

# **Don't Be Baffled by CT**

## Optimizing Disinfection Contactor Performance through Design and Tracer Studies

Todd Reynolds, PE, BCEE  
Kennedy Jenks Consultants

**PNW AWWA – Water 2025**  
Boise, Idaho – May 7 to 9

# The SWTR requires Pathogen Reduction through Multi-Barrier Treatment

Pathogen	Required Log Reduction (Bin 1)
Giardia	3-log
Cryptosporidium	2-log
Virus	4-log

## Filtration – physical removal of pathogens.

Pathogen	Typical LRV Credits
Giardia	2.5-log
Crypto	2-log
Virus	2-log

## Disinfection – inactivation of pathogens.

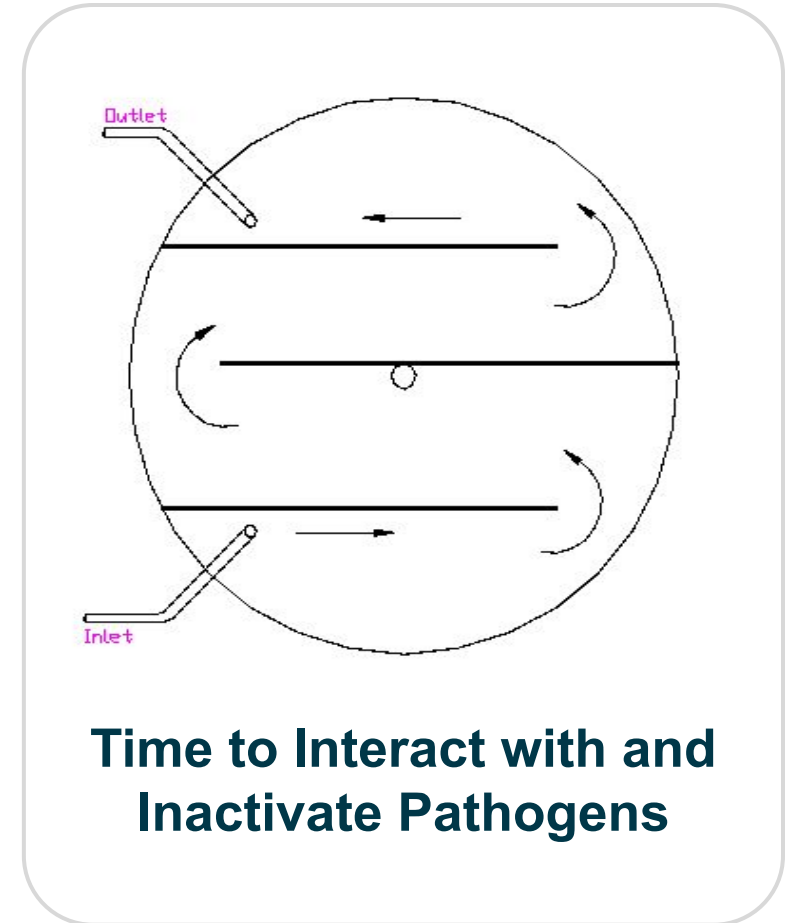
Pathogen	Req. LRV
Giardia	0.5-log
Crypto	--
Virus	2-log

# Chemical Disinfection requires a Measurable Residual after a Period of Time -- the “CT Value” -- to provide Log Inactivation

## Disinfectants

- Free Chlorine
- Ozone
- Chloramine
- Chlorine Dioxide

**Units of CT: mg/L-minutes**



# Design Disinfection CT Values Should be at Worst Case Conditions

Table D-7. CT Values for Inactivation of Viruses by Free Chlorine

		Log Inactivation					
		2.0		3.0		4.0	
pH		6-9	10	6-9	10	6-9	10
Temperature (C)							
	0.5	6	45	9	66	12	90
	5	4	30	6	44	8	60
	10	3	22	4	33	6	45
	15	2	15	3	22	4	30
	20	1	11	2	16	3	22
	25	1	7	1	11	2	15

*EPA provides CT Tables for Log Inactivation by different disinfectants.*

Table D-8. CT Values for Inactivation of *Giardia* Cysts by Chlorine Dioxide

		Temperature (C)					
		< = 1	5	10	15	20	25
	0.5-log	10	4.3	4	3.2	2.5	2
	1-log	21	8.7	7.7	6.3	5	3.7
	1.5-log	32	13	12	10	7.5	5.5
	2-log	42	17	15	13	10	7.3
	2.5-log	52	22	19	16	13	9
	3-log	63	26	23	19	15	11

*Log Inactivation depends on dose, temperature and pH.*



# Disinfection / Tracer Study Terminology

## CT

The disinfection dose (CT) is the product of:

- the disinfectant concentration residual (C), and
- the 10% Time the disinfectant is in contact with the water, ( $T = t_{10}$ ).

## $t_{10}$

The time for 10% of the water (or tracer) entering the contactor, to exit the contactor.

$$t_{10} = HDT * BF$$

## Hydraulic Detention Time (HDT)

Hydraulic Detention Time (HDT) is the flowrate through the contactor (Q) divided by the volume of the contactor (V).

$$HDT = \frac{Q}{V}$$

## Hydraulic Efficiency (Baffling Factor)

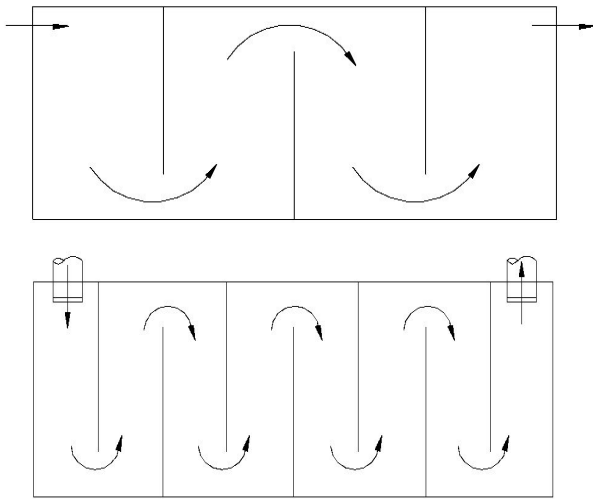
Specific to each Contactor:

- The BF is estimated or determined through a tracer study.

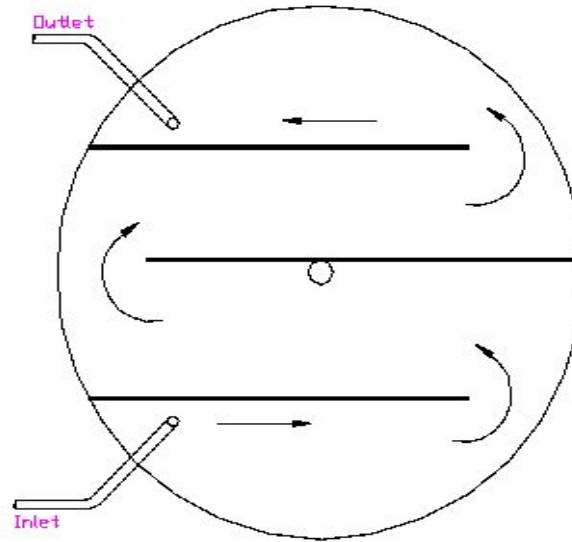
$$BF = \frac{t_{10}}{HDT}$$

# How do You Estimate the BF of Typical Disinfection Contact Tanks

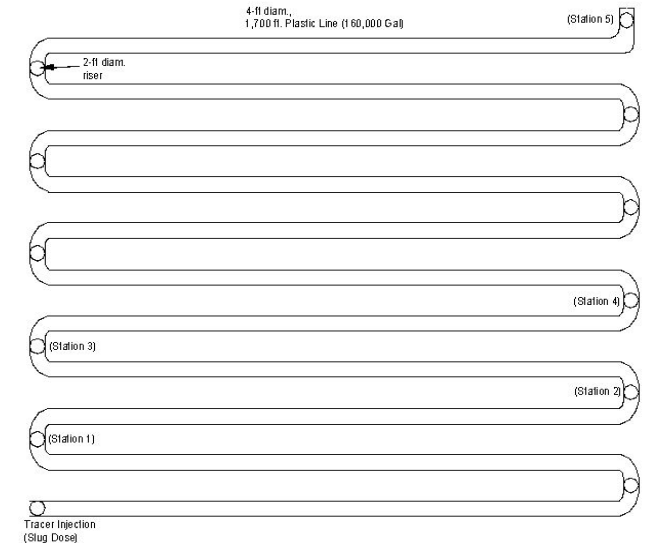
## Rectangular Contactor



## Baffled Circular Tank



## Pipeline Contactor



# Initial (1990s) Contactor Baffling Factor Guidance was Pretty Basic.

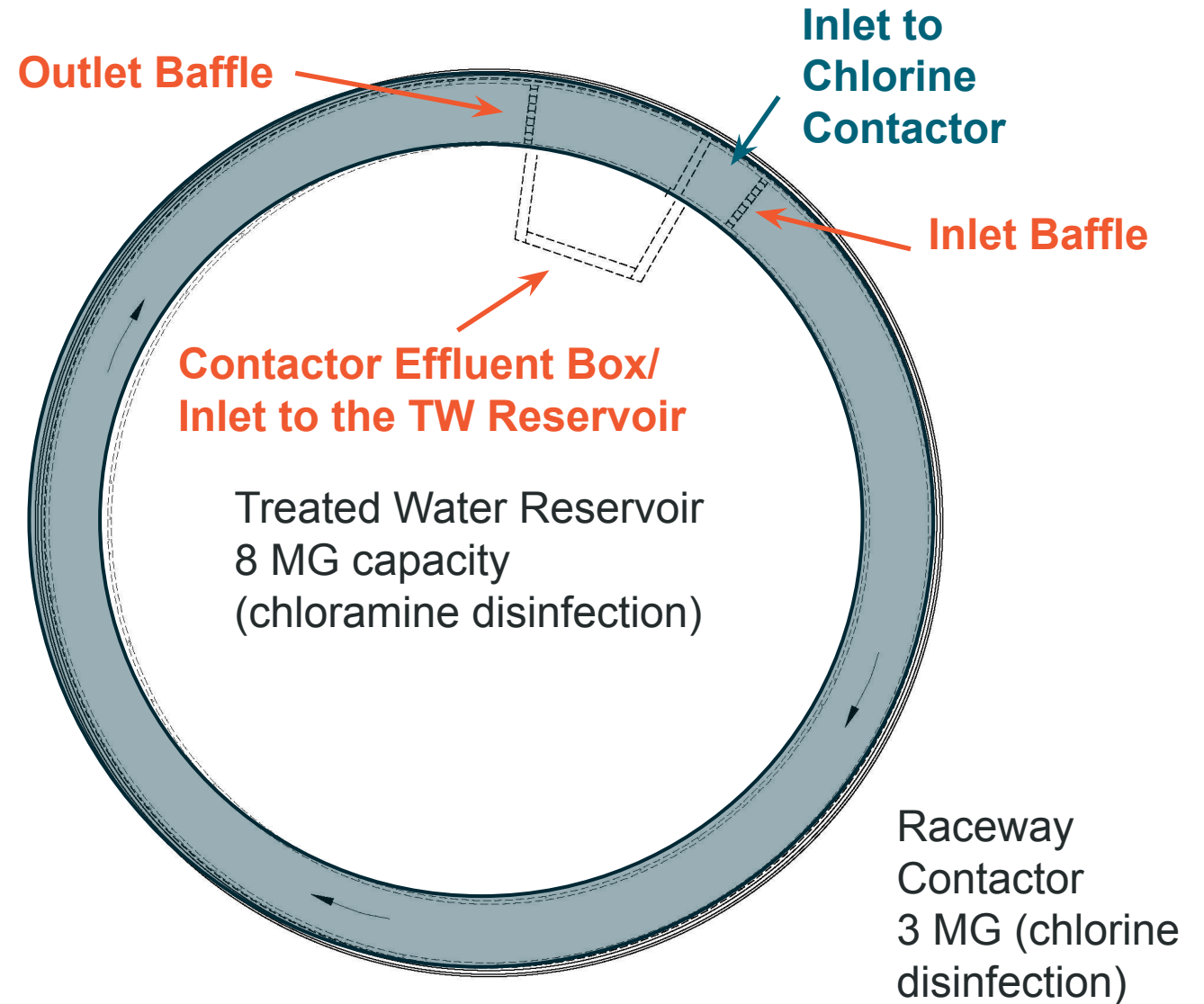
Table 4-2. Baffling Factors

Baffling Condition	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 intra-basin baffles.
Average	0.5	Baffled inlet or outlet with some intra-basin baffles.
Superior	0.7	Perforated inlet baffle, serpentine or perforated intra-basin baffles, outlet weir, or perforated launders.
Perfect (plug flow)	1.0	Very high length to width ratio (pipeline flow), perforated inlet, outlet and intra-basin baffles.

Source: USEPA. March 1991.

**In the 1990's, the Surface Water Treatment Rule guidance had general descriptions for how to estimate the baffling factor for a proposed contactor.**

# Raceway Design for SFPUC Disinfection Contactor – What BF to Use?



# AWWA Water Science Article - 2018

## Baffling Efficiency Insights Gained from Tracer Studies at 32 Washington Treatment Plants.

Porter, Stewart, Feagin, Perry

Provides comparison of actual  
vs estimated baffling factors  
for various configurations.

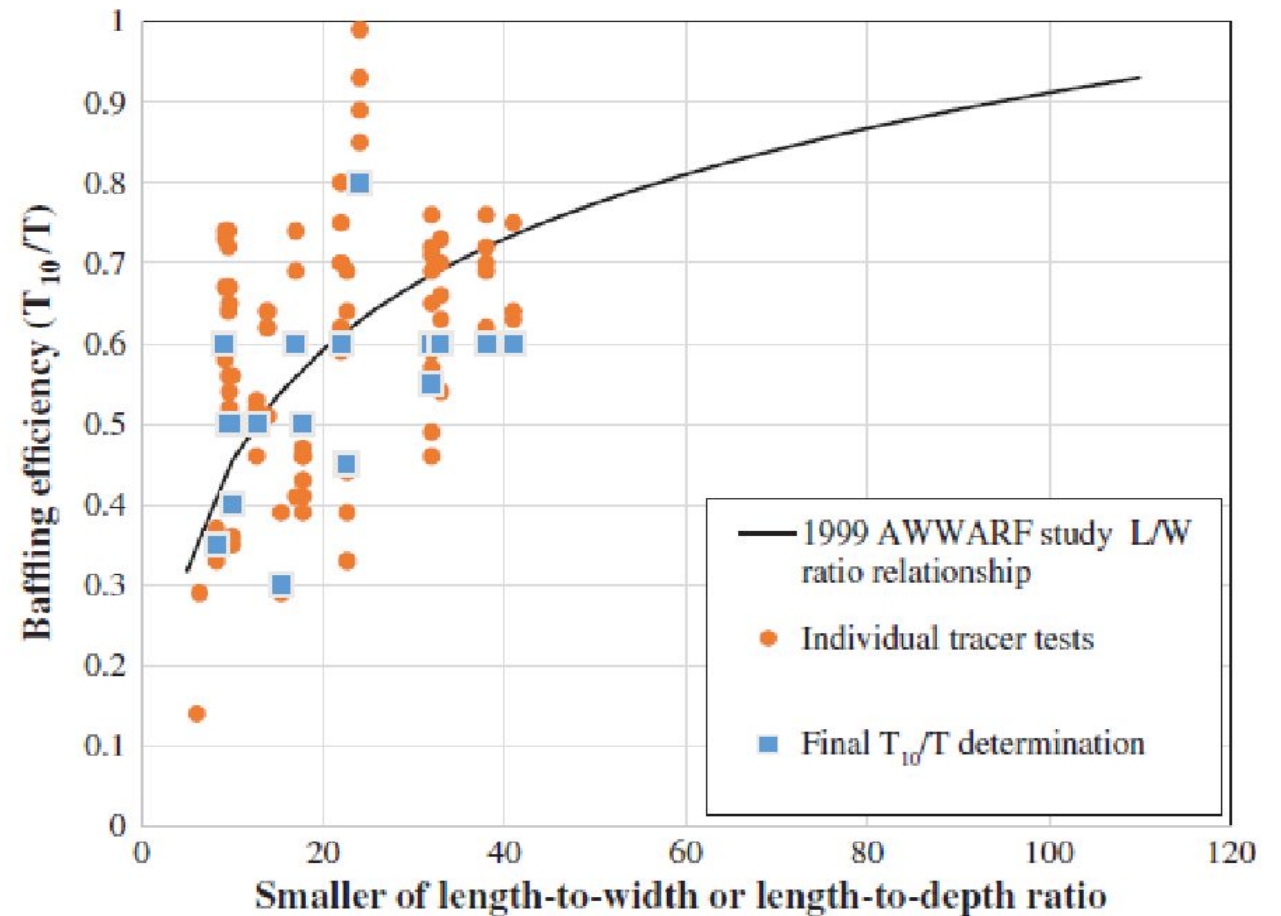


FIGURE 7 Comparison of the smaller of baffled clearwell length-to-width ratios or length-to-depth ratios and baffling efficiencies (BEs) as determined by tracer analysis



# CA SWRCB DDW - CT Contact Tank Design Guidance (2019)

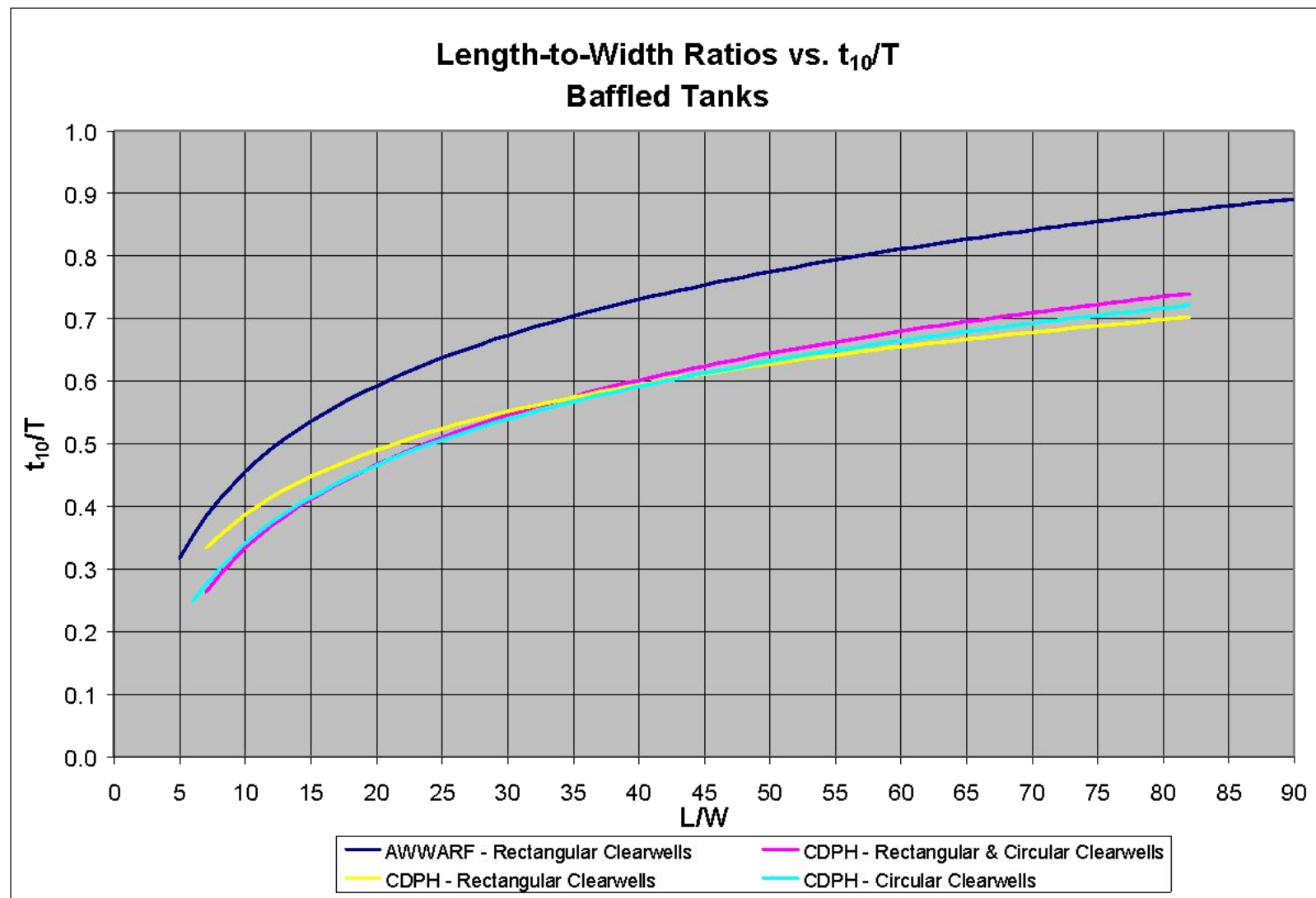
Extensive compilation of data from tracer studies of different types and configurations of disinfection contact tanks.

## Lead Author:

Guy Schott, PE  
SWRCB, Santa Rosa  
707-576-2732  
Guy.schott@waterboards.ca.gov

Main Menu	
CT Contact Tank Design Guidance_tracer_studies_db_1_24.xls Chlorine Contact Chamber Design and Flow Evaluation Version 1.24	
Tracer Database	Displays different contact tanks with and without baffles and related flow parameters.
Length-Width Graph	Graph plot: Length-to-Width (L:W) ratio vs. $t_{10}/\text{HRT}$ (baffle factor, BF). Individual data points are associated to a tracer study. It may be used to predict $t_{10}/\text{HRT}$ based on L:W ratio and to develop a best-fit curve for individual data points.
Length-Width Graph2	Graph plot: Length-to-Width ratio vs. $t_{10}/\text{HRT}$ . Individual data points are not associated to the person or company that conducted the test. This graph may be used to develop the best-fit curve.
Length-Width Graphs	Graph plot: Length-to-Width ratio vs. $t_{10}/\text{HRT}$ for all data points excluding Marske and Boyle results. This graph may be used to develop the best-fit curve.  Graph plot: Length-to-Width ratio vs. $t_{10}/\text{HRT}$ for under-and-over flow configurations.  Graph plot: Log (Length-to-Width ratio * horizontal velocity) vs. $t_{10}/\text{HRT}$ .
Predicted $t_{10}/\text{HRT}$	The short-circuiting index $t_{10}/\text{HRT}$ is calculated for different L:W ratios based on data points as a whole and data points from test conducted by individual person(s) or Company. New: predicted baffling factor ( $t_{10}/\text{HRT}$ ) when considering horizontal velocity.
Definition	Defines performance parameters commonly used in conventional analysis of contact basins
Reference	List the references of person(s) or company that conducted the tracer studies listed in this data base.
For questions and comments, you may contact:	Guy Schott, P.E. Associate Civil Engineer Mendocino District 50 D Street, Suite 200 Santa Rosa, CA 95404 707-576-2732, email: guy.schott@waterboards.ca.gov

# 2019 CA Guidance for Rectangular and Circular Disinfection Contactors BFs

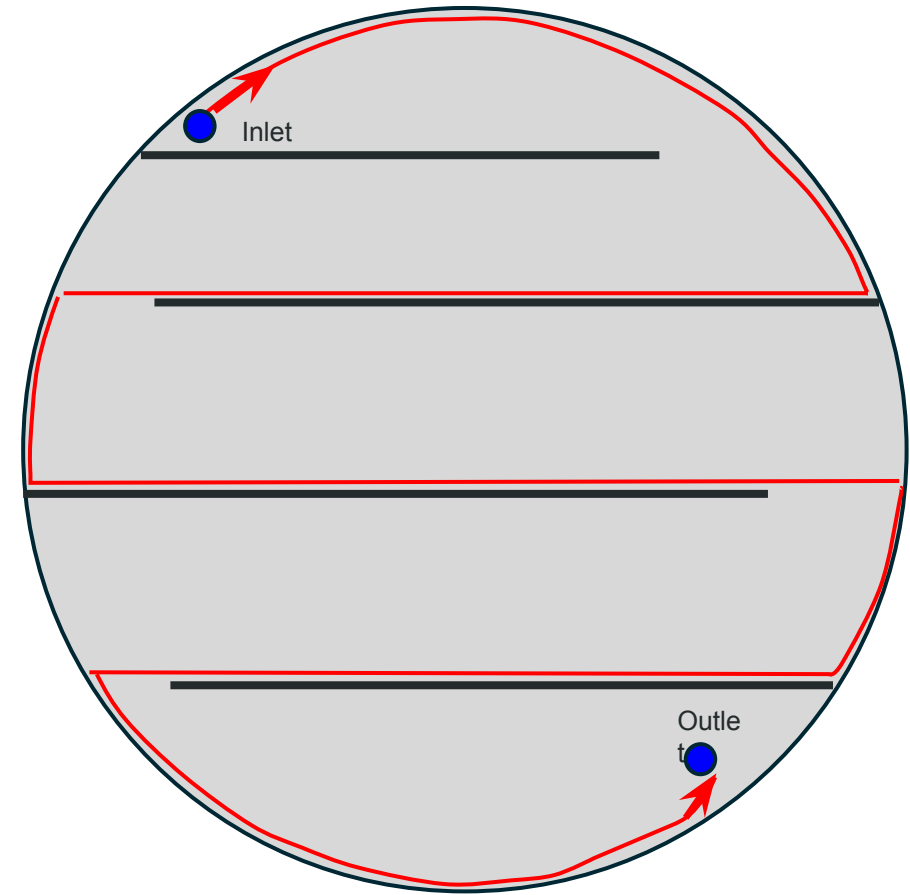


Source: Presentation on Tracer Studies by Guy Schott, CA DDW, July 9, 2014

# CT Contactor Guidance uses Length-to-Width Ratio for Estimating Baffling Factor

The Length-to-Width (L:W) Ratio for the flow path in a proposed contactor has shown good correlation to the Baffling Factor.

*Source: Presentation on Tracer Studies by Guy Schott, CA DDW, July 9, 2014*



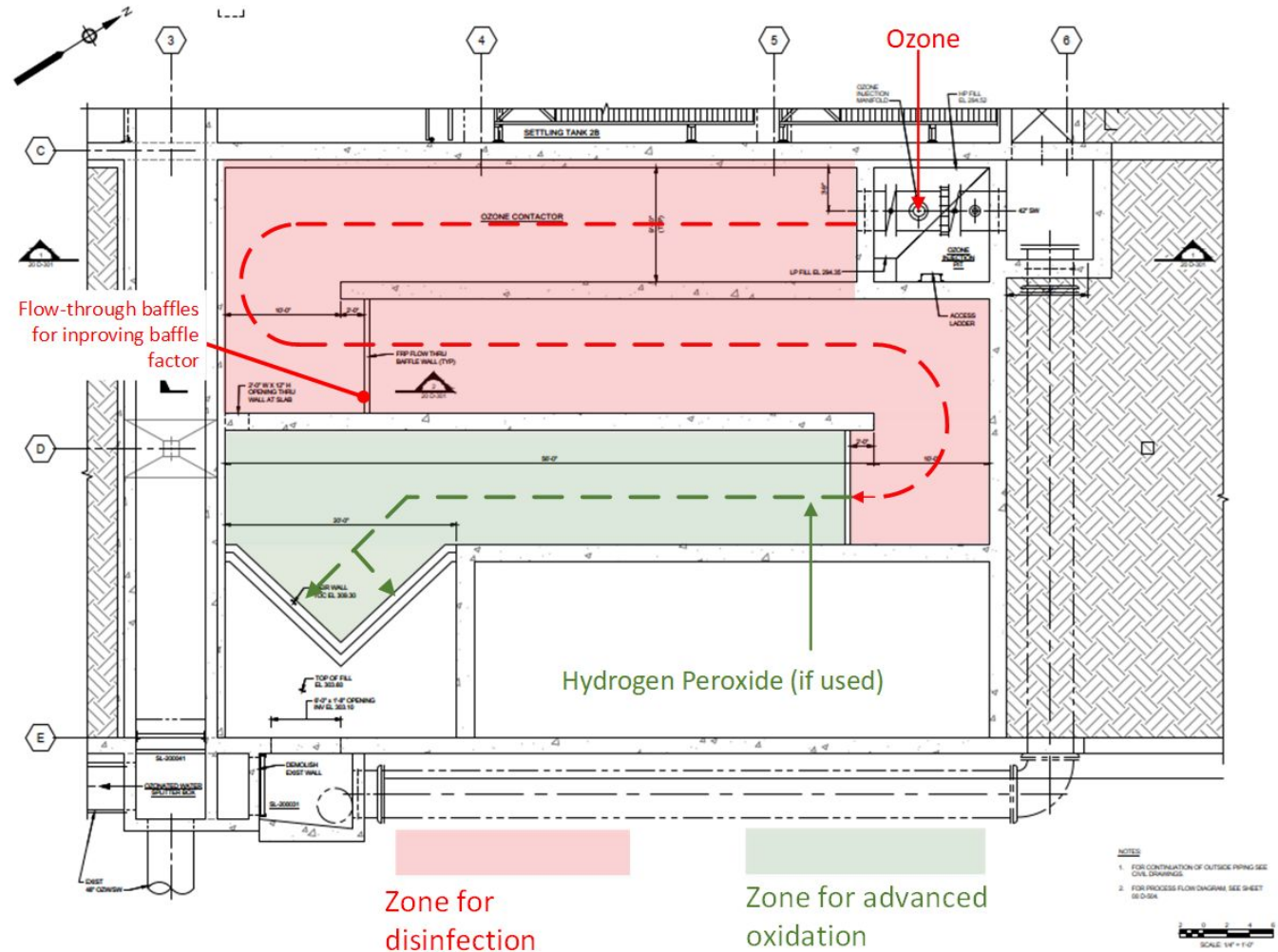
Length is longest flow path (red line).

Width is the average channel width for each flow path.



# CDF Modeling to Predict Baffling Factor

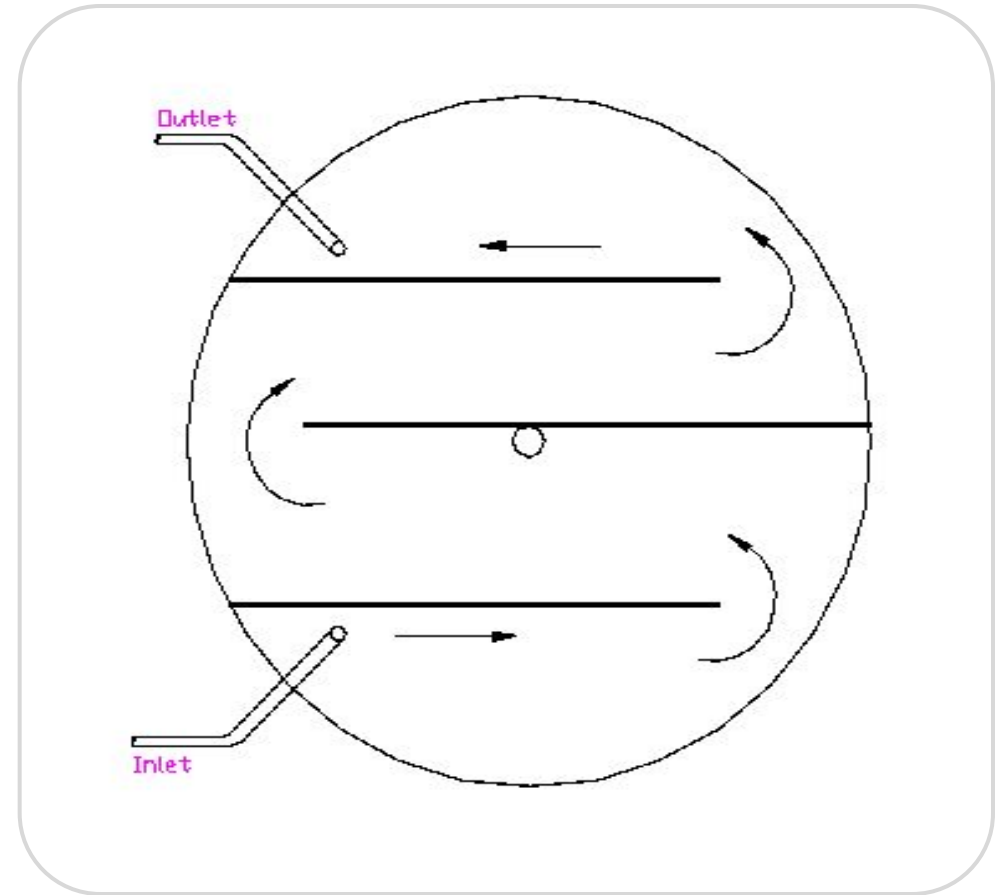
- **CFD Modeling determined likely BF**
  - 53% with no baffles
  - 64% with only the first baffle
  - 71% with two baffles
- **For design purposes:**
  - Include two baffles (71%) but design assumes the 53% BF is initially granted by regulators
- **Tracer study to confirm the efficiency for final reporting**



# CT and CT Contact Tank

## Design Tips for Operational Flexibility

- Design with low Disinfectant Residual; low temp; high pH.
- Design with a safety factor to achieve required CT.
- Design for Contactor L/W of  $>40$ , if possible.
- Use the CA SWRCB DDW CT Contact Tank Design Guidance or CFD to estimate BF.
- Use a lower BF than estimated to calculate your design  $t_{10}$  value.
- Be prepared for Regulator to assign a more conservative BF than you estimated.



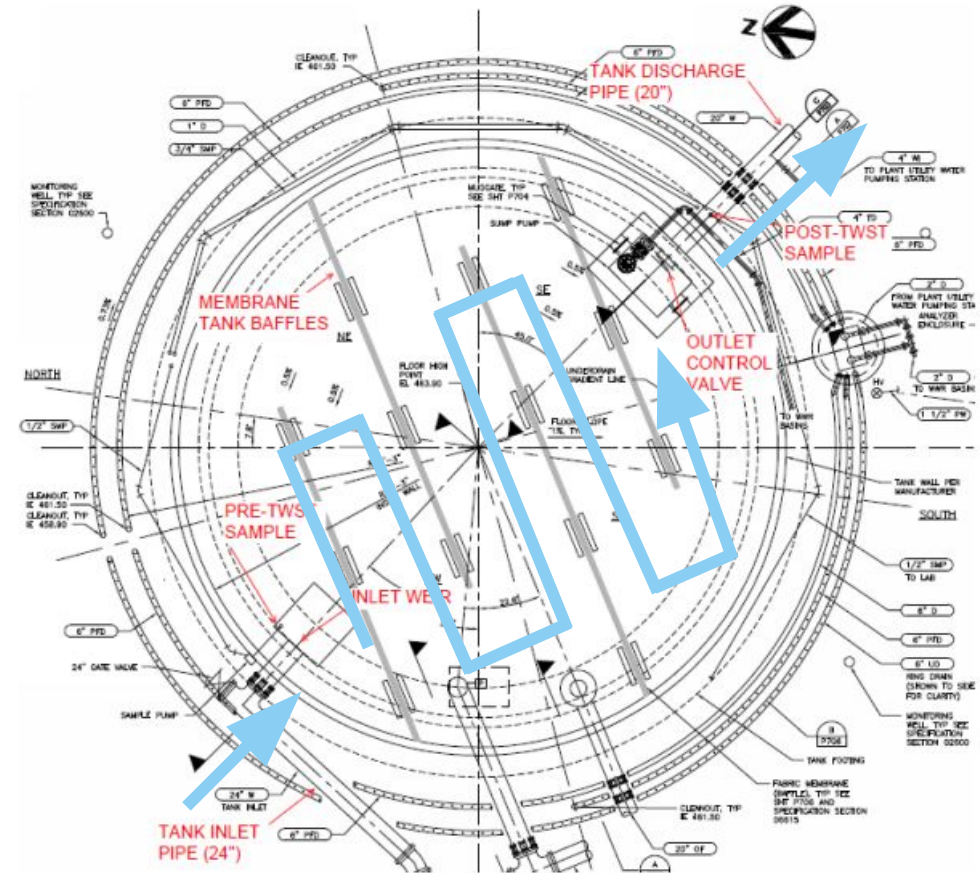
# West Hills WTP 0.5 MG Baffled Clearwell Tracer Study Objective: Demonstrate a Higher Baffling Factor

## Background

- Baffled Clearwell flow-path L:W Ratio = ~30
- Expected Baffling Factor = 0.5 to 0.6
- Regulator Assigned Baffling Factor = 0.2

## Benefits of Tracer Study

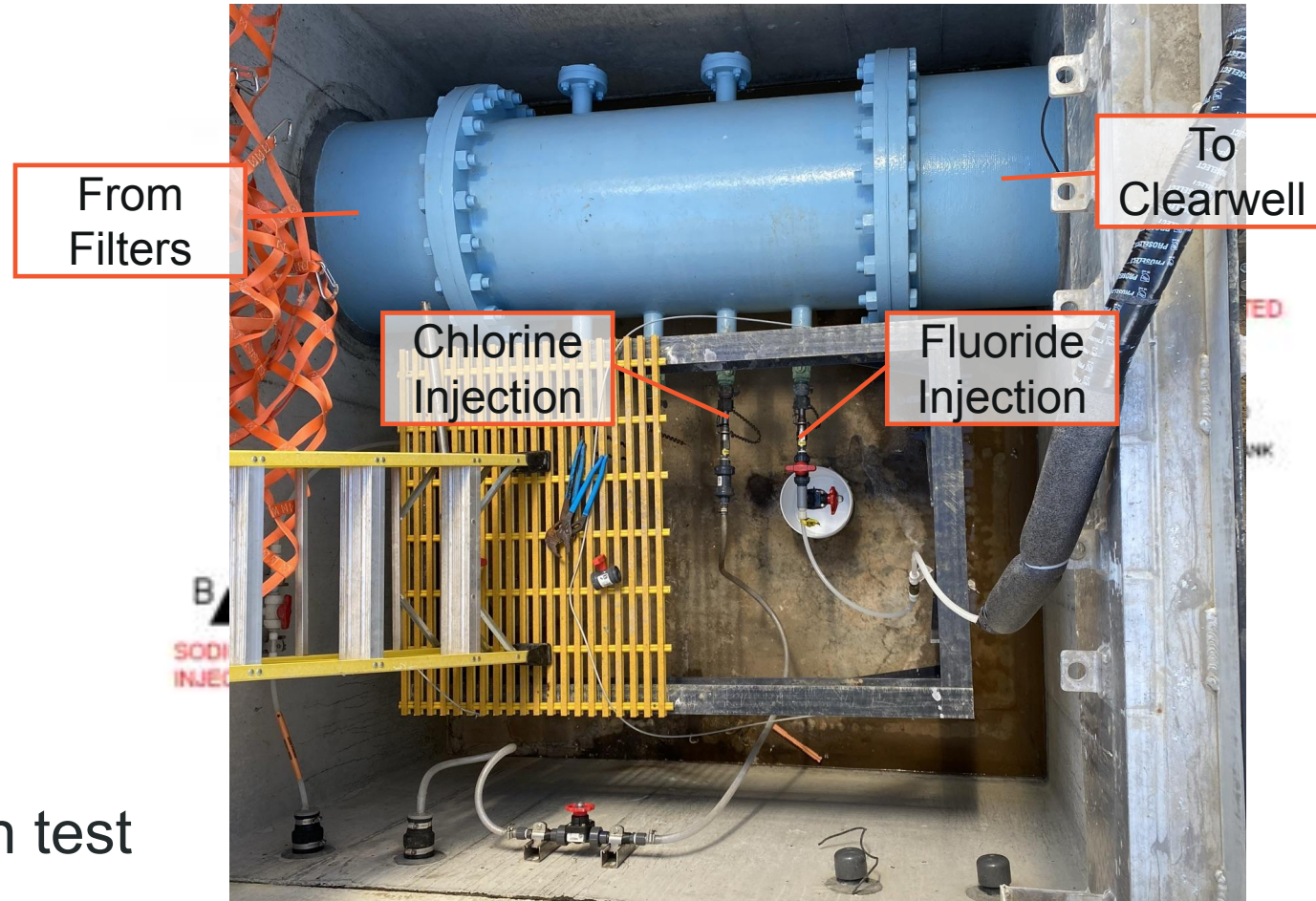
- Demonstrate increased BF to Regulators.
- Lower chlorine dose to achieve disinfection CT.
- Operators can use more of the Clearwell volume to meet variable distribution demands.





# West Hills Tracer Study Summary

- Step Input Method
- Two Flow Rates
  - Low Flow Test (1.6 MGD)
  - High Flow Test (4.2 MGD)
- Fluoride Tracer
  - Injected into Filtered Water Line
- Three Sampling Locations
  - Filter Effluent (Background)
  - Pre - Clearwell (TWST)
  - Post - Clearwell (TWST)
- 250 Field and Lab Samples for each test

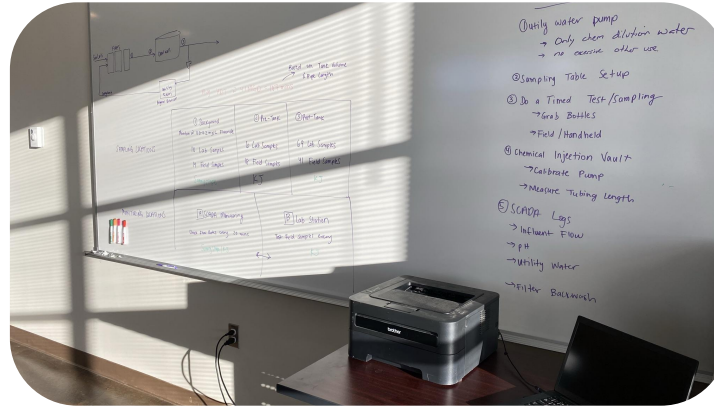




# Detailed Planning Is Essential for a Successful Study



Labeling Lab & Field Sample Bottles



Presenting the Test Plan to the Team



Setting Up Fluoride Injection



Calibrating Metering Pump



Setting Up Sample Stations





# Execute Study as Planned, Be Prepared to Adjust as Necessary



Collect Samples

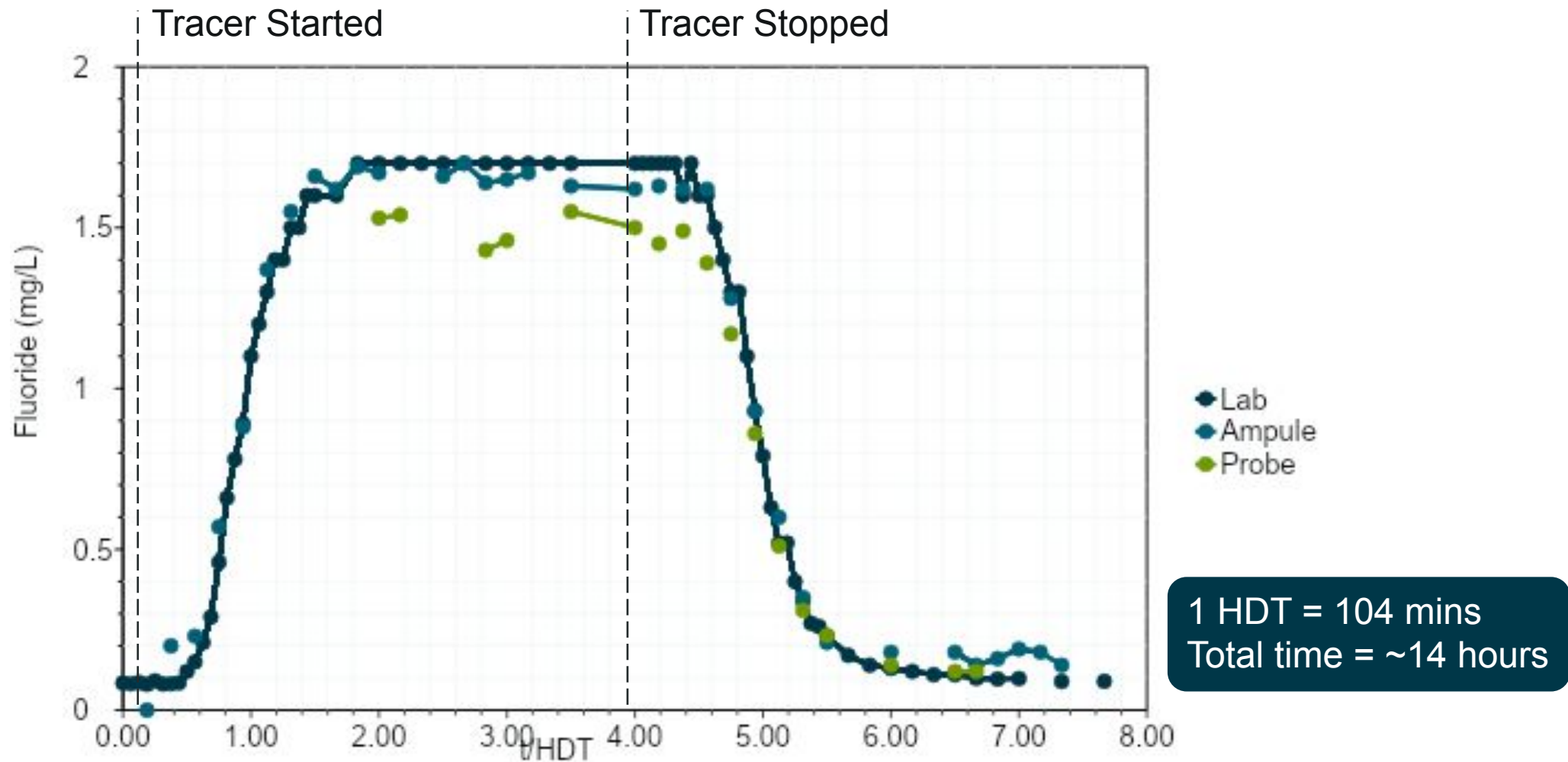


Run Field Analysis

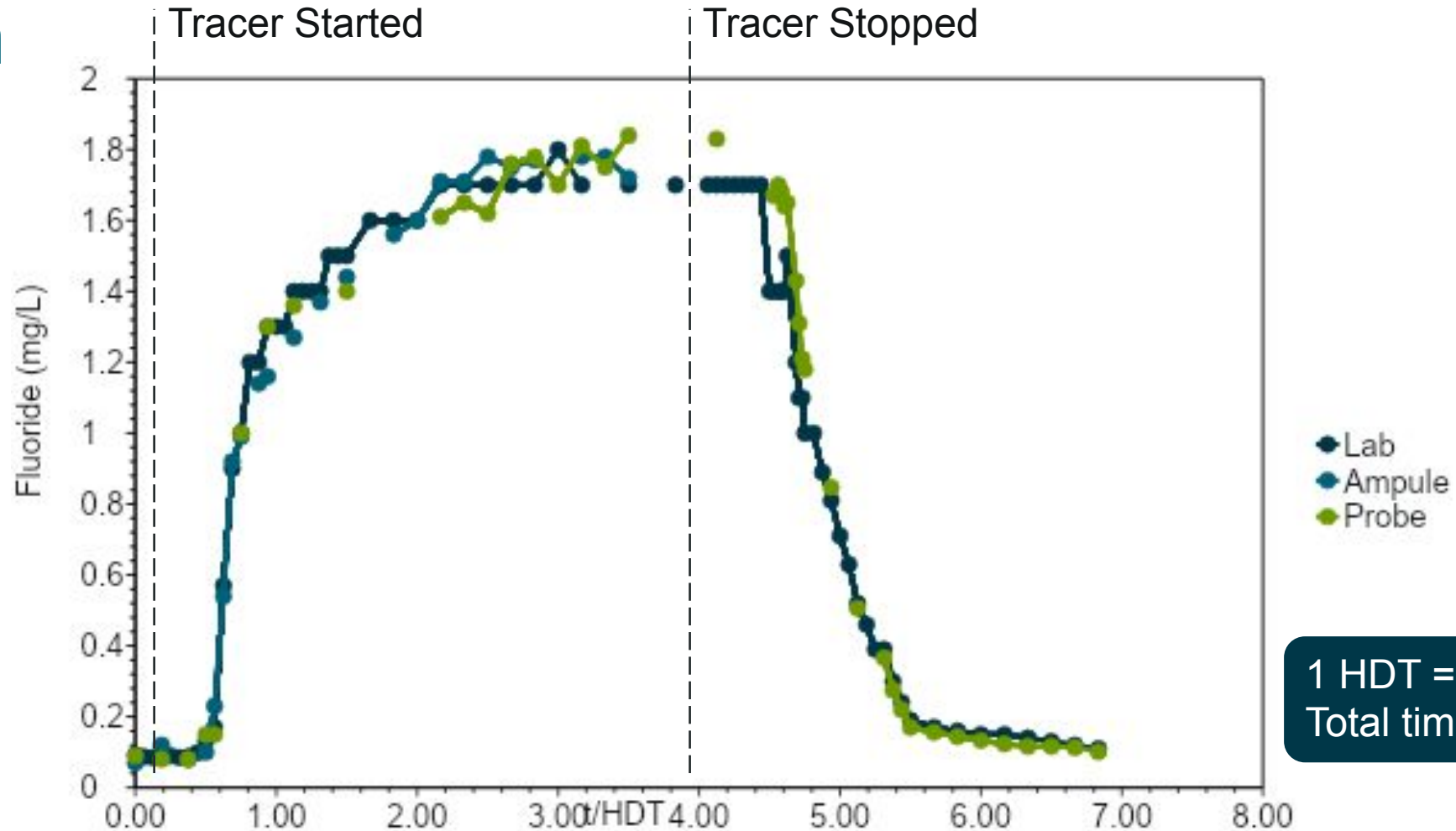


①				②				③			
Time	Sample	Conc (mg/L)	Notes	Time	Sample	Conc (mg/L)	Notes	Time	Sample	Conc (mg/L)	Notes
7:10pm	0.14 mg/L			11:00am	0.13 mg/L			11:10pm	0.10 mg/L		
10:10pm	0.16 mg/L			11:05am	0.12 mg/L			11:20pm	0.12 mg/L		
10:40pm				11:10am	1.45 mg/L			11:25pm	1.84 mg/L		
				11:15am	1.63 mg/L			11:30pm	1.74 mg/L		
				11:20pm	1.65 mg/L			11:33pm	1.74 mg/L		
				11:25pm	1.51 mg/L			11:36pm	1.74 mg/L		
				11:30pm	1.78 mg/L			11:39pm	1.74 mg/L		
				11:35pm	1.84 mg/L			11:42pm	1.74 mg/L		
				11:40pm	1.78 mg/L			11:45pm	1.74 mg/L		
				11:45pm	1.78 mg/L			11:50pm	1.74 mg/L		
				11:50pm	1.78 mg/L			11:55pm	1.74 mg/L		
				11:55pm	1.78 mg/L			12:00pm	1.74 mg/L		
				12:00pm	1.78 mg/L			12:05pm	1.74 mg/L		
				12:05pm	1.78 mg/L			12:10pm	1.74 mg/L		
				12:10pm	1.78 mg/L			12:15pm	1.74 mg/L		
				12:15pm	1.78 mg/L			12:20pm	1.74 mg/L		
				12:20pm	1.78 mg/L			12:25pm	1.74 mg/L		
				12:25pm	1.78 mg/L			12:30pm	1.74 mg/L		
				12:30pm	1.78 mg/L			12:35pm	1.74 mg/L		
				12:35pm	1.78 mg/L			12:40pm	1.74 mg/L		
				12:40pm	1.78 mg/L			12:45pm	1.74 mg/L		
				12:45pm	1.78 mg/L			12:50pm	1.74 mg/L		
				12:50pm	1.78 mg/L			12:55pm	1.74 mg/L		
				12:55pm	1.78 mg/L			1:00pm	1.74 mg/L		
				1:00pm	1.78 mg/L			1:05pm	1.74 mg/L		
				1:05pm	1.78 mg/L			1:10pm	1.74 mg/L		
				1:10pm	1.78 mg/L			1:15pm	1.74 mg/L		
				1:15pm	1.78 mg/L			1:20pm	1.74 mg/L		
				1:20pm	1.78 mg/L			1:25pm	1.74 mg/L		
				1:25pm	1.78 mg/L			1:30pm	1.74 mg/L		
				1:30pm	1.78 mg/L			1:35pm	1.74 mg/L		
				1:35pm	1.78 mg/L			1:40pm	1.74 mg/L		
				1:40pm	1.78 mg/L			1:45pm	1.74 mg/L		
				1:45pm	1.78 mg/L			1:50pm	1.74 mg/L		
				1:50pm	1.78 mg/L			1:55pm	1.74 mg/L		
				1:55pm	1.78 mg/L			2:00pm	1.74 mg/L		
				2:00pm	1.78 mg/L			2:05pm	1.74 mg/L		
				2:05pm	1.78 mg/L			2:10pm	1.74 mg/L		
				2:10pm	1.78 mg/L			2:15pm	1.74 mg/L		
				2:15pm	1.78 mg/L			2:20pm	1.74 mg/L		
				2:20pm	1.78 mg/L			2:25pm	1.74 mg/L		
				2:25pm	1.78 mg/L			2:30pm	1.74 mg/L		
				2:30pm	1.78 mg/L			2:35pm	1.74 mg/L		
				2:35pm	1.78 mg/L			2:40pm	1.74 mg/L		
				2:40pm	1.78 mg/L			2:45pm	1.74 mg/L		
				2:45pm	1.78 mg/L			2:50pm	1.74 mg/L		
				2:50pm	1.78 mg/L			2:55pm	1.74 mg/L		
				2:55pm	1.78 mg/L			3:00pm	1.74 mg/L		
				3:00pm	1.78 mg/L			3:05pm	1.74 mg/L		
				3:05pm	1.78 mg/L			3:10pm	1.74 mg/L		
				3:10pm	1.78 mg/L			3:15pm	1.74 mg/L		
				3:15pm	1.78 mg/L			3:20pm	1.74 mg/L		
				3:20pm	1.78 mg/L			3:25pm	1.74 mg/L		
				3:25pm	1.78 mg/L			3:30pm	1.74 mg/L		
				3:30pm	1.78 mg/L			3:35pm	1.74 mg/L		
				3:35pm	1.78 mg/L			3:40pm	1.74 mg/L		
				3:40pm	1.78 mg/L			3:45pm	1.74 mg/L		
				3:45pm	1.78 mg/L			3:50pm	1.74 mg/L		
				3:50pm	1.78 mg/L			3:55pm	1.74 mg/L		
				3:55pm	1.78 mg/L			4:00pm	1.74 mg/L		
				4:00pm	1.78 mg/L			4:05pm	1.74 mg/L		
				4:05pm	1.78 mg/L			4:10pm	1.74 mg/L		
				4:10pm	1.78 mg/L			4:15pm	1.74 mg/L		
				4:15pm	1.78 mg/L			4:20pm	1.74 mg/L		
				4:20pm	1.78 mg/L			4:25pm	1.74 mg/L		
				4:25pm	1.78 mg/L			4:30pm	1.74 mg/L		
				4:30pm	1.78 mg/L			4:35pm	1.74 mg/L		
				4:35pm	1.78 mg/L			4:40pm	1.74 mg/L		
				4:40pm	1.78 mg/L			4:45pm	1.74 mg/L		
				4:45pm	1.78 mg/L			4:50pm	1.74 mg/L		
				4:50pm	1.78 mg/L			4:55pm	1.74 mg/L		
				4:55pm	1.78 mg/L			5:00pm	1.74 mg/L		
				5:00pm	1.78 mg/L			5:05pm	1.74 mg/L		
				5:05pm	1.78 mg/L			5:10pm	1.74 mg/L		
				5:10pm	1.78 mg/L			5:15pm	1.74 mg/L		
				5:15pm	1.78 mg/L			5:20pm	1.74 mg/L		
				5:20pm	1.78 mg/L			5:25pm	1.74 mg/L		
				5:25pm	1.78 mg/L			5:30pm	1.74 mg/L		
				5:30pm	1.78 mg/L			5:35pm	1.74 mg/L		
				5:35pm	1.78 mg/L			5:40pm	1.74 mg/L		
				5:40pm	1.78 mg/L			5:45pm	1.74 mg/L		
				5:45pm	1.78 mg/L			5:50pm	1.74 mg/L		
				5:50pm	1.78 mg/L			5:55pm	1.74 mg/L		
				5:55pm	1.78 mg/L			6:00pm	1.74 mg/L		
				6:00pm	1.78 mg/L			6:05pm	1.74 mg/L		
				6:05pm	1.78 mg/L			6:10pm	1.74 mg/L		
				6:10pm	1.78 mg/L			6:15pm	1.74 mg/L		
				6:15pm	1.78 mg/L			6:20pm	1.74 mg/L		
				6:20pm	1.78 mg/L			6:25pm	1.74 mg/L		
				6:25pm	1.78 mg/L			6:30pm	1.74 mg/L		
				6:30pm	1.78 mg/L			6:35pm	1.74 mg/L		
				6:35pm	1.78 mg/L			6:40pm	1.74 mg/L		
				6:40pm	1.78 mg/L			6:45pm	1.74 mg/L		
				6:45pm	1.78 mg/L			6:50pm	1.74 mg/L		
				6:50pm	1.78 mg/L			6:55pm	1.74 mg/L		
				6:55pm	1.78 mg/L			7:00pm	1.74 mg/L		
				7:00pm	1.78 mg/L			7:05pm	1.74 mg/L		
				7:05pm	1.78 mg/L			7:10pm	1.74 mg/L		
				7:10pm	1.78 mg/L			7:15pm	1.74 mg/L		
				7:15pm	1.78 mg/L			7:20pm	1.74 mg/L		
				7:20pm	1.78 mg/L			7:25pm	1.74 mg/L		
				7:25pm	1.78 mg/L			7:30pm	1.74 mg/L		
				7:30pm	1.78 mg/L			7:35pm	1.74 mg/L		
				7:35pm	1.78 mg/L			7:40pm	1.74 mg/L		
				7:40pm	1.78 mg/L			7:45pm	1.74 mg/L		
				7:45pm	1.78 mg/L			7:50pm	1.74 mg/L		
				7:50pm	1.78 mg/L			7:55pm	1.74 mg/L		
				7:55pm	1.78 mg/L			8:00pm	1.74 mg/L		
				8:00pm	1.78 mg/L			8:05pm	1.74 mg/L		
				8:05pm	1.78 mg/L			8:10pm	1.74 mg/L		
				8:10pm	1.78 mg/L			8:15pm	1.74 mg/L		
				8:15pm	1.78 mg/L			8:20pm	1.74 mg/L		
				8:20pm	1.78 mg/L			8:25pm	1.74 mg/L		
				8:25pm	1.78 mg/L			8:30pm	1.74 mg/L		
				8:30pm	1.78 mg/L			8:35pm	1.74 mg/L		
				8:35pm	1.78 mg/L			8:40pm	1.74 mg/L		
				8:40pm	1.78 mg/L			8:45pm	1.74 mg/L		
				8:45pm	1.78 mg/L			8:50pm	1.74 mg/L		
				8:50pm	1.78 mg/L			8:55pm	1.74 mg/L		
				8:55pm	1.78 mg/L			9:00pm	1.74 mg/L		
				9:00pm	1.78 mg/L			9:05pm	1.74 mg/L		
				9:05pm	1.78 mg/L			9:10pm	1.74 mg/L		
				9:10pm	1.78 mg/L			9:15pm	1.74 mg/L		
				9:15pm	1.78 mg/L			9:20pm	1.74 mg/L		
				9:20pm	1.78 mg/L			9:25pm	1.74 mg/L		
				9:25pm	1.78 mg/L			9:30pm	1.74 mg/L		
				9:30pm	1.78 mg/L			9:35pm	1.74 mg/L		
				9:35pm	1.78 mg/L			9:40pm	1.74 mg/L		
				9:40pm	1.78 mg/L			9:45pm	1.74		

# Post Clearwell Data for High Flow Test Shows “Textbook” Results



# Low Flow Test Also Shows Good Results — Some Diffusion





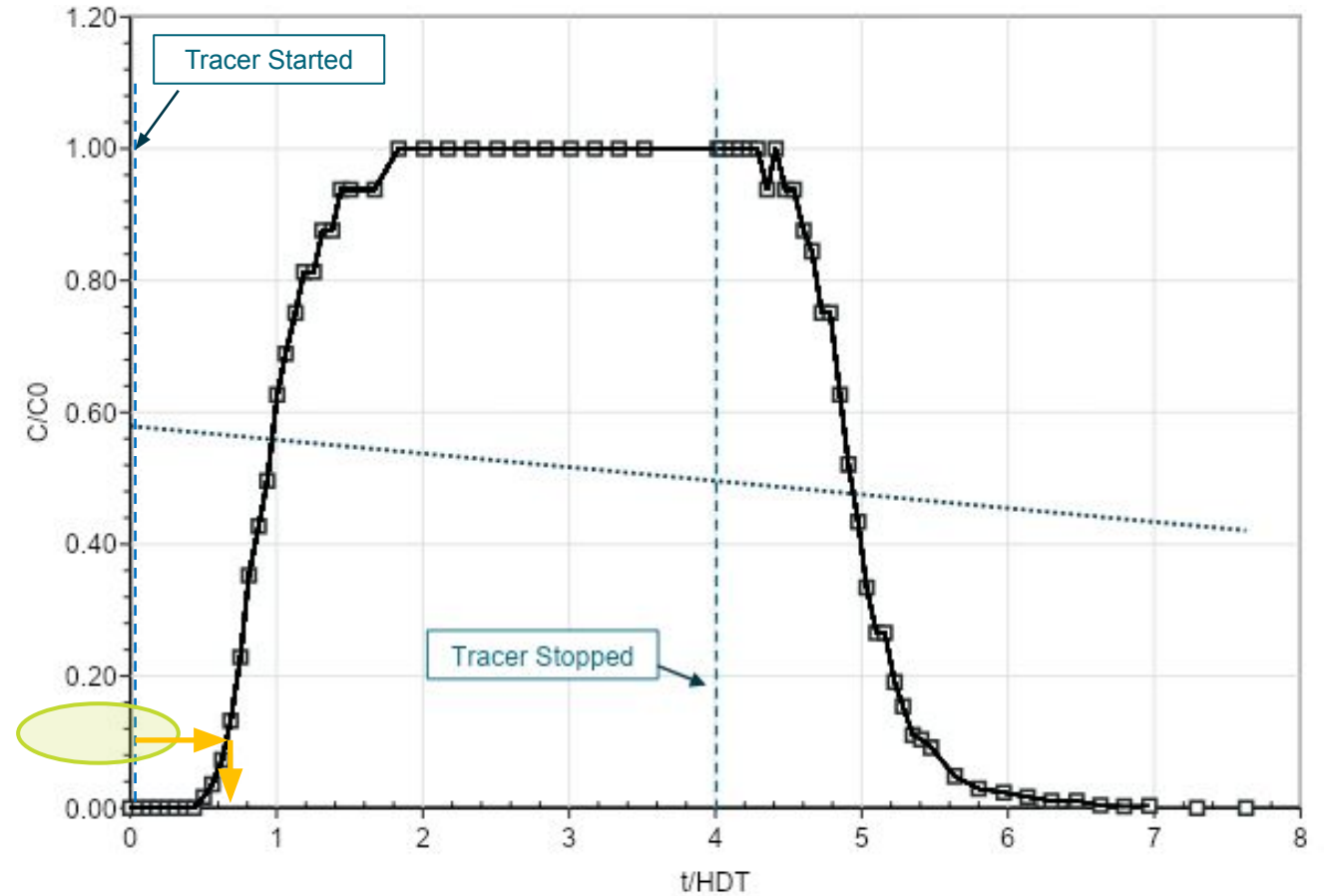
# EPA Methods to Determine the Baffling Factor

## 1. Graphical Method:

- Develop a Normalized F Curve from data
- Visual determination of time at  $C/C_0=0.10$

## 2. Best Fit Line Method:

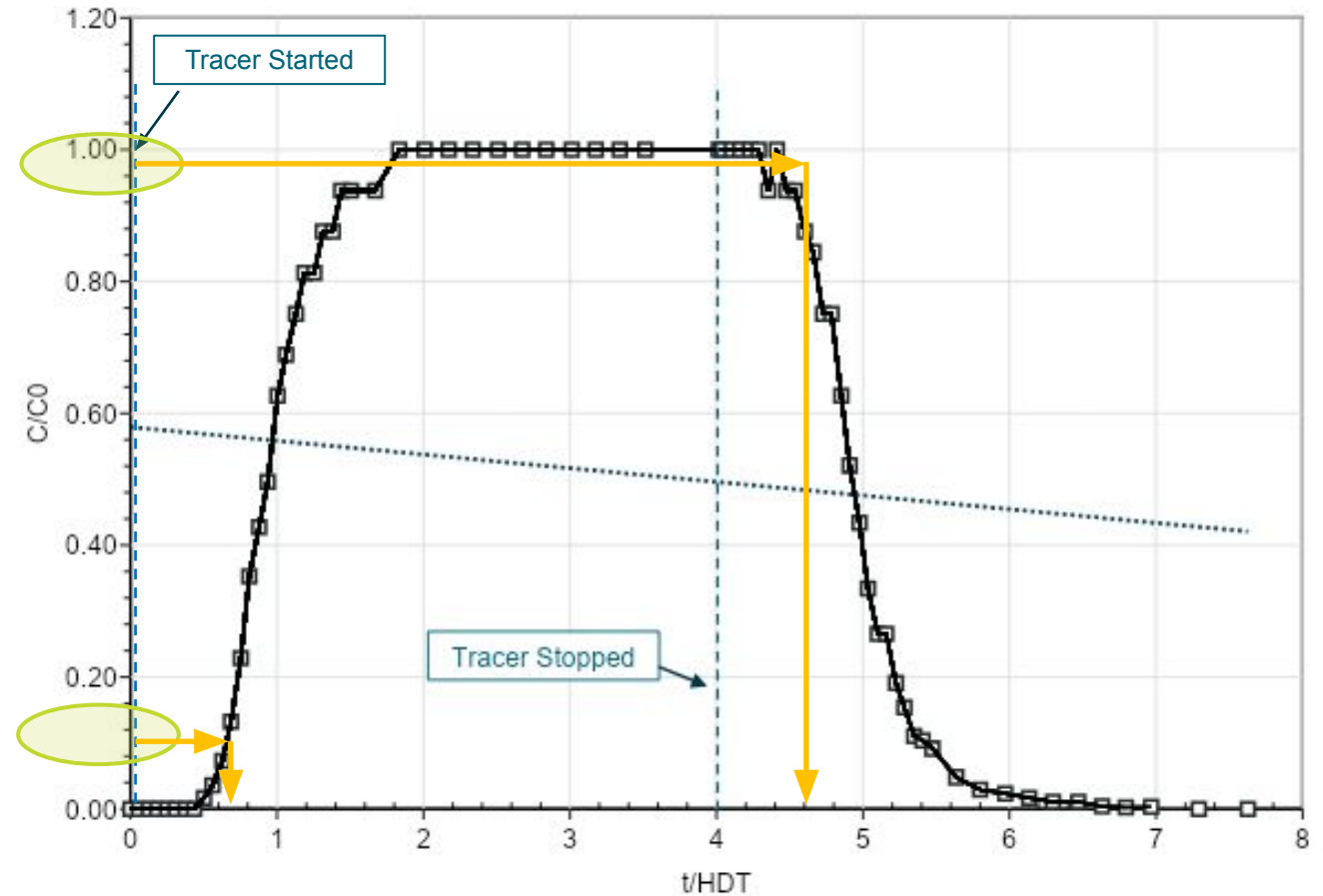
- Develop a mathematical equation for the best-fit line through data.
- Use equation to solve for time at  $C/C_0=0.10$



Normalized F Curve for the High-Rate Tracer Test

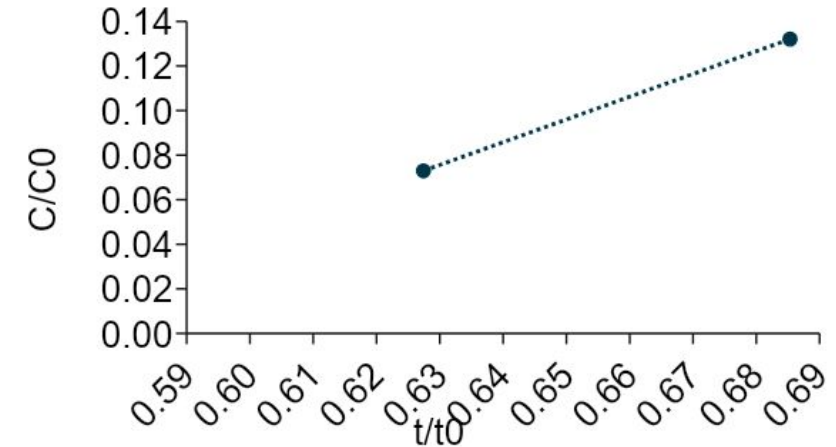
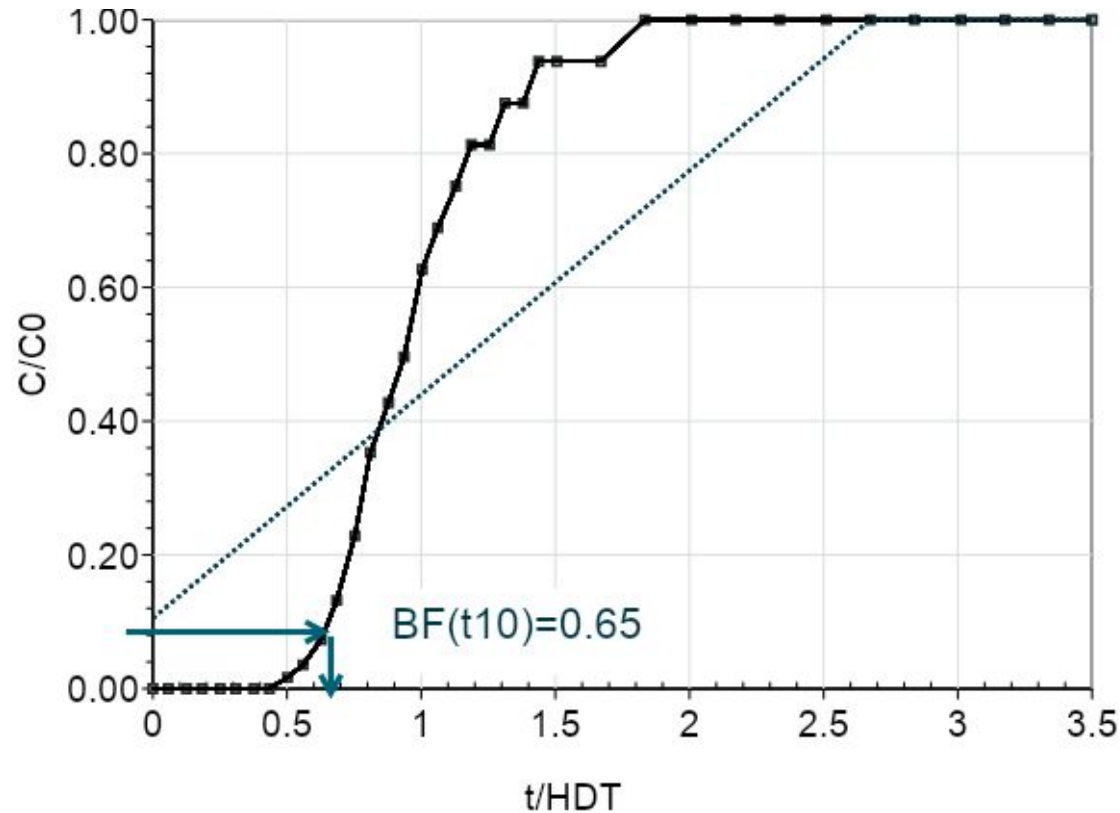
# West Hills Test Runs and Methods Provide 8 Baffling Factor Data Points

- Two Test Runs – High and Low Flow Rates, each with:
- Ascending Curve ( $t_{10}$ )
  - Visual Method
  - Best Fit Line Method
- Descending Curve ( $t_{90}$ )
  - Visual Method
  - Best Fit Line Method



Normalized F Curve for the High-Rate Tracer Test

# High Flow Test Ascending – t10 Methods Show Close Agreement

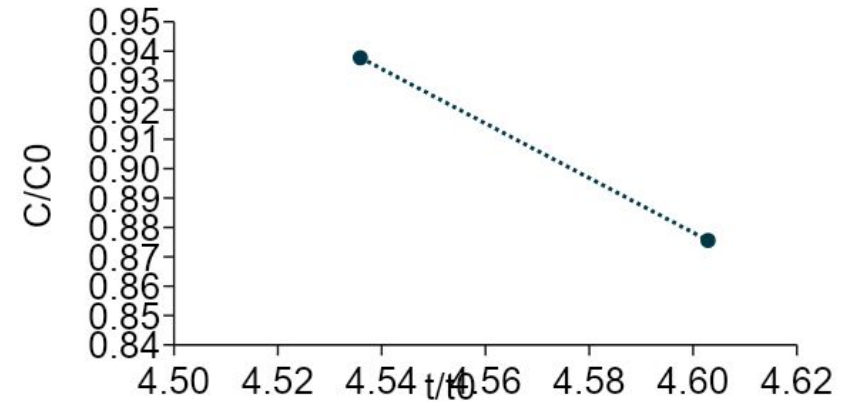
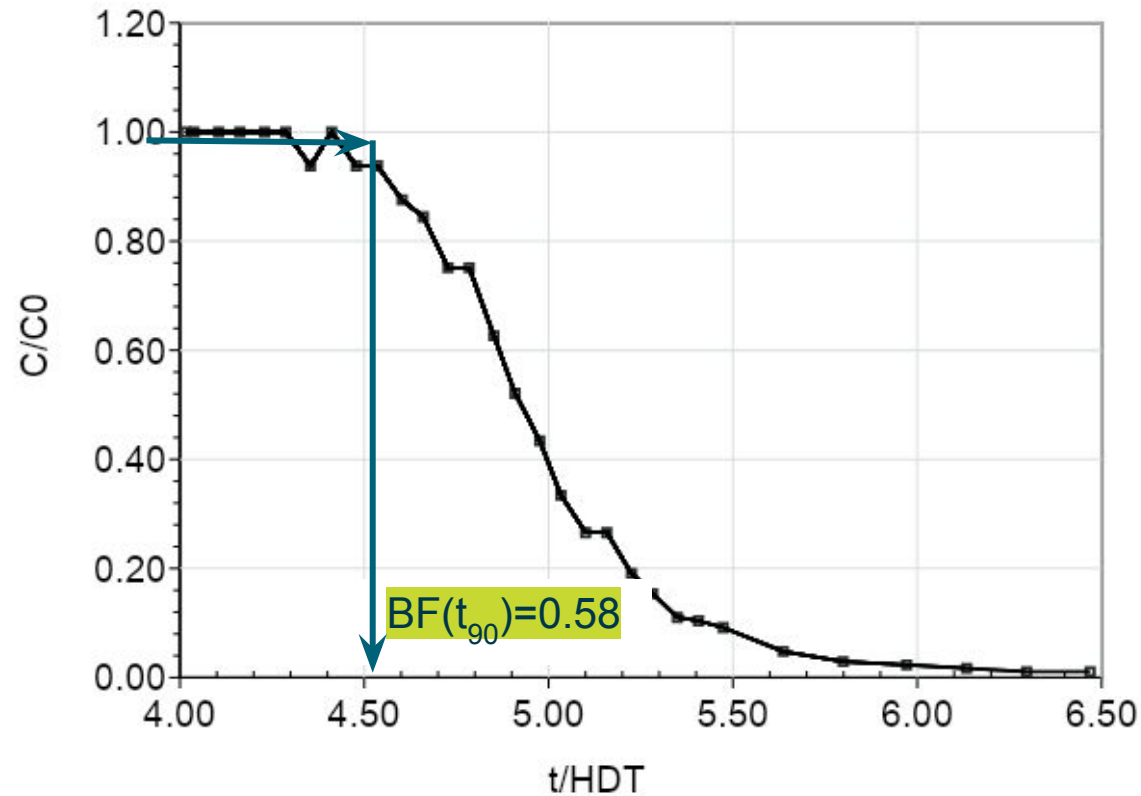


$$y = 1.0206x - 0.5674$$

$$y=0.10$$

$$x=0.6539$$

# High Flow Test Descending - $t_{90}$ Methods Show Good Agreement



$y = -0.9288x + 5.1508$	
$y=0.90$	$x=0.5612$

# Summary of Baffling Factor ( $t_{10}/\text{HDT}$ Ratio) Results

## Tabulated Results

Test No.	Nominal Flow (MGD)	Ascending Curve			Descending Curve			Mean $T_{10}$ HDT Ratio
		HDT (min)	$T_{10}$	$T_{10}$ HDT Ratio	HDT (min)	$T_{90}$	$T_{90}$ HDT Ratio	
High Flow – Graphical	4.2	103.6	67.7	0.65	104.5	58.6	0.56	0.61
– Best Fit	4.2	103.6	67.3	0.64	104.5	60.1	0.58	0.61
Low Flow – Graphical	1.6	273.7	158.2	0.58	279.1	144.5	0.52	0.55
– Best Fit	1.6	274	158.7	0.58	281	136.8	0.50	0.54
Overall Mean				0.61			0.54	0.58

## Recommended Baffling Factor

0.58 based on lowest Ascending Curve ( $t_{10}/\text{HDT}$ ) graphical and best fit value. Also, it is the mean of all the data points.

**CA DDW approved a new BF ( $t_{10}/\text{HDT}$ ) = 0.57**



# Tracer Study Lessons Learned



Communicate Thoroughly



Think on the Fly



Work as a Team



Stay Energized





# A Special Thank You To:

- San Benito County Water District
- Sunnyslope County Water District Operations Staff
- California Division of Drinking Water Staff – District 5



