Recreation Water Filtration & Recirculation System **Design Examples**

Summary of the Current State of Sand Filtration in US Swimming Pools

A typical sand filter in a US swimming pool (compliant with all state and local regulations and health codes and certified by NSF) could have as little as 10 inches of "pool filter sand" (meaning sand of unknown effective size and uniformity coefficient) and operate at 15 gpm/ft^2 (too high to be effective) and also backwash at the same 15 gpm/ft^2 (too low to be effective) without using any coagulant (like alum) ahead of the filter. Without coagulant use, sand filters are ineffective at removing pathogenic microorganisms (that are typically less than 1/10th the size of the smallest pores in the filter bed). *Cryptosporidium* (the most common cause of swimming pool outbreaks in the US) is removed by such a filter with about 25% efficiency per turnover (typically every 6 hours). Since *Crypto* is chlorine-resistant, it must be removed by the filter to prevent accumulation and long-term exposure of swimmers. Outbreaks of diarrheal illness caused by *Crypto* are quite common in the US in the summer months when pools are open. Ineffective pool filters increase the risk of illness and outbreaks (and hence lawsuits, facility closures, and damaged reputations). Fortunately, there are ways to do swimming pool filtration correctly…

<u>Tips for Effective Pool Filtration</u>

1. Sand Filters should:
    a. have at least 24-inch depth of sand above the laterals,
    b. filter at less than 10 gpm/ft^2,
    c. backwash at more than 20 gpm/ft^2, and
    d. dose a minimum of 0.1 mg Al/L of Polyaluminum chloride ahead of the filter.
2. Sand filters (without coagulant feed systems) should:
    a. switch media and use Ultrafine Ceramic Sand*
       *(at least 18" of CeraFlow 70, at least 30" of CeraFlow 50)
    b. filter at < 10 gpm/ft^2 without any need for a coagulant.
    c. backwash at more than20 gpm/ft^2,
    d. only one known source: Wateropolis Corp.
3. Sand filters can convert to precoat filters (at higher perlite usage rates) and should:
    a. dose 2.5 lbs. of perlite per 10 ft^2 of sand surface area
    b. replace perlite after each backwash
    c. feed perlite as a slurry in the skimmer (when the pool is not occupied)
4. Precoat Filters should:
    a. dose at least 0.73 kg/m^2 (1.5 lbs/10 ft^2)* DE = 0.37 kg/m^2 (.75 lbs./10 ft^2) Perlite.
       *Yes, 50% more than current standard!
    b. avoid flow interruptions without replacing the media
    c. verify precoat media support material is both clean and intact
5. Ceramic membrane filters are some of the most effective filters available.
    a. new technology seeking approvals.
    b. only one known source: Saint Gobain

<u>Note:</u> More effective filters will clog more quickly because particles that used to pass through the filters on consecutive passes will be retained, build pressure faster, and require more frequent backwashing. Faster clogging is not a problem to avoid but rather a goal!

Design Problem #1: Removal of *Cryptosporidium* from Swimming Pool over Time
We can calculate how fast a pool can remove pathogens, but what happens if change the filters from 25% efficient to 90% efficient or more to remove 99.9% of *Cryptosporidium* (leaving the turnover time constant at 4 hours).

$$t_n = \frac{-\ln(1-n)}{\alpha}\,\tau$$

t_n = time required to achieve desired contaminant removal fraction
n = desired contaminant removal fraction
τ = theoretical detention time
α = treatment efficiency

<u>For 25% efficient filters:</u>

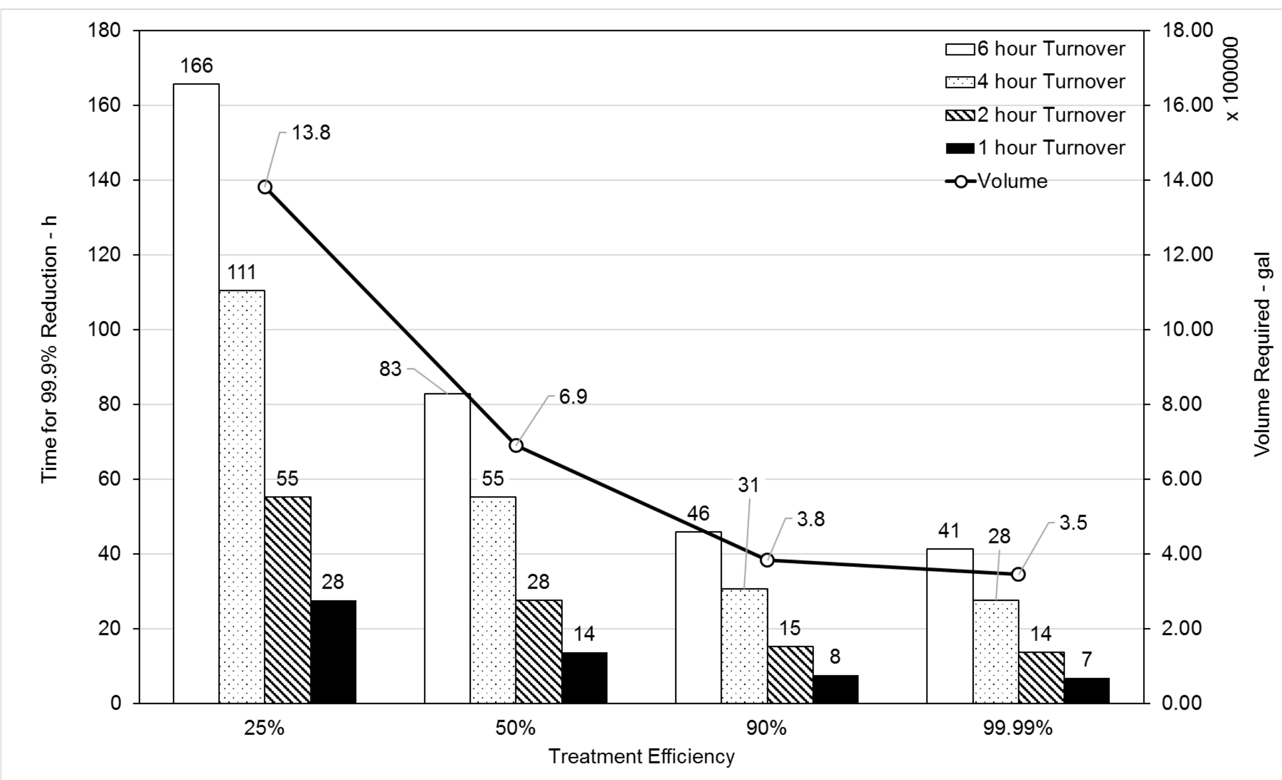
t_n = -ln(1-.999)/(.25) x 4 hrs. = 6.91/(.25) x 4 hrs. = 110.5 hrs =**4.6 days**

<u>For 90% efficient filters:</u>

t_n = -ln(1-.999)/(.90) x 4 hrs. = 6.91/(.90) x 4 hrs. = 30.7 hrs =**1.3 days**

<u>For 99.9% efficient filters:</u>

t_n = -ln(1-.999)/(.999) x 4 hrs. = 6.91/(.999) x 4 hrs. = 27.7 hrs =**1.2 days**



***Alansari, Amburgey, and Madding (2018). *Journal Water & Health* 16(3):449-459.**

Design Problem #2: Sand Filter Sizing
A pool is 75 feet long by 25 feet deep with an average depth of 4.5 feet. Please design a filter system to filter the water in this pool at a filter loading rate of 10 gallons per minute per square foot of filter surface area with a pool turnover time of 4 hours.

First, calculate the pool volume: 75 ft. x 25 ft. x 4.5 ft = 8437.5 ft^3

Convert volume to gallons: 8437.5 ft^3 x 7.48 gal/ft^3 = 63,113 gal

Calculate the flow rate to achieve a 4 hour turnover: 63,112.5 gal ÷ 4 hours = 15,778 gal/hr

Convert flow to gallons/min: 15,778 gal/hr * 1 hr/60 min = 263 gal/min

This flow is large for a single filter, let's try a design with 3 equally sized filters:

Flow per filter = 263 gpm/ 3 filters = <u>87.7 gpm (per filter)</u>

Calculate surface area: 87.7 gpm/ 10 gpm/sq. ft. = 8.77 sq. ft. (per filter)

Calculate diameter of a round filter: Area = pi * $diameter^2$ ÷ 4

Rearrange equation: Diameter = Square Root (4 * Area/ pi)= $\sqrt{(4 * 8.77\ ft^2/3.14)}$ = 3.34 ft

Convert feet to inches: 3.34 ft. * 12 in/1 ft. = 40.1 inches

So, a filter with a diameter of at least 40 inches would work (e.g., 40 inch or 42 inch).

The final design would include three (3) 40-inch diameter filters.

Design Problem #3: Backwash Flows & Piping Design

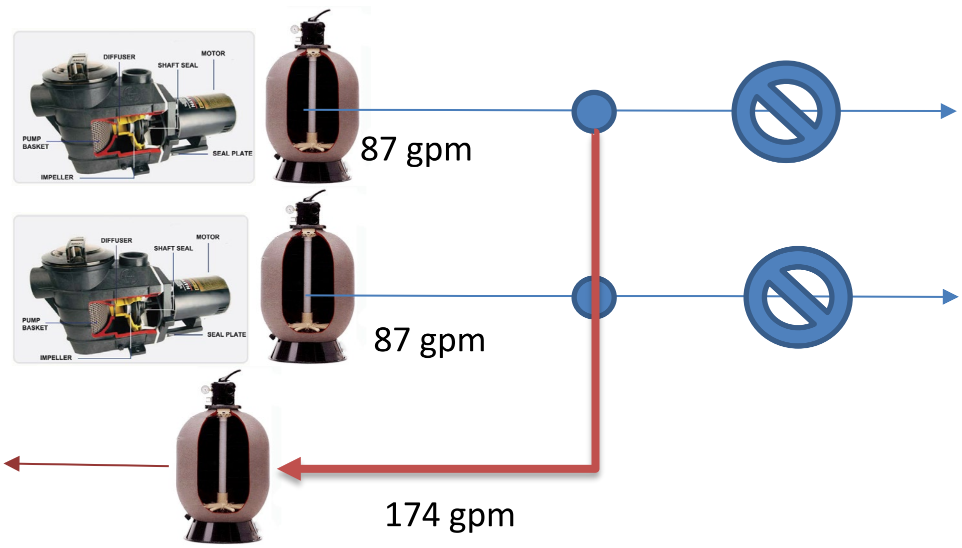
Using the filter system above, design a backwashing system to deliver at least 20 gpm/ft^2 of backwash water at water temperature of 29° C.

Calculated area of 1 filter: Area = pi * diameter^2 ÷ 4 = 3.14 (40 in. ÷ 12 in./ft)^2 ÷ 4 = 8.72 ft^2

Calculated the flow required = backwash rate x area of filter = 20 gpm/ft^2 x 8.72 ft^2 = **174.4 gpm**

Chose water source: unfiltered pool water or filtered pool water? Filtered pool water is preferred.

Design valves to direct flow from each of the other 2 filters into the backwashing filter.



Design Problem #4: Coagulant Pump Sizing (for a Sand Filter System)
Size a coagulant feed pump to deliver a dose of 0.1 mg of Aluminum per liter of water treated with polyaluminum chloride (that is 9% aluminum and has a specific gravity of 1.37).

Normally, 0.1 mg/L is 0.1 ppm (part per million), which means 0.1 mL of coagulant per 1 million mL pool water treated. Because 1 mg is one millionth of the weight of a Liter of water (1000 g or 1,000,000 mg).

Now, 0.1 mL of coagulant per 1 million mL can be converted to 0.1 mL per 1,000 L.

Multiplying by 0.264 gal/L yields 0.1 mL per 264 gal of water treated.

Since our system is designed for 261 gpm of flow, we have to scale the dose to the flow.

$$\frac{0.1\ mL\ Coag}{264\ gal.water}\ x\ \frac{261\ gal.water}{min} = (0.099\ mL\ Coag)/(min)$$

So, our design flow rate is: 0.099 mL coagulant per minute.

Now, we correct of % aluminum (since 91% of the solution is not aluminum) by dividing the 0.099 mL/min rate by 0.09, which becomes 1.1 mL/min.

Kemira Water Solutions, Inc.

PAX-18

Polyaluminum Chloride

*Kemira's PAX-18 is a high performance liquid polyaluminum chloride coagulant that generally offers superior clarification in either potable or wastewater. The aluminum in PAX-18 is highly charged, enabling less of it to do more. Advantages available to many end users are **Reduced Sludge, Minimized pH Adjustment, Longer Filter Runs, Superior Finished Water Quality, and Optimized Cold Water Performance**. PAX-18 is a general-purpose coagulant, versatile enough to handle any type of challenge.*

PRODUCT SPECIFICATION

Appearance	Yellowish Liquid
Aluminum (Al)	9.0 ± 0.2%
Al_2O_3	17.1 ± 0.4%
Iron (Fe)	< 0.01%
Specific Gravity (25°C)	1.37 ± 0.03
pH	0.9 ± 0.3
Basicity	42 ± 2%
Active Material	3.33 moles/kg
Viscosity (25° C)	30 ± 5 cP
Freezing Point	-20° C / -4° F

CERTIFICATION / APPROVAL
PAX-18 meets or exceeds all **AWWA** standards for polyaluminum chloride. PAX-18 is **ANSI/NSF Standard 60** certified for use in potable water treatment up to 200 mg/l.

DOSING
PAX-18 should be fed straight without dilution. A diaphragm-metering pump of non-corrosive material is suitable.

STORAGE

Storage tanks and piping should be constructed of suitable non-corrosive material such as fiberglass or cross-linked polyethylene. PAX-18 is mildly corrosive and will attack most metals over a period of time. PAX-18 has a recommended shelf life of 8 months. As with any chemical, it is recommended to clean the storage tank every 1-2 year.

HANDLING / SAFETY
The handling of any chemical requires care. Anyone responsible for using or handling PAX-18 should familiarize themselves with the full safety precautions outlined in our Material Safety Data Sheet.

DELIVERY
55 gal. plastic drums / 275 gal. tote bin
Bulk tank trucks, Railcar
Corrosive Liquid, Acidic, Inorganic, n.o.s. 8, UN, 3264, P.G. III

PRODUCTION
Kemiron has coagulant production plants in

Bartow, FL	Rowley, UT
Fontana, CA	Saint Louis, MO
Houston, TX	Savannah, GA
Mojave, CA	Spokane, WA
	East Chicago, IN

Then, we correct for the density since we are delivering more actual mass than if the density was 1.00 (as assumed in the ppm conversion), so we divide 1.1 mL/min by 1.37, which yields a PACl feed rate of 0.80 mL/min.

0.80 mL PACl per min would achieve our goal of dosing 0.1 mg Al/L of pool water for this pool.

0.80 mL/min of PACl solution can be converted to mL/hr. by multiplying by 60 min/hr. = **48 mL/hour (or 0.048 L/hr).**

At this flow rate, a 55 gal drum would last ~181 days.

So, we need a very small pump! For example, a Grundfos DME 2-18 pump has a maximum dosing rate of approximately 2.5 L/hr with a 1:1,000 speed reduction ratio. This pump can accurately and effectively dose down to 2.5 mL/hr. versus our design flow of 48 mL/hr (roughly 20 times the minimum flow).

This and all chemical feed pumps pulse, which could be an issue if the pump is only dosing 1 sec. every 1 min because some water volumes gets overdosed while other water volumes get no coagulant at all. Grundfos reports that this pump doses in pulses as low as 0.000018 mL/pulse, which would be about 44,000 pulses per min (~740 pulses per second). So, this pump should work fine as a coagulant feed pump for this pool delivering an almost continuous supply of PACl at the low dosage of 0.8 mL/min (or 0.048 L/hr).

Design Problem #5: Backwash Rate Calculation for Sand of Known Specifications
Sand can be specified and delivered to meet that spec by screening out the grains that are too big or small for a given application. Let's assume your media specification was 0.55 mm effective size (ES) sand with a uniformity coefficient (UC) of 1.5 and a density of 2.65 g/cm^3. What is the minimum design backwash rate to achieve at least 20% bed expansion and fluidization of this sand during backwashing at 30° C?

First, let's calculated the size of the larger sand grains. We'll call this value the d_{90}, which means 90% of the sand grains are smaller based on percent mass.

The d_{90} can be calculated from the effective size (d_{10}) and the uniformity coefficient (UC = d_{60}/d_{10}), where d_{90} = d_{10} x 10^(1.67 x Log (UC)) = 0.55 mm x 10^(1.67 x Log (1.5)).

Simplifying… d_{90} = 0.55 mm x 10^(1.67 x (.176)) = 0.55 mm x 10^(.294) = .055 mm x 1.97 =1.08 mm

The d_{90} value (1.08 mm) now becomes the d_{eq} value in the equations below:

$$V_{mf} = \frac{\mu}{\rho d_{eq}}\left(33.7^2 + 0.0408 Ga\right)^{0.5} - \frac{33.7\mu}{\rho d_{eq}}$$

$$Ga = d_{eq}^3 \frac{\rho\left(\rho_s - \rho\right) g}{\mu^2}$$

Where μ is the viscosity of water at 30° C (0.00798 g/cm*s) and ρ is the density at 30° C (0.9957 g/cm^3) while ρ_s is the density of sand (2.65 g/cm^3) and g is the acceleration due to gravity of 981 cm/s^2.

The second equation is solved first to yield a Galileo Number (Ga) = 32,189. This value is used in the first equation to yield a value of 1.17 cm/s for the V_{mf} (or the minimum fluidization Velocity).

In this example, V_{mf} = 1.17 cm/s = 1.17 cm/s x 100 cm/1 m x 60s/1min x 60min/1hr = 42.1 m/hr.

Converting V_{mf} to Standard American English units by dividing by 2.444, we get that the V_{mf} is equal to 17.2 gpm/ft^2. This is the value that will barely fluidize 90% of the sand grains in this filter.

To fully fluidize all of the grains in this sand filter at 20% bed expansion, we multiply the V_{mf} by 1.3 to get the **actual backwashing rate of 22.4 gpm/ft^2.** We could design to this backwashing rate, or we could choose our sand specs to require a smaller backwash flow (smaller size and uniformity coefficient).

For example, 0.50 mm sand with a UC of 1.5 (and standard density of 2.65 g/cm^3) would produce a recommended backwash rate of 19.3 gpm/ft^2 at 30° C.

Design Problem #6: Amount of DE/Perlite to Use in a Precoat Filter

You own a DE filter with 60 ft^2 of surface area, and the manufacturer recommends you use 6 lbs. of DE (12 1-lb. coffee cans). How much DE or Perlite should you actually use according the recommendations provided here?

First, the manufacturer is recommending 6 lbs/ 60 ft^2 of surface area = 0.1 lbs/ft^2

I recommend 0.15 lbs/ft^2. Multiply .15 lbs/ft^2 x 60 ft^2 and you get 9 lbs of DE per filter.

The manufacturer recommended 12 1-lb. coffee cans to get 6 lbs. of DE (because ~50% of the space in the coffee can is air instead of DE). So, you would need **2 cans/lb. x 9 lb. = 18 1-lb. coffee cans of DE.**

Table 2

Filter Area (sq. ft.)	Weight of D.E.	No. of 1 lb. Coffee Cans
24	2.4 lbs.	6
36	3.6 lbs.	8
48	4.8 lbs.	10
60	6.0 lbs.	12

You would need the same number of 1 lb. coffee cans of Perlite as DE to achieve the same thickness of the media layer (~1/8"), but the perlite would only weigh about ½ as much if you weighed it on a scale, which would be **4.5 lbs. of perlite to provide an equivalent volume of 9 lbs. of DE. However, both would be delivered by 18 1-lb. coffee cans to achieve the same thickness of the filter media layer (~1/8").**

It is ideal to avoid interrupting flow in a precoat filter for the entire duration of the filter run until the media is clogged and ultimately discarded.

Precoat filters should be able to recirculated in a closed loop to avoid discharging filter media that is not trapped by the filter on the first pass (as the precoat layer is accumulating) into the swimming.

Design Problem #7: Air Scour Backwashing of a Sand Filter
If you wanted to air scour a swimming pool sand filter, how would you design it?

Standard air scour rates are 2-3 scfm/ft^2 of filter, which is recommended for 1-2 minutes per backwash. This means 2 standard cubic feet of air per minute (scfm) per square foot of filter.

In our previous design example (#1), we had 3 40-inch diameter filters with an area of 8.77 ft^2 each. So, we would need 2 scfm/ft^2 x 8.77 ft^2 = **17.54 scfm of air flow to backwash one filter.**

Air compressors come with specs, but a general rule of thumb is 4 cfm per 1 Horsepower. So, a 5 HP motor on a compressor would get you around 20 cfm of air. More power is required at a higher pressure, but bubbling air through a filter is a low pressure affair. So, a 5 HP compressor could supply about 17.5 cfm of air for a filter wash of 1-2 minutes.

Filter media could be lost if the filter is not designed for air scour backwash.

Air scour improves our ability to remove dirt from the filter media.

Design Problem #8: Pipe sizing for 50% Hydraulic Overdesign
If you wanted to overdesign a pipe by roughly 50%, then how much would the diameter change? Let's assume that your design standard for this pipe is 6 feet per second (fps).

With a flow of 235 gpm in a 4-inch diameter pipe, the velocity would be 6 fps.

So, a 50% overdesigned pipe could handle 50% more flow = 1.5 x 235 gpm = 353 gpm and still be under 6 fps.

Changing to a 4.9-inch diameter pipe, you would get 6 fps for a 353 gpm flow. So, a 5-inch diameter pipe would be more than 50% overdesigned relative to a 4-inch diameter pipe.

Changing the pipe diameter 50% larger (e.g., from 4" to 6") is not how to overdesign a pipe for 50% more flow. Actually, changing from 4" to 5" is more than 50% of overdesign.

When deciding whether to overdesign pipes flow by 50%, think about all of the headache of jack-hammering up a bunch of concrete to have plumbers change all of the pipes in a pool (by just an inch or less larger) to accommodate a 50% higher flow rate through the filters to solve a cloudy water problem that could have been avoided with a modest overdesign of the pipes.

Design Problem #9: Installing Ultrafine Ceramic Sand in a Filter
Ultrafine sand is so small that it will pass through the laterals of many existing sand filters. If you wanted to design a filter bed to support ultrafine sand, then what supporting filter materials would be required?

The ideal installation configuration would be as follows:

1. Cover the laterals in an empty sand filter vessel with water.
2. Install #16 garnet (ES 1.0 mm) media under, around and to 3" over the top of the lower laterals. Level smooth by hand.
3. Install # 36 garnet (ES 0.5 mm) to a depth of 3" on top of lower garnet layer. Level smooth by hand.
4. Install Ceraflow-70 to an 18" (or greater) depth measuring from the top of the upper garnet layer. Level media by hand.
5. Fill the tank with water from the top and let the media soak for 30 minutes to help get air out of the filter bed.
6. Backwash at 8.0 gpm/ft^2 (for ~50% bed expansion) or 6 gpm/ft^2 for ~30% expansion.
7. Begin filtration at a flow rate of 10 gpm/ft^2

Ceraflow-50 uses the same support bedding with 30 inches of ultrafine sand. The backwash at 10 gpm/ft^2 for ~50% bed expansion and relatively fast expulsion of solids. Alternately, use 8.0 gpm/ft^2 for ~ 30% expansion at 80° F.

Design Problem #10: Design a water replenishment system for a pool
A water replenishment system is a means of intentionally discharging and measuring the volume of discharged pool water (in addition to the filter backwashing system). A water replenishment system is recommended to be installed and designed to discharge a volume of water of up to 8 gallons (30 L) per bather per day per facility through an air gap. This water volume is an international standard. The intent is to slow and consistently remove contaminants that cannot be filtered out of the water (e.g., sweat, urine, cosmetics, and all those things that make bathtub water look grey by the time you get out of the tub).

The MAHC requires 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.

If the pool has 550 visitors per week and backwashes every Sunday for 5 minutes at 174 gpm for each of three filters, then how much water would be discharged through the water replenishment system in gallons per minute with a constant flow system designed to discharge the international standard volume of 8 gallon per person per day.

Total Required discharge volume = 550 people x 8 gal./person = 4,400 gal. per week
Backwash volume discharged = 174 gal/min x 5 min x 3 filters = 2,610 gal. per week
Water replenishment system discharge required = 4,400 gal. -2610 gal. = 1790 gal./week
1,790 gal/week x (1 week/7 days) = 256 gal./day x (1 day/ 24 hours) = 10.7 gal/hour x (1 hour/60 min) = 0.18 gallon per minute.

Note: backwashing alone discharged 4.75 gal/person/day and exceeded the US minimum standard (4 gal/person/day) for this pool.

SUPPLEMENTAL INFORMATION (Similar to MAHC Annex):

Hydraulic Overdesign Standard. Pool piping, inlets, outlets should be designed to accommodate 50% more than the actual planned flow rates. Space should also be left in the filter room to add a pump and filter should that be desirable in the future. This recommendation ensures that if the popularity (bather load) is greater than expected and the water quality becomes worse than acceptable, then an upgrade in the treatment system will be relatively painless. Energy consumption is also likely to be lower with slightly overdesigned piping.

Dye test procedure.

Dye Tests: "Dye testing should be performed to determine and adjust the performance of the recirculation system." Dye studies tend to be qualitative in nature (Alberta Code, 2006).

Materials

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

Procedure

1. Use a scale to weigh out the correct amount of crystal violet 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 nonchlorinated water 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 pools disinfection system, and then measure the chlorine concentration of the pool. On the same day, 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 min 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. Now make sure all assistants are in place to record video, take pictures, collect data, etc.

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 min. After 16 min cut 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).

13. Record any observations or patterns, including dead spots and/or short circuiting, and the corresponding times that they were noticed throughout the test.

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 pools current disinfection system.

15. Observe and record what you see as the dye is removed from the pool through chlorination.

Oversizing the Gutter System 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. The State of Iowa tried 2 gal/ft^2 for a few years, but found that to be unnecessary.

Flotation test procedure.

Materials

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

Initial Conditions

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

Procedure

Test 1: Circulation

1. Determine how many stars are necessary by the using the following:

   - Pool surface area < 2,500 sq ft. use a minimum of 55 stars
   - 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.

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.

Piping Velocities. Recirculation system piping should be designed so the water velocities should not exceed 10 feet (3 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 by 75% to ¼ (25%) of the original value). In the interest of conserving energy, velocities in the range of 6 to 8 feet per second are recommended. Without a minimum inlet velocity, uniform water distribution within the supply piping will not happen.

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 be prepared by a qualified engineer.

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 3 feet per second value is a value derived from common practice with no clearly identifiable theoretical basis.

Drainage and Installation. 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 biocorrosion of metal components of the recirculation system.

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.

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 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 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 later.

Flow Meters.

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) as well as less potential for fouling, but the aforementioned flow meters tend to be more expensive. An ultrasonic flow meter (such as the clamp-on transit-time models produced by GE Sensing, Sierra, and Dynasonics) 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.

A comparison of more than a dozen existing (acrylic and paddle wheel) flow meters on pools in the Charlotte, NC area versus an ultrasonic flow meter (GE Sensing, TransPort® PT878) revealed that measurement error ranged from -12% to +23% of the flow reading determined by the ultrasonic flow meter. More than 75% of the existing flow meters overestimated the flow, which would cause pool operators to think that the turnover time for the pool was higher than it actually was. For example, a 36,000 gallon pool with a 6-hour turnover time would have a required recirculation flow rate of 100 gpm, but an actual flow rate of 77 gpm (i.e., 23% less than the actual reading) would cause the turnover time to be 7.8 hours.

Variable Frequency Drives. 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.

Flow Rates/Turnovers.

A new methodology is being proposed to calculate the recommended minimum design recirculation flow rate, which is called the maximum sustainable bather load (MSBL) calculation. The MSBL calculation is described below (based on the values in Table 4.7.1.9.2 and adjusted by all applicable multipliers in Table 4.7.1.9.3) as the maximum turnover period allowable based on the pathogen load and chlorine demand imparted by bathers. Whereas, the traditional turnover period values (required in Table 4.7.1.9.1) 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 rate for the zone based on the lesser turnover time calculated by the procedures already described. All of the maximum turnover rates provided in Table 4.7.1.9.1 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.

(1) Zone Volume (ft^3) = Zone Surface Area (ft^2) x Average Depth (ft)

(2) Zone Bather Load Factor (bathers/ft^3) = $\dfrac{1}{(\text{Surface Area per Bather } (ft^2/\text{bather})) \times (\text{Average Depth } (ft))}$

(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 period (h) = $\dfrac{\text{Water volume (gal)}}{\text{Recirculation rate (gal/min)} \times (60 \text{ min}/ 1 \text{ hr})}$

Table 1. Bather Loading Estimates.

Depth		Surface Area Per Bather	
<3	Feet	25	Square Feet
3 to 6	Feet	30	Square Feet
6.1 to 10	Feet	22	Square Feet
>10.1	Feet	16	Square Feet

Table 2. 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 gallon
High-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 swimm 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 wit associated attraction or activity.
Showering recommended (showering reduces bather load)	1.15	Pool/Spa must recommend showering prior to entry.

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) = $\frac{1}{(30\ ft^2/bather) \times (5ft)} = 0.00666\ bathers/ft^3$

(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 period (h) = $\frac{3{,}000\ ft^3 \times 7.48\ gal/ft^3}{106.8\ gal/min \times 60\ min/\ 1\ hr} = 3.5\ h$

(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 the turnover table of 5 h and use the lower value = 5 h. Additional example calculations are provided in Table 3.

Table 3. Recirculation Rate Calculation Examples (based on bather load) by Pool Type:

									factor 1	factor 2	factor 3	Bathers		gpm	min	**Raw**
	Volume		Avg. Depth		Surf. Area		Sq. Side		bathers/ft3	bathers/ft3	bathers/ft3	Total	K	Q	turnover	**turnover**
Large indoor pool	322000	gal.	7.33	ft	5870.20	ft^2	76.62	ft	0.007346	0.006011	0.003821	219.09	5.34	1171	275	**4.58**
Wave Pool	750000	gal.	4.98	ft	20120.54	ft^2	141.85	ft	0.025	0.007778	0.005039	797.52	5.34	4261	176	**2.93**
Activity Pool	50000	gal.	3.00	ft	2228.16	ft^2	47.20	ft	0.02	0.009445	0.009445	78.81	5.34	421	119	**1.98**
Spray Pad	20000	gal.	1.00	ft	2673.80	ft^2	51.71	ft	0.04	0.04	0.04	106.95	5.34	571	35	**0.58**
Kiddie Pool	1000	gal.	1.00	ft	133.69	ft^2	11.56	ft	0.04	0.04	0.04	5.35	5.34	29	35	**0.58**
Spa	750	gal.	1.50	ft	66.84	ft^2	8.18	ft	0.026667	0.026667	0.026667	2.67	5.34	14	53	**0.88**
Deep diving pool	100000	gal.	16.00	ft	835.56	ft^3	28.91	ft	0.003906	0.003906	0.003906	52.22	5.34	279	358	**5.97**
Small pool	35000	gal.	5.00	ft	935.83	ft^2	30.59	ft	0.009445	0.007346	0.00655	34.93	5.34	187	188	**3.13**

(Hours)	>100K gallons			>90 F			Plain pools only:	**(Hours)**	**with a**	**Standard**
Raw	Large Pool	Small Pool	Activity Pools	Hot water	Indoor Pools	Shower Required	Apartment/Condo/H	**Final**	**Required**	**Table**
turnover	Edge Load Fa	High-risk Factor	Density/Line Factor	High Temp. F	Env. Protect F	Bather Load Reducti	Limited-use Factor	**Turnover**	**Shower**	**Values**
4.58	1.1	0.75	0.5	0.5	1.15	1.15	1.33	**5.80**	**6.67**	**4-5**
2.93	1.1	0.75	0.5	0.5	1.15	1.15	1.33	**1.61**	**1.86**	**1.5-2**
1.98	1.1	0.75	0.5	0.5	1.15	1.15	1.33	**0.99**	**1.14**	**1-1.5**
0.58	1.1	0.75	0.5	0.5	1.15	1.15	1.33	**0.22**	**0.25**	**0.25**
0.58	1.1	0.75	0.5	0.5	1.15	1.15	1.33	**0.44**	**0.50**	**0.5**
0.88	1.1	0.75	0.5	0.5	1.15	1.15	1.33	**0.22**	**0.25**	**.25-.5**
5.97	1.1	0.75	0.5	0.5	1.15	1.15	1.33	**7.56**	**8.69**	**6-8**
3.13	1.1	0.75	0.5	0.5	1.15	1.15	1.33	**4.16**	**4.78**	**5**

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 (2009) 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.

The recommended design turnover rate 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 could be considered a high-risk pool requiring more aggressive treatment. Facilities that recommend showering prior to pool entry could reduce the organic load on the pool by 35-60% with showers lasting only 17 seconds (Keuten et al., 2009). The bather load calculation based on surface area of the pool has been proposed by PWTAG (2009) in 1999 and has influenced the codes proposed by the World Health Organization (WHO, 2006) and Australia (NSW, 2010). 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, turnover tables were developed to provide some maximum turnover 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 rates.

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 (2009) and WHO (2006). The maximum turndown of 25% was selected to save energy while not necessarily compromising the ability of the recirculation system 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 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.

Filtration. A swimming pool filtration system should be designed to remove physical contaminants and maintain the clarity and appearance of the water. However, good clarity does not mean that water is microbiologically safe. With chlorine-resistant 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 more than microbial quality. 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-resistant pathogens suspended in the water for longer periods of time. As a future recommendation, 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.

"If filtration is poor, water clarity will decline and drowning risks increase. 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."(WHO, 2006, p. xix).

One of the most significant recommended changes for pools is changing the filtration system from one that only provide good clarity and appearance to one that efficiently removes waterborne human pathogens from the 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. (Yoder et al., 2010). With chlorine-resistant 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 (WHO, 2006, p. 82; PWTAG, 2009, p. 62). Furthermore, an accidental fecal release could overwhelm the disinfectant residual and leave physical removal as the only means of removing pathogens (WHO, 2006, p. 40). 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 (WHO, 2006, p. 88).

Effective filtration is a crucial process in controlling waterborne disease transmission and protecting public health (WHO, 2006, p. 82; PWTAG, 2009, p. 62).

Review of the *Cryptosporidium* Threat in Recreational Water. *Cryptosporidium* is chlorine-resistant protozoan pathogen that causes the majority of waterborne disease outbreaks in swimming pools in the U.S. as shown in Figure 1 (Yoder et al., 2008).Surveillance for *Cryptosporidium* in the United States indicates that the reported incidence of infection has increased dramatically since 2004 (Yoder & Beach, 2010). Figures 2 and 3 demonstrate the increased incidence as well as the overall number of outbreaks of cryptosporidiosis since 2004, respectively (Yoder et al, 2010).

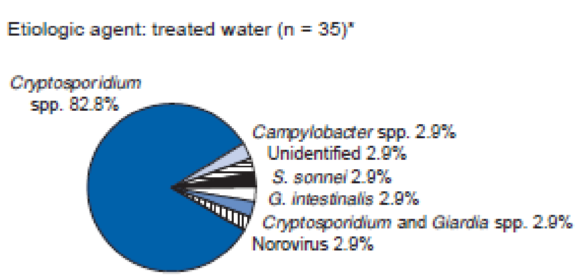
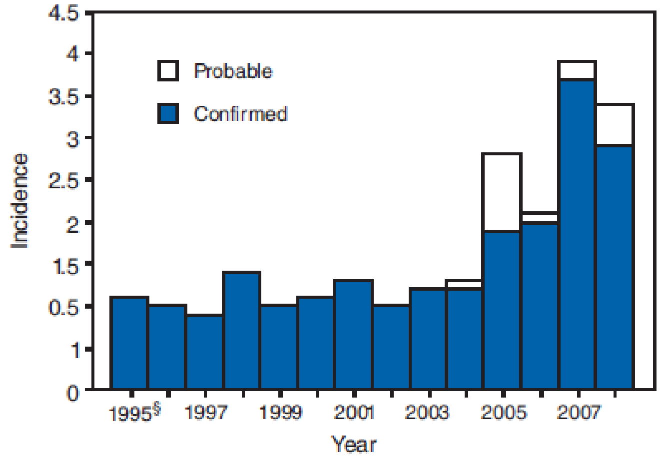


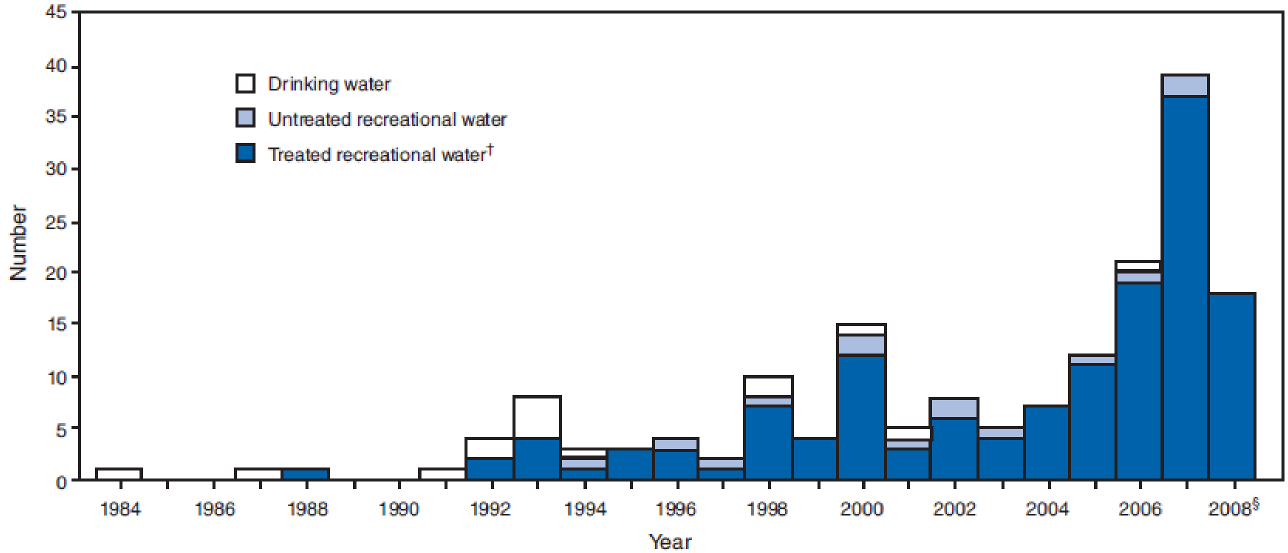
FIGURE 1. Recreational water-associated outbreaks of gastroenteritis, by etiologic agent for treated water — United States, 2005–2006 (Source: Yoder et al., 2008).



* Per 100,000 population.
† N = 68,907.
§ First full year of national reporting.

FIGURE 2. Incidence* of cryptosporidiosis, by year — National Notifiable Disease Surveillance System, United States, 1995–2008† (Source: Yoder et al., 2010).

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 (Shields et al., 2008b). 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 lot of people will 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 (Amburgey et al, 2007, 2008, 2009ab, 2011). 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.



* 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.

FIGURE 3. Number* of outbreaks of cryptosporidiosis associated with water, by water type — Waterborne Disease and Outbreak Surveillance System, United States, 1988–2008 (Source: Yoder et al., 2010).

Figure 3 shows that the majority of outbreaks of cryptosporidiosis occur in "treated" recreational water. Figure 4 shows a drastic 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 (Shields et al., 2008a).

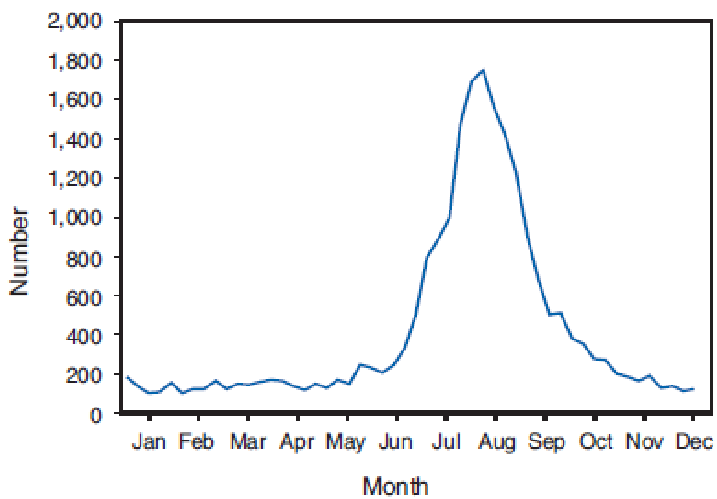


FIGURE 4. Number* of cryptosporidiosis case reports, by date of illness onset — National Notifiable Disease Surveillance System, United States, 2006–2008 (Source: Yoder et al., 2010)

Review of Recreational Water Filtration Research Findings. 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 (Amburgey et al., 2007, 2008, 2009ab, 2011). A quantitative risk assessment model of *Cryptosporidium* in swimming pools confirmed there is a "significant public health risk" (Pintar et al., 2010). 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 (PWTAG, 2009; Croll et al, 2007; Amburgey et al., 2007, 2008, 2009b, 2011). 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 well-documented and recommended in all U.S. surface water treatment facilities for drinking water production by the USEPA (Letterman, 1999, p. 6.1; AWWA, 2000, p. 86; and Logsdon, 2008, p. 12; Logsdon et al., 1981; Logsdon and Fox, 1982; USEPA, 2003). 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 (USEPA, 2003). 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 has been set at 90% (1 log) single pass.

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. As shown in Figure 5, sand filters (without coagulant addition) and cartridge filters were shown to achieve oocyst (and polystyrene *Cryptosporidium*-sized microsphere surrogate; not shown) removals of less than 40% (Amburgey et al., 2009a). Figure 5 also shows that precoat filters using either DE or perlite were effective at removing greater than 99% of *Cryptosporidium* oocysts without coagulant addition. This finding indicates that existing filtration technologies can meet the new 1 log removal recommendation for pools and that some pools are already exceeding this recommendation. Precoat filtration is not the only option for *Cryptosporidium* removals exceeding 1 log, and alternate approaches will be discussed subsequently.

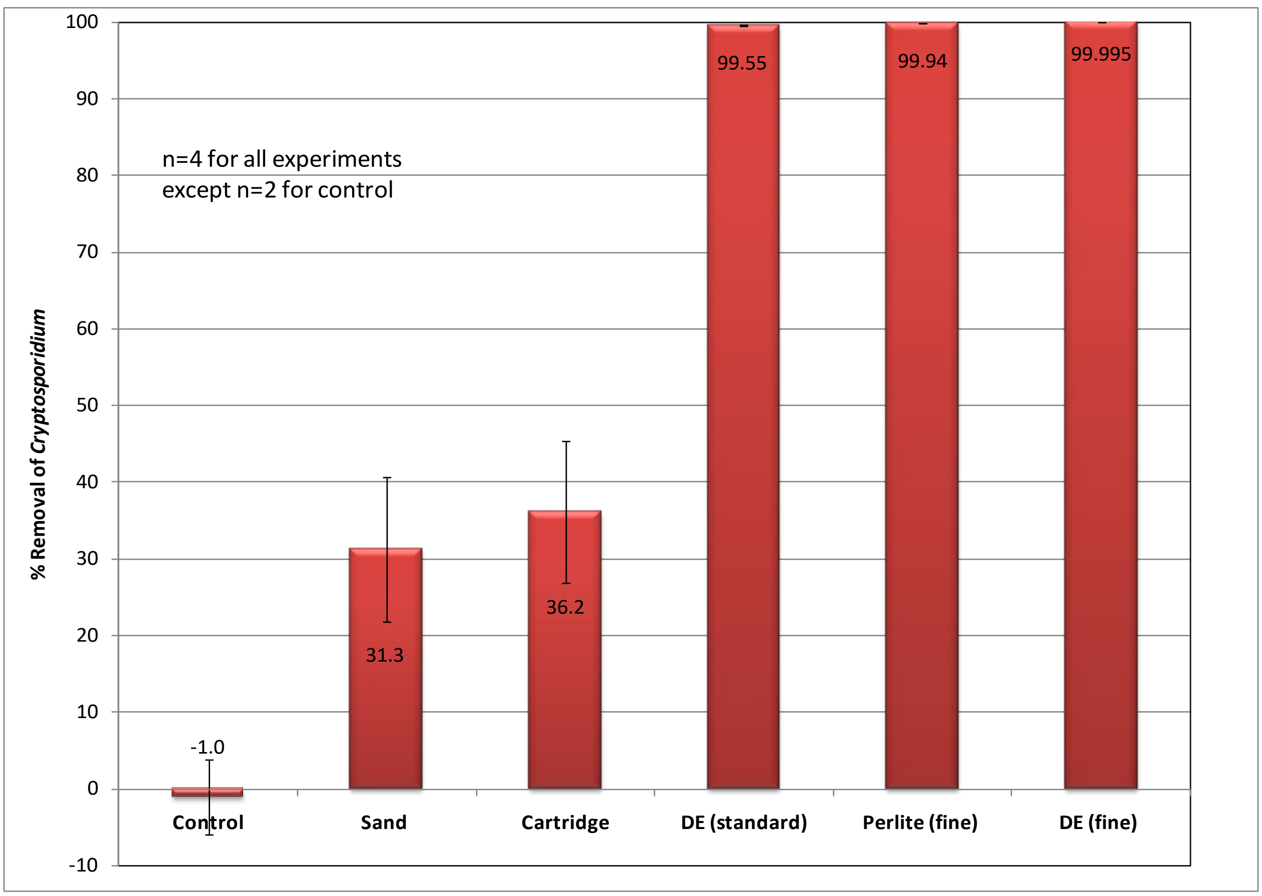


Figure 5. *Cryptosporidium* removal by filter/media type (Source: Amburgey et al., 2009a)

Table 4 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 (Amburgey et al., 2007). Table 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.

Table 4. Pilot-Scale Filter Removal Results for *Cryptosporidium* or *Crypto*-sized Microspheres in pool water

Filter Type	Media Depth	Surface Loading Rate	Coagulant Type	Coagulant Dosage	Removal (%)	Reference(s)
Cartridge	n/a	0.25 gpm/ft^2	none	n/a	20.7-47.9%	Amburgey et al., 2009a
Sand	24 in.	20 gpm/ft^2	none	n/a	22%	Amburgey et al., 2009b
Zeolite	24 in.	20 gpm/ft^2	none	n/a	22-32%	Amburgey et al., 2009b
Sand	24 in.	10 gpm/ft^2	none	n/a	25-46%	Croll et al., 2007; Amburgey et al., 2011
Sand	12 in.	15 gpm/ft^2	none	n/a	31-33%	Amburgey et al., 2009a, 2011
Sand	12 in.	15 gpm/ft^2	Alum	0.1 mg/L as Al	31-49%	Amburgey et al., 2011
Sand	24 in.	10 gpm/ft^2	Alum	0.1 mg/L as Al	33-95%	Amburgey et al., 2011
Sand	24 in.	10 gpm/ft^2	PACl	0.014 mg/L as Al	54.2%	Croll et al., 2007
Sand	12 in.	15 gpm/ft^2	PACl	0.1 mg/L as Al	56.0-87.5%	Amburgey et al., 2011
Sand	24 in.	10 gpm/ft^2	PACl	0.006 mg/L as Al	62.0-64.3%	Croll et al., 2007
Sand	24 in.	10 gpm/ft^2	Alum	0.06 mg/L as Al	65-68%	Croll et al., 2007
Bumped DE	0.1 lbs/ft^2	2.5 gpm/ft^2	none	n/a	83.4-90%	Amburgey et al., 2009b
Sand	24 in.	10 gpm/ft^2	PACl	0.76-0.92 mg/L as Al	87.8-98.0%	Croll et al., 2007
Sand	24 in.	10 gpm/ft^2	PACl	0.065 mg/L as Al	91.5-97.3%	Croll et al., 2007
Sand	12 in.	10 gpm/ft^2	PACl	0.1 mg/L as Al	92.0-95.7%	Amburgey et al., 2011
Sand	24 in.	10 gpm/ft^2	Alum	0.1 mg/L as Al	94-95%	Croll et al., 2007
Sand	24 in.	10 gpm/ft^2	Alum	0.3 mg/L as Al	96-97%	Croll et al., 2007
Bumped DE (fine)	0.1 lbs/ft^2	2.5 gpm/ft^2	none	n/a	97.5%	Amburgey et al., 2009b
Sand	24 in.	15 gpm/ft^2	PACl	0.1 mg/L as Al	98.1-99.2%	Amburgey et al., 2011
Sand	12 in.	15 gpm/ft^2	SuperBlue	3.1 mg/L as product	99.2-99.7%	Amburgey et al., 2011
Sand	24 in.	10 gpm/ft^2	PACl	0.1 mg/L as Al	99.3-99.7%	Amburgey et al., 2011
DE (standard)	0.1 lbs/ft^2	2.5 gpm/ft^2	none	n/a	99.4-99.6%	Amburgey et al., 2009a
Sand	24 in.	10 gpm/ft^2	PACl	0.43-0.45 mg/L as Al	99.5-99.8%	Croll et al., 2007
Sand	24 in.	10 gpm/ft^2	PACl	0.21 mg/L as Al	99.6-99.8%	Croll et al., 2007
Sand (w/ Perlite)	24 in.	20 gpm/ft^2	(Perlite)	0.25 lbs/ft^2	99.7%	Amburgey et al., 2009b
Perlite (fine)	0.1 lbs/ft^2	2.5 gpm/ft^2	none	n/a	99.91.99.95%	Amburgey et al., 2009a
Sand	24 in.	20 gpm/ft^2	PolySheen Blue	1.6 mg/L as product	99.92-99.95%	Amburgey et al., 2009b
Sand (w/ DE)	24 in.	20 gpm/ft^2	(DE)	0.5 lbs/ft^2	99.97-99.98%	Amburgey et al., 2009b
DE (fine)	0.1 lbs/ft^2	2.5 gpm/ft^2	none	n/a	99.991-99.995%	Amburgey et al., 2009a

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 Table 1.

Brief Historical Review of Water Filtration Practices for Aquatic Venues. 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 coagulant (Cary, 1929; AJPH, 1926).While high-rate sand filters are definitely cheaper and smaller, they are also less effective at removing *Crypto*-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 (Croll et al., 2007, Amburgey et al., 2007, 2008, 2009ab, 2011).

Increased Headloss Development Rates. 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.

***Cryptosporidium* oocysts and Microsphere Surrogate Particles.** *Cryptosporidium* oocysts (Iowa-isolate from the CDC) and fluorescent polystyrene microspheres (Polysciences, Inc., Warrington, PA) were not shown to have statistically significant differences in zeta potentials in simulated pool water with organics (i.e., artificial sweat and urine) (Amburgey et al., 2007). However, this was not the case for other water matrices tested (e.g., tap water or 1 mM KCl). While heat-inactivated and viable *Cryptosporidium* were shown to have a statistically significant difference in zeta potential in simulated pool water between pH 2 and 8, there was no statistically significant difference between pH 7 and 8 where pools normally operate (Amburgey et al., 2007). The chemicals used in the processing and storage of *Cryptosporidium* oocysts (purified from calf stool) have demonstrated potential to drastically alter the zeta potential of oocysts (Amburgey et al., 2008). The optional "defatting agents" ethyl acetate or diethyl ether appear to have the greatest potential to move the zeta potential from the unprocessed levels (typically -20 to -25 mV in simulated pool water) closer to zero (-8 mV to 0 mV) after processing (Amburgey et al, 2008). Based on the observed similarity in removals between *Cryptosporidium* oocysts and polystyrene microspheres (Amburgey et al., 2007; 2009a), recent research has been conducted almost exclusively with polystyrene microspheres (Amburgey et al., 2009b, 2011).

Importance of Scale in Design of Research Studies on Aquatic Venues. Previous research has shown that sand filters can remove greater than 99% of oocysts per passage through the filter when a coagulant is added prior to filtration in lab-scale filtration systems and only about 25% without coagulant (Amburgey et al., 2007). Unfortunately, the removals in the full-scale trials with coagulation were only slightly higher than 25% for reasons that were not determined (Amburgey et al., 2007). In later experiments, the removals in a spa-scale sand filtration system with coagulant addition only averaged 61% (Amburgey et al., 2009a). In trying to determine why the earlier lab-scale *Cryptosporidium* removal experiments with coagulant addition and sand filtration did not achieve same high levels of removal following scale-up to spa-scale or full-scale pools, Amburgey and coworkers (2009b) constructed a spa-scale sand filter proportioned for a 4.4 hr turnover of a 200 gal. spa at 15 gpm/ft^2 (instead of the commercial pool filter operating at 20 gpm/ft^2 for a 5.3 min turnover as in the previous study). By changing the filter diameter from 19-inches to 3-inches and increasing the depth of the sand from 12 inches to 24 inches, they achieved removals greater than 99.9% with continuous feed of clarifier for up to 3 days (Amburgey et al., 2009b). Others have also reported excellent performance of sand filters for removing *Cryptosporidium*-sized particles from pool water with proper coagulation and filtration conditions (Croll et al., 2007).

The necessity of coagulation prior to sand filtration in pools as well as the potential benefits of lower filtration rates and deeper beds of sand have recently been reported (Amburgey, 2010; Amburgey et al., 2011).The massively overdesigned filter originally installed (Amburgey et al., 2009a) with approximately 40-fold greater filter surface area than recommended on the spa was thought to be the primary cause of the poor performance in the earlier coagulation trials (due to coagulant demand exerted by the negatively charged sand grains at startup). However, the filter loading rate was also reduced, the depth of sand was increased, and the shear forces in the system were reduced by switching from a centrifugal pump throttled back with a ball valve to a gear pump controlled by a variable frequency drive. 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. However, it is clear that current swimming pool sand filtration practices in the U.S. are not effective at preventing waterborne disease outbreaks.

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/ft^2 does not mean this filter should be operated at 20 gpm/ft^2. 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/ft^2 reflects 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.

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 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.

High-rate granular media filters should be designed to operate at no more than 12 gpm/ft^2 (36.7 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 20 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.

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.

The performance of high-rate granular media filters at removing pathogens and particles can contingent upon the depth of the filter media (as shown in Table 4), 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 (WHO, 2006, p. 90; PWTAG, 2009, p. 54-55). The standard sand filter bed depth typically varies from 0.55 to 1 m (22 to 39 inches) in the UK (PWTAG, 2009, p. 55).

Drinking Water Research Perspectives on 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.

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. In some recent (still unpublished) experiments, filters with 12" of sand filtering simulated pool water coagulated with 1.6 mg/L of cationic polymer (BioLab, Inc.) were not able to remove an average of greater than 90% (1 log) of *Cryptosporidium*-sized polystyrene microspheres in 2 out of 3 trials at 15 gpm/ft^2. At least one sample in each trial failed to meet the 1 log removal level goal. Whereas, at 10 gpm/ft^2 under otherwise identical conditions (i.e., coagulation with 1.6 mg/L of cationic polymer), all individual samples demonstrated removals greater than 1 log with a mean of 93.7% removal. Furthermore, filters with 24 inches of sand were able to achieve an average removal of 99% (1.98 log) at 15 gpm/ft^2. Similar removal results have been also been observed with another cationic polymer (Lonza) in laboratory trials at UNC Charlotte. Research is ongoing regarding how long these removals can be sustained. Based on these initial results, it appears that filter depth has a greater potential to improve pathogen removal than filtration rate, but both deeper filter beds and lower filter loading rates improve filter performance. Similar effects of filtration rate on particle removal have been reported elsewhere (Gregory, 2002). 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 (Cary, 1929; AJPH, 1926). The minimum depth of sand in pool filters was 36-inches in 1926 (AJPH, 1926). 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 media grain (Cleasby and Logsdon, 1999, p. 8.20). For example, a 0.6 mm effective size sand would recommend a minimum 0.6 m (23.6-inches) bed depth for a L/d of 1000, but a 12-inch (0.3 m) deep sand bed with 0.5 mm sand grains would have an L/d of only 610.

Backwash System Design. For a granular media filter system to be able to backwash at a rate of at least 20 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 20 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 used a backwashing rate of 25 gpm/ft^2 (61 m/h) to achieve 25% bed expansion of their filter (Croll et al., 2007). 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 (WHO, 2006, p. 90). Backwashing swimming pool sand filters with air scour is common in the UK and elsewhere (WHO, 2006, p. 89; PWTAG, 2009, p. 57). It has also been reported that air-scour washed swimming pool filters are more efficient than filters washed by water only (Neveu et al., 1988). 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 (Hendricks, 2006). 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 on a recurring basis. PWTAG recommends air-scouring filters at 32 m/h (at 0.35 bar) (PWTAG, 2009, p. 57).

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

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 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. (PWTAG, 2009, pg. 56) 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.

Filter Media and Backwashing Recommendations.

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 (Lyons and Kapur, 1977). 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 backwashing. These backwashing recommendations are based on drinking water treatment practice (Cleasby and Logsdon, 1999, p. 8.15). For a sample of Mystic White II pool filter sand examined in the laboratory 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 Figure 6 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 (2000, p. 213) was graphically estimated to be 20.9 gpm/ft^2 at 20° C. This is the rationale for requiring the 20 gpm/ft^2 backwashing rate of all swimming pool sand filters.

To ensure compatibility with the minimum recommended backwashing rate of 20 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 Figures 6 and 7. 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 0.425 mm (40 mesh). In order to achieve fluidization at a lower flow rate, a 30/40 mesh could be specified, where the larger (harder to fluidize) sand grains that set the minimum backwash rate would be 0.60 mm (30 mesh) instead of 0.85 mm (20 mesh).

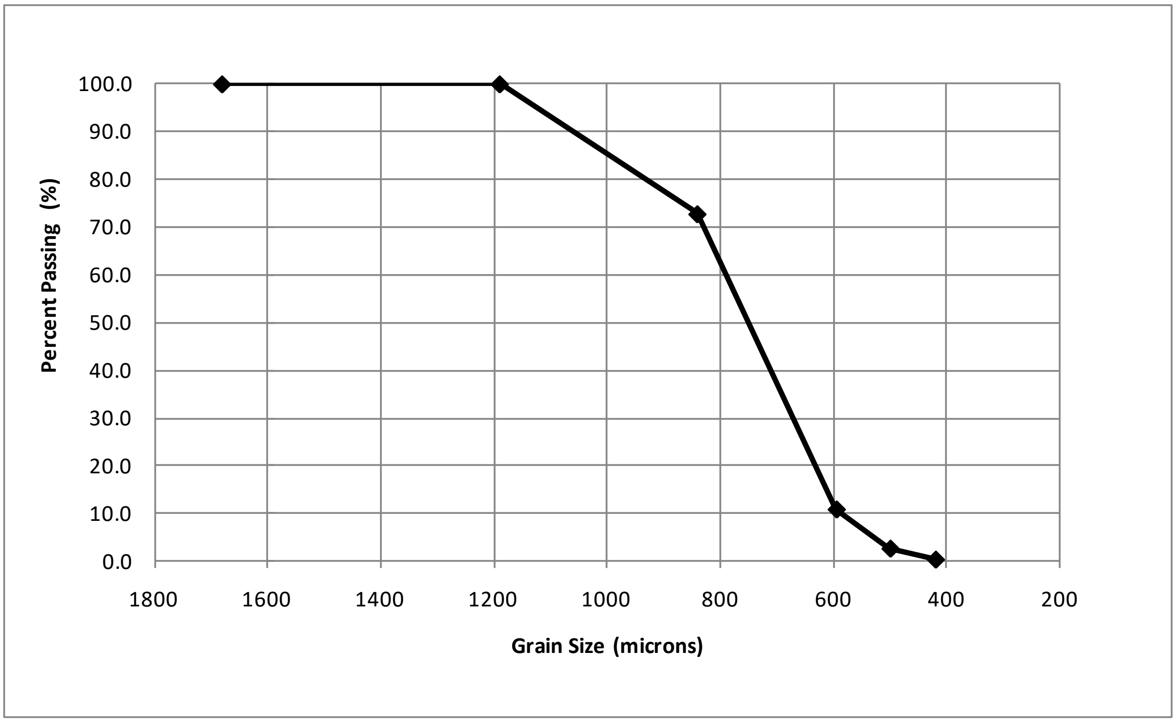


Figure 6. Grain size distribution of pool filter sand (US Silica, Mystic White II).

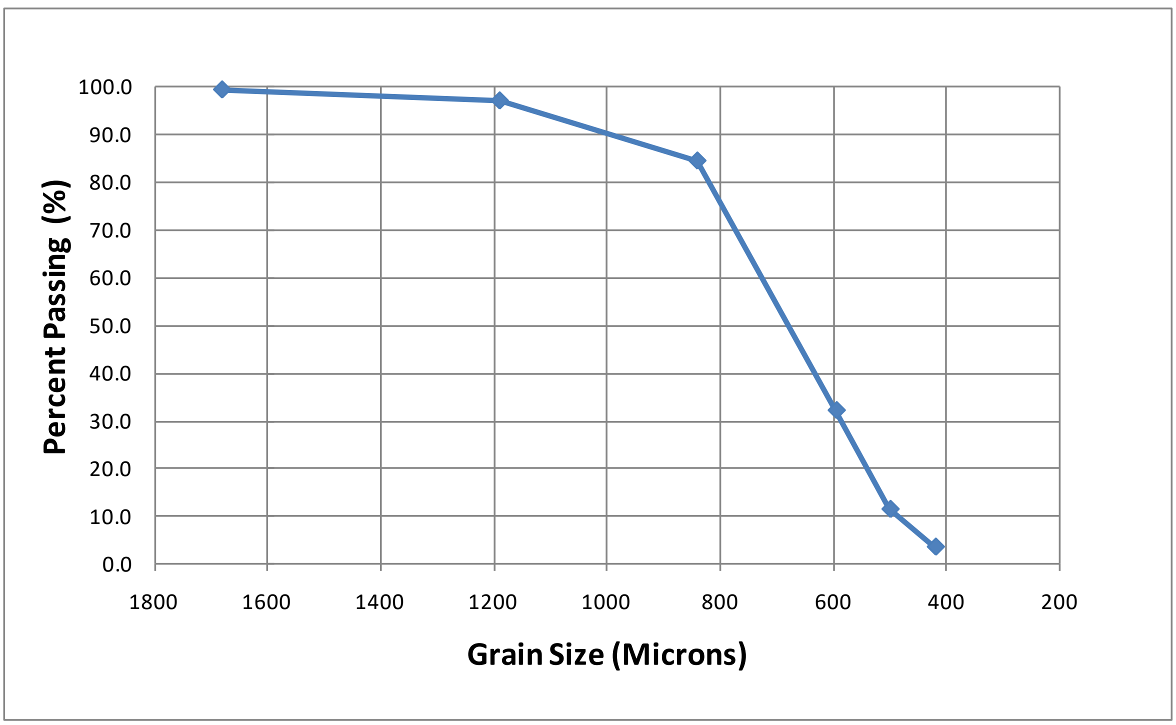


Figure 7. Grain size distribution of pool filter sand (Pavestone, Inc.)

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

Experiments were conducted at UNC Charlotte 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. 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 Table 6. The 20/30 mesh fraction of the same filter media was examined under the same conditions, and the experimental results are provided in Table 7. 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 (1999) 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 (Dharmarajah and Cleasby, 1986). 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) (PWTAG, 2009, p. 57). 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 (Croll et al., 2007). 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.

The primary purpose of support gravel in a filter is to provide backwash water distribution below the filter media layer. This distribution ensures uniform fluidization and prevents water from flowing up only one side (or the center) of the filter. With uneven backwash water distribution, portions of the filter not will not get cleaned effectively. In general, installing filter sand on a slotted PVC hub/lateral or hub/radial distribution system is not advisable. My personal preference is concrete below the laterals and at least one layer of gravel above the laterals. Limited space in a filter can push installers and regulators to arrive at less than ideal solutions.

Table 6. Pool Filter Sand at 20° C (U.S. Silica Sand Mystic White II)

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 7. Pool Filter Sand Sieved 20/30 mesh at 20° C (U.S. Silica Sand Mystic White II)

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

Coagulant Injection Equipment. This recommendation is intended 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 (Letterman, 1999, p. 6.1; AWWA, 2000, p. 86; and Logsdon, 2008, p. 12; Logsdon et al., 1981; Logsdon and Fox, 1982). 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. Research has shown that without coagulation, swimming pool sand filters typically remove only about 25 to 50% of *Cryptosporidium*-sized particles (Croll et al., 2007, Amburgey et al., 2007, 2008, 2009ab, 2011). This demonstrated lack of efficient pathogen removal is the rationale for recommending 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 is known to impair performance.

Initial laboratory experiments with the recommended dosage (currently 1.6 mg/L as product) of Polysheen Blue and SuperBlue have shown these dosages to be effective for enhancing *Cryptosporidium* and *Crypto*-sized microsphere removal (Amburgey et al, 2007,2009b, 2011). Although polyaluminum chloride (PACl) is not a widely used coagulant in the U.S. at present, it has been used extensively abroad (PWTAG, 2009; Croll et al, 2007). 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 (Croll et al., 2007). Preliminary research at UNC Charlotte has shown that 0.1 mg/L as Al dosages of PACl (Kemira, Inc.) was not effective with 12-inches of sand at 15 gpm/ft^2. However, PACl did look promising at 0.1 mg/L as Al for filtration at 10 gpm/$ft^2$with 24-inches of sand. Table 4 provides a summary of published research results at pilot-scale pools.

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 (Hendricks, 2006, p. 585). 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 (Cary, 1929; AJPH, 1926; PWTAG, 2009; Croll et al., 2007; DIN Std. 19643-3, Sect. 4.3).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.

Precoat Filters

Filter 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 (Logsdon, 2008 p. 237). However, drinking water applications typically use finer grades of precoat media at application rates of 0.2 lbs/ft^2 (1 Kg/m^2) (Logsdon, 2008, p.243). Lange and coworkers (1986) 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 (2001) 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. 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 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 could recommend removal of precoat media prior to discharge in sewer systems.

Filter Media. 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 (Logsdon, 2008, p. 242).

Cartridge Filters. 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. Due to these health and safety concerns, cartridge filter use is not recommended.

As shown in Figure 4.7.2.5 and listed in Table 4.7.2.1, cartridge filters were not shown to achieve oocyst (and polystyrene *Cryptosporidium*-sized microsphere surrogate) removals of greater than 50% (Amburgey et al., 2009a). Cartridge filters with the media currently used for pools are simply not effective for *Cryptosporidium* removal and cannot meet the recommended 1 log (90%) removal standard set by this code. There are *Cryptosporidium* size-rated cartridges, but they might need to be used following a sand filter (or other pretreatment) to prevent rapid fouling.

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 them. Exposure concerns exist since concentrated streams containing *Legionella*, *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.

Filtration Rates. Cartridge filters 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 filters 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 proper filter performance (or minimum pool turnover requirements) over time. For example, if a filter only recovers to 80% of the original flux after one or more cleaning cycles, then a filter flow rate of 0.375 gallons per minute per square foot (0.26 L/s/m^2) would drop to 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.

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

Spare Cartridges. An extra set of cartridges, 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 cartridges.

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.

Water Replenishment System.

A means of intentionally discharging and measuring the volume of discharged pool water (in addition to the filter backwashing system) is recommended to be installed and designed to discharge a volume of water of up to 8 gallons (30 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 (WHO, 2006, p. 90; PWTAG, 2009, p. 24; DIN, 1997, 19643-1, Sect. 13.5) have been widely used. PWTAG (2009, p. 24) states that as much as half of the recommended amount could be associated with filter backwashing. There does not appear to 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 patron 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 treatment system. For example, it would not be allowable 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).

Wastewater Disposal System. 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.

Air Gaps. 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.

Separation Tanks. 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.

Operation and Maintenance

Recirculation Systems and Equipment. 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 (Dick et al., 1960). 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 (PWTAG, 2009). 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 cases (Dick et al., 1960). 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. (PWTAG, 2009, p. 45)

Combined Venue Treatment.

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.

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

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.

Turndown Feedback System.
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.

Granular Media Filters.

Backwashing. 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 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. 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.
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. Coagulants should be used at all times. 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*.

Performance: Water Clarity and Visibility 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 proposed turbidity limit for pools 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.

Precoat Filters

Precoating. 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. 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 (Logsdon, 2008, p. 239). Allowing the media to fall off of the filter septum decreases the capability of the filter to remove particles (Logsdon, 2008, p. 246). 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 (Logsdon, 2008, p. 249).

Cleaning. 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.

Filter Media Feed. 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.

Bumping. 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.

Bumping is strongly discouraged in any precoat filter application where pathogen removal is a concern pending future research. 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 (Logsdon and Fox, 1982). Cyst-contaminated water used for precoating filters led to much higher cyst concentrations in the filter effluent (Logsdon and Fox, 1982). Precoat filters have been demonstrated to remove greater than 99% of the oocysts as shown in Figure 4.7.2.5. However, when the flow was interrupted through the precoat filter and the media was allowed to drop off of the support structures (i.e., bumped) as the 3-way filter effluent valves were switched, uneven re-coating was suspected because removal efficiency was significantly impaired (Amburgey et al., 2009b). Fine DE removals of 4.5-micron microspheres decreased from 99.996% (4.44 log) to 97.5% (1.6 log), and standard DE removals decreased from 99.44% (2.25 log) to 90% (1 log) or less (Amburgey et al., 2009b). While additional research on bumping precoat filters is desirable, discarding and replacing precoat media is recommended following interruptions of flow through the filters. Not using dirty precoat media to precoat filters as well as maintaining continuous flow is recommended (Logsdon et al., 1981; Lodsdon and Fox, 1982; Logsdon, 2008, p. 249).

Filter Media. 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 8.

Table 8. Recommended Use Rates for Precoat Media.

Media type	Pounds per 10 ft^2 of filter area	Approximate precoat depth
DE	1.5 - 2.0	3/32th – 1/8 inch
Perlite	0.75- 1.0	3/32th – 1/8th inch

Drinking water applications typically recommend using DE at application rates of 0.2 lbs/ft^2 (1 Kg/m^2) (Logsdon, 2008, p.243). 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 (Logsdon et al., 1981). Under the range of conditions tested, Logsdon and coworkers (1981) 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 (Lange et al., 1986). Logsdon (2008, p. 241) 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 Replenishment.

Water replenishment volume.

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.

Water Replenishment Frequency.

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.

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Acknowledgements:

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