Model Aquatic Health Code

Recirculation Systems and Filtration Module ANNEX Sections for the First 60-day Review

Posted for Public Comment on 07/02/2013
Currently Open for Public Comment that Closes on 08/31/2013

In an attempt to speed the review process along, the MAHC steering committee has decided to release MAHC draft modules prior to their being fully complete and formatted. These drafts will continue to be edited and revised while being posted for public comment. The complete versions of the drafts will also be available for public comment again when all MAHC modules are posted for final public comment. The MAHC committees appreciate your patience with the review process and commitment to this endeavor as we all seek to produce the best aquatic health code possible.

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MAHC Recirculation Systems and Filtration Module Abstract

Health issues related to waterborne diseases as well as exposure to chemicals associated with pool water are increasingly being documented. The Recirculation Systems and Filtration Module is a first step towards improving water quality at aquatic facilities and reducing associated health effects. The Recirculation Systems and Filtration Module contains design and construction requirements that are, unless otherwise specified, applicable only for new or modified construction. New and improved elements include:

1) More aggressive turnover times and more uniform standards for recirculation system design and operation.
2) Filter design and operation standards that will promote more effective and efficient filtration.
3) Requiring water replenishment to dilute out the dissolved contaminants that cannot be removed by pool filters.
4) Development of a long-term plan to use pool filters for pathogen removal in addition to water clarity in a multiple barrier system that would complement all disinfection processes
5) Use of improved flow meters

MAHC Recirculation Systems and Filtration Module Review Guidance

The **Model Aquatic Health Code (MAHC) Steering** (http://www.cdc.gov/healthywater/swimming/pools/mahc/steering-committee/) **and Technical** (http://www.cdc.gov/healthywater/swimming/pools/mahc/technical-committee/) **Committees** appreciate your willingness to review this draft MAHC module. Your unique perspectives and science-based suggestions will help ensure that the best available standards and practices for protecting aquatic public health are available for adoption by state and local environmental health programs.

Review Reminders:

- Please download and use the **MAHC Comment Form** (http://www.cdc.gov/healthywater/swimming/pools/mahc/structure-content/) to submit your detailed, succinct comments and suggested edits. Return your review form by 08/31/2013, as an email attachment to **MAHC@cdc.gov**.

- If part of a larger group or organization, please consolidate comments to speed the MAHC response time to public comments.

- To provide context for this module review, please consult the **MAHC Strawman Outline** (http://www.cdc.gov/healthywater/pdf/swimming/pools/mahc/structure-content/mahc-strawman.pdf). Section headers of related content have been included in this draft module to assist reviewers to see where each section fits into the overall MAHC structure. Additional MAHC draft modules that contain this content will be or already have been posted for your review.

- The complete draft MAHC, with all of the individual module review comments addressed will be posted again for a final review and comment before MAHC publication. This will enable reviewers to review modules in the context of other modules and sections that may not have been possible during the initial individual module review.

- The published MAHC will be regularly updated through a collaborative all-stakeholder process.

Please address any questions you may have about MAHC or the review process to **MAHC@cdc.gov**. You may also request to be on the direct email list for alerts ("Get Email Updates" is in a box on the right hand side of the Healthy Swimming website at www.cdc.gov/healthyswimming) on the other draft MAHC modules as they are released for public comment.

Thank you again, and we look forward to your help in this endeavor.
Sincerely,

Douglas C. Sackett, Director
MAHC Steering Committee

The Recirculation Systems and Filtration Code Module shows a Table of Contents giving the context of the Recirculation Systems and Filtration Design, Construction, Operation and Maintenance in the overall Model Aquatic Health Code's Strawman Outline (http://www.cdc.gov/healthywater/pdf/swimming/pools/mahc/structure-content/mahc-strawman.pdf).

Reviewer Note on Module Section Numbering:

Please use the specific section numbers to make your comments on this Draft Model Aquatic Health Code module. These numbers may eventually change during the editing of the compiled Draft that will be issued for a final round of comments

Reviewer Note on the MAHC Annex

Rationale

The annex is provided to:
- (a) Give explanations, data, and references to support why specific recommendations are made;
- (b) Discuss the rationale for making the code content decisions;
- (c) Provide a discussion of the scientific basis for selecting certain criteria, as well as discuss why other scientific data may not have been selected, e.g. due to data inconsistencies;
- (d) State areas where additional research may be needed;
- (e) Discuss and explain terminology used; and

(f) Provide additional material that may not have been appropriately placed in the main body of the model code language. This could include summaries of scientific studies, charts, graphs, or other illustrative materials.

Content

The annexes accompanying the code sections are intended to provide support and assistance to those charged with applying and using Model Aquatic Health Code provisions. No reference is made in the text of a code provision to the annexes which support its requirements. This is necessary in order to keep future laws or other requirements based on the Model Aquatic Health Code straightforward. However, the annexes are provided specifically to assist users in understanding and applying the provisions uniformly and effectively. They are not intended to be exhaustive reviews of the scientific or other literature but should contain enough information and references to guide the reader to more extensive information and review.

It is, therefore, important for reviewers and users to preview the subject and essence of each of the annexes before using the document. Some of the annexes (e.g., References, Public Health Rationale) are structured to present the information in a column format similar to the code section to which they apply. Other annexes or appendices provide information and materials intended to be helpful to the user such as model forms that can be used, recreational water illness outbreak response guidelines, and guidelines for facility inspection.

Appendices

Additional information that falls outside the flow of the annex may be included in the Model Aquatic Health Code Annex

Acronyms in this Module: See the Recirculation Systems and Filtration Module, Code Section

Glossary Terms in this Module: See the Recirculation Systems and Filtration Module, Code Section

Preface: *This document does not address all health and safety concerns, if any, associated with its use. It is the responsibility of the user of this document to establish appropriate health and safety practices and determine the applicability of regulatory limitations prior to each use.*

Model Aquatic Health Code
Recirculation Systems and Filtration Module Annex
4.0 Design and Construction

Keyword	Section	Annex
	4.0	**Design Standards and Construction**
	4.1	**Plan Submittal**
	4.2	**Materials**
	4.3	**Equipment Standards**
	4.4	**Pool Operation and Facility Maintenance**
	4.5	**Pool Structure**
	4.6	**Indoor/Outdoor Environment**
	4.7	**Recirculation and Water Treatment**
	4.7.1	**Recirculation Systems and Equipment**

4.7.1.1 General

Rationale for Prescriptive Approach

Recirculation and water treatment systems guidance tends to be more prescriptive than performance based because it is quite difficult and expensive to measure the performance of the filtration and recirculation system with regard to pathogen removal and/or inactivation. Even the measurement of water clarity (e.g., turbidity) can be difficult (due to potential bubble formation, instrument fouling, and instrument calibration procedures) and can cost more than a thousand dollars to continuously measure turbidity at a single point.

Reasons to exceed the minimum standards

There is no single turnover time or one type of filtration system that is optimal for every pool. Requiring the most aggressive design for every pool is not the intent of the MAHC (or even necessary). However, some pools, particularly those with high numbers of bathers per unit water volume, could need higher recirculation rates and more efficient filtration than the minimum standards. Since it is not always possible to predict the number of bathers in a pool, the MAHC recommends a modest overdesign of the recirculation system pipes and thus ample space be left for expansion of pumping and filtration capacities, which will be referred to henceforth as the hydraulic flexibility recommendation. Future editions of the MAHC could have higher minimum standards that pool facilities might wish to comply with without having to remove and replace a lot of concrete to accommodate slightly larger pipes.

Hydraulic Flexibility

The hydraulic flexibility recommendation made in the section

Keyword Recommendation	Section	Annex
		above will also reduce friction losses in the pipes that may lead to energy savings and reduced operating costs. With the formalization of a new turndown system for pools, it is hoped that pools may be designed for worst-case conditions and then operated according to the demands placed on the system. A turndown system could be used to operate below the minimum operational standards set by the MAHC when the pool is not occupied as an additional cost-saving measure as long as water quality criteria are maintained.
Combined Venue Treatment	***4.7.1.2***	***Combined Venue Treatment***
		There are some important considerations to take into account when considering combined venue treatment, and this practice is generally discouraged for most installations. First, to respond to a contamination event, it would be necessary to shut down all pools and water features on a combined venue treatment system. Second, including an increased risk aquatic venue on a combined system would require secondary disinfection for all venues on the recirculation system. The two scenarios are isolating the *Cryptosporidium* to a single pool (limiting the number of bathers exposed while keeping the concentration high) or diluting it as much as possible between all pools (to limit the maximum concentration or exposure level while increasing the number exposed). Based on the ID-50 concept (i.e., the number of oocysts required to be ingested to cause an infection), diluting *Cryptosporidium* or other contaminants is one way of reducing outbreak potential although the high numbers of *Cryptosporidium* oocysts that may be excreted may overwhelm modest dilution factors while increasing the number of people exposed. While the number of bathers exposed may increase, the exposure level will decrease if circulation rates were the same meaning dilution of a very small pool into a large pool might reduce the *Cryptosporidium* level from 1000's of oocysts per mL swallowed to less than 1 per mL in the combined system. However, smaller pools can be circulated at faster rates through the secondary disinfection system and therefore can have oocysts loads reduced faster if they are in a small volume, rapidly circulating aquatic venue. Design modeling is needed to compare the efficacy of these two scenarios under different oocyst concentrations. The dilution scenario only works if an increased risk aquatic venue of small volume is combined with a large volume aquatic venue. For pools similar in size, the impact of dilution is small while the number of people

Keyword	Section	Annex
		exposed might double. There could also be benefits with a combined system that would make it easier to provide more stable water quality parameters (in terms of pH and chlorine level) because larger water volumes tend to be easier to control. Again, the potential positive impact of combined treatment is limited to combining small pools with much larger pools, which is not likely if the disinfection requirements differ between the venues. Hydraulically isolating a given venue on a combined treatment system with valves is discouraged because doing so necessarily prevents filtration and recirculation of the water. However, isolation capabilities are recommended for maintenance purposes (as well as separate drain piping).
Inlets	**4.7.1.3**	**Inlets**
General	4.7.1.3.1	General
Flow Velocity		The velocity of flow through any inlet orifice (at between 100% and 150% of the total recirculation flow rate chosen by the designer) should normally be in the range of 7 to 20 feet per second (2 to 6 m/s). The range of velocities through the inlets was selected to balance two competing goals. The velocity should be high enough to push water effectively to the center of the pool (or to within the range of the floor inlets for wider pools), but the velocity should not be so high as to waste an unnecessary amount of energy. The inlets still being within design range at 150% of the design recirculation flow rate is to accommodate the hydraulic flexibility recommendation discussed previously. This recommendation ensures proper operation at both the current and any future flow rates up to at least 150% of the recirculation flow.
Floor Inlets	4.7.1.3.2	Floor Inlets
Maintain and Measure		The use of floor inlets might require additional considerations for draining them when the pool is not in use. The likelihood of biofilm proliferation in pipes not in use is thought to increase significantly as the free chlorine residual is dissipated. Drinking water distribution pipes are normally coated with biofilm even in the presence of a constant chlorine residual[1,2]. Since it is more difficult to inactivate

[1] Niquette P, Servais P, Savoir R. Impacts of pipe materials on densities of fixed bacterial biomass in a drinking water distribution system. Water Research. 2000;34(6):1952-1956.

Keyword	Section	Annex
		microorganisms in a biofilm[2], there is potentially increased risk of human exposure to pathogens shielded by biofilm once the pool reopens. Leoni and coworkers found mycobacteria in 88.2% of pool water samples analyzed and reported that swimming pools provided a suitable habitat for the survival and reproduction of mycobacteria[3]. Significant damage to the recirculation system pipes and surroundings can result from the expansion of water as it freezes. Both dangers may be alleviated by simply draining water from the pipes when the pool is not in use. Provisions might also be recommended to prevent the pipes from refilling with water once drained.
Wall Inlets	*4.7.1.3.3*	*Wall Inlets*
Effective Mixing	4.7.1.3.3.2	The vertical range of a wall inlet to mix treated water returning to the pool is limited, especially near the wall. For this reason, a recommended inlet system for diving and other areas deeper than 10 feet (3 m) in pools less than 50 feet (15.2 m) in width is two rows of wall inlets, one within 3 feet (.9 m) of the bottom, or floor inlets. For standard swimming pools, since the majority of the water leaving the pool does so at the surface, locating the inlets 24-inches (61 cm) below the design operating water level would reduce short-circuiting of water from the inlets to the surface removal system.
Inlet Spacing	4.7.1.3.3.4	Wall inlets have a limited range for how far they can push water out toward the center of the pool especially as the flow of water is being pulled out of the pool at the wall via gutters or skimmers. The likelihood of forming regions in the center of the pool that are not efficiently filtered or chlorinated increases as the width of the pool increases. For pools less than 4 feet in depth, the average velocity of the water is thought to be increased as the volume of water served by a single inlet is expected to decrease assuming equal spacing. Floor inlets are thought to more effectively distribute chlorinated filtered water to the center of the pool thereby reducing the magnitude or likelihood dead zones in the center of the pool. The designer should take into account climate

[2] Goeres DM et al. Evaluation of disinfectant efficacy against biofilm and suspended bacteria in a laboratory swimming pool model. Water Research. 2004;38(13):3103-3109.
[3] Leoni E et al. Prevalence of *Mycobacteria* in a swimming pool. Environment. J. Applied Microbiology. 1999;87(5):683-688.

Keyword	Section	Annex
		when designing the inlet system and provide proper drainage instructions.
Dye Testing	4.7.1.3.3.6	**Dye Test Procedure**
Procedures in Appendix		Please See Appendix 1 for Dye Test Procedures. Dye testing should be performed to determine and adjust the performance of the recirculation system. Dye studies tend to be qualitative in nature[4]. Some judgment is generally required to determine whether a dye study should be classified as passing or a failing. In general, dead zones (or areas of poor circulation) would indicate a failure that could be fixed by adjusting the inlets or other system hydraulics. If the pool does not reach a uniform color within 15-20 minutes, then adjustments are required.
Overflow Systems	***4.7.1.4***	***Overflow Systems/Gutters***
General	*4.7.1.4.1*	*General*
Skimming	4.7.1.4.1.1	Perimeter Overflow/Gutter Systems are intended to remove surface water from the pool (spa, etc.) for treatment and recirculation. They need to remove water from all parts of the pool equally. Much of the dirt, oil, bacteria, floating debris and possibly undissolved chemicals are in the top inch of water. There may also be less disinfectant due to aerosolization and oxidant demand. Indoors, there is some evidence that disinfection by-products build up in the top layer where they are more likely to aerosolize and contribute to poor air quality and bather discomfort. Areas that do not have circulation due to lack of gutters or return grates (e.g., zero-depth entries) or which have gutters that are not level may not have adequate flow in these areas and may develop "dead spots" where the disinfectant is not present at adequate levels to prevent recreational waterborne illnesses or algae growth. The corners of pools with skimmers are a case in point. Unsightly debris such as "oil slicks", blowing paper, dead bugs and leaves may also collect in these "dead zones".

[4] Alberta. Pool Standards, 2006 for the Swimming Pool, Wading Pool, and Water Spray Park Regulation. (Last accessed 1/1/2011).http://www.health.alberta.ca/documents/Standards-Pools.pdf

Keyword	Section	Annex
Designs		Novel designs (e.g., gutters located on only the two longest sides of the pools) should be subject to approval by the local authority with proper engineering justification (e.g., a computational fluid dynamics (CFD) model of the pool design demonstrating acceptable hydraulic balance and mixing).
Size and Shape	*4.7.1.4.2*	*Gutter Size and Shape*
Continuous Water Removal		A value of 125 percent of the total recirculation flow rate chosen by the designer is recommended for hydraulic flexibility.
		Oversizing the skimmer capacity for "point surge." As patrons swim, play, dive and splash, they create waves that exceed the normal recirculation one might see when the pool is empty. Upsizing the gutter system allows capture of the waves without flooding the gutter, which would make the gutter ineffective. Human body density is approximately equal to water (fat is less and muscle is more) at approximately 1 g/mL. A 200 pound person displaces approximately 24 gallons. (200 lbs. x 0.454 kg/lb. x 1L/kg x 0.264 gal/L = 24 gallons) The average patron is not 200 pounds, so this conservative parameter provides extra capacity in the surge system for more dynamic wave instances.
		Surge capacities recommended by state health departments of 1 gallon per square foot of pool water are common. For an average of 24 (typically 16 to 30) square feet of water per person and 24 gallons per person to be conservative, the net surge capacity is 1 gallon per square foot of pool. This is not new information and was considered over a decade ago. The State of Iowa tried 2 gal/ft^2 for a few years, but found that to be unnecessary. It continues to work well in the pool designs we see. Once again, the oversized gutter system is recommended to account for how patrons enter and displace the pool water adjacent to the gutter. The 125% gutter capacity and the 1 gallon of surge per square foot of area both continue to work well in practice. The gutter capacity must be even greater for designs relying on play feature and slide flow being returned through the gutter.
Outlets	*4.7.1.4.3*	*Gutter Outlets*
Design Capacity		A value of 125 percent of the total recirculation flow rate chosen by the designer is recommended for hydraulic

Keyword	Section	Annex
		flexibility. The design goal is to avoid inadequate outlet spacing in these old gutter channels. The spacing between drain outlets should not exceed 10 feet (3 m) for two inch (5.1 cm) diameter drains or 15 feet (4.6 m) for two and one half inch (6.4 cm) drains, unless hydraulically justified by the design engineer.
Surge Capacity	4.7.1.4.4	**Surge Tank Capacity**
Draining		Surge tanks should be provided with means for complete draining to allow routine inspections, maintenance, and cleaning. Proper maintenance will reduce the chances of biofilm formation and bio-corrosion. Surge tanks should also have a means of draining for winterization, where applicable. An overflow is recommended to prevent a pool from flooding deck areas (indoor) if over filled and flooding filter rooms during rainfall events. An air break is recommended to prevent a cross-connection with the pool water that could introduce contaminated to the pool.
Contain		Surge tanks can contain valves, piping, float controls, heating system manifolds or heat exchangers, makeup water controls and large basket screens for large pool facilities. They also can act as a settling basin for large particles and debris coming directly from the main drains and gutters. It is reasonable to drain these tanks to access equipment and remove settled materials.
Tolerances	4.7.1.4.5	**Tolerances**
		Gutters tolerances were chosen to keep water flowing in even proportions from all sections of the pool and to avoid dead spots and scum lines. Tighter tolerances may be needed for competitive pools.
Makeup Water	4.7.1.4.6	**Makeup Water System**
		Other backflow prevention devices may include the following: • reduced pressure principle assembly (RP), • pressure vacuum breaker assembly (PVB), • spill-resistant vacuum breaker assembly (SVB), or an • atmospheric vacuum breaker assembly (AVB).
		All devices may not be appropriate for all installation

Keyword	Section	Annex
		conditions.
Skimmers	***4.7.1.5***	***Skimmers and Alternative Gutter Technologies Using In-pool Surge Capacity***
General	*4.7.1.5.1*	*General*
Provided	4.7.1.5.1.2	The use of skimmers could be limited to pools with surface areas of less than 1,600 square feet (149 m^2), and the maximum width for pools using skimmers could be restricted to less than 30 feet (9.1 m).The use of skimmers has been limited to smaller pools with light bather loads since their inception. The limitations of skimmers versus gutters appear to be physical in nature. For example, a 30 ft x 50 ft (9.14 m x 15.24 m) swimming pool may be served 3 skimmers rated at 500 square feet each. If each skimmer is 1 foot wide, then all of the skimmed water is being drawn off from only 3 foot of the pool perimeter (i.e., 1.9 % of the total perimeter). This would lead to higher water velocities over the floating weirs and water being collected from a greater depth (as opposed to actual surface skimming) relative to a gutter system that extends around the perimeter of the pool. In this example, 98.1% of the perimeter of the pool is not being used to skim water and could produce regions of limited flow and scum collection. Theoretically, enough skimmers might be added to produce effective skimming comparable to a gutter system, but the research to demonstrate this in practice could not be found. Practical experience says that having no scum lines or dead zones in corners with stagnant debris are inherent advantages. There could also be practical hydraulic limitations for heavily loaded pools related to use of in-pool surge as opposed to a surge tank. Equalizer lines are recommended to prevent skimmers from pulling air into the pump and potentially causing loss of prime, flow surges, and interference with proper filter operation.
Hybrid Systems	4.7.1.5.1.3	Hybrid systems that can switch between skimmers and overflow gutters through the use of in-pool surge should meet all of the requirements specified for each system. Since the number of bathers determines the type of surface overflow system in use, the hybrid systems should be able to meet all code requirements regardless of how many bathers are present and which components are in active use.
Design Capacity	4.7.1.5.1.5	The 100 percent of the total recirculation flow rate chosen by the designer is recommended as part of the hydraulic

Keyword	Section	Annex
		flexibility recommendation.
Location	*4.7.1.5.2*	*Skimmer Location*
Flow Rate	*4.7.1.5.3*	*Skimmer Flow Rate*
NSF 50		Skimmers should provide for a flow-through rate of 30 gallons per minute (1.9 L/s), or 3.75 gallons per minute per linear inch (9.3 L/s/m) of weir, whichever is greater. The authority having jurisdiction may approve alternate flow-through rates so long as the skimmer are NSF listed (or equivalent) and manufacturer's design specifications are not exceeded.
Control	*4.7.1.5.4*	*Control*
Tolerances	*4.7.1.5.5*	*Tolerances*
Testing	*4.7.1.5.6*	*Testing*
Procedure		***Flotation test procedure***
Materials		***Materials Needed:***

- Yellow wooden stars (55 -110 minimum depending on the pools surface area)
- Video camera
- Tripod

Initial Conditions

Conditions prior to test:

- Turnover time and recirculation flow rate are operated as normal for the pool
- Inlets and outlets are positioned as normal for the pool
- Skimmers or gutter system is not flooded
- If using skimmers make sure that the weirs are present
- Water level is at the appropriate height above the weir/gutter (about ¼")
- Set up video camera to record

Test 1

Test 1: Circulation

1. Determine how many stars are necessary by using the following:
    - Pool surface area < 2,500 sq ft. use a minimum of 55 stars

Keyword	Section	Annex
		• Pool surface area > 2,500 sq ft. use a minimum of 110 stars 2. Randomly toss the stars into the swimming pool. Try to toss the stars so that there is an even distribution throughout the surface of the pool. 3. Record and observe the stars as they travel. 4. Record the motion of the stars in each area of the pool (e.g., clockwise, counter-clockwise, no movement) and any other observations. 5. Passing criteria may vary, but suggestions include 90% removal within 1 hour.
Test 2		***Test 2: Skimmer/Gutter Draw***
		1. Stand behind one of the skimmers or the gutter and drop a star into the water at arm's length distance (about 2 ft) in front of it. 2. Record how long it takes for the star to enter the skimmer or gutter. Then repeat this process at the same location three times.
Submerged Suction Outlet	***4.7.1.6***	***Submerged Suction Outlet***
General	*4.7.1.6.1*	*General*
Number and Spacing	*4.7.1.6.2*	*Number and Spacing*
Tank Connection	*4.7.1.6.3*	*Tank Connection*
Flow Distribution	*4.7.1.6.4*	*Flow Distribution and Control*
Design Capacity	4.7.1.6.4.1	The 125% of the total recirculation flow rate chosen by the designer is recommended as part of the hydraulic flexibility recommendation Annex 4.7.1.1. The proportioning valve(s) are recommended to restrict flow by increasing the head loss in the pipe(s) typically on the main drain lines where flow rates are less than those from the surface overflow system lines.
Flow Velocities	*4.7.1.6.5*	*Flow Velocities*

Keyword	Section	Annex
Piping	***4.7.1.7***	***Piping***
Design	*4.7.1.7.1*	*Design*
Velocity	*4.7.1.7.2*	*Velocity in Pipes*
Discharge Piping	4.7.1.7.2.1	Recirculation system piping should be designed so the water velocities should not exceed 8 feet (2.4 m) per second on the discharge side of the recirculation pump. This is a maximum value as opposed to a good design value. The head loss in a pipe (and hence the energy loss in the recirculation system) is proportional to the square of the velocity in the pipe (i.e., if you cut the velocity in half, then you reduce the head loss to ¼ (25%) of the original value). In the interest of conserving energy, velocities in the range of 6 to 8 feet (1.8 m x 2.4 m) per second are recommended. Without a minimum inlet velocity, uniform water distribution within the supply piping will not happen.
Suction Piping	4.7.1.7.2.2	The maximum velocity in suction piping is 6 feet (1.8 m) per second. The real limitation in suction piping is net positive suction head (NPSH) recommended by the pump. Net positive suction head refers to the pressure energy at the suction inlet to the impeller. Pump problems can result from incorrect determination of net positive suction head (NPSH). Inadequate NPSH can reduce pump efficiency and capacity and lead to cavitation. If cavitation continues and the pump conditions deteriorate, vibration problems can lead to destruction of the pump impeller and damage to other pump hardware. Failure to provide sufficient NPSH for the pump can result in cavitation, high power usage, and premature failure of the pump and other recirculation system components. The velocities recommended could be lower depending on the size and configuration of the piping as well as the elevation and water temperature. The available NSPH should be at least 20% greater than the recommended NPSH. The available NPSH should be calculated for each pool pump and each pool feature pump. The available NPSH should be compared with the NPSH recommended by each pump manufacturer. Cavitation will occur if the available NPSH is less than the recommended NPSH. The available NPSH is calculated as follows: absolute pressure on the liquid surface - friction losses in the suction line – vapor pressure of the water + static head of liquid above impeller eye (all terms in feet). Hydraulic calculations for piping and pumps should

Keyword	Section	Annex
		be prepared by a qualified engineer.
Gravity Piping	4.7.1.7.2.3	Gravity piping must be sufficiently sized to accommodate the recommended flow (including surges) without water surcharging above the inlet. Careful consideration of available head, the head losses, and the combined flow from multiple inputs into a single pipe is a necessity. The 2 feet per second value is a value derived from common practice with no clearly identifiable theoretical basis.
Drainage and Installation	*4.7.1.7.3*	*Drainage and Installation*
Draining Recommendation		The draining recommendation for all equipment and piping serves multiple functions. First, any sediment or rust particles that gather in the pipe can be flushed by means of the drainage system. Since bacteria and biofilms are mostly water, drying out a biofilm can be an effective means of controlling growth. Whereas leaving a pipe full of water during a period of maintenance or no use could lead to dissipation of the chlorine residual and proliferation of a biofilm inside of pipes and/or equipment. Biofilms can lead to bio-corrosion of metal components of the recirculation system and serve as protection for microbes and pathogens.
Designed		All equipment and piping should be designed and constructed to drain completely by use of drain plugs, drain valves, and/or other means. All piping should be supported continuously or at sufficiently close intervals to prevent sagging and settlement. All suction piping should be sloped in one direction, preferably toward the pump. All supply and return pipe lines to the pool should be provided to allow the piping to be drained completely.
Individual Drain		The individual drain to facilitate emptying the pool in case of an accidental gross contamination event is intended to prevent further contamination of any pipes, pumps, multi-port valves, filters, or other equipment associated with the recirculation system, which might be more difficult to clean than the inside of the pool. In the case of combined aquatic venue treatment systems, this drain could prevent cross-contamination of multiple aquatic venues.
Component Identification	*4.7.1.7.4*	*Piping and Component Identification*
Clearly Marked		Clearly marking pipes will prevent misidentification that could lead to cross-connections and contamination of the pool. Pipe

Keyword	Section	Annex
		marking will also facilitate easier identification of locations for additional equipment installation and/or sample lines. Color Coding Recommendations: Pipes and valves, when color-coded, may be color-coded in accordance with the following: • Potable water lines (Dark blue), • Backwash waste (Dark brown), • Filtered water (Aqua), • Sewer (Dark gray), • Skimmer or gutter return (Olive green), • Deck drains (Light brown), • Main drain (Black), • Alum (Orange), • Chlorine (gas/solution) (Yellow), • Compressed air (Dark green), • Soda ash (White), • Gas (Red), and • Acid (Pink).
Testing	*4.7.1.7.5*	*Testing*
Strainers and Pumps	***4.7.1.8***	***Strainers and Pumps***
Strainers	*4.7.1.8.1*	*Strainers*
Pumping Equipment	*4.7.1.8.2*	*Pumping Equipment*
Variable Frequency Drives	4.7.1.8.2.1	Variable frequency drives (VFDs) may be allowed because the energy savings could be substantial if flow is reduced at night and water quality criteria are continuously maintained. At this time, we are not aware of public health benefits associated with VFD use so these pumps are allowed but not required. Operators should be aware that VFDs can flatten out a pump curve so if they are installed on a filter pump, operators may want more active control to maintain operations. It is recommended that operators use VFDs with a compatible flow meter with a feedback control to optimize VFD function.
Total Dynamic Head	4.7.1.8.2.2	The recirculation pump should be selected to meet the recommendations of the designer for the system. However, the following guidelines are suggested as starting points for designers. The recirculation pump(s) must be selected to

Keyword	Section	Annex
		provide the recommended recirculation flow against a minimum total dynamic head of the system, which is normally at least 50 feet (15.2 m) for all vacuum filters, 70 feet (21.3 m) for granular media and cartridge filters, or 60 feet (18.3 m) for precoat filters. A lower total dynamic head could be shown to be hydraulically appropriate by the designer by calculating the total head loss of the system components under worst-case conditions.
Operating Gauges	*4.7.1.8.3*	*Operating Gauges*
Pressure Measurements		A second set of pressure measurement ports could be recommended (tapped into the pump volute and discharge casing) to accurately calculate the flow of the pump. These gauges are a way of verifying the pump curve is correct. One can also back check the flow meter and look for differences between the two. During startup, it is possible to shut off a valve on the discharge side of the pump and verify that the maximum discharge pressure measured agrees with the value on the pump curve. It is recommended that all pumps be located on a base so as to be easily accessible for motor service.
Vacuum Limit Switches		The vacuum limit switch is intended to limit the amount of clogging that can occur in a filter (and hence the recirculation system). The maximum vacuum limit of 18 inches (45.7 cm) of mercury was chosen for the same function as a pressure limit is established in pressure filters.
Flow Measure and Control	***4.7.1.9***	***Flow Measurement and Control***
Flow Meters		Over 22% (approximately 20,000) of the pool inspections that led to pool closures in the state of Florida in 2012 were caused by non-functioning flow meters. This section of the MAHC is intended to improve this flow meter reliability problem (as well as to address a problem with accuracy). Since flow rates are critical for proper filtration, sizing, and operational calculations, it is recommended that operators purchase a more accurate flow meter for all systems or when replacing older flow meters on their existing system. Improved accuracy improves an operators chance of understanding the true flow in their system. Operators should be mindful of flow meter placement by installing according to manufacturer recommendations and adhering to recommended distance

Keyword	Section	Annex

parameters.

A flow meter or other device that gives a continuous indication of the flow rate in gallons per minute through each filter should be provided. If granular media filters are used, a device should be provided to measure the backwash flow rate in gallons per minute for each filter. Flow meters should have a measurement capacity of at least 150% of the design recirculation flow rate through each filter, and each flow meter should be accurate within +/-5% of the actual design recirculation flow rate. The flow measuring device should have an operating range appropriate for the anticipated flow rates and be installed where it is readily accessible for reading and routine maintenance. Flow meters should be installed with 10 pipe diameters of straight pipe upstream and 5 pipe diameters of straight pipe downstream or in accordance with the manufacturer's recommendations. Acrylic flow meters will not meet the accuracy requirement (and are prone to fouling/clogging) and hence should not be installed as the primary flow meter on any recirculation system. However, acrylic flow meters could prove useful as a backup or auxiliary flow meter. A paddle-wheel flow meter, when used, should be located on the effluent side of the filter to prevent fouling.

More accurate flow meters are recommended to conserve energy and increase regulatory compliance. Magnetic and ultrasonic flow meters offer greater accuracy (typically less than +/- 1% error) and less potential for fouling, but the aforementioned flow meters tend to be more expensive (e.g., $1,000 or more). An ultrasonic flow meter (such as clamp-on transit-time models) can be used to measure flows through the wall of a pipe, so they can be installed and uninstalled without modifying the existing plumbing. One ultrasonic flow meter could be used to routinely verify the flow readings of multiple other flow meters that are more prone to error. An annual cleaning and evaluation of flow meter accuracy could be useful in maintaining compliance with existing regulations.

Flow Rates/ Turnover

4.7.1.10 Flow Rates/Turnover

Maximum Allowable

4.7.1.10.1 Recommended Flow Rates

The minimum backwash rate of 20 gallons per minute per square foot of filter area through each filter of a granular media filter system is intended to facilitate efficient

Keyword	Section	Annex
		backwashing of the granular media filters. Lower backwash rates have been used with some success for years, but the new recommendation of a coagulant feed system ahead of the filters will place greater burden on the filters and recommend more effective backwashing. With sand typically used in U.S. pool filters, the new minimum backwash rate should provide efficient backwashing in most cases. Filter systems have traditionally been designed to filter at less than the maximum filtration rate, which has frequently caused backwashing at rates proportionally lower and insufficient to fluidize the entire filter bed. A bed expansion of at least 20% is recommended for pool filters, which could require flow rates greater than the minimum value above and will be discussed in MAHC Annex section 4.7.2.1.4.1.
Calculated	4.7.1.10.2	A new methodology is being proposed for use in the future that calculates the recommended minimum design recirculation flow rate, which is called the maximum sustainable bather load (MSBL) calculation. The MSBL calculation is based on the values in MAHC Annex Table 4.7.1.10.2 (below) and adjusted by all applicable multipliers in MAHC Annex Table 4.7.1.10.3 (below) as the maximum turnover time allowable based on the pathogen load and chlorine demand imparted by bathers. Whereas, the traditional turnover time values (required in MAHC Code Table 4.7.1.10) are based on physical transport processes of contaminants and disinfectant in the pool. The MSBL design turnover rates should use the adjustment factors provided. For mixed-use pools, each zone of the pool should individually meet the recommended turnover time for the zone based on the lesser turnover time calculated by the procedures already described. All of the maximum turnover times provided in MAHC Code Table 4.7.1.10 are required for aquatic venues as defined in the MAHC. The MSBL values calculated might help to identify pools that could be slightly over-designed to meet the demands placed on the venue. Furthermore, the MSBL approach actually identifies risk factors that might require higher or lower levels of treatment based on the actual system.
Equation		1) Zone Volume (ft^3) = Zone Surface Area (ft^2) x Average Depth (ft) 2) Zone Bather Load Factor (bathers/ft^3) = 1/ {Surface Area per Bather (ft^2/bather)} x (Average Depth (ft))

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Keyword Section Annex

3) Estimated Maximum Number of Bathers Per Zone = Zone Bather Load Factor (bather/ft^3) x Zone Volume (ft^3)

4) Raw Recirculation Flow Rate Per Zone (gal/min) = Estimated Maximum Number of Bathers Per Zone x 5.34 (a constant)

5) Turnover time (h) = Water volume (gal) / {Recirculation rate (gal/min) x (60 min/ 1 hr)}

Table 4.7.1.10.2

Table 4.7.1.10.2. Bather Loading Estimates

Depth (in Feet)	Surface Area Per Bather (square feet)
<3	25
3 to 6	30
6.1 to 10	22
>10.1	16

Table 4.7.1.10.3

Table 4.7.1.10.3. Recirculation Rate Multipliers (Adjustment Factors)

Adjustment Reason	Adjustment Factor	Recommendation(s)
Edge Loading (more bather at edge of larger pools)	1.1	Pool must be greater than 100,000 gallons/ Spa > 10,000 gallons
Increased-risk (diaper-aged patrons present)	0.75	Pool designed for at least 10% of patrons to be diaper-aged.
Activity/Line (Attractions increase bather density)	0.5	Any pool/spa with an associated ride or activity (besides swimming) or line to enter
High-temperature (increased sweat production)	0.5	Pool/Spa with water temperatures routinely exceeding 95 F.
Indoor (protected from some environmental factors)	1.15	Pool/Spa must be located completely indoors year round.
Limited-use (pools that are frequently lightly loaded)	1.33	Pool must be at an Apartment, Condominium, or Hotel/Motel with no associated attraction or activity.
Showering recommended (showering reduces bather load)	1.15	Pool/Spa must recommend showering prior to entry.

Example Calculation

For example, here is a set of example calculations for an indoor pool in a hotel that is 20 ft wide x 30 ft long with an even floor slope that goes from 4 ft at the shallow end to 6ft at the deep end.

1) Zone Volume (ft^3) = 20 ft x 30 ft x 5 ft = 3,000 ft^3

2) Zone Bather Load Factor (bathers/ft^3) = 1/(30 ft^2/bather) x (5ft) = 0.00666 bathers/ft^3

3) Estimated Maximum Number of Bathers Per Zone = 0.00666 bather/ft^3 x 3,000 ft^3 = 20 bathers

4) Raw Recirculation Flow Rate Per Zone (gal/min) = 20

bathers x 5.34 = 106.8 gal/min

5) Turnover time (h) = 3,000 ft^3 x 7.48 gal/ft^3/(106.8 gal/min) x (60 min/1 hr) = 3.5 h

6) Adjustments for indoor pool and limited use pool: 3.5 h x 1.15 x 1.33 = 5.35 h

7) Compare the MSBL value of 5.35 h to the value in Table 4.7.1.10.3 of 5 h and use the lower value = 5 h. Additional example calculations are provided in Table 4.7.1.10.4.

Table 4.7.1.10.4

Table 4.7.1.10.4: Recirculation Rate Calculation Examples (based on bather load) by Pool Type

	Large Indoor Pool	Wave Pool	Activity Pool	Spray Pad	Kiddie Pool	Spa	Deep Diving Pool	Small Pool
Volume (gal.)	322,000	750,000	50,000	20,000	1,000	750	100,000	35,000
Average Depth (ft.)	7.33	4.98	3.00	1.00	1.00	1.50	16.00	5.00
Surf Area (ft^2)	5870.20	20120.5	2228.16	2673.80	133.69	66.84	835.56	935.83
Sq. Side (ft)	76.62	141.85	47.20	51.71	11.56	8.18	28.91	30.59
Factor 1 (bathers/ft^3)	0.007346	0.025	0.02	0.04	0.04	0.02667	0.003906	0.00945
Factor 2 (bathers/ft^3)	0.006011	0.00778	0.009445	0.04	0.04	0.02667	0.003906	0.00735
Factor 3 (bathers/ft^3)	0.003821	0.00504	0.009445	0.04	0.04	0.02667	0.003906	0.00655
Total Bathers	219.09	797.52	78.81	106.95	5.35	2.67	52.22	34.93
K	5.34	5.34	5.34	5.34	5.34	5.34	5.34	5.34
gpm Q	1171	4261	421	571	29	14	279	187
Minimum Turnover	275	176	119	35	35	53	358	188
Raw Turnover	4.58	2.93	1.98	0.58	0.58	0.58	5.97	3.13
>100K gallons/ Large Pool Edge Load Factor	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Small Pool High Risk Factor	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Activity Pools Density/Line Factor	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
>90*/Hot Water High Temp. Factor	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Indoor Pools Env. Protect Factor	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15
Shower Required Bather Load Reduction	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15
Plain Pools Only: Apartment/Condo/ Hotel Limited Use Factor	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33
Final Turnover (Hours)	5.8	1.61	0.99	0.22	0.44	0.22	7.56	4.16
w/ a Required Shower	6.67	1.86	1.14	0.25	0.5	0.25	8.69	4.78
Standard Table Values	4.0-5.0	1.5-2	1-1.5	0.25	0.50	.25-.5	6.0-8.0	5.0

When pool recirculation rate recommendations are broken down to their essential elements, it is essentially about removing suspended matter (including microbial contaminants) with the filters and effectively maintaining uniform free chlorine residual at the proper pH. Both the free chlorine residual and the microbial concentrations are a function of the number of bathers in a given volume of water. While it is not possible to always accurately predict the bather load for a given pool on a given day, it is generally possible to estimate the maximum number of bathers likely to be in any given type of pool per unit surface area (since most bather have at least their head above water most of the time and the primary activity in a pool often dictates the comfort level in regards to bathers per unit surface area and hence the likelihood of bathers entering or leaving the pool). After establishing a maximum sustainable bather load (MSBL) or maximum number of bathers expected in a pool, it is possible to calculate the recommended flow of recirculated water necessary to be treated in order to handle the pathogen load and chlorine demand imparted by the bathers. An empirically-derived multiplier was used by PWTAG[5] to convert the MSBL to the recommended recirculation rate. The empirical multiplier used in this code was derived independently using English units specifically for use in the U.S. The value of the U.S. multiplier is approximately 29% smaller than the PWTAG value using equivalent units because pool design in the UK is more conservative than in the US.

Turnover Rates 4.7.1.10.4 The recommended design turnover time can then be calculated by dividing the volume by the recommended flow. This procedure can be performed for individual sections of a pool or the entire pool depending on the number of zones, which are based on depth of the water. Adjustments can then be made to this calculation to account for extraordinary conditions. For example, since a spa has higher water temperature than a pool a patron would be expected to sweat more, an indoor pool might experience less contamination from pollen, dust, and rain than an equivalent outdoor pool, and a pool filled with diaper-age children would be considered an increased-risk pool requiring more aggressive treatment. Facilities that enforce showering prior to pool entry could reduce the organic load on the pool by 35-60% with showers

[5] Pool Water Treatment Advisory Group (PWTAG). *Swimming Pool Water: Treatment and Quality Standards for Pools and Spas, 2nd Ed.* 2009. Micropress Printers, Ltd. ISBN: 0951700766.

lasting only 17 seconds[6]. The bather load calculation based on surface area of the pool has been proposed by PWTAG[5] in 1999 and has influenced the codes proposed by the World Health Organization[7] and Australia[8]. This approach has been adapted for use in the U.S. by slightly increasing the area recommended per bather in shallow waters and decreasing the area in deep pools to account for the intensity of deep water activities, the relatively low surface area to volume ratios of deep waters relative to shallow waters, the typically poorer mixing efficiency in deeper water, the increased amount of time typically spent underwater in deeper water, and the larger average size of bathers commonly found in deeper water. These values were empirically derived for the MAHC to match typical U.S. practices at the time of this writing and can be changed as necessary to achieve the desired water quality goals.

Effectively handling bather load in terms of pathogen removals and chlorine demand is a paramount concern for which the above calculations should provide some science-based guidance. However, there are other factors that must be considered when selecting a recirculation rate for an aquatic venue. For example, effectively distributing treated water to avoid dead spots recommends minimum water velocities to reach the pool center and extremities. Similarly, effective surface skimming recommends adequate velocities at the surface of the pool to remove floating contaminants. Due to the kinetics of disinfection and chlorine decay, chlorine must be replenished at some minimum intervals to maintain the recommended free chlorine residual. For these reasons, MAHC Code Table 4.7.1.10 was developed to provide some maximum turnover time limits for venues that are not dominantly influenced by bather load to help ensure proper physical transport of contaminants and disinfectant. Values in this table are derived from historical practice and design experience worldwide. All venues must be designed to meet the lesser of the two maximum turnover times.

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[6] Keuten MGA et al. Definition and quantification of initial anthropogenic pollutant release in swimming pools. Water Research. 2012;46:3682-3692.

[7] World Health Organization (WHO). *Guidelines for Safe Recreational Water Environments: Vol. 2- Swimming Pools and Similar Environments.* 2006. WHO Press, Geneva, Switzerland. ISBN: 9241546808.

[8] NSW (New South Wales) Department of Health. Public Swimming Pool and Spa Pool Code of Practice. 2010. Available at: http://www.health.nsw.gov.au/environment/publicpools/Pages/default.aspx.

Flow Turndown System

4.7.1.10.6 The flow turndown system is intended to reduce energy consumption when pools are unoccupied without doing so at the expense of water quality. The turbidity goal of less than 0.5 NTU has been chosen by a number of U.S. state codes (e.g., Florida) as well as the PWTAG[5] and WHO[7]. The maximum turndown of 25% was selected to save energy while not necessarily compromising the ability of the recirculation system to remove, treat, and return water to the center and other extremities of the pool. Future research could determine that more aggressive turndown rates are acceptable. Some pools are already reportedly using the turndown system without a turbidimeter or precise flow rates. The intent of this section is to formalize a system for doing the turndown that does not compromise public health and safety. Additional research in this area could identify innovative ways to optimize and improve this type of system. The likelihood of turbidimeters being cleaned and maintained is likely to be good because turbidimeters tend to give higher reading when not maintained properly.

Pools designed above the minimum design standards would have the flexibility to increase system flows to maintain excellent water quality during periods of peak activity. The flow turndown system is intended to reduce energy consumption when pools are unoccupied without doing so at the expense of water quality.

An electronic turbidity and recirculation system flow feedback system would provide a quantifiable means of determining the water quality suitability if a facility desires to "turndown" the recirculation pumps to achieve a flow of up to 25% less than the minimum required recirculation flow rate when the pool is not occupied. The integration of feedback from both the flow meter and turbidimeter must be maintained for the VFD to be able to reduce the system flow rate below the level required to achieve the turnover time requirement.

VFDs

4.7.1.10.6.3 Variable frequency drives (VFDs) offer the benefits of energy savings, operational flexibility, and in most cases the ability to automatically increase the pump flow as the filter clogs by interfacing the VFD with a flow meter (or potentially a filter effluent pressure transducer) by means of a proportional-integral-derivative (PID) controller. VFDs may also offer the added benefits of protecting piping, pumps, and valves. Energy savings and benefits will vary depending on the design of the system.

Filtration

4.7.2 Filtration

System Design

The filtration system should be designed to remove physical contaminants and maintain the clarity and appearance of the pool water. However, good clarity does not mean that water is microbiologically safe. With chlorine-tolerant human pathogens like *Giardia* and *Cryptosporidium* becoming increasingly common in pools, effective filtration is a crucial process in controlling waterborne disease transmission and protecting public health. The filtration system of U.S. swimming pools has traditionally been designed to remove physical contaminants and maintain the clarity and appearance of the pool water. Good clarity is important and will help prevent drowning and underwater collisions. Poor clarity can actually compromise the disinfection process as well as leaving chlorine-tolerant pathogens suspended in the water for longer periods of time. As a future recommendation for discussion, filtration systems should be capable of removing *Cryptosporidium* oocysts or an acceptable 4.5-micron surrogate particle with an efficiency of at least 90% (i.e., a minimum of 1 log reduction) single pass.

Water Quality

"If filtration is poor, water clarity will decline and drowning risks increase since swimmers in distress cannot be seen from the surface as well as needed. Disinfection will also be compromised, as particles associated with turbidity can surround microorganisms and shield them from the action of disinfectants. Particulate removal through coagulation and filtration is important for removing *Cryptosporidium* oocysts and *Giardia* cysts and some other protozoa that are resistant to chemical disinfection."[7].

Pathogen Removal

One of the most significant recommended changes of the MAHC is changing the filtration system from one that only provides good clarity and appearance to one that efficiently removes waterborne human pathogens from the pool water. Water clarity is only an indicator of potential microbial contamination, but it is the most rapid indicator of possible high contamination levels. Chlorine residual can be sufficiently high to kill indicator bacteria while leaving protozoa relatively unharmed and infective. Therefore, testing for indicator bacteria may not be useful as a measure of pool water quality, and testing for *Giardia* cysts and *Cryptosporidium* is very expensive and time-consuming. So, both measures are impractical as an operational tool for water quality measurement. *Cryptosporidium* is a widespread threat responsible for causing outbreaks in aquatic venues each year in the U.S.[9] With chlorine-tolerant human pathogens like *Giardia* and *Cryptosporidium* becoming increasingly common in pools, effective filtration is a crucial process in controlling waterborne disease transmission and protecting public health.[5,7] Furthermore, an accidental fecal release could overwhelm the disinfectant residual and leave physical removal as the only means of removing pathogens.[7] Filtration has been cited as the "critical step" for the removal of *Cryptosporidium*, *Giardia*, and free-living amoebae that can harbor opportunistic bacteria like *Legionella* and *Mycobacterium* species.[7]

Crucial

Effective filtration is a crucial process in controlling waterborne disease transmission and protecting public health.[5,7]

Cryptosporidium

Cryptosporidium is a chlorine-tolerant protozoan pathogen that causes the majority of waterborne disease outbreaks in swimming pools in the U.S. as shown in MAHC Annex Figure 4.7.2.1.[10] Surveillance for *Cryptosporidium* in the United States indicates that the reported incidence of infection has increased dramatically since 2004.[11] MAHC Annex Figures 4.7.2.2 and 4.7.2.3 demonstrate the increased incidence as well as the overall number of outbreaks of cryptosporidiosis since 2004, respectively.[9]

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[9] Yoder JS et al. . Cryptosporidiosis surveillance — United States, 2009–2010. MMWR Surveill Summ. 2012;61:1-12. Available at: http://www.cdc.gov/mmwr/preview/mmwrhtml/ss6105a1.htm

[10] Hlavsa MC et al. . Surveillance for waterborne disease outbreaks and other health events associated with recreational water use — United States, 2007–2008. MMWR Surveill Summ. 2011;60:1-37.

[11] Yoder JS and Beach MJ. *Cryptosporidium* surveillance and risk factors in the United States. Experimental Parasitology. 2010;124(1):31-39.

Figure 4.7.2.1

FIGURE 4.7.2.1. Recreational water-associated outbreaks of gastroenteritis, by etiologic agent for treated water — United States, 2007–2008[10]

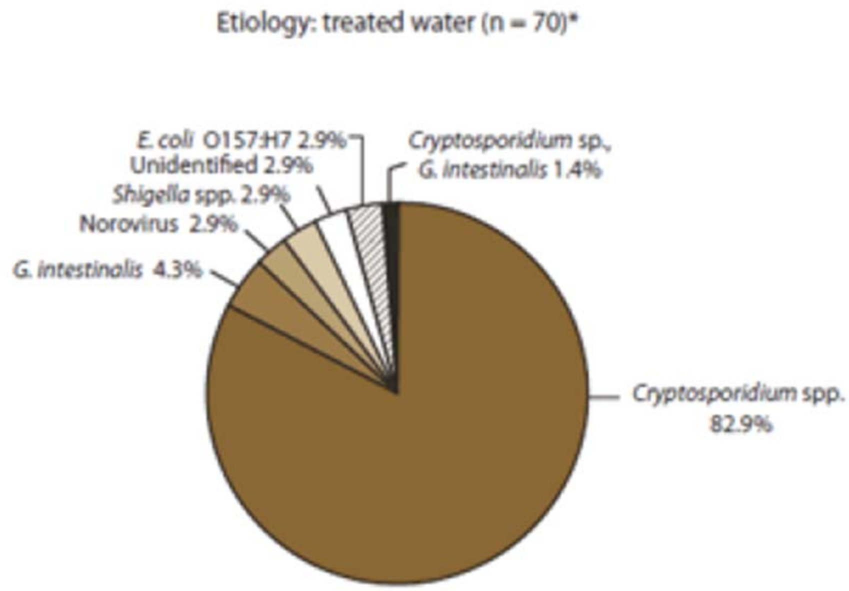
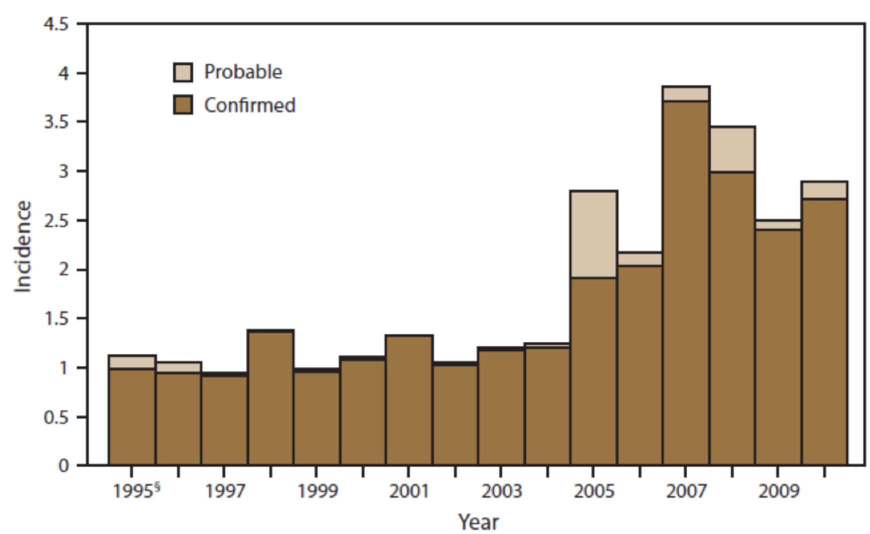


Figure 4.7.2.2

FIGURE 4.7.2.2. Incidence* of cryptosporidiosis, by year — National Notifiable Disease Surveillance System, United States, 1995–2010†[9]



* Per 100,000 population.

† N = 85,514.

§ First full year of national reporting.

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3-Log Reduction

The current Ct values for a 3-log reduction in viability of fresh *Cryptosporidium* oocysts with free chlorine are 10,400 mg/L·min (Iowa-isolate) and 15,300 mg/L·min (Maine-isolate) at pH 7.5.[12] At a concentration of 1 mg/L, free chlorine can take more than 10 days to inactivate 99.9% of *Cryptosporidium* oocysts (Ct=15,300 mg/L·min), but a many people are likely to be swimming in the pool during that 10-day period and risk being exposed to infective parasite concentrations. Infected individual may then return to the pool and/or visit other pools to perpetuate the spread of the parasite. Sand filters are commonly used and often serve as the only potential physical barrier to *Cryptosporidium* in U.S. pools, but sand filters without coagulant typically only remove about 25% of oocysts per passage through the filter[13] . Based on the slow kinetics of chlorine inactivation of *Cryptosporidium*, the known inefficiency of sand filter to remove oocysts, and the recent incidence of cryptosporidiosis in the U.S., additional measures appear necessary to effectively safeguard public health.

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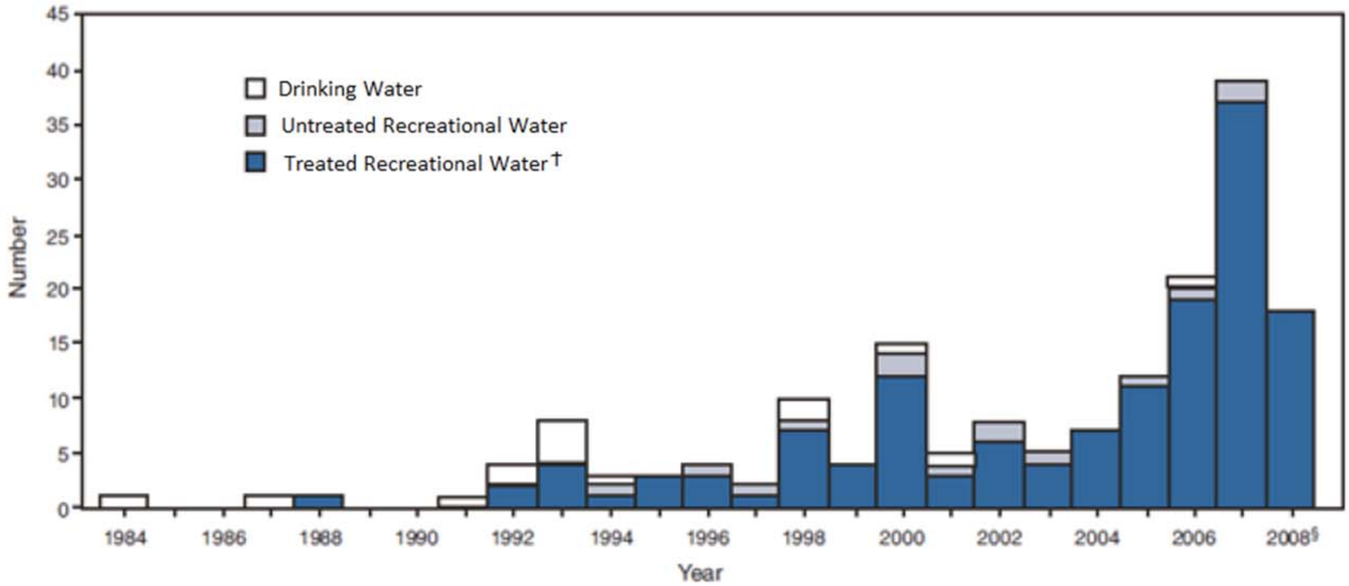
[12] Shields JM et al. Inactivation of *Cryptosporidium parvum* under chlorinated recreational water conditions. Journal Water Health. 2008;6(4):513-520.

[13] Amburgey JE et al. Removal of *Cryptosporidium* and polystyrene microspheres from swimming pool water with sand, cartridge, and precoat filters. J Water Health. 2012;10(1):31-42.

Figure 4.7.2.3

FIGURE 4.7.2.3. Number* of outbreaks of cryptosporidiosis associated with water, by water type — Waterborne Disease and Outbreak Surveillance System, United States, 1988–2008[14]



* N = 172.

† Water that has undergone a treatment process (e.g., chlorination and filtration) to make it safe for recreation.

§ Data for 2007 and 2008 are provisional.

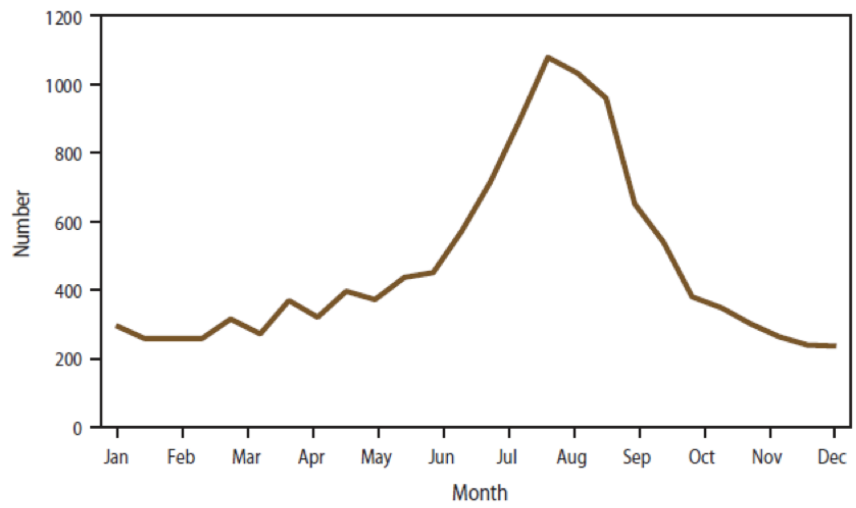
Explanation

MAHC Annex Figure 4.7.2.3 (above) shows that the majority of outbreaks of cryptosporidiosis occur in "treated" recreational water. MAHC Annex Figure 4.7.2.4 (below) shows a dramatic increase in the number of cases of cryptosporidiosis during the warmer months of the year when outdoor public pools are normally open in the U.S. While it is difficult to assess the prevalence of protozoan parasites in public pools during normal operation, a study of 160 filter backwash water samples from Atlanta, GA showed that 13 (8.1%) were positive for *Giardia* or *Cryptosporidium* or both.[15]

[14] Yoder JS, Harral C, Beach MJ. Cryptosporidiosis surveillance---United States, 2006 - 2008. MMWR Surveill Summ. 2010;59(SS06):1-14.
[15] Shields JM, Gleim ER, and Beach MJ. Prevalence of *Cryptosporidium spp.* and *Giardia intestinalis* in swimming pools, Atlanta, Georgia. Emerging Infectious Diseases. 2008;14(6):948-950.

Figure 4.7.2.4

FIGURE 4.7.2.4: Number* of cryptosporidiosis case reports, by date of illness onset — National Notifiable Disease Surveillance System, United States, 2006–2009[9]



* N = 16,607; date of onset for 4,381 patients was unknown.

Research Findings

Review of Recreational Water Filtration Research Findings

Sand Filters

Sand filters often provide the only physical barrier to *Cryptosporidium* in U.S. pools, but sand filters meeting the recommendations of pre-existing pool codes typically only remove about 25% of oocysts per passage through the filter[16]. A quantitative risk assessment model of *Cryptosporidium* in swimming pools confirmed there is a "significant public health risk".[17] Some changes are necessary to effectively safeguard public health and will be discussed subsequently. Recent research in the U.S. and U.K. has shown that sand filters can remove greater than 99% of oocysts per passage when a coagulant is added prior to filtration[5,18] . The addition of coagulants to swimming pool filters used to be common practice in the U.S. with rapid sand filters, but it fell out of favor as high-rate sand filters began to dominate the U.S. pool market. The importance of coagulant addition to efficient pathogen removal in drinking water is

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[16] Amburgey JE et al. Removal of *Cryptosporidium* and polystyrene microspheres from swimming pool water with sand, cartridge, and precoat filters. J Water Health. 2012;10(1):31-42.
[17] Pintar KD et al. A risk assessment model to evaluate the role of fecal contamination in recreational water on the incidence of cryptosporidiosis at the community level in Ontario. Risk Analysis. 2010;30:1:49-64.
[18] Croll BT, Hayer CR, and Moss S. Simulated *Cryptosporidium* removal under swimming pool filtration conditions. Water Environment Journal. 2007;21:149-156.

well-documented and recommended in all U.S. surface water treatment facilities for drinking water production by the USEPA.[19,20,21,22,23] The USEPA expects drinking water treatment facilities to remove or inactivate a minimum of 99% (2 log) of *Cryptosporidium* oocysts and up to 99.997% (4.5 log) for facilities treating source water with the highest concentration of oocysts.[20] While more research and quantitative risk assessment models will be recommended to determine the safe level of removal in most swimming pools, it is clear that the current removal rates of approximately 25% can lead to a significant number of outbreaks each year. Based on the research available for existing swimming pool filtration technologies and risk models, a new minimum removal goal for *Cryptosporidium* removal by filters used in new and renovated swimming pools is recommended to be at least 90% (1 log) per single pass.

Filtration Systems

Multiple types of pool filtration systems have already been shown to achieve removals exceeding 99% depending on the filter design, water quality, and operational variables.

MAHC Annex Table 4.7.2.1 (below) contains a current summary of published research on *Cryptosporidium* or *Crypto*-sized microsphere removals via filtration in pilot-scale trials. Bench-scale results were not included due to concerns that the laboratory results might not be reproducible at pilot- or full-scale as has been observed in previous studies . Table 4.7.2.1 is in sorted in order of increasing filter removal efficiency, and the data is roughly divided into three groupings (i.e., <90%, 90-99%, and >99% removal). Operating conditions falling into the first group would not be expected to reliably meet the new 90% (single pass) removal recommendation that is recommended for all new and renovated aquatic venues. Coagulant dosage, surface loading rate, and media depth can significantly impact filtration removals. Careful selection of both design and operating values is essential to achieving excellent pathogen removal with pool filters.

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[19] Letterman RD. Water Quality and Treatment. 1999. 5th Ed.McGraw-Hill, NY.
[20] AWWA. Operational Control of Coagulation and Filtration Processes: AWWA Manual. 2010;M37, 3rd ed. American Water Works Association, Denver, CO. ISBN: 978-1-58321-801-3
[21] Logsdon GS et al. Alternative filtration methods for removal of *Giardia* cysts and cyst models. Journal AWWA. 1981;73(2):111-118.
[22] Logsdon GS and Fox K. Getting your money's worth from filtration. Journal AWWA. 1982;74(5):249-256.
[23] USEPA. National Primary Drinking Water Regulations: Long Term 2 Enhanced Surface Water Treatment Rule (Proposed Rule). 40 CFR Parts 141 and 142. Federal Register. 2003;68(154).

Table 4.7.2.1

Table 4.7.2.1. Pilot-Scale Filter Removal Results for Cryptosporidium or Crypto-sized Microspheres in Pool Water[24]

Filter Type	Media Depth	Surface Loading Rate	Coagulant Type	Coagulant Dosage	Removal (%)
Sand	24 in.	10 gpm/ft^2	None	n/a	25-46%
Sand	24 in.	10 gpm/ft^2	PACI	0.014mg/L as A1	54.2%
Sand	24 in.	10 gpm/ft^2	PACI	0.006mg/Las A1	62.0-64.3%
Sand	24 in.	10 gpm/ft^2	Alum	0.06 mg/L as A1	65-68%
Sand	24 in.	10 gpm/ft^2	PACI	0.76-0.92 mg/L as A1	87.8-98.0%
Sand	24 in.	10 gpm/ft^2	PACI	0.065 mg/L as A1	91.5-97.3%
Sand	24 in.	10 gpm/ft^2	Alum	0.1 mg/L as A1	94-95%
Sand	24 in.	10 gpm/ft^2	Alum	0.3 mg/L as A1	96-97%
Sand	24 in.	10 gpm/ft^2	PACI	0.1 mg/L as A1	99.3-99.7%
Sand	24 in.	10 gpm/ft^2	PACI	0.21 mg/L as A1	99.6-99.8%

Filtration Products

At the time of this writing, the following filtration products are believed to be untested for *Cryptosporidium*/4.5-micron carboxylated microsphere removal in swimming pool water:

- regenerative media filters,
- sand followed by cartridge (with 5-micron absolute or 1-micron nominal rating),
- Macrolite filter media,
- charged zeolite media,
- crushed-recycled glass filter media, and
- any others not listed in MAHC Annex Table 4.7.2.1.

Historic Practices

Brief Historical Review of Water Filtration Practices for Aquatic Venues

1920's

In the U.S. in the 1920's, rapid sand filters on swimming pools were typically operated at 3-5 gpm/ft^2 with coagulation prior to filtration, but high-rate sand filters have largely replaced rapid sand filters because they operate at 15-20 gpm/ft^2 without

[24] Croll BT et al. Simulated *Cryptosporidium* removal under swimming pool filtration conditions. Water and Environment Journal. 2007;21:149-156.

coagulant.[25,26] While high-rate sand filters are definitely cheaper and smaller, they are also less effective at removing *Cryptosporidium*-sized particles. The majority of U.S. drinking water treatment facilities still use rapid sand filters with coagulation and typically operate them at 3-5 gpm/ft^2. The USEPA, after an extensive review of peer-reviewed research, decided to give drinking water treatment facilities credit for removing 99% of *Cryptosporidium* oocysts for properly employing this technology *(i.e., granular media filtration with coagulation prior to filtration*). Research has shown that high-rate swimming pool sand filters can only consistently deliver 22 to 48% removal of *Cryptosporidium* oocysts and/or a microsphere surrogate without coagulation[27]..

Headloss

Increased Headloss Development Rates

Pressure Development

More efficient filtration of pool water will, in most cases, lead to higher rates of pressure development in filters and more frequent backwashing of filters. The smaller the pores in the filter media at the surface of the filter, the more rapidly pressure would be expected to increase. Fortunately, there are a number of options available to design engineers that could reduce the rate of pressure development. These options include the use of more uniformly graded filter media, skimming fines from filter media prior to startup, more efficient backwashing of filters, lowering the flow rate per unit surface area, and the use of two types of filter media in filters.

Granular Media Filters

4.7.2.1 Granular Media Filters

General

4.7.2.1.1 General

Required

4.7.2.1.1.1 Sufficient floor space should be available to accommodate installation of additional filters to increase the original filtration surface area by up to 50% should it be recommended by future regulations or to meet current water quality standards. This is part of the hydraulic flexibility recommendation of newly constructed pools. The idea is to recommend space for additional filters should they become necessary at some point in the future. The 'extra' space could be utilized to make

[25] Cary WH. Administration of Swimming Pool Standards in Detroit. Am. J. Public Health 1929;20(7):727-733.
[26] AJPH. Swimming Pools and Other Public Bathing Places: Standards for Design, Construction, Equipment, and Operation. Am. J. Public Health.1926;16:1186-1201.
[27] Amburgey JE et al. Removal of *Cryptosporidium* and polystyrene microspheres from swimming pool water with sand, cartridge, and precoat filters. J Water Health. 2012;10(1):31-42.

equipment rooms safer and more functional.

A port and ample space for easy removal of filter media is also recommended. Filter media might be changed every 5 years. This process could be exceedingly difficult if filters are not designed with a port for this purpose or if the filters are installed without proper clearance to access the media removal port.

Design Tip

Design Tip: When a single pump feeds two filters at 10 gpm/ft^2, redirecting the entire flow through one filter into the backwash line of the other should result in a backwash rate of approximately 20 gpm/ft^2. The backwash water would be unfiltered water that would have to be plumbed to bypass the filter. With three filters, it would be possible to redirect water from two filters into the backwash influent pipe of the third filter to provide clean backwash water.

Listed

4.7.2.1.1.4 Equipment testing of filters to industry standards is critically important, but it is only one aspect of performance. A filter certified with the hydraulic capability to pass water at 20 gpm/ft2 does not mean this filter should be operated at 20 gpm/ft2. Granular media filters perform better at removing particles and microbes at lower filter loading rates (all other factors equal), and this finding has been repeatedly observed in practice and can be explained theoretically. Filters might need to be held to higher standards of performance in terms of water quality than the current industry standard.

Manufacturers and testing laboratories might need to work together to produce more effective filters and new testing procedures. The maximum filtration rate of 12 gpm/ft2 is the first step toward a change in filter design standards aimed at improving microbial removal and preventing recreational water illnesses. The MAHC is intentionally more restrictive than the current NSF Standard 50 flow requirements.

Filter Location and Spacing

4.7.2.1.2 Filter Location and Spacing

Rates

4.7.2.1.3 Filtration and Backwashing Rates

Operate

4.7.2.1.3.1 Ideally, high-rate granular media filters should be designed to operate at no more than 12 gpm/ft^2 (29.3 m/h) for filters with a media depth above the laterals of at least 24 inches (0.61 m). Filters with less than 24 inches of media between the top of the laterals and the top of the filter bed should operate at no more than 10 gpm/ft^2 (24.4 m/h). The granular media filter system should be designed to backwash each filter at a rate of at least 15 gallons per minute per square foot (48.9 m/h) of filter bed surface area, unless explicitly prohibited by the filter manufacturer. Specially graded filter media should be recommended in filter systems backwashing at less than 20 gpm/ft^2 (48.9 m/h) to be able to expand the bed at least 20% above the fixed bed height at the design backwash flow rate, which is subject to approval by the local authority. Filtration and backwashing at the same flow rate is likely to lead to poor performance of both processes. Backwashing at double the filtration rate is not all that complicated with a 3-filter system, where the flow of two filters is used to backwash the third. Further, backwashing with unfiltered water is possible in a 2-filter system by backwashing with the entire recirculation flow through each filter individually. Variable drive pumping systems and accurate flow meters also contribute to the likelihood of successful backwashing as well as effective filtration.

Drinking Water Research

Perspectives on Filtration from Drinking Water Research

Effective Filtration

Filtration at 10 gpm/ft^2 is really pushing the envelope for attaining effective filtration and would not be recommended for a municipal drinking water system using sand filters due to doubts about the ability of such a filter to remove particulate contaminants reliably. There are instances where multi-media deep bed filters or mono-medium filters with large diameter anthracite and 6 foot deep or greater beds of media are used, such as those owned and operated by the Los Angeles Department of Water and Power.

Effective filtration of drinking water at high filtration rates recommends careful and exact management of coagulation. Whereas filtration rates are not explicitly addressed in much of the research on water filtration, the experience of researchers, regulators, and consultants is that high rate filtration recommends extra attention and talent. For example, over 3 decades ago the State of California allowed the Contra Costa Water District to operate filters at 10 gpm/ft^2 but other water utilities were not allowed to do this. The exception was permitted because of the design and the high level of operating capability at the plant where the high rate was used. Operation at very high rates either causes very rapid increases of head loss in sand filters [water utility experience resulted in the conclusion that operating sand filters at rates above 3 or 4 gpm/ft^2 was impractical] or very little particle removal occurs as water passes through the sand bed, thus enabling filters to operate for a long time at high rates. For this reason following World War II, the use of anthracite and sand filters became the norm for filters designed to operate at 4 or 5 gpm/ft^2 or higher. Finally, in the 1980s, workers in Los Angeles showed that a deep [6 ft] filter with 1.5 mm effective size anthracite media could effectively filter water at rates of close to 15 gpm/ft^2. However, for very high rates of filtration to be effective, pretreatment has to be excellent, with proper pH and coagulant dosage, probably use of polymer, and in some cases, use of a pre-oxidant to improve filter performance. This is well understood by filter designers and professors who specialize in water filtration. Articles published on the Los Angeles work done by James Montgomery Engineers showed the importance of proper pretreatment. Papers written by experts on filtration have noted the importance of effective pretreatment [including proper coagulation] for dependable filter performance, and those writers were focused on rates employed in municipal filtration plants (e.g. 3 to 10 gpm/ft^2). As filtration rate increases, water velocity through the pores in the sand bed increases, making it more difficult for particles to attach to sand grains and remain in the bed instead of being pushed on through the bed and into filter effluent. When filters do not work effectively for pathogen removal, the burden is put on disinfection to control the pathogens. For *Cryptosporidium* the disinfection approach that is typically most cost-effective is UV, so a very high rate filter may need to be followed by UV for pathogen inactivation, and the very high rate filters would just have to clarify the water sufficiently that there is no interference from particulate contaminants with the UV inactivation process.

Backwash

4.7.2.1.3.2 Backwash System Design

For a granular media filter system to be able to backwash at a rate of at least 15 gallons per minute per square foot (48.9 m/h) of filter bed surface area, the pump(s), pipes, and filters must be designed accordingly. As many professionals have sought to improve water quality by decreasing the filtration rate to values lower than 15 gpm/ft^2, they have sometimes failed to recognize that while lowering the filtration rate may generally produce a positive change in performance, a similarly lower backwash rate could lead to a total filtration system failure. In cases where a backwash rate of 15 gpm/ft^2

is explicitly prohibited by the filter manufacturer, the filter may still be used provided that specially graded filter media is installed that will expand to a minimum of 20% bed expansion at the specified backwash flow rate. Viewing windows are highly recommended in all filters since they will allow direct observation of the bed expansion during backwashing, cleanliness of the media and backwash water, and the depth of the sand in the filter. Croll and coworkers[28] used a backwashing rate of 25 gpm/ft^2 (61 m/h) to achieve 25% bed expansion of their filter.

WHO Recommends

The WHO recommends a backwash rate of 15-17 gpm/ft^2 (37-42 m/h) for sand filters, but the media specifications are not given nor is it clear whether or not air-scour is expected prior to backwashing.[7] Backwashing swimming pool sand filters with air scour is common in the UK and elsewhere.[5,7] It has also been reported that air-scour washed swimming pool filters are more efficient than filters washed by water only.[29] It is reasonable that lower backwashing rates would be used for water backwash when following air-scour since the air-scour dislodges most of the particles attached to the media grains (as opposed to relying on the shear force of the water passing over the surface of the particles). It is not feasible to operate sand filters in drinking water treatment plants without an auxiliary backwash system such as air scour.[30] The practice of operating swimming pool sand filters (that were not using coagulation) without air scour has been standard practice in the U.S. for many years, which has seen mixed results ranging from no problems to total system failures requiring replacement of all filter media. PWTAG recommends air-scouring filters at 32 m/h (at 0.35 bar).[5]

Polyphosphate Products

Polyphosphate products are sometimes used to sequester metals in pools, but this practice is not recommended when granular media filters are used because polyphosphate is an effective particle dispersant that can reduce the removal efficiency

Filter Bed Expansion

Sufficient freeboard (or space between the top of the media

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[28] Croll BT, Hayer CR, and Moss S. Simulated *Cryptosporidium* removal under swimming pool filtration conditions. Water Environment Journal. 2007;21:149-156.
[29] Neveu A et al. Evaluation of Operation and performance of Swimming Pool filtration Plants. Francaisd'Hydrologie. 1988;19:2:203-213.
[30] Hendricks D. *Water Treatment Unit Processes, Physical and Chemical*. 2006. CRC Press (Taylor & Francis Group), Boca Raton, FL. ISBN: 0824706951.

and the backwash overflow) to allow for a minimum of 35% filter bed expansion during backwashing adds a factor of safety when the target bed expansion is 20% to prevent the washout of filter media during backwashing.

The regions underneath the lateral underdrains in granular media filters can become stagnant when filled with sand or gravel, which can lead to low disinfectant residuals and ultimately biofilm growth. Filling this area with concrete at the time of installation may prevent this potential problem.[5] It is fundamentally difficult to suspend (i.e., fluidize) and hence clean filter media or gravel that is below the level where the backwash water enters the filter.

Depth Requirement

4.7.2.1.4 Filter Media Depth Requirement

The performance of high-rate granular media filters at removing pathogens and particles is contingent upon the depth of the filter media (as shown in MAHC Annex Table 4.7.2.1), especially at rates of 15 gpm/ft^2 (36.7 m/h), which is why these filters recommend at least 24 inches (0.61 m) of filter media. The WHO recommends filtration at 10-12 gpm/ft^2 (25-30 m/h) for sand filters while the PWTAG recommends 4-10 gpm/ft^2 (10-25 m/h) as the maximum filtration rate for all non-domestic pools using sand filters.[5,7] The standard sand filter bed depth typically varies from 0.55 to 1 m (22 to 39 inches) in the UK.[5]

Minimum

4.7.2.1.4.1 ***Filtration Rates and Filter Depth: Design Relationship***

For swimming pool filters with less than 24 inches of media between the top of the laterals and the top of the filter bed, lower filtration rates (e.g., 10 gpm/ft^2 (24.4 m/h) are recommended to efficiently remove particles and pathogens. Improvements in particle removal with decreasing filtration rates have been documented.[31] Drinking water treatment facilities typically limit filtration to less than 4 gpm/ft^2, which is similar to the filtration rates recommended in swimming pools in the 1920's.[21, 22] The minimum depth of sand in pool filters was 36-inches in 1926.[22] Sand filters are typically designed in drinking water treatment for an L/d ratio of 1000 or greater, where L is the depth of the media and d is the diameter of the

[31] Gregory R. Bench-marking Pool Water Treatment for Coping with *Cryptosporidium*. Journal of Environmental Health Research. 2002;1(1):11-18.

media grain.[32] For example, a 0.6 mm effective size sand would recommend a minimum 0.6 m (23.6-inches) bed depth, and a 12-inch (0.3 m) deep sand bed with 0.5 mm grains would have an L/d of only 610.

The minimum depth of filter media above the underdrains (or laterals) is recommended be 24 inches (0.61 m) or greater with sufficient freeboard (or space between the top of the media and the backwash overflow) to allow for a minimum of 35% filter bed expansion during backwashing. Sand or other approved granular media should be carefully graded to ensure fluidization of the entire filter bed during backwashing.

A design backwash rate of at least 30% higher than the minimum fluidization velocity of the d_{90} size of the media in water at the larger of 86° F (30° C) or the maximum anticipated operating temperature is recommended. A backwash rate higher than the minimum could be necessary to effectively clean the media during backwashing. Variations in the media type, density, water temperature, effective size, or uniformity coefficient may cause changes in the recommended backwash flow rate and/or bed expansion, which should be subject to approval by the local authority provided hydraulic justification by the design engineer.

Sand or other approved granular media should be carefully graded to ensure fluidization of the entire filter bed during backwashing. The specifications of pool filter sand (or lack thereof) can lead to filter media being installed that cannot be effectively cleaned during backwashing. Sand that cannot be properly cleaned can lead to filter failures and/or biofilms in the bottom of a filter. Researchers have found nematodes, rotifers, ciliates, zooflagellates, amoebic trophozoites and cysts, as well as bacterial masses in the backwash water of swimming pool sand filters.[33] A design backwash rate of at least 30% higher than the minimum fluidization velocity of the d_{90} size of the media in water at the larger of 86° F (30° C) or the maximum anticipated operating temperature is recommended, but a backwash rate higher than the minimum could be necessary to effectively clean the media during

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[32] Cleasby JL and Logsdon GS. Chapter 8: Granular Bed and Precoat Filtration. In *Water Quality and Treatment, 5th Ed*. McGraw Hill, Inc. NY:1999. ISBN: 0070016593.
[33] Lyons TB and Kapur R. Limax Amoebae in Public Swimming Pools of Albany, Schenectady, and Rensselaer Counties, New York: Their Concentration, Correlations, and Significance. Applied and Environmental Microbiology. 1977;33(3):551-555.

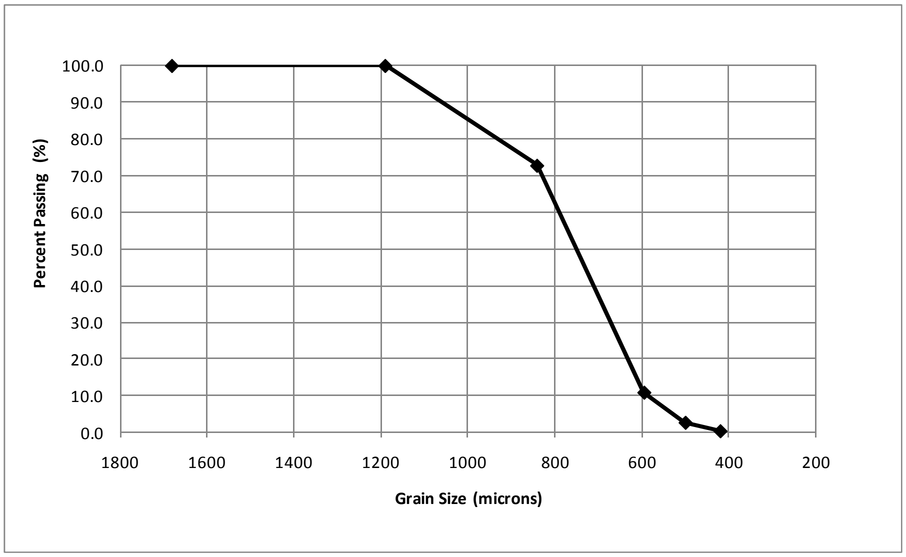
backwashing. These backwashing recommendations are based on drinking water treatment practice.[34] For a sample of pool filter sand examined at UNC Charlotte, the d_{90} size (i.e., 90% of the grains smaller than this diameter) of the media was estimated from the sieve analysis results in MAHC Annex Figure 4.7.2.1.4.1 to be 1.06 mm. The calculated minimum fluidization velocity of this sized sand grain in water at 30° C was calculated to be 16.7 gpm/ft^2. Since this backwash velocity would be expected to leave approximately 10% of the grains in the filter that were larger than the d_{90} unfluidized, common practice is to recommend a backwashing rate 30% greater than this minimum value (or 21.7 gpm/ft^2). The recommended backwash flow for this media by Kawamura[35] was graphically estimated to be 20.9 gpm/ft^2 at 20° C. This is the rationale for requiring at least 15 gpm/ft^2 backwashing rate of all swimming pool sand filters.

To ensure compatibility with the minimum recommended backwashing rate of 15 gpm/ft^2 (48.9 m/h), filter sand should pass through a number 20 U.S. standard sieve or equivalent (i.e., all sand grains should be smaller than approximately 0.85 mm). While this recommendation of “#20 Silica sand” is common in swimming pool manuals and by filter manufacturers, it does not appear to be representative of the actual sand that might be installed. Sieve analyses of two brands of commercially available “pool filter sand” are provided in MAHC Annex Figures 4.7.2.1.4.1 and 4.7.2.1.4.2. Sand can also be specified by an effective size (E.S.) of 0.45 mm with a uniformity coefficient (U.C.) of less than or equal to 1.45, which is roughly equivalent to a 20/40 mesh sand. A 20/40 mesh sand would pass through a #20 (0.85 mm sieve) and be retained on a #40 (0.42 mm) sieve. In order to reduce the rate of headloss accumulation at the top of the filter bed (and the frequency of backwashing), a 20/30 mesh sand could be specified where the smallest grains at the top of the filter would be approximately 0.60 mm (30 mesh) instead of 0.42 mm (40 mesh).

[34] Cleasby JL and Logsdon GS. Chapter 8: Granular Bed and Precoat Filtration. In *Water Quality and Treatment, 5th Ed*. McGraw Hill, Inc. NY:1999. ISBN: 0070016593.
[35] Kawamura, S. Integrated Design and Operation of Water Treatment Facilities. 2000. John Wiley and Sons, Inc., NY.

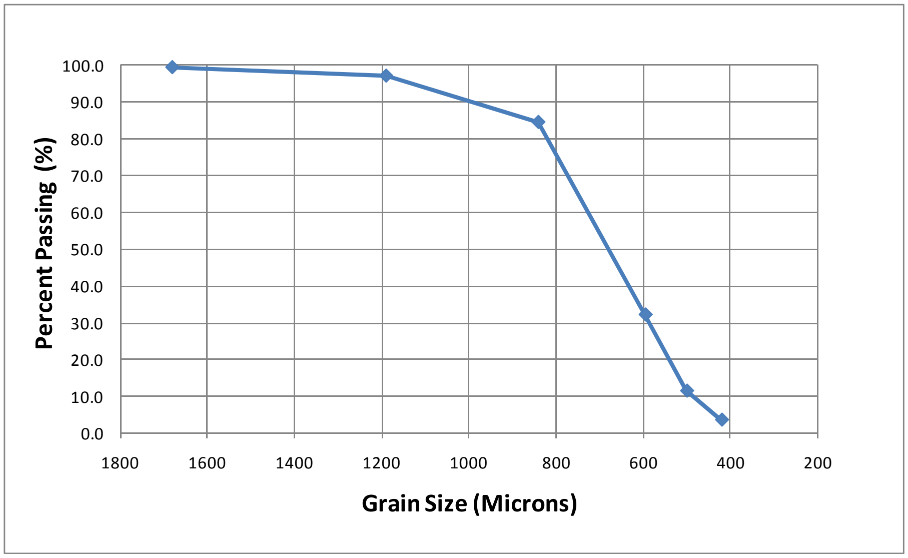
Figure

Figure 4.7.2.1.4.1. Grain size distribution of pool filter sand .



Figure

Figure 4.7.2.1.4.2.Grain size distribution of pool filter sand



The depth of the expanded bed during backwashing should be at least 20% greater than the depth of the fixed bed after backwashing.

Experiments to determine experimentally the backwashing rates recommended to fluidize a bed of pool filter sand in 3-inch and 6-inch diameter clear PVC filter columns based on visual observation were conducted. Fluidization is somewhat subjective when observed visually because sand grains could be moving sluggishly prior to fluidization and because the smaller grains at the top of the filter will fluidize long before the larger grains at the bottom. For this reason, bed expansion was measured and recorded along with visual observations of when the bed actually fluidized. Fluidization was visually observed to occur between 20 and 23 gpm/ft^2, which coincided with 19-23% bed expansion in both sized columns for the unaltered commercial filter media at 20° C. Expansion data from the 3” diameter filter column is shown in MAHC Annex Table 4.7.2.1.4.1. The 20/30 mesh fraction of the same filter media was examined under the same conditions, and the experimental results are provided in MAHC Annex Table 4.7.2.1.4.2. The media was observed to be fully fluidized at 19.9 gpm/ft^2 with a bed expansion of 21.8% at 20° C. Calculations based on Cleasby and Logsdon[36] indicate that filter backwashing rates should increase by approximately 18% for this media as the temperature is increased from 20° to 30° C due to changes in the viscosity of water with temperature. Fluidization can be somewhat complicated to estimate, but filter bed expansion can be easily measured in the field with granular media filters that use viewing windows. Futhermore, a model exists that can be used to calculated filter bed expansion of sand in a filter during backwashing.[37] The preceding model tends to be sensitive to fixed bed porosity, but using a value of 42% porosity with a sphericity of 0.85 and density of 2.65 g/cm^3 yielded a bed expansion of 22.7% at 20 gpm for water at 30° C. This is the rationale for requiring the depth of the expanded bed during backwashing being at least 20% greater than the depth of the fixed bed. PWTAG recommends 15-25% bed expansion following air scouring at 32 m/h (at 0.35 bar).[5] In a study funded by PWTAG, researchers used a backwashing rate of 25 gpm/ft^2 (61 m/h) to achieve 25% bed expansion of their filters.[15] Variations in the media type, density, water temperature, effective size, or uniformity coefficient may cause changes in the recommended backwash flow rate and/or bed expansion, which should be subject to approval by the local authority provided hydraulic justification by the design engineer.

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[36] Cleasby JL and Logsdon GS. Chapter 8: Granular Bed and Precoat Filtration. In *Water Quality and Treatment, 5th Ed*. McGraw Hill, Inc. NY:1999. ISBN: 0070016593.
[37] Dharmarajah AH and Cleasby JL. Predicting the Expansion Behavior of Filter Media. Journ. AWWA. 1986;78(12):66-76.

Table

Table 4.7.2.1.4.1: Pool Filter Sand at 20° C

Backwash Flow (gpm/ft^2)	Bed Expansion (%)
12.4	3.6
16.3	11.4
18.5	16.3
20.3	19.3
22.1	22.5

Table 4.7.2.1.4.2: Pool Filter Sand Sieved 20/30 mesh at 20° C

Backwash Flow (gpm/ft^2)	Bed Expansion (%)
12.2	4.8
15.8	13.0
17.9	17.4
19.9	21.8
21.5	25.6
23.9	31.2

Differential Pressure

4.7.2.1.5 Differential Pressure Measurement

Coagulant Injection Equipment

4.7.2.1.6 Coagulant Injection Equipment

Coagulant Injection Equipment

4.7.2.1.6.1 To enhance filter performance, a coagulant feed system, when used, should be installed with an injection point located ahead of the filters and recirculation pump(s) capable of delivering a variable dose of a coagulant (e.g., polyaluminum chloride or a pool clarifier product) to enhance filter performance. Pumps should be properly sized to allow for continuous delivery of the recommended dosage of the selected coagulant. Products used to enhance filter performance should be used according to the manufacturers' recommendations. The coagulant feed system should consist of a pump, supply reservoir, tubing, isolation valve, and backflow prevention device. Sand filters used as prefilters for membranes or cartridge filters with 1-micron nominal or 5-micron absolute size ratings or less should not be recommended to have coagulant injection equipment. Specialized granular filter media capable of removing *Cryptosporidium* oocysts or an acceptable 4.5-micron surrogate particle with an efficiency of at least 90% (i.e., a minimum of 1 log reduction) without coagulation should not be recommended to provide coagulant injection equipment, but this media should be replaced or reconditioned as recommended to sustain the minimum recommended particle removal efficiency stated above. Sand filters located ahead of a UV or Ozone disinfection system may be excluded from supplying coagulation equipment with the approval of the local authorities. Local authorities should consider the efficiency of the supplemental disinfection process for *Cryptosporidium* inactivation but should also consider that a side-stream system does not have any effect on the *Cryptosporidium* oocysts that bypass the system on each turnover. For example, a UV system that is 99.999% effective at inactivating *Cryptosporidium* that only treats half of the recirculated water flow is on average only 50% effective (per pass) because all of the *Cryptosporidium* in the bypass stream remain unaffected by the UV.

Coagulation is the key to effective granular media filtration, which has long been recognized in the drinking water industry.[16,17,18,19,38] Operation of granular media filters without coagulation is not permitted by USEPA regulations for drinking water treatment, with the exception of slow sand filters. Thus, if pathogen removal is a goal of water filtration for swimming pool sand filters, coagulation would be essential. This is the rationale for recommending future consideration of coagulation in swimming pools. A coagulant feed system should be installed with an injection point located ahead of the filters to facilitate particle removal by filtration (instead of settling to the bottom of the pool), and injection ahead of the recirculation pump(s) will provide mixing to evenly distribute the coagulant among the particles. A variable dose of a coagulant (e.g., polyaluminum chloride, or pool clarifier) is recommended because coagulant dosages may vary with bather load. Products used to enhance filter performance should be used according to the manufacturers' recommendations since overfeed or underfeed of coagulants

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[38] Logsdon GS. *Water Filtration Practices: Including Slow Sand Filters and Precoat Filtration*. 2008. American Water Works Association, Denver, CO. ISBN: 9781583215951.

is known to impair performance.

Although polyaluminum chloride (PACl) is not a widely used coagulant in the U.S. at present, it has been used extensively abroad.[5,7] However, recommended dosages abroad may not be optimized for pathogen removal. PWTAG recommends a polyaluminum chloride dosage of 0.005 mg/L as Al, but research has shown that 0.05 mg/L is recommended to exceed 90% removal and 0.21 mg/L or higher could be optimal with filters operated based on U.K. standards.[15]

New Challenges: The Impact of Coagulation on Backwashing

Coagulation is likely to make cleaning of sand filters more challenging. Drinking water treatment facilities in the U.S. employ auxiliary backwash systems such as air-scour to improve the cleaning process. Water only backwashing has not been found to be effective for media cleaning in drinking water treatment applications.[39] Air scour systems are common in European pool filters and should be investigated further in the U.S. More frequent backwashing is recommended with water-only backwash, and the clean-bed headloss (pressure) should be recorded after each backwash to detect early signs of ineffective backwashing and prevent filter system failures.

Initial Headloss and Headloss Accumulation Rate

Increased headloss (or pressure buildup) in filters is expected with coagulation as particles are likely to be removed faster (more efficiently) and closer to the top of the filter thereby clogging the top of the filter more quickly. This is actually a sign that the coagulation/filtration system is working effectively. The initial headloss after backwashing should remain relatively constant however. Coagulants have been used successfully in the U.S. in the past and are currently being used in pools abroad. [5,15,21,22,40] In systems not properly designed to backwash with filter effluent from other filters, the coagulant feed system should not be operated during backwashing so as to prevent introduction of coagulant into the backwash water.

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[39] Hendricks D. *Water Treatment Unit Processes, Physical and Chemical*. 2006. CRC Press (Taylor & Francis Group), Boca Raton, FL. ISBN: 0824706951.
[40] DIN. Treatment and Disinfection of Water Used in Bathing Facilities, Part 1: General Requirements. 1997. Ref. No. 19643-1.

Precoat Filters

4.7.2.2 Precoat Filters

General

4.7.2.2.1 General

Filtration Rates

4.7.2.2.2 Filtration Rates

The design filtration rate of 2.0 gallons per minute per square foot (4.9 m/h) might be overly conservative and is the same upper limit on filtration rate typically used in drinking water treatment applications.[41] However, drinking water applications typically use finer grades of precoat media at application rates of 0.2 lbs/ft^2 (1 Kg/m^2).[32] Lange and coworkers[42] have used filtration rates up to 4 gpm/ft^2 (9.8 m/h) with no adverse effect on *Giardia* cyst removal although the removal of turbidity and bacteria were decreased. Ongerth and Hutton[43] actually found better removals at 2 gpm/ft^2 than at 1 gpm/ft^2 for *Cryptosporidium* oocysts under drinking water treatment conditions (i.e., 0.2 lbs/ft^2 of DE with body-feed).

Media Introduction System

4.7.2.2.3 Precoat Media Introduction System

Suction Side

4.7.2.2.3.1 A pump strainer basket may be sufficient for this purpose. Systems may choose to feed precoat media through a skimmer while flowing the filter to waste, but these systems should use the maximum recommended precoat media load permitted by the manufacturer to account for media lost to the waste stream during precoating. Three-way valves or multiport valves should not be installed in the recirculation loop in such a manner that it would recommend the interruption of flow through the filter following precoating to allow the effluent stream to be redirected to the pool.

Precoating of filters is done using a recirculated slurry in filters because the slurry gradually builds up on the septum and in early stages some of the filter aid passes through. Precoat has to be introduced ahead of the filter. Simply sending the water containing diatomite or perlite out to pool instead of closed-loop recirculation or waste it would result in

[41] Logsdon GS. *Water Filtration Practices: Including Slow Sand Filters and Precoat Filtration*. 2008. American Water Works Association, Denver, CO. ISBN: 9781583215951.
[42] Lange KP et al. Diatomaceous Earth Filtration of *Giardia* Cysts and Other Substances. *Journal AWWA.* 1986;78(1):76-84.
[43] Ongerth JE and Hutton PE. Testing of Diatomaceous Earth Filtration for Removal of *Cryptosporidium* Oocysts. Journal AWWA. 2001;93(12):54-63.

filter aid being deposited in the pool. The recirculation setting on a multi-port valve does not accomplish the goal of closed loop recirculation. Rather, it would return the media to the pool without passing through the filter.

Separation Tank

Precoat filter media has the potential to settle out of suspension in sewer pipes depending on the flow velocities, which could lead to fouling or clogging of sewer pipes. Local authorities may recommend removal of precoat media prior to discharge in sewer systems so pool operators should check the AHJ.

Filter Media

4.7.2.2.4 Continuous Filter Media Feed Equipment

Filters performance can be significantly impacted by the selection of the precoat filter media, which could alter water clarity, pathogen removal, and cycle length. Multiple grades of precoat media are available in the marketplace. Precoat media can be specified by median particle size of the media or by permeability of the media.[32]

Cartridge Filters

4.7.2.3 Cartridge Filters

Listed

4.7.2.3.1 Cartridge filters have not been demonstrated to remove pathogens like *Cryptosporidium* efficiently using the standard swimming pool cartridges, and the non-standardized manual cleaning methods for cartridges may lead to pathogen and/or chemical exposure risks to patrons and employees at aquatic venues while the fouling of cartridges may lead to pools exceeding their maximum recommended turnover times. Poor use of personal protective equipment and non-standard cleaning of spa cartridge filters led to non-tuberculous mycobacterial infections in spa workers[44]. Due to these health and safety concerns, cartridge filter use is not recommended in pools.

Cleaning procedures for cartridges are not well-established and education in proper cleaning procedures is likely necessary to avoid contaminated cartridges being reinstalled into filters potentially providing a protected region for proliferation of biofilm bacteria the could lead to an outbreak. Cartridge filter elements are typically cleaned manually usually by hosing them down with a water hose and replacing

[44] Moraga-McHaley SA et al. Hypersensitivity pneumonitis with Mycobacterium avium complex among spa workers. J Occup Environ Health. 2013;19(1):55-61.

them. Exposure concerns exist since concentrated streams containing *Legionella*, Mycobacteria, *Cryptosporidium*, and other pathogens can potentially be sprayed or splashed on the operator/lifeguard as well as the surrounding environment perhaps even including the inside of the filter or the surfaces surrounding the pool.

An extensive survey of manufactures' cleaning recommendations was conducted after there was a *Legionella* outbreak in a facility with cartridge filters. *Legionella, Pseudomonas,* and biofilms were found in the filters. The cleaning procedure employed was to take them outside, rinse them with a water hose, and replace them. Operators reported that they would occasionally degrease or bleach them. Further investigation revealed that this cleaning procedure was common at other facilities.

Filter manufacturers were surveyed for cleaning procedures and most often did not have a cleaning process and simply deferred to the cartridge manufacturer since many filter manufacturers do not make the cartridges. The cartridge manufacturers also did not have a cleaning procedure or a very minimal one that did not account for biofilms or heavy organic loads commonly encountered in spas. Chlorine is generally ineffective at inactivating bacteria in a biofilm or removing particulate or organic filter foulants. One effective way to control the biofilms is to completely dry them out.

Based on the known poor performance in removing pathogens increasing the likelihood of waterborne disease outbreaks and the potential for dangerous microbial (and perhaps chemical) exposures to the operators during routine maintenance, the consensus is that cartridge filters are not currently recommended. This is not to say that all of the current issues and/or concerns with cartridge filters could not be resolved.

Pool Filtration Rates

4.7.2.3.2 Cartridge filter elements should have a maximum flow rate of 0.375 gallons per minute per square foot (0.26 L/s/m^2), but the design filtration rate for surface-type cartridge filter should not exceed 0.30 gallons per minute per square foot (0.20 L/s/m^2).The 0.375 gallons per minute per square foot (0.26 L/s/m^2) design criterion is acceptable, but the cartridges don't recover 100% capacity when cleaned after fouling. Systems designed to the maximum limit cannot sustain performance (or minimum pool turnover requirements) over time. For example, if a filter only recovers to 80% of the original flux after cleaning, then a filter flow rate of 0.375 gallons per minute per square foot (0.26 L/s/m^2) would become 0.30 gallons per minute per square foot (0.20 L/s/m^2). Cartridge replacement would be necessary following fouling levels greater than 20% of the maximum rated capacity.

Elements 4.7.2.3.3 The pore size and surface area of replacement cartridges shall match the manufacturer's recommendations.

Spare Cartridge 4.7.2.3.4 An extra set of elements, with at least 100 percent filter area, and appropriate cleaning facilities and equipment should be provided to allow filter cartridges to be thoroughly cleaned. Two sets of filter cartridges should be supplied to allow for immediate replacement and cleaning procedures that involve complete drying of the filter elements.

Disinfection

4.7.3 Disinfection

Chemical Addition

4.7.3.1 Chemical Addition Methods

Feed Equipment

4.7.3.2 Feed Equipment

General

4.7.3.2.1 General

Feeder Engineering

4.7.3.2.2 Sizing of Disinfection Equipment

Sizing

4.7.3.2.2.1 Chlorine System Design Guidelines for Standard Use Pools

Table 4.7.3.2.2.1: Chlorine System Design Guidance for Standard Use Pools- 1

	Outdoor	Indoor
PPM Feed	2.50	2.00
Turnover (hrs)	4.00	4.00
Turnovers/Day	6.00	6.00

Table 4.7.3.2.2.2: Chlorine System Design Guidance for Standard Use Pools- 2

Pool Volume (gal)	FREE AVAILABLE CHLORINE (lbs/day), or CHLORINE GAS (lbs/day), or 12% SODIUM HYPOCHLORITE (gal/day)		Calcium Hypochlorite (65% FAC [lbs/day])	
	Outdoor	Indoor	Outdoor	Indoor
10,000	1.25	1.00	1.9	1.5
20,000	2.5	2.0	3.8	3.1
30,000	3.8	3.0	5.8	4.6
40,000	5.0	4.0	7.7	6.2
50,000	6.3	5.0	9.6	7.7
60,000	7.5	6.0	11.5	9.2
70,000	8.8	7.0	13.5	10.8
80,000	10.0	8.0	15.4	12.3
90,000	11.3	9.0	17.3	13.9
100,000	12.5	10.0	19.2	15.4
110,000	13.8	11.0	21.2	16.9
120,000	15.0	12.0	23.1	18.5
150,000	18.8	15.0	28.9	23.1
200,000	25.0	20.0	38.5	30.8
250,000	31.3	25.0	48.1	38.5
300,000	37.5	30.0	57.7	46.2
350,000	43.8	35.0	67.4	53.9
400,000	50.0	40.0	77.0	61.6
450,000	56.3	45.0	86.6	69.3
500,000	62.6	50.0	96.2	77.0
550,000	68.8	55.0	105.9	84.7
600,000	75.1	60.0	115.5	92.4
650,000	81.3	65.1	125.1	100.1
700,000	87.6	70.1	134.7	107.8
750,000	93.8	75.1	144.3	115.5

NOTE: The intent of the above MAHC Annex Table 4.7.3.2.2.2 is to provide a design guideline for properly sized chlorine feeders and feed pumps that can respond quickly during high demand periods to maintain the minimum required chlorine residual in the pool.

SAMPLE CALCULATIONS:

1. OUTDOOR FREE AVAILABLE CHLORINE:

1.25 FAC (LB/DAY) = 10,000 GAL / 1,000,000 x 2.5 PARTS/MILLION FAC x 8.34 POUNDS/GAL x 6 TURNOVERS/DAY

2. INDOOR FREE AVAILABLE CHLORINE:

1.0 FAC (LB/DAY) = 10,000 GAL / 1,000,000 x 2.0 PARTS/MILLION FAC x 8.34 POUNDS/GAL x 6 TURNOVERS/DAY

3. OUTDOOR CAL HYPO @ 65% FAC:

1.9 FAC (LB/DAY) = 10,000 GAL / 1,000,000 x 2.5 PARTS/MILLION FAC/0.65 x 8.34 POUNDS/GAL x 6 TURNOVERS/DAY

4. INDOOR FREE AVAILABLE CHLORINE:

1.5 FAC (LB/DAY) = 10,000 GAL / 1,000,000 x 2.0 PARTS/MILLION FAC/0.65 x 8.34 POUNDS/GAL x 6 TURNOVERS/DAY

Chlorine System Design Guidelines for High Use Pools

Table 4.7.3.2.2.3: Chlorine System Design Guidance for High Use Pools- 1

	Outdoor	Indoor
PPM Feed	2.70	2.20
Turnover (hrs.)	2.00	2.00
Turnovers/Day	12.00	12.00

Table 4.7.3.2.2.4: Chlorine System Design Guidance for High Use Pools- 2

Pool Volume (gal)	FREE AVAILABLE CHLORINE (lbs/day), or CHLORINE GAS (lbs/day), or 12% SODIUM HYPOCHLORITE (gal/day)		Calcium Hypochlorite (65% FAC [lbs/day])	
	Outdoor	Indoor	Outdoor	Indoor
10,000	2.70	2.20	4.2	3.4
20,000	5.4	4.4	8.3	6.8
30,000	8.1	6.6	12.5	10.2
40,000	10.8	8.8	16.6	13.5
50,000	13.5	11.0	20.8	16.9
60,000	16.2	13.2	24.9	20.3
70,000	18.9	15.4	29.1	23.7
80,000	21.6	17.6	33.3	27.1
90,000	24.3	19.8	37.4	30.5
100,000	27.0	22.0	41.6	33.9
110,000	29.7	24.2	45.7	37.3
120,000	32.4	26.4	49.9	40.6
150,000	40.5	33.0	62.4	50.8
200,000	54.0	44.0	83.1	67.7
250,000	67.6	55.0	103.9	84.7
300,000	81.1	66.1	124.7	101.6
350,000	94.6	77.1	145.5	118.6
400,000	108.1	88.1	166.3	135.5
450,000	121.6	99.1	187.1	152.4
500,000	135.1	110.1	207.9	169.4
550,000	148.6	121.1	228.6	186.3
600,000	162.1	132.1	249.4	203.2
650,000	175.6	143.1	270.2	220.2
700,000	189.2	154.1	291.0	237.1
750,000	202.7	165.1	311.8	254.0

NOTE: The intent of the above MAHC Annex Table

4.7.3.2.2.4 is to provide a design guideline for properly sized chlorine feeders and feed pumps that can respond quickly during high demand periods to maintain the minimum required chlorine residual in the pool.

SAMPLE CALCULATIONS:

1. OUTDOOR FREE AVAILABLE CHLORINE:

2.70 FAC (LB/DAY) = 10,000 GAL / 1,000,000 x 2.7 PARTS/MILLION FAC x 8.34 POUNDS/GAL x 12 TURNOVERS/DAY

2. INDOOR FREE AVAILABLE CHLORINE:

2.20 FAC (LB/DAY) = 10,000 GAL / 1,000,000 x 2.20 PARTS/MILLION FAC x 8.34 POUNDS/GAL x 12 TURNOVERS/DAY

3. OUTDOOR CAL HYPO @ 65% FAC:

4.2 FAC (LB/DAY) = 10,000 GAL / 1,000,000 x 2.7 PARTS/MILLION FAC/0.65 x 8.34 POUNDS/GAL x 12 TURNOVERS/DAY

4. INDOOR FREE AVAILABLE CHLORINE:

3.4 FAC (LB/DAY) = 10,000 GAL / 1,000,000 x 2.20 PARTS/MILLION FAC/0.65 x 8.34 POUNDS/GAL x 12 TURNOVERS/DAY

Types

4.7.3.2.3 Feeder Engineering

Introduction of Chemicals

4.7.3.2.4 Introduction of Chemicals

Feeder Controls

4.7.3.2.5 Feeder Controls

Compressed Chlorine Gas

4.7.3.2.6 Compressed Chlorine Gas

Types of Feeders

4.7.3.2.7 Types of Feeders

UV Systems

4.7.3.2.7.1 All UV units shall be installed into the system by means of a bypass pipe to allow maintenance on the UV unit while the pool is in operation.

Location 4.7.3.2.7.6 Chlorine gas is an extremely toxic gas and its use at aquatic facilities requires enhanced training in use and safety requirements. Most communities require some form of disaster response planning to be in place if it is stored on site. Since the gas is heavier than air it should not be stored below grade where leaks would lead to accumulation of the gas in the storage room that may immediately overwhelm staff who descend into the area. The added time, risk, and disaster response requirements have led most aquatic facilities to switch to safer alternatives for disinfection.

Salt Electrolytic Chlorine Generators

4.7.3.2.8 Salt Electrolytic Chlorine Generators, Brine Electrolytic Chlorine or Bromine Generators

pH Feeders

4.7.3.2.9 Feeders for pH Adjustment

Chemical Controllers

4.7.3.2.10 Controllers

High Use Facilities 4.7.3.2.10.5.1 High use facilities, such as water parks and health clubs, require a greater capacity of feed equipment and production. These facilities generally have higher recirculation rates and experience accelerated consumption and should be sized differently to provide the minimum dosing.

Replenishment and Disposal

4.7.4 Water Replenishment and Disposal

Water Replenishment System

A water replenishment system allows for pool water to be removed from the pool and properly disposed of so that it can be replaced with fresh water containing lower concentrations of dissolved contaminants. A water replenishment system should be used to control the dissolved organic contaminant concentrations (e.g., sweat, oils, chlorination by-products, and urine) and dissolved inorganics (e.g., salts and metals) because pool filtration systems are not effective at removing dissolved contaminants.

Local Authority 4.7.4.1 Pool waste streams (including filter backwash water and pool drainage water) should be discharged through an air gap to sanitary sewers, storm sewers, drain fields, or by other means, in accordance with local municipal and building official recommendations including obtaining all necessary permits. The discharge should occur in a manner that does not result in a nuisance condition.

Discharge and Measure 4.7.4.2 A means of intentionally discharging and measuring the volume of discharged pool water (in addition to the filter backwashing system) should be installed and designed to discharge a volume of water of up to 4 gallons (15 L) per bather per day per facility through an air gap. Water replacement or replenishment at a rate of 8 gallons (30 L) per bather per day per facility[5,7,31] have been widely used. PWTAG[5] states that as much as half of the recommended amount could be associated with filter backwashing. There does not appear to be any research to support the use of the 30L/day/bather number used abroad. So, since 4 gal/day/bather is roughly half of this amount (and typically met by filter backwashing alone), it seems like a reasonable place to start. A requirement could be made once the science is there to support a higher or lower value. With a water replenishment system in place, facility operators will be able to experiment with higher water replenishment rates to obtain better water (and indoor air) quality . It should also be easy to comply with any future regulations related to water replenishment as only the flow rate would require adjustment. Water replenishment for a large water park would be based on the number of bathers in the entire facility (not the total number swimming in a particular pool on a given day since most patrons are expected to distribute their bather load over a range of pools and/or rides on a given day). However, water replenishment should be proportional to the number of bathers in each individual treatment system. It would not be allowable to send to waste all of the water from the wave pool and none from the other attractions (unless the water was shared through a combined venue treatment system).

Air Gap

Each waste line should have a unique air gap. Waste lines from different sources (e.g. pool, spa, overflow, sump pump, etc.) should not be tied together, but multiple waste lines may discharge into a common sump or receptacle after an air gap.

Prohibit

If local or State codes prohibit disposal of backwash filter media (perlite, cellulose or diatomaceous earth) directly to sanitary sewer, a separation tank may be recommended. The separation tank is to be designed for the conditions of the specific facility filtration system. The separation tank should be designed to accommodate the volume of water and spent media recommended for at least a single backwash (media change), without overflowing. The separation tank may include separation screens or a settling pit to allow for the spent media to be removed and properly disposed of according to AHJ requirements.

Spas

4.7.5 Spas

General

4.7.5.1 General

Filtration Inlets

4.7.5.2 Filtration System Inlets

Jet Inlets

4.7.5.3 Jet System Inlets

Model Aquatic Health Code
Recirculation Systems and Filtration Module Annex
5.0 Operation and Maintenance

Keyword	Section	Annex
	5.0	**Operation and Maintenance**
	5.1	**Plan Submittal**
	5.2	**Materials**
	5.3	**Equipment Standards**
	5.4	**Pool Operation and Facility Maintenance**
	5.5	**Pool Structure**
	5.6	**Indoor/outdoor Environment**
	5.7	**Recirculation and Water Treatment**
	5.7.1	**Recirculation Systems and Equipment**
General	***5.7.1.1***	***General***
Gutter/ Skimmer Pools	5.7.1.1.3	The recommendation for gutter or skimmer pools with main drains to have the majority of the water (at least 80% of the recommended recirculation flow) be drawn through the perimeter overflow system and no greater than 20% through the main drain during normal operation is based on subsurface distribution of bacteria data that showed most pools had higher surface concentrations of bacteria.[45] For the 65 pools examined, surface concentrations of bacteria were an average of 3.4 times greater at the surface. However, about 30% of the pools showed the opposite trend with higher subsurface concentrations, which is why some operational flexibility is provided with these values. For reverse flow (upflow) pools, 100% of the recommended circulation flow should be through the perimeter overflow system, which is consistent with the German DIN Standards.[5] Efficient removal of surface water is critical for maintaining water quality because surface water contains the highest concentration of pollutants from body oils, sunscreens, as well as other chemicals or particles that are less dense than water. Bacteria appear to follow the same trend in most

[45] Dick EC, Shull IF, and Armstrong AS. Surface-Subsurface Distribution of Bacteria in Swimming Pools – Field Studies. Am. J. Pub. Health. 1960;50:5:689-695.

Keyword	Section	Annex

cases.[46] The distribution of chlorine-resistant pathogens like *Cryptosporidium* is not known at present.

The majority of the organic pollution and contamination is concentrated at or near the surface irrespective of the mixing effects of the circulation.

Combined Venue Treatment

5.7.1.2 Combined Venue Treatment

Inlets

5.7.1.3 Inlets

During regular seasonal operation following initial adjustments, inlets should be checked at least weekly so that the rate and direction of flow through each inlet has not been changed substantially from the original conditions that established a uniform distribution pattern and facilitated the maintenance of a uniform disinfectant residual throughout the entire facility without the existence of dead spots.

A tracer test (e.g., with a sodium chloride tracer injected on the suction side of the pump) should be conducted annually at startup and documented to quantitatively assess distribution pattern in the pool. An amount of salt sufficient to increase the baseline conductivity by at least 20% should be added over a 1 minute period, and the conductivity or TDS should be measured at 1 minute intervals until the conductivity increases by 20% and/or stops changing for 10 consecutive readings after an initial increase. Samples may also be taken at the corners, center, and bottom of the pool (via a sample pump with the pool unoccupied) in small labeled containers for later measurement to increase the amount of information available to assist in interpreting the results. Increases greater than predicted by the amount of salt added to the pool volume indicate poor mixing. Areas with conductivities lower than in the return stream at the time the sample was collected are likely to be areas with poor recirculation flows.

Note: It is possible to do a tracer test, which is quantifiable in terms of salt concentration ratios and/or time required to reach equilibrium concentration near the filter.

Surface Skimming

5.7.1.4 Surface Skimming Devices

[46] Dick EC, Shull IF, and Armstrong AS. Surface-subsurface distribution of bacteria in swimming pools – field studies. Am. J. Pub. Health. 1960;50:5:689-695.

Keyword	Section	Annex
Devices		
Submerged Drains	***5.7.1.5***	***Submerged Drains/Suction Outlet Covers or Gratings***
Piping	***5.7.1.6***	***Piping***
		Winterization may involve dropping the water level below the level of the inlets, blowing or draining all of the water out of the pipes, adding antifreeze, and closing off both ends. Pipes should be drained or winterized in regions where freezing temperatures are expected to be reached inside of the pipes. This should not be done with car antifreeze, and the antifreeze should not be toxic to humans.
Strainers & Pumps	***5.7.1.7***	***Strainers and Pumps***
Flow Meters	***5.7.1.8***	***Flow Meters***
		Flow meters are important for the maintenance of proper filtration, backwashing, and recirculation flow rates. It is also feasible to save money on electrical costs by using the flow meter to monitor and adjust the speed of the pump.
Flow Rates/ Turnovers	***5.7.1.9***	***Flow Rates/Turnovers***
		Turbidimeter Maintenance. Turbidimeters used in a flow turndown system should be cleaned and calibrated as often as necessary to maintain accurate readings but at an interval no longer than recommended by the instrument manufacturer. Seasonally operated pools should be calibrated at the beginning of the swim season and thereafter at an interval no longer than recommended by the instrument manufacturer. Flow rates should be sufficient to displace the water volume in the turbidimeter in accordance with the flow range set by the manufacturer.
	5.7.2	**Filtration**
Granular Media Filters	***5.7.2.1***	***Granular Media Filters***
Backwashed	5.7.2.1.4	Backwashing frequency is important for multiple reasons. First, solids attach more strongly to the filter media over time and can be more difficult to remove following infrequent backwashing. Secondly, the organic particles (e.g., skin cells) held in the filter in contact with free chlorine can break down over time and produce disinfection by-products and/or

Keyword	Section	Annex
		combined chlorine. The potential to form "mudballs" also increases with solids loading inside of a filter and can cause filter failures. The preceding items are the rationale for requiring backwashes at prescribed pressure losses through the filter as well as at prescribed time intervals. Some data suggests tainted backwash water remains inside of the filter at the conclusion of the backwash procedure and therefore should be wasted to drain for at least the first 2 minutes after restarting.
Filtration Enhancing Products	5.7.2.1.7	Coagulants should be used with caution due to potential for filter bed fouling. Maintaining records of clean bed headloss is recommended to help detect problems of filters not being adequately cleaned via backwashing. If a facility decides to use coagulants, they should be used continuously. Not using coagulants when the water is clear to save money will significantly impair the capabilities of the filters to remove pathogens like *Cryptosporidium* and *Giardia*.
Precoat Filters	***5.7.2.2***	***Precoat Filters***
Precoating	5.7.2.2.2	In closed-loop mode, it will be necessary to charge the media slurry to the suction side of the pump or precoat tank, prior to closing down the loop and putting the system into recirculation. Precoating of a filter typically takes 5 to 10 minutes. At the end of the precoat cycle, the discharge out of the filter should be clear and free of filter media. If the discharge is not clear, the filter should be opened, inspected, and repaired as necessary.
Operation	5.7.2.2.3	When flow or pressure is lost in the filter, the precoat layer may become unstable and fall off of the filter septum. To reduce the likelihood of debris and contaminants being returned to the pool, it is recommended that prior to restarting the filter, it should be backwashed and/or cleaned and the precoat re-established with new filter media in a closed loop recirculation mode or with water wasting until the discharge of the filter is clear to minimize the potential of media or debris returning to the pool. It is important that flow not be interrupted after the precoating process is completed and the flow out of the filter is redirected from the recirculation or waste piping back to the pool. It is acceptable to open and close valves on the filter effluent stream as long as the closed valves are opened first so that the filter effluent water can flow continuously.[32] Allowing the media to fall off of the filter septum decreases the capability of the filter to remove

Keyword	Section	Annex
		particles.[32] The critical importance of always cleaning the filter and replacing the media when the flow is interrupted for any reason is related to uneven recoating permitting pathogen passage as well as fouling of the media support layers.[32]
Cleaning	5.7.2.2.4	Septum covers should be properly cleaned and inspected to maintain proper performance of precoat filters. Filters should be backwashed following a significant drop in the flow rate or when the pressure differential across the filter is greater than 10 pounds per square inch (68.9 KPa). Vacuum–type precoat filters should be cleaned when the vacuum gauge reading increases to greater than 8 inches (203 mm) of mercury or as recommended by the manufacturer. If after precoating with fresh media, the filter pressure does not return to the normal initial starting pressure noted on filter start-up, it would be advisable to disassemble the filter and clean the elements (septum covers) per the filter manual. Septum covers should be cleaned or replaced when they no longer provide effective filtration or create a friction loss preventing maintenance of the recommended recirculation rate. Water and spent media should be discharged in a manner approved by the appropriate regulatory agency.
Bumping	5.7.2.2.6	Bumping is the act of intentionally stopping the filter and forcing the precoat media and collected contaminants to be removed from the filter septum. Bumping may impair pathogen removal and could facilitate the release of pathogens previously trapped in the filter. Therefore, bumping should be performed in accordance with the manufacturer's recommendations. Prior to restarting a bumped filter, it is recommended that the precoat be re-established in a closed loop recirculation mode or with water wasting until the discharge of the filter is clear to minimize the potential of media or contaminants returning to the pool.
		Pending future research, bumping is strongly discouraged in any precoat filter application where pathogen removal is a concern. Bumping may impair pathogen removal as pathogens once trapped at the surface of the cake could be positioned close to the septum and penetrate the filter during operation.[47] Cyst-contaminated water used for precoating filters led to much higher cyst concentrations in the filter

[47] Logsdon GS et al. Alternative filtration methods for removal of Giardia cysts and cyst models. Journal AWWA. 1981;73(2):111-118.

Keyword | Section | Annex

effluent.[19] Precoat filters have been demonstrated to remove greater than 99% of the oocysts as shown in MAHC Annex Figure 4.7.2.5. Not using dirty precoat media to precoat filters as well as maintaining continuous flow is recommended.[18,19,32]

Filter Media 5.7.2.2.7

Continuous filter media feed (or body-feed) can be used to increase the permeability of the cake, maintain flow, and extend cycle length as it becomes coated with debris. Body-feed is filter media added during the normal filtration mode on a continuous basis. The amount of body-feed used is dependent upon the solids loading in the pool. Turbidity is the best available method to quantify and estimate solids loading. For filter influent turbidities greater than 1.5 NTU, body-feed may be beneficial with addition rates ranging from 1.0 to 4.0 ounces of DE per square foot of filter area per day dependent on the solids loading in the pool. The lowest effective concentration of suspension should be used in a body-feed system. The concentration of the suspension may not exceed 5% by weight. The body-feed system head and lines should be flushed once every 15 minutes for at least one minute to assure proper and continuous operation. Water from the discharge side of the recirculation pump may be used. If connection is to a potable water supply line, the supply line should be equipped with an approved backflow prevention device.

Precoat media should normally be fed into the filter at a concentration not to exceed 5% by weight. Since perlite is approximately half the density of DE, half of the weight of perlite will achieve a similar depth of media inside of the filter as shown in Table 5.7.2.2.7.1.

Table 5.7.2.2.7.1

Table 5.7.2.2.7.1: Required Use Rates for Precoat Media

Media Type	Pounds per 10 ft^2 of filter area	Approximate Precoat Depth
DE	1.0 - 2.0	$1/16^{th}$ – 1/8 inch
Perlite	0.5- 1.0	$1/16^{th}$ – $1/8^{th}$ inch

Keyword	Section	Annex
Diatomaceous Earth	5.7.2.2.7.1	Drinking water applications typically recommend using DE at application rates of 0.2 lbs/ft^2 (1 Kg/m^2).[32] This practice seems to be based on research showing that the removal of 9-micron (*Giardia*-sized) microspheres increased from greater than 99% to greater than 99.9% as the precoat amount increased from 0.5 to 1 Kg/m^2.[18] Under the range of conditions tested, Logsdon and coworkers[48] found that the amount of DE had a greater impact on microsphere removal than did the grade of DE. Alum-coated DE has been shown to significantly improve the removal of turbidity and bacteria not normally removed by DE filters.[49] Logsdon[50] reported that alum could be added at 0.05 g of alum as $Al_2(SO_4)_3 \cdot 14\ H_2O$ per 1 g of DE in a slurry to form a precipitate on the surface to enhance performance.
Water Clarity and Visibility	5.7.2.2.8	The USEPA sets turbidity limits at 0.3 NTU for drinking water facilities, but the goal at most treatment sites is to keep all filtered water turbidities below 0.1 NTU. A current MAHC proposed turbidity limit for pools with turndown systems is to recommend 0.5 NTU in the filtered water of swimming pools with the eventual goal of maintaining 0.5 NTU water in the filter influent since this is representative of the water in the pool.
Cartridge Filters	***5.7.2.3***	***Cartridge Filters***
NSF Standards	5.7.2.3.1	Cartridge filter elements should be cleaned (or replaced) when the differential pressure across the filter exceeds 10 psi (69 KPa). Every cartridge filter should have two sets of cartridges. This will allow for one set to be in use while the other is being cleaned (soaking and drying are recommended).
Filtration Rates.	5.7.2.3.2	The 0.375 gallons per minute per square foot (0.26 L/s/m^2) maximum design flow rate is acceptable, but an allowance is necessary to accommodate irreversible fouling of cartridges (i.e., cartridges that do not recover 100% of the original capacity when cleaned after fouling). Systems designed for a

[48] Logsdon GS et al. Alternative filtration methods for removal of Giardia cysts and cyst models. Journal AWWA. 1981;73(2):111-118.
[49] Lange KP et al. Diatomaceous earth filtration of *Giardia* cysts and other substances. Journal AWWA. 1986;78(1):76-84.
[50] Logsdon GS. Water filtration practices: including slow sand filters and precoat filtration. 2008. American Water Works Association, Denver, CO. ISBN: 9781583215951.

Keyword Section Annex

given turnover time with a filter flow rate of 0.375 gallons per minute per square foot (0.26 L/s/m^2) would not be in compliance if partially fouled cartridges dropped the flow rate to 0.30 gallons per minute per square foot (0.20 L/s/m^2). Therefore, an acceptable operating range is provided beyond which cartridge replacement would be necessary.

Filter Elements 5.7.2.3.3

Cartridges should be cleaned when the gauge pressure differential is 10 psi (69 KPa) and in accordance with manufacturer's instructions. Cleaning equipment should include a soaking container properly sized to immerse the filter elements, a rinsing area with proper drainage, and a drying area protected from contamination (e.g., birds and insects). New filters do not regain 100% of their capacity. Perhaps only about 80% of the capacity is recoverable, regardless of the treatment. If the recommended design flow rate exceeds 80% of the maximum flow allowed on the filter, the filter may be undersized.

Cleaning Procedure 5.7.2.3.3.1

Facilities with cartridge filters are recommended to have the equipment on-site to clean the cartridges. This includes a basin or tub large enough immerse the entire cartridge in. Water from the cleaning and soaking process must be discharged to the sanitary sewer. Proper cleaning is critical. Failure to clean the cartridge properly can lead to disease outbreaks.

Cartridge Cleaning

To clean the cartridges:

- **RINSE THOROUGHLY** - Rinse the cartridge of as much dirt and debris as possible by washing inside and out with a garden hose and spray nozzle – DO NOT use a pressure washer. High flow/pressure can drive the dirt into the interior and permanently damage it
- **DEGREASE** - Cartridge filters need to be degreased <u>each</u> time they are cleaned. Body oil, suntan oil, cosmetics, hair products and/or algae and biofilms can form a greasy coating on the filter pleats, which will clog the pores and reduce the filter capacity.
    1. Soak the cartridge overnight in filter cleaner/degreaser OR a solution of water with 1 Cup of TSP (tri-sodium phosphate) OR 1 Cup of automatic dishwashing detergent per 5 gallons of water.
    2. **NEVER USE MURIATIC ACID OR PRODUCTS WITH ACID IN THEM PRIOR TO**

Keyword	Section	Annex
		DEGREASING. ACID MAY PERMANENTLY SET THE GREASE AND RUIN THE CARTRIDGE.
		• **SANITIZE** - To remove or prevent biofilms, algae and bacteria growing on the cartridge, add 1 quart of household bleach to the degreasing solution and soak one hour before rinsing. • **RINSE** - Remove the clean cartridge from the soak water and rinse thoroughly with a hose. • **DRY**- After the filter is cleaned and degreased it should be allowed to dry completely. Some bacteria (e.g., Legionella spp.) that survive the cleaning process can be killed by drying. Do not allow the filter to become contaminated with dirt or soil after it is cleaned. Put the cartridges in a clean plastic trash bag if they are to be transported and the original boxes are not available.
		ACID WASH – ONLY IF NECESSARY - Excessive calcium or mineral deposits on the filter media can be cleaned with a 1:20 solution of clean water and Muriatic Acid. Put a few drops of muriatic acid on the filter. If it foams, it might need to be acid washed. Very few filters need to be acid washed.
Pressure Washer	5.7.2.3.3.3.2	A pressure washer should not be used as high flow/pressure can drive the dirt into the interior and permanently damage the cartridge or can aerosolize pathogens in the filter biofilm, which exposed and infected workers when cleaning the cartridge filters in an enclosed space[51].
Disinfection	**5.7.3**	**Disinfection**
Chemical Addition	***5.7.3.1***	***Chemical Addition Methods***
Feed Equipment	***5.7.3.2***	***Feed Equipment***
General	*5.7.3.2.1*	*General*
Sizing	*5.7.3.2.2*	*Sizing of Disinfection Equipment*
Engineering	*5.7.3.2.3*	*Feeder Engineering*

[51] Moraga-McHaley SA et al. Hypersensitivity pneumonitis with Mycobacterium avium complex among spa workers. J Occup Environ Health. 2013;19(1):55-61.

Keyword	Section	Annex
Introducing Chemicals	*5.7.3.2.4*	*Introduction of Chemicals*
Controls	*5.7.3.2.5*	*Feeder Controls*
Compressed Chlorine	*5.7.3.2.6*	*Compressed Chlorine Gas*
Types	*5.7.3.2.7*	*Types of Feeders*
Gas Feed Systems	5.7.3.2.7.6	The Chlorine Institute has checklists and guidance at http://chlorineinstitute.org/stewardship/ci-checklists.cfm for working with compress chlorine gas.
Electrolytic Generators	*5.7.3.2.8*	*Salt Electrolytic Chlorine Generators, Brine Electrolytic Chlorine or Bromine Generators*
Water Replenishment	**5.7.4**	**Water Replenishment**
Volume	5.7.4.1	See MAHC Annex section 4.7.4 for more information. A minimum of 4 gallons (15 L) of water per bather per day must be discharged from the pool, but a volume of 8 gallons (30 L) per bather per day is recommended. Backwash water will count toward the total recommended volume of water to be discharged, but evaporated water will not count since inorganic contaminants (e.g., salts and metals) and many organic contaminants (e.g., sweat and urine)can simply be concentrated as water evaporates. Backwash water or other discharged water may not be returned to the pool without treatment to reduce the total organic carbon concentration, disinfection by-product levels, turbidity, and microbial concentrations less than the limits set for tap water by the USEPA.
Showering		Shower usage by bathers prior to entering the pool can slow the accumulation of particulate (e.g., skin cells, dirt, and hair) and organic (e.g., sweat, urine, and fecal material) contaminants in the pool.
Spas	**5.7.5**	**Spas**
Water Replacement	5.7.5.5	For example, a 600 gallon spa divided by 3 yields 200 divided by 25 (the average users per day) produces an 8 day water replacement interval.

ADDITIONAL DOCUMENTS:

Appendix 1: Dye Test Procedure

Dye testing should be performed to determine and adjust the performance of the recirculation system. Dye studies tend to be qualitative in nature.[52]

Some judgment is generally required to determine whether a dye study should be classified as passing or a failing. In general, dead zones (or areas of poor circulation) would indicate a failure that could be fixed by adjusting the inlets or other system hydraulics. If the pool does not reach a uniform color within 15 minutes, then adjustments are required.

Materials

- Crystal violet ($C_{25}N_3H_{30}Cl$)(20 g/ 50,000 gal)
- Sodium thiosulfate penta-hydrate ($Na_2S_2O_3 \cdot 5H_20$) (1.2 oz/ 1 ppm FC/ 10,000 gal)
- Sodium hypochlorite (Bleach 5.7% available chlorine) (6.64 L/ 50,000 gal)
- Two containers (20 L or 5 gal)
- Video camera
- Photo camera (optional)
- Tripod
- Chlorine detection kit
- Pump (capable of 700 mL/min or 0.18 gpm)
- Tubing (~6.4 mm or 1/4 inch ID)
- Tubing clamps
- Fittings, adapters, and Teflon tape (for threaded connections)
- Scale
- Gloves
- Timer

Procedure

1. Use a scale to weigh out the correct amount of crystal violet

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[52] Alberta. Pool Standards, 2006 for the Swimming Pool, Wading Pool, and Water Spray Park Regulation. (Last accessed 1/1/2011).http://www.health.alberta.ca/documents/Standards-Pools.pdf

needed. Be sure to wear proper safety equipment when handling any chemicals.

2. Make the stock crystal violet solution by mixing the crystal violet and three gallons of non-chlorinated water in a container.
3. If you do not plan to use the pools existing disinfection system during the dye removal process, then it will be necessary to prepare a sodium hypochlorite solution. To do this follow the recommend dose of 6.64 liters of bleach (5.7% available chlorine) per 50,000 gallons of pool water. Place the correct amount into a separate container.
4. Two days prior to the dye study cut off the pool's disinfection system, and then measure the chlorine concentration of the pool. On the same day as the disinfection system is turned off, weigh out enough sodium thiosulfate penta-hydrate to neutralize the chlorine that is present and dump it around the perimeter of the pool. It is necessary to neutralize the chlorine because it will react with the dye. Come back the following day to make sure there is no chlorine, and likewise on the day of the dye study.
5. Prepare the pump by attaching the tubing to the existing piping and calibrate the flow rate to 700 mL/min. At this flow rate, the stock solution of dye will be injected into the pool over a 16 minute period. Tube clamps may be used to secure the connection between the tubing and the connectors.
6. Prepare the filter room by laying down a trash bag (or similar item) as protection from a potential chemical spill/leak. Then place the pump and containers containing the dye stock solution and sodium hypochlorite solution on the plastic cover.
7. Prepare a location in the pipe network (preferably after the filter) to inject the chemicals. If a location does not already exist (e.g., an existing chlorine feed or acid feed point) then one will need to be made by tapping the pipe and inserting the proper fitting.
8. Attach the tubing from the pump to the existing or newly created injection point. Depending on what fitting is present you might need an adapter for the tubing. The other end of the tubing should be placed in the chemical container holding the dye.
9. Make sure all assistants are in place to record video, take pictures, collect data, and time injection to 15 minute pass/fail observation point.
10. When ready to start, turn on the pump. The dye should begin to flow into the pool. Start the timer at the same time as the pump is turned on (pump on, time (t) = 0 min). The stock dye solution should be depleted in 16 minutes. After 16 minutes, turn the pump off so that air will not be introduced into the system.
11. Record the time when the dye is first observed coming into the pool.
12. Record the time when the pool water is <u>completely</u> dyed (having uniform color).

- *Most pools should be uniformly dyed within 15-20 minutes (and generally no more than 30 minutes) when the recirculation system is hydraulically balanced.*

13. Record any observations or patterns, including dead spots and/or short circuiting, and the corresponding times that they were noticed throughout the test.
    - *Adjustments should be made to the recirculation system to correct for any problems observed. Adjustments could include the following:*
        a. *the direction of inlets (up and down as well as left and right),*
        b. *the velocity of water through the inlets (when adjustable by inlet modification or turnover time adjustment), and*
        c. *the proportion of water from the surface overflow and main drain components of the recirculation system.*
14. Remove the dye by re-chlorinating the pool. Switch the tubing from the container of dye to the one containing the sodium hypochlorite and turn the pump back on. Another option would be to restart the pool's current disinfection system.
15. Observe and record what you see as the dye is removed from the pool through chlorination.

A Note About Resources:

The resources used in all MAHC modules come from peer-reviewed journals and government publications. No company-endorsed publications have been permitted to be used as a basis for writing code or annex materials.

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Additional Resources

CES Water Quality News. VFD's - how they work and can save you money. Accessed 06/05/2013. http://www.ceswaterqualitynews.org/CESWaterQualityNews/Entries/2008/1/20_VFDs_-_how_they_work_and_can_save_you_money..html

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Research Needs

1. Recirculation system assessment: comparing gutters, skimmers, stainless gutters, etc. Should the use of skimmers be limited to pools with surface areas of less than 1,600 square feet (149 m^2) and a maximum width of less than 30 feet (9.1 m)? What is the optimal overflow rate for a gutter or skimmer?

2. Develop a standardized pathogen removal test to evaluate all types of filters by NSF or equivalent (with a coagulation system for granular media applications). The standardized test method could be used to evaluate the capability of various filtration technologies to remove at 4.5-micron (*Cryptosporidium*-sized) particles.

3. Combined perlite/sand filters need to be evaluated long-term at full-scale for sustainable filter cleaning.

4. Several new filters medias are on the horizon that will require further evaluation (e.g., Macrolite, crushed recycled glass, and dual-charged Zeolite).

5. Evaluating recirculation systems with varied inlet velocities, inlet depths, and water depths as well as floor inlets versus wall inlets.

6. Development of new pool designs with no main drains for U.S. application.

7. Computation fluid dynamic models need to be developed and used for evaluating and improving pool recirculation.

8. How do we make filters sustainable? Filter performance at removing pathogens needs to be sustainable as well as the cleaning methods (i.e., backwashing) to prevent filter failures. The proper coagulant dosages and control techniques need to be further refined to ensure sustainable pathogen removal and filter operation. Further research will be needed to better understand how changes in filter design, water quality, and operational variables impact the overall rate of removal of *Cryptosporidium*-sized particles in pool water.

9. The use of the proper air and water backwash flow rates needs to be determined for granular media pool filters.

10. Determine how to use cartridge filters effectively for pathogen removal, perhaps following sand filters.

11. Develop appropriate and safe cleaning protocols for cartridge filters.

12. Regenerative media filters need to be evaluated as do standard DE/Perlite filters in terms of the effect of bumping on pathogen removal and long-term performance/durability testing of the media support layers. Bumping may impair pathogen removal and could facilitate the release of pathogens previously trapped in the filter.