Concentration-Time (CT) Workshop with GW and SW Application Examples

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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

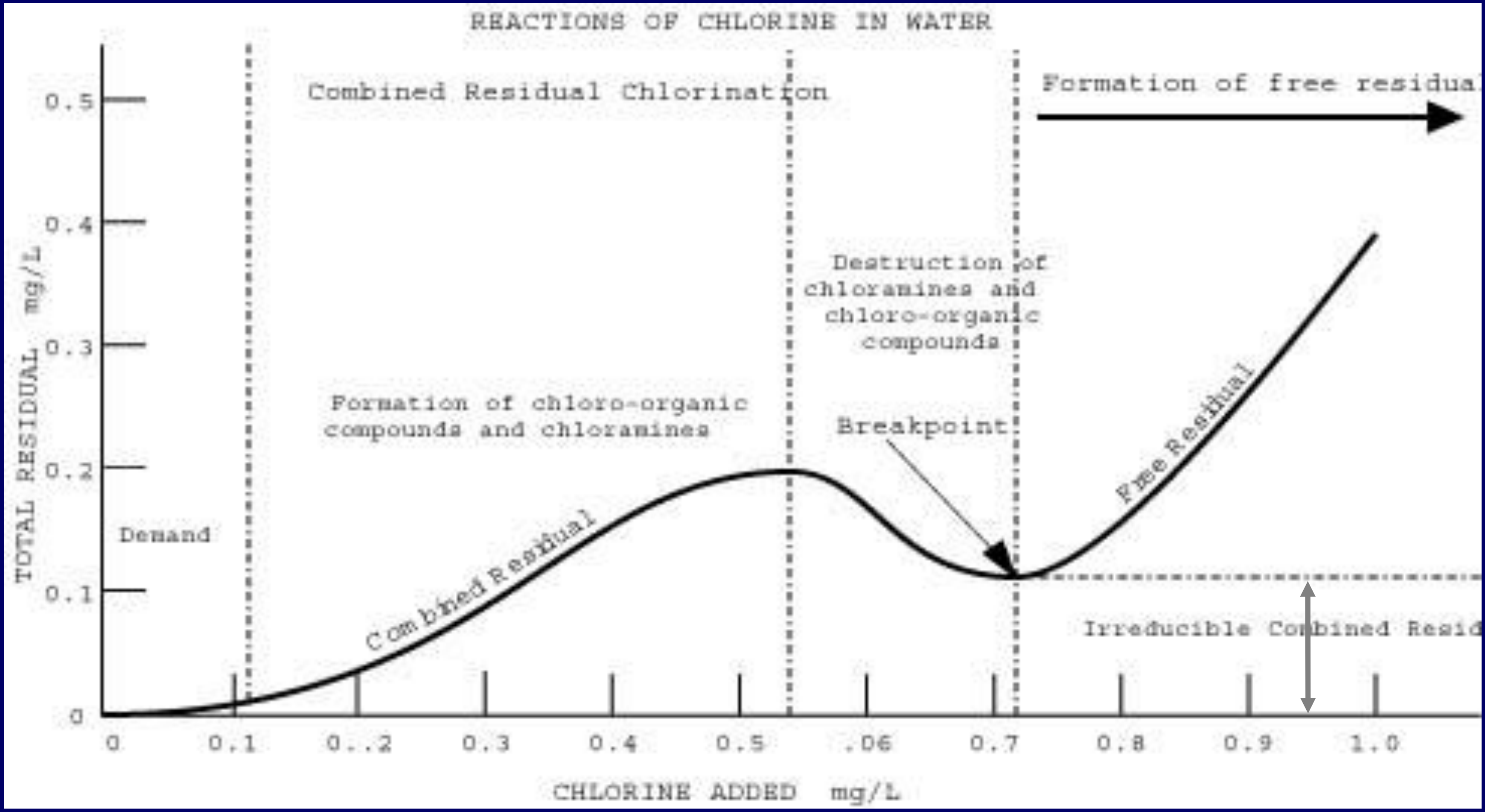
Chlorine Residuals

- **Free Chlorine Residual**
  - Uncombined chlorine in the form of HOCl, hypochlorous acid or OCl, hypochlorite ion
- **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 satisfy all demand reactions
  - 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 = $100 (1 - 1/10^{<\text{log removal}>})$

For example:

for 0.5-log removal, % removal =

$100 (1 - 1/10^{<0.5>}) = 100 (1 - 1/3.16) = 100 (1 – 0.316) = 100 (0.684) = 68.4\%$

Log Removal Summarized

- 1-log reduction = 90% removed or inactivated
- 2-log reduction = 99% removed or inactivated
- 3-log reduction = 99.9% removed or inactivated
- 4-log reduction = 99.99% removed or inactivated

Understanding CT

CT = C x T

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

$$\frac{\text{capacity (gal) of system component (pipe, storage tank)}}{\text{system flow (gpm)}}$$

- **CT** is expressed as (mg-min)/L

Calculating CT, GWR Example

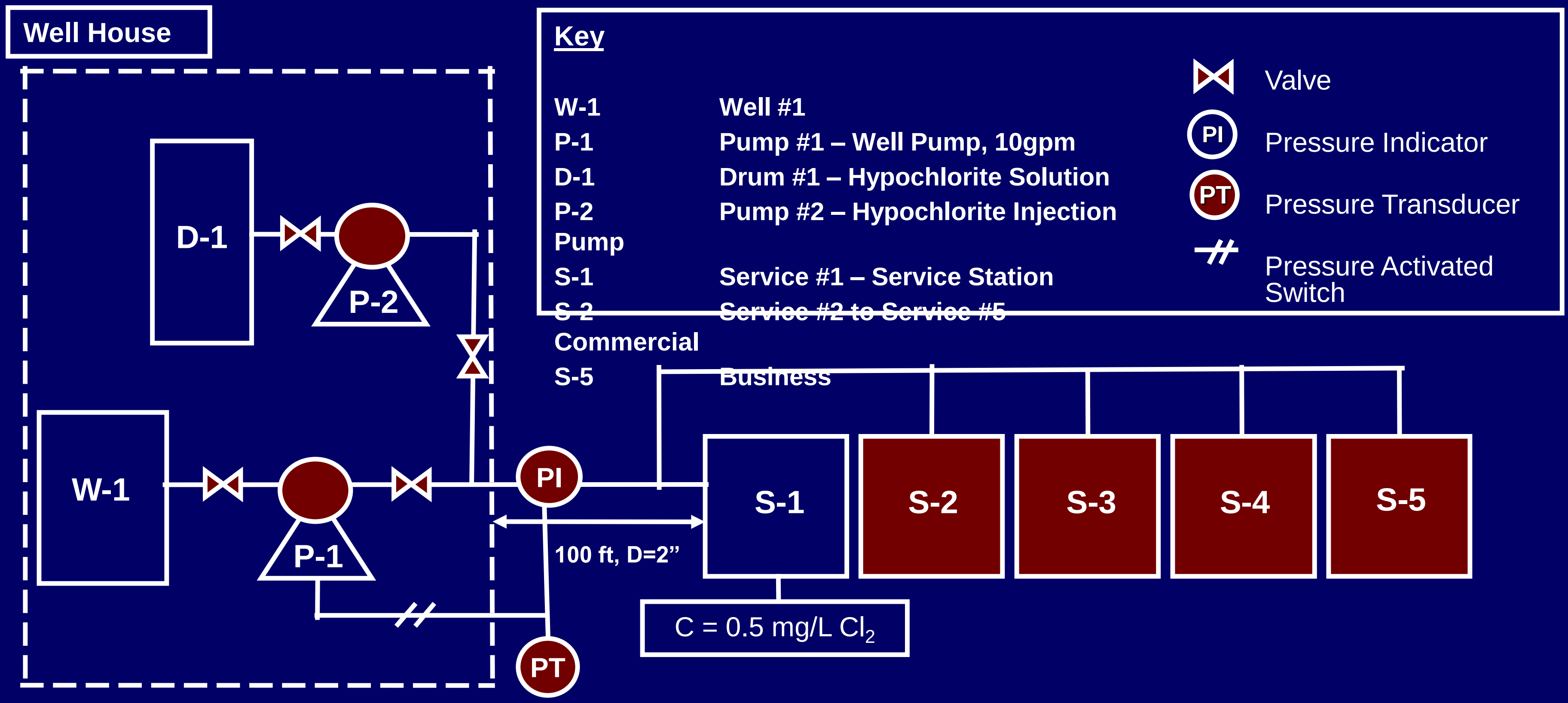
- **You will need to know:**
  - **C (mg/L or ppm), the measured disinfectant residual at or before the first customer**
  - **Length (ft) of each pipe between point where disinfectant is applied and where it is measured**
  - **Diameter (ft) of each pipe between point where disinfectant is applied and where it is measured**
  - **Volume of water (in 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 CT Calculation
Redwood Road Water System

- Well pump has manufacturer's rating of 5 gpm
- Water is injected with liquid sodium hypochlorite in well house
- 100 ft of 2-in diameter pipe between well house 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 = ($\pi \div 4$) x (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 = ($\pi \div 4$) x (diameter^2)

    = (3.14 ÷ 4) x (diameter^2) = 0.785 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

  - Disinfect. Contact Time = Volume in pipe ÷ flow

    = 16.4 gals ÷ 5 gals per minute = 3.3 minutes

  - CT = 0.5 mg/L $\times$ 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

Degrees 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 & no short-circuiting**

- **Actual detention time can be less than theoretical due to short-circuiting**
  - **baffling factor, BF**
    - ✓ **0.1 = no baffling; agitated basin, hi velocities**
    - ✓ **0.3 = poor; single or multiple inlets, outlets**
    - ✓ **0.5 = average; baffled inlet, outlet, some intra-basin**
    - ✓ **0.7 = superior; perf inlet, perf/serp intra-basin, outlet weir or perf launders**
    - ✓ **1.0 = perfect plug flow; very hi L:W, perf inlet, outlet & intra-basin**

CT Work Sheet

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=1000gpm	Cl_2=2mg/L	Temp=6°C	pH=6.1		Total Log-Removal		

<u>Calculations & Discussion</u>

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 regs
- Need log inactivation for viruses if using different primary disinfectant
  - O_3, chloramines, chlorine dioxide
  - not as effective for inactivating viruses as inactivating *Giardia*
- 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 req'd for desired log inactivation based on
    - residual & 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 “9’s” – the log number coincides with the number of 9’s 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%
- 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 & 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})
    - ✓ regs require 3-log removal or inactivation for *Giardia*
  - actual virus log inactivation = 4 x (CT_{calc}/CT_{reqd})
    - ✓ regs 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?