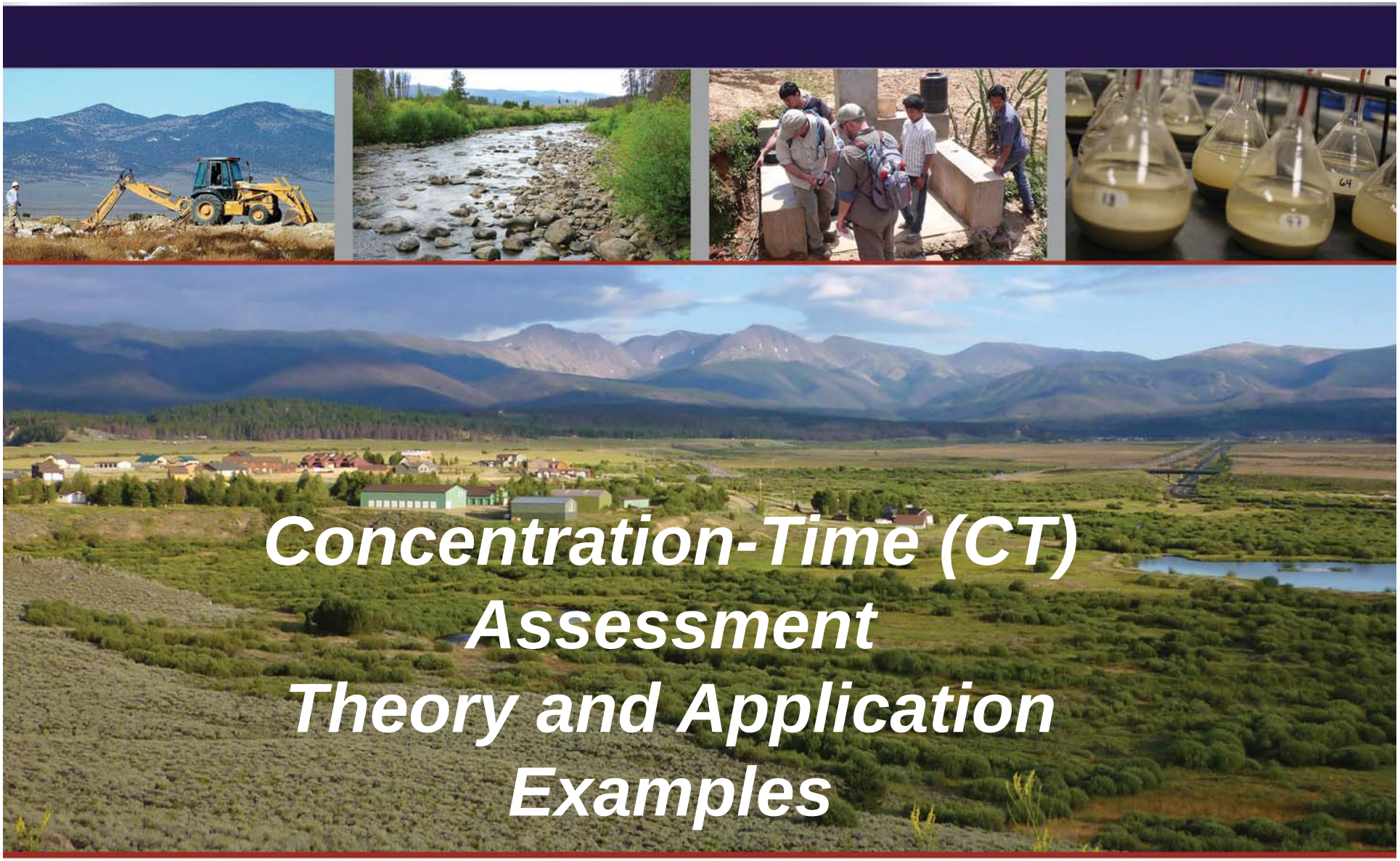


Concentration-Time (CT) Assessment
Theory and Application
Examples

Daniel B. Stephens & Associates, Inc.

Chlorine Demand

The consumption of the chlorine used for disinfection

What is added	What is used	What remains
Dosage	– Demand	= Residual

- Organics
- Microorganisms
- Ammonia-Nitrogen
- Nitrate
- Iron
- Silt

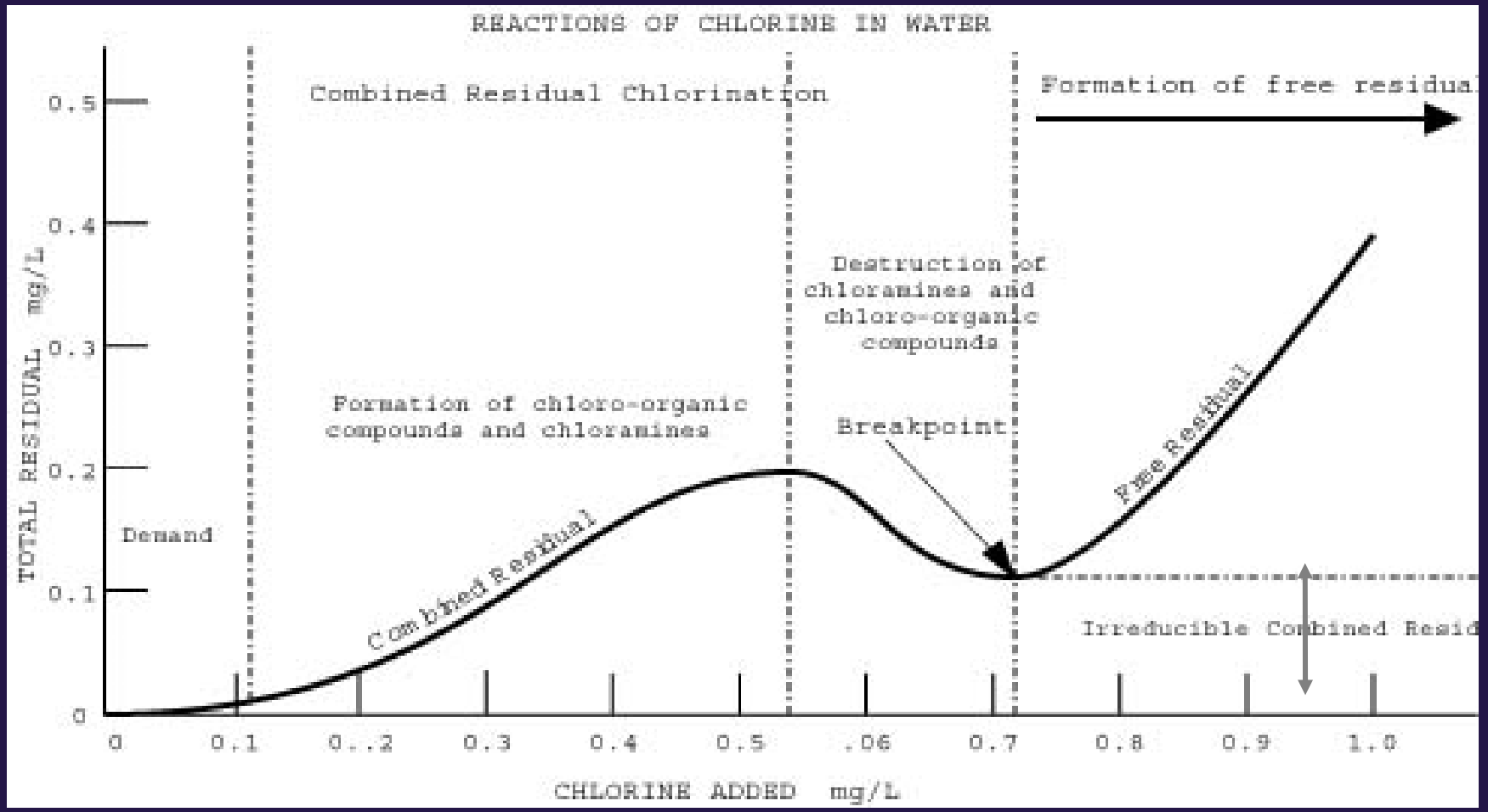
Chlorine Residuals

- Free chlorine residual
  - Uncombined chlorine in the form of hypochlorous acid (HOCl) or hypochlorite ion (OCl)
- Combined chlorine residual
  - Chlorine that is combined with ammonia-nitrogen to form chloramines: NH_2Cl, $NHCl_2$, NCl_3
- Total chlorine residual
  - Free residual + Combined residual = Total residual

Chlorination

- Breakpoint chlorination
  - Addition of enough chlorine to destroy majority of nitrogen compounds
  - Irreducible combined residual
- Total chlorine residual
  - Free + combined residual
- Effectiveness
  - Lower pH, higher temperature
  - Free > combined residual
  - Combined lasts longer
  - Combined forms fewer TTHMs

The Breakpoint Curve



Concentration–Time (CT) Calculations

Table of Log Removal

Log Cycle	initial amount, %	% removal	amount removed, %	% remaining
1	100	90	90	10
2	10	90	9	1
3	1	90	0.9	0.1
4	0.1	90	0.09	0.01
		Total Removed, %	99.99	4-Log Removal

For any number of log cycles, % removal = $100\ (1 - 1/10^{\langle \text{log removal} \rangle})$

For example, for 0.5-log removal, % removal =
$100\ (1 - 1/10^{\langle 0.5 \rangle}) = 100\ (1 - 1/3.16) = 100\ (1 - 0.316) = 100\ (0.684) = 68.4\%$

Understanding CT

$$CT\ [(mg\text{-}min)/L] = C \times T$$

- C = Concentration of disinfectant residual (mg/L)
  - Must be measured before or at first customer
  - For systems using chlorine, can be measured with portable kit or continuous monitor using an EPA-approved method
- T = contact time (minutes) between point of application of disinfectant and point where disinfectant residual is measured
  - Based on system components

Calculating CT, GWR Example

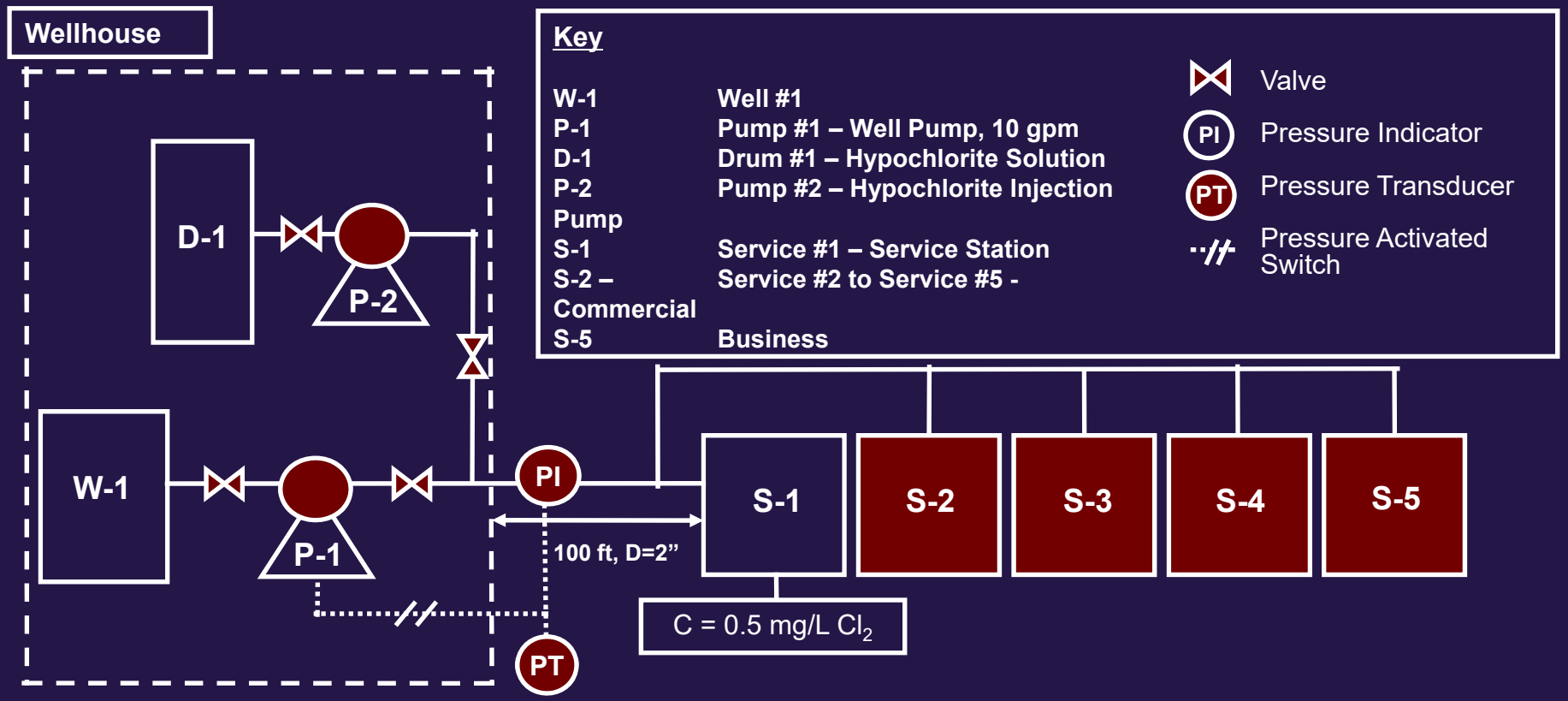
- You will need to know:
  - C (mg/L or ppm), the measured disinfectant residual at or before the first customer
  - Length (ft) of each pipe between point where disinfectant is applied and where it is measured
  - Diameter (ft) of each pipe between point where disinfectant is applied and where it is measured
  - Volume of water (gallons) of any storage tank used to provide disinfectant contact time and baffling factor for the tank
  - Maximum daily flow (gpm) of system, measured with flow meter, maximum capacity of pump, or another state-approved method

Example: Redwood Road Water System

- Well pump has manufacturer's rating of 5 gpm.
- Water is injected with liquid sodium hypochlorite in wellhouse.
- 100 ft of 2-inch-diameter pipe between wellhouse and first service connection.
- Free chlorine residual at first service connection is 0.5 mg/L as Cl_2.

How much CT does the system have?

Schematic: Redwood Road Water System



Note: Figures not drawn to scale

CT Calculation, GWR Example

- Basic Formulas:
  - Calculating pipe cross-sectional area = $(\pi \div 4) \times (\text{diameter}^2)$
  - Calculating pipe volume = pipe length x cross-sectional area
  - Calculating disinfectant contact time = pipe volume ÷ flow
  - Calculating CT = disinfectant residual x contact time

CT Calculation, GWR Example

- Calculating CT using actual conditions:
  - Pipe cross-sectional area = (π ÷ 4) x (diameter^2) = (3.14 ÷ 4) x (diameter^2) = 0.785 x (2/12 ft)^2 = 0.022 ft^2
  - Pipe volume = pipe length x pipe cross-sectional area = 100 ft x (0.022 ft^2) = 2.2 ft^3 = 2.2 ft^3 x 7.48 gallons/ft^3 = 16.4 gallons
  - Contact time = Volume in pipe ÷ flow = 16.4 gallons ÷ 5 gpm = 3.3 minutes
  - CT = 0.5 mg/L × 3.3 minutes = 1.7 mg-min/L

Compare with CT required by GWR to achieve 4-log inactivation of viruses.

CT Table (from GWR)

CT Values for Inactivation of Viruses by Free Chlorine, pH 6.0-9.0

°C	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Inactivation (log)																				
2	5.8	5.3	4.9	4.4	4.0	3.8	3.6	3.4	3.2	3.0	2.8	2.6	2.4	2.2	2.0	1.8	1.6	1.4	1.2	1.0
3	8.7	8.0	7.3	6.7	6.0	5.6	5.2	4.8	4.4	4.0	3.8	3.6	3.4	3.2	3.0	2.8	2.6	2.4	2.2	2.0
4	11.6	10.7	9.8	8.9	8.0	7.6	7.2	6.8	6.4	6.0	5.6	5.2	4.8	4.4	4.0	3.8	3.6	3.4	3.2	3.0

CT values provided in the tables are modified by linear interpolation between 5°C increments.

Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources

www.epa.gov/safewater/mdbp/guidsws.pdf

Considerations for Calculating CT for SWT

- Chlorine effectiveness, extrapolate or worst-case (EPA tables)
  - pH, temperature
- Detention time (DT)
  - Plug flow vs. CSTR
  - CSTR
    - Theoretical DT
    - Actual DT
      - Baffling factor (WaDoH handout)

Detention Time

- Theoretical detention time (TDT) = volume ÷ flow
  - Basin, pipe, process volume
  - Peak instantaneous flow
  - Amount of time water is in basin assuming perfect plug flow and no short-circuiting

Detention Time (cont.)

- Actual detention time can be less than theoretical due to short-circuiting
  - Baffling factor (BF)
    - 0.1 = no baffling; agitated basin, high velocities
    - 0.3 = poor; single or multiple inlets, outlets
    - 0.5 = average; baffled inlet, outlet, some intra-basin
    - 0.7 = superior; perforated inlet, perf/serp intra-basin, outlet weir or perforated launders
    - 1.0 = perfect plug flow; very high L:W, perforated inlet, outlet and intra-basin
  - ADT = TDT x BF, which is also disinfectant contact time

CT Worksheet

Unit Process	Volume gal	Theoretical T_D, min	Baffle Factor	Actual T_D, min	CT, mg*min/L	Total CT	Log Removal
transmission	45,000		1				
rapid mix	50		0.1				
flocculation	15,000		0.1				
sedimentation	60,000		0.3				
filtration	10,000		0.5				
clearwell	80,000		0.6				
Q = 1,000 gpm	Cl_2 = 2 mg/L	Temp = 6˚C	pH = 6.1		Total Log-Removal		

Calculations and Discussion

Calculate CT for each unit process and for total system.

Determine CT required for 1-log removal of *Giardia lamblia* at the given conditions.

Determine total log removal for the entire treatment system.

What options are available to obtain required CT if clearwell can not provide CT?

variables: flow, chlorine residual, baffle factor, injection point

Calculating Inactivation

- Need log inactivation for *Giardia* per regulations
- Need log inactivation for viruses if using different primary disinfectant
  - O_3, chloramines, chlorine dioxide
  - Not as effective for inactivating viruses as it is for inactivating *Giardia*

Calculating Inactivation (cont.)

- Compare calculated CT to required CT from tables
  - Separate CT tables for different disinfectants due to varying effectiveness
  - Separate CT tables for *Giardia* and viruses
  - CT required for desired log inactivation based on residual and pH (for chlorine), temperature

Log Reduction

- Refers to logarithmic theory
- Relates to the percentage of microorganisms physically removed or inactivated by a given process
- Rule of "9s": the log number coincides with the number of 9s in the percent reduction
  - 1-log reduction = 90% removed or inactivated
  - 2-log reduction = 99% removed or inactivated
  - 3-log reduction = 99.9% removed or inactivated
  - Round up to next highest integer for 0.5-logs
    - 3.5-log → 4-log = 99.99%

Log Reduction (cont.)

- Regulations allow credit for some physical processes
  - Total log reduction = physical log removal + log removal from disinfection

Determining Required CT

- Calculate CT based on system operating parameters and configuration
- Use CT tables to determine required CT
  - Find appropriate table for disinfectant used
  - Find appropriate table for target microorganism
  - For chlorine
    - Find appropriate portion of table based on worst-case (lowest measured) temperature
    - Find appropriate column based on worst-case (highest measured) pH
    - Find appropriate row based on worst-case (lowest measured) residual
    - Identify CT required from row/column convergence

Determining Actual Log Inactivation

- Actual log inactivation is based on ratio of calculated CT to required CT from table
- Depends on whether system is required to achieve 3-log *Giardia* or 4-log virus inactivation
  - Actual *Giardia* log inactivation = 3 x (CT_{calc}/CT_{reqd})
    - Regulations require 3-log removal or inactivation for *Giardia*
  - Actual virus log inactivation = 4 x (CT_{calc}/CT_{reqd})
    - Regulations require 4-log removal or inactivation for viruses
  - Can modify either equation for multiple disinfection segments within treatment process

www.epa.gov/safewater/mdbp/pdf/ profile/lt1profiling.pdf

Any Questions?