

Tracer Studies 101
Design, Regulatory Approval, and Implementation of Tracer Studies

Claire Jing

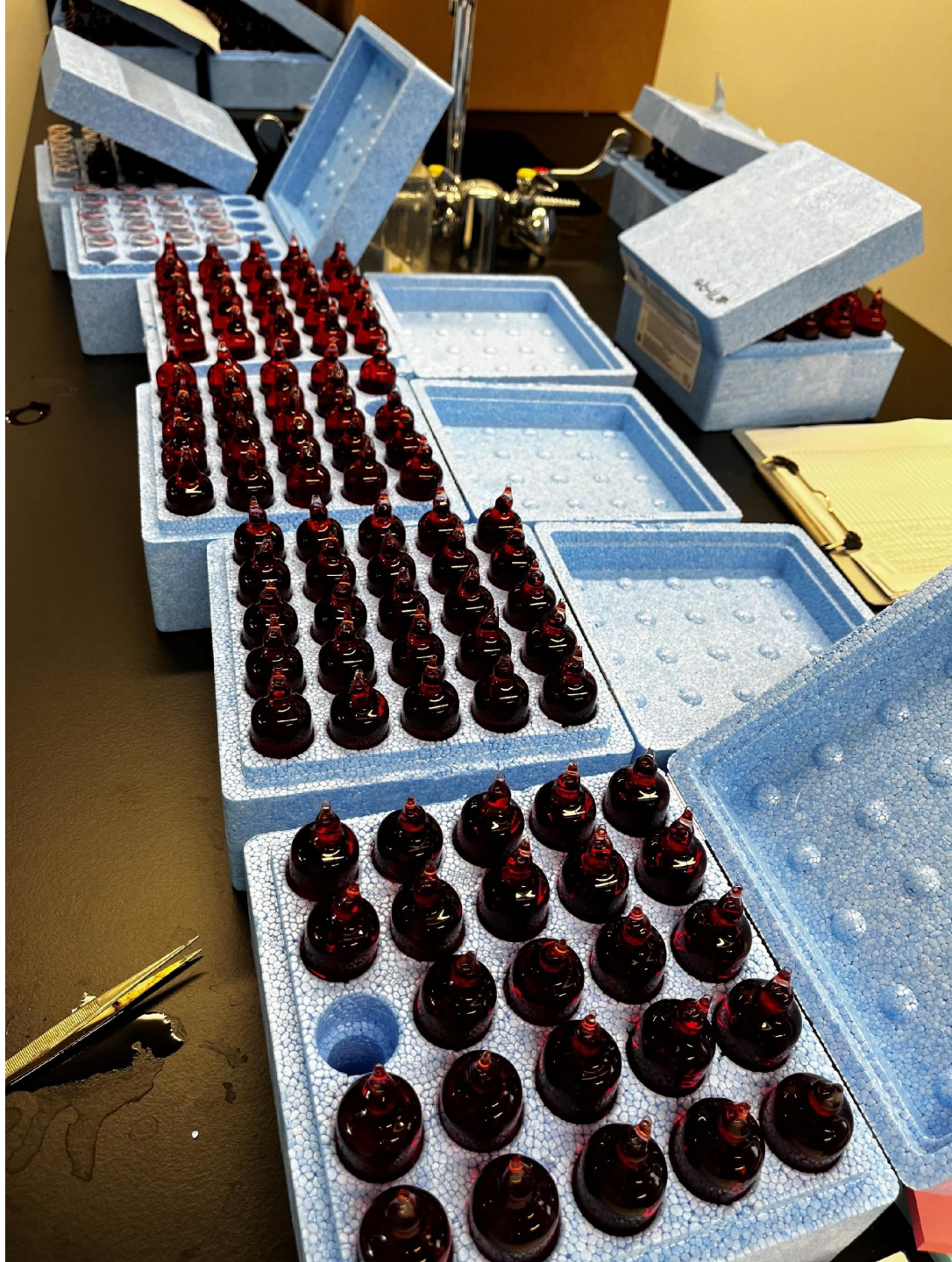
May 7th, 2026

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Challenging today.
Reinventing tomorrow.

Agenda

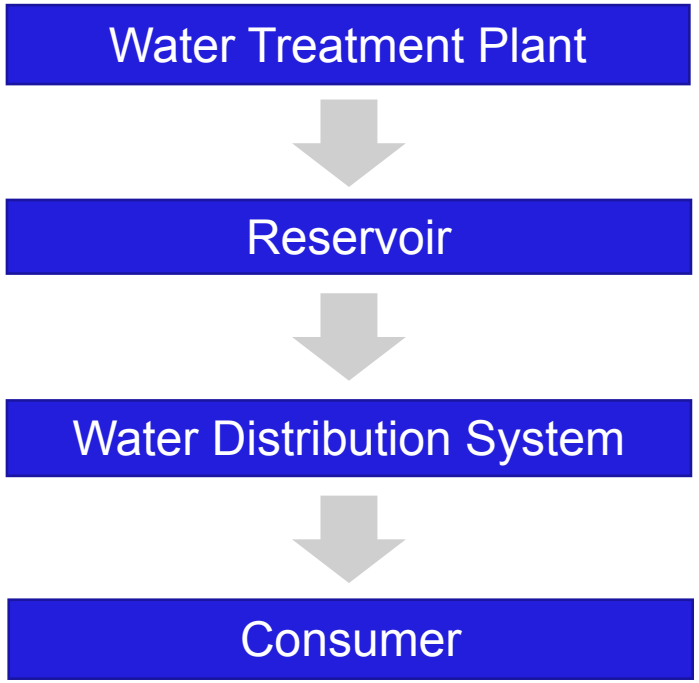
- Purpose of Tracer Studies
- Regulatory Approval Process
- Case Study: Medford Water Robert A. Duff Water Treatment Plant 3-MG Reservoir Tracer Study
- Key Takeaways



Purpose of Tracer Studies

What is a tracer study?

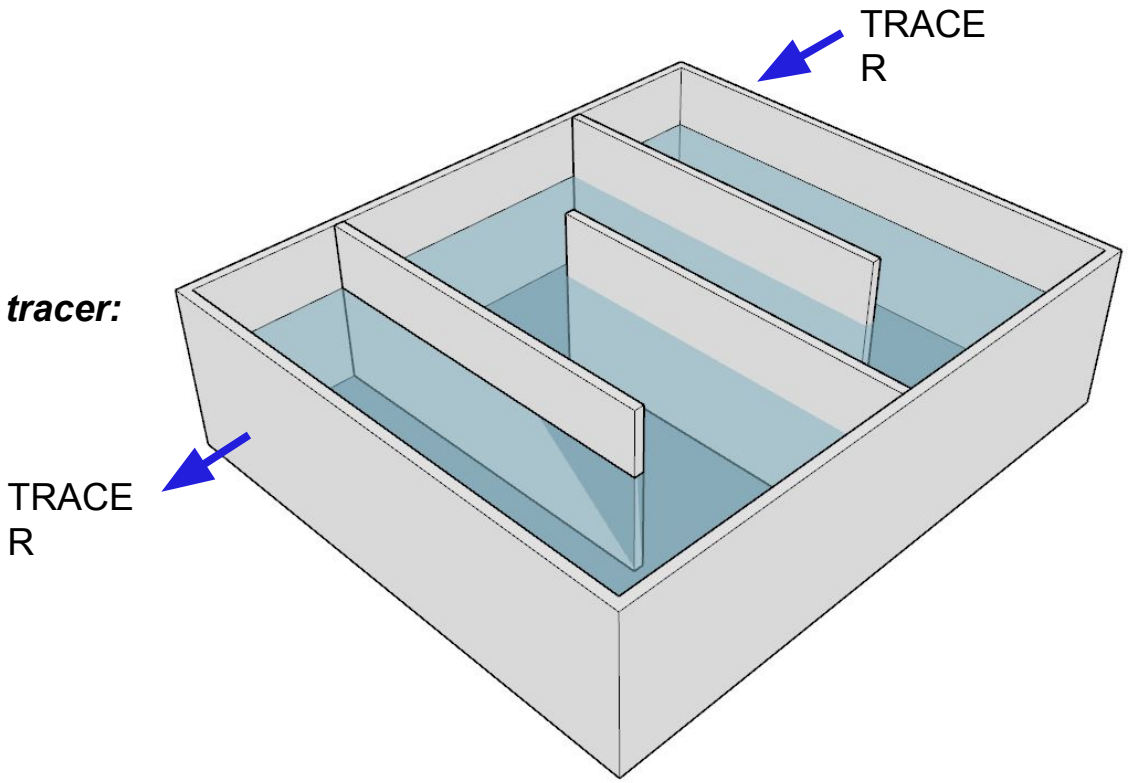
Tracer studies are used to determine the hydraulic or disinfectant exposure time of water through the reactors.



Tracer

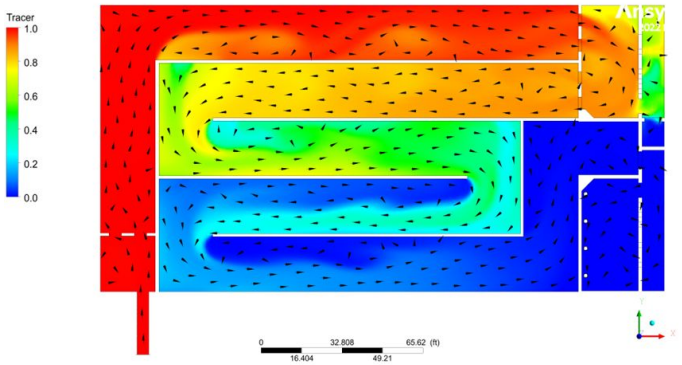
Most commonly used tracer:

- *Fluoride*
- *NaF*
- *Rhodamine WT*
- *Chloride*
- *Chlorine*



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Why do we need a tracer study?



- **Reservoirs sometimes don't behave as designed**
  - Water may short circuit
  - Water may stagnate
  - Operational impacts
- **Water quality is important**
  - Need to ensure sufficient disinfection
  - Reduce risks of DBPs
- **Regulatory Compliance**
  - Tracer studies are often required by the state
  - CT credit is based on the actual system performance instead of theoretical detention time
  - Avoid overstating T10

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Motivation for a tracer study

- CT is regulated to determine the amount of disinfection a treatment plant achieves and to comply with the SWTR.

- CT simply stands for the product of **concentration (*C*)** and **contact time (*T*)**.
  - ***C***: the disinfectant residual concentration measured in mg/L at peak hourly flow
  - ***T***: the time, measured in minutes, that the disinfectant is in contact with the water at peak hourly flow. It is measured from the point of disinfectant injection to a point where the residual is measured.

$$CT_{calc}\ (\text{minutes-mg/L}) = C \times T$$

C = Residual disinfectant concentration measured during peak hourly flow in mg/L.
T = Time, measured in minutes, that the water is in contact with the disinfectant.

Contact Time (T10): the time it takes for 10% of the water entering the reservoir to exit.

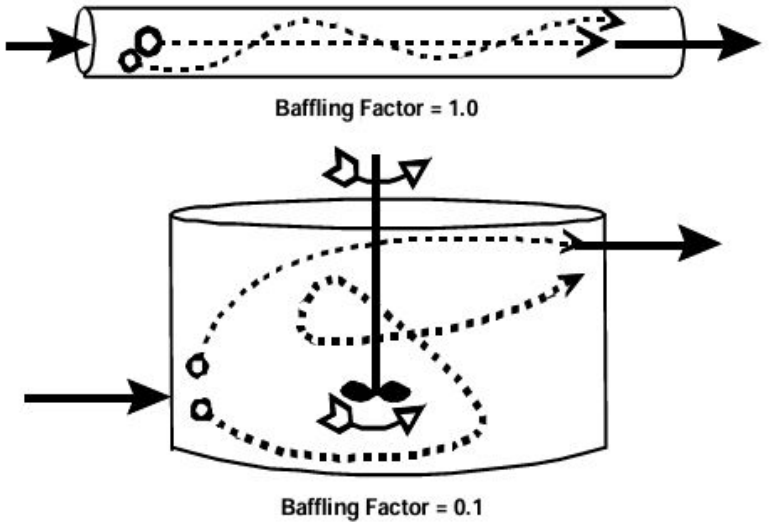
U.S. Environmental Protection Agency. 2020. Disinfection Profiling and Benchmarking Technical Guidance Manual.
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What we evaluate in a tracer study?

- **Baffling factor (BF) = T10/T**
  - Determined by the tank geometry
  - Unchanged unless the reservoir is modified
  - Can be conservatively assigned or verified

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.



U.S. Environmental Protection Agency. 2020. Disinfection Profiling and Benchmarking Technical Guidance Manual.
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How to determine “T”?

- **Reservoir volume (V)**
- Theoretical detention time (TDT) or hydraulic residence time (HRT)
  - The theoretical time that the water is in a basin, pipe, or unit process assuming perfect plug flow. Perfect plug flow assumes no short-circuiting within the basin, pipe, or unit process and all the water follows a single flow path.

$$TDT = V / Q$$

TDT = Theoretical Detention Time, in minutes
V = Volume based on low water level, in gallons (gal)
Q = Peak hourly flow, in gpm

HRT (or TDT) *is* ***not used*** *for T10 because the reservoir is not a perfect plug flow reactor.*
T10 *represents the worst-case scenario and is always less than the HRT.*

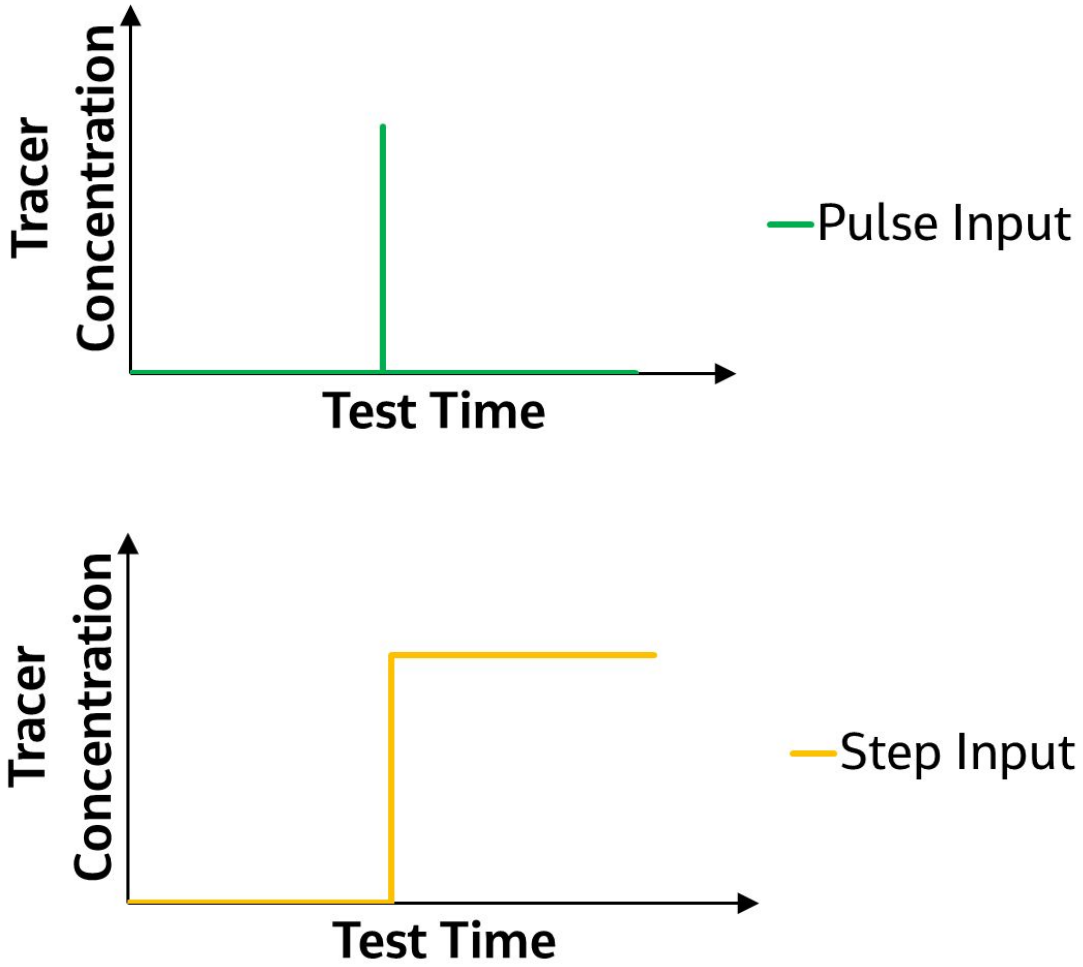
U.S. Environmental Protection Agency. 2020. Disinfection Profiling and Benchmarking Technical Guidance Manual.
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What parameters do we measure in a tracer study?

- Tracer concentration
- Time
- Flow rate
- Sampling locations
- Reservoir levels (or volume of reactor)
- Supporting parameter – Temperature, pH, etc.

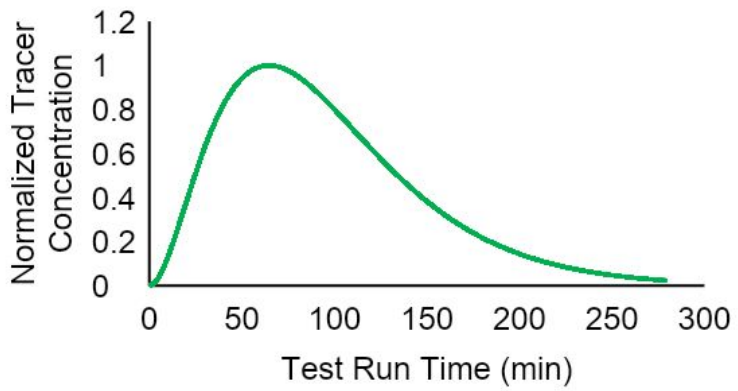
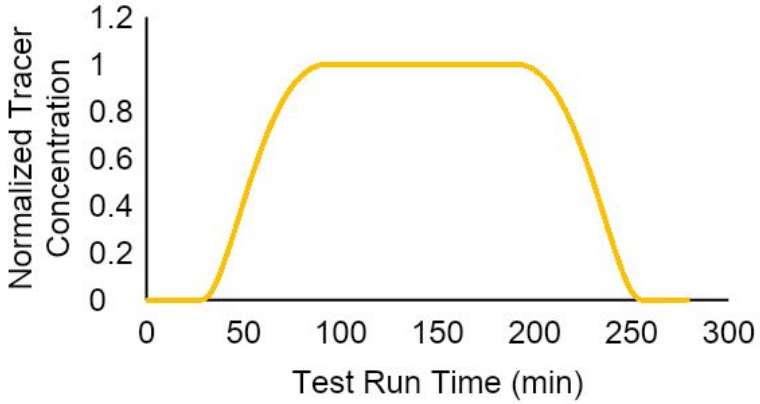
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Tracer Study Distribution Curve – Perfect Reactors



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Tracer Study Distribution Curve - Reality

	Pros	Cons
Pulse Dose 	▪ Shorter test duration ▪ Easy data interpretation ▪ Less chemical usage ▪ Less risk of short-circuiting	▪ Difficult to implement in field with a single curve for determining T10 ▪ Sensitive to start up ▪ Potential lower outlet concentration due to dilution ▪ Challenging to introduce a clean spike
Step Dose 	▪ Easier field control and execution ▪ Clear plateau in the curve ▪ Less sensitive to noise ▪ Two curves to confirm the result	▪ Longer test duration ▪ Higher risks of short-circuiting ▪ High chemical usage

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Regulatory Approval Process

Regulatory Framework for Tracer Study

- **U.S. EPA Surface Water Treatment Rule (SWTR) Requirement**
  - Utilities need to meet ***CT*** targets for disinfection

Site Specific Conditions

You must calculate your system's total inactivation ratio daily and provide 3-log *Giardia lamblia* and 4-log virus inactivation daily except any 1 day each month in 11 of 12 months (on an ongoing basis). You must take daily measurements before or at the first customer at each residual disinfectant concentration sampling point and must measure:

- Temperature.
- pH (if chlorine is used).
- Disinfection contact time (at peak hourly flow).
- Residual disinfectant concentration (at peak hourly flow).

T = contact time
C = disinfectant concentration

You must comply with the MCL for total coliforms [40 CFR 141.63(a) and (b)] and the MCL for *E. coli* [40 CFR 141.63(c)] in at least 11 of the 12 previous months, and you must meet the requirements of the Stage 1 DBPR and Stage 2 DBPR.

- **EPA DOES NOT require utilities to perform a tracer study.**
- **Implementation and enforcement are state-specific.**

 U.S. Environmental Protection Agency. 2020. Surface Water Treatment Rules – What Do They Mean to You?

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What if a tracer study is not practical?

- A conservative BF may be used when a tracer study is not feasible and is approved by the state.

OREGON HEALTH AUTHORITY

- Tracer study is preferred.
- Follow EPA's *Disinfection Profiling and Benchmarking Technical Guidance Manual* when assumptions need to be made.

Washington State Department of HEALTH

- Tracer study is strongly recommended unless it is not feasible.
- Upper limit of conservative BF without tracer study is 0.7 according to EPA's guidance but not common.
- Additional analysis may be expected.

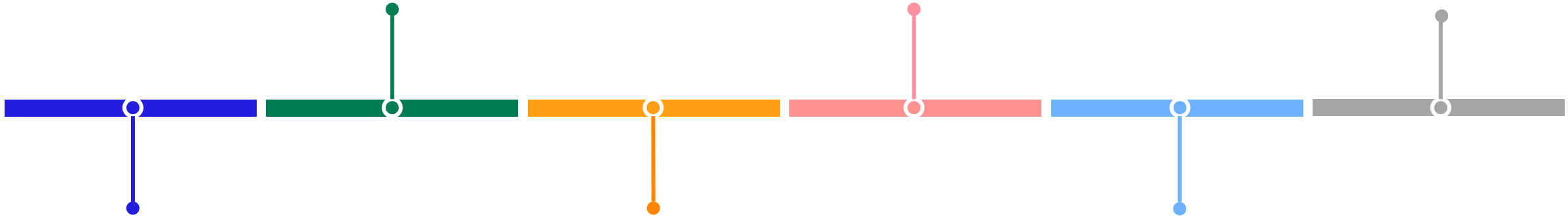
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Source: USEPA. March 1991.

U.S. Environmental Protection Agency. 2020. Disinfection Profiling and Benchmarking Technical Guidance Manual.
Washington State Department of Health Division of Environmental Health Office of Drinking Water. 1995. Guidance Manual Surface Water Treatment Rule.
Oregon Health Authority. 2022. Drinking Water Services Plan Review requirements for new disinfectant systems at existing public water systems.

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Typical Regulatory Approval Timeline



Pre-coordination with state regulator

- Study objectives
- Project details
- Discuss state-specific requirements

Submit a tracer study plan

- Study objectives
- Proposed tracer
- Sampling plan
- Analytic methods

Regulatory review and approval

- Is the testing approach appropriate?
- Plan approval

Conduct tracer study

- Follow the approved tracer study plan
- Document any deviations

Submit final report

- Breakthrough curves
- T10 calculation
- Interpretation
- Documentation during testing

Regulatory Acceptance

Are the results acceptable for compliance?

- Baffling factor
- Chlorine concentration

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State Regulatory Process

Before the study	• ***Submit an engineering report or technical memorandum, including:*** ✔ Study objectives ✔ Reservoir details ✔ Proposed study approach • ***Coordinate with DOH on tracer study procedures and T10 determination methods***	• ***Mandatory tracer study plan submission*** ✔ Personnel and schedule ✔ Tracer type and dosage ✔ Reservoir volume and operating range ✔ Peak hourly flow conditions ✔ Injection and sampling locations ✔ Flow control method ✔ Detailed system schematic • ***OHA review and approval***
During the study	• ***Conduct tracer study under approved design conditions***	• ***Must follow the approved plan exactly*** • ***Must maintain disinfection residual***
After the study	• ***Submit final report*** ✔ Breakthrough curve ✔ T10 calculation ✔ Engineer's interpretation of testing results • ***DOH review and approval***	• ***Submit final report using Tracer Study Reporting Form template provided by the state*** ✔ Data and curve ✔ T10 calculation ✔ QA/QC • ***OHA review and approval***

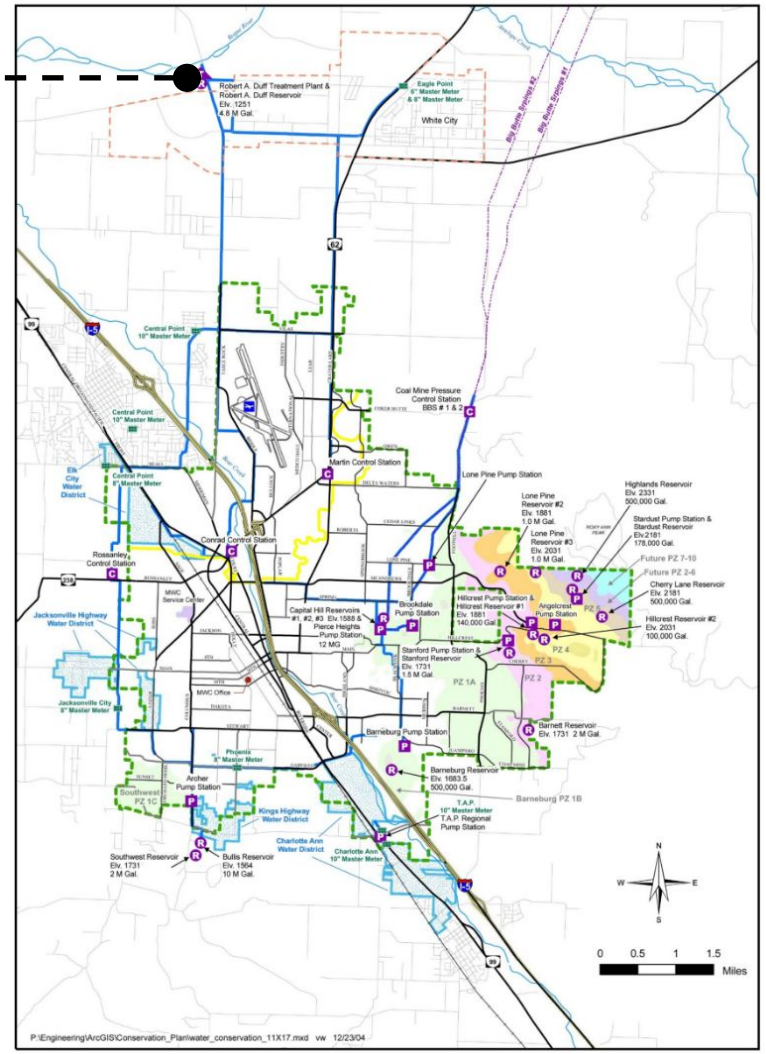
Case Study

Medford Water Robert A. Duff Water Treatment Plant 3-MG Reservoir Tracer Study

Project Background

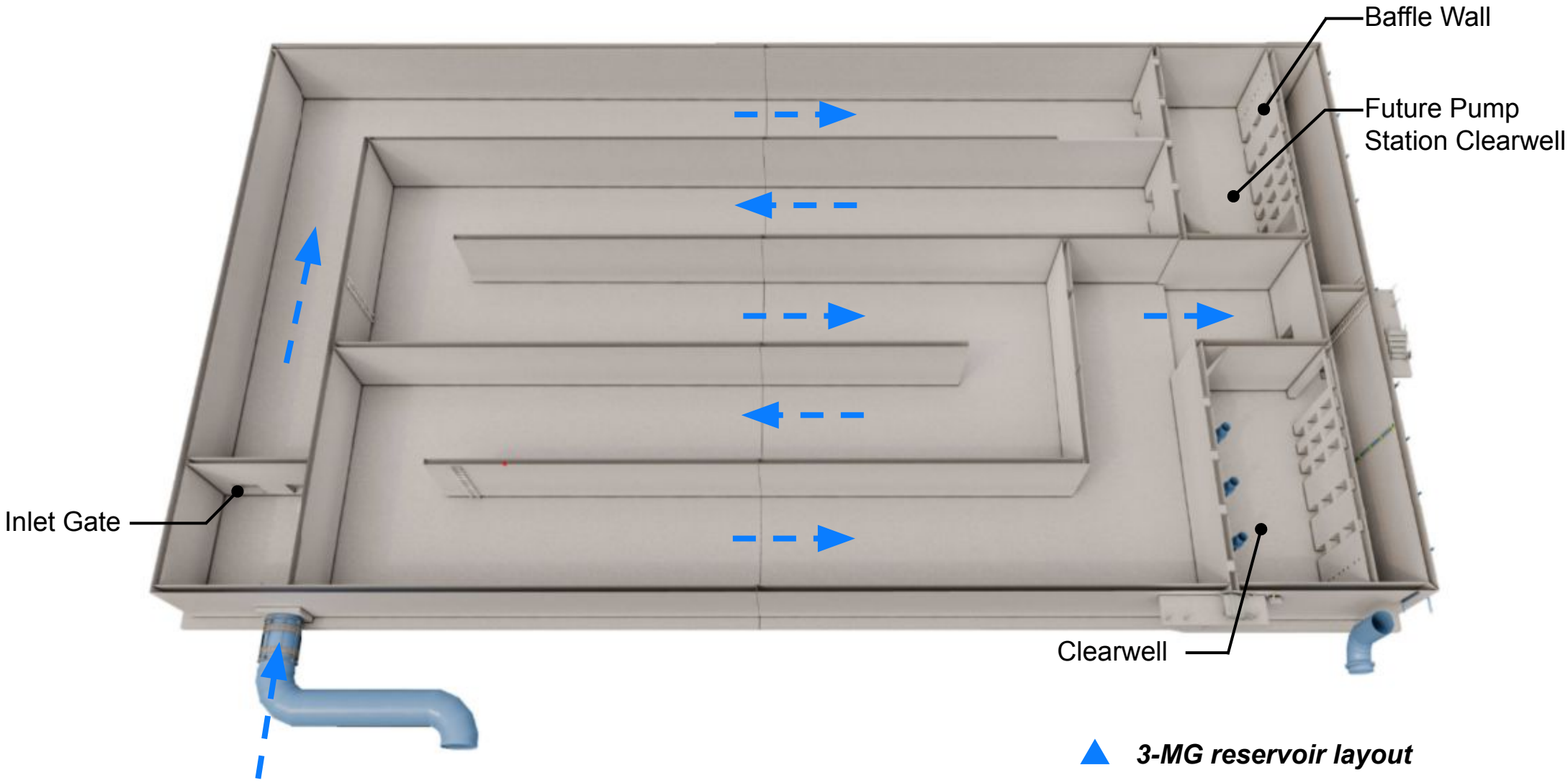


Medford Water Robert A. Duff Water Treatment Plant



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3-MG Reservoir Configuration



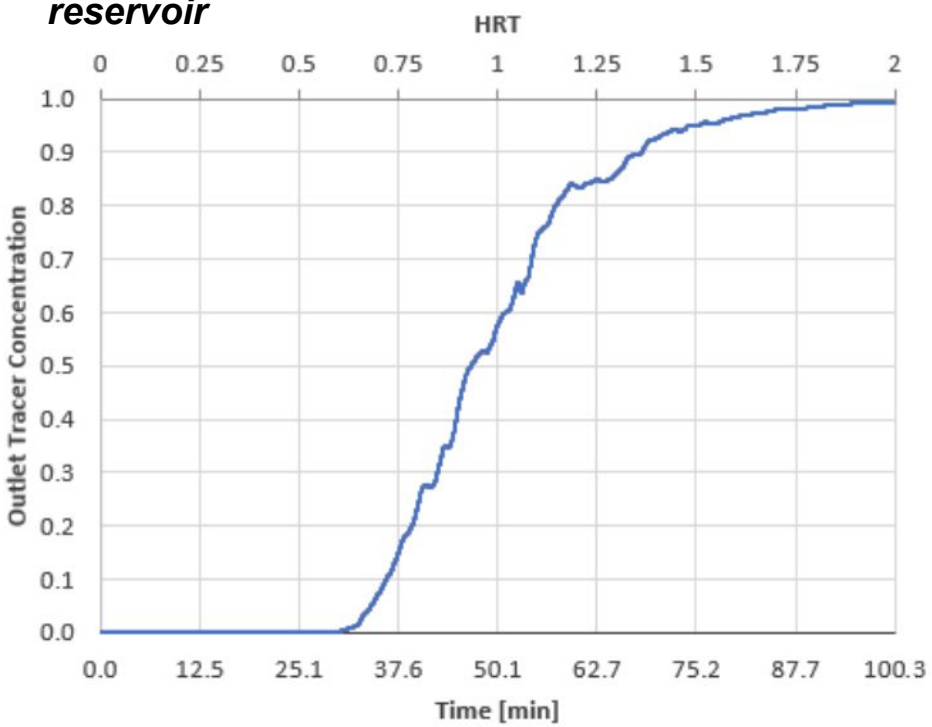
▲ ***3-MG reservoir layout***

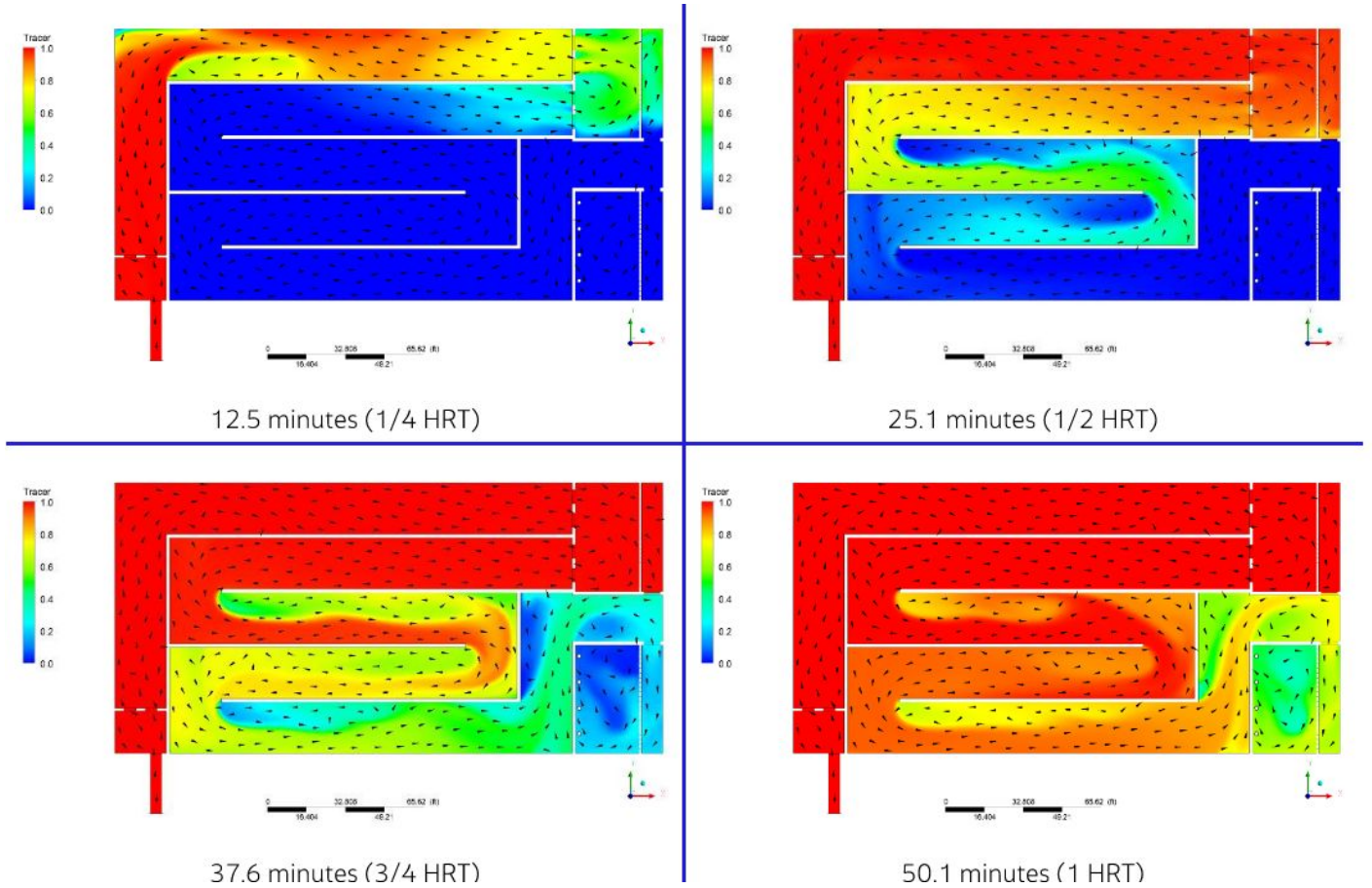
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Theoretical Tracer Distribution Over Time

- Theoretical T10 = 36.1 min
- **Theoretical BF = 0.72**

Tracer concentration over time in reservoir





Tracer distribution over time in reservoir

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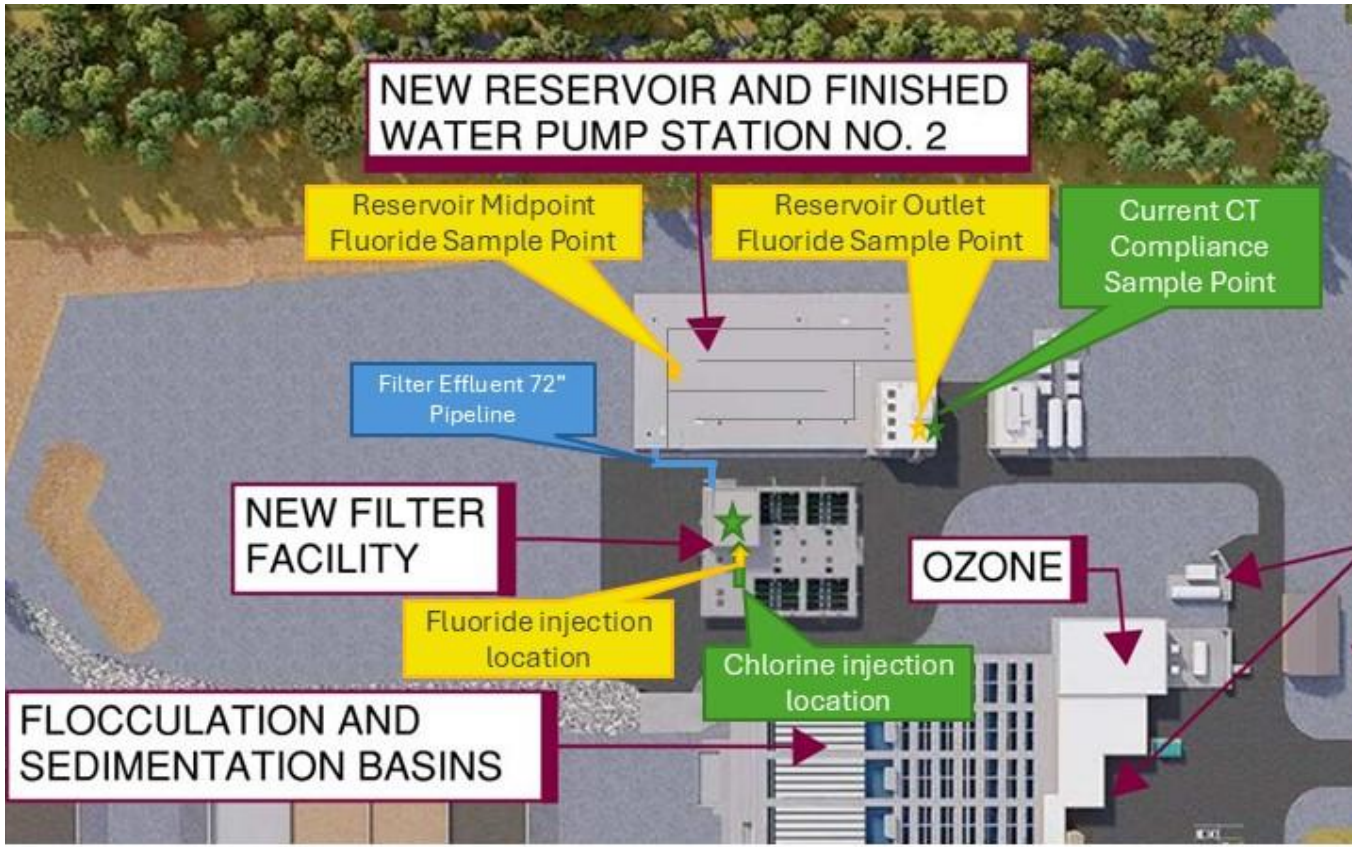
Tracer Study Background

- 3-MG Reservoir
  - Increase plant capacity to 65 mgd
  - Increase finished water storage

★ ***Tracer Study Plan***

Oregon Health Authority

- ❑ Determine BF = T10/T
- ❑ Obtain ranges of flow and reservoir level to use approved baffle factor



▲
- ***Tracer injection point:*** *chlorine diffuser in filter seal weir*
- ***Tracer measurement point:*** *finished water pump station (CT compliance sample point)*

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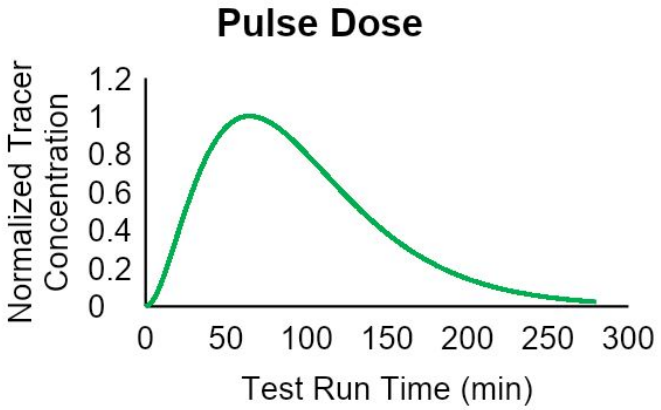
How to plan for a tracer study?

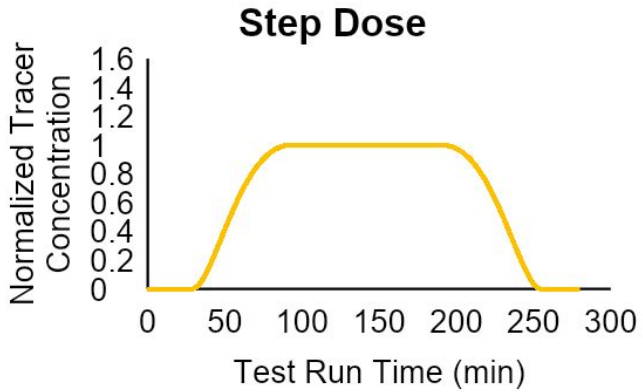
- **Tracer type**

Tracer is non-reactive

Fluoride	Chloride	Rhodamine WT	Others
▪ Hydrofluosilicic Acid (H_2SiF_6) ▪ NaF			▪ Chlorine

- **Test approach**
  - Pulse input: Tracer mass is introduced at t = 0
  - Step input: Tracer concentration is introduced for all t ≥ 0



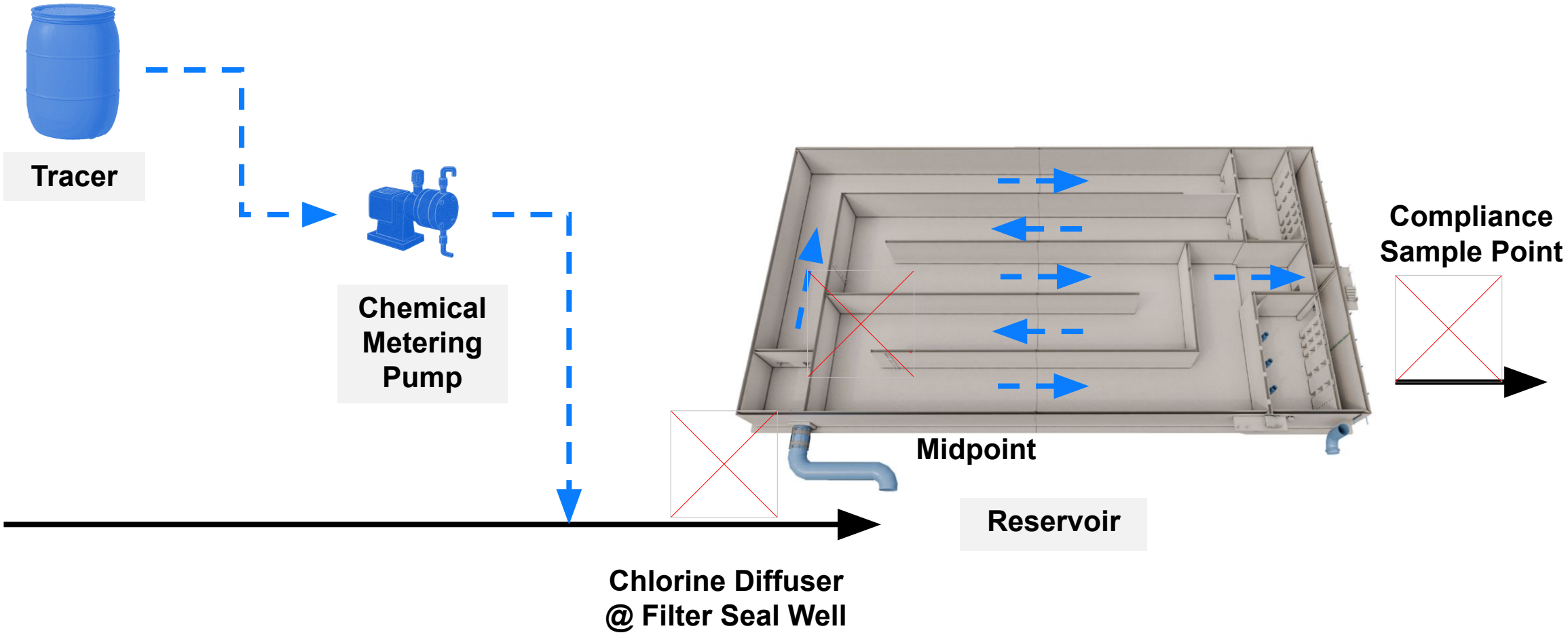




Hydrofluorosilicic Acid

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Tracer Testing Process Scheme



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Tracer Test Plan

Test Approach

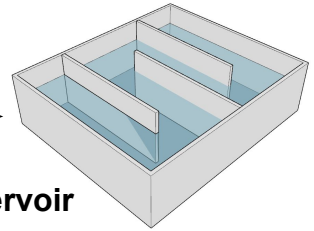
Tracer Type:
Hydrofluorosilicic acid (Fluoride)
(NSF 60 certified)





Chemical Metering Pump
(NSF 61 certified)

Step Test
Fluoride: 1.0 → 0 mg/L



3MG Reservoir

Test Preparation

1. Test Flow & Reservoir level – *Peak Flow*
OHA allows WTP to operate 10% higher than the flow during the test

2. Test Conditions & Targets
- FWPS flow rate
- Reservoir level
- Reservoir T10 with conditionally approved conservative BF
- CT compliance point: free chlorine residual, water temperature, maximum pH
- Required CT
- Actual CT with conservative BF

3. Test Duration

4. Sample Location

5. Staffing

6. Equipment
Spectrophotometer, colorimeter, etc.

Test Procedures

1. Prior to test
- Adjust reservoir to provide needed level and reservoir volume
- Stabilize flow before testing
- Increase flow rate to test setpoint
- Record background fluoride concentration
- Confirm sample collecting frequency

2. Starting test
- Begin fluoride injection
- Perform test according for planned test duration
- Record data using previously prepared data log

3. After test
- Reporting and analysis

QA/QC

Verify the quality of the test results:

1. Constant flow rate
2. Constant water level
3. Monitor tracer test until steady state fluoride concentration is reached at the CT compliance point, typically clearwell effluent.
4. Equipment accuracy

The test plan should be detailed and cover all necessary instructions!

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Test Equipment



Spectrophotometer
HACH DR 6000



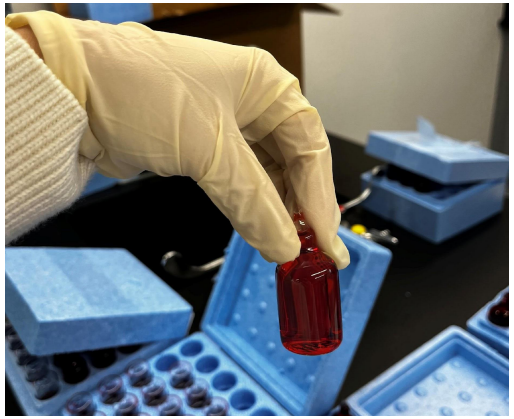
Walkie-Talkies



Kimtech Kimwipes

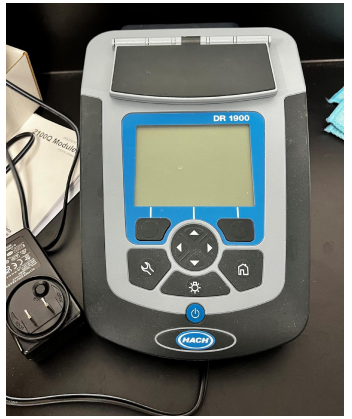


Chemical Metering Pump



SPADNS Fluoride Reagent AccuVac® Ampules





Colorimeters
HACH DR 1900
HACH DR 900

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Test Data Log

Record the sampling point and sample name (e.g., midpoint, sample station, etc.)

Sample Point: Sampler Name:

MW Tracer Study (3 MG Reservoir)

Date: 9/9/2025

#	Sample Time	Fluoride (mg/L)	Notes
1			
2			
3			
4			
5			
6			
7			

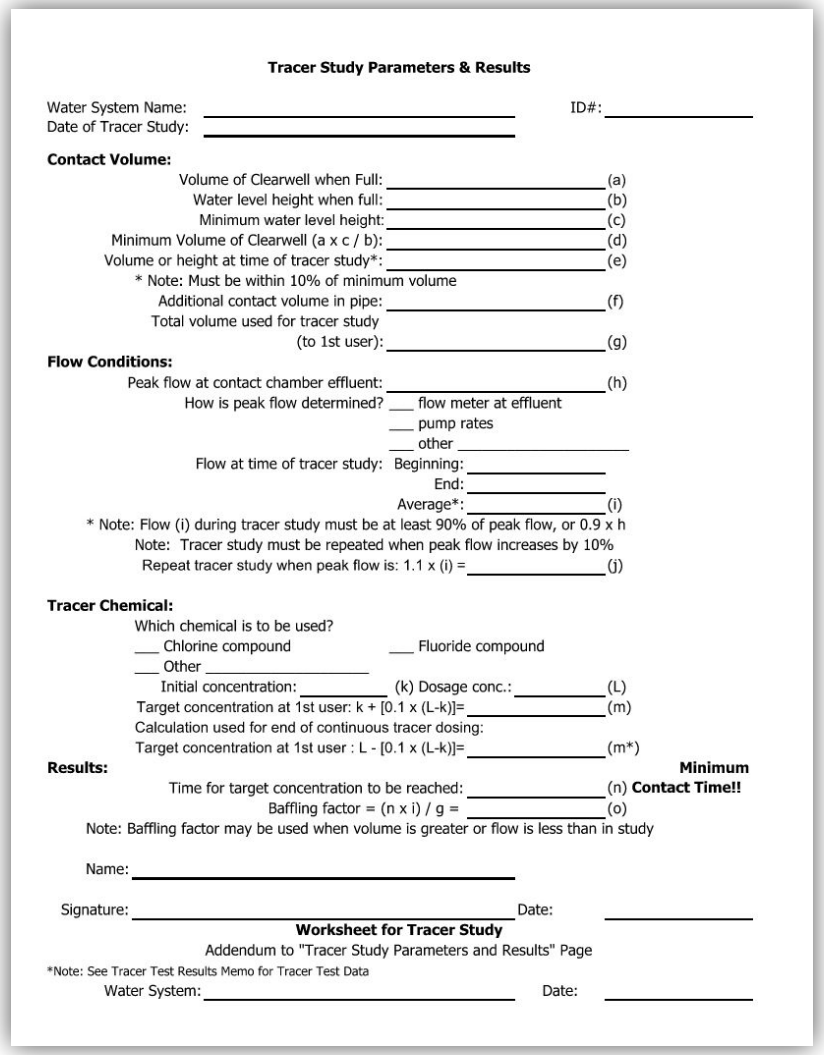
Record sampling time

Read fluoride concentration using colorimeter every 1 min

Record notes for the sampling process

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Test Results and Reporting



Tracer Study Parameters & Results

Water System Name: _____ ID#: _____
Date of Tracer Study: _____

Contact Volume:

Volume of Clearwell when Full: _____ (a)
Water level height when full: _____ (b)
Minimum water level height: _____ (c)
Minimum Volume of Clearwell (a x c / b): _____ (d)
Volume or height at time of tracer study*: _____ (e)
* Note: Must be within 10% of minimum volume
Additional contact volume in pipe: _____ (f)
Total volume used for tracer study
(to 1st user): _____ (g)

Flow Conditions:

Peak flow at contact chamber effluent: _____ (h)
How is peak flow determined? ___ flow meter at effluent
___ pump rates
___ other _____
Flow at time of tracer study: Beginning: _____
End: _____
Average*: _____ (i)
* Note: Flow (i) during tracer study must be at least 90% of peak flow, or 0.9 x h
Note: Tracer study must be repeated when peak flow increases by 10%
Repeat tracer study when peak flow is: 1.1 x (i) = _____ (j)

Tracer Chemical:

Which chemical is to be used?
___ Chlorine compound ___ Fluoride compound
___ Other _____
Initial concentration: _____ (k) Dosage conc.: _____ (L)
Target concentration at 1st user: k + [0.1 x (L-k)]= _____ (m)
Calculation used for end of continuous tracer dosing:
Target concentration at 1st user : L - [0.1 x (L-k)]= _____ (m*)

Results: **Minimum**
Time for target concentration to be reached: _____ (n) **Contact Time!!**
Baffling factor = (n x i) / g = _____ (o)
Note: Baffling factor may be used when volume is greater or flow is less than in study

Name: _____

Signature: _____ Date: _____

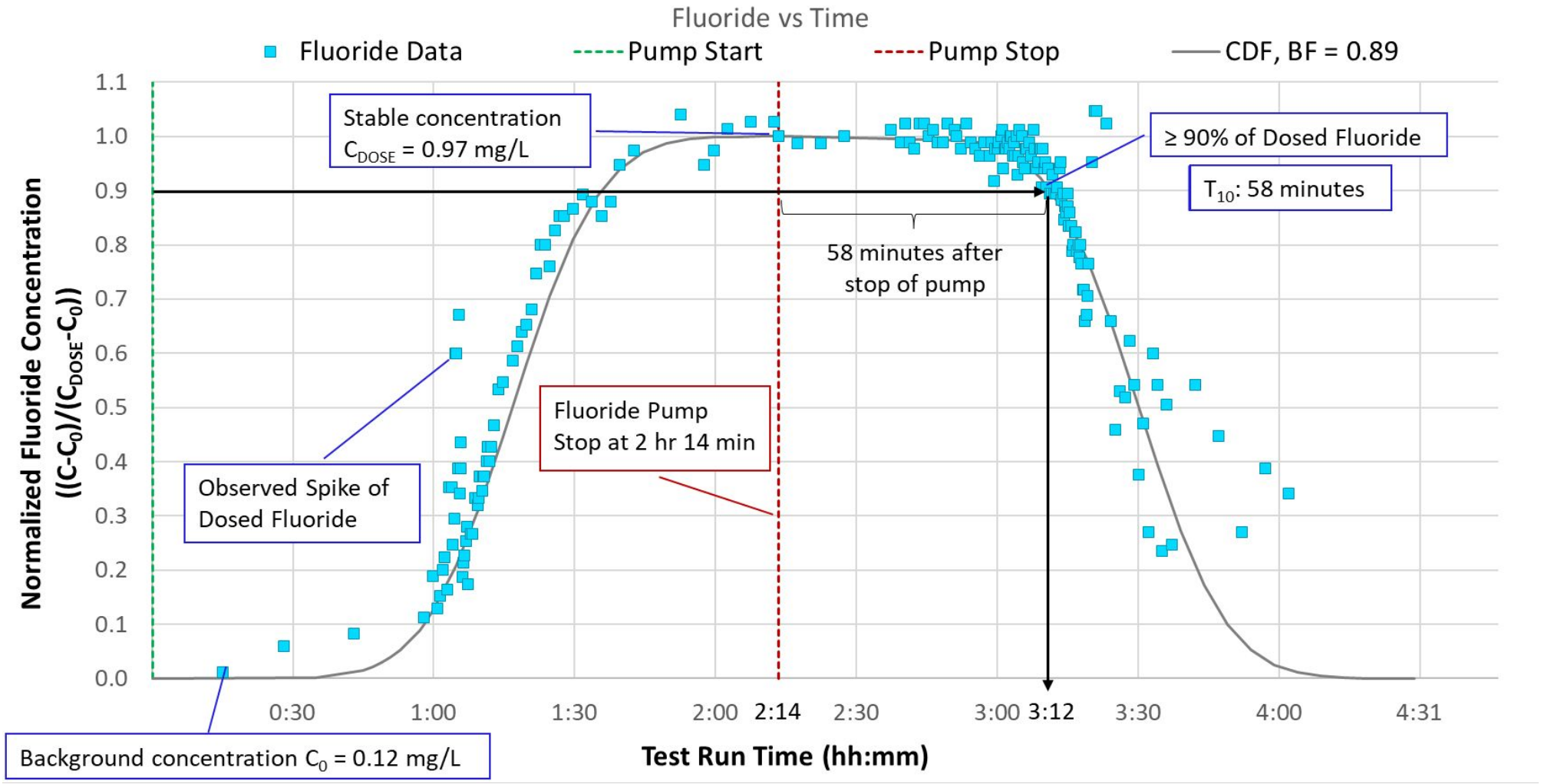
Worksheet for Tracer Study
Addendum to "Tracer Study Parameters and Results" Page
*Note: See Tracer Test Results Memo for Tracer Test Data
Water System: _____ Date: _____

Tracer Study Data Summary

Description	Test 1
Time Test Start, Time Start of Fluoride Injection (hh:mm:ss)	6:02:00 AM
Time Fluoride Injection Stopped (hh:mm:ss)	8:16:00 AM
Time Fluoride Samples Stopped (hh:mm:ss)	10:32:00 AM
CT Sample Point Free Chlorine, Average	0.88 mg/L
Clearwell Level, Average	8.9 ft
Finished Water Pump Wet Well Level, Average	11.9 ft
Finished Water Pump Station Flow, Average	39.9 mgd
Combined Filter Effluent Flow, Average	40.3 mgd

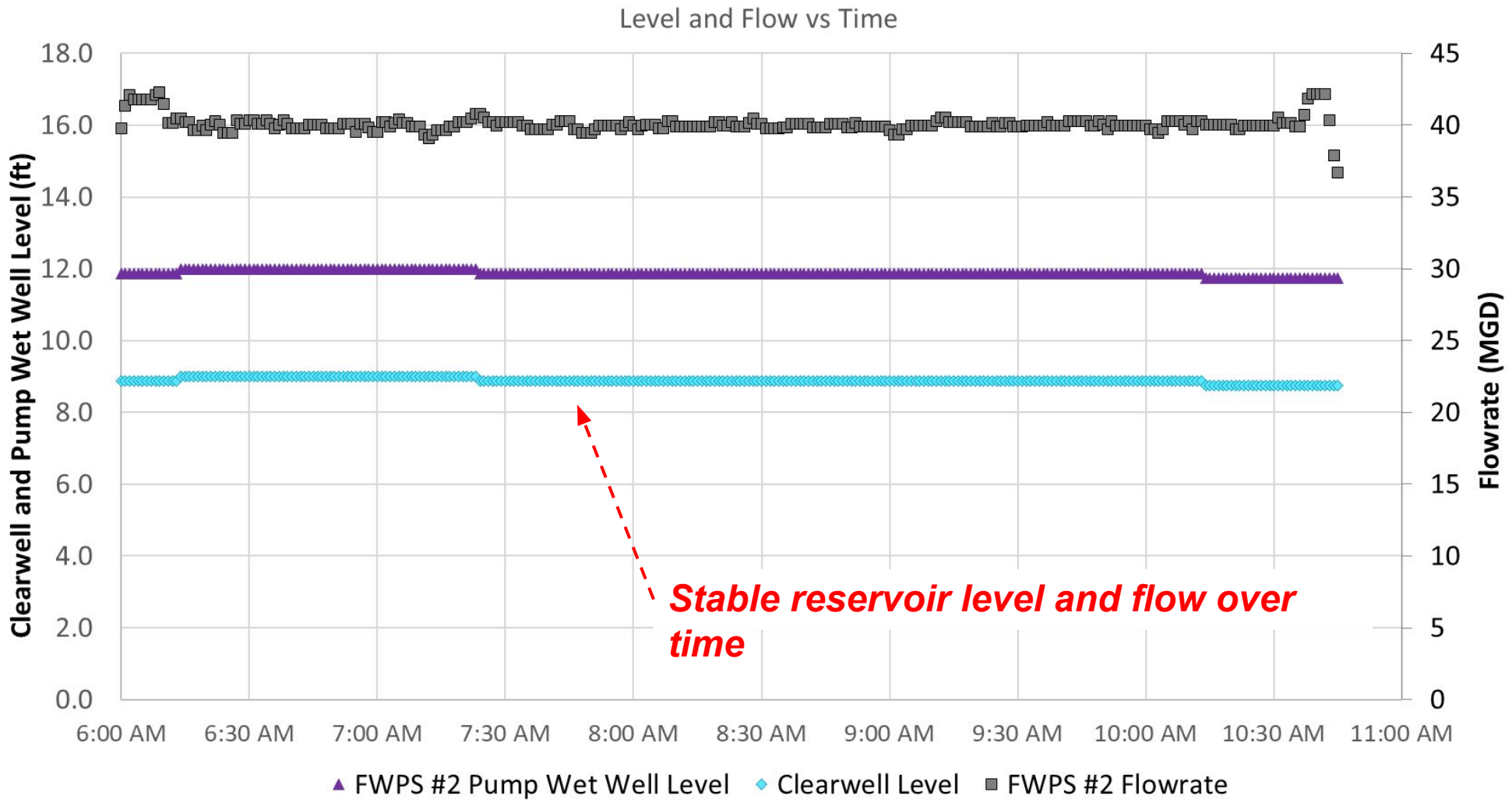
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Test Results and Reporting



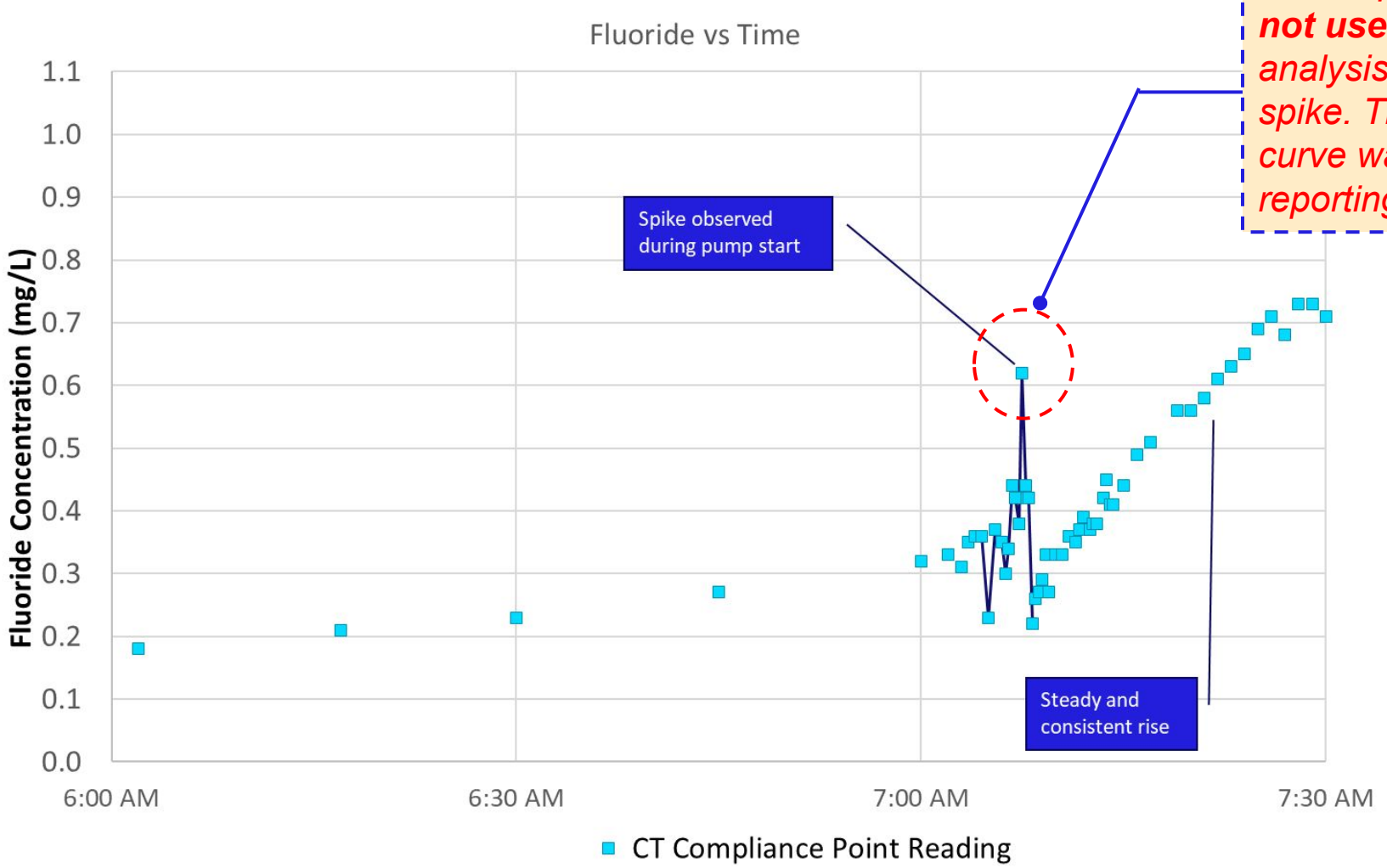
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Test Results and Reporting



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Test Results and Reporting



*The step-up curve was **not used** in the data analysis due to the spike. The step-down curve was used for reporting purpose.*

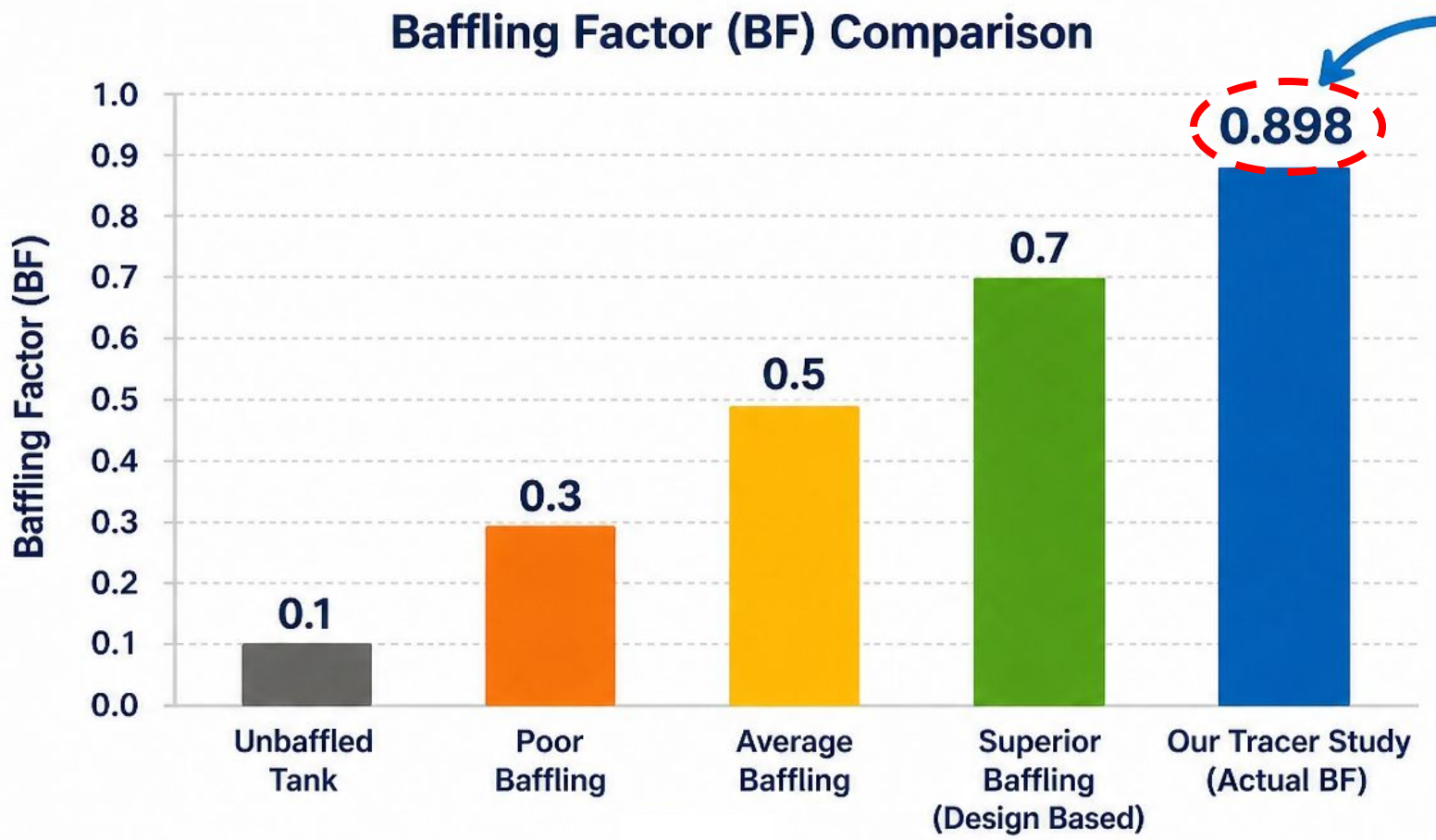
Potential reasons for the spike:

- Incomplete mixing
- Slug injection
- Inconsistent tracer feed

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EXCELLENT DESIGN!

This is because we got very high BF for our tracer study



VERY HIGH BF ACHIEVED!

Our tracer study resulted in a BF of **0.898**, significantly higher than the design-based assumption of **0.7!**

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Key Takeaways

- Prepare a thorough test plan, including details regarding procedures, data collection, staffing, equipment, test conditions, etc.
- Strictly follow approved test plan
- Rehearse before test
- Be clear on staffing roles
- Communicate during testing
- Keep key notes during testing
- Process data right after the test



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Acknowledgements



Tessora Young, EIT, Ph.D.
Drinking Water Treatment Engineer



Joshua Kennedy, MS, PE
Water Treatment Department Lead
and Project Manager

MEDFORD WATER

Thanks for all the support from Medford Water!

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Q&A

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About Me



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Disinfection Log Inactivation

$$-\text{Log}\,(I/I_0) = \text{Log}\,(1 + 2.303 \times k_{10} \times C \times HDT)$$

$-\text{Log}\,(I/I_0)$ = the log inactivation
k_{10} = log base 10 inactivation coefficient (L/mg-min)
C = Concentration (mg/L)
HDT = Hydraulic detention time (minutes)

- All surface water systems or GWUDI systems are required to achieve
  - **3-log (99.9%)** removal and/or inactivation of **Giardia** (40 CFR 141.70(a)(1)).

$$\text{Log Inactivation of Giardia} = 3 \times \sum (\text{CTcalc} / \text{CT99.9})$$

  - **4-log (99.99%)** removal and/or inactivation of **viruses** (40 CFR 141.70(a)(2)).

$$\text{Log Inactivation of Viruses} = 4 \times \sum (\text{CTcalc} / \text{CT99.99})$$

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Regulatory Framework for Tracer Study

Minimum Removal and Inactivation Requirements for All Surface Water and GWUDI Filtered Systems

Microorganism	Required Log Removal and/or inactivation	Treatment
Giardia	3-log (99.9%)	Removal and/or Inactivation
Viruses	4-log (99.99%)	Removal and/or Inactivation
*Cryptosporidium**	2-log (99%)	Removal

* The IESWTR and LT1SWTR specify that the 2-log treatment requirement for *Cryptosporidium* can only be achieved through removal. If a PWS is required to meet additional log credits under LT2ESWTR, additional treatment credits beyond the 2-log requirement can be achieved with toolbox options, including inactivation. Refer to the *Long Term 2 Enhanced Surface Water Treatment Rule Toolbox Guidance Manual* (USEPA, April 2010) for more information regarding toolbox options.

Typical Removal Credits and Inactivation Requirements for Various Treatment Technologies

Process	Log Removal and/or Inactivation Required		Typical Log Removal Credits		Resulting Disinfection Log Inactivation Requirements	
	Giardia	Viruses	*Giardia*	Viruses	*Giardia*	Viruses
Conventional Treatment	3.0	4.0	2.5	2.0	0.5	2.0
Direct Filtration	3.0	4.0	2.0	1.0	1.0	3.0
Slow Sand Filtration	3.0	4.0	2.0	2.0	1.0	2.0
Diatomaceous Earth Filtration	3.0	4.0	2.0	1.0	1.0	3.0
Alternative (membranes, bag filters, cartridges)	3.0	4.0	*	*	*	*
Unfiltered	3.0	4.0	0	0	3.0	4.0

Source: USEPA. March 1991.

* PWSs must demonstrate to the state by pilot study or other means that the alternative filtration technology provides the minimum required log removal and inactivation shown in Table 1-1.

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How to plan for a tracer study?

Before Test

1. Tracer approach
2. Tracer type
3. Tracer dose
4. Reservoir flow and operation conditions
5. Test duration
6. Sample locations and frequency
7. QA/QC
8. Staffing
9. Equipment

Submit tracer test plan to state authority. The plan should include details on items listed above

During Test

1. Strictly follow approved tracer test plan
2. Ensure communication between staffing
3. QA/QC
4. Record sampling data and make notes as needed

After Test

1. Data compilation
2. Data analysis
3. Report drafting
4. Fill out the result form
5. Complete the final test report and submit to state authority

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