New York Legionella Regulations: Are They Missing The Boat?

by Sarah Ferrari

Abstract
A large outbreak of Legionnaires’ disease in the Bronx in 2015 prompted NYC to enact law and NYS to propose emergency regulations on the registration and maintenance of cooling towers. This paper describes the fundamental characteristics of point sourced vs. potable water sourced outbreaks and discusses the Bronx outbreak from those perspectives. Ultimately a case is made that these new regulations will not have a measurable impact on reducing the incidence of Legionellosis. Rather, more detailed and open-minded investigations of future outbreaks, including investigation of potential potable water sources, are called for to inform appropriate regulations and disease prevention activities.

Introduction
Legionnaires’ disease (LD) is a severe form of pneumonia which is contracted by inhaling or aspirating water droplets containing Legionella deeply into the lungs. For many years it was believed the disease could be transmitted only by large equipment which emits aerosols or by equipment designed to aerosolize. Thus spas, decorative fountains, grocery misters, spray humidifiers, cooling towers and other aerosol sources were the only water systems investigated when an outbreak occurred. In the early 1980s investigations of potable water systems in hospital outbreaks indicated that the potable water is also a vector in disease transmission, either via aspiration of Legionella from the mouth into the lungs or via inhalation of droplets emitted by sinks and showers. It now appears that many LD outbreaks were initially blamed on cooling towers due to a “detection bias” that has not been widely recognized, and that these outbreaks were actually caused by potable water issues. In more recent years it has been found that the primary source of hospital-acquired Legionnaires’ disease is potable water.

In the United States there have been requirements to address Legionella in hospital potable water systems from the Joint Commission on the Accreditation of Healthcare Organizations (JCAHO), Allegheny County (Pittsburgh), Maryland, New York, and others; however, until recently there have been no similar mandates in the United States for cooling towers. Although not mandated, many industrial groups such as CTI, ASHRAE, and AWT have published best practice guides that describe methods for maintaining equipment to minimize the risk of Legionellosis.

More than fifty Legionella species have been identified, but not all have been linked to disease. Legionella pneumophila serogroup 1 is the most virulent strain causing the majority of infections. Virulence varies not only between strains and their subtypes but can also vary within a particular cell. There are two major phases to the life cycle; a non-pathogenic vegetative phase and a virulent transmissive phase. The concepts of “infectious dose” or of “relative Legionella concentrations’ discussed within this paper pertain only to the virulent, or infectious, form of the bacteria.

The vast majority of LD occurs as apparently isolated cases. Of cases reported to the CDC, 96% are classified as sporadic and are not typically investigated. A cluster of cases is classified as an outbreak when two or more people are exposed to Legionella and get sick in the same place at about the same time. Recognized outbreaks of LD are rare; but when they occur, they provide opportunities to understand the epidemiology of the illness and improve prevention strategies. This opportunity is wasted if the extensive data that is generated during an outbreak is not evaluated impartially.

The recent outbreak in the South Bronx has resulted in New York City enacting a local law on the registration and maintenance of cooling towers in the city. Also, the State of New York has proposed emergency regulations for the registration and maintenance of cooling towers state-wide. As more facts have emerged, it appears that the hastily prepared emergency regulations have fallen victim to the “detection bias” referred to in the first paragraph above and that authorities have not only squandered an opportunity to expand our understanding of the disease but imposed regulations and cost on cooling tower owners that have little chance of reducing the incidence of disease.

This paper will describe the outbreak in the Bronx that instigated these regulations. While a specific cooling tower was identified as the source of the original outbreak, two subsequent outbreaks occurred. Potable water in the building where people lived was positively identified as the source for second outbreak. Two months after the third outbreak ended a cooling tower was identified as the source, even though all of the cooling towers in the area had been recently cleaned in accordance with the newly enacted NYC laws.

The Bronx outbreak and regulatory response has many similarities to a French outbreak in the winter of 2003-2004. In Pas-de-Calais a large outbreak was attributed to a cooling tower and resulted in the promulgation of regulations for the registration and maintenance of cooling towers. The inconsequential result of those regulations on the reduction of the incidence of disease will also be described in this paper.

Outbreak Characteristics
Aerosol Point-Source
There have been many Legionnaires’ disease outbreaks traced to an aerosolized point source of the bacteria. Point sources of aerosols include decorative fountains, spas, grocery misters, and cooling towers. Investigation of these outbreaks typically reveals a close relationship between time spent near the source and incidence of infection. A dose-response relationship between exposure and illness has been demonstrated in numerous carefully investigated
studies. This is particularly true for indoor sources where proximity to the aerosol source has been identified as an essential factor for infection. For cooling tower sources the same relationship exists, i.e., a close correlation between proximity to the source and incidence of disease. However, for some outbreaks where the purported source is a cooling tower there is little spatial correlation between the incidence of disease and the alleged source. The unstated assumption is that there is a hidden variable that causes disease seemingly randomly a great distance from the source. This lack of spatial correlation was evident in the South Bronx outbreak where there was no clustering of cases near the purported tower at the Opera House Hotel. What that hidden variable could be is not clear. The following paragraphs describe several well studied outbreaks where, as one would expect, proximity to the source strongly affected the incidence of disease.

In 1999 a spa at a floral trade show in the Netherlands was identified as the source of a large outbreak of Legionnaires’ disease. Among exhibitors a close correlation was found between elevated antibodies to Legionella and proximity of their booth to the source. The most important visitor-related risk factor was pausing at the whirlpool spa display7.

Clive Brown et al. investigated a 29-case community outbreak of Legionnaires’ disease in 1994 linked to a hospital cooling tower8. This investigation showed that the risk of infection decreased by 20% for each 0.1 miles from the hospital and increased by 80% for each visit to the hospital. The paper described an Aerosol Exposure Unit defined as the ratio of time spent near the source and the distance from the source and found a strong correlation between exposure and incidence of disease. The image in Figure 1 taken from this study illustrates the expected distribution of cases of disease from a single aerosol source. The cases are clustered near the source and taper off rapidly at increasing distance.

Proximity was well demonstrated in a 1993 outbreak at a Michigan prison which was traced to a hospital cooling tower. Fourteen (0.6%) of 2253 prisoners who used exercise yards each day within 100 yards of the prison hospital were infected, compared with only two (0.1%) of the 2270 inmates who used yards at least 400 yards from the prison hospital.9 This equates to roughly a 50% reduction in infection risk in 0.1 miles.

The influence of prevailing wind on aerosol dispersion was addressed by P. Wilmot et al. using geographic information system (GIS) data10. They developed plume dispersion models to help locate a potential cooling tower source during outbreak investigations. A plume refers to the moist exhaust air from a cooling tower. The plume will mix with ambient air as it travels away from the tower becoming more and more dilute. If a case occurs outside of the plume dispersion model “the chance that it originated from that cooling tower remains highly unlikely”. Figure 2 displays a case where the cooling tower would not be considered a likely source. The plume is diluted with increasing distance from the tower reducing the concentration of Legionella in the air. Legionella can live only a relatively short time in the air and contamination at a large distance from the tower is unlikely. A person would need to spend sufficient time near to the tower in order to inhale an infectious dose of bacteria.

Dr. Richard Miller at the University of Louisville has stated: “Legionnaires’ Disease, like all infectious diseases, requires a minimum infectious dose in order to cause disease. While the exact number required for humans varies depending on the susceptibility (i.e. immune status) of the individual, it is likely that the number for most individuals is relatively large. It should be apparent from the ubiquitous nature of this bacterium in the environment, that in order to cause disease, the number of Legionella in the water would need to be much higher than that found in most normal aquatic habitats11.”

The virulence of a particular genetic type of Legionella is not a constant and may change during its lifecycle and also may change by exposure to chemicals, heat, or interaction with amoebae. Nevertheless, the ubiquity of Legionella in nature implies that everyone has been exposed to at least a low concentration of the bacteria.

In addition to dilution of the aerosol over distance, cooling towers have made dramatic improvements in drift eliminator technology. Drift eliminators are the component of cooling towers that separates recirculating water from exiting air. Over a period of about five years ending around 2000 all major manufacturers of factory-built cooling towers developed low-drift eliminators. These modern drift eliminators reduce aerosol emissions by an order of magnitude from the previous generation of towers. If the water in a cooling tower was contaminated with 1,000 CFU/ml of Legionella, a person standing on top of the tower and breathing in only tower exhaust for 1 hour would breathe in droplets containing a total of 10 bacteria12. As a comparison of transmission pathways between inhalation and aspiration, a person drinking 4 ounces of water from a potable water source contaminated with only 10 CFU/ml would consume over 1,000 bacteria in the few seconds it took to drink the water. These bacteria would be in the mouth and not in the lungs, but the numbers of bacteria that can enter the body are significantly higher with an aspiration route from potable water than inhalation from a modern cooling tower.

As the C. Brown hospital study, the Netherlands flower show study, and the Michigan prison study imply, there should be a dose-response with exposure and incidence of disease. The higher the dose that a particularly susceptible individual receives, the higher will be the likelihood of infection. Also, because of Legionella’s ubiquitous presence in nature, there should be a threshold dosage below which there is no disease.

The key characteristics of an aerosolized point source exposure to Legionella are:

1. The original source of the bacteria is colonization of the potable water supply.
2. While many water-based devices could be contaminated due to an upset in the potable water system, only in one will the bacteria find hospitable growing conditions for amplification and susceptible individuals to infect.
3. The bacteria reproduce in an individual aerosol producing device. This usually requires the water in the equipment to reach temperatures that permit amplification.
4. The bacteria are emitted from a single point.

There is a strong correlation between incidence of infection and proximity of the individual to the aerosol source in both time and space.

While a correlation between proximity to the aerosol source and disease incidence seems fundamental, there are many outbreaks where investigations concluded that this was not the case. This is particularly true of outbreaks attributed to cooling towers. There have been numerous cases, including the July 2015 outbreak in the Bronx, where a cooling tower in the general area was blamed for causing disease without any apparent association of patients with the aerosol source. This lack of spatial correlation between disease incidence and the purported source is an extremely strong indication that the specific cooling tower is not the source of the outbreak.
**Potable Water Supply Source**

Municipal potable water systems in the United States and European countries have been very effective at reducing, but not eliminating, waterborne diseases. Potable water is sanitary but not sterile. Disinfection is designed to eliminate many pathogens transmitted by the oral-fecal route, such as cholera and typhoid, however many other bacteria that are natural inhabitants of aquatic environments may survive. Most water pipes contain a layer of biofilm. This biofilm may harbor many non-pathogenic bacteria but can also harbor bacteria such as *Legionella*. When a known upset occurs, such as a power outage or water main break which causes loss of system pressure, warnings to boil water before using are sent to the system users. There are an estimated 240,000 water main breaks per year in the United States. Minor upsets such as pressure surges that could disturb biofilms in the pipes may seem unremarkable or go unnoticed yet could release bacteria into the water stream. A study conducted in Wales and northwest England from 2001 to 2002 found a very strong association between self-reported diarrhea and reported low water pressure at the home tap. The investigators hypothesized that most of the reported episodes of pressure loss were due to main breaks in which contamination entered the distribution system. As the infrastructure ages, the frequency of upsets that can potentially cause contamination in the system has increased.

The first incidence in which a municipal water system was found to be the vector for disease transmission occurred during the cholera epidemics in mid-19th century London. Sir John Snow, an English physician, prepared a map of where cholera deaths had occurred. This map clearly showed that most of the deaths were in buildings that received their water from a particular contaminated well. However, it took 20 years after Snow generated his map and 8 years after Snow passed away before the correlation between contaminated water and cholera was accepted. The “detection bias” that cholera was caused by airborne “miasma” was too firmly entrenched in the nineteenth century zeitgeist to be easily dislodged. Figure 3 reproduces Sir John Snow’s map. Cholera fatalities are indicated by small red circles; public drinking water wells are indicated by larger blue circles. The cases are spread uniformly over the area where the contaminated water was used.

A more recent potable waterborne infection occurred in Denmark in 2007. There an outbreak of gastroenteritis affected a high percentage of residents in one section of the city. Investigation showed massive contamination of a part of the water distribution system, while other parts of the distribution system appeared to be unaffected. The source was eventually identified as backflow from the municipal water distribution system. Figure 4 shows the case map for this outbreak with contamination in one subsection of the water supply.

Legionellosis is a waterborne disease. Since the early 1980’s, potable water has been known to be a vector for Legionnaires’ disease. The best studied cases with a potable water source are hospital acquired infections. A hospital’s internal piping system can become contaminated with *Legionella* from the municipal potable water supply. In warm areas of piping, particularly if there is a biofilm on surfaces or sediment in the system, the *Legionella* can multiply and occasionally release large numbers of bacteria into the water. The bacteria may be transmitted to many hospital patients via aspiration of contaminated drinking water or ice chips or, more commonly, via aerosols generated by sinks and showers. *Legionella* are not as virulent as cholera this contamination may infect only a few patients per year and appear somewhat sporadically.

The key factors of a potable water outbreak of Legionnaires’ disease are:

1. The original source of the bacteria is colonization of the potable water supply.
2. While many buildings could be contaminated due to an upset in the potable water system, only in some buildings will the bacteria find hospitable growing conditions for amplification and susceptible individuals to infect.
3. The bacteria reproduce within several building potable water piping systems to reach infectious levels. This usually requires the water in the system to reach temperatures that permit amplification.
4. The bacteria are emitted at multiple points in multiple buildings throughout the affected portion of the municipal water distribution system.
5. Since the bacteria are emitted from widespread sources there is a seemingly random distribution of cases of disease all within the same municipal water distribution system.

Potable water has also been identified as the source for Legionnaires’ disease in non-hospital settings, but again usually with very low infection rates. High risk buildings tend to be tall with complex piping and many residents. If *Legionella* from the municipal water supply colonize sediment and biofilm in a building water system there may be occasional incidents of disease. When multiple cases occur in a single building, the health department will evaluate that building for contamination but rarely investigate other buildings receiving water from the same municipal system. An incident in the municipal potable water supply system that contaminated many buildings over a short period of time could result in an outbreak of disease occurring in the area downstream from the incident over a relatively short period of time.

**Epidemiology – Not an Exact Science**

Determining the source of a particular outbreak requires gathering and sifting through large amounts of information. Patients are interviewed, commonality between sites visited by patients is evaluated, possible sources are examined, and an attempt is made to match the DNA of infectious bacteria grown from patient isolates to that found in the environment. It is only when all of these fall in line that a source of the disease can be definitively imputed.

As of this writing, there are approximately 2,000 different *Legionella* pneumophila genotypes known worldwide, but only 10% of those are known to be associated with disease in the US. A DNA match between environmental and patient isolates is not as determinative of the infection source as one might expect. In a specific geographical region there are usually fewer than several dozen genotypes endemic to the water systems. Since potable water is the ultimate source of the bacteria, many water features in an area can be contaminated with the same genotype of bacteria. In fact particular genetic types of *Legionella* can become endemic to a given water system with the same genetic match appearing in seemingly unrelated environmental sources. Thus the lack of a DNA match can disprove that a particular feature is the source, but a DNA match on its own cannot prove that it is the source.

The difficulty of determining a source was clearly seen in an outbreak in South Dakota in 2007. There had been a dramatic increase in the incidence of Legionnaires’ disease over a short period of time. There was little in common with the patients except that they spent time in Rapid City. To the investigators this at first ap-
peared to be a likely cooling tower issue, though there was no clear relationship with time spent near a tower and incidence of disease.

Cooling towers throughout the city were located and sampled. Many had detectable levels of Legionella and were required to be disinfected. However, none of the towers Legionella were a genetic match to the patients’ isolates. The investigators continued to look for other aerosol sources without success as infections were still occurring. Then the investigators noticed that many of the patients had eaten at the same restaurant during their likely infection period. When investigators revisited the restaurant they sampled a small fountain and found both a high level of Legionella in the fountain and an exact genetic match to the Legionella found in the patients. The fountain was removed and no additional infections occurred.

It was fortunate that none of the cooling towers testing positive for Legionella were a genetic match to the particular bacteria that infected patients. Had there been a match, even with little data showing that infected persons spent more time near the towers than the general population, that tower may likely have been declared the source and the fountain would have continued to infect restaurant patrons.

2015 Bronx Outbreaks

Initial Outbreak in South Bronx

During the summer of 2015 a large outbreak of Legionnaires’ disease occurred in the South Bronx. The onset dates, 2 to 10 days after the infection dates, were between July 8th and August 3rd. The outbreak was officially declared over on August 20th. During this outbreak 133 individuals were diagnosed with the disease with 16 deaths. The graph in Figure 5 is from the NYC Department of Health. This epidemic curve is characteristic of disease with 16 deaths. The graph in Figure 5 is from the NYC Department of Health. This epidemic curve is characteristic of Legionnaires’ disease with 16 deaths. The graph in Figure 5 is from the NYC Department of Health.

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A particular strain is likely to be present throughout the potable water system, so commonality in activity among patients relative to a particular potential source must be established in order to deduce the specific source(s) of infections.

The particular cooling tower located at the Opera House Hotel circulated water at 800 gpm; at full fan power it moves 49,700 CFM; and it is equipped with drift eliminators that reduce the drift to less than 0.001%. The drift rate then is: 0.00001 x 800 gpm x 3785 ml/gal = 30 ml/min. At full fan power this drift results in a concentration of: 30/49700CFM x 1CF/7.48 gal x 1 gal/3.785 liters = 0.00002 ml of drift/liter of exhaust air. If each ml contained 1000 CFU of Legionella, then on average there would be 0.02 Legionella per liter of undiluted tower exhaust air or in every 50 liters of air there would be a single bacteria. If a typical person has a 500 ml tidal volume and takes 15 breaths per minute, and if they were breathing only undiluted tower exhaust for an hour, they would inhale 0.5 x 15 x 60 = 450 liters of air or only about 10 bacteria. As one moves away from the tower the exhaust air containing the drift becomes more dilute and a person would require much longer time in the diluted exhaust air to inhale a similar number of bacteria. Recall that proximity has been well established in aerosol point-sourced outbreaks, with reduced infection rates at increasing distance from a source. The circle around the Opera House Hotel in Figure 6 indicates a 0.1 mile radius. This is the area where one would expect the highest cluster of cases, but there is no cluster of cases at or immediately adjacent to the hotel. There is no gradient with radial or,-presuming wind, with directional distance. Rather, the cases appear randomly across a broad area, producing a case map with more similarity to the waterborne cholera outbreak. Cooling towers and fountains were sampled as part of the investigation, but potable water was not. City officials repeatedly claimed that “the drinking water is unaffected”. This claim was not substantiated with data by NYC because no testing of potable water was performed. In fact it was dramatically disproven in only a few weeks when the cases associated with the Melrose Houses were more fully evaluated.

Outbreak at Melrose Houses

There was a second outbreak of four cases of Legionnaires disease at the Melrose Houses in the South Bronx identified after the initial outbreak. An arrow in Figure 6 indicates the location of the Melrose Houses, less than 0.4 miles from the Opera House Hotel. The first case in the Melrose Houses outbreak occurred in March 2015 and was not investigated at that time. Two more cases occurred during the July outbreak and were originally included in that outbreak, and the latest occurred in late August after the July outbreak was declared over. No potable water sources were investigated by the NYC DOH until four cases were identified at a single location at Melrose Houses. When the potable water at Melrose Houses with over two thousand residents was investigated, Legionella were found in the potable water and the potable water was positively identified as the source of infection. Point-of-use water filters were installed on all faucets and showerheads and a copper-silver ionization system was installed in the buildings’ potable water piping. In spite of 3 cases occurring in the same facility over a period of only a few months, potable water was not sampled. It was only after the original outbreak was declared over yet an additional case occurred that the potable water was sampled and identified as the source of the infections.
**Outbreak at Morris Park**

A third outbreak of Legionnaires’ disease occurred in the Morris Park neighborhood of the Bronx. Morris Park is about 4 miles from the Opera House Hotel in the East Bronx. There were 43 cases in this outbreak and 1 death. Figure 7 shows the epidemic curve for this outbreak. The onset dates for all but one of the cases included in the outbreak were between September 14th and September 21st with infection occurring 2 to 10 days prior. On August 6 a city wide order had been issued which mandated that:

“Regardless of the outcome of the evaluation required by item (2) above, direct the environmental consultant to carry out a disinfection/treatment sufficient to remove organic material, biofilm, algae and other contaminants and disinfect in a manner sufficient to control for the presence of Legionella organisms within 14 days of receipt of this letter”

Due to this city-wide order, all cooling towers in the area were tested for Legionella and 15 had detectable levels of the bacteria. These 15 towers were disinfected for a second time beginning September 29th, significantly after the outbreak had ended. A press release issued by the NYC DOH on November 20, fully two months after the outbreak had ended, identified a cooling tower as the source. With this outbreak it is unequivocally clear that none of the testing and cleaning of cooling towers demanded by the NYC DOH had any effect on ending the outbreak.

In late September, thirty-five cooling towers in the area were tested for Legionella and 15 had detectable levels of the bacteria. These 15 towers were disinfected for a second time beginning September 29th, significantly after the outbreak had ended. A press release issued by the NYC DOH on November 20, fully two months after the outbreak had ended, identified a cooling tower as the source. With this outbreak it is unequivocally clear that none of the testing and cleaning of cooling towers demanded by the NYC DOH had any effect on ending the outbreak.

Impact of regulations on public health

**Incidence of Disease in the United States and Europe**

Legionnaires’ disease is a reportable illness in the United States and many European Countries. Records are made available by the CDC\(^{25}\) in the US and the ECDC\(^{28}\) in Europe. For 5 European countries these records go back at least to 2003. Figure 8 shows the reported incidence of LD for these countries and the US in illness per 100,000 of population.

There are many factors which can affect the shape of the curves besides actual incidence of disease. Legionnaires’ disease is believed to be underreported. The US reported incidence rate has steadily increased over the period shown. The CDC believes that this may be partially due to:

“An increasing population of older persons contributed to the increase in reported legionellosis cases. Other factors that might have contributed include an increasing population of persons at high risk for infection; improved diagnosis and reporting, possibly stimulated by the 2005 CSTE endorsement of more timely and sensitive legionellosis surveillance; and increased use of urine Legionella antigen testing”\(^{25}\).

The graph in Figure 8 shows that there is little difference in the incidence rate of Legionnaires’ disease between Western Europe and the United States. This lack of difference exists in spite of burdensome regulation of cooling towers which has been in place in Europe for many years.

**Legionella Regulations in France**

France provides an interesting study of the effects of cooling tower regulations on the incidence of disease. Guidelines to improve underreporting of the disease were written in 1997 along with introduction of the urinary antigen detection test\(^{25}\). In the winter of 2003 to 2004 a large outbreak with 86 confirmed cases and 18 fatalities occurred in Pas-de-Calais, France\(^{31}\). An industrial cooling tower was implicated as the source for the contamination. As a result of this outbreak regulations were promulgated for the control of cooling towers. Cooling tower regulations for hospitals had been enacted in 2003 but with the Pas-de-Calais outbreak they were extended to all cooling towers\(^{32}\).

The 2004 regulations require frequent testing of cooling towers for Legionella. The regulations mandate monthly testing for Legionella unless 12 consecutive monthly tests are less than 1 CFU/ml then the testing can be reduced to quarterly. If the reading exceeds 100 CFU/ml the tower must be immediately shut down and cleaned. More frequent testing is then required until the system again meets the strict low limits.

The graph in Figure 9 indicates that the incidence rate for LD infection has been hovering around 2 per 100,000 of population for over a decade. After the regulations were issued at the end of 2004, there was an increase in the reported incidence of LD. This could well be due to a heightened awareness of the disease from both the issuing of the regulations and the widely publicized outbreak at Pas-de-Calais. There has been a gradual decline in the reported incidence since 2005, but a dramatic reduction has not been observed since the regulations were implemented. The author believes that these results indicate that the cooling tower regulations had little to no effect on the incidence of sporadic cases of Legionnaires’ disease.

**Conclusion**

There are outbreaks of Legionnaires’ disease which have been clearly linked to a sole aerosolized source of bacteria. In these outbreaks, acute proximity and duration were shown to govern exposure and incidence of Legionnaires’ disease. However, there are many outbreaks attributed to a cooling tower source which do not adhere to these rules. These outbreaks have case profiles which are more random and cover larger areas. These outbreaks mimic the documented profile of certain potable water outbreaks where a single “upstream” source contaminates multiple exposure sites.

The source(s) of future Legionnaires’ disease outbreaks must be investigated more thoroughly, exploring the possibility of multiple exposure sites including potable water, in order to advance our understanding of LD transmission. The traditional epidemiological models that assume causality with a genetic match but with only a tenuous exposure mechanism have resulted in the promulgation of regulations that have not resulted in a significant reduction in the incidence of disease. Increased awareness and the issuing of explicit orders for the care of cooling towers did not prevent the outbreaks from occurring at Melrose Houses or in Morris Park. Strict cooling tower regulations imposed in France after the Pas de Calais outbreak have not resulted in any significant reduction of disease. Is it time we say, perhaps, that it is not always the cooling tower? And what is it necessary in order to have a significant positive effect on public health?
Figure 1 – Case Map from Aerosolized Point-Source

Figure 2 – Case Outside Dispersion Model

Figure 3 – Cholera Epidemiology London 1854

Figure 4 – Gastroenteritis Epidemiology Denmark 2007

Figure 5 – Epidemic Curve of Initial Outbreak in South Bronx 2015

Figure 6 – Map of Cases and Cooling Towers in South Bronx July 2015 Outbreak
Figures:

Figure 7 – Epidemic Curve for the Third Outbreak in East Bronx 2015

Figure 8 – Incidence of Legionnaires’ Disease in the US and Western European Countries

Figure 9 – Incidence of Legionnaires’ Disease in France

References:

5. Local Laws of the City of New York No. 77, Article 317 Cooling Towers
11. Miller, R., Reducing the risk of Legionnaires’ Disease, Environmental Safety Technologies
24. Private Communications with CDC.
25. NYC DOH Order of the Commissioner, August 6, 2015.

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WQA Annual Education Kit, Vol VIII
Article 3: Cost Benefits of Point-Of-Use Devices in Reduction of Health Risks from Drinking Water

Excerpted from the WQRF Research Report, Cost Benefits of Point-Of-Use Devices in Reduction of Health Risks from Drinking Water, prepared by Marc Verhougstraete, PhD, Kelly Reynolds, PhD, Akrum Tamimi, PhD, Charles Gerba, PhD. Environment, Exposure Science, and Risk Assessment Center, The University of Arizona, Tucson, Arizona, USA, Nov 16, 2016.
[Edited for clarity]

1.0 Introduction
Since the passage of the Safe Drinking Water Act in 1974 the United States Environmental Protection Agency (USEPA) has been responsible for the development of standards to limit the exposure of harmful substances via drinking water. There are two types of standards. Primary standards regulate substances harmful to human health and secondary standards address substances related more to aesthetics. Maximum Contaminant Level (MCL) refers to the maximum concentration of a harmful substance designed to protect human health allowed in the drinking water. Achievement of the MCL does not mean that no risk exists, but that it has been reduced to a very low level. [For potential carcinogens] risk estimates [...] always [have] a level of uncertainty because they are often derived from studies based on animals- primarily mice and rats- and the need to extrapolate probability of cancer to very low levels of exposure via drinking water to humans. To compensate for this uncertainty safety factors are used extensively.

Contaminants are any physical, chemical, biological or radiological substances or matter in water. The Maximum Contaminant Level Goal (MCLG) is the level at or below which there are no known adverse effects to all humans. MCLG is often zero for many chemicals based on existing studies and interpretations.

1.1 Why treatment at the tap?
There are a number of reasons why treatment at the tap has potential additional health benefits (Table 1). The additional removal of contaminants below the MCL will result in further lowering the risk from exposure to potentially harmful substances, thus lowering the risk of an adverse health outcome. This aids in reducing the uncertainty used in risk estimates. Assessing the potential health effects is a continuing effort by regulatory agencies as new data becomes available.
Table 1. Why treatment at the tap?

<table>
<thead>
<tr>
<th>Additional reduction of risk</th>
<th>Reduction of risk below MCL from that level or occasional higher levels that may occur due to treatment deficiencies or excursions to higher levels from averages. This further reduces uncertainty and provides additional protection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protection from unknown/unregulated contaminants</td>
<td>Additional contaminants are likely to be regulated in the future as better data becomes available.</td>
</tr>
<tr>
<td>Protection from contamination in the distribution system</td>
<td>Contamination post-municipal treatment before or after household delivery.</td>
</tr>
<tr>
<td>Use of untreated water sources</td>
<td>Use of untreated groundwater by domestic individual homeowners or systems not regulated by government agencies.</td>
</tr>
<tr>
<td>Aesthetic concerns or preferences</td>
<td>Improved taste or smell from municipal or untreated waters.</td>
</tr>
</tbody>
</table>

### 1.1.1 Additional reduction of risk
Reducing risk below an MCL from that level or occasional higher levels that may occur due to treatment deficiencies or excursions to higher levels from averages is possible with treatment at the tap. Point-of-Use (POU) devices may provide the consumer with an additional protection and lower the risk further from any adverse health effects. This also helps reduce uncertainty that is inherent in any risk assessment used to set an MCL.

### 1.1.2 Protection from unknown contaminants
The USEPA reviews potential regulation of additional contaminants in drinking water as new information becomes available on a five-year cycle. These include both chemical and microbial contaminants. Current technologies used to treat water at the tap are capable of dealing with contaminants likely to be regulated in the future.

### 1.1.3 Protection from contamination in the distribution system
The delivery of water to facilities/homes usually requires transport through many miles of pipe. Although the water may have been treated it is subject to recontamination during travel through the utility distribution system and the piping system within a home or facility. Illicit connections and cracks in utility distribution systems occur, allowing the potential for contaminants to enter the distribution system. In addition, it has been shown that routine repair and maintenance of the distribution system can result in contamination of the drinking water.

The additional protection allotted from POU devices is important for sensitive populations where exposures to drinking water contaminants are more likely to result in adverse health outcomes including increased mortality. These populations include newborns, children, pregnant mothers, immunocompromised individuals, and the elderly.

### 1.1.4 Individual drinking water wells
Domestic wells in the US are unregulated and their owners are often unaware of the chemical and microbial quality of their drinking water. Privately owned wells are less likely to be routinely monitored and treated. Results indicated that domestic well users accounted for 12% of the US population or 37.7 million persons (Kumar et al., 2010). Domestic wells are usually shallower than public and more susceptible to contamination from surface waters (Kumar et al., 2010). In addition domestic wells may be more susceptible to contamination from natural deposits of minerals such as arsenic, radon, uranium,
and nitrates.

1.1.5 Cost of POU/POE devices

There are many options for treating drinking water at the point-of-use (POU) and each approach has unique capabilities and associated costs. A brief list of POU types, associated costs, and certified removal capabilities are described in Table 2 and Table 3. Using a simple POU calculator (http://www.cyber-nook.com/chart/default.asp), over a five year period there was not a large difference in costs between reverse osmosis ($680), activated carbon filtration ($546), and pour-through filtration units ($645). UV treatment (POE) ($1,499), adsorptive media ($936), and distillation ($740) were nearly twice as expensive over the 5 year cost of operations. Ion exchange (POE) ($1,870) was the most expensive option over 5 years.

Table 2. Point-of-use/point-of-entry devices and associated costs

<table>
<thead>
<tr>
<th>POU/POE</th>
<th>Initial cost</th>
<th>Operation and maintenance cost (per year)</th>
<th>5 year total cost *</th>
<th>Annual cost over 5 years **</th>
<th>Lifetime unit cost (70 years) ***</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>No treatment</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>-</td>
</tr>
<tr>
<td>Reverse Osmosis</td>
<td>$300</td>
<td>$95</td>
<td>$680</td>
<td>$136</td>
<td>$9,520</td>
<td>(Johnson, 2014; NSF International, 2015; USEPA,)</td>
</tr>
<tr>
<td>UV treatment</td>
<td>$1,059</td>
<td>$110</td>
<td>$1,499</td>
<td>$300</td>
<td>$20,986</td>
<td>(NSF International, 2015; USEPA, 2006)</td>
</tr>
<tr>
<td>Adsorptive Media</td>
<td>$520</td>
<td>$104</td>
<td>$936</td>
<td>$187</td>
<td>$13,104</td>
<td>(NSF International, 2015; USEPA, 2006)</td>
</tr>
<tr>
<td>Distillation</td>
<td>$340</td>
<td>$100</td>
<td>$740</td>
<td>$148</td>
<td>$10,360</td>
<td>(Harrison, 1999; Johnson, 2014; NSF International,)</td>
</tr>
<tr>
<td>Ion Exchange (softener)</td>
<td>$1,150</td>
<td>$180</td>
<td>$1,870</td>
<td>$374</td>
<td>$26,180</td>
<td>(Harrison, 1999; NSF International, 2015; Sargent-Michaud et al., 2007)</td>
</tr>
</tbody>
</table>

*5 year cost based on the initial cost plus annual costs for four additional years and assuming on the sixth year, the unit is completely replaced and thus a cost equal to the initial cost is required again. Costs based on data from http://www.cyber-nook.com/chart/default.asp?Usage=10&Years=4 (accessed May 9, 2016)

** 5 year cost divided by 5 years

*** Annual cost over 5 years times 70 years
Table 3. American National Standards Institute (ANSI) and National Sanitation Foundation (NSF) approved point-of-use/point-of-entry device removal claims

<table>
<thead>
<tr>
<th>POU/POE</th>
<th>ANSI/NSF Standard number and reduction claim</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activated Carbon</td>
<td>Bacteria and protozoa, Lead (53)*</td>
<td>(NSF International, 2015; United States Environmental Protection Agency</td>
</tr>
<tr>
<td>UV treatment</td>
<td>Bacteria, viruses, Protozoa</td>
<td>(NSF International, 2015; USEPA,</td>
</tr>
<tr>
<td>Adsorptive Media</td>
<td>Arsenic (53)</td>
<td>(NSF International, 2015; USEPA,</td>
</tr>
<tr>
<td>Ion Exchange (softener)</td>
<td>Hardness, barium, radium (44)</td>
<td>(Harrison, 1999; NSF International 2015;</td>
</tr>
</tbody>
</table>

* Microorganism contamination reduction claim under NSF P231 or USEPA Purifier Guide Standard. POU devices are required to ‘remove, kill or inactivate all types of pathogenic organisms’ at the following rates: Bacteria: 6 Log; Viruses: 4 Log; Protozoan cysts: 3 Log

[...] 3.0 Inorganic contaminants

There are many drinking water contaminants of concern regulated by USEPA and most of [their levels] can also be reduced by POU treatment systems (“WQA Technical Fact Sheet: Lead,” 2013). We discuss a few of the well-studied contaminants (e.g. arsenic, nitrates, lead, and chromium) in the following sections.

3.1 Arsenic

Arsenic is a naturally occurring element widely distributed in the earth's crust. Its occurrence in water largely results from its release from natural deposits. It was previously used in pesticides, as a preservative, and other manufactured products. Two forms of arsenic are common in natural waters: arsenite (AsO$_3^{3-}$) and arsenate (AsO$_4^{3-}$), referred to as arsenic (III) and arsenic (V), respectively.

Arsenic has been associated with various types of cancer (skin, lung and urinary bladder) and non-cancer health effects, such as skin lesions, cardiovascular, pulmonary, immunological, neurological, and endocrine (e.g., diabetes) effects. The MCL for arsenic is 10 µg/L and is based on chemical toxicity rather than carcinogenicity (USEPA, 2013). Arsenic associated cancer prevalence and mortality rates in the United States are unknown (USEPA, IRIS 1998). Kurttio et al., (1999) conducted a case-cohort design study of 61 bladder and 49 kidney cancer cases and 275 controls to evaluate the risk of these diseases with respect to arsenic drinking water concentrations. In this study the median exposure was 0.1 µg/L, the maximum reported was 64 µg/L, and 1% of the exposure was greater than 10 µg/L. The authors reported that very low concentrations of arsenic in drinking water were significantly associated with bladder cancer when exposure occurred two to nine years prior to diagnosis.
3.1.1 Occurrence in water
Arsenic exposure largely results from groundwater sources. Welch et al., (2000) found that nearly half of the 30,000 arsenic analyses from groundwater, recorded in the U.S. Geological Survey’s National Water Information System (NWIS) and other agency databases, were ≤1 µg/L and 10% exceeded 10 µg/L. The authors also reported that arsenic concentrations exceeding 10 µg/L appear to be more frequently found in the western states than in the eastern states.

[...] In general, [groundwater provided by] public wells [has] less arsenic compared to domestic wells because the municipal water is treated (Peters et al., 1999). [...]A review of arsenic concentration in groundwater in various regions of the US demonstrated that the concentration remains unchanged over time.] With this assumption, this data can be applied for any time period in the past and can be extended to apply in the future.

Analysis of variance (ANOVA) [...] showed that there was a significant statistical difference between regions (p < 0.005, α = 0.05). This indicates that regional classification is essential when considering concentrations of arsenic in groundwater.

[...] Kumar et al. pointed out that while private domestic wells account for only 12% of the United State population, they represent 29% of the overall exposure to arsenic when the 10 µg/L limit is met by public water. [(Kumar et al., 2010)]

3.1.2 Groundwater arsenic risk assessment deterministic modeling
Arsenic concentration in groundwater (Table 9) reflects the regional concentrations at both public and rural wells before treatment. The USEPA recommends a maximum contamination level (MCL) of 10 µg/L. Public water treatment plants are required to remove arsenic in drinking water to at or below this level. Frey and Edwards (1997) reported regional percent arsenic removal at public water treatment plants (Table 10) ranged from 12-44%. Additionally, a recent study focused on a small community in the Southwestern United States found that POU devices removed up to 99% of arsenic concentrations (Lothrop et al., 2015). [Arsenic in this study was primarily in the pentavalent form.]

Table 9. Average concentration of arsenic in U.S. wells by region

<table>
<thead>
<tr>
<th>Dataset Start Date</th>
<th>Dataset End Date</th>
<th>Sample size (n)</th>
<th>Minimum (µg/L)</th>
<th>Average (µg/L)</th>
<th>Maximum (µg/L)</th>
<th>95% Upper CI*</th>
<th>95% Lower CI*</th>
<th>Standard Deviation</th>
<th>Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>All U.S. Regions</td>
<td>New England</td>
<td>Mid-Atlantic</td>
<td>Southeast</td>
<td>Midwest</td>
<td>South Central</td>
<td>North Central</td>
<td>West</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7219</td>
<td>541</td>
<td>479</td>
<td>760</td>
<td>1143</td>
<td>1909</td>
<td>140</td>
<td>2247</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.022</td>
<td>0.027</td>
<td>0.025</td>
<td>0.022</td>
<td>0.031</td>
<td>0.026</td>
<td>0.093</td>
<td>0.034</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.88</td>
<td>2.10</td>
<td>1.55</td>
<td>1.54</td>
<td>4.08</td>
<td>3.46</td>
<td>3.39</td>
<td>4.90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>130</td>
<td>73</td>
<td>73</td>
<td>68</td>
<td>128</td>
<td>61</td>
<td>49</td>
<td>54</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.08</td>
<td>2.62</td>
<td>1.95</td>
<td>1.84</td>
<td>4.67</td>
<td>3.70</td>
<td>4.56</td>
<td>5.37</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.69</td>
<td>1.58</td>
<td>1.15</td>
<td>1.24</td>
<td>3.50</td>
<td>3.21</td>
<td>2.23</td>
<td>4.43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8.6</td>
<td>6.2</td>
<td>4.5</td>
<td>4.2</td>
<td>10.1</td>
<td>5.4</td>
<td>7.0</td>
<td>11.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.1</td>
<td>0.3</td>
<td>0.2</td>
<td>0.2</td>
<td>0.3</td>
<td>0.1</td>
<td>0.6</td>
<td>0.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*CI: Confidence Interval
The researchers determined the cost effectiveness of POU treatment technologies for arsenic by reviewing the following parameters for bladder cancer:

- The potential number of cancer cases associated with arsenic over the current population of the US
- The associated cost of medical treatment
- The drinking water arsenic concentration reduction possible with POU technologies
- The reduction in cancer rates and associated medical costs
- The cost of ownership of the POU treatment system over a 70 year lifetime...

The greatest cancer risk reduction from POU devices occurs in rural areas where untreated well water leads to higher exposures of arsenic concentrations. More specifically, risk reduction is greatest in rural wells in the Midwest, West, South Central, and North Central U.S. regions. For public water supplies, the only significant reduction in risk appears to be in the West where arsenic concentrations are the greatest. Figure 1 shows the lifetime cancer risk for arsenic concentrations in drinking water found in the U.S. between 1991 and 2014.

Figure 1. Risk of lifetime cancer vs. arsenic concentration in drinking water

3.1.4 Discussion of POU devices to remove arsenic

The ability for POU devices to remove arsenic in water depends on many variables including pH and redox potential which control arsenic speciation and thus drive treatment options. Activated carbon has been studied extensively for arsenic removal (Mohan and Pittman, 2007), but carbon only removes a few milligrams of metal ions per gram of activated carbon. Other popular treatment options include reverse osmosis, adsorptive media (e.g. iron based media and alumina), and distillation. A summary of common
POU treatment devices and reported arsenic removing capabilities are described in Table 13.

### 3.1.5 Cost-effectiveness analysis for arsenic in drinking water

Calculating the cost-benefit of a POU intervention includes the cost of the POU (initial investment plus maintenance and unit replacement projections) compared to savings due to averted costs of disease burden. Diseases related to arsenic where cost estimates are available include bladder, skin (nonmelanoma), and lung cancers. Table 14 lists medical costs, estimated arsenic associated cases per year and the total annual cost estimate for each disease along with cumulative yearly expenses. The annual population cost of arsenic related cancer (bladder, skin and lung) is $1.6B. However, for the cost-effectiveness calculations in this study, we assumed only bladder cancer response to arsenic exposure through drinking water as the other adverse health outcomes (skin and liver cancers) are associated with inhalation and dermal exposure of arsenic contaminated water, not ingestion of contaminated drinking water.

[...] The cost (USD) per unit risk reduction was defined for each POU device (Table 15). Cancer rates are not linear with relation to arsenic exposure and thus an annual cost-effectiveness value was not derived. This calculation assumes the device is used routinely for 70 years and each POU device has a 5 year lifetime then is replaced for the initial unit cost. The cost-effectiveness details for each POU device are presented in Table 15. Distillation is capable of the largest reduction in lifetime cancer risks (1.50 cases in 10,000 individuals) while adsorptive media is the most cost-effective when compared to the other approved POU devices.

[...] The cost of no intervention was calculated to be $61,054. This value is based on the discounted cost of medical treatment for arsenic-associated bladder cancer after 30 years and a 12 month compound interest cycle of 3% at $150,000 in 2015 (Present Value of Lump Sum calculation). This cost does not account for mortality, adjusted life years, quality of life losses, or inflation since these values are currently unknown but could be assumed with acknowledgement of uncertainty. Risk reduction input parameters vary by POU intervention type and risk reduction with no intervention is assumed to be zero.

[...]

### 3.1.7 Discussion

Overall, based on the available health information, the cost of bladder cancer due to arsenic in drinking water is estimated at $215.3M per year. The annual costs to implement a national POU intervention over 5 years of continued operation (i.e. annual average) in all households (assuming a US population of 325,310,000 and 2.58 persons per household) would range from $17.1B (reverse osmosis) to $23.6B (adsorptive media). Thus, under water quality conditions that meet the USEPA arsenic MCL, it would not be cost-effective to supply a point-of-use device in every household across the United States for arsenic removal alone.

In general, consumer perception that they are at risk of developing cancer (i.e., cancer risk probability is 1 in an individual life from arsenic exposure in water) drives the purchase of a POU device to avert disease. While the individual risk of cancer from arsenic is low, if an individual was certain to be the cancer case that would have been averted with a POU device, we can estimate the individual cost of a POU device relative to the aversion of a certain cancer case. See Table 16 for cost savings estimates for an individual at risk of developing cancer at 10 ppb arsenic concentration. While the assumption of a cancer probability of 1 is not plausible, targeting specific higher risk groups for POU intervention increases the individual cost benefit.
To better explain the cost-effectiveness of arsenic removal using a POU device, we aimed to highlight a community exposed to high levels of arsenic in drinking water. However, under our assumptions of a cancer probability of 1, the risk and cost-effectiveness remain largely unchanged despite higher levels of arsenic exposure. In order to improve upon the cost-effectiveness of POU devices to remove arsenic and reduce arsenic associated cancer (e.g. bladder) risks, rates of cancer at various concentrations in drinking water must be measured and incorporated into the developed calculator.

A device certified for arsenic reduction as per ANSI/NSF Standard 53 must demonstrate a minimum reduction of 80% for an influent concentration of 50 ppb or a minimum of 96.7% for an influent challenge level of 300 ppb. The range of cost and benefit values presented in Table 10 are similar to the ANSI/NSF Standard and thus encompass both optimal and real-world study results. If and when a family is concerned about the cancer risk associated with arsenic in drinking water and decides to buy and install a certified POU device, their own specific benefit derived from such an action will range from $36,388 to $60,443 (see Table 16).
### Table 15. Cost-effectiveness for each POU device

<table>
<thead>
<tr>
<th>POU Type</th>
<th>Lowest reported post filter concentration (μg/l)</th>
<th>Cost of unit (initial)</th>
<th>Cost of unit (annual maintenance)</th>
<th>5 year cost</th>
<th>Lifetime cost of unit (70 years)</th>
<th>Risk of lifetime cancer at lowest reported post filter concentration (10,000)</th>
<th>Delta risk from USEPA (10 μg/l = 5)</th>
<th>Cost per risk reduction B</th>
</tr>
</thead>
<tbody>
<tr>
<td>No treatment</td>
<td>10.00</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>5.00</td>
<td>0.00</td>
<td>$0</td>
</tr>
<tr>
<td>Reverse Osmosis</td>
<td>0.03</td>
<td>$300</td>
<td>$95</td>
<td>$680</td>
<td>$9,520</td>
<td>0.60</td>
<td>4.40</td>
<td>$23,233</td>
</tr>
<tr>
<td>Adsorptive Media</td>
<td>0.69</td>
<td>$520</td>
<td>$104</td>
<td>$936</td>
<td>$7,644</td>
<td>0.30</td>
<td>4.70</td>
<td>$22,149</td>
</tr>
<tr>
<td>Distillation</td>
<td>3.00</td>
<td>$340</td>
<td>$100</td>
<td>$740</td>
<td>$10,360</td>
<td>1.50</td>
<td>3.50</td>
<td>$28,967</td>
</tr>
</tbody>
</table>

A. Lifetime unit cost assuming unit replaced every 5 years for 70 years
B. Assuming equal USD value for 70 years

### Table 16. Cost savings given cancer probability of 1 and initial arsenic concentration of 10 µg/l

<table>
<thead>
<tr>
<th>Point-of-Use device</th>
<th>% As reduction</th>
<th>Post filter concentration</th>
<th>Post intervention lifetime cancer risk (per 10,000)</th>
<th>Lifetime POU cost</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>No treatment</td>
<td>0%</td>
<td>10.0</td>
<td>5.00</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>Reverse Osmosis</td>
<td>81.0</td>
<td>1.90</td>
<td>0.95</td>
<td>$9,520</td>
<td>$49,454</td>
</tr>
<tr>
<td>Adsorptive Media</td>
<td>59.7</td>
<td>4.03</td>
<td>2.02</td>
<td>$7,644</td>
<td>$36,388</td>
</tr>
<tr>
<td>Distillation</td>
<td>99.0</td>
<td>0.10</td>
<td>0.05</td>
<td>$10,360</td>
<td>$60,443</td>
</tr>
</tbody>
</table>
Bibliography


Among people whose job it is to engineer systems and size equipment, there is a phrase commonly used by all: “You can’t do that!” Playing with numbers and ignoring the laws of physics and mathematics will land one in a world of trouble—costing time, money and resources. There is a place for sound science and engineering and it is found in the numbers. While math was not a favorite subject for many students, it was an effective form of sedation. For those who slept through math class, it is not too late to learn—water math is crucial to effective water treatment. The good thing is the math whiz folks within the industry simplified many of the equations and developed handy charts and graphs to help the mathematically challenged avoid trouble. In this article, take a math refresher course and possibly discover a few new ways of viewing complex equations and difficult hydraulic theory.

Square footage (sq. ft./ ft²)

One of the most important and most used values in water math is square feet (ft²) (see Figure 1). It determines filter loading rates (capacities), media backwash rates, pressure drop through a media bed and the starting calculation in establishing media volumes and bed depths (see Figure 2).

The equation for calculating the square feet within a circle is $\pi r^2$ ($\pi = 3.14$), where $r$ is the radius or half the diameter (D). The industry sizes tanks and pipes in inches. Media and flowrate specifications come in square feet. Here is an easy shortcut to simplify a diameter expressed in inches and have the equation’s result come out in square feet. The equation is: $D^2/183$ or $(D \times D)/183$. For further discussion, note that $A + B$ is mathematically represented as $A$ over $B$ or $A/B$.

This equation replaces $\pi r^2 + 144$, where $r$ is inches and there are 144 square inches in a square foot. $D^2 + 183$ ($D^2/183$) is accurate, quick and easy because manufacturers give their tank sizes in diameter inches.

Here is an example of the calculations for a 10-inch-diameter tank using both equations: $\pi r = 3.14$. $\pi$ is not a mysterious number. It is simply the number of times a circle’s diameter goes around that circle’s circumference.

$D = 5; D^2 = 5 \times 5 = 25$

$\pi r^2 + 144 = 3.14 (25)/144; 78.5/144 = 0.54 \text{ ft}^2$ within a 10-inch circle or

$D^2 + 183 = (10 \times 10) + 183 = 100/183 = 0.54 \text{ ft}^2$

Again, it is a quick and easy equation to use and remember $(D^2 + 183 = D^2/183)$. Try it. A 30-inch tank is $900/183 = 4.9 \text{ ft}^2$. It works every time.

A rectangle or square is simply sides $A \times B$. If $A = 2 \text{ ft.}$ and $B = 3 \text{ ft.}$; then the squared value is $2 \times 3 = 2 (3) = 6$. For further discussion, note that $A \times B$ is mathematically represented as $A$ next to $B$ or $A(B)$ (see Figure 3).

Volume (cubic feet) (cu. ft./ ft³)

Volumes are three dimensional, requiring three measurements. If the square footage is known, simply multiply by the height and the result is cubic feet (see Figure 4). The geometric equation for calculating the cubic feet within a cylinder (tank) is: $\pi r^2 h$. Knowing the square footage of the cylinder, simply multiply $\text{ft}^2$ times the height. Looking at the 10-inch tank with 0.54 $\text{ft}^2$, then each foot of depth is 0.54 $\text{ft}^3$ (cubic feet). A three-foot bed depth in a 10-inch-diameter tanks is:

$D^2/183 \times 3 = 100/183 \times 3 = 0.54 \times 3 = 1.62 \text{ ft}^3$

Another example is a 24-inch-diameter tank with a three-foot bed depth:

$D^2/183 \times 3 = D^2/183 (3) = (24 \times 24/183) (3) = 3.14 (3) = 9.42 \text{ ft}^3$

A rectangle is $W \times L \times H$. Use measurements in feet to get cubic feet.

Loading per square foot

Manufacturers provide hydraulic loading rates in their specifications under operating conditions (see Figure 5). Using a common loading rate of five gallons per
minute per square foot (5 gpm/ft²), here is the math to determine the size of a media filter vessel to filter 20 gpm:

20 gpm ÷ 5 gpm/ft² = 20/5 = 4 ft²

Knowing that particulate (i.e., iron, turbidity, etc.) loads at a rate of five gpm/ft² and the flow is 20 gpm, then the application requires 4 ft² of filter surface area. Using the available tank sizes (see Chart A), one can easily choose the tank required to handle the filtration of 20 gpm @ 5 gpm/ft². From the chart, it takes a 30-inch-diameter tank to handle 20 gpm at a hydraulic loading rate of 5 gpm/ft².

Here is a real-world application. Birm has a maximum service flowrate of 5 gpm/ft² (from manufacturer’s conditions for operation). If one puts the proper amount of Birm in a 12-inch-diameter tank (30 to 36-inch bed depth) then the max flow through this filter is:

\[ \frac{D^2}{183} = \frac{(12 \times 12)}{183} = \frac{144}{183} = 0.79 \text{ ft}^2 \]

5 gpm/ft² x 0.79 ft² = 3.95 gpm

Backwash rate per square foot (gpm/ft²)

Having the square foot calculation for a tank, one can easily calculate the backwash flowrate required for that tank. Assuming a backwash flowrate of 12 gpm/ft² and a 12-inch-diameter tank with 0.79 ft² (from Chart A), then the required flow to drain during backwash is:

12 x 0.79 = 12 (0.079) = 9.48 gpm

Because there is no such thing as a 9.48-gpm drain line flow control (DLFC), it makes sense to round out to a DLFC of 10 gpm. Just double-check the bed expansion curve to ensure that there is adequate freeboard to handle the bed expansion during backwash.

Bed expansion

Bed expansion (Figure 6) is a function of bed depth and the lift or expansion of the bed at a given flowrate to the drain during the backwash cycle. Filter beds require expansion during backwash to lift the captured material loaded on and in the top surface of the bed (see Figure 7). Allowing for a 30-percent specified bed expansion and 50°F water, looking at Figure 6, it specifies a 15 gpm/ft² flowrate. Note: Best practices look for 30 psi feed pressure at the given backwash flow for optimum results in residential applications. For large commercial and industrial systems, it typically requires 40 psi for adequate lift during backwash. Assuming a 30-inch bed depth, the bed will expand:

30 (30 percent) = 30 (0.3) = 9 inches

Knowing this, a 30-inch bed will expand to 39 inches during backwash. To ensure that the bed material remains in the tank
during backwash make sure that the freeboard (open space between the top of the media bed and the top of the tank) is greater than nine inches. It is common practice to leave 50-percent freeboard in media tanks. Note: Only use the side shell height (Figure 1) in calculating available freeboard and bed depth. If the media reaches the curvature of the tank during backwash, it is lost to the drain (see Figure 8).

Empty bed contact time (EBCT)

Empty bed contact time is a calculation used in adsorption, ion exchange and retention time. It is a calculation of how long water is in contact with media or chemicals. If an arsenic adsorptive media requires two minutes of EBCT, water must take two minutes to pass through the media. To calculate EBCT in measurements learned earlier in this lesson, use 7.48 gallons/ft³. To calculate a 10-gpm flow with an EBCT of two minutes in cubic feet (ft³), use these equations:

- 2-min. EBCT expressed in cubic feet is:
  
  \[
  \frac{(7.48 \text{ gals/ft}^3)/2 \text{ minutes}}{2} = \frac{7.48}{2} = 3.74 \text{ gpm/ft}^3
  \]
- 10 gpm with 2-minute EBCT is:
  
  \[
  \frac{10 \text{ gpm}}{(3.74 \text{ gpm/ft}^3)} = 2.7 \text{ ft}^3
  \]

Bed volumes (BV)

Bed volumes are a measurement of how much water can pass through a media bed before it reaches exhaustion—commonly called throughput. Staying with arsenic adsorption, a bed-life estimate for arsenic adsorptive media with 50 ppm As(V), ortho-phosphate 0.15 ppm, silica 20 ppm and a pH of 7.2 is 55,000 BV. One can calculate how many gallons will pass through the media before arsenic breaks through above the maximum contaminant level. Knowing that there are 7.48 gallons per cubic feet, one cubic foot of arsenic adsorptive media with a throughput of 55,000 BV will treat 7.48 gals/ft³ (55,000 BV) = 441,400 gallons.

Playing with the numbers

Whenever an operating specification calls out a BV, maximum flowrate, EBCT, etc., it is providing the best-case scenario. An automobile engine is not designed to run at 8,000 rpm just because it can. The same engine runs optimally around 2,000 rpm. In the Olympics, the 100-meter dash is classified as a sprint. The 5,000-meter race is classified as long distance. This is because human beings cannot sprint for 5,000 meters. They will exhaust and fail.

Try to be conservative when looking at operating specifications and look for the optimum numbers, not the maximums. Manufacturers of POE and POU systems, media and related products provide conditions of operations. Refer to these specifications and use good old common sense when applying water technologies.

Sound science and engineering

Designing and troubleshooting equipment requires that one knows the math. Learning and using water math requires practice. Do the homework. Once the equations become part of everyday use, the numbers and calculations become instinctive—and make everyone smarter and better professionals.

About the author

Matthew Wirth, Layne Christensen Commercial Sales, Water Technologies POE/POU Division, is responsible for the region west of the Mississippi River. He is a 32-year professional in the water industry and an active trainer for several national organizations. Wirth has extensive experience in light C&I, POE and POU problem-water applications. A graduate of Concordia University in St. Paul, MN with a BA Degree in organizational management and communications, he received engineering training at the South Dakota School of Mines and Technology in Rapid City, SD. He can be reached at matthew.wirth@layne.com or cell phone, (319) 333-4174.

About the company

Layne Water Technologies (www.laynewater.com) owns the LayneRT adsorptive technology and offers it in multiple residential and commercial configurations through a network of approved professionals. They can be contacted at (800) 216-5505.
1. In the **square footage section**, the author points out that square feet (ft²) is a very common value in water math. The specific value the author is discussing is also known as the cross-sectional area of a media bed. The flowrate distributed over this area, reported most often by media manufacturers in gallons/minute/square foot (gpm/ft²) is sometimes referred to as the surface flow.

2. Also in the **square footage section**, the illustration of the diameter and radius calculations for a 10 inch diameter tank, the value of 5 inches is incorrectly indicated as diameter. It is the radius, and as such, the first line of the calculation should look as follows:
   \[ r = 5 \]
   \[ r^2 = 5 \times 5 = 25 \]

3. Including the units in a calculation can help verify that the calculation was set up correctly. When the units calculate to the correct value, the numbers will also.

   The conversion factor of 183 which helps to quickly convert from D² in square inches to the area of a circle (A) in square feet has the units of in²/ft². If D = 10 in, then:
   \[ D^2 = 10 \text{ in} \times 10 \text{ in} = 100 \text{ in}^2 \]
   The formula for area, using the author’s shortcut is:
   \[ \text{Area} = \frac{D^2}{183} \]
   Adding the numbers and units we get:
   \[ \text{Area} = \frac{100 \text{ in}^2}{183 \text{ in}^2/\text{ft}^2} = 0.54 \text{ ft}^2 \]
   Note: \( \frac{1}{(1/\text{ft}^2)} = \text{ft}^2/1 = \text{ft}^2 \)
   When dividing by a fraction, the denominator (bottom number) of the fraction becomes the numerator (top number) of the answer.

4. In the **backwash rate per square foot section**, the author demonstrates how to determine the required backwash flowrate based on the media manufacturer’s specification of 12 gpm/ft² and a known tank size, 12 inches in diameter. Chart A is a convenient reference for determining the cross-sectional area of the tank, which is 0.79 ft².

   Adding units to the sample calculation provided by the author helps verify that the calculation was set up correctly. Because we’re looking for flowrate, the correct units would be gallons per minute (gpm). Using the **dimensional analysis method** to end up with only gpm, the calculation would be set up as follows:
Surface flowrate ($\text{gpm/ft}^2$) x Surface area ($\text{ft}^2$) = Backwash flowrate (gpm)

12 $\text{gpm/ft}^2 \times 0.79 \text{ ft}^2 = 9.48 \text{ gpm}$

5. In the **empty bed contact time section**, the author introduces a conversion factor of 7.48 gallons/ft³. Those familiar with EBCT calculations will recognize it as the conversion from volume in gallons to the volume in cubic feet.

6. **Author’s updated bio and company information**

   Matthew Wirth is the Director of Training for North America at Canature WaterGroup. He is a 37-year professional in the water industry with experience in Industrial, Municipal, Commercial, POE, and POU water applications. He received his engineering training at the South Dakota School of Mines and Technology in Rapid City, SD and is a graduate of Concordia University in St. Paul, MN with a BA Degree in Organizational Management and Communications. He can be reached at matthew.wirth@canaturewg.com.

   Hydrotech, a division of Canature WaterGroup, is part of the fastest growing, most innovative manufacturer of high-quality water conditioning products in the world. Our 1.2 million sq. ft. ISO9001:2008 Quality Assurance Certified Facility features NSF Certified control valves, FRP tanks and assembled systems. With over 1000 years of industry experience, our team is dedicated to providing products with better features, quality and overall value – all backed by experienced, dedicated support.