Viral Pathogen Inactivation Requirements for Groundwater Treatment Systems

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In 1990 the EPA's Science Advisory Board concluded that exposure to microbial contaminants such as bacteria, viruses, and protozoa (e.g., *Giardia lamblia* and *Cryptosporidium*) was likely the greatest remaining health risk management challenge for drinking water suppliers.

These concerns were realized as the result of a *Cryptosporidium* outbreak that caused intestinal illness in 400,000 people in Milwaukee in 1993. More than 4,000 were people hospitalized, and at least 50 deaths were attributed to the disease. There were also confirmed cryptosporidiosis outbreaks in Nevada, Oregon, and Georgia over the past several years.(1)

Over the past 10 years, the EPA, through the provisions of the Safe Drinking Water Act, has been addressing safety concerns actively with specific microbial surface water pathogens in drinking water that are resistant to traditional disinfection practices. The agency has developed surface water treatment rules to minimize risks from these contaminants. The EPA measures include maintaining an acceptable level of disinfection to inactivate harmful pathogens.

Groundwater sources are typically protected from surface-water pathogens by separation, natural filtration, and protective measures to prevent flooding and other surface microbial pathways, but if groundwater protections are compromised, the source water can become contaminated with fecal matter.

Fecal matter may enter the treatment system from fissures or other pathways that allow contaminated groundwater to mix with normally uncontaminated well water. Birds, vermin, and insects provide other pathways for contaminated matter to enter open tanks used in the treatment process.

Groundwater occurrence studies and a careful review of disease outbreak data have demonstrated that pathogenic viruses and bacteria can occur in public water systems that use groundwater supply sources. These studies conclude that people drinking this type of groundwater can become ill, and in isolated cases, fatalities could occur. The EPA has estimated that an average of 42,000 illnesses and four deaths occur each year as a result of source contamination when disinfection is inadequate or interrupted.(3)

This potential is of great concern in Florida, where groundwater provides over 99 percent of the source supplies for potable water. For this reason, the Florida Department of Environmental Protection (FDEP) requires documentation of proper levels of disinfection where it has been demonstrated that fecal contamination is present in groundwater or where pathogen contamination is possible.

The FDEP has incorporated rules in the Florida Administrative Code (FAC) requirements for these impacted groundwater treatment systems to use disinfection methods proven to inactivate viral pathogens. The viral removal methodologies used are the same ones that were developed by the EPA for surface water treatment plants.

Pathogen Inactivation

In water treatment, the primary method to inactivate pathogenic organisms is disinfection, which achieves this goal in three ways:

1. Destroying or impairing cellular structural organization.
2. Interfering with energy-yielding metabolism.
3. Interfering with biosynthesis and growth.

Proper viral inactivation, then, is reducing the numbers of pathogens and impairing the ability of the remaining pathogens to cause human health problems.

Water Borne Diseases in Groundwater Sources

Pathogenic agents in groundwater may be both bacterial and viral; in most cases, the specific pathogen causing the illness is not identified. Since viruses are much smaller than bacteria, viruses are capable of passing through natural filtration barriers and are the focus of concern in groundwater pathogen inactivation.

Typically, people with bacterial and viral illnesses caused by contaminated groundwater have gastrointestinal symptoms (diarrhea, vomiting, etc.) These illnesses are frequently self-limiting in healthy individuals, rarely require medical treatment, and go unreported, but these same symptoms are much more serious and can even be fatal for young children, elderly people, and those with compromised immune systems.

In recent times, very serious outbreaks of other types of waterborne illnesses have made national news headlines. In November of 2003, the Pennsylvania Department of Health and the Centers for Disease Control (CDC) investigated an outbreak of hepatitis A outbreak among patrons of a restaurant in Monaca, Pennsylvania. Approximately 555 persons with hepatitis A were identified, including at least 13 food service workers and 75 residents of six other states who ate there. Three persons have died from the illness.

A case-control study implicated green onions as the source of the outbreak. The suspected source of hepatitis A virus contamination was HAV-likely water used in irrigation, or in processing of the onions on farms in Mexico. HAV is transmitted by the fecal-oral route.

Even more recently in 2006, a California natural foods company was linked to a nationwide E. coli outbreak from raw spinach. The FDA identified the pathogen as O157:H7, the same E. coli strain that in 2000 killed seven people in Walkerton, Ontario. It has been linked to the death of one person and has sickened nearly 100 others.

In the most recent case involving the spinach, supermarkets across the country pulled spinach from shelves and consumers have been advised to dispose of any of the purchased product. The Food and Drug Administration stated that it had received reports of illness in 21 states. The bug has sickened at least 94 people across the nation. According to the CDC, 29 people have been hospitalized, 14 of them with kidney failure. E. coli is transmitted by the fecal-oral route.

These two recent occurrences of water transmission of viral and bacterial agents illustrate the inherent health impacts associated with contaminated groundwater.

Table 1 illustrates some of the well-known viral pathogens that have been identified in waterborne disease transmission, the names of the illnesses, their various symptoms, and areas of the body that each virus affects.

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Group	Subgroup	No. of (Sub)Types	Associated Disease	Organs Where Virus Multiplies
Enterovirus	Poliovirus	3	Muscular paralysis Aseptic meningitis Febrile episode	Intestinal mucosa, spinal cord, brain stem Meninges Intestinal mucosa and lymph
	Echovirus	34	Aseptic meningitis Muscular paralysis Guillain-Barre's Syndrome[1] Exanthem Respiratory diseases Diarrhea Epidemic myalgia Pericarditis and myocarditis Hepatitis	Stem Intestinal mucosa, spinal cord, brain Spinal cord Skin Respiratory tracts and lungs Gastrointestinal tract Respiratory tract and gastrointestinal tract Pericardial and myocardial tissue Liver
	Coxsackie	>24	Herpangina[2]	Mouth
			Acute lymphatic pharyngitis Aseptic meningitis Muscular paralysis Hand-foot-mouth disease[3] Respiratory disease Infantile diarrhea Hepatitis Pericarditis and myocarditis	Lymph nodes and pharynx Meninges Intestinal mucosa, spinal cord, brain stem Skin of hands-feet, and much of mouth Respiratory tracts and lungs Intestinal mucosa Liver Pericardial and myocardial tissue
Enterovirus		6	Pleurodynia[4] Aseptic meningitis Muscular paralysis Meningoencephalitis Pericarditis, endocarditis, myocarditis Respiratory disease Hepatitis or Rash Spontaneous abortion Insulin-dependent diabetes Congenital heart anomalies	Intercostal muscles Meninges Intestinal mucosa, spinal cord, brain stem Meninges and brains Pericardial and myocardial tissue Respiratory tracts and lungs Liver Placenta Langerhan's cells of pancreases Developing heart
Reovirus		6	Not well known	
Adenovirus		31	Respiratory diseases Acute conjunctivitis Acute appendicitis Intussusception Subacute thyroiditis Sarcoma in hamsters	Respiratory tracts and lungs Conjunctival cells and blood vessels Appendia and lymph nodes Intestinal lymph nodes Thyroid Muscle cells
Hepatitis		>2	Infectious hepatitis Serum hepatitis Down's Syndrome	Liver Liver Frontal lobe of brain, muscle, bones

Table 1: Groundwater Viral Pathogens, Diseases, and Organs Affected

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Microbially Impacted Groundwater & Viral Inactivation Requirements

Monthly source well monitoring for total coliform is required by the FDEP. If a well raw-water sample is positive, the well must be disinfected and bacteriologically surveyed. The survey must include taking 20 samples at least six hours apart and investigating for the presence of total coliform and E. coli, which has long been used in water treatment as a specific indicator of the presence of enteric contamination and is a more definitive indicator of recent fecal contamination than fecal coliform.(4)

Inactivation of viruses that may contaminate groundwater well sources provides a higher level of protection to the public than bacterial inactivation because viruses are much smaller in size than a bacterium and thus may be more easily and rapidly transmitted through small soil pores. Viral pathogens must be inactivated where presence of E. coli has been confirmed in a groundwater source or persistent total coliform contamination is identified.

Similarly, when treatment units are left open to the atmosphere, microbial pathogens may find their way into the treatment system. If disinfection is inadequate, human illness can result.

The FDEP has issued rules for impacted or potentially impacted groundwater sources. FDEP requirements for groundwater source protection are found in FAC 62-555.315(6)(b) and (f). These requirements cover the start-up of a well that has been out of operation for more than six months and the sampling requirements that must be performed before start-up is approved.

#	Factor Description	Disinfection Activity
1.	Disinfectant type	The stronger the disinfectant, the quicker the disinfection process.
2.	Disinfectant dose	Increasing the disinfectant dose will increase the disinfection rate and inactivation, but may also increase the formation of harmful byproducts.
3.	Contact time	In general, increasing the contact time will decrease the disinfectant dose required for pathogen inactivation.
4.	pH	pH may affect the disinfectant form and, in turn, the efficiency of the disinfectant.
5.	Temperature	Typically, increasing the temperature will increase the rate of disinfection.

Table 2: Summary of Factors that Affect Disinfection Efficiency

The regulation states that, "if any sample shows the presence of E.coli, the well shall be considered microbially contaminated, unless the Department invalidates the sample or the supplier of water determines and eliminates the source of the E. coli."

Subsection (f) has similar requirements, stating that water suppliers must periodically sample raw groundwater for microbiological contamination and further stating, "if any sample is positive for E.coli, the relevant well(s) shall be considered microbially contaminated unless the Department invalidates the sample or the supplier of water determines and eliminates the source of the E. coli …"

Systems with wells that are "susceptible mircobially," are also required to inactivate viruses in accordance with FAC 62-555.315(6)(b) when notified by the FDEP to do so. Typically, viral inactivation is required by the FDEP when groundwater systems have two or more routine monthly/quarterly samples that are positive for total coliform. These systems will be notified in writing when the system has had three or more total coliform-positive samples in a well in any 12-month period.

Treatment protection requirements are found in FAC 62-555.320(12)(b), which states that " … suppliers of water using groundwater that is not under the direct influence of surface water but that is exposed during treatment to open atmosphere and possible microbial contamination, shall provide treatment that reliably achieves at least 4-log inactivation or removal of viruses before or at the first customer at all flow rates." This section also requires systems that meet the definitions in subsections (b) and (f) to also meet the 4-log inactivation or removal of viruses.

For the purposes of groundwater supply protection, a 4-log viral inactivation requirement must be met at the peak flow during water production. Peak flow is considered to be the time when the greatest volume of water passes through the treatment system during any 24-hour period.

Principles of Virus Inactivation Using Chemical Disinfectants

To identify the effectiveness of disinfection and microbial inactivation, the EPA identified and studied a number of properly operating water treatment plants throughout the country and tested the removal efficiency of various chemical disinfectants at these locations. From these studies, the agency derived tables for microbial and viral inactivation that could be achieved reliably. This inactivation data was then converted to theoretical levels of inactivation for various plant disinfection conditions that could be expected.

In properly operated groundwater treatment systems, viral inactivation has been found to be dependant on the disinfectant type, disinfectant dose, temperature, pH, and the amount of time that the disinfectant is in contact with the pathogen. These factors and their disinfection activity are illustrated in Table 2.

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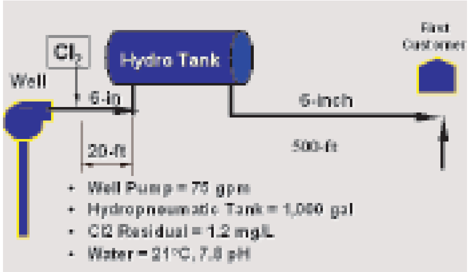
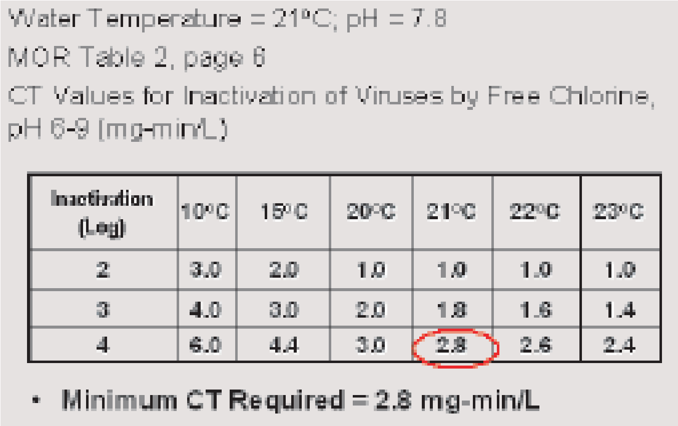


Segment	Disinfectant Concentration (mg/l)	Contact Time (min)	Calculated CT (mg-min./l)
20' Pipe	1.2	0.4	.46
Hydro Tank	1.2	0.4	.46
500' Pipe	1.2	9.8	11.76
		Total CT =	12.68


Water Temperature = 21°C; pH = 7.8

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CT Values for Inactivation of Viruses by Free Chlorine, pH 6-9 (mg-min/L)

Inactivation (Log)	10°C	15°C	20°C	21°C	22°C	23°C
2	3.0	2.0	1.0	1.0	1.0	1.0
3	4.0	3.0	2.0	1.8	1.6	1.4
4	6.0	4.4	3.0	2.8	2.6	2.4

- Minimum CT Required = 2.8 mg-min/L

Figure 1: Example - Calculating Viral Inactivation for a Simple Groundwater Treatment System

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Using CT Values to Determine Viral Inactivation

Viral inactivation is expressed as the product of the concentration of the disinfectant in mg/l (C) and the time of contact with the pathogen in minutes (T). Ranges of CT values are found in CT tables published by the FDEP. These tables indicate the levels of viral inactivation required under various treatment plant operating conditions.

As the CT value is increased, a greater percentage of viruses are inactivated by chemical disinfectant. Thus, applying greater doses of the disinfectant and/or increasing the time that the water is in contact with the disinfectant will increase the CT value.

The level of inactivation is generally referred to in terms of "log inactivation." Viral inactivation is measured on a logarithmic scale (i.e., orders of magnitude reduction of viruses). For example, a 2-log inactivation of viruses corresponds to inactivating 99 percent of the existing number of viruses through the disinfection process.(2)

Variables in the Viral Deactivation Process for GroundWater Systems

In order to properly identify viral inactivation, plant process operational information must be collected by the water treatment system on a daily basis. This information is used to compute actual CT viral inactivation values for each treatment process, referred to as "segments".

The values computed for each segment are then added together to determine the actual inactivation level achieved. This actual inactivation value is then compared to the required log reduction inactivation value found in the FDEP tables. An actual combined CT value must equal or exceed the corresponding 4-log inactivation value found in the table.

A simple example is illustrated in Figure 1 for a small water treatment system where free chlorine is injected just after the well and measured just before the first customer.

For this particular treatment system, the calculated 12.68 mg-min/L is greater than the 2.8 mg-min/L found in the Tables and is more than adequate for inactivating any viruses.

CT as Representative of Water Treatment Viral Inactivation

As shown in Figure 1, the residual disinfectant concentration is determined before or at a sampling point connected to a pipeline that provides water for human consumption. The CT Equation in the appropriate units is:

CT (minutes x mg/L) = C x T where:
C = Residual disinfectant concentration measured before or at the first customer during peak flow in mg/l.
T = Time, measured in minutes during peak flow, from the point of disinfectant injection, to a point where the residual is measured before or at the first customer or at the next disinfectant application point.

Log Removal Credits for Viruses

The FDEP may grant log removal credits for filtration. A credit is subtracted from the 4-log removal requirement and the CT requirement is then based on the smaller value. Credits will typically vary, depending on the treatment process used (such as conventional, direct, or alternative filtration).

Credits will be valid only if filtration systems are operated according to accepted operating parameters. For properly operated conventional filters, a 2-log credit is typically allowed. This means that 2-log inactivation will be accomplished by disinfection and 2-log inactivation will be accomplished with filtration.

Referring to the Table in Figure 1 and considering that filtration treatment process was added before the hydro-tank, the inactivation required by disinfectant addition would change from the 2.8 mg-min/l shown in the example, to 1.0 mg-min/l as shown for 2-log inactivation in that the table used in the example.

Log Viral Removal Requirements for Non-Filtration Type Water Treatment Systems

For unfiltered water treatment systems, 4-log inactivation must be achieved through disinfection.

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Segment	Disinfectant Concentration (mg/l)		Contact Time (min)	Calculated CT (mg-min./l)	Disinfectant 4-Log Removal Ratio
	Cl$_2$	NH$_2$Cl			
20' Pipe	1.2		0.4	.46	.46/2.8 = 0.16
Hydro Tank	1.2		0.4	.46	.46/2.8 = 0.16
500' Pipe		2.4	9.8	23.52	23.52/746 = 0.03
					Total CT = 0.35

Figure 2: Calculating Viral Inactivation Using both Free Chlorine and Chloramines (see plant layout in Figure 1)

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When more than one disinfectant is used, the actual log inactivation achieved is determined by calculating the log inactivation provided in each treatment process and dividing it by the required log inactivation required found in the FDEP table (DEP Form 62-555.900(3) Alternate). The actual log inactivation for viruses can be calculated by the following formula:

Log Inactivation for Virus Equation
4-Log Inactivation of Viruses = $CT / CT_{99.99}$

CT = value calculated for water treatment systems.
$CT_{99.99}$ = value obtained from 4-Log inactivation found in FDEP Table.

To achieve compliance, the 4-log inactivation of viruses that is calculated using the above equation must always yield a value greater than unity (1), i.e. 4-log inactivation of viruses > 1.

For example, if the disinfection scheme in Figure 1 were changed to chloramination at the end of the hydro-tank and the residuals were measured as free chlorine before the chloramination point at 1.2 mg/l, chlorimine was added just after this point and measured at the same point in the distribution systems as in Figure 1 at 2.4 mg/l as chloramine. Calculating the 4-log viral inactivation for this system proceeds as follows in Figure 2.

Note that for free chlorine the required 4-log inactivation is 2.8 mg-min/l and for chloramine (NH_2Cl) the 4-log inactivation value was found in a different table to be 756 mg-min/l at a temperature of 21°C and a pH of 7.6. This system would not meet the viral inactivation requirements, since the CT value is less than one (1), i.e. CT Calculated < CT of 1 required for 4-log viral inactivation.

Considerations for Determining Contact Time for Unit Process

The unit processes that comprise each disinfection treatment process segment may include sedimentation, filtration, and pipeline flow. If there are other processes, these need to be included also.

Each of these processes exhibits specific hydraulic characteristics affecting the contact time that must also be accounted for. When more than one disinfection application point is used, CT must be calculated for each treatment segment. Calculated CT values are additive in determining the total CT value achieved; that is, the inactivation achieved by each segment is determined using the above equation.

In totally submerged pipelines, the contact time can be assumed equivalent to the theoretical detention time and is calculated by dividing the internal volume of the pipeline by the peak flow rate through the pipeline. Pipeline flow is assumed to be plug flow because there are no dead zones or unutilized volume in the pipe; therefore, each unit of water is assumed to spend the same time in the pipeline.

For treatment basins, the time spent by the water in the reactor may vary over a wide range, depending on how the basin is used. For example, some basins may be partially empty or may contain solids. These conditions must be accounted for when calculating basin volumes. Factors that impact contact time in a basin include:

1. Flow rate (when unknown use pump rating)
2. Water level in the unit (recorded observation or from chart recorder)
3. Geometric shape of the unit
4. Inlet/outlet locations
5. Baffle types and locations in the basin
6. Whether filling or emptying (recorded observation or chart recorder)
7. Sludge depth in the basin (recorded or measurement)
8. Seasonal dry or wet conditions (recorded or measurement)
9. Thermal stratification in basins (observation)
10. Covered or uncovered treatment process basin (uncovered basins can not be used in calculating CT)

The actual contact volume of water in each basin, pipe, or unit process must be used to calculate contact time. Since many treatment basins will have fluctuating water levels

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No.	Basin Type or Condition	Value to be Used in Calculating Contact Time at Peak Flow
1.	All Covered Basin Types	Minimum Water Level
2.	Hydro-Tank with separate inlet and outlet	Use the water level in the tank at minimum operating pressure. This will be 10% to 25% of gross volume of the tank. A hydro-tank with a minimum operating pressure of 35 psi typically will be operated 5 to 10 psi below this pressure.
3.	Covered Storage Reservoirs	Minimum Water Level minus dead or system pressure storage.
4.	Uncovered Filters	Depth of Water below Media Surface minus the volume of the media (assumed to be 60% of the volume)
5.	Covered Sedimentation Basin Conventional	Minimum Depth of Water above Sludge surface. Depth should be at the highest sludge blanket condition observed in the basin.
6.	Covered Solids Contact Type Sedimentation Basin	Minimum Depth of Water above Slurry (Separation Zone.) Depth should be at the highest sludge blanket condition observed in the basin.
7.	Clearwells	Minimum Depth of Water in Basin.
8.	Pipelines	Full volume if submerged

Table 3: Guidelines for Determining Basin Capacities for Calculating Contact Time

Baffling Condition	T_{10}/T or Baffling Factor	Baffling Description
Unbaffled (mixed flow)	0.1	None, agitated basin, very low length to width ratio, high inlet and outlet flow velocities
Poor	0.3	Single or multiple unbaffled inlets and outlets, no intrabasin baffles
Average	0.5	Baffled inlet or outlet with some intra-basin baffles
Superior	0.7	Perforated inlet baffle, serpentine or perforated intrabasin, media filters. baffles, outlet weir or perforated launders
Perfect (plug flow)	1.0	Very high length-to-width ratio (pipeline flow), perforate inlet, outlet, and intra-basin baffles

Table 4: Baffling Classifications and Factors for Various Basin Configurations

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that affect volume, the most conservative value at the peak flow should be chosen.

Basins in the treatment process that are open to the atmosphere may not be used in contact-time calculations, since they are subject to recontamination. Filters that are open to the atmosphere present a special condition for groundwater systems that must be accounted for. The water level above the media can not be used in contact calculations, since it is subject to recontamination from the atmosphere. The water that passes through the media, however, can be used in the contact-time calculations.

Where information is not available for the peak condition, then the minimum volume that can occur in the treatment unit or the lowest volume realized for the peak flow should be used. The operator who performs the contact time calculation must identify and include an accurate representation when determining basin volumes. Table 3 provides some suggestions.

Determining Contact Time in Mixing Basins & Storage Reservoirs

In mixing basins and storage reservoirs, the theoretical detention time is not the actual disinfectant contact time as previously discussed, so determining contact time is more complicated with basins.

Most clearwells and some other treatment basins were not designed to provide optimal hydraulic characteristics for contact with a disinfectant. For the purpose of determining compliance with the disinfection requirements, the contact time of mixing basins and storage reservoirs used in calculating the actual CT should be the detention time in which 90 percent of the water passing through the unit is retained within the basin, known as T_{10}.

Information provided by tracer studies should be used for estimating T_{10} for the purpose of calculating the actual CT when available. For most systems, these are not available and a theoretical detention time and baffling factor approach may be used.

A plant with multiple treatment trains and different operating characteristics must identify the critical train with the shortest detention time.

Most basins will exhibit some level of short circuiting; that is, velocity currents will develop that carry viruses along at a faster rate through the tank than actually calculated. It is therefore necessary to rate basins using a factor called a "baffling factor." Baffling factors have been calculated for a wide variety of basin configurations, based on the time during which 90 percent of the water remains in the unit process.

Theoretical detention time (T) is computed by dividing the volume of a unit process in gallons by the peak flow rate in gallons per minute (T=V/Q). Baffling factors or (T_{10}/T) are selected for the specific unit process. The baffling factors are multiplied by the theoretical detention time to yield an estimate of the actual contact time.

Remember that in computing contact times, basin volume must first be adjusted for the actual conditions listed in Table 3. Table 4 illustrates the derating or baffling factors (T_{10}/T) that must be multiplied by the theoretical detention time (T) to arrive at the actual contact time (T_{10}.) used in calculating CT when tracer study results are not available.

Conclusion

This article identifies the many considerations for properly computing viral inactivation for groundwater sources that may be or may potentially be microbially contaminated. The requirements for CT calculations are found in current FDEP rules.(8) Where inactivation is required, CT values must be submitted on the proper form with the water treatment plant's monthly operating report (MOR).

Water treatment plants exhibit various process configurations and use different disinfectants, so each plant requires a custom approach to properly calculate CT values. The Florida Rural Water Association has published guidelines, titled, "Calculating and Reporting CT Values for Groundwater Treatment Systems" which provide examples for typical water treatment plant configurations and illustrate the proper methods for calculating viral inactivation discussed in this article. These guidelines may be downloaded online at the association's Web site, www.frwa.net.

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