile, Polystyrene, 60 x				x				–			x						
4			ity				x													
1		ea	Dish, Evaporating, Coors, Porcelain, 120 ml Capac-	x																
		ea	Desiccators, Plain, 250 mm, with Porcelain Plate	x																
		ea	Crucible Holders, Walters, Rubber	x					x											
5		ea	Crucible, Coors, Filtering, Gooch, Porcelain, 25 ml	x			x													
3	6	ea	Flask, Filtering, with Side Tube, Pyrex	x					x											
2	4		125 ml						x											
2		Pai	250 ml	x																
2		ea	500 ml	x				x												
	3	ea	Flask, Erlenmeyer, Pyrex, Narrow Mouth:	x										x		x				
4	2	ea	Filter, Glass Fiber, 25 ml, Gooch Crucible (box/100)	x										x						
	2	ea	White grid, Millipore or Gelman (pk/100)	x																
6	1	ea	Filters, Membrane, 0.45 u Pore Size, 47 mm Diam.,									x								
12		ea	Filter Holder, Hydrosol Stainless, 47 mm Filter	x																
4	1	ea	250 ml	x																
		ea	500 ml	x												x				
		ea	1000 ml	x																
3	1	ea	Flask, Volumetric, T Stoppered, Pyrex						Residue, total											
2		ea	1000 ml																	
2			TD:													x				
2	1		Graduated Cylinder, w/bumper, Double Reading,											–						
2	1	ea	Gloves, Chemical Resistant, Neoprene	x																
3	2	ea	Gloves, thermal insulating, 11 inch																	
6		ea	Glasses, safety													x				
4	2		Funnel Ring, open, 4-inch Diam.													x				
4		Box	Funnel, Glass, Short Stem, 150 mm ID																	
2			Forceps, Dissecting, Curved, 115 mm																	
		Pack	100 ml																	
		ea																		
2		ea	Labels, Gummed, 1/2- x 3/4-inch, roll/1000	x												x				
4		Pack	trollable 35°C ± 0.5°C	x																
4			Incubator, Laboratory, Electric, 115 V, 40 W, con-																	
4		Case	temperature 140°C																	
2			Hot Plate/Magnetic Stirrer, 6- x 6-inch, Surface																	
		ea	25 ml																	
1		ea	100 ml	x																
		ea	250 ml																	
1		ea	500 ml																	
1		Box	Nephelometer 0-40 NTU range, 0.02 unit grada	x																
2		Set	nocular	x																
2		ea	Microscope, Student, Stereoscope, Wide Field Bi-	x																
			Mortar and Pestle																	
1		ea	Magnetic Stirrer	x																
			Fans, Utility, Stainless Steel																	
		Set	ically controlled to ± 1°C	x																
1		ea	Oven, Electric, Forced Air, to 105°C, thermostat																	
			tions																	
3		ea	[illegible]	x																

Table C-2. Minimum laboratory equipment for military treatment plants (Cont'd)

Treatment Class A	B	Unit	Item Description	Gen'l Lab Equipment				Coliform total	total	F		x	Test for		pH	Cont.	Temperature	Turbidity	Color	Odor
1	1	ea	100.00 ml	x																
1	12	ea	Pipet, Volumetric, Transfer:	x																
1		ea	1.0 ml in 0.1 ml	x									x							
	10	lt	5.0 ml in 0.1 ml	x								x								
	3	ea	10.0 ml in 0.1 ml	x																
1	2	ea	plugged tip, case/400:	x																
12	1	ea	Pipet, Serological, Sterile, Disposable, with	x																
12	3	ea	2 ml	x																
20		ea	5 ml																	
6	6	ea	Pipet, Measuring, Mohr, Graduated to 0.1 ml:																	
4	2	ea	range, glass electrode																	
2			*pH Meter, temperature compensating, 0-14																	
4	1	ea	pH Indicating Paper, pH range 0-14	x								x								
1			Pen, Diamond, Marking									x								
6		ea	Residual Chlorine, DPD Comparator Kit																	
2	1	ea	Refrigerator, 12 cu ft.																	
			Reference Electrode for Fluoride, Sleeve type	x																
1		ea	Pipet Washer	x										x						
	1	ea	Pipet Dryer, Stainless Steel																	
1	2	ea	2- x 16-inch																	
1	1	Cal	Pipet Container, Aluminum or Stainless Steel, 2- x	x																
1		ea	1.00 ml	x																
1	2	ea	2.00 ml	x																
4	1	ea	5.00 ml																	
2	1	ea	10.00 ml	x																
	1	ea	15.00 ml	x																
2	1	ea	20.00 ml																	
2	2	ea	50.00 ml	x																
			Spectrophotometer, minimum 510-525 nm range,	x																x
1			*Specific ion meter for fluoride with electrode																	x
1	4	ea	Spatulas, Stainless Steel, 4-inch blade	x																
1	4	ea	Soap, Biodegradable	x										x						
1	2	ea	Teflon Stopcocks and Stoppers	x																
2	4	ea	Separatory Funnel, 125 ml, Squibb Form T or	x																
	6	ea	Rings, Iron, with Clamp, 6 inches	x									x							
4	4	ea	1/4-inch	x																
4	6	ea	-inch																	
2	6	ea	Stirring Bar, Teflon Coated: 6-phase, Variable																	
4	6	ea	Stirring Bar Retriever					x												
6			Speed					x								x				
4	2	Case	Stirring Apparatus, Multiple,					x								x				
6	2	Case	Still, Water, Electric, 1 gal/hour													x				
6	2	Case	Light Path 1 cm	x																
6			60°C ± 1°C	x																
			Constant Temperature water bath capable of																	
2	6	ea	Odor flasks, glass stoppered, 500 ml, Erlenmeyer																	
2	6	ea	Nessler Tube, 50 ml, tall form with stand																	
2			Tubing, Tygon, vacuum, 1/4-inch ID	x		x														
			Tube, T, Glass, 5/16-inch OD	x																
	1	ea	Tripod, base support with 20-inch rod												x					
12	1	Roll	Tongs, Stainless Steel																	
12	1	ea	Thermometer, -10°C to 110°C																	
			Stop Watch or Electric Timer with Second Hand																	

C-4 Minimum laboratory chemicals for military water treatment plants.

Military water treatment plants will have the chemical supplies listed in table C-3.

Table C-3. Minimum laboratory chemicals for military treatment plants

Treatment Class A	Treatment Class B	Unit	Item Description	General Lab. Chemicals	Alkalinity	Calcium	Chlorine Residual	[illegible]	[illegible]	[illegible]	[illegible]	Jar Test	Manganese	pH	[illegible]	Temperature	[illegible]	Color
6		pt	ACS Grade															
8		gm	Ammonium Hydroxide, Concentrated, Reagent or															
		pt	Ammonium Chloride															
4		lb	Ammonium Acetate															
1		gm	Alcohol, isopropyl or ethyl, 95%															
7		pt	Grade															
18		lb	Acid, Sulfuric, Concentrated, Reagent or ACS								x							
		lb	Grade															
		lb	Acid, Phosphoric, Concentrated, Reagent or ACS															
8		lb	Acid, Perchloric, 60%	x														
1		lb	Acid, Nitric, Concentrated, Reagent or ACS Grade															
2		pt	Grade															
4		lb	Acid, Hydrochloric, Concentrated, Reagent or ACS															
		lb	Acid, Glacial Acetic															
		pt	Eriochrome Black T Indicator															
1/4		pt	Eriochrome Blue Black R, Indicator	x														
1	1		EDTA, Magnesium Salt, Reagent or ACS Grade		x													
1/4	1	lb	EDTA, Disodium Salt, Reagent or ACS Grade															
1/4	1	lb	Desiccant, Dierite, 10-20 mesh, indicating															
1/4		lb	Desiccant, Drierite, 10-20 mesh,															
1/4		lb	Calcium Carbonate, anhydrous, Primary Standard															
2	4	lb	Bromcresol Green Sodium Salt															
10		lb	Grade								x							
1/4		lb	Ammonium Persulfate, Solid, Reagent or ACS								x							
50		lb	LES ENDO Agar															
		gm	Hydroxylamine hydrochloride															
2			Hydrogen Peroxide, 30%															
1/4	1	lb	Hydrazine Sulfate, Reagent or ACS Grade								x							
5			Hexamethylenetetramine, Reagent or ACS Grade															x
2		lb	Fluoride Standard, 2 ppm															
1		lb	Fluoride Standard, 1 ppm															
1		lb	ACS Grade															
1/4	2	pt	Ferrous Ammonium Sulfate, Crystal, Reagent or															
8	2		pH Buffer, Standard, pH 4.0															
1		lb	Phenolphthalein, Indicator solution															
20			1,10-phenanthroline monohydrate								x							
1/4		lb	Orthotolidine, Solution for Chlorine Test Kit															
1/2		pt	M-TGE Broth								x							
2		lb	Methyl Red Sodium Salt								x							
2			Methyl Orange, Indicator, Reagent or ACS Grade				x											
2		lb	Mercuric Sulfate															
1		lb	M-ENDO Medium															
10		pt	Total Ionic Strength Buffer															
8		oz	Stopcock Grease															
1			ACS Grade								x							
10		lb	Sodium Thiosulfate, Crystal, Reagent or				x											
1		lb	Sodium Nitrate, Reagent or ACS Grade				x				x							
1/4		lb	Sodium Hydroxide, Pellet, Reagent or ACS Grade	x			x			x	x							
1		lb	Sodium Dichromate, Technical Grade	x						x								
1		lb	Sodium Chloride, Reagent or ACS Grade				x				x							
1/4	2	lb	Sodium Carbonate, Primary Standard															
1		lb	Sodium Bisulfite, Reagent or ACS Grade															
1/4	9	pt	Sodium Arsenite Solution for Chlorine Test Kit															
1/4		lb	Sodium Acetate															
2		gm	Silver Nitrate, Reagent or ACS Grade															
2		lb	Potassium Permanganate															
		lb	Potassium Iodide, Crystal, Reagent or ACS Grade															
1		pt	pH Buffer Standard, pH 9.1															x
8	8	pt	pH Buffer, Standard, pH 6.8															x
2		qt	Platinum-cobalt standard solution	x												x		

APPENDIX D

METRIC CONVERSION FACTORS

MASS	1.356	W (watt)
oz (avdp)	0.7457	kW
lb (avdp)	*1.0	W
ton (2000 lb)	*1.0	kW
POWER		
ft-lbf/s	28.35	g
hp (550 ft-lbf/s)	0.4536	kg
W	9.072×10^2	kg
kW		
Customary Unit#	*0.3048	m
AREA	*25.4	mm (millimeter)
Acres	*1.609344	km
ft^2	*0.9144	m
in^2		
mi^2		
yd^2	4.448	N (newton)
CONCENTRATION		
lb/gal		
lb/mil gal	1.233×10^3	m^3/d
(lb/million gallons)	2.832×10^{-2}	m^3/s
lb/mil gal	1.093×10^{-4}	$m^3/s/ha$
lb/mil gal	6.309×10^{-5}	m^3/s
lb/mil gal	6.309×10^{-2}	L/s
	0.6791	$L/s/m^2$
ENERGY	4.075×10^{-2}	$m^3/d/m^2$
Btu (mean)	1.242×10^{-2}	$m^3/d/m$
ft-lbf	3.785×10^3	m^3/d
hph		
kWh		
Wh	1.056×10^3	J (joule)
	1.356	J
FLOW	2.685×10^6	J
acre-ft/d	$*3.6 \times 10^6$	J
ft^3/s (cfs)	$*3.6 \times 10^3$	J
$ft^3/s/mi^2$		
gal/min (gpm)		
gal/min	0.1198	$kg/1000m^3$
$gal/min/ft^2$	1.198×10^2	mg/L
$gal/d/ft^2$	0.1198	µg/L (microgram/liter)
gal/d/ft		
mgd	1.198×10^2	g/L (gram/liter)
(million gallons daily)	0.1198	g/m^3
FORCE		
lbf (pound-force)	0.4047	ha (hectare)
	$*9.290304 \times 10^{-2}$	m^2 (sq meter)
LENGTH	$*6.4516 \times 10^{-4}$	m^2
ft	2.590×10^2	ha
in	0.8361	m^2
mi		
yd	Table D-1	Metric Unit
	Multiplier	

APPENDIX E

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B404	Liquid Sodium Silicate
B405	Sodium Aluminate
B406	Ferric Sulfate
B501	Caustic Soda
B502	Sodium Hexametaphosphate
B600	Powdered Activated Carbon
B602	Copper Sulfate
B603	Potassium Permanganate
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