Kennedy Jenks

# Don't Be Baffled by CT
## Optimizing Disinfection Contactor Performance through Design and Tracer Studies

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**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.**

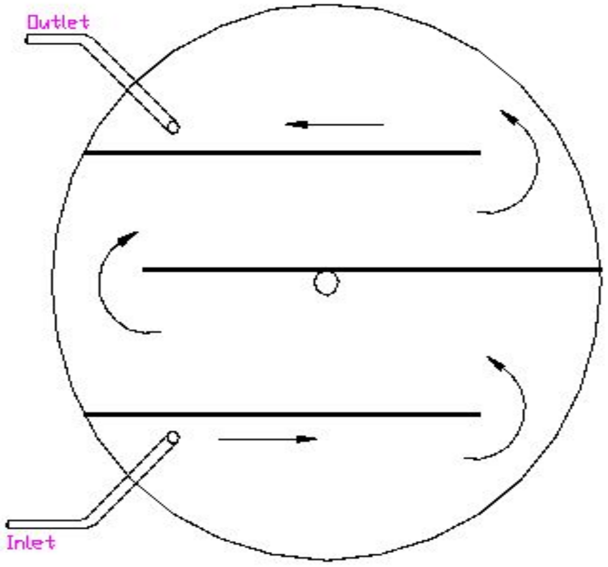
| Pathogen | Req. LRV |
|---|---|
| Giardia | 0.5-log |
| Crypto | -- |
| Virus | 2-log |

# 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**




**Time to Interact with and Inactivate Pathogens**

# 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.

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

## 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)

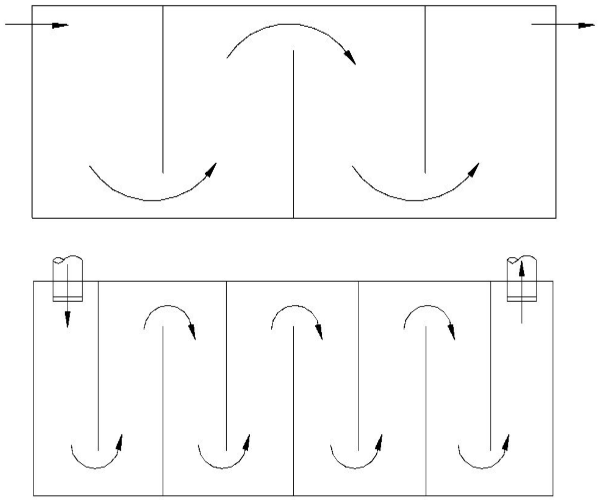
Specific to each Contactor:

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

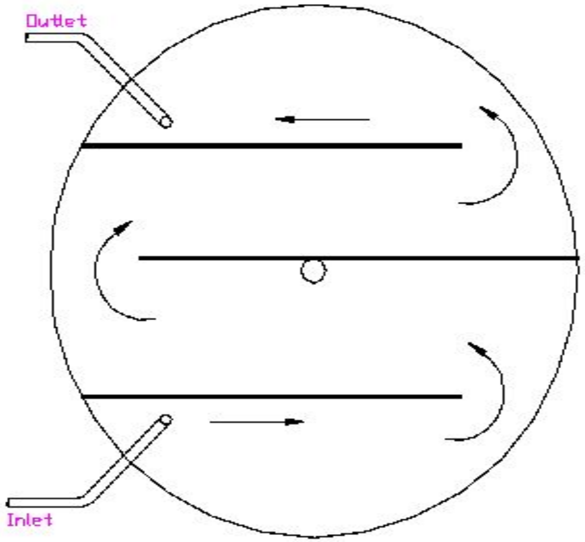
$$\mathrm{BF} = \frac{t_{10}}{HDT}$$

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

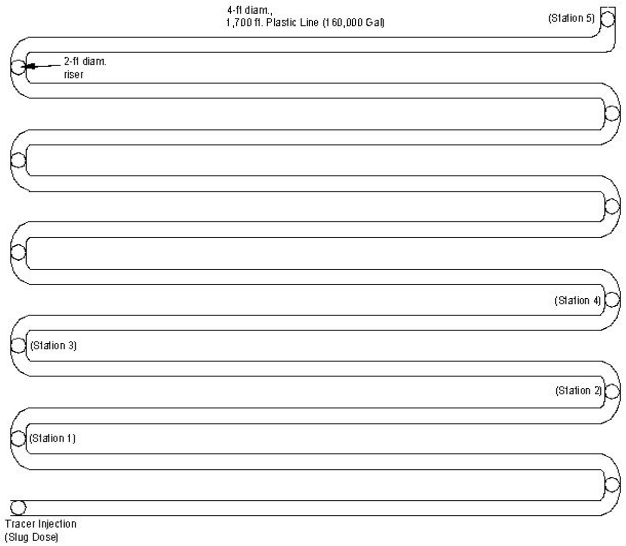
## Rectangular Contactor



## Baffled Circular Tank




## Pipeline Contactor



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

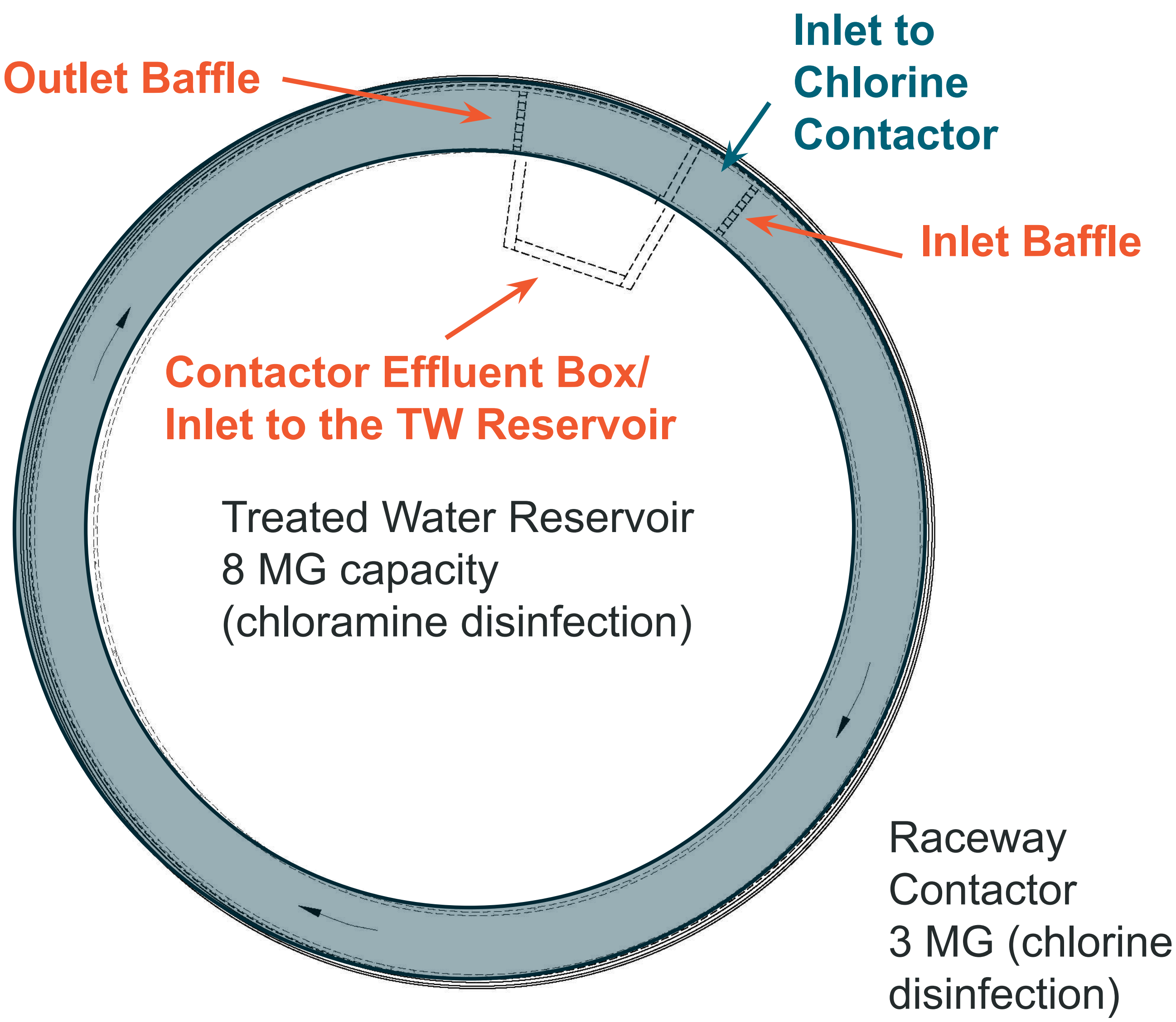
**Table 4-2. Baffling Factors**

| 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.

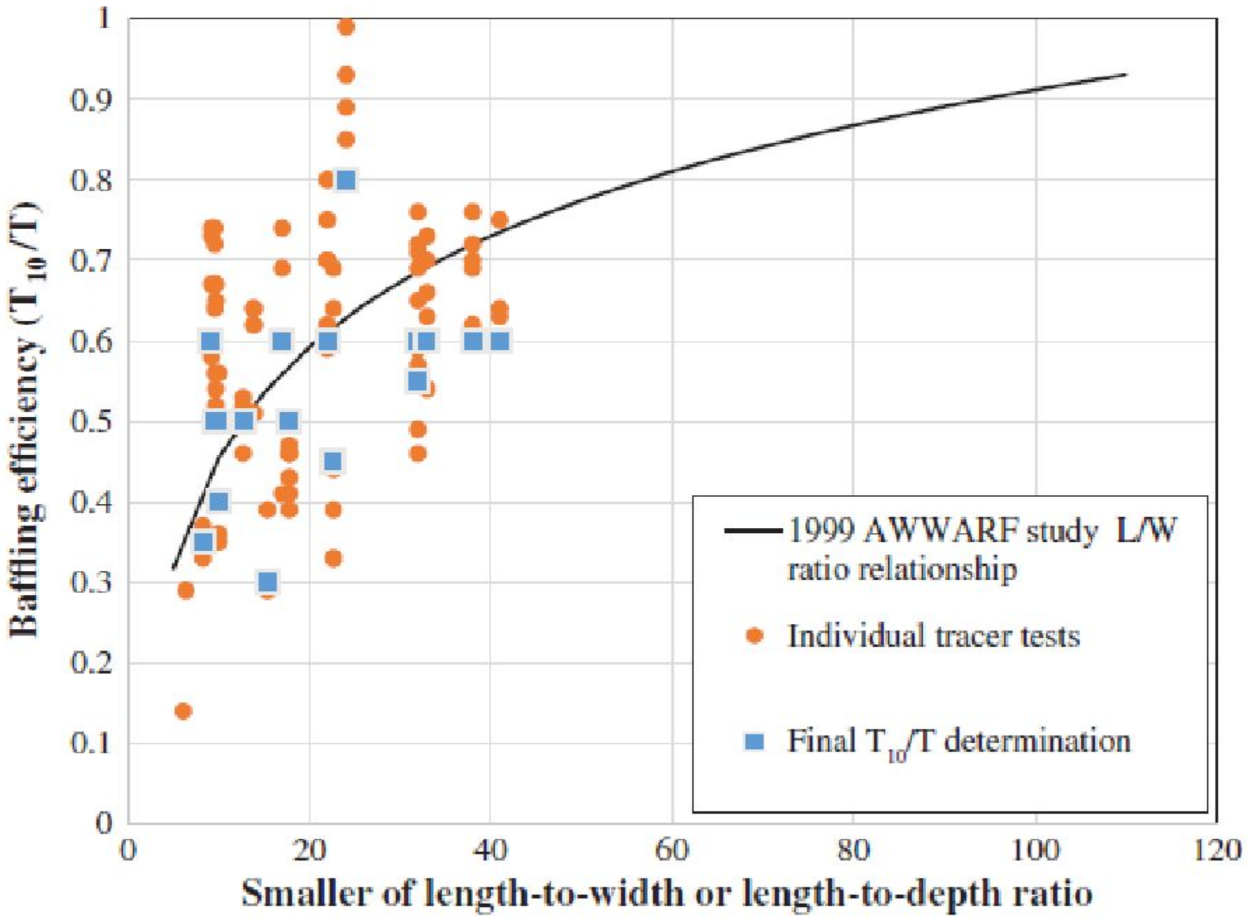



FIGURE 7 Comparison of the smaller of baffled clearwell length-to-width ratios or length-to-depth ratios and baffling efficiencies (BEs) as determined by tracer analysis

# 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.

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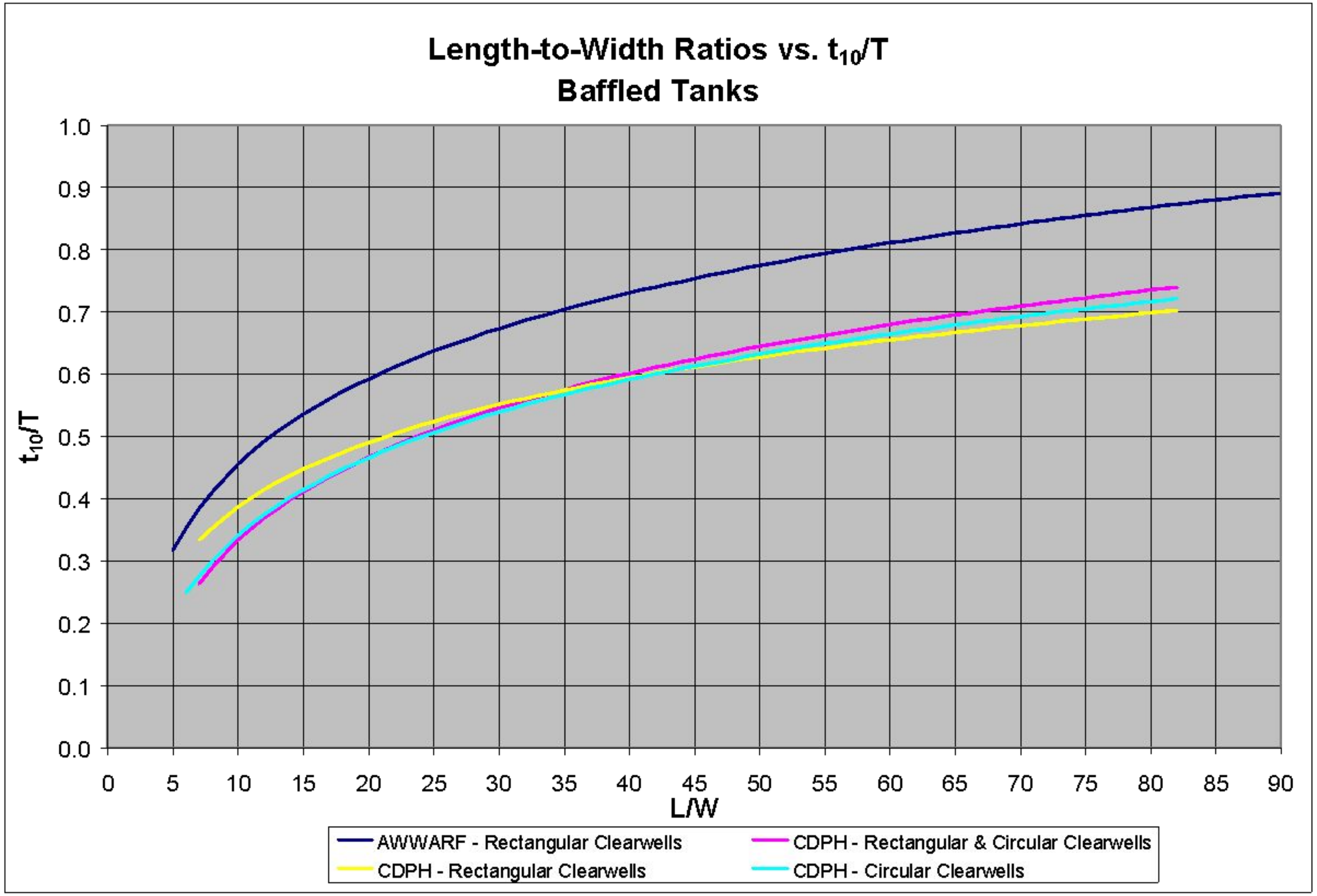
**Main Menu**

*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. $t_{10}$/HRT (baffle factor, BF). Individual data points are associated to a tracer study. It may be used to predict $t_{10}$/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. $t_{10}$/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 Graph3 | Graph plot: Length-to-Width ratio vs. $t_{10}$/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. $t_{10}$/HRT for under-and-over flow configurations. |
| | Graph plot: Log (Length-to-Width ratio * horizontal velocity) vs. $t_{10}$/HRT. |
| Predicted $t_{10}$/HRT | The short-circuiting index $t_{10}$/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 ($t_{10}$/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.<br>Associate Civil Engineer<br>Mendocino District<br>50 D Street, Suite 200<br>Santa Rosa, CA 95404<br>707-576-2732, email: guy.schott@waterboards.ca.gov |

# 2019 CA Guidance for Rectangular and Circular Disinfection Contactor BFs

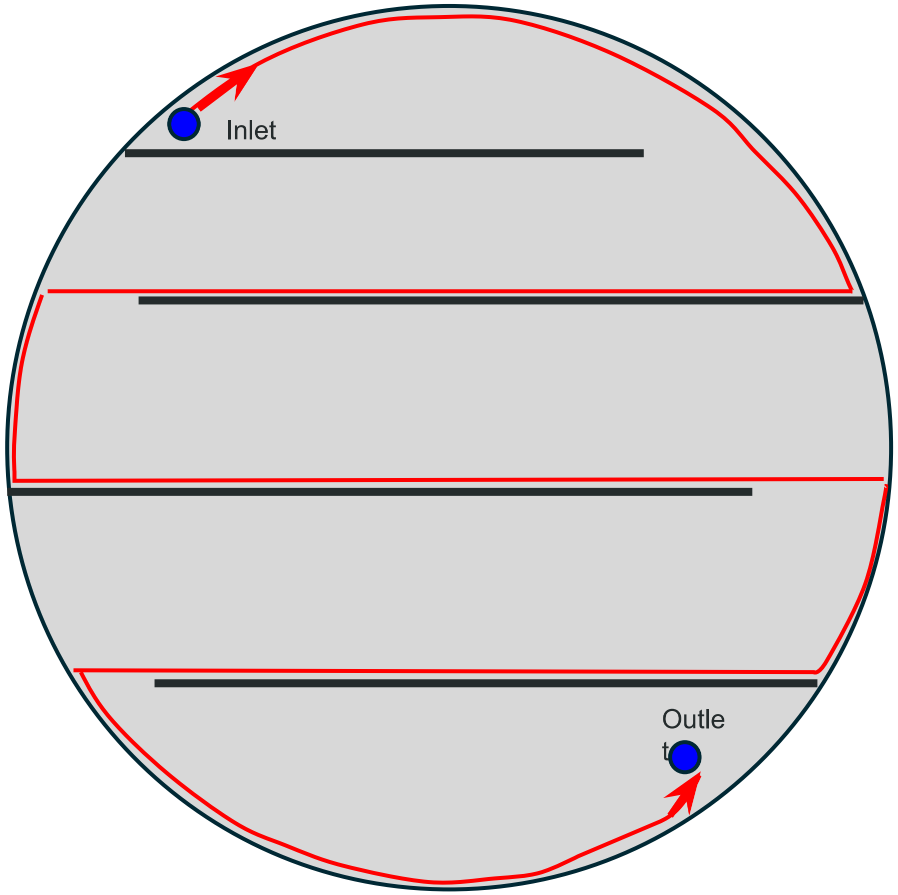



*Source: Presentation on Tracer Studies by Guy Schott, CA DDW, July 9, 2014*

# 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).

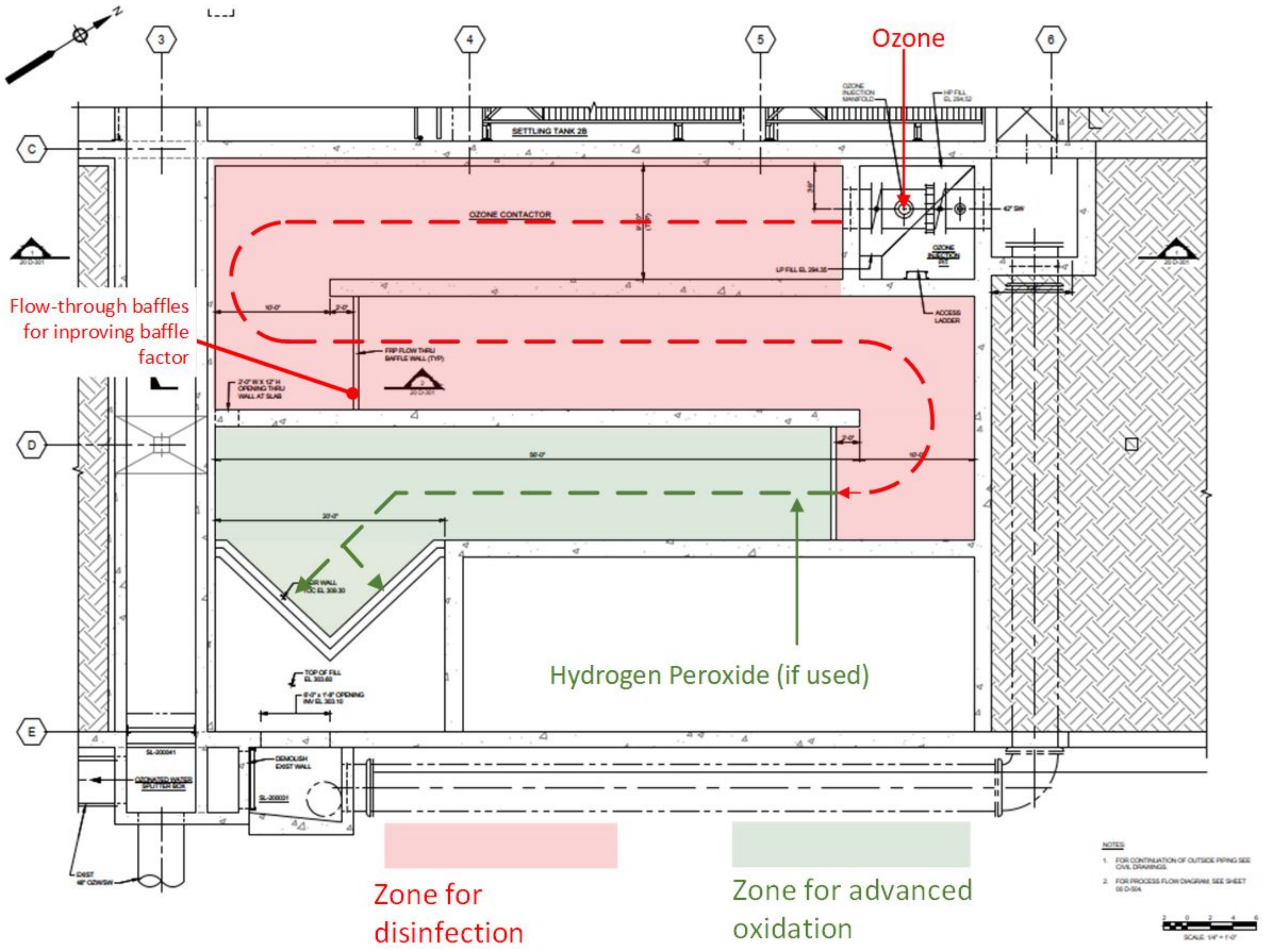
**Width** is the average channel width for each flow path.

# 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

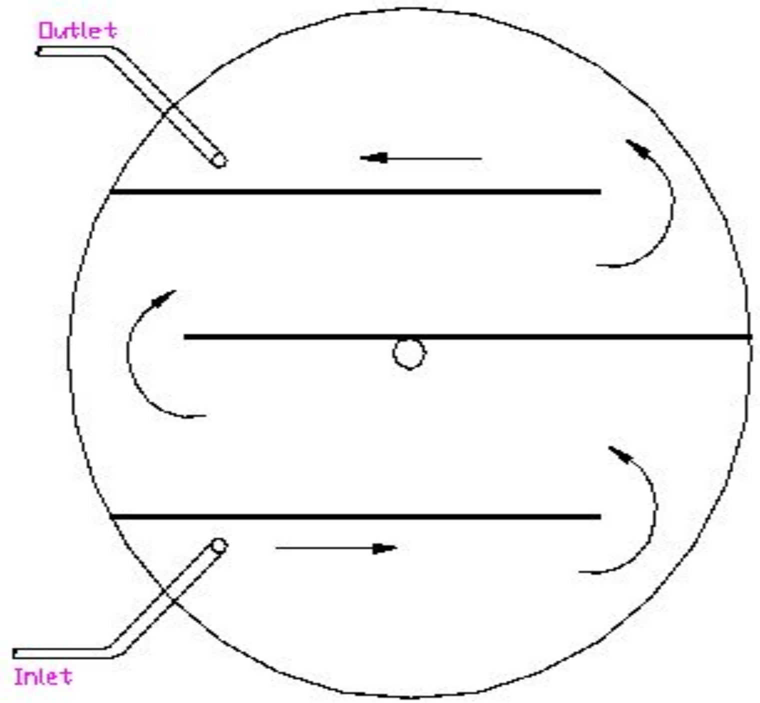
- **For design purposes:**
  - Include two baffles (71%) but design assumes the 53% BF is initially granted by regulators

- 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 t10 value.
- Be prepared for Regulator to assign a more conservative BF than you estimated.



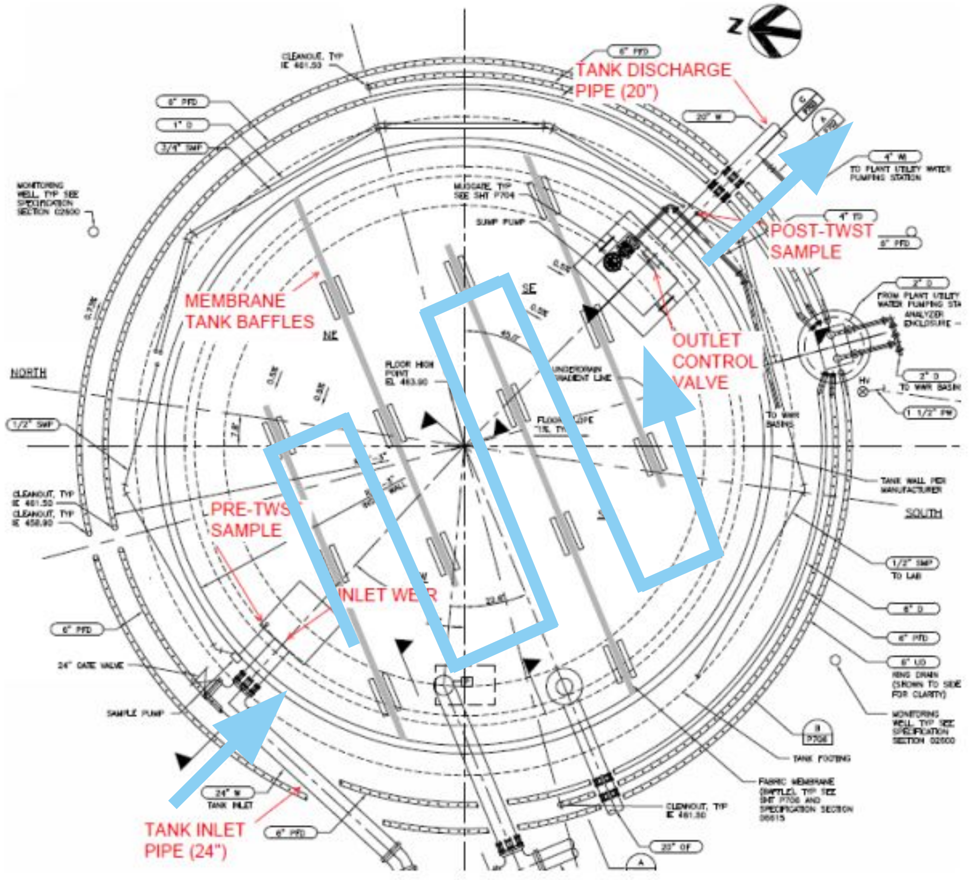
# West Hills WTP 0.5 MG Baffled Clearwell Tracer Study Objective: Demonstrate a Higher Baffling Factor

## Background

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

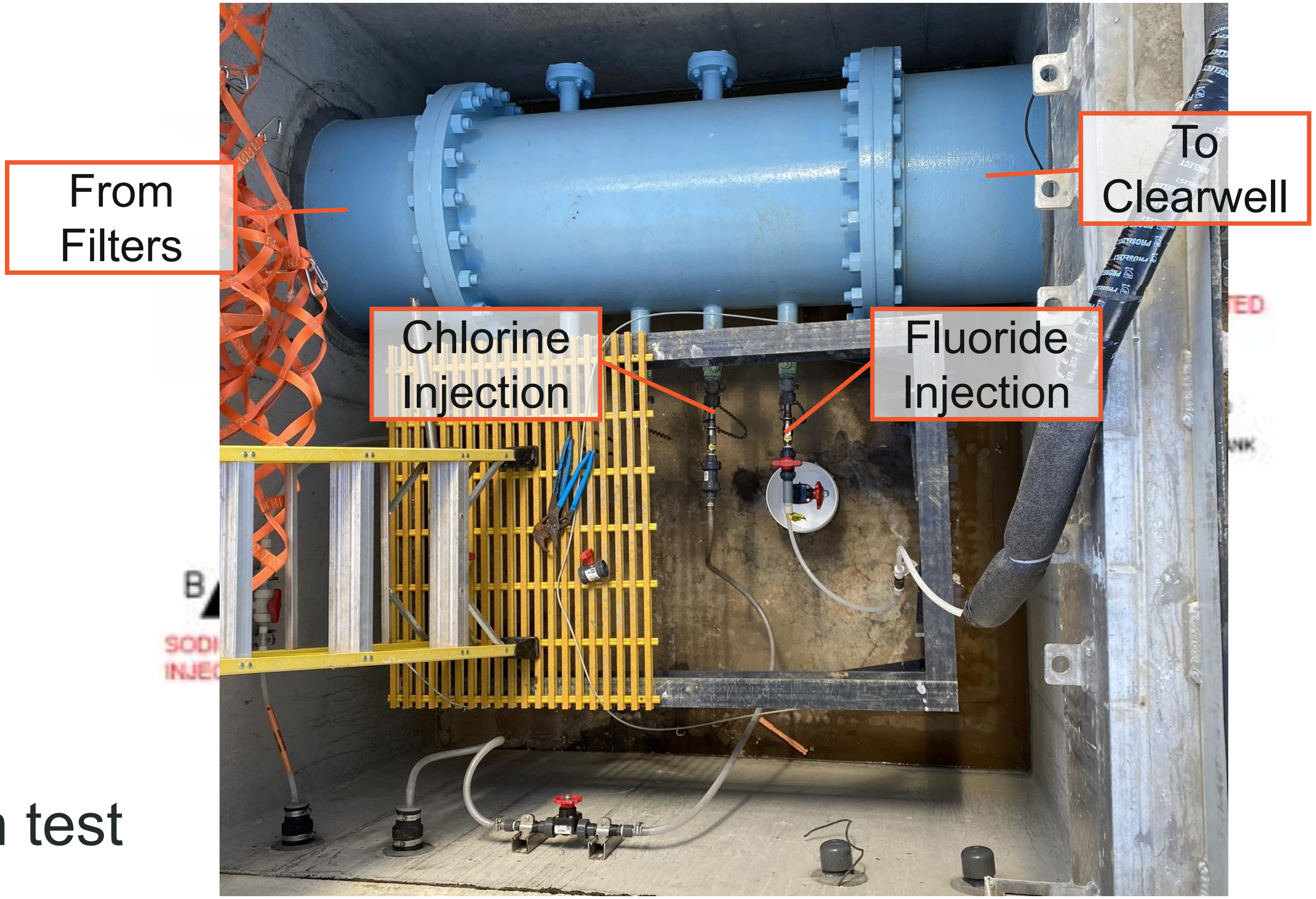
## Benefits of Tracer Study

- 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.



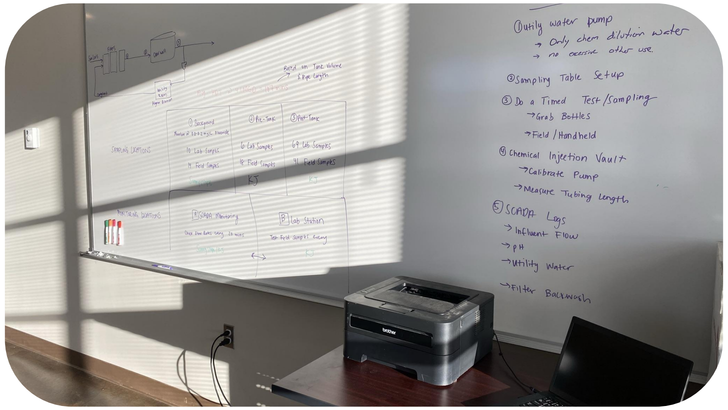
# West Hills Tracer Study Summary

- 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

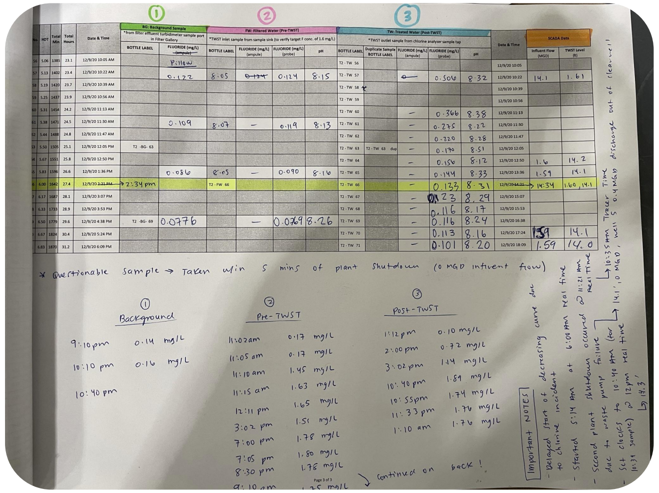

Calibrating Metering Pump

Setting Up Sample Stations

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

Collect Samples

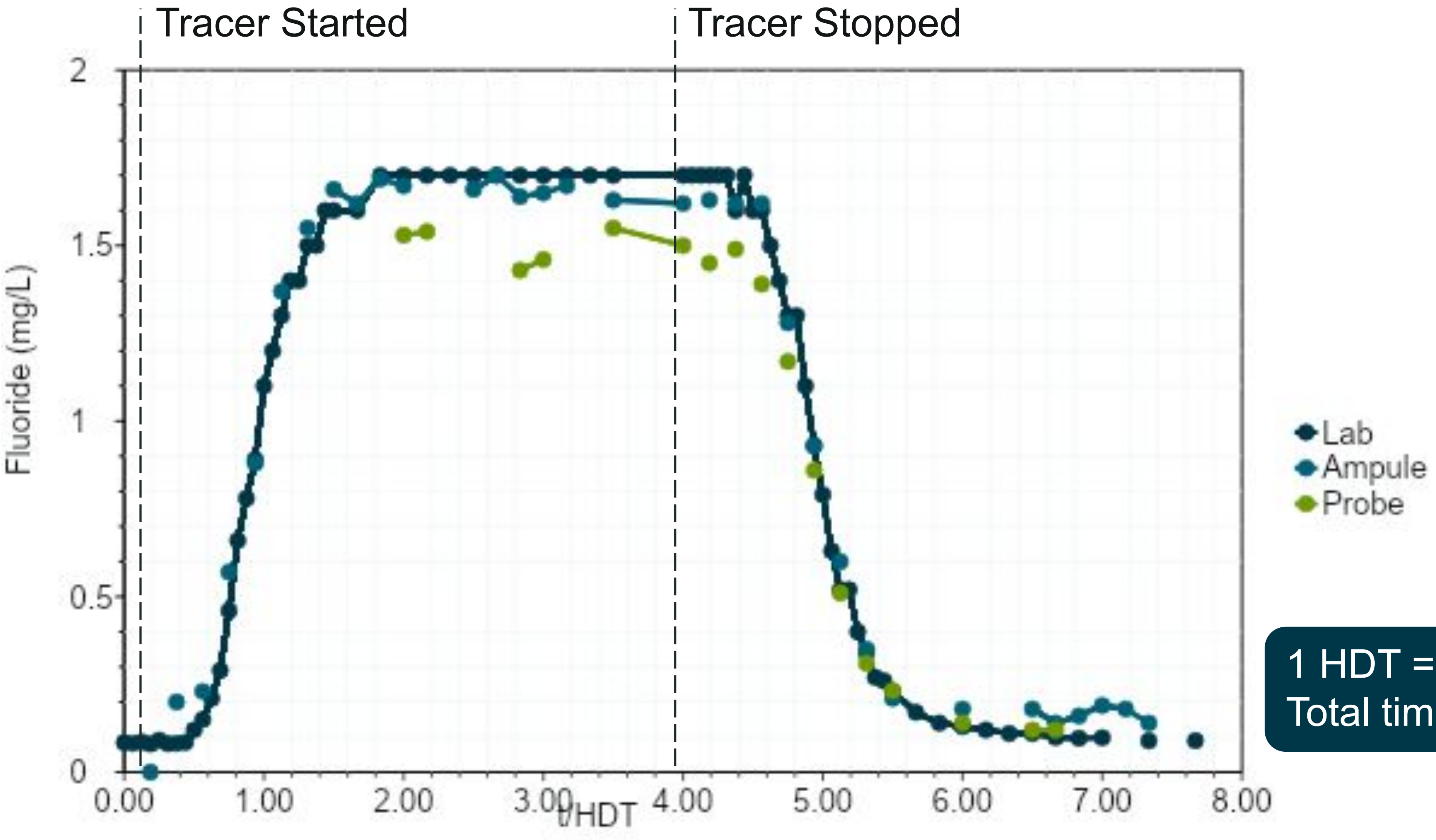
Run Field Analysis



Record Data

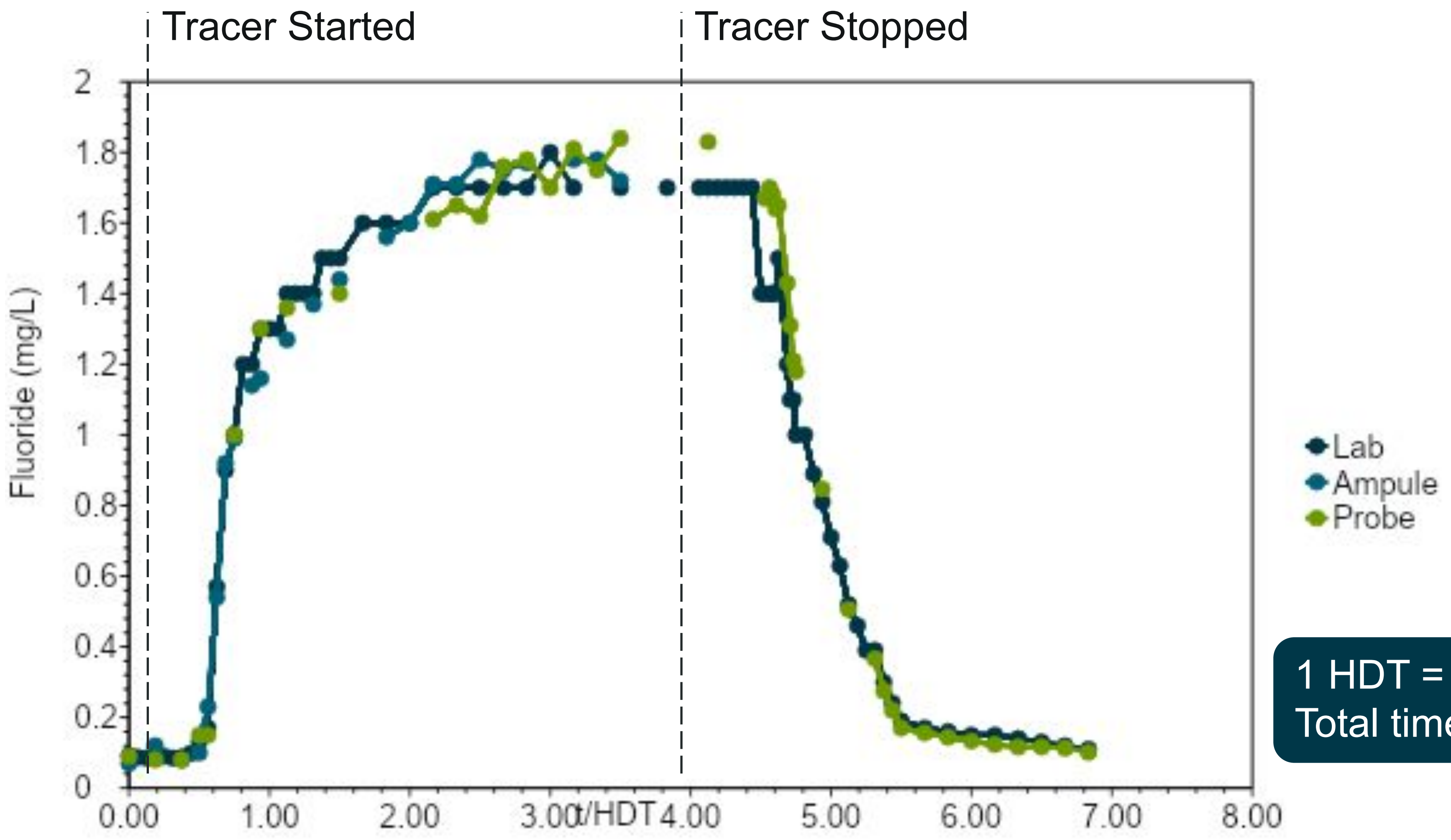
Refrigerate Lab Samples

# Post Clearwell Data for High Flow Test Shows "Textbook" Results




1 HDT = 104 mins
Total time = ~14 hours

# Low Flow Test Also Shows Good Results — Some Diffusion




1 HDT = 280 mins
Total time = ~32 hours

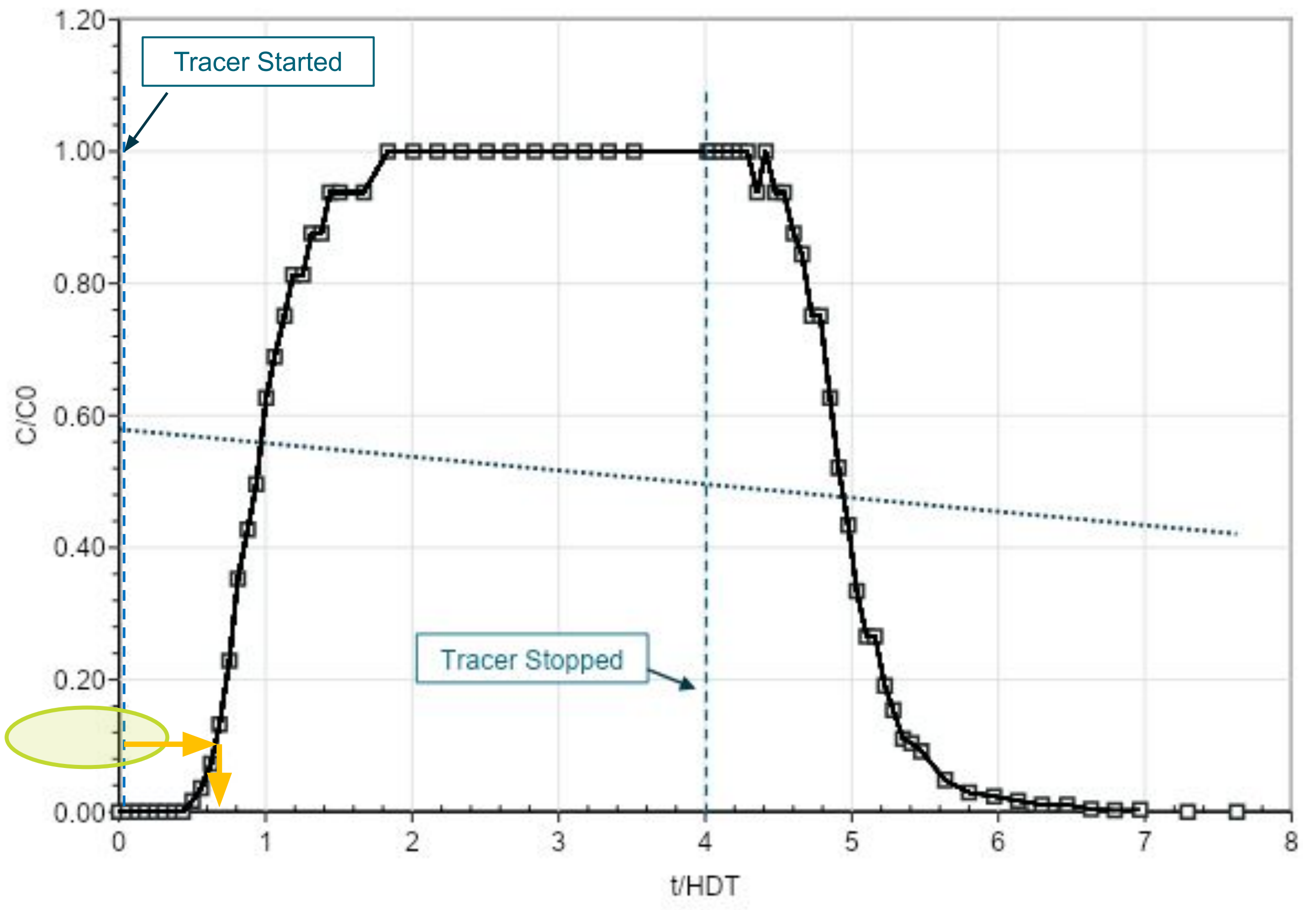
# EPA Methods to Determine the Baffling Factor

## 1. Graphical Method:

- Develop a Normalized F Curve from data
- Visual determination of time at C/C0=0.10

## 2. Best Fit Line Method:

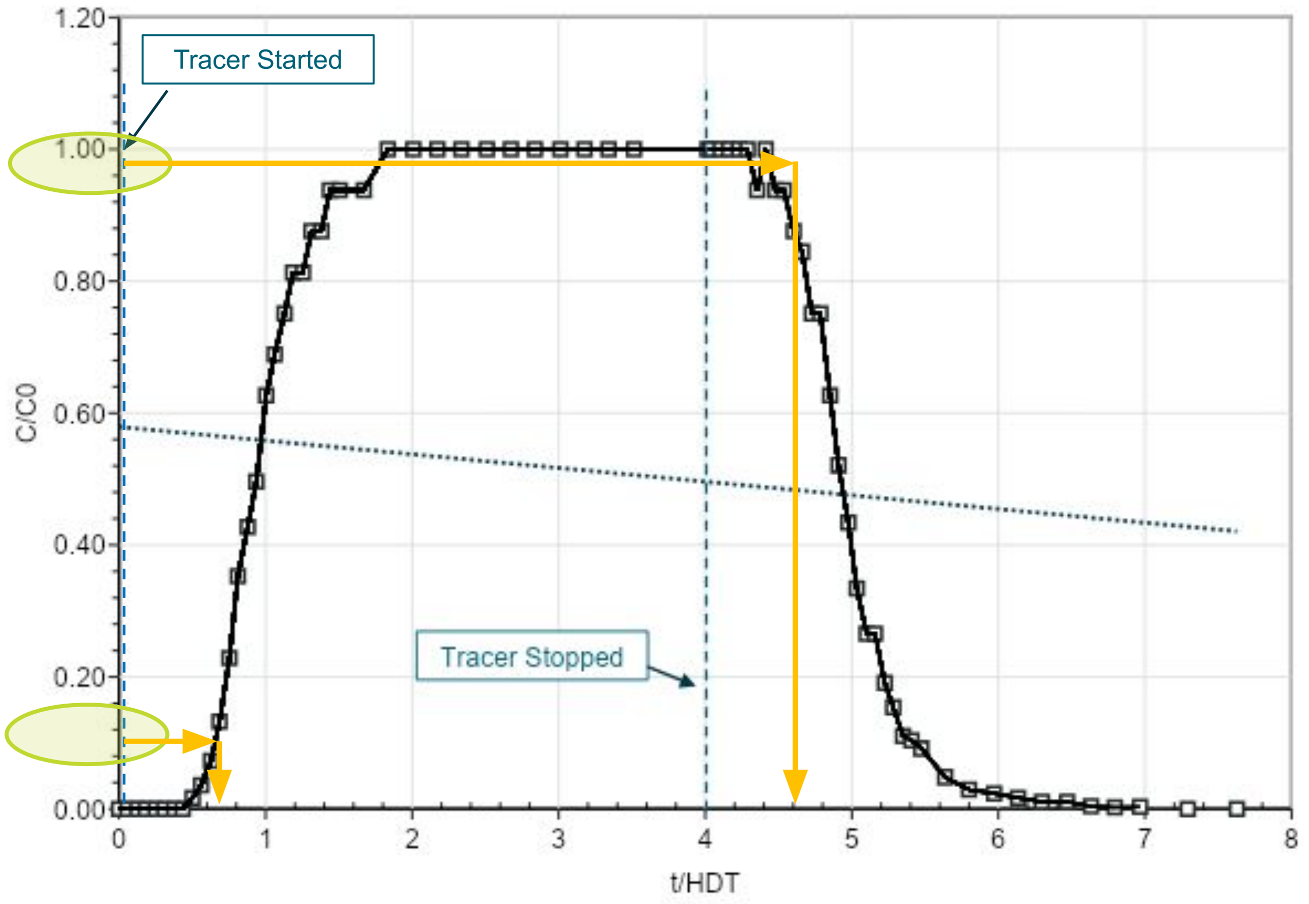
- Develop a mathematical equation for the best-fit line through data.
- Use equation to solve for time at C/C0=0.10




Normalized F Curve for the High-Rate Tracer Test

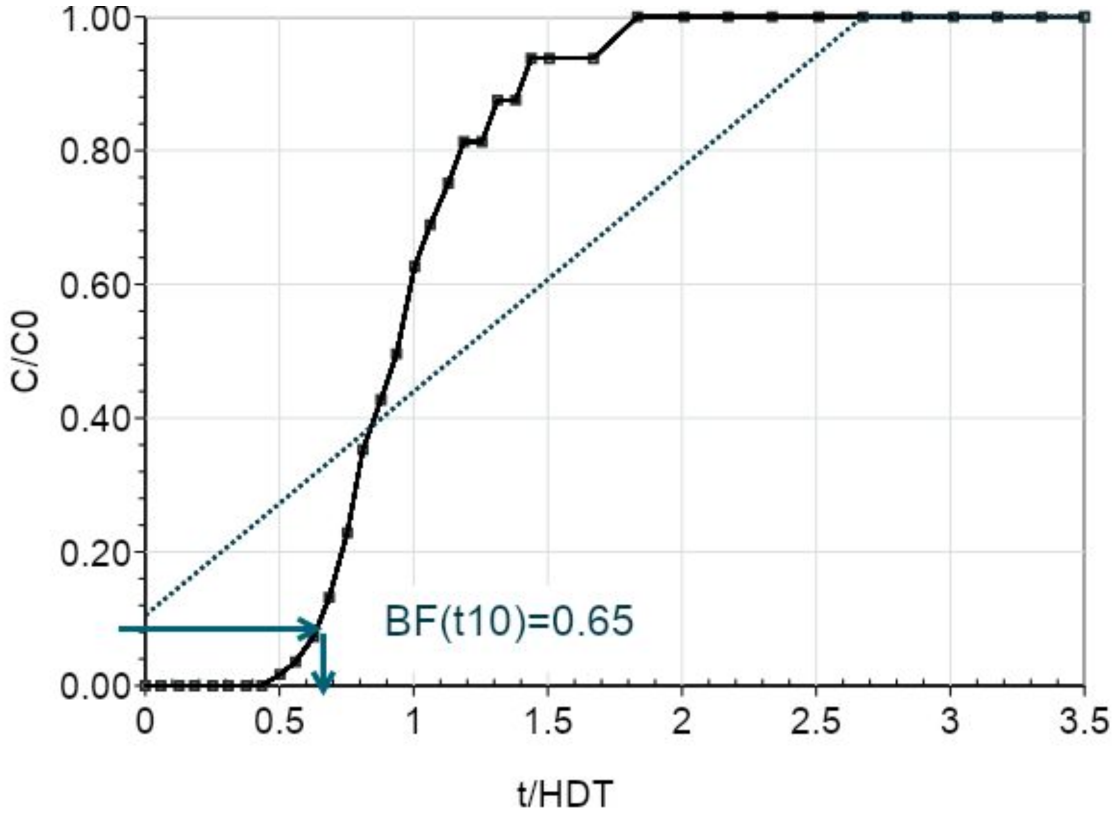
# West Hills Test Runs and Methods Provide 8 Baffling Factor Data Points

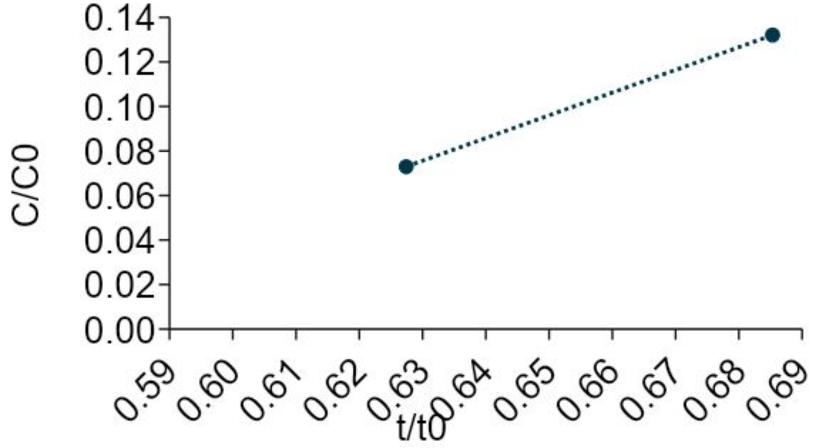
- Two Test Runs – High and Low Flow Rates, each with:
- Ascending Curve (t10)
  - Visual Method
  - Best Fit Line Method
- Descending Curve (t90)
  - Visual Method
  - Best Fit Line Method




Normalized F Curve for the High-Rate Tracer Test

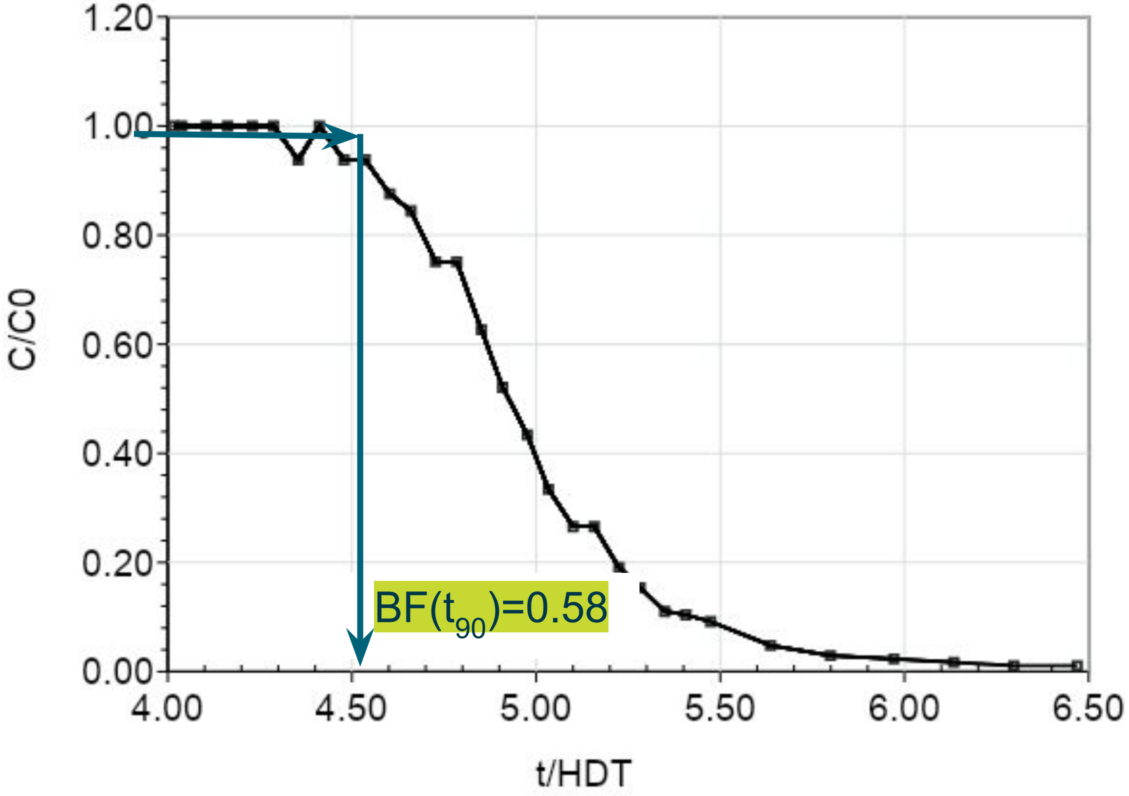
# High Flow Test Ascending – t10 Methods Show Close Agreement

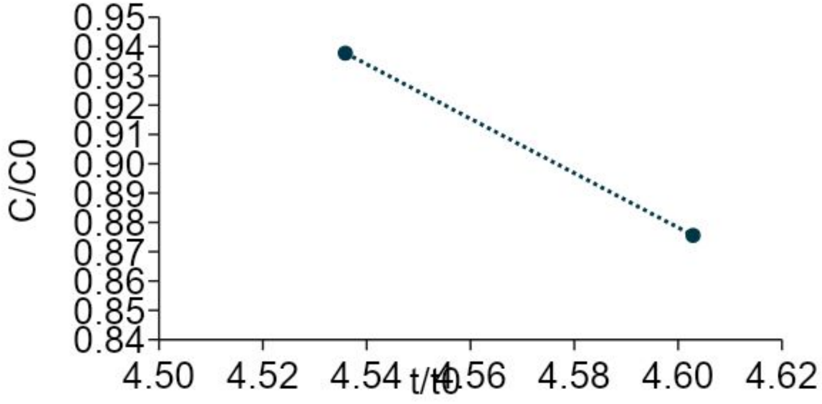



| | |
|---|---|
| y = 1.0206x - 0.5674 | |
| y=0.10 | x=0.6539 |

# 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 (t10/HDT Ratio) Results

**Tabulated Results**

| Test No. | Nominal Flow (MGD) | Ascending Curve HDT (min) | Ascending Curve $T_{10}$ | Ascending Curve $T_{10}$ HDT Ratio | Descending Curve HDT (min) | Descending Curve $T_{90}$ | Descending Curve $T_{90}$ HDT Ratio | Mean $T_{10}$ 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 ($t_{10}$/HDT) graphical and best fit value. Also, it is the mean of all the data points.

**CA DDW approved a new BF ($t_{10}$/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

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