Maintaining High Drinking Water Quality in Finished Water Storage Tanks and Reservoirs

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INTRODUCTION AND HISTORICAL PERSPECTIVES

Environmental regulations for drinking water, legislated by the Safe Drinking Water Act, ensure that consumers are drinking safe and appealing water. Regulations address monitoring and quality requirements in water sources, at the treatment plant, in the distribution system, and at the customers' taps. In the past 10 years, there has been a sharp increase in the number of regulations that relate to the water distribution system. How the Army installation operates its water distribution system can affect water quality and regulatory compliance. Most Federal and state regulations either do not address or only provide a very general guidance on water related operational issues such as inspection, maintenance operation, and design considerations to maintain water quality. This information paper (IP) provides more detailed operational guidance on one major element of the water distribution system; the storage tank or reservoir. All but the smallest water systems have some type of storage in their system; thus, small, medium, and large installations should find this information useful.

HOW TO USE THIS DOCUMENT

This IP was designed to serve as a reference manual for both regulated and unregulated drinking water systems. Although information can be read front to back, particular information can be readily extracted through use of the table of contents. Water quality problems associated with storage reservoirs are described in Chapter 3. Identification and monitoring of water quality problems in storage reservoirs can also be found in Chapter 3. Guidelines for inspection and maintenance can be found in Chapter 4, and guidelines for operations are located in Chapter 5. Engineering design and retrofit considerations are discussed in Chapter 6. All references for this IP are contained in Appendix A.

ASSISTANCE AVAILABLE

One of the most common obstacles water systems have is obtaining technical and analytical assistance. The U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM) Water Supply Management Program (WSMP) provides consultative expertise to Army and Department of Defense (DOD) installations worldwide for environmental health aspects of drinking water supply, treatment, and distribution at relatively low cost. The USACHPPM's matrixed resources include a fully accredited laboratory, drinking water engineers and scientists, risk assessment and communication experts, and a team of physicians. Assistance can range from quick telephone consultations to onsite visits.

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For an overview of our program and to view copies of some of our technical guidance documents, be sure to visit our **World Wide Web site** at http://chppm0b.apgea.army.mil/dwater/index.html

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CHAPTER 1
INTRODUCTION AND REGULATORY ASPECTS

1-1. Background Information. Protection of drinking water from contamination relies on the use of the multiple barrier approach that includes:

a. source protection,
b. treatment to remove contaminants,
c. disinfection to inactivate microbial contaminants,
d. properly operated and maintained water distribution systems, and
e. monitoring and response.

The subject of this Information Paper (IP) is finished water storage reservoirs, which are an important component of water distribution systems. Finished water storage facilities have been designed and constructed in water distribution systems to equalize water demand, reduce pressure fluctuations, and provide reserves for fire fighting, power outages and other emergencies. The Army's designs have followed guidance in Technical Manual 5-813-4, Water Supply - Water Storage (reference 1). Historically, most finished water tanks/reservoirs have been operated to provide adequate pressure, and have been kept full to be better prepared for emergency conditions. This type of operation can cause water quality degradation. Neither the design nor the operation of storage facilities has been oriented toward maintaining water quality.

1-2. Army Facilities. There are over 400 storage reservoirs at Army facilities in the continental U.S. (CONUS). There is no readily available source of consolidated information on the condition of these facilities nor is there information on the normal operational procedures. As such, this IP will assume that the condition and operating procedures related to Army reservoirs is similar in nature to the civilian sector.

1-3. Civilian Infrastructure Needs. The 1992 Water Industry Database provides summary information on more than 10,000 finished water storage facilities in the United States (reference 2). In 1995, a similar database was developed for Canadian utilities (reference 3) with information on 684 finished water storage facilities. Statistics from these databases are summarized in Tables 1 and 2.

TABLE 1. TYPES OF FINISHED WATER STORAGE FACILITIES

Type of Storage Facility	United States	Canada
	% Total Storage Facilities	
Below Ground	19	37
Elevated	24	19
Ground Level	54	41
Uncovered Reservoir	3	3
Total	100	100

TABLE 2. MATERIALS OF CONSTRUCTION IN FINISHED WATER STORAGE FACILITIES

Tank Type	Material of Construction	United States	Canada
		% Total Storage Facilities	
Elevated	Steel	97	80
Elevated	Concrete	3	20
Ground	Steel	74	16
Ground	Concrete	26	84

The condition of many of these storage facilities has come into question in a recent report to Congress (reference 4). The report estimates that the 20-year need to maintain and upgrade storage facilities to meet Safe Drinking Water Act (SDWA) to be $12.1 billion dollars. This is 9 percent of the total infrastructure needs, which were estimated to be $138.4 billion for the 20-year horizon in the United States.

1-4. Drinking Water Quality Regulations. In the United States, the U.S. Environmental Protection Agency (EPA) has promulgated a number of Federal regulations under the SDWA (reference 5) to control distribution system water quality. Storage reservoirs can have a major affect on distributed water quality and regulatory compliance. The current regulations and their related requirements are listed below and summarized in Table 3.

a. The Total Coliform Rule (TCR) has a direct effect on finished water storage facilities, by requiring all public water systems to analyze distribution system water samples for total coliform bacteria on a monthly basis. The number of required samples is determined based on the population served. For systems required to collect 40 or more samples each month, total coliform bacteria must be absent from 95 percent of the samples. For systems collecting fewer than 40 monthly samples, total coliform bacteria must be absent from all but one sample each month. Further, a system monitoring plan is required, and samples must be taken at customer taps or sample taps which are representative of the entire distribution system. The TCR does not include specific requirements to collect and analyze water samples from storage facilities or their outlets. Nevertheless, it has been demonstrated time and again that water from storage reservoirs has a direct effect on water quality in the distribution system.

b. The Surface Water Treatment Rule (SWTR) currently requires all public water systems using surface water supplies to provide a minimum disinfectant residual of 0.2 mg/L entering the distribution system, and a measurable disinfectant residual throughout the distribution system in 95 percent of the monthly samples. Heterotrophic plate count bacteria can be used as an alternative method of compliance for the requirement of a measurable disinfectant residual in the distribution system. A heterotrophic plate count of 500 colony forming units per ml or less is considered to be equivalent to a measurable disinfectant residual. The SWTR requirement relating to primary disinfection has caused many utilities to rehabilitate existing clearwells or storage facilities at the treatment site, or to design new facilities. The new designs use baffles, separate inlet and outlets, and other design features to increase contact time. This experience with primary disinfection is applicable to secondary disinfection, including finished water storage facilities where poor water circulation is causing water quality problems.

c. The current Total Trihalomethane (TTHM) Rule requires public water systems serving more than 10,000 people to collect and analyze distribution system water samples for total trihalomethanes on a quarterly basis. The annual average of these samples must be less than 100 g/L for TTHM. Total trihalomethane levels increase with time in the system and with exposure to free chlorine. The TTHM Rule emphasizes the need to control detention time and disinfectant levels of water in the distribution system, including finished water storage facilities.

d. The Lead and Copper Rule (LCR) has an indirect impact on the operation and maintenance of finished water storage facilities. The LCR requirement for measuring lead and copper levels at the customers' taps has focused attention on distribution system water quality, and the need to preserve the quality of water achieved at treatment facilities. Further, monitoring for water quality parameters may need to occur in the distribution system, and monitoring for lead and copper is to occur at the customers' taps.

e. The Information Collection Rule (ICR) applies to systems serving populations greater than 100,000 and requires monitoring of disinfection by-products in the distribution system.

f. The proposed Disinfectants/Disinfection By-Products (D/DBP) rule would apply to all public water systems that add a primary or secondary disinfectant to the water. It would replace the current TTHM rule, reducing the maximum contaminant level for TTHMs to 80 g/L in Stage 1 and possibly 40 g/L in Stage 2. Haloacetic acids (HAA) would also be controlled by the D/DBP rule. Generally, both TTHM and HAA levels in water increase with time and with exposure to free chlorine. Further, the proposed D/DBP Rule would establish maximum disinfectant residual levels (MDRL) for chlorine (4 mg/L), chloramines (4 mg/L) and chlorine dioxide (0.8 mg/L) in the distribution system.

g. The pending Groundwater Disinfection Rule, although in the early planning stages, may require groundwater systems to maintain a detectable disinfectant residual in the distribution system. Without a disinfectant residual, monitoring and system operating requirements may be more stringent.

h. Regarding volatile organic compound (VOC) emissions from tank coatings, the Joint Industry, Government and Regulatory committee reached a tentative agreement in 1993 to set the VOC limit in industrial maintenance coatings to 3.5 lb./gal. A draft rule has not been developed to date. This VOC limit is generally used as a guideline across the U.S. and is a law in some states.

i. In addition to the regulatory implications, finished water quality resulting from poorly maintained and operated storage reservoirs has caused disease outbreaks. Army waterworks throughout the world have experienced their share of drinking water concerns. Many of these have been related to distribution and storage: including lack of flushing, inadequate disinfection of repaired depressurized programs, and the absence of contingency plans. Monitor samples for lead and copper and possibly the distribution system for water quality parameters (reference 6).

TABLE 3. Summary of Regulatory Implications on Water Quality in Storage Reservoirs/ Distribution Systems

Regulation/Rule	Implication/Issue
Total Coliform Rule	Presence/absence approach. Sampling in distribution system.
Surface Water Treatment Rule	95 percent samples need detectable disinfectant residual.
Total Trihalomethane Rule	100 g/L for annual average of quarterly samples in distribution system.
Lead and Copper Rule	Monitor distribution system for water quality parameters and tap samples for lead and copper.
Information Collection Rule	Monitor disinfection by-products in distribution system.
Proposed Disinfectants/ Disinfection By-Products Rule	80 g/L TTHM and 60 g/L HAA in distribution system, based on annual average.
Pending Groundwater Disinfection Rule	May require a disinfectant residual in distribution system.

CHAPTER 2
TYPES OF FINISHED WATER STORAGE

2-1. Introduction. To understand the implications of storage reservoirs for water quality degradation, it is useful to categorize and describe the various types of finished water storage. The following descriptions are found in TM 5-813-4 (reference 1). There are several types of finished water storage facilities that can be categorized by their physical shape, dimensions, and location. For purposes of this discussion, two categories will be used: (1) ground storage, and (2) elevated storage. Clearwell storage, which is usually part of the water treatment plant, is generally not considered as part of distribution storage. Distribution storage will be defined as facilities that are not part of the treatment or contact time requirements to meet 3 log removal or inactivation for *Giardia* per the Surface Water Treatment Rule mentioned earlier.

2-2. Ground Storage. Ground storage is usually located remote from the treatment plant but within the distribution system. Ground storage is used to reduce treatment plant peak production rates and also as a source of supply for re-pumping to a higher pressure level. Such storage for re-pumping is common in distribution systems covering a large area, because the outlying service areas are beyond the range of the primary pumping facilities. Ground storage may also be located on hills to enable gravity outlet flow.

Ground storage tanks or reservoirs, below ground, partially below ground, or constructed above ground level in the distribution system, may be accompanied by pump stations if not built at elevations providing the required system pressure by gravity. However, if the terrain permits, the design location of ground tanks at elevations sufficient for gravity flow is preferred. Concrete reservoirs are generally built no deeper than 20-25 feet below ground surface. If rock is present, it is usually more economical to construct the storage facility above the rock level. In a single pressure level system, ground storage should be located in the areas having the lowest system pressures during periods of high water use. In multiple pressure level systems, ground storage is usually located at the interface between pressure zones with water from the lower pressure zones filling the tanks/reservoirs and being passed to higher pressure zones through adjacent pump stations. Pneumatic tanks, though not normally considered storage, are used by many smaller installations to maintain pressure. They have a pressure vessel partly filled with water to leave an air cushion above to produce the desired water pressure. Pneumatic tanks may be located within buildings, at outside locations, or underground.

2-3. Elevated Storage.

a. Elevated storage is provided within the distribution system to supply peak demand rates and equalize system pressures. In certain systems, elevated storage is more effective and economical than ground storage because it reduces pumping requirements. The storage can also serve as a source of emergency supply since system pressure requirements can still be met temporarily when pumps are out of service.

b. The most common types of elevated storage are elevated steel tanks, and standpipes. Some smaller ones may be made of wood. In recent years, elevated tanks supported by a single pedestal have been constructed where aesthetic considerations are an important part of the design process.

c. A standpipe is a tall cylindrical tank normally constructed of steel or reinforced concrete. Only the portion of the storage volume of a standpipe that provides an estimated 75-psi, or other system requirement, is considered useful storage for pressure equalization purposes. The lower portion of the storage acts to support the useful storage and to provide a source of emergency water supply.

d. Elevated storage tanks are often located in the areas having the lowest system pressures during intervals of high water use to be effective in maintaining adequate system pressures and flows during periods of peak water demand. Elevated tanks are generally located at some distance from the pump station(s) serving a distribution pressure level, but not outside the boundaries of the service area, unless the facility can be placed on a nearby hill. Additional considerations for siting of elevated storage are conditions of terrain, suitability of subsurface soil and/or rock for foundation purposes, and hazards to low-flying aircraft. Elevated tanks are built on the highest available ground, up to static pressures of an estimated 75-psi in the system, so as to minimize the required construction cost and heights.

CHAPTER 3
IDENTIFICATION AND MONITORING OF WATER QUALITY PROBLEMS IN STORAGE RESERVOIRS

3-1. Background. There are three categories of problems that occur in finished water storage reservoirs: microbiological, chemical, and physical. The long detention time in many storage reservoirs is probably the most important factor causing water quality deterioration. Perhaps the most significant deterioration that can occur includes loss of chlorine residual, growth of heterotrophic plate count (HPC) bacteria and occurrence of coliform bacteria. Nitrification can also present serious problems in chloraminated supplies. These and other water quality problems are described below and summarized in Table 4 (reference 7). Potential methods for improving these problem areas may be found in Table 5 (reference 7).

TABLE 4. POSSIBLE CAUSATIVE FACTORS OF PROBLEMS FINISHED WATER STORAGE FACILITIES

Water Quality Problem	Category	Possible Causative Factors
Loss of disinfectant residual	Chemical Microbiological	Long detention time Depletion from exposure to sun/atmosphere Entry of chlorine demanding contaminants Source water with continued chlorine demand Increase in temperature Increase in HPC Nitrification
Increase in HPC bacteria	Microbiological	Loss of chlorine residual Contaminant entry Sediment or biofilm
Coliform Bacteria occurrence	Microbiological	Loss of chlorine residual Contaminant entry Sediment or biofilm
Disinfection By-Product formation	Chemical	Long detention time Increase in pH Increase in chlorine residual Boosting chlorine NOM contamination or algae growth
Sediment build-up	Physical Chemical	Source water contains suspended material Minimal velocities allow deposition Contaminant entry Excess lime sediment

Development of taste and odor	Chemical Microbiological	Long detention time Growth of algae or other biological organisms Contaminant entry Leachate from internal coatings Source water with potential for taste and odor
Growth of algae or other biological organisms	Microbiological	Exposure to sun Loss of chlorine residual Long detention time Sediment Biofilms Presence of nutrients
Contaminant entry	Physical Microbiological	Uncovered reservoirs Damaged or missing screens on vents and other openings Cross connection (at drain or overflow) Improper design of floating cover features
Increase in pH	Chemical	Long detention time in concrete facility
Biodegradation on internal coatings	Microbiological	Loss of chlorine residual allowing biological growth Selecting the wrong internal coating
Biofilm growth	Microbiological	Loss of chlorine residual Nutrients from coatings Corrosion of surface allowing for growth sites Infrequent cleaning allowing for growth build-up Assimilable organic carbon introduction Algae growth Bacterial seeding
Nitrification	Microbiological	Long detention time Increase in temperature Loss of chloramine residual Excess ammonia
Color	Microbiological Physical	Decaying vegetative matter Algae growth in uncovered reservoirs Sediment scouring
Red Water	Chemical	Metals uptake from metal surfaces Lack of or improper cathodic protection
Build-up of iron and manganese	Chemical	Presence in source water coupled with long detention time allowing for oxidation and settling Improper sequestering agent dose
Hydrogen sulfide	Chemical	High levels of H_2S in source water Sediment/biofilms
Leachate from internal coatings	Chemical	Improper curing/application Selecting the wrong internal coating

TABLE 5. POTENTIAL METHODS FOR IMPROVEMENT OF WATER QUALITY IN FINISHED WATER STORAGE FACILITIES

Water Quality Problem	Design/Construction	Operations	Inspection and Maintenance
Loss of disinfectant residual	Cover open reservoirs Install baffles Install recirculating system Rechlorinate Relocate inlet/outlet Size facility for frequent turnover Install bird wires and fences Install diffuser inlet Install mechanical mixers Install pumping to increase turnover	Increase turnover rate Fluctuate water levels more Improve influent water quality Avoid having facilities "ride the system" Reduce free ammonia residual	Clean storage facility Maintain screens Increase monitoring Inspect coating
Increase in HPC bacteria	Prevent loss of chlorine residual - see above	Prevent loss of chlorine residual - see above Proper training in sample collection	Prevent loss of chlorine residual - see above Clean floating cover
Coliform bacteria occurrence	Prevent loss of chlorine residual - see above	Prevent loss of chlorine residual - see above Proper training in sample collection	Prevent loss of chlorine residual - see above Clean/repair floating cover
Disinfection By-Product formation	Reduce detention time (baffles, recirculation , etc.) Look at alternative disinfectants	Control chlorine residual Improve influent water quality Increase turnover rate Change chlorine application point	Provide internal coating on concrete walls to prevent pH increase Increase monitoring
Sediment build-up	Install riser on outlet pipe Change inlet/outlet to improve flow patterns	Improve influent water quality Avoid scouring	Clean more frequently Inspect more frequently
Development of taste and odor	Cover open reservoirs Reduce detention time (baffles, recirculation, etc.)	Improve influent water quality Flush distribution system lines Chlorinate	Apply coatings properly Clean storage facility as needed Increase monitoring
Growth of algae or other biological organisms	Cover open reservoirs Reduce detention time (baffles, recirculation, etc.)	Improve influent water quality Reduce AOC or bacterial input Chlorinate	Overflow reservoir to skim surface Increase monitoring
Contaminant entry	Cover open reservoirs Install bird wires and fences Provide overflow and drain pipes with air gaps Design floating cover drain systems properly Rehab underground basins		Maintain screens Lock all hatches Operate pumping system on floating cover drainage Inspect more often Repair holes in covers

Increase in pH	Provide coating on concrete walls Provide corrosion control treatment	Increase turnover rate Fluctuate water levels more	Provide internal coating on concrete walls
Biodegradation of internal coatings	Prevent loss of chlorine residual - see above Select an NSF approved coating	Store a non-corrosive water	Increase cleaning frequency
Biofilm growth	Prevent loss of chlorine residual - see above Select an NSF approved coating	Prevent loss of chlorine residual - see above Chlorinate Physical removal	Increase cleaning frequency Apply coatings properly Improve monitoring
Nitrification	Provide baffles Provide recirculation	Increase turnover rate Remove from service - breakpoint chlorinate Change Cl_2:ammonia ratio	Improve monitoring
Color	Cover open reservoirs	Improve influent water quality	Inspect and apply coatings Increase cleaning frequency
Red Water	Provide proper corrosion treatment	Calibrate cathodic protection Use sequestering agent	Apply coatings properly Install and maintain cathodic protection properly
Build-up of iron and manganese	Reduce detention time Provide recirculation	Improve influent water quality Reduce detention time Optimize sequestering dose	Increase cleaning frequency
Hydrogen sulfide	Install aeration process Install ventilation systems on storage facilities	Chlorinate	Monitor
Leachate from internal coatings	Select an NSF approved coating Apply coatings properly	Sample water before returning to service Ventilate before returning to service (>30 days)	Avoid coatings with excess volatile organic chemicals

3-2. Microbiological Problems.

a. Open reservoirs or storage facilities that are not properly protected are subject to contamination from bird droppings, which can potentially transmit diseases to the finished water. Several documented cases of Salmonellosis were caused by drinking water reservoirs contaminated with bird droppings (references 8 and 9). Salmonellosis is a serious disease and can cause death.

b. Microorganisms can be introduced into open or inadequately covered reservoirs from windblown dust, debris, and animal droppings. Based on the Water Industry Database, less than 300 open distribution reservoirs are presently used in the U.S. (reference 2).

c. Covered storage facilities are generally better protected than open reservoirs; however, they can be susceptible to airborne microorganisms entering through penetrations including access hatches, roofs, and vents. Microorganisms can also be introduced into storage facilities from cross-connections, biofilm in distribution system mains, new or repaired mains which were not properly disinfected, or inadequately treated water.

d. Other factors that provide optimum conditions for microorganisms to multiply include warm temperatures, adequate nutrient levels, dissolved oxygen depletion, and long water detention times. Bacterial growth is common on tank surfaces and in other non-circulating zones of a tank. Bacterial re-growth is a concern because of the risk of waterborne disease. In addition, the presence of microorganisms can contribute to increased chlorine demand, red water problems, lowered dissolved oxygen levels, and taste and odor problems.

e. The loss of disinfectant residual is a common problem in finished water storage facilities due to long detention times or poor water circulation. Where this problem occurs, finished water is not protected from additional bacterial sources in the distribution system downstream, potentially compromising public health.

3-3. Physical Problems.

a. A floating membrane cover on a reservoir can be a source of water quality contamination if it is torn by debris, vandals, or ice action, or its seams separate due to age, faulty construction methods, or materials. Potential sources of contamination include bird droppings, leaves and other vegetative matter, contaminated surface water or other accumulated debris on the cover surface. Openings and penetrations of fixed covers that are improperly designed or maintained can allow contaminants to enter the reservoirs. Examples of openings include vents, hatches, and overflows.

b. Sediment frequently accumulates in storage tanks and can be re-suspended due to surges in flow. This is a potential source of water quality degradation and may contribute to the water's chlorine demand. One utility traced elevated coliform bacteria levels in reservoir water to accumulated sediment (reference 10).

c. Aesthetic water quality problems in finished water storage facilities include taste and odor, the presence of algae or midge fly larvae, iron and manganese sediment, and color. Color can be introduced to finished water by decaying vegetative matter and microscopic organisms present in storage facilities. Iron and manganese, which settle in a storage facility, can be reintroduced into the finished water during high demand periods.

3-4. Chemical Problems.

a. A potential chemical problem in storage facilities is the increase in disinfection by-products that can occur as a result of the presence of free chlorine in contact with the water for long storage times. These by-products include trihalomethanes and haloacetic acids.

b. The pH levels can increase or decrease in storage. Prolonged exposure to cement materials, especially when new, can increase pH, alkalinity, and calcium levels. On the other hand, pH can decrease based on the absorption of carbon dioxide.

c. Coatings and linings used to protect metals or other components can release volatile chemicals into the stored water. This normally occurs when water is placed into a storage facility immediately after field application of a coating, perhaps before the material has had a chance to fully cure. The release of volatile chemicals has both regulatory and aesthetic implications (taste and odor).

3-5. Water Quality Monitoring.

a. Monitoring in storage reservoirs is often a difficult task because sampling taps or ports have not normally been installed during the initial construction. Thus, the utility worker must usually gain access through vents and hatches, which are often inconvenient and can present safety problems. Existing hatch locations may or may not afford access to representative monitoring locations within the reservoir. Although not specifically required by regulations, sampling in tanks and reservoirs should be performed to enable the utility to know the condition of water throughout the facility. Simply sampling the inlet or outlet water will not indicate what is happening inside the storage facility. Short circuiting, and lack of use may cause water quality to vary widely throughout the reservoir contents.

b. The monitoring program, including location, frequency, parameters, and methods should be designed to accomplish its objectives. For example, routine monitoring could be very different than a special study designed to calibrate a computer model. Typical parameters for routine monitoring would include chlorine residual (free and total), temperature, HPC, total coliform, fecal coliform, pH, and total dissolved solids. Sampling of sediment at the bottom of the storage facility should also be considered. Water level elevations, hydraulic conditions, flow directions, inlet and outlet configurations, and valve positions should be documented when conducting the sampling. Safety precautions should be adhered to especially when heights or confined spaces are encountered.

c. On-line monitoring equipment, especially on the outlets of reservoirs, should be considered. This will help document how reservoir water quality affects the distribution system. Within the tank/reservoir, permanently installed sampling lines could prove very useful to facilitate monitoring.

Depending on the locations, these could operate by gravity or may need to be pumped. Freeze protection and a method to dispose of water to flush the lines prior to sampling should be considered. Other monitoring devices might include apparatus to measure corrosion rates, such as metal coupons, or specially designed slides to facilitate biofilm monitoring.

CHAPTER 4
GUIDELINES FOR INSPECTIONS AND MAINTENANCE

4-1. Inspections.

a. Inspections can take many forms and can include routine, periodic, and comprehensive. Both interior and exterior inspections are needed to assure maintenance of physical integrity, security and high water quality. The type and frequency of the inspection is driven by the type of tank/reservoir, its susceptibility to vandalism, age, condition, time since last cleaning or maintenance, history of water quality, plus other local criteria. Exterior inspections for obvious signs of intrusion or vandalism might occur daily or weekly. Periodic inspection of hatches, vents, and overflows might occur on a monthly or quarterly basis. A comprehensive inspection of the interior is normally conducted when the tank/reservoir is drained for cleaning. The requirements for comprehensive inspections, cleaning, and repainting of finished water storage facilities are generally recognized by the water industry; however, no consistent guidelines are provided on the necessary frequency of these maintenance activities. This may be because conditions vary so widely throughout the utility industry.

b. The American Water Works Association (AWWA) Standard D 101-53 (reference 11) recommends a 5-year maximum inspection interval. Many states require disinfection when returning a tank/reservoir to service, and “Ten States Standards” (reference 12) for design features but they are silent on inspection frequencies. The frequency is normally left to the discretion of the utility.

c. In Europe, the inspection frequency varies by country. United Kingdom guidelines specify a minimum of once every 10 years. In Switzerland and France, reservoirs have to be totally drained, cleaned, and disinfected once a year.

d. The TM 5-660 (reference 13) goes into great detail on what and when to inspect. Table 6 summarizing the recommended frequency of inspections has been extracted from reference 13 and included here. It is important to inspect and evaluate for settlement and leakage of ground storage. Likewise the supporting structure for elevated tanks should be checked for corrosion, loose, missing or bowed, broken or bent members, misalignment of tower legs and other evidence of instability. Left unchecked these items can have serious consequences and can result in a failure of the storage facility. Penetrations and openings for vents, overflows, and hatches need to be checked carefully to ensure they are screened and/or locked.

TABLE 6. MAINTENANCE PROCEDURES FOR STORAGE FACILITIES

Inspection	Action	Frequency
Foundations, concrete	Check for settlement, cracks, spalling, and exposed reinforcing; repair as necessary with 1 part cement to 1 part sand.	SA
Foundations, wood	Check wood foundations and pads for checked, split, rotted or termite infested members; also check for direct contact of untreated wood with soil; repair or eliminate undesirable conditions as necessary.	SA
Concrete tanks (ground level storage).		
Walls	Check exterior for seepage; mark spots	SA
	Check exterior and interior for cracks, leaks, spalling, etc.	A (Spring)
	Remove loose, scaly, or crumbly concrete; patch with rich cement grout; paint grout with iron waterproofing compound.	A
	Chip out cracks, repair with cement slurry	A
	For cracks in prestressed tanks, consult designing and/or erecting company.	A
Expansion joints	Check for leakage; check for missing filler; clean and repair as necessary.	SA
Roofs	Check condition; check hatches; check screens on openings. Clean as necessary.	SA
Earth embankments	Check for erosion, burrowing animals, improper drainage and leakage through embankment, repair as necessary; if leakage through embankment exists, drain tank and look for crack in tank walls or bottom.	SA
Concrete tanks (underground storage)	Check and repair	SA or A
Steel tanks (ground level storage)	Check for ice damage in spring; repair as necessary.	A
Walls and bottom	Examine exterior and interior for rust, corrosion products, loose scale, leaky seams, and rivets, and for condition of paint.	SA
	Replace rivets or patch leaking areas, as necessary.	V
	Check painted surfaces for deterioration; paint as necessary.	SA
Roofs	Check condition, hatches, screens, manholes, and paint; lock hatches; remove spider rods if corroded; repair, replace or paint as necessary.	SA

Steel tanks (underground storage)	Check tank interior, roof, and appurtenances	SA
Steel tanks (elevated storage)	If problem is noted during inspection, arrange for an outside contractor to repair the steel tank	SA
Tanks	Use contractor	SA
Tower structures	Check for corrosion; loose, missing, bowed, bent or broken members; loose sway bracing; mis-alignment of tower legs; evidence on instability; repair as necessary.	SA
	Check surface of lattice bars, anchor bolts, boxed channel columns, and pockets where water or trash collects; clean, repair, provide drainage or fill pockets; paint as necessary.	SA
Roofs	Check obstruction and navigation lights, hoods, shields, receptacle and fittings for missing or damaged parts, or inoperation; also check lightning rods, terminals, cables and ground connections; repair, replace or renew; paint as necessary.	SA
Risers and heating systems	Two months before freezing weather, check riser pipe insulation and repair as necessary; also check heating system operation.	A
	One month before freezing weather, operate heating system for eight hours; repair or adjust defective parts.	A
Cathodic protection	In addition to the following instructions, see Chapter 7 (reference 13).	A or V
	Check flow of current; if absent, check fuses, electrodes, ground wire connections and immersion of electrodes; adjust or repair as necessary; if current flow or amperage is above desired level, adjust as necessary; make certain that connections to rectifier are not reversed.	V
	Check operating records to make sure that electrodes are immersed at all times.	V
	Check anode condition; replace as necessary.	V
	In freezing climates, protect electrodes against ice damage, or remove and store for winter season.	V
	Test effectiveness of cathodic protection.	V
Wooden Tanks		
Towers	Check operating records to make certain tank is kept filled; also check structural condition of tank for soundness, evidence of leakage, and corrosion of steel bands; also check all appurtenances, ladders, roofs, screens, etc; make any repairs or adjustments necessary.	SA

Tank	Check operating records to make certain tank is kept filled; also check structural condition of tank for soundness, evidence of leakage and corrosion of steel bands; also check all appurtenances, ladders, roofs, screens, etc.; make any repairs or adjustments necessary.	SA
	Paint metal parts; paint timber only if necessary for appearance.	A
Pneumatic tanks	Inspect air pump and motor; check operating record of time cycle; check for air leaks, if time cycle is too short; check valve operations , particularly pressure relief valves.	Q
	Check tank for signs of corrosion; take steps necessary to eliminate corrosion or protect against it.	A
Appurtenances	Check ladders, walkways, guardrails, handrails, stairways, and risers for rust, corrosion, poor anchorage, missing pieces, general deterioration or damage; replace or repair parts as necessary.	SA
Miscellaneous appurtenances	Check all electrical connections and conduits leading to tanks; make any repairs or adjustments necessary.	SA
Grounds	Check for accumulations of debris, trash, and foliage; clean the area.	SA

Note: A - Annually
Q - Quarterly
SA - Semiannually
V - Variable, as conditions may indicate
The frequencies shown are suggested frequencies which may be modified by local command, as individual installation conditions warrant.

d. The types of comprehensive interior inspections fall into three categories: (1) drain, clean and inspect; (2) underwater inspection; or (3) float down inspection. One of the more popular methods is drain, clean and inspect; however, underwater inspections with either a diver or a remotely operated vehicle are increasing dramatically. Float down is likely the least used method. Common problems found by inspectors are no bug screens on vents and overflows, cathodic protection systems not operating or not adjusted properly, hatches not locked, the presence of lead paint interior, lead paint exterior, and the presence of non-NSF approved paints.

e. Keeping records and thorough documentation cannot be emphasized enough. Consistent forms and checklists help ensure that the same points are inspected and evaluated each time. Quantitative measurements are also important to document condition of paints, coatings, and structural integrity. Photographs with adequate field notes can be a valuable tool as can videotaping with audio explanation.

4-2. MAINTENANCE.

a. Maintenance of storage facilities is conducted on a very system specific basis. Maintenance activities include cleaning, painting, and repair to structures to maintain serviceability. Based on a review of state regulations, they leave much to the discretion of the utility, but many do recommend adhering to AWWA Standards, National Sanitation Foundation (NSF), American National Standards Institute (ANSI), and others for disinfection procedures and approval of coatings. Most states do not recommend a cleaning frequency. Guidance in AWWA publications (reference 14) indicates that water storage facilities should be drained, cleaned and disinfected annually. The surfaces of the walls and floors should be cleaned thoroughly with a high-pressure water jet, sweeping, scrubbing or other methods. All water and dirt should be flushed from the tank. Painting is suggested on an as needed basis. There are many references relating to procedures for preparing and painting surfaces, for welded steel tanks, factory coated steel tanks, circular prestressed and fiberglass reinforced plastic tanks (references 15 - 20). In addition to AWWA standards, all painting application should be completed according to the Tri-Service Manual (DOD) TM 5-618, NAVFAC MO-110, AFM 85-3.

b. After cleaning and/or painting, water storage tanks must be disinfected before being placed in service. Liquid chlorine, sodium hypochlorite solution, or calcium hypochlorite granules or tablets may be used. Three alternate methods of chlorination are recommended by AWWA C652 (reference 15), Standard for Disinfection of Water Storage Facilities. The state water supply agency should be consulted for any specific requirements. In the first method, the volume of the entire tank is chlorinated, so that the water will have a free chlorine residual of at least 10 mg/L after the proper detention time. The detention time is 6 hours if the disinfecting water is chlorinated before entering the tank, and 24 hours if the water is mixed with hypochlorite in the tank. The second method involves spraying or painting all interior tank surfaces with a solution of 200 mg/L available chlorine. This is a hazardous procedure and should only be done by trained, experienced, and properly equipped personnel. In the last method, 6 percent of the tank volume is filled with a solution of 50 mg/L available chlorine for at least 6 hours. Then the tank is completely filled and the solution held for 24 hours. Dechlorinate highly chlorinated water and check with wastewater department personnel before discharging into a sanitary sewer. Check with the state environmental agency before discharging highly chlorinated water elsewhere.

CHAPTER 5
GUIDELINES FOR OPERATIONS

5-1. Excess Detention Time in Storage Facilities. The major problem with storage tanks/reservoirs is that water loses chlorine residual, which increases the propensity to grow bacteria. There are several causes for loss of chlorine residual including the presence of oxidizable substances, organics and inorganics, higher temperatures, the presence of biofilm, and long detention times. This section will address the important parameter of detention time. The lengthy detention times result from lack of turn over or flow through because reservoir design and operation results in dead zones. The distribution system operations staff have one effective tool to reduce detention time, that is turn the water over on a routine basis. This approach runs counter to historical methods of reservoir operation and in many cases, will require a significant change in operating philosophy. Often times pumping is required to move water and that costs money.

5-2. Turnover Rates.

a. Water can be considered a perishable product and has a shelf life (detention time), a preservative (chlorine or chloramine), and packaging (pipes and reservoirs). Storage reservoirs affect detention time and are part of packaging. Thus, many utilities are developing their own system operating strategies to improve the quality of water in storage facilities. For example, a large west coast utility (reference 21) has a goal of maintaining a minimum chlorine residual of 0.5 mg/L in covered tanks/reservoirs and attempts to have a full turn over of water in open distribution reservoirs once every 5 days. The state of Ohio suggests a turn over rule and they require that 20 percent of the volume change over daily. This equates to a turn over rate of once every 5 days. The German experience suggests a 5 to 7 day maximum retention time in reservoirs with cement-based internal surface. The Swiss experience suggests a 1 to 3 day maximum retention time due to lower chlorine residuals carried in that country. Each tank/reservoir will have its own needs and characteristics. One point for certain, tanks and reservoirs that ride the system for long periods during low demand periods are cause for concern. Both the science and field experience indicates that such operation is a recipe for future problems.

b. To help establish a turnover rate, the utility should, at the very least, consider the issues of water quality and reservoir configuration. Regarding water quality, the utility needs to determine the chlorine decay rate of water in the reservoir. With the inlet chlorine residual and the decay rate, the utility can calculate a theoretical turnover rate to maintain a pre-established chlorine residual goal. This is most applicable for facilities that function in a plug flow mode. The physical configuration and flow characteristics of the storage facility will dictate mixing in the facility. If the facility has a common inlet and outlet, then there are likely to be dead zones where water may age for weeks. Thus fresh water near the inlet may have an adequate chlorine residual but water in dead zones may have no residual. In such a case, the utility could consider retrofitting the reservoir with a hydraulic circulation system. This also emphasizes the need for monitoring in the reservoir as described in Chapter 3-5.

c. In addition to establishing an average turnover rate (e.g., once in 3, 5 or 7 days), the utility should establish a water level fluctuation approach that will turn over a majority of the water in one continuous operation. This is especially true for reservoirs with common inlets and outlets such as standpipes. Simply withdrawing 20 percent of the volume of a stand pipe each day and immediately refilling will still leave a major portion of storage volume untouched for long periods. It would be advisable to fluctuate the level to withdraw an estimated 60 percent of the volume in one day and refill it the next.

d. Operations staff can do much to enhance water quality; however, many tanks/reservoirs will need to be upgraded with recirculation systems, rechlorination systems, or baffles to maintain water quality. These features are discussed below under design and engineering considerations.

CHAPTER 6
ENGINEERING DESIGN AND RETROFIT CONSIDERATIONS

6-1. Background.

a. Historically, storage requirements have been driven by pressure, flow equalization, and emergency reserve. The quantity of storage has been developed based on average or peak day demands, plus fire flow requirements, plus emergency storage. Only recently has water quality been of significant interest to designers and constructors of finished water storage reservoirs.

b. One of the most significant problems associated with storage tanks/reservoirs is that they have not been designed as either plug flow reactors or completely mixed reactors. They have often been somewhere in between, and hence dead zones with very long detention times have resulted in some facilities. Many tanks/reservoirs have common inlets and outlets which have exacerbated the dead zone problem. The key to reservoir configuration from a water quality standpoint is to design it so that it approaches either a completely mixed state or a plug flow.

6-2. Hydraulic Circulation System. A properly designed pumped circulation system can provide good mixing while not subjecting finished water to potential contamination or significantly increasing maintenance requirements. In addition, pumped circulation can be easily designed and operated to provide a variable intensity of mixing, and it simplifies the re-chlorination process, if required. A circulation system would not be recommended for plant storage (a clearwell) which is being used to achieve a certain level of disinfection, e.g. disinfection contact time (CT), before serving the first customer. A pumped circulation system is described below (reference 21).

a. System Sizing; Objectives and Basis. The water quality objectives of a circulation system in a reservoir are to maintain acceptable chlorine residuals throughout the reservoir and to minimize bacteria occurrences and maintain disinfection by-products at low levels. The hydraulic objectives of reservoir circulation are to reduce dead zones of stagnant water and to apply and mix chlorine when rechlorination is practiced. Since the intent of a circulation system is to make the reservoir contents as homogenous as possible, the water leaving the reservoir should be nearly the same quality as the mixed water inside. A separate inlet and outlet for the reservoir would help ensure that the newest water is collected and discharged into the circulation system.

b. Mixing in a specific reservoir will be influenced by numerous factors. A few factors are summarized below.

(1) Reservoir shape (length to width ratio)
(2) Reservoir surface area
(3) Reservoir depth
(4) Inlet pipe location relative to reservoir geometry
(5) Inlet pipe discharge depth
(6) Direction of exit velocity from inlet pipe and any baffling/diffuser installed

(7) Outlet pipe location, depth
(8) Exchange ratio
(9) Wind effects if open and broad
(10) Thermal stratification effects if open and broad
(11) Buoyance effects of inlet discharge if there is a difference in temperature between reservoir water and entering water

c. All of the factors outlined above affect the amount of energy being dissipated in the reservoir and the distribution of this energy. It is proposed that the energy or velocity gradient be used as a basis for establishing the power needed to maintain adequate mixing in a reservoir. The equation is

G= SQRT
{P}

where G = energy or velocity gradient, sec^{-1}
P = power input, ft-lb/sec
= dynamic viscosity, $lbf\text{-}sec/ft^{2}$
V = volume, ft^{3}

The energy gradient has long been utilized in the design of rapid mix and flocculation unit operations. However, its use in establishing power requirements for reservoir mixing is a relatively new concept. A "G" factor of 10/sec has been suggested to provide adequate mixing in storage reservoirs (reference 21).

d. The energy gradient calculation yields the total power requirement, but does not address how mixing energy should be distributed throughout the reservoir. In comparison with a rapid mix basin, a reservoir has vastly more volume, and is generally fairly shallow and broad with substantial surface area. Adequate distribution of the energy throughout the reservoir is critical in achieving good mixing.

e. The circulation system should re-introduce the circulated water into the reservoir as uniformly as possible. At the same time, the system should promote adequate mixing to approach homogeneity of the water inside the reservoir. Diffusers, defined as pipes with a series of strategically placed and sized orifices, or ports, should be used to re-introduce the circulated water into the reservoir.

f. A rechlorination system could be included and would operate automatically using a chlorine residual analyzer to control the chemical feed pump. A recirculation system could be operated continuously or intermittently with either timer control or residual paced control.

The following procedure may be used as an approach for design of the circulation system:

(1) Select the energy gradient goal
(2) Determine port spacing and placement
(3) Select port diameter and circulation flow
(4) Design piping system, compute head losses and check system for proper distı
(5) Choose the orientation of jets
(6) Select pump
(7) Decide whether a rechlorination system is needed

6-3. Baffling Systems.

a. Baffling to promote plug flow inside the reservoir can be accomplished with several different materials including:

(1) Cast-in-place concrete,
(2) Concrete masonry units (CMUs),
(3) Framing (stainless steel, aluminum, or fiber-reinforced-plastic [FRP]), and
(4) Flexible membranes (polypropylene or hypalon) hung as curtains.

b. The type of material used in the reservoir may dictate which baffling system is most appropriate to use. The framed or hanging curtain systems may be more amenable to retrofitting into existing reservoirs, but they are also used in new reservoirs. The concrete and CMU materials would be longer lasting. If two or more options are available, a present worth life cycle cost comparison could be used to help select the best alternative.

c. The baffles should extend from the reservoir floor to above the maximum water level. Small openings at the floor level can be provided to facilitate drainage and cleaning, or multiple floor drains can be provided for the same purpose. Preferably, any openings in the baffles should be plugged during normal operation to avoid short-circuiting. Removable walk-through openings or doors have been used in baffles to facilitate inspections and reservoir maintenance. Such baffles could be designed using CMUs for the walls, and flexible membranes for openings and doors. In seismic design zones, baffles and their support systems must be structurally designed for the effects of seismic action and the resulting waves within the reservoir.

d. For circular reservoirs, a configuration using three to seven baffles is suggested, depending on water quality concerns and the expected degree of stagnant water. Placing more than seven baffles in circular reservoirs typically is not cost-effective, and achieves little additional efficiency in reducing dead zones within a reservoir.

e. For rectangular basins, baffling should be arranged to provide a length-to-width ratio of about 20:1, maximum. The width is measured as channel width, or spacing between baffles, and the length is total traveled distance through all channels. Attaining a length-to-width ratio greater than 20:1 in rectangular reservoirs does not significantly improve the plug flow regime, so these criteria are considered to be maximum limits for baffling spacing. Less baffling may be justifiable if stagnant zones are not expected to be a problem. Also, physical modeling prior to design should be considered to provide detailed information on piping, baffles, and inlet/outlet facilities.

6-4. Inlets and Outlets.

a. Separate inlets and outlets are mandatory in plug flow reservoirs and preferred over combined inlet/outlets in circulation mixing reservoirs. Separate inlets and outlets also allow for better flow rate monitoring in and out of the reservoir and facilitate the application of chlorine. Reservoirs that are not hydraulically connected to the distribution system (e.g., pumped storage) typically have separate inlets and outlets; a fill line with a level-controlled valve and a suction line for the pump station. Reservoirs that are hydraulically connected to (e.g., float on) the distribution system may have a single connection point. In this case, the connection pipe would be split into separate lines with check valves in opposite directions for the inlet and outlet pipes entering the reservoir.

b. When no baffling exists in the reservoir, it is usually best to locate the inlet and outlet as far apart as possible. The inlet and outlet pipes can be configured to promote circulation. For example, providing a 90 degree bend on the inlet oriented parallel to the wall of a circular reservoir will help move water around in the reservoir before flowing to the outlet pipe. Some experiences have indicated that good resistance to short-circuiting can be achieved with a 90 degree bend on the inlet as described above and a center-located outlet.

c. Inlets and outlets should be designed to distribute and collect water evenly over the entire water depth. An inexpensive method of accomplishing this uses a perforated riser pipe. The inlet riser can be the same diameter as the service pipe; however, the outlet pipe should be a larger diameter to provide more orifice area to reduce orifice headloss. The orifices of a riser pipe should be sized and spaced so that headloss through the inlet orifices is 1 to 2 feet to help ensure uniform dispersion. If the source of supply filling the reservoir has additional head available, the inlet can be sized for greater head loss (up to about 5 feet) to get even better distribution over the full depth. Because the outlet is normally gravity flow, head loss through the outlet orifices should be no more than 0.5 foot. For larger reservoirs or shallow reservoirs where riser pipes would be inadequate as diffusers, a dispersion baffle in an inlet and outlet compartment of the first and last baffle chamber could be used. Both inlet and outlet should terminate above the reservoir floor surface. This will help keep any sediment that has accumulated from entering the distribution system.

d. A standpipe often has the most stagnant zones of any type of reservoir when a bottom connection is used. To help remedy this, a separate inlet pipe which rises to at least 75 percent of the full water depth should be considered.

6-5. Design and Engineering Practices. Finished water storage facilities are designed to provide stability and durability as well as to protect the quality of the stored water.

a. Tank Appurtenances. General design criteria for storage facilities, including piping and other appurtenances, are provided by The Water Authorities Association (1988) (reference 22) in the United Kingdom, and the Ten States Standards (1992) (reference 12) in the U.S. Similar criteria are found in all the European Union countries. Design criteria which affect finished water quality are described below.

(1) Multiple compartments or a by-pass arrangement are recommended to enable maintenance to occur without disrupting service. This is especially important if a system has only one storage facility. Storage facilities should be designed to allow the tank to be drained without causing loss of pressure in the distribution system. Internal surfaces should be easy to sweep out and clean.

(2) The overflow pipe should be equipped with noncorrodible screen or a flap to prevent the entrance of animals or vandals. The overflow pipe should not have a shutoff valve, and should not be directly connected to sewer pipes or storm drains.

(3) Inlet and outlet piping should have shutoff valves to isolate the tank for maintenance. Separate inlet and outlet pipes are recommended to improve water circulation. They should be located on opposite sides of the tank, with the outlet near the bottom. Piping should be arranged to avoid introduction of silt to the storage facility. Likewise, the outlet should be above the floor level to preclude settled material from entering the distribution system.

(4) Surface water or roof drains should not pass through the storage facility, nor should they be directly connected to overflow pipes. The drainage system should minimize surcharging of any peripheral wall drains or underdrains so as to avoid any risk of groundwater entering the storage facility. No piping should be directly connected to sewer pipes, storm drains, or overflow pipes.

(5) Access hatches should be sized and located to allow convenient access for cleaning and maintenance. Manholes should be located above the waterline. Access hatch covers should be easily operated by one person, and should be watertight and vandal resistant.

(6) Adequate ventilation should be provided to safeguard the structure in the event of rapid drawdown due to a burst main or similar occurrence. Vents should prevent entrance of rainwater and surface water, and should be equipped with noncorrodible screening to exclude birds and animals, insects and dust to the greatest extent possible.

(7) Sampling taps should be provided in inlet and outlet piping and at various tank levels to allow collection of water samples. Sampling pumps can be installed at access hatches.

(8) Internal catwalks should have a solid floor with raised edges so designed that shoe scrapings and dirt will not fall into the water.

(9) Recirculation systems, baffles, and mechanical mixers are used to improve water circulation patterns in a tank, reducing possible water quality degradation. These appurtenances are especially useful during low demand periods.

(10) Rechlorination systems may be installed at storage facilities to provide higher chlorine residuals in the distribution system.

(11) Midge-fly larvae can be controlled through installation of 20 mesh noncorrodible screen on all vents and cover openings.

(12) Thermal insulation of a storage facility can control humidity and condensation, which often cause corrosion of hydraulic and electromechanical equipment. Hammer and Marotz (reference 23) found that thermal stratification in storage facilities contributed to bacterial regrowth, and suggested that insulation could be used to minimize thermal influences. Houlmann (reference 24) recommended a one meter cover of soil above the reservoir as insulation. To correct condensation problems, Baur (reference 25) recommended the use of mobile air dryers in piping as a cost and energy effective remedy.

b. Flexible Membrane Covers. Flexible membrane covers can be installed on open reservoirs to eliminate water quality problems from sources such as algae, midge-fly larvae, and microbial contaminants. They can be fabricated to fit any shape or size reservoir. Conventional construction methods require draining the water from the reservoir and installing the membrane in the dry. However, there is a technique, “launching,” in which the cover is floated into place. This method has only been used infrequently on smaller reservoirs, 10 MG or less. Design and installation considerations are provided in the AWWA Manual M25 (reference 26). The AWWA Standard D130 provides material specifications, construction requirements, and field installation requirements. The NSF Standard 54 provides material specifications and ASTM test methods. Appurtenances which remove accumulated surface water and debris from the cover surface are an important design feature affecting finished water quality. Design, construction, and maintenance of seams are especially important for minimizing damage and potential contamination of the potable water.

APPENDIX A

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PREPARATION

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