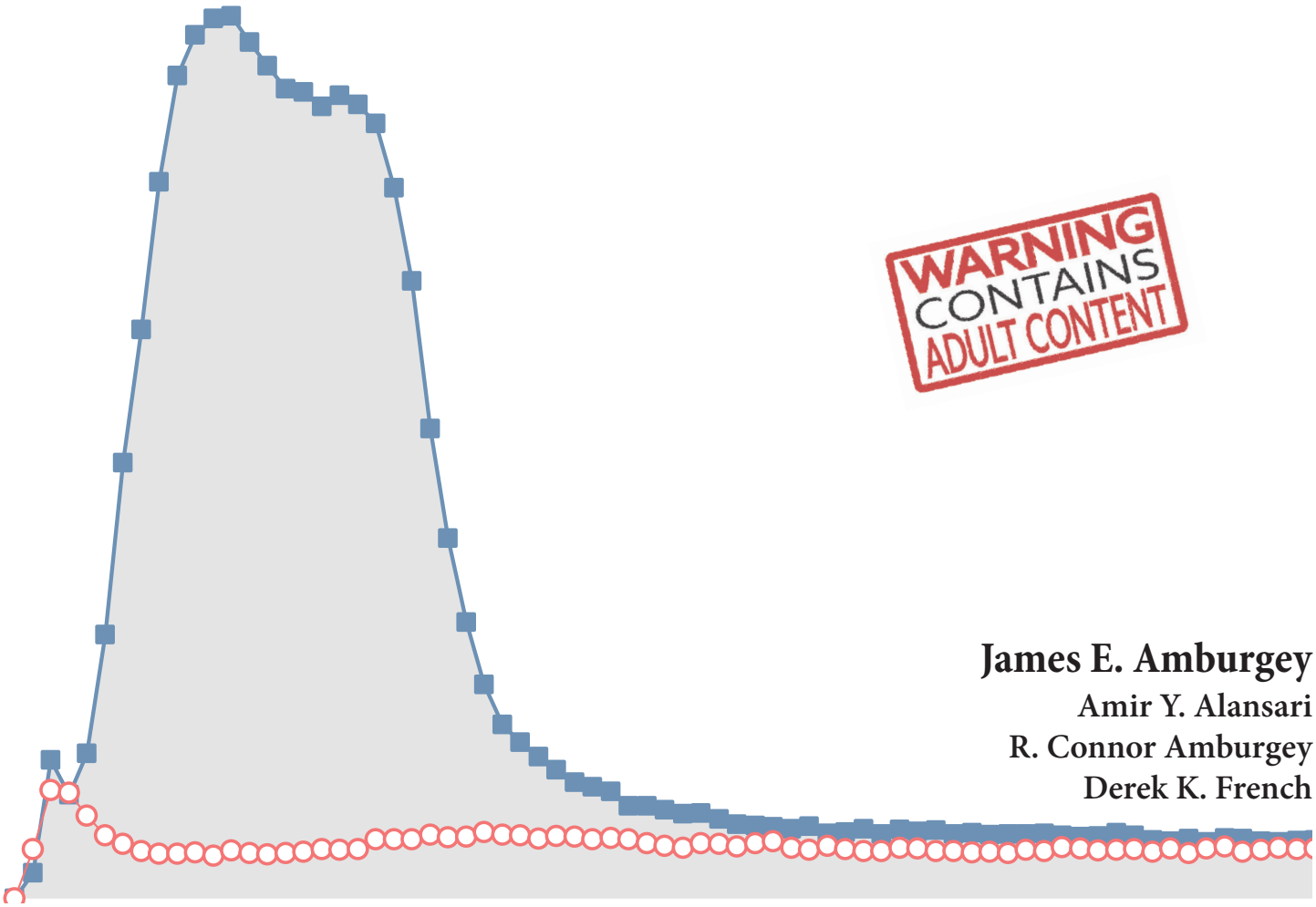
ETSW 2020 *& BEYOND...*

EXTENDED TERMINAL SUBFLUIDIZATION WASH (ETSW) 2020 & Beyond:

Optimizing the Water Treatment Process through the Backdoor



WARNING CONTAINS ADULT CONTENT

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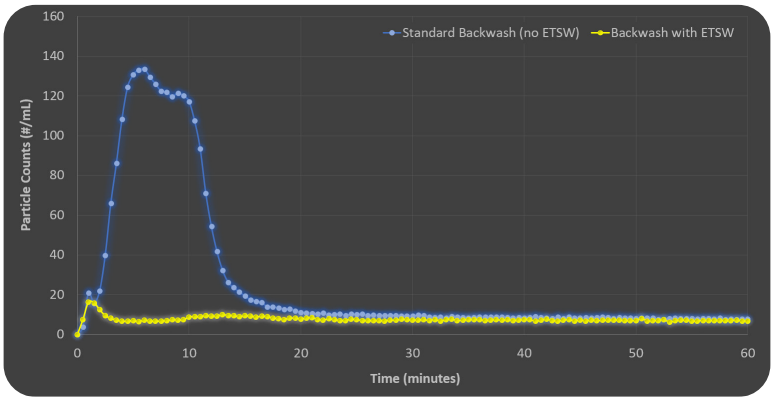
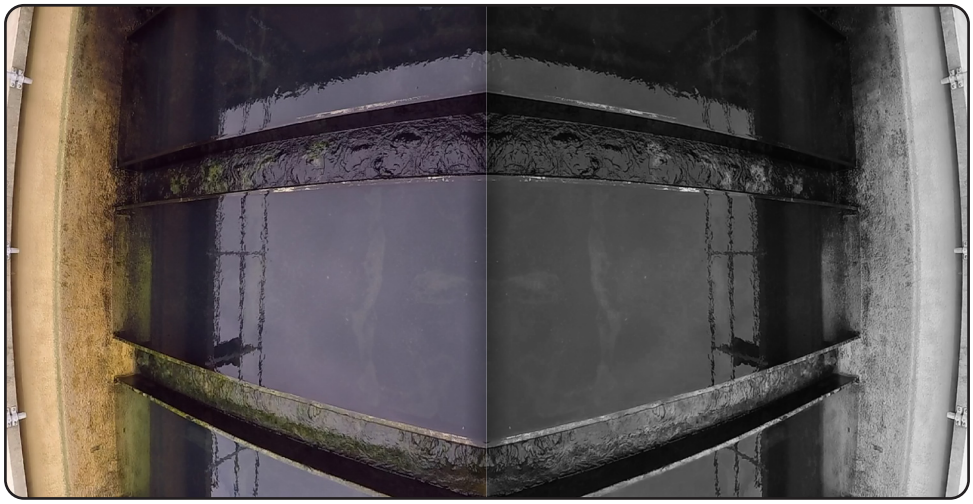
OVERVIEW



Elevated particle counts or turbidity immediately following the restart of a backwashed filter (shown above) is commonly known as the filter ripening period, which can be responsible for more than 90% of particles passing through a filter during a filter run. ETSW is a backwashing technique that can prevent filter ripening and has been around for nearly 20 years, but it is still not well-understood or widely practiced. ETSW is an acronym that defines itself: Extended (typically 5-10 min.), Terminal (last step of a backwash), Subfluidization (low flow rates with no media expansion or fluidization), Wash (washes out backwash remnant particles normally left in the filter after backwashing). State regulations still commonly prevent or hinder its use by requiring filter-to-waste, and consulting engineers and operators alike often struggle to perform it correctly. The USEPA Partnership for Safe Water Program has led to multiple states success fully promoting and using ETSW. The purpose of this paper is to educate the drinking water industry on both understanding and efficiently dealing with filter ripening pathogen passage and implementing ETSW properly. The goal is to use as few words as possible to communicate the facts. There will not be a wordy introduction, no literature review, no equations, no methods section, or even any references (although those things have all been published previously in six peer-reviewed journal articles on ETSW that are not freely available to the general public due to copyrights). A collection of short factual statements of just a few lines with figures to back them up follow (with a companion spreadsheet to do ALL of math for you). **This paper will introduce a totally new concept of optimization coagulation (and all drinking water treatment processes) by using optimized ETSW backwashes and monitoring the filtered water quality carefully during the first 60 minutes of filter operation**.

WARNING: this is an education and implementation document with completely unnecessary adult themes and attempts at humor.

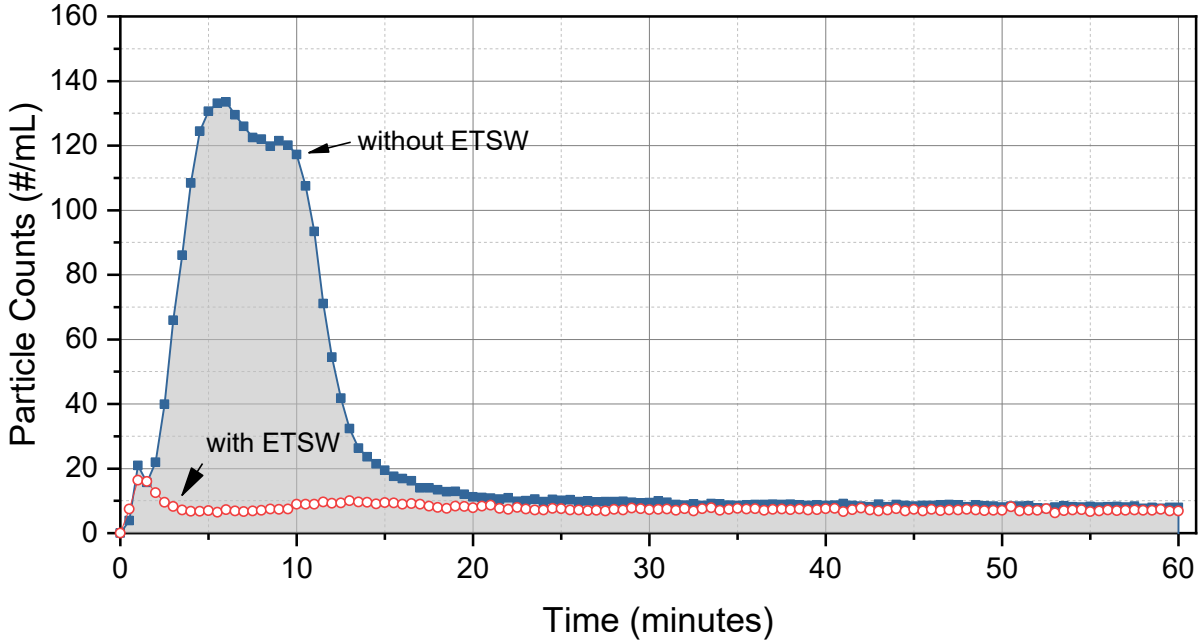
Dirty Two-faced Filters



Filtration is a dirty treatment process, which **only** works well when **both** the physics **and** chemistry are correct. A filter will treat you right and fill your life with good memories, and then that same filter will do you so very wrong if you neglect its needs. The filter's physical needs (physics) include the size/depth of the media, filtration rate, and backwashing efficiency. Filters also require the right chemistry, which is primarily optimized coagulation (but could include other chemistry factors like polyphosphate in the backwash water or cold-water coagulation reaction changes). ETSW can help your relationship with your filter, but ETSW only changes the backwash efficiency (physics) and cannot ever fix sub-optimal (poor) coagulation (chemistry). ETSW is just a backwash flow rate for the final step of backwashing and a corresponding time based on your filter design (physics) that can clearly indicate poor coagulation conditions (chemistry).

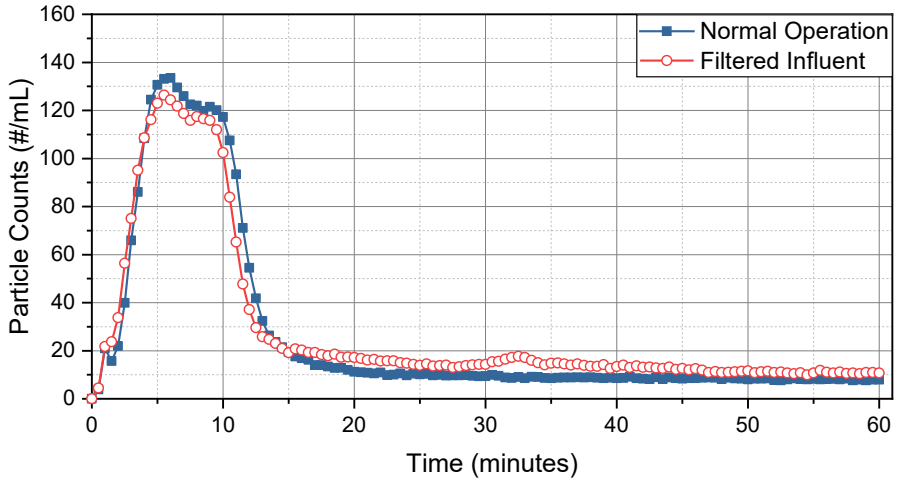
Partnering with a Dirty Two-faced Filter

When coagulation (chemistry) is optimized (all cases in the next figure), ETSW can remove the backwash remnant particles (normally sheared off the media surfaces by high backwash rates) by simply washing them out of the filter at low (subfluidization) backwash rates. It is the backwash remnant particles that cause filter ripening spikes (or problems in your relationship) as shown below. Notice how all filters returned to baseline within 20 minutes (~ the volume of water inside the filter, which contained the remnant particles). With ETSW (red-circles in the next graphic) the remnant particles are backwashed out thereby preventing a ripening spike. Without ETSW (blue squares), the same filter will do you dirty every time you backwash.

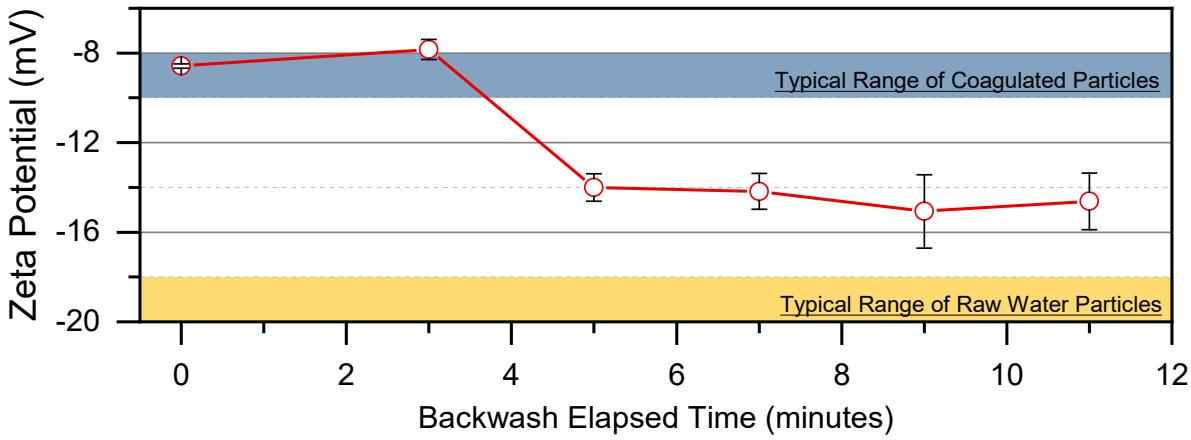


The Cause of All Your Problems

Backwash remnant particles (detached during backwashing) cause filter ripening spikes. This can be proven by using filtered water (which contains little to no particles) as the influent water to the filter after a backwash as shown in red below. The small increase at 33 minutes is when the water was switched from filtered back to unfiltered water.

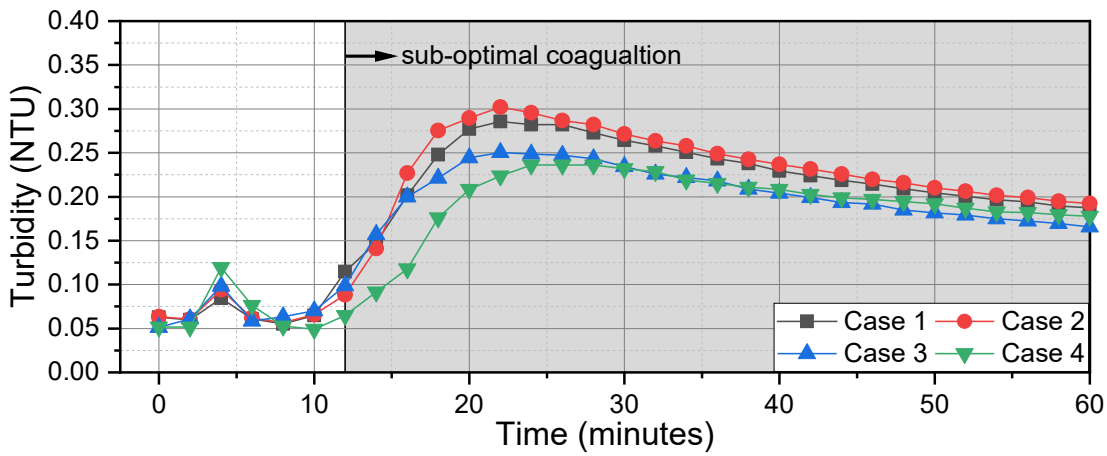


The reason that backwash remnant particles are not removed by filters and pass into the effluent (despite having once been removed by the filter) is that the charge on these particles becomes more negative as they sit on the media inside the filter due to unbound natural organic matter (NOM) adsorbing onto their surfaces (credit goes to Charlie O'Melia for this insight). When the surface charge (or zeta potential) of backwash remnant particles are measured over the course of a backwash, they grow more negative as the particles on the outer surface layer of the coated media are removed first and followed by the older innermost particles as shown here.

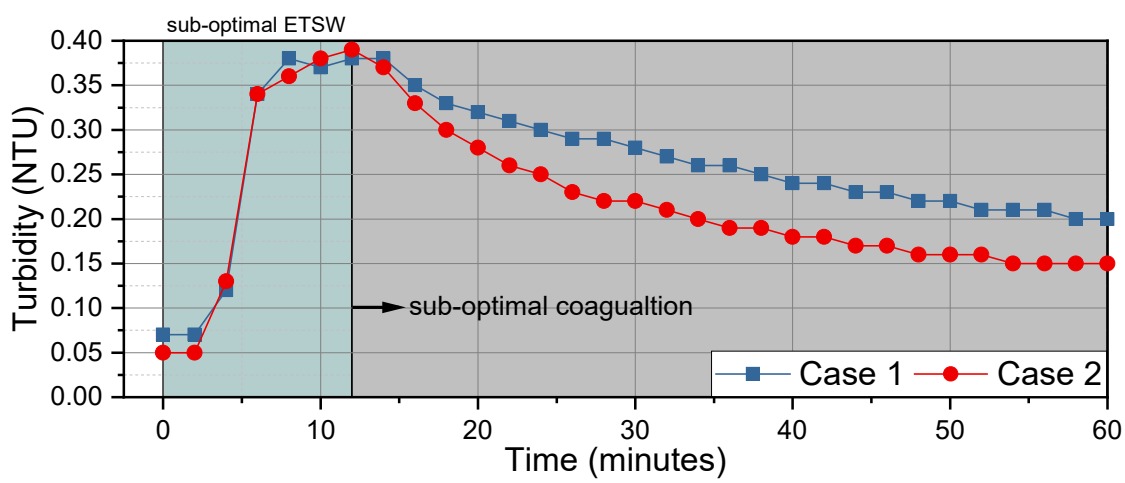


Know when you're settling and deserve better!

When the chemistry is not right - coagulation is not optimized (due to factors such as cold water temperatures, sub-optimal pH, and/or sub-optimal coagulant dose), your filter can really play some dirty tricks on you by spiking the turbidity behind your back (i.e., after 20 minutes when the backwash remnant water has been replaced with newly influent, poorly coagulated, water). In this case, ETSW (physics) worked well to control ripening during the first 12-15 minutes, but coagulation (chemistry) failed after 20 minutes when only newly influent water was exiting the filter.



A relationship with poor chemistry (sub-optimal coagulation) and bad physics (a non-ETSW backwash) is double trouble, which is shown next and differs significantly from the previous figure. When a filter needs 60 minutes or longer to return to less than 0.10 NTU, the coagulation conditions (chemistry) requires adjustment. You should seek counseling quickly!



Professional Counseling on your Partnership

The EPA's Partnership for Safe Water has established a goal of 0.3 NTU for the maximum filter effluent turbidity during filter ripening along with a goal of 0.1 NTU or less within 15 min of restart. The previous filter relationship with poor chemistry (coagulation) and poor physical relations (non-ETSW backwash) does not meet either of the EPA's recommendations for a good partnership. No, this is not the bitter end of this story. As long as you and your filter are both willing to learn and change, then this can become a happy partnership again.

Physical Inadequacies in your Partnership

We might as well as start with the physical inadequacies of your filter as well as the pathetic way you've been backwashing it. Your filter media might not be adequately sized or deep enough, but state regulations typically keep this from getting too far out of hand. You might be pushing your filter a little too fast, but state regulations help here too. Unfortunately, you might be going too long between backwashes, which the states do not normally regulate. The longer dirt sits in your filter, the stronger it binds to the media grains. Worse yet, infrequent backwashing leaves the removed particles and organics in the filter longer to react with disinfectants (to form disinfection by-products) and increase the amount of negative charge on backwash remnant particles. While some operators brag about going 7 days or longer between washes, a lot of filters are getting it much more often to the tune of every 48 hours like clockwork. Backwashing used to be something to avoid as long as possible (due to the disappointment that came afterwards), but that was only because it was being performed incorrectly.

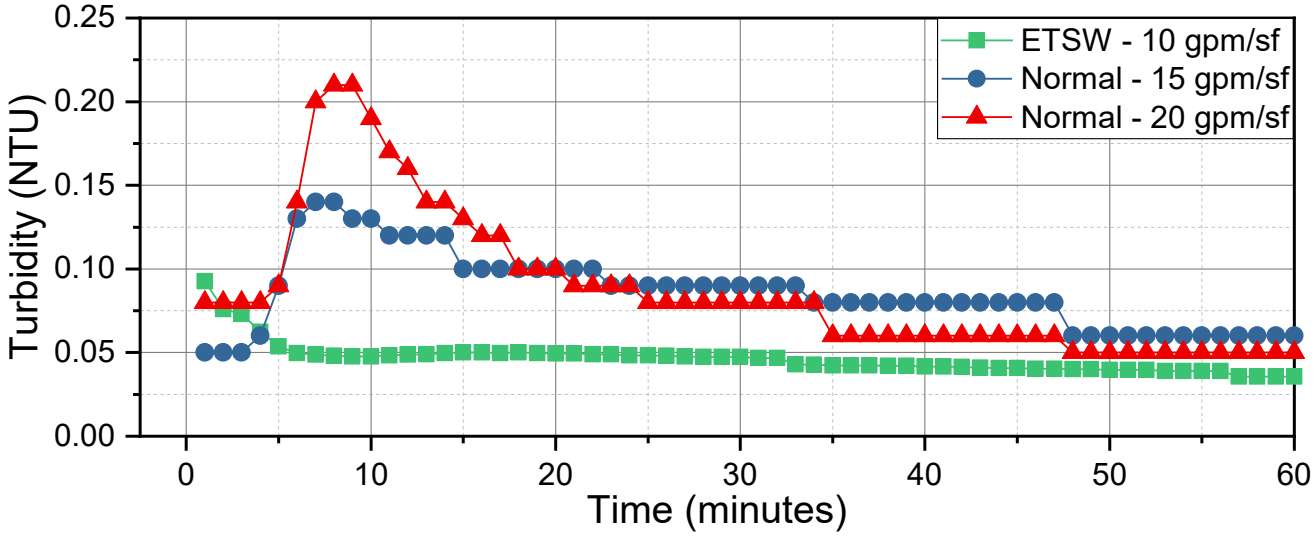
All filters are different

While all granular media filters share similar features, they are also different in small yet significant ways. Specifically, the type, number, effective size (ES), uniformity coefficient (UC), depth (D), and density of filter media can all vary between filters. Further, some filters are taller (distance from the top of the media to the overflow of the backwash troughs) and larger (wider and longer). You should probably take some time and get to know your filter a little better right now.

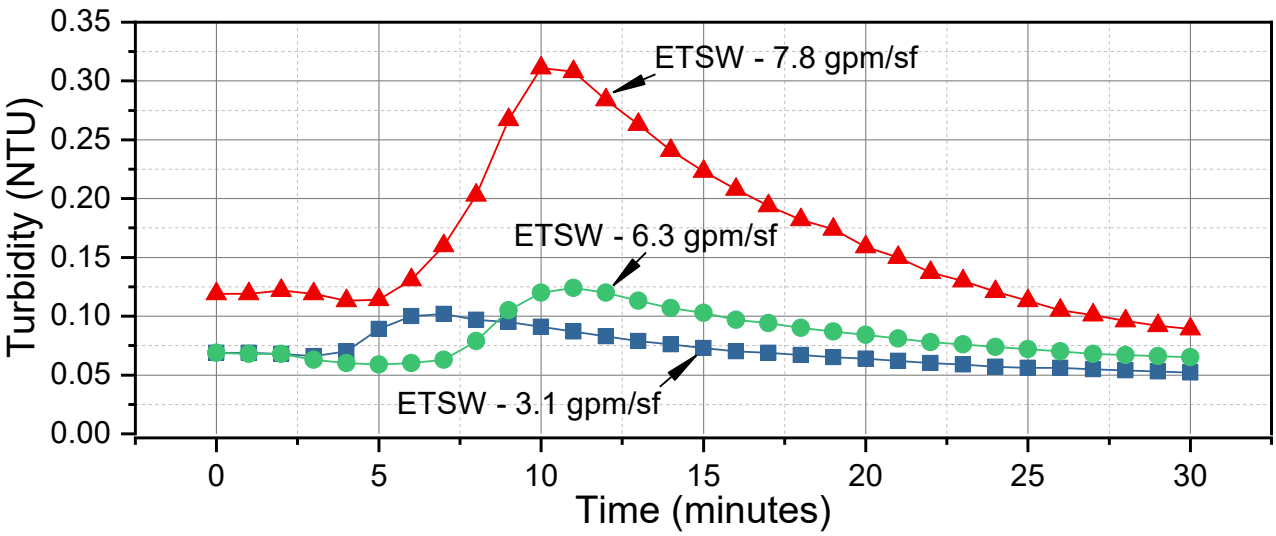
How to Perform ETSW to Satisfy your Partner

ETSW requires you to find the right speed and maintain it for the right amount of time to be successful. This can be done entirely by trial-and-error, but there is no reason to make it any harder than it needs to be. A good spreadsheet can calculate everything for you while you relax and enjoy the experience. ETSW is just a backwash flow rate and a corresponding time based on your filter design (physics) that can be optimized (shortened) based on the water temperature and coagulation conditions (chemistry).

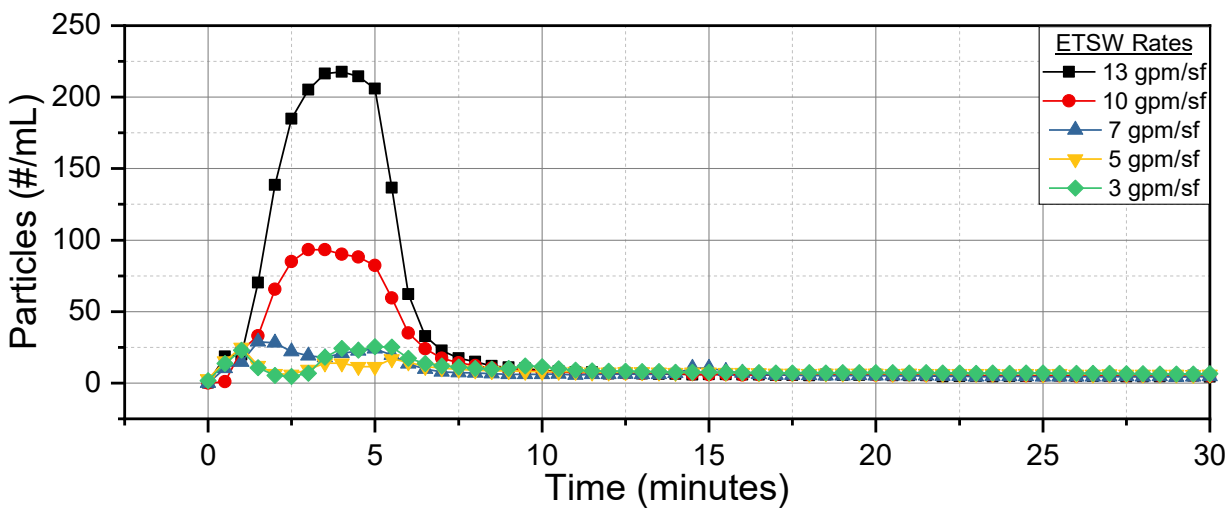
In the case of a deep-bed filter using larger media, it might be possible to get ETSW to work at 10 gpm/sf as shown (when 20 gpm/sf is the "normal" backwash shown in red). A 15 gpm/sf backwash (blue) has lower filtered turbidity than the normal backwash (red), but ETSW needed to be performed at 10 gpm/sf or less in this facility (at 25° to 30° C).



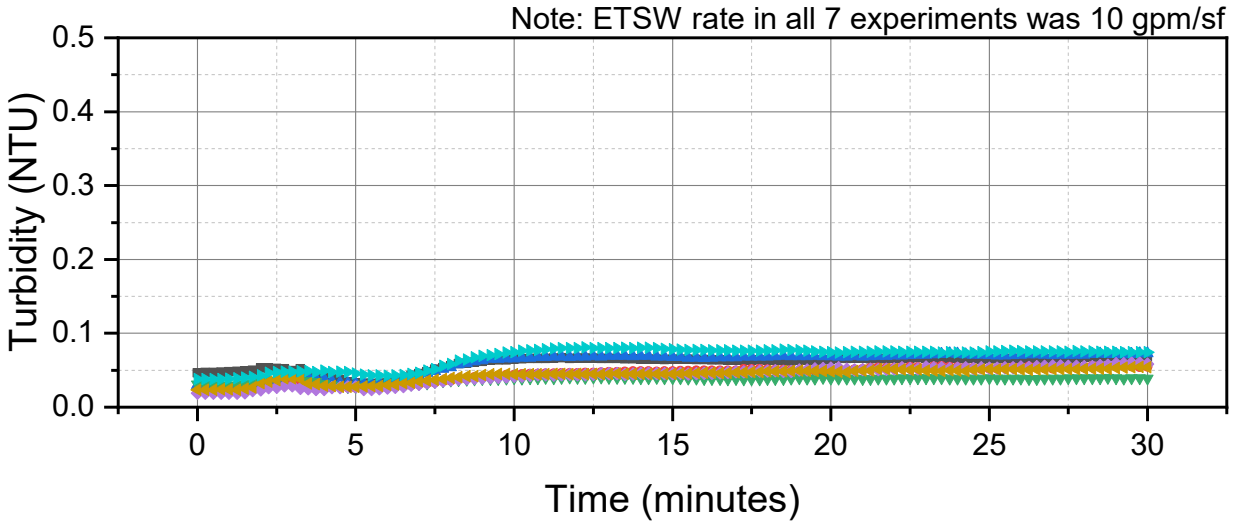
In the case of a conventional filter (shown below) using typical media grades at 10° C, the ETSW rates must be lower. The series in red below is 7.8 gpm/sf and peaked above 0.3 NTU. The green series (6.3 gpm/sf) peaked above 0.1 NTU, so a rate of 3.1 gpm/sf was used to keep the turbidity down to 0.1 NTU or less. These three values are roughly equal to minimum fluidization velocities (V_{mf}) of d_{90}, d_{60}, and d_{10} media sizes, respectively. The Vmf values are calculated in the corresponding spreadsheet and tell us the flow rate at which different sized media grains begin to fluidize (and expand the filter bed).



The next filter is a deep-bed granular activated carbon (GAC) filter. Due to the lower density of GAC, ETSW rates are typically lower to get similar performance. While 10 gpm/sf worked earlier for similarly-sized anthracite coal filter media, both 13 and 10 gpm/sf resulted in a sizable particle count peaks below. Even 7 gpm/sf was a bit higher in effluent particles than 3 or 5 gpm/sf.

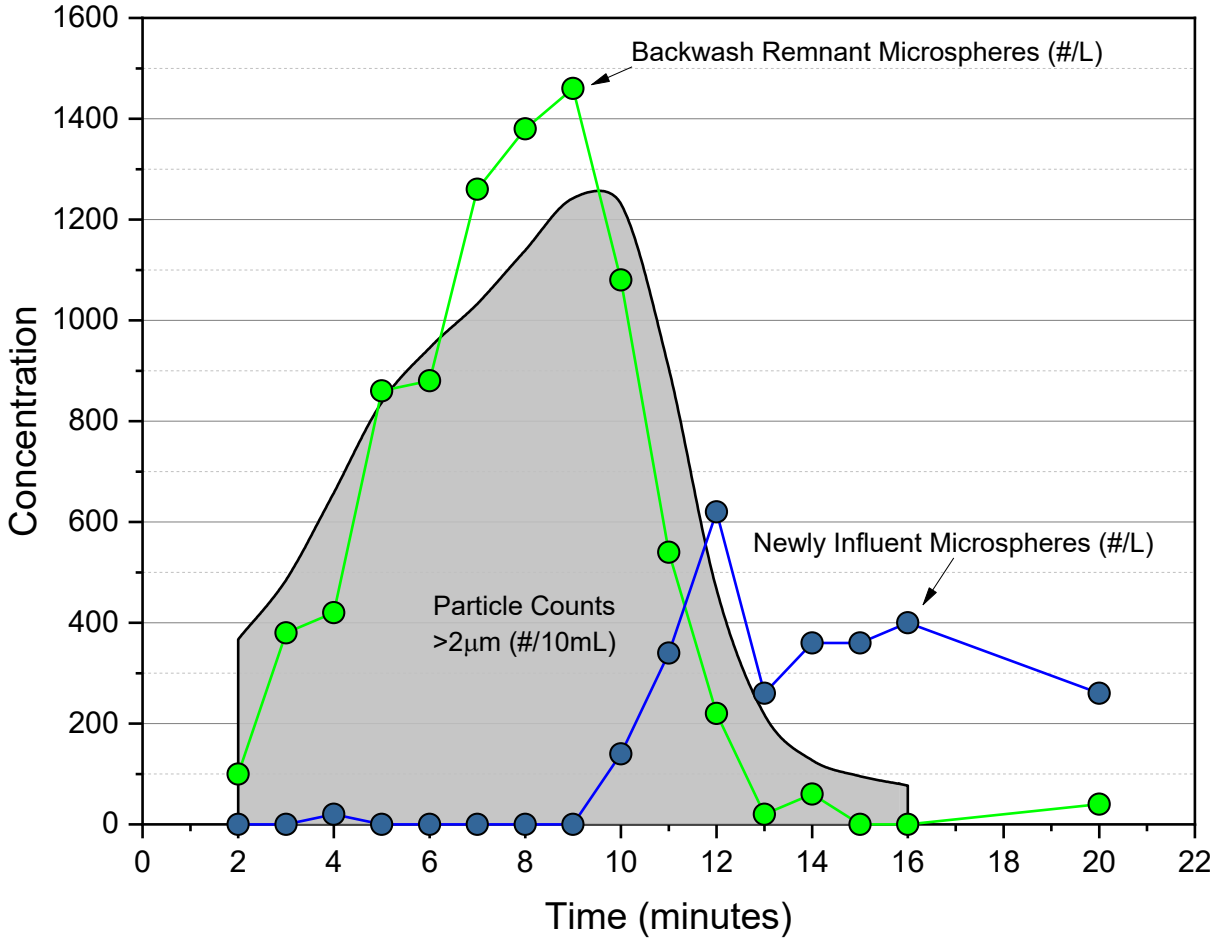


Once ETSW is being performed at the correct backwashing rate for the correct amount of time (with optimal coagulation), the filter ripening sequence (FRS) turbidities could actually be lower than the turbidity afterwards. This makes sense because filtered water is simply being filtered a second time during proper ETSW. Seven such backwashes of a deep-bed anthrtacite-sand filters with 60-inches of media are shown below .

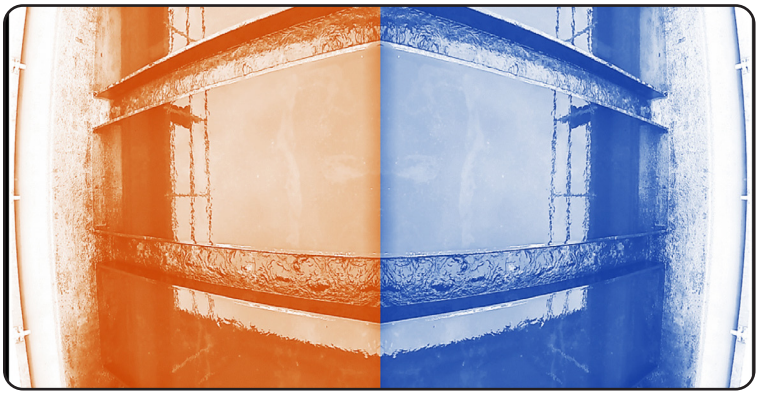


Always Practice Safe "Backwashing"

Using two colors of Cryptosporidium-sized microspheres (green for one entire filter run and then blue microspheres in the influent after backwashing), it is easy to see that the FRS turbidity/particle count spike (black line and highlighted grey area) corresponds to the green microsphere concentrations (green line) from the previous filter run. The newly influent blue microspheres (blue line) only begin to exit the filter after 9 minutes of operation for this non-ETSW backwash where peak concentration were above 1400 Crypto-sized microspheres per liter of water. Similar trials with ETSW backwashes yielded zero microspheres passing during the FRS for biological and conventional filters containing anthracite coal and sand. Whereas poly-phosphate in the backwash water increased microsphere concentrations 5-10 fold above the normal backwash levels.



They run hot and cold



You can find good filters down south while others can be found up north. If you know anything about filters, then you know they all get hot sometimes and turn cold other times. You might not know that your backwash procedure is supposed to change with the temperature of water. This is true for the fluidization flow rate as well as the ETSW flow rate and its corresponding duration. Filters can get very bent out of shape, even downright nasty, if they are not properly washed for months at a time due to use of the wrong flow rates. According to the first table below (from the ETSW spreadsheet), the backwashing rate should approximately double between the coldest and warmest water temperatures each year. Similarly, the second table shows that the ETSW rate of 3 gpm/sf in cold water could be increased to 5 or 6 gpm/sf in warm water.

0°C	11.2	gpm/sf
5°C	12.9	gpm/sf
10°C	14.7	gpm/sf
15°C	16.5	gpm/sf
20°C	18.3	gpm/sf
25°C	20.0	gpm/sf
30°C	21.6	gpm/sf

Vmf (0°C)	2.71	gpm/sf
Vmf (5°C)	3.16	gpm/sf
Vmf (10°C)	3.65	gpm/sf
Vmf (15°C)	4.16	gpm/sf
Vmf (20°C)	4.69	gpm/sf
Vmf (25°C)	5.23	gpm/sf
Vmf (30°C)	5.77	gpm/sf

Getting your spreadsheet to spread like butter

You first have to download the latest version of the ETSW spreadsheet (http://www.wateropolis.com/resources/). With the effective size (ES), uniformity (UC), depth (D), and density of each media layer in your filter, you can get to second base. Measuring the distance from the top of the media to the overflow of the backwash troughs along with the width and length of the filter will get you to third base. To make it home, you just need to find out your minimum, maximum, and current water temperatures. Once you input all of this information, your spreadsheet should spread like butter and produce satisfying backwash rates and durations for fluidization and ETSW.

Parameter	Description	Value	Units			
Effective Size (**ES**)	sand	0.52	mm		<==User Input Values	
Uniformity Coefficient (**UC**)	sand	1.53	d60/d10			
Media Density	sand	2.65	g/cm^3			
Media Depth **(D)**	sand	1.00	feet			
Effective Size (**ES**)	anthracite	1.01	mm			
Uniformity Coefficient (**UC**)	anthracite	1.49	d60/d10			
Media Density	anthracite	1.55	g/cm^3			
Media Depth **(D)**	anthracite	1.50	feet			
Freeboard (top of media to overflow)	filter at rest	3.00	feet	Width (ft)	Length (ft)	Area (ft^2)
Surface Area of Filter (or one side)	basis for flows	392	sq. ft.	14	28	392
Water Temperature	**for your use!***	12.0	°C			

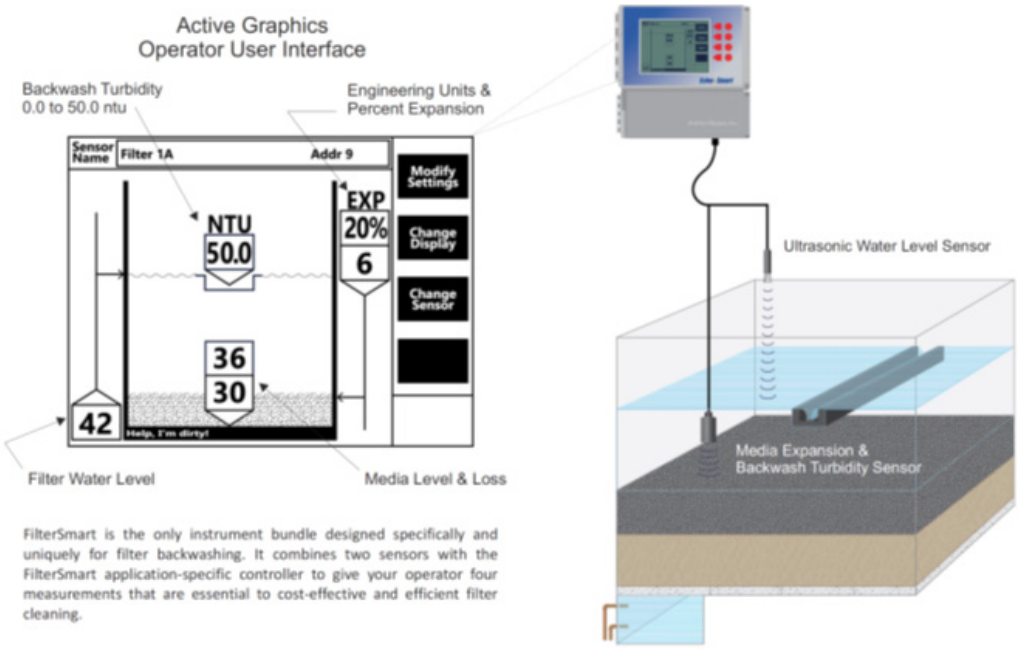
Time to put the rubber to the road

Now you're ready put your skills to the test! Take your best shot at an ETSW backwash, and your partner will let you know right after you finish if you hit the nail on the head or need to go back to the drawing board. Even before you restart an ETSW backwashed filter, you should have a pretty good idea of how well you did by looking deep into the filter at the media. If the view (and your water) is cloudy, then you are not quite finished.

Based on the information provided above:			
Your recommended initial fludization rate would	**7,889 gpm**	**for**	**5 minutes**
Step #1, start with an ETSW (subfluidization) rate	**1,119 gpm**	**for**	**13 minutes**
Step #2, with ripening peaks < 0.10 NTU, try ETSW	**1,865 gpm**	**for**	**8 minutes**
Step #3, with ripening peaks < 0.10 NTU, try ETSW	**4,052 gpm**	**for**	**4 minutes**
Use a lower ETSW rate whenever filter ripening turbidity exceeds goal (or ~0.10 NTU)			
****Find a more optimal coagulant dose/pH combo when turbidity exceeds 0.10 NTU after 1 filter volume***			

If you don't care to pay for it…

While it is possible to do the deed of ETSW (a 4-letter acronym) with only a spreadsheet, your favorite filter, and a little elbow grease. It is also possible to pay for professional equipment to fine-tune the process. There are instruments that measure media expansion during backwash as well as the turbidity of the water at the top of the filter near the backwash trough.



FilterSmart is the only instrument bundle designed specifically and uniquely for filter backwashing. It combines two sensors with the FilterSmart application-specific controller to give your operator four measurements that are essential to cost-effective and efficient filter cleaning.

The FilterSmart™ unit from Entech Design and Analytical Technology, Inc. (ATi) is designed to fine-tune the backwashing process (http://www.entechdesign.com/pdfs/Document17.pdf). With this equipment, you could maintain a fixed amount of media expansion (e.g., 25%) during fluidization (high-rate backwash) year-round as water temperature changes without any calculations as well as 0% media expansion during ETSW. It is also possible measure the turbidity of the filter backwash water exiting the top of the filter through the backwash troughs during backwashing (instead of looking to see if it is clear or not) to know when to stop backwashing. Sensitive and accurate measurements of bed expansion and water quality will allow you to respond faster to problems with either the physics or the chemistry (like sub-optimal coagulation).

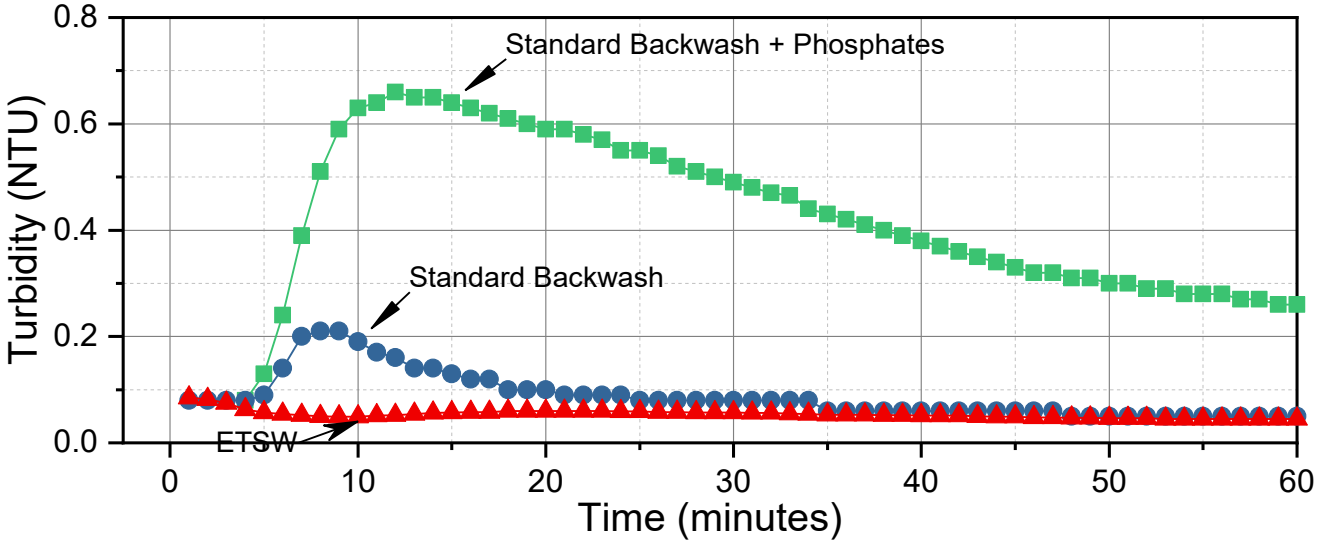
Should you get wasted while you do it?

Filter-to-waste (FTW) is a common procedure where filtered water is diverted away from the drinking water supply until the turbidity of the water reaches the desired level (e.g., <0.10 NTU). However, all treatment plants are not designed with this capability. Sometimes FTW equipment could fail, and the volume of water "wasted" with FTW could be larger than the volume required to perform ETSW. Furthermore, the opening and closing of valves resulting in changing filtration rates, may cause additional spikes in effluent turbidity immediately following redirection of filtered water into the finished water supply channel. However, some states require FTW, which takes some of the benefit out of using ETSW.

Do NOT try this at home!

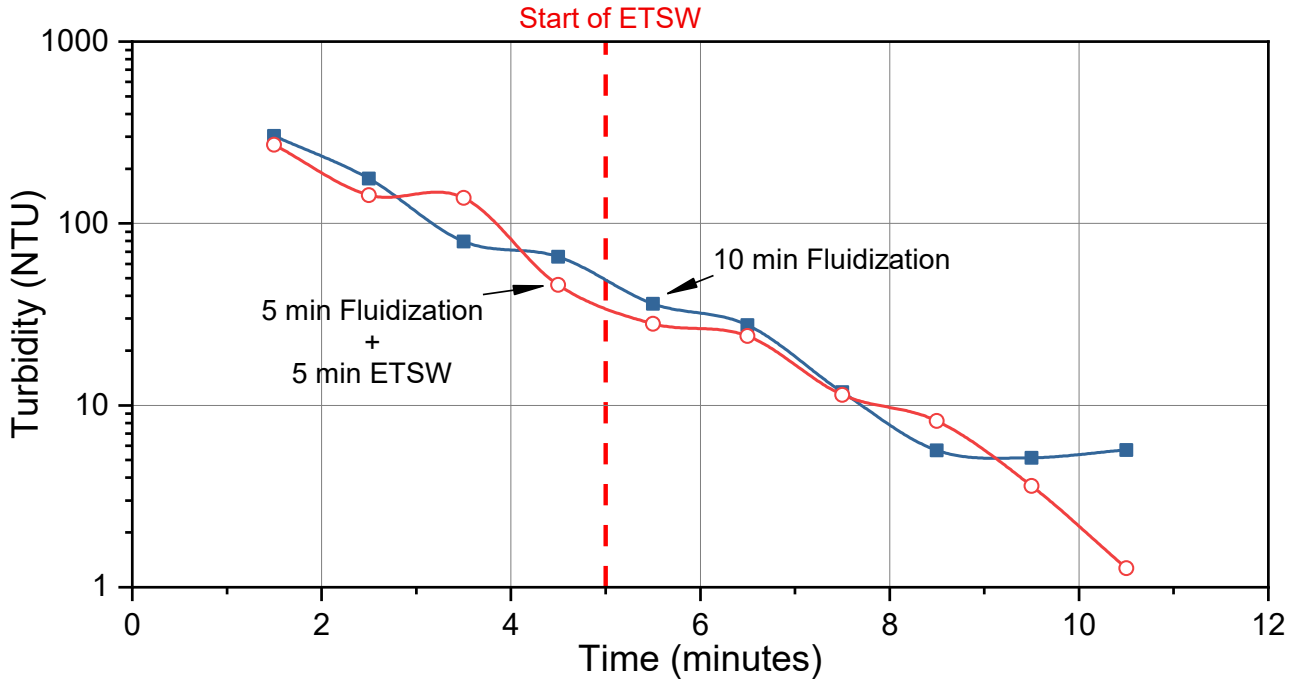
Procedures involving coagulant addition to a filter during or after backwashing have also been employed, but typically lead to floc formation in finished water storage tanks and carryover into the distribution system. Slow-start and delayed-start techniques of restarting a backwashed filter have also been used to reduce filter ripening turbidity spikes, but the primary mechanism appears to be re-distribution of the backwash remnants from one filter into multiple other filters to make the impact appear smaller when the same number of remnant particles are spread across multiple filters.

One of the most severe impacts on filter ripening turbidity spikes and duration of the ripening period is the presence of poly-phosphates (or blended phosphates) in the backwash water. These compounds should not ever be in the water used for backwashing because they are chemicals used to control corrosion in the pipes of the distribution system. Here is an example of what happens with this type of bad chemistry.



You should always keep it clean!

You should always keep your filters clean. It is not desirable for solids to accumulate inside the filter. A solids retention analysis is one method of determining if your filters are being sufficiently backwashed. The turbidity profile below (from sampling at the backwash trough during backwashing) show the turbidity profiles are nearly identical with or without ETSW (except at the very end). Most solids are dislodged during air scour or surface wash (not fluidization). Fluidization (high-rate backwash) is intended to expand the media enough to allow these dislodged particles to escape the filter media pores. Once the remnant particles escape, either high-rate (fluidization) backwash or ETSW can wash them out of the filter box, which is why ETSW (a lower flow rate) can reduce the total volume of backwash water consumed (i.e., by shortening the fluidization time that was previously required to wash out the remnant particles). Low ETSW flow rates do not dislodge new remnant particles oof of the dirty filter media but carry the existing remnant particles out of the filter. At the very end of the backwash the water inside the filter (and going over the backwash troughs) should be low turbidity, thus making it easy to clearly see the filter media grains at the top of the filter bed. In the figure below, the non-ETSW backwash reaches a steady-state of about 5 NTU after 10 minutes whereas the ETSW backwash continues to drop lower. The ETSW flow rate started at 5 minutes in this filter (and continued past the 10-min end of the fluidization-only backwash).



Can you get it TOO clean?

Legend has it that operators used to "over wash" filters, which led to filters that were so clean that they did not work well. Water treatment facilities that have brand new or newly rebuilt filters should have very clean media that does NOT take weeks or months to get "dirty enough" to start working. Having seen filters backwashed twice in a row, it is worth noting that dirt came out on the second wash and the filtered water turbidity was fine. Don't get me wrong, some filters do get worse turbidity after backwashing and take hours to get back to normal. Data from one such filter was used previously to illustrate what sub-optimal coagulation looks like. **ETSW is a tool that can be used for sensitive early detection of sub-optimal coagulation**. When a filter is backwashed with ETSW and never has a turbidity peak suddenly gets one, it could be sub-optimal coagulation (or a shift in water temperature requiring a lower ETSW rate). Unfortunately, both are likely to occur as the water temperature drops in the winter. Alum (aluminum sulfate) tends to be infamous for not performing well in cold water. Luckily, the backwash remnant peak and the sub-optimal coagulation peak can be separated with ETSW allowing independent identification of the problem(s).

Turning a Trick

By using ETSW, you can effectively shorten the fluidization backwash interval to leave the filter dirtier (if you like it that way). After fluidization stops and ETSW starts, no new backwash remnant particles are dislodged leaving the filter dirtier with shorter fluidization times. If you prefer more cleaning with a shorter fluidization time, then simply use air scour or surface wash for longer, then follow either with a short fluidization period and ETSW. You can have it extra-dirty or extra-clean if you prefer. ETSW gives you more options to influence the final condition of your filter.

Dealing with your Mother-in-law

Coagulation is the "mother-in-law" of all drinking water treatment processes. Flocculation, sedimentation, filtration, and even disinfection share the same vice of being heavily dependent on a fickle mother-in-law (that we call coagulation). Nobody is gonna be happy if she ain't happy.

Anybody up for Swinging?

There's nothing like swinging to make your mother-in-law (coagulation) unhappy. If you have ever sat in a swing, then you know there are highs and lows that keep on repeating. Some swings are higher than others, and some are lower. However, every water treatment facility must deal with temperature swings. While all swings are different, it would not unreasonable for the water temperature to change from near 0° C (32° F) to over 30° C (86° F) in a given year.

One reason that your mother-in-law (coagulation) is going to be really unhappy is because you want to act like nothing is happening. While both coagulant dose and pH are important to coagulation, you can keep both exactly the same as the temperature swings. However, this would be a huge (though common) mistake and will NOT make your mother-in-law happy. If you think about the most basic coagulation reaction with aluminum to form floc…

$$Al^{3+} + 3OH^- \longrightarrow Al(OH)_3$$ *Yes, this is the "floc"!

There is no pH term in there. Note: pH is defined as the negative log of the concentration of H+, and it is the H^+ that is missing from the equation above. While water can break apart to form both H+ and OH-, as shown below.

$$H_2O \leftrightarrow H^+ + OH^-$$

The H^+ is NOT what is involved in coagulation. The OH- is the important player in coagulation reactions. So, keeping the pH (or H^+) constant as temperature changes actually causes the problem with your mother-in-law. The smart play is to keep the (OH^-) constant as the temperature changes, which requires changing the pH (not keeping it constant year-round).

A long time ago in a chemistry course, you might have learned that at pH 7 the concentration of H^+ and OH^- are exactly the same (i.e., 10^{-7}). This can be true, but it is ONLY true at one temperature (25° C) as shown in the table below (highlighted yellow) because pKw changes with temperature (and pH + pOH has to always equal pKw). So, holding pH constant (bad idea) forces the pOH to change every time the temperature changes as shown in this table (far right hand column due to the constant pH shown in red).

Constant pH of 7.0

Temperature (°C)	pKw	**pH**	pOH
0.0	14.94	***7.00***	7.94
5.0	14.73	***7.00***	7.73
10.0	14.53	***7.00***	7.53
15.0	14.35	***7.00***	7.35
20.0	14.17	***7.00***	7.17
25.0	14.00	***7.00***	7.00
30.0	13.83	***7.00***	6.83
35.0	13.68	***7.00***	6.68
40.0	13.53	***7.00***	6.53

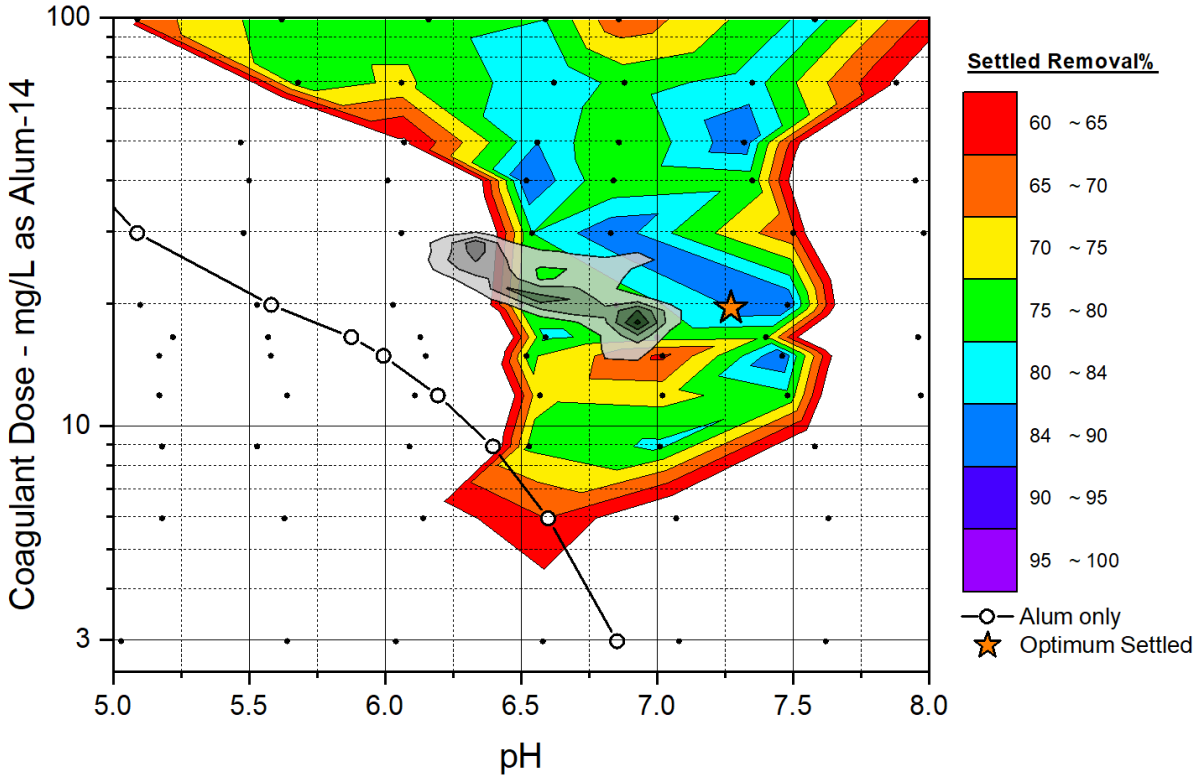
The opposite approach is to hold the pOH constant (good idea), which forces the pH to change every time temperature changes (as shown in red in the table below). A pH of 6.5 at 25° C is the coagulation equivalent of a pH of 7.23 at 5° C (highlighted yellow in the table below, *with constant pOH and changing pH*). This approach keeps the mother-in-law happy because she does not see a change in the one thing that is important to her (OH^-). Note that all these conversions are included in the companion spreadsheet. While the pH meter and the thermometer are both saying things are changing, she doesn't listen to them. However, if you keep changing the only thing she (coagulation) cares about (pOH), then something (turbidity) is eventually going to hit the fan. This is not to say that other things (like water quality changes or faulty equipment) couldn't possibly upset your mother-in-law, but pOH is the most important thing (along with coagulant dose). Free tip: pH electrode junctions typically foul/clog with time and use decreasing accuracy and seldom last for more than 1 year.

Constant pOH of 7.5

Temperature (°C)	pKw	**pH**	pOH
0.0	14.94	*7.44*	**7.50**
5.0	14.73	*7.23*	**7.50**
10.0	14.53	*7.03*	**7.50**
15.0	14.35	*6.85*	**7.50**
20.0	14.17	*6.67*	**7.50**
25.0	14.00	*6.50*	**7.50**
30.0	13.83	*6.33*	**7.50**
35.0	13.68	*6.18*	**7.50**
40.0	13.53	*6.03*	**7.50**

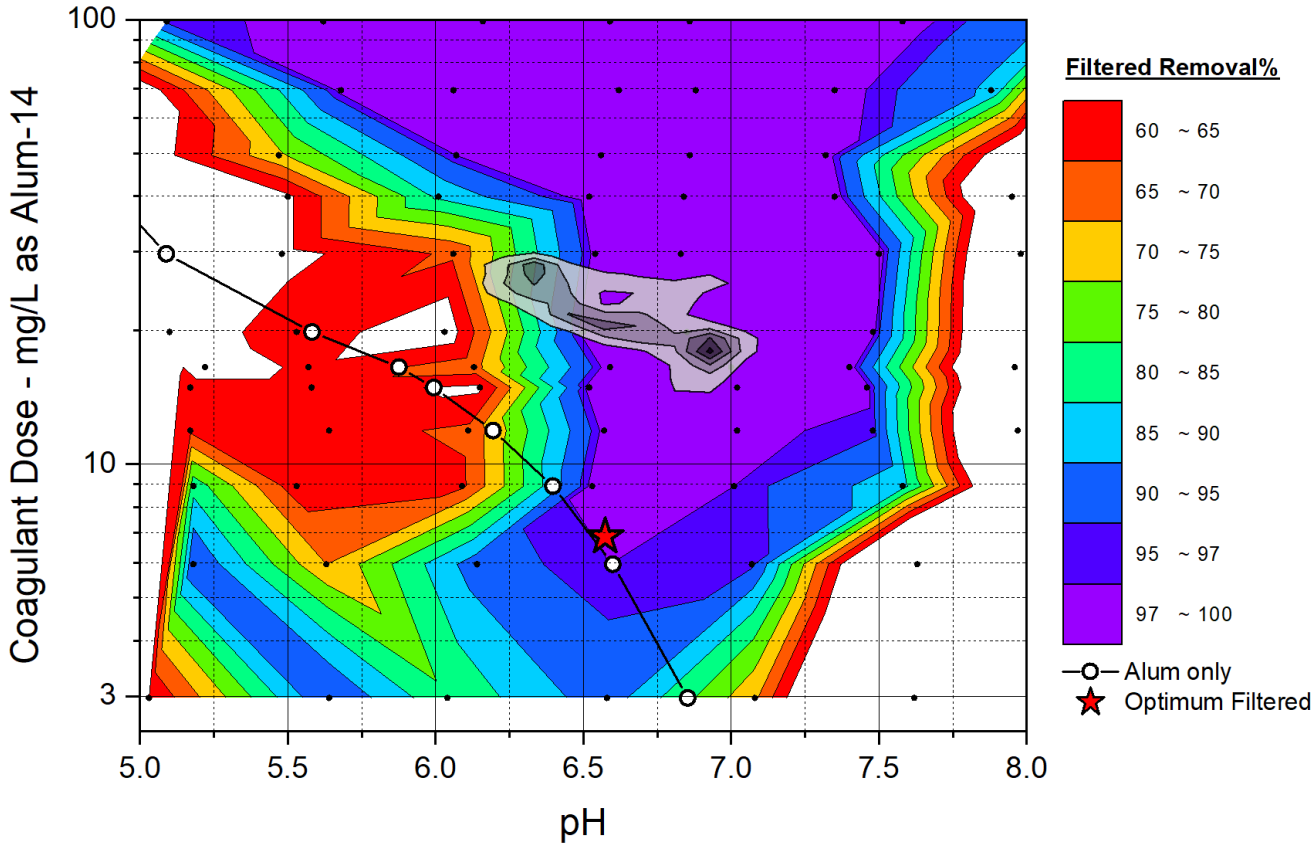
You've got to set your Mother-in-law straight right now

Coagulation (your mother-in-law) can be one of the most confusing and frustrating things in your life. While all waters are different, there are some general rules that might help speed your understanding. The advice a mother-in-law (coagulation) gives you directly (a jar test) will typically not match the advice given to your partner (the filter). Jar tests have always been based on sedimentation in a jar, but filter performance is not based on sedimentation or a jar. A small neutrally charged floc will typically filter out very easily, while the same floc might not settle efficiently in jar. The figure below is a contour plot showing standard jar test performance over a range of alum dosage and pH combinations at 22 C. The white areas are terrible with each dot representing one jar in a jar test, and blue areas are good. There are a bunch of small blue areas that could be hard to find with an orange star representing the lowest alum dose/pH corresponding to the largest blue zone. The grey areas are a "heat map" of where this treatment facility normally operated in 2017. The blue and grey areas are similar, but the two areas do not overlap (agree). This is not unusual. Jar tests should be based on granular media filtration (not sedimentation) to optimize the performance of granular media filters. More detailed information on jar testing can be found here: https://www.amiralansari.com/jartest



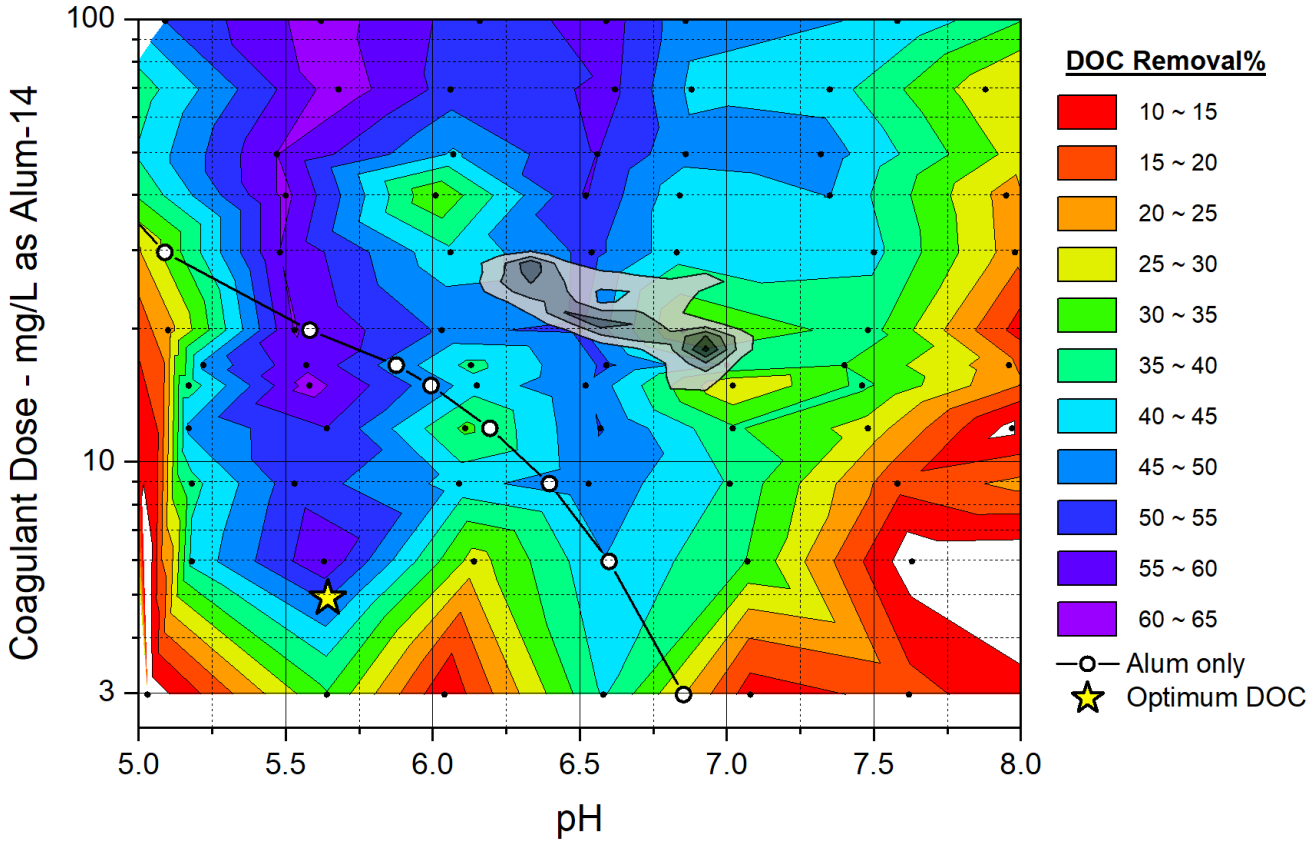
That was the wrong way. This is the right way!

Recreating the same contour plot with turbidities from granular media filters (instead of sedimentation in jars) produced an entirely different result. Notice how the "optimum" zone (now purple) has shifted, expanded, and became consistent. Also notice how the "heat map" of operating conditions has shifted relative to the lowest pH and coagulant dose for "optimal" treatment represented by a red star. Operating at pH 6.6 with 7 mg/L of alum not only uses about 1/3 as much coagulant as 20 mg/L, but this dose/pH combination falls on the alum-only titration curve meaning that no pH adjustment is required. Treatment costs and sludge production can be significantly reduced when you set your mother-in-law (coagulation) straight by changing your jar testing approach (to include granular media filters).



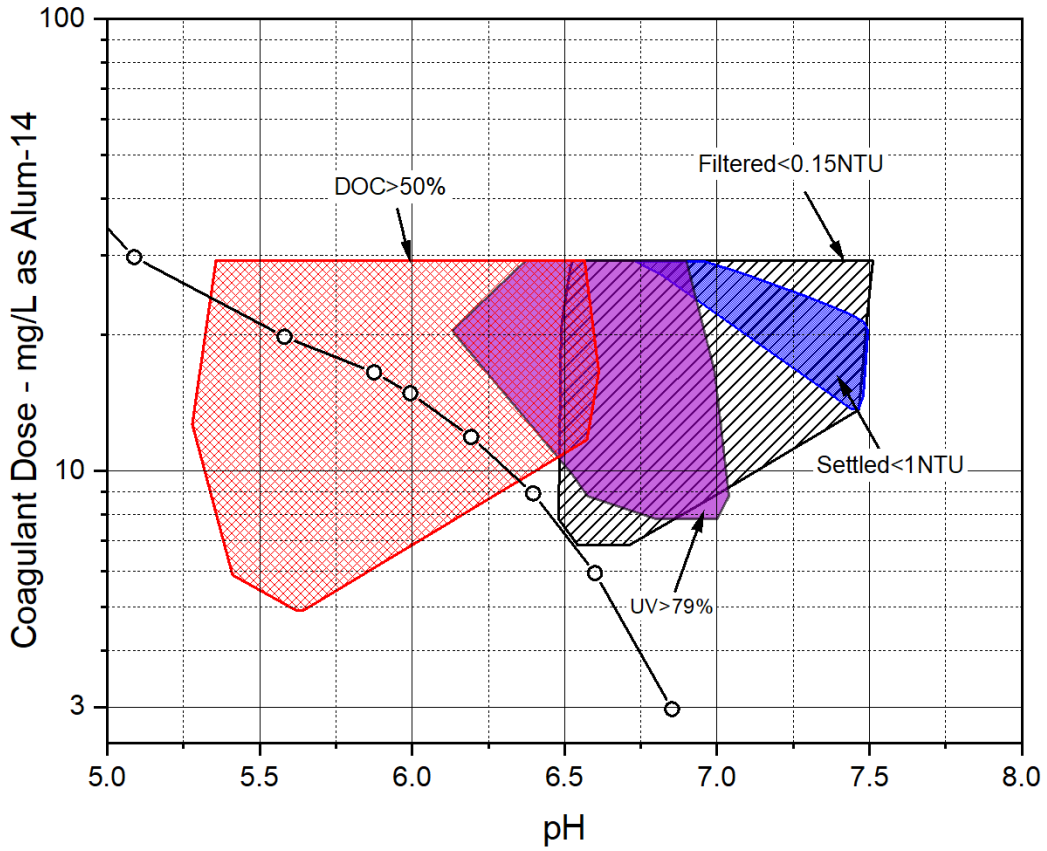
Jack-of-all-trades and Master of None

You've probably heard it said that a slave cannot serve two masters. Doing the best job for one master will often involve short-changing the other one. Coagulation can be optimized to achieve the best overall filtered turbidity, organics removal, settled turbidity, UV254 absorbance, color removal, or treatment cost. The real question is whether all optimums can be achieve at one alum dose/pH combination. Let's take a look at dissolved organic carbon (DOC) removal for the same water using the same contour plot approach. Notice how the purple zones have shifted down to pH ~5.5 for organics removal (versus pH 6.5 for filtered turbidity removals). Do you choose one goal over the others, or do you compromise on multiple goals at once?



The cold hard truth of compromise

You just can't have it all your way! While the raw water quality and treatment goals can differ at every water treatment facility, decisions will need to be made about which parameter(s) is/are most important. The figure below shows how multiple lesser goals can be achievable simultaneously. Instead of only looking for ~60% organics removal (purple zones in previous figure), a goal could be set at 50% or higher (blue zones). Similarly compromised jar testing goals could be set for UV254 of >79%, settled turbidity < 1 NTU, and filtered water turbidity <0.15 NTU. While all 4 zones do not overlap simultaneously in the figure below, three overlap at pH 6.5 with greater than 11 mg/L of alum. Further optimizing for sedimentation would increase the pH, alum dose, and treatment costs while compromising on DOC removal. A slave (coagulation) cannot serve four masters, and more troubling is that we did not look at optimizing treatment costs or minimizing sludge production (six masters). Different parameters and goals will dominate at different facilities, which is fine as long as outside parties do not mandate conflicting goals. The key is that the facilities now have a platform/method for assessing and optimizing their goals at the bench scale.



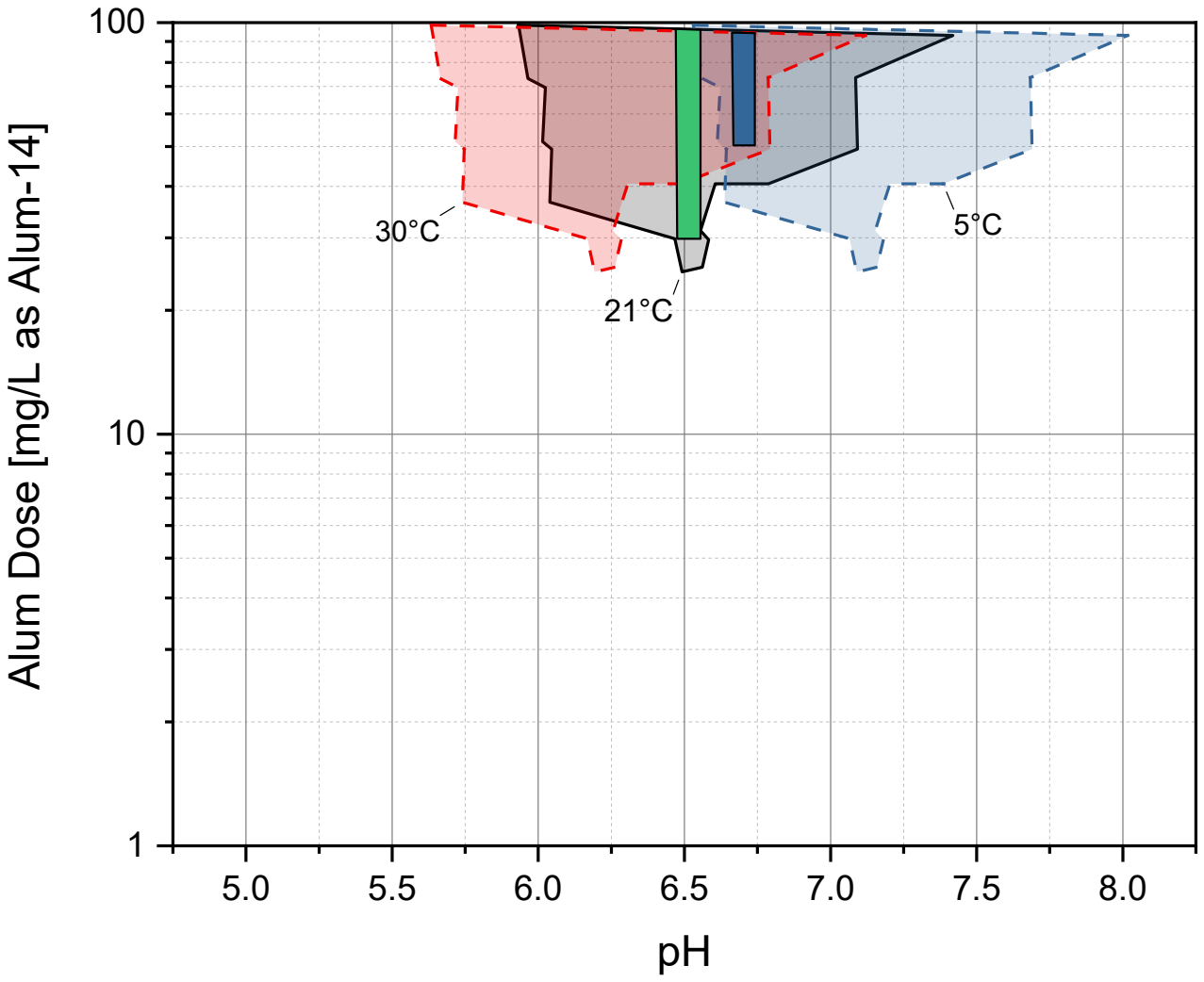
Directions to the G-spot

The G-spot is still something of a mystery. Some folks deny its existence while others cannot stop talking about it. For alum, a dose of 30 mg/L as alum (2.7 mg Al/L) at pH 6.5 is nearly always a Good-spot (G-spot) for coagulation at a water temperature of 21° C (as represented by the green bar in the figure below). Sweep coagulation tends not to be sensitive to water quality changes like lower charge-neutralization dosages., but sweep coagulation is still temperature-sensitive as illustrated by the optimum coagulation zone shifting with temperature as represented by the red (30° C), grey (21° C), and blue (5° C) zones in the figure below. Temperature corrections of pH (for a constant pOH of 7.6, which is pH 6.5 at 22° C) are shown in the table below. A pH 7.13 at 5° C is equivalent to pH 6.5 at 22° C as shown in the yellow highlighted regions of the table below. Temperature corrections of optimal coagulation pH values (by holding a constant pOH) is recommended to all drinking water treatment facilities as shown below.

Constant pOH (vs. pH 6.5 at 22° C)

Temperature (°C)	pKw	**pH**	pOH
0.0	14.94	*7.34*	**7.60**
5.0	14.73	*7.13*	**7.60**
10.0	14.53	*6.93*	**7.60**
15.0	14.35	*6.75*	**7.60**
20.0	14.17	*6.57*	**7.60**
22.0	14.10	*6.50*	**7.60**
25.0	14.00	*6.40*	**7.60**
30.0	13.83	*6.23*	**7.60**
35.0	13.68	*6.08*	**7.60**

Many pH meters have auto-temperature correction functions, but these meters only correct for the temperature of the calibration buffers used to calibrate the meter (NOT the optimal pH for coagulation). Without temperature-corrected pH based on constant pOH (worse idea), a higher alum dose of 50 mg/L as alum (4.5 mg Al/L) at a higher pH of 6.7 is required to overlap all 3 temperature-zones in the figure below (represented by a blue bar in the figure) and be a nearly universal G-spot for coagulation in waters with temperatures between 5° and 30° C.


100
10
1
Alum Dose [mg/L as Alum-14]
5.0
5.5
6.0
6.5
7.0
7.5
8.0
pH
30°C
21°C
5°C

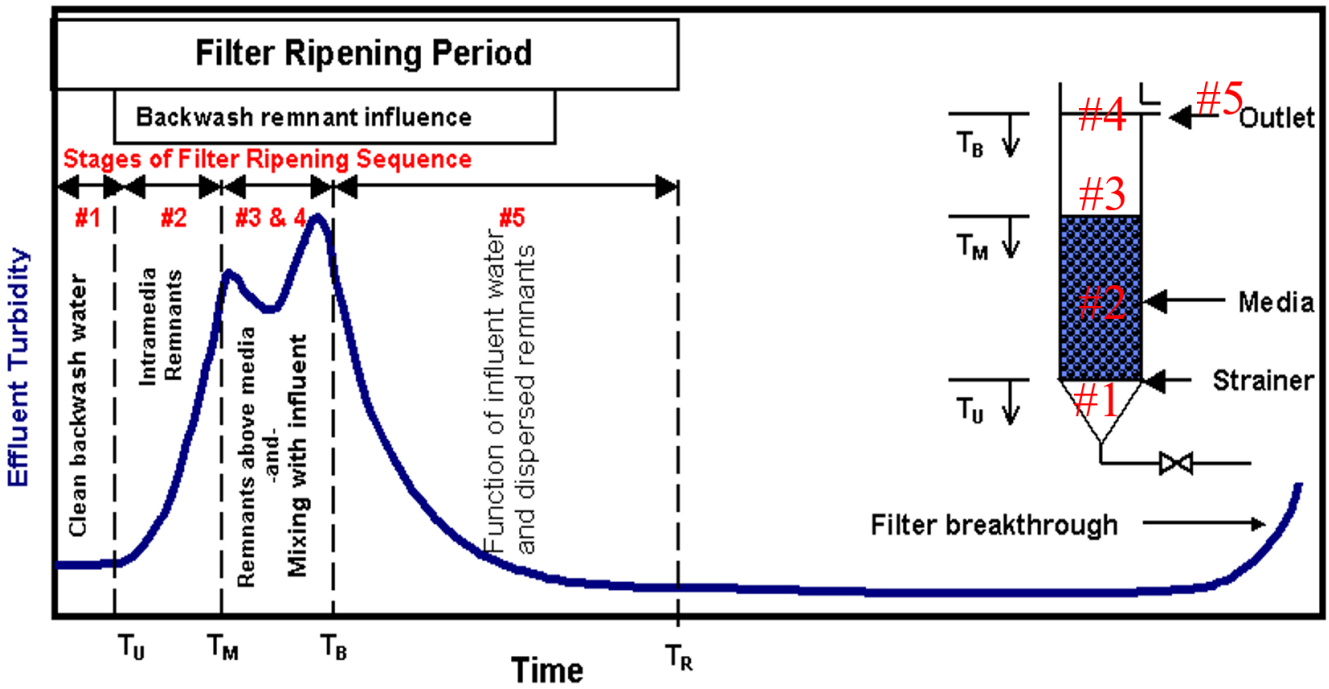
Length Really Does Matter

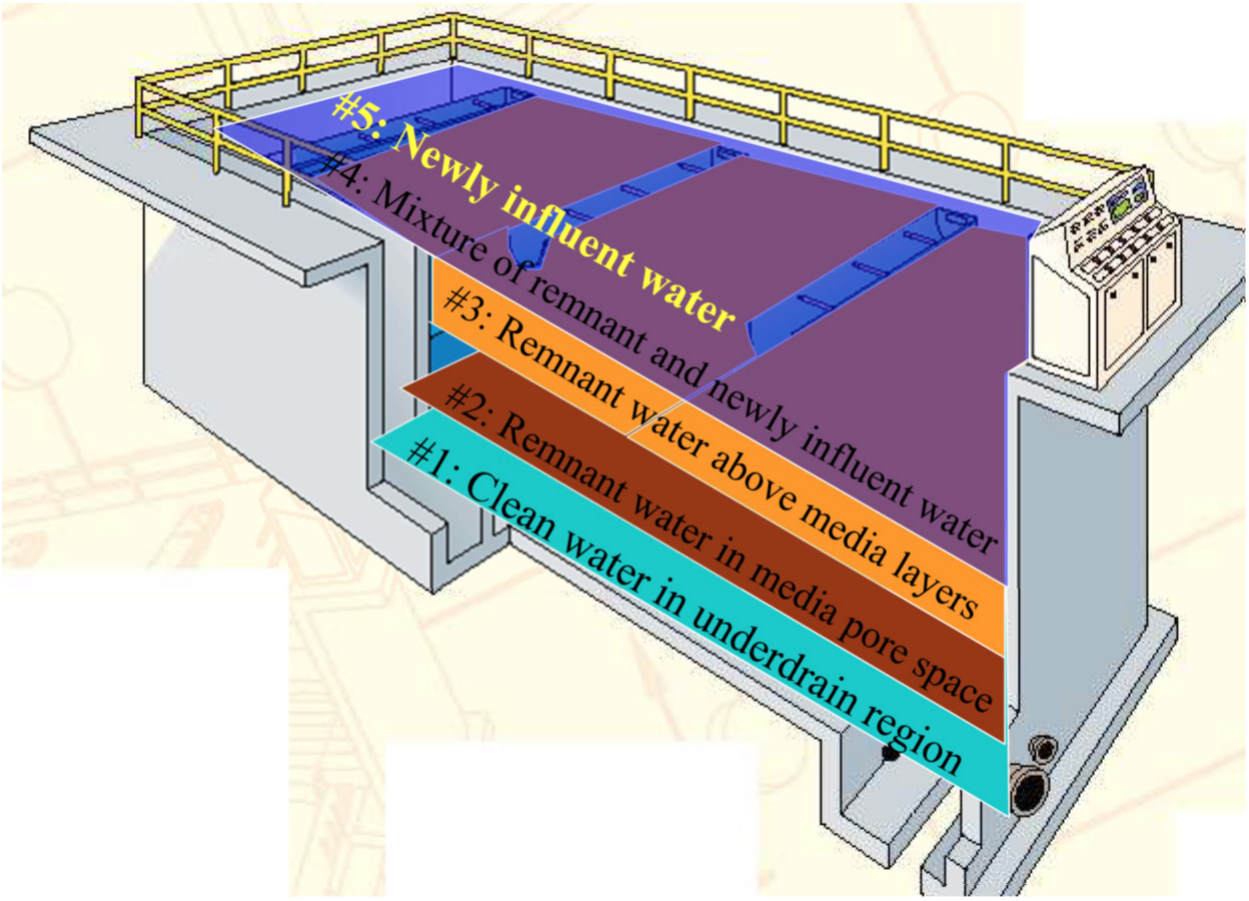
ETSW is a procedure that involves passing one theoretical filter volume of water through the filter box at a subfluidization flow rate to conclude the backwashing process. The length of the ETSW is very important, but there is no one length that will work for everyone. The length must be based on the flow rate, which will likely change with temperature. The length of ETSW must be sufficient at the flow rate being used to remove all of the water (and most of the remnant particles) from the water inside the filter box. This is calculated for you with the spreadsheet.

To understand the importance of length (and to be able to troubleshoot ETSW problems), a general understanding of the Filter Ripening Sequence (FRS) is important. The FRS can be divided into five distinct stages based on the location of the water in the filter at the end of a backwash and corresponding remnant concentrations. First, the backwash water in the underdrain exits the filter. Stage 1 water is remnant free and does not impact filtered water quality. Stage 1 water is followed by intra-media remnant water, above-media remnant water, and mixture of remnant water with newly influent water as shown below. The numbers in the figures correspond with the distinct stages of the FRS in both the diagram and filter drawings below.

Stages of Filter Ripening Sequence (FRS):

1. Clean (filtered) water returning from the underdrain without any remnants
2. Water from the media pores (fewer remnants because media is cleanest at the end)
3. Dirtier water above the media (more remnants due to dirtier media)
4. Mixing of most concentrate remnant particles with destabilized influent particle
5. Dispersed remnant followed by “additional collector” ripening due to poor coagulation


Filter Ripening Period
Backwash remnant influence
Stages of Filter Ripening Sequence
#1
#2
#3 & 4
#5
Effluent Turbidity
Clean backwash water
Intramedia Remnants
Remnants above media -and- Mixing with influent
Function of influent water and dispersed remnants
Filter breakthrough
T_U
T_M
T_B
Time
T_R
#4
#5
Outlet
#3
#2
Media
Strainer
#1


#5: Newly influent water
#4: Mixture of remnant and newly influent water
#3: Remnant water above media layers
#2: Remnant water in media pore space
#1: Clean water in underdrain region

Friends with Benefits

ETSW (is your friend and) offers many potential benefits that range from eliminating backwash remnant particles and allowing visual inspection of the filter media to reducing backwash water usage while fine-tuning the amount of cleaning in each filter. ETSW can be customized to limit media cleaning, minimize backwash water usage, reduce total backwashing time (without filter-to-waste), and minimize particle and pathogen passage through the filter during the Filter Ripening Sequence. Perhaps most importantly, ETSW can help identify sub-optimal coagulation (and fix it) by monitoring the filtered water turbidity after backwashing.

Are you finally ready to do it?

Now that have the read this paper, understand ETSW, and want to give it a try; let's work through a simple example together. First, collect the specs on the filter media inside your filters as shown in the table below.

Media Type:	**Sand**	**Anthracite**
Effective Size (ES) d_{10} (mm)	0.5	0.9
Uniformity Coefficient ($UC=d_{60}/d_{10}$)	1.6	1.3
Depth (ft)	1	2
Media density (g/cm^3)	2.65	1.55

With these values you only need to know the distance from the top of the media to the backwash trough overflow (to calculate the ETSW time), which will be 3 feet in this example. At this point, all ETSW values would be given in gpm/sf. In cold water, a first ETSW rate might be 2.4 gpm/sf for 16 minutes. In warmer water, you might start at 4.1 gpm/sf for 9.5 minutes. Assuming the first trial is successful, you could stay there or increase the rate slightly until the FRS turbidity starts to increase. It is unlikely that any ETSW rate over 8.4 gpm/sf would work well for this media.

	Sand	Anthracite	**Average**	Units	**ETSW Time**	Units
Recommended Initial ETSW rate	2.4	2.5	**2.4**	**gpm/sf**	**16.0**	**minutes**
Reasonable Initial ETSW rate (25 C)	4.0	4.2	4.1	gpm/sf	9.5	minutes
Max Recommended ETSW rate	10.6	6.3	8.4	gpm/sf	4.6	minutes
Absolute Maximum ETSW rate (25 C)	16.2	9.8	13.0	gpm/sf	3.0	minutes

Calculating the square footage of the top of your filter bed to multiply by this rate would give you the flow in gpm. For example, 20 ft. by 10 ft. filter bed has an area of 200 sf. Using 200 sf, the preceding table is converted to flows in gpm.

	Sand	Anthracite	**Average**	Units	**ETSW Time**	Units
Recommended Initial ETSW rate	471	505	**488**	**gpm**	**16.0**	**minutes**
Reasonable Initial ETSW rate (25 C)	794	844	819	gpm	9.5	minutes
Max Recommended ETSW rate	2119	1254	1687	gpm	4.6	minutes
Absolute Maximum ETSW rate (25 C)	3250	1966	2608	gpm	3.0	minutes

On the "MAIN (START) + Summary" tab of the spreadsheet, you can enter all of these values in the yellow boxes and get a table of recommendations like this:

Your recommended initial fludization rate would be:	**3,390**	**gpm**	**for**	**6 minutes**
Step #1, start with an ETSW (subfluidization) rate of:	**488**	**gpm**	**for**	**16 minutes**
Step #2, with ripening peaks < 0.10 NTU, try ETSW at:	**819**	**gpm**	**for**	**10 minutes**
Step #3, with ripening peaks < 0.10 NTU, try ETSW at:	**1,687**	**gpm**	**for**	**5 minutes**

Use a lower ETSW rate whenever filter ripening turbidity exceeds goal (or ~0.10 NTU)

****Find a more optimal coagulant dose/pH combo when turbidity exceeds 0.10 NTU after 1 filter volume***

IF you try an ETSW rate that exceeds your turbidity goal during the first filter volume of water, then reduce ETSW rate until it works efficiently again. If an ETSW rate that has been working well for a while starts to fail (and the water temperature decreased), then the ETSW rate might need to decrease also (use the spreadsheet). If an ETSW rate that has been working well for a while starts to fail (and the water temperature has not changed), then the coagulant dose/pH combination might need to be changed.

Let's Hit It one last time!

Remember that using ETSW allows you to distinguish between suboptimal ETSW (peaks during stages 1 thru 4 of the FRS, typically in the first 10 minutes of a filter run) and suboptimal coagulation (peaks during stage 5 of the FRS, typically 15-60 minutes into a filter run). By properly applying ETSW, you have a tool to reduce filter ripening particle/pathogen passage AND to rapidly identify suboptimal coagulation so that it can be optimized to improve every core treatment process in your facility. This is the first time this concept has been shared publicly (even though this was the original idea on how best to use ETSW). We initially felt that linking backwashing directly to coagulation optimization was too complicated until a decent number of folks first understood and practiced ETSW for filter ripening particle passage. A valuable technique for temperature-adjusting your optimal coagulation pH (based on a constant pOH) is included to help you avoid poor coagulation in the first place, which is not new and has been promoted by Jim Edzwald and others for decades. A next-generation jar test method based on filtration is new and available for free (https://www.amiralansari.com/jartest), which is recommended for replacing all existing methods of coagulation optimization in conventional treatment facilities. Unlike ETSW, which can now be used to optimize filtered water turbidity and minimize pathogen passage, next-gen jar testing can be used to optimize multiple treatment parameters as demonstrated above. This paper also introduced the idea of a universal coagulant dosage for drinking water treatment (a G-spot, or a Good-spot for alum coagulation at every drinking water treatment facility). The G-spot can be used for emergencies or everyday operation, and there is an alum dose/pH combination for use with temperature correction for a constant pOH or a higher dose/pH for use without temperature correcting the pH. **Finally, you won't get very far if you don't have all the right tools in your arsenal, don't forget to download the latest version of the ETSW spreadsheet (http://www.wateropolis.com/resources/).**