

Potable Water Reuse Report

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Tapping into untapped potential: Three approaches to develop new pathogen crediting frameworks

Key Takeaways:

- Potable reuse requires high levels of pathogen reduction, but many treatment processes do not have frameworks for claiming pathogen credits.
- There are three approaches that can be used to develop pathogen crediting frameworks:
 - **Modeling Approach:** used for treatment processes whose mechanisms of pathogen reduction are well understood and whose performance can be accurately predicted using a model (e.g., an equation) with inputs that can be continuously measured.
 - **Surrogate Approach:** relies on a parameter that: a) can be continuously monitored at the influent and effluent of the treatment process; and b) correlates well with the amount of pathogen reduction provided by the treatment.
 - **Operational Envelope Approach:** establishes pathogen credits based on empirical studies conducted at one or multiple facilities. Credits are based on log reductions observed during the studies but requires the system to operate within the specific limits (i.e., the operational envelope) used during the study.
- The recently-developed frameworks for pathogen reduction crediting in membrane bioreactors provide an example of how new crediting frameworks can provide many benefits for the reuse industry.

1. Introduction

The first two issues of this series described [why pathogen crediting frameworks are needed](#) for potable reuse treatment trains and how [pathogen crediting for under-credited processes](#) like reverse osmosis can be improved. Now we ask: why do some treatment processes get pathogen reduction credits while others do not? And what can be done about the treatment processes that remove pathogens, but currently receive no credit? In this issue, we answer these two questions, showing the types of processes that are currently uncredited and the approaches that can be used to earn them credits.

Why do disinfection processes like chlorine, ozone, and ultraviolet (UV) treatment have well-established pathogen crediting frameworks? They are used in conventional drinking water treatment where crediting frameworks were developed for the Surface Water Treatment Rule, the first US regulation to implement log reduction value (LRV) requirements. Table 1 shows these credited processes.

However, there are also several uncredited processes; these are also shown in Table 1. Many of these are

processes used at wastewater treatment facilities, which do not typically have pathogen LRV requirements. In Australia, water reuse professionals and researchers developed the WaterVal program to address this crediting gap. As Marty Hancock, Research Manager at Water Research Australia, explains:

“The WaterVal framework streamlined the validation of uncredited water treatment processes by providing a consistent, research-backed methodology to assess their log removal performance. This structure has created crediting approaches that are trusted by both regulators and the water industry.”

WaterVal has helped facilitate the development of new crediting frameworks for processes such as membrane bioreactors (MBRs). Similar efforts—such as [CalVal](#)—are currently underway in the United States to standardize crediting. Still, there are treatment processes that do not receive pathogen reduction credits. So, what can be done about these treatment processes?

In this issue, we will explore three different approaches that can be used to assign pathogen reduction credits to a treatment process: (1) a modeling approach, (2) a

surrogate approach, and (3) an operational envelope approach. Underlying each of these crediting approaches is the need for continuous monitoring. As noted by Amos Branch from Carollo Engineers:

“Ideally, you prove that you are controlling pathogens via continuous monitoring of a relevant parameter—such as a surrogate or an indicator—to justify the credit in real-time and to enable rapid corrective actions in the event of a treatment failure.”

The next three sections describe the fundamentals behind each of these crediting approaches and their pros and cons.

Table 1: Examples of treatment processes with and without crediting frameworks.

Processes with pathogen crediting frameworks	Processes without pathogen crediting frameworks
Chlorine disinfection	Activated sludge and its variants
Ozone disinfection	Trickling filters
Ultraviolet (UV) disinfection	Tertiary media filters
Membrane filtration	Biological activated carbon (BAC) filters

2. Modeling Approach

The modeling approach has three components: (1) theoretical understanding of the mechanisms of pathogen reduction, (2) empirical confirmation of the theory’s applicability, and (3) the ability to continuously monitor the factors influencing performance (i.e., the model inputs). If these conditions apply, we can develop models to accurately predict pathogen LRVs based on online monitoring data.

Chlorination is a good example of a disinfection process that receives LRV credit through the modeling approach. As explained in [Issue 1](#) of this series, pathogen inactivation by free chlorine follows well-characterized disinfection profiles (i.e., first order kinetics) that depend primarily on two factors: chlorine concentration and contact time (i.e., the CT value). We know that other key influencing factors such as pH and temperature also impact the rate of pathogen inactivation. Understanding of these mechanisms allows us to develop models and equations that accurately predict pathogen inactivation based on chlorine concentration, contact time, pH, and temperature. These equations are used to develop the CT tables that are widely used for crediting.

But just understanding these factors is not enough: we also need to be able to measure them in real-time. In the case of free chlorine, there is a direct relationship between CT and pathogen inactivation. LRV credits increase and

decrease directly with CT, but other influencing factors, such as pH, have the opposite effect. This results in the ability to directly calculate pathogen LRVs in real-time based on continuous monitoring of all of the influencing factors (Figure 1).

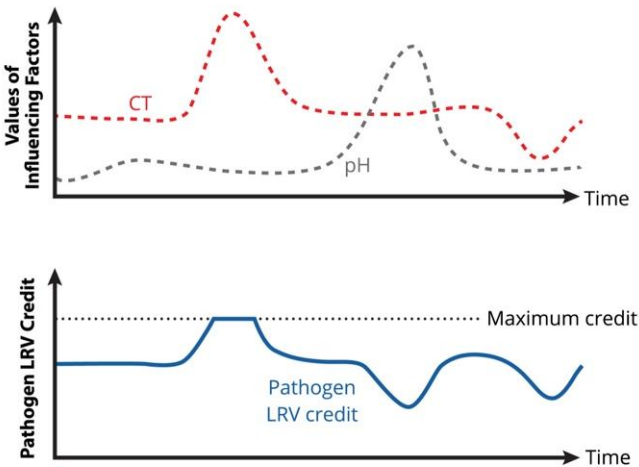


Figure 1: The Modeling Approach can be applied for treatment processes in which the pathogen reduction mechanisms are well understood and can be monitored continuously. Factors influencing pathogen reduction are input into a mathematical model to calculate pathogen LRV credits in real time. For example, chlorination pathogen LRV is directly related to CT except when pH rises, which causes a drop in the obtained credit.

Models cannot be developed, however, if we have incomplete understanding of the mechanisms or an inability to measure the key influencing parameters. One example of this is media filtration. In this case, we can use filtration theory to develop mathematical models that predict pathogen reduction, but we cannot yet measure the key model inputs using online meters. For this reason, a modeling approach to assign pathogen LRV credits for media filters does not exist.

Fortunately, there are alternatives for crediting these processes. The alternative approaches rely more on the observed performance of the process, either based on a surrogate or the performance of a system within a known operational envelope. These approaches expand the range of processes that can be credited, but come with their own sets of pros and cons.

3. Surrogate Approach

As discussed in [Issue 1](#), a surrogate is a parameter that correlates with pathogen reduction through treatment and can be continuously monitored in the influent and effluent of the process. The surrogate’s removal should be equal to or greater than an actual pathogen. With the surrogate

approach, the LRV credit provided for the process is equal to the log reduction of the surrogate parameter (Figure 2). An example of a process that is credited using the surrogate approach is reverse osmosis (as discussed in [Issue 2](#)), where the reduction of a surrogate (e.g., electroconductivity) is used to conservatively estimate the reduction of virus, *Giardia*, and *Cryptosporidium*.

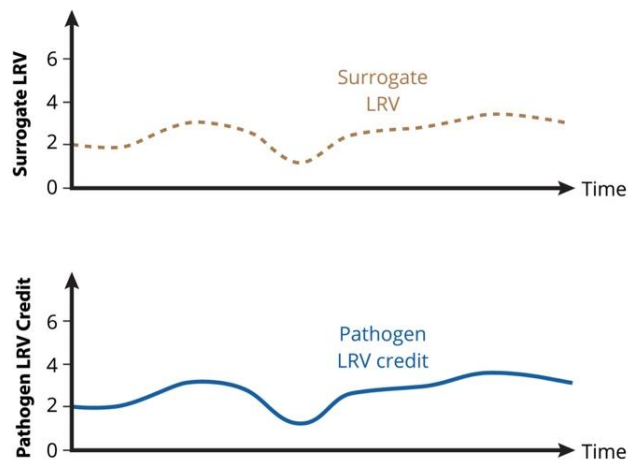


Figure 2: The Surrogate Approach can be applied when there is a surrogate available that mirrors pathogen removal and can be monitored continuously. The pathogen LRV credit is based on the log reduction of the surrogate through the treatment process using continuous monitoring of the surrogate in the influent and effluent.

4. Operational Envelope Approach

If neither a modeling nor a surrogate approach is available, there is still one additional way to seek pathogen credits: an operational envelope approach. This approach involves collecting pathogen data in the influent and effluent to calculate the LRV through the process. Instead of tying the LRV to a model or a surrogate, the third approach focuses on how the process was operated during the period that pathogen data was collected. If the process is maintained within the same “operational envelope” in the future, then the same LRVs are assumed to be achieved. Typically, the operational envelope is defined by validation studies that identify a minimum set of key parameters to monitor to ensure the consistency of pathogen removal performance. The operational envelope is defined by upper and/or lower critical limits.

A key distinction of this approach compared to the other two approaches is that this approach provides a *fixed* LRV credit. You either get full credit because you are within the operational envelope, or you get no credit because you are outside the critical limits (Figure 3). Pathogen crediting can apply to a single facility based on a site-specific study, or it could be applied universally if it is built on the results

from several studies. A main benefit of this approach is that it does not require a full understanding of the reduction mechanisms or the causes of variability in pathogen LRV. Instead, it is based on a record of pathogen reduction across a range of conditions and then assigns a conservative LRV credit that is assumed to be achieved under similar operating conditions.

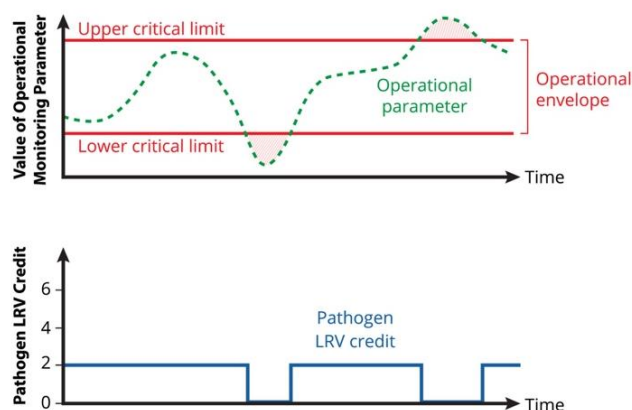


Figure 3: The Operational Envelope Approach can be applied after research is carried out to establish pathogen removal achieved under specific operational conditions. Conservative LRV credit is given as long as the system operates within the pre-established critical limits (the operational envelope). If critical limits are not met, no credit is given.

Given that empirical pathogen LRV data are typically spread across a distribution and not consistent, one challenge of this approach is determining which value should be used for crediting. The mean LRV? The minimum? The precedent in many locations is to use a conservative, low percentile value to assign the LRV. For example, Australia, California, and Colorado have all adopted the use of the 5th percentile into their approaches for pathogen crediting. The use of lower percentiles conveys that: (1) we know that pathogen LRVs fluctuate but, (2) we don’t fully understand the mechanisms causing this fluctuation and, (3) we therefore assign a conservative LRV that should apply nearly all of the time (e.g., a 5th percentile LRV should apply 95% of the time).

The operational envelope approach offers a pathway to assign credits to potentially any unit process, regardless of whether the mechanisms of reduction are fully understood. However, it does not give credit for the full pathogen reduction potential of a unit process because it relies on a conservative LRV (e.g., 5th percentile value). Furthermore, if site-specific studies are required, it can be an expensive approach. A site-specific pathogen study can cost more than US\$500,000 if credits are sought for enteric viruses, *Giardia*, and *Cryptosporidium*.

Calculating a 5th percentile LRV

Many regulators require the calculation of the 5th percentile LRV for pathogen crediting based on the operational envelope approach. But calculating the 5th percentile from your data is not as straightforward as it may seem. Suppose 20 samples from the influent and effluent of a treatment process were analyzed for a reference pathogen. We cannot simply pair the samples collected on the same dates to calculate 20 individual LRVs, then take the 5th percentile of those 20 values. The influent and effluent samples do not represent the same “plug” of water, especially for reactors with mixing and recycling. And [studies](#) have shown that simply offsetting sample collection times by the mean hydraulic retention time does not help. One conservative approach is to define distributions to represent the influent and effluent concentrations and then calculate the 5th percentile of the difference between them using a Monte Carlo method. But this approach is more challenging if there are a lot of non-detects or if the concentrations do not follow a known (e.g., lognormal) distribution. The question of how to calculate 5th percentile LRVs from influent and effluent concentrations is a topic of [ongoing research and debate](#).

5. Success Story: MBR

MBRs have been used for decades but only recently began receiving credits for pathogen reduction. The [WaterVal MBR crediting framework](#) used an operational envelope approach to develop conservative, baseline LRV credits (1.5/2/4 log for viruses, protozoa, and bacteria). Because the credits were based on a [wide-ranging review of data](#) from multiple, full-scale MBR facilities, the findings can be applied to any MBR system meeting the operational limits. This extensive work led other regulators to develop confidence in the use of the operational envelope approach. As Brian Bernados, a former regulator from the California Division of Drinking Water, recalls:

“We saw the work being done by the Australians and decided that those validation protocols were robust. We definitely borrowed from them.”

[WRF Report 4997](#) adapted the WaterVal MBR pathogen crediting protocol for use in the US. Similar to the WaterVal protocol, WRF 4997 provides a default set of conservative “Tier 1” credits (1.0- $\log_{10}$ for viruses and 2.5- $\log_{10}$ for protozoa) based on a statistical analysis of historical MBR performance data. Like WaterVal, WRF 4997 offers an opportunity for systems to seek higher “Tier 2” credits through additional empirical testing. This requires a site-specific study to calculate the 5th percentile LRV for a

system operating within a designated envelope. For MBRs, the operating envelope may be defined by parameters such as effluent turbidity or other operational parameters, but it is up to the facility to identify the criteria and critical limits for these parameters during the site-specific study.

The Australia and US MBR pathogen crediting frameworks have had an important impact on the potable reuse industry. Agencies have always looked to MBRs to produce high-quality filtered water, but now they can also receive pathogen credits and more fully realize the technology’s potential. It is no surprise that the recent proliferation of MBRs in potable reuse coincided with the development of a pathogen crediting framework, highlighting the importance of pathogen crediting in technology selection. According to Stephen Katz, Municipal Business Development and Large Program Director at Veolia Water Technologies & Solutions:

“The development of the crediting framework had a major impact on programs considering MBRs. MBRs have many benefits for potable reuse including footprint and cost savings as well as effluent quality, but they didn’t receive any pathogen credit. Having an accepted baseline pathogen credit has allowed programs to confidently move forward with MBR implementation.”

In the US, much of the potable reuse work related to pathogen crediting frameworks has been done at the state level, however federal investments, such as the development of the US EPA’s *Membrane Filtration Guidance Manual* have been helpful to serve as a starting point for framework development. Future efforts at the federal level, such as updating the *Membrane Filtration Guidance Manual*, could continue to provide value for pathogen crediting in potable reuse systems.

6. Carving a Path Forward for Uncredited Processes

In summary, current pathogen crediting schemes rely on one of three approaches. For the modeling approach, we need a well-developed understanding of the mechanisms of pathogen control and the ability to measure the influencing parameters in real-time. For the surrogate approach, we need to identify an easily-monitored surrogate whose reduction through the treatment process is conservative compared to pathogens. If neither of these approaches is available, we can characterize pathogen reduction through a process over a range of operational conditions. While this operational envelope approach provides an avenue for nearly any process to receive credits, it typically assigns conservative LRV credits on a pass/fail basis, potentially leaving pathogen LRVs on the

table. Figure 4 presents a decision tree to aid in the selection of a crediting framework for a new unit process.

Research is needed to further uncover the mechanisms of pathogen reduction and to develop new sensors to monitor surrogates and key influencing factors. This research would allow us to move away from the use of conservative 5th percentile credits and toward modeling and surrogate approaches. One effort that would support the transition toward additional modeling- and surrogate-based approaches is the collection of more pathogen data. Amos Branch promotes the development of:

“...a repository where the data from site-specific pathogen validation studies can be compiled, anonymized, and screened. This would be valuable to find correlations between pathogens, surrogates, and influencing factors.”

Given the high pathogen LRVs required for potable reuse, agencies must consider how and where to seek credits.

Some projects may prefer to invest in the equipment and staffing to implement new surrogates (e.g., strontium) to get higher LRV credits for a process like reverse osmosis (see [Issue 2](#)). Others may opt to allocate resources toward site-specific pathogen studies for undercredited processes (e.g., a Tier 2 MBR study) or uncredited processes (e.g., activated sludge).

Important work remains to develop frameworks for uncredited treatment processes. Despite the cost and effort, the development of new frameworks can benefit the whole reuse industry, as has been the case with MBR. The momentum that began with WaterVal has extended to CalVal, which will continue to develop and expand frameworks for potable reuse. Further research could have similar positive effects, allowing projects to gain more credit for their existing processes and improve the economics of reuse.

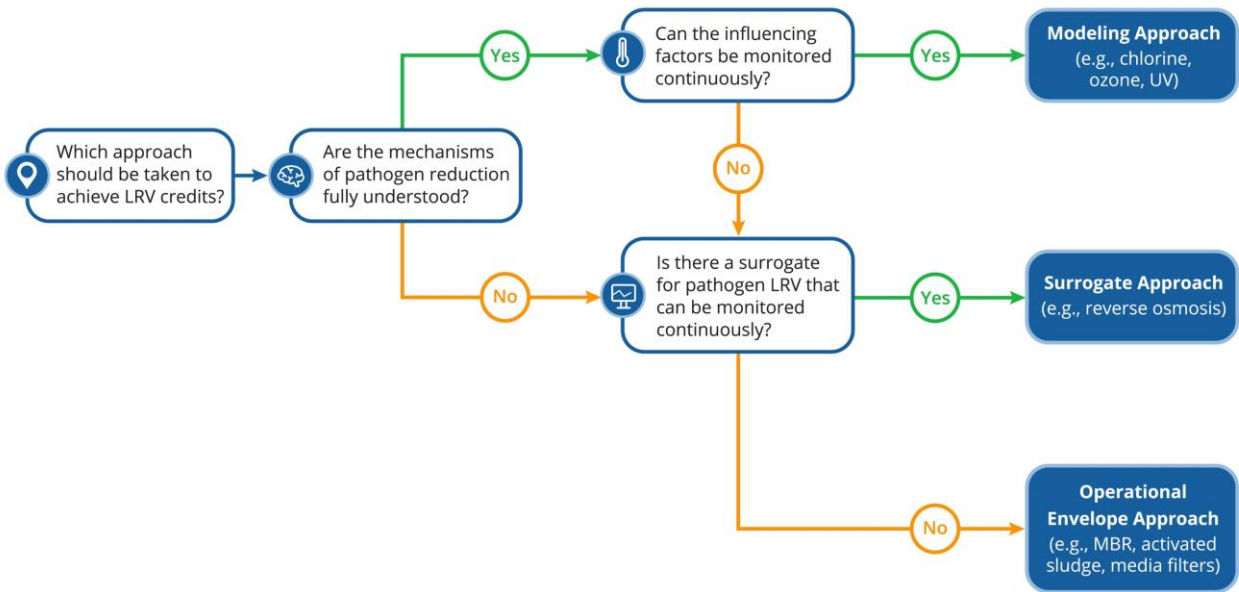


Figure 4: Decision tree to select from the three presented approaches for pathogen crediting.

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