2017 Pilot Dye Test Results

Tyco Fire Products LP

Marinette, WI

December 2017

ch2m

Overview

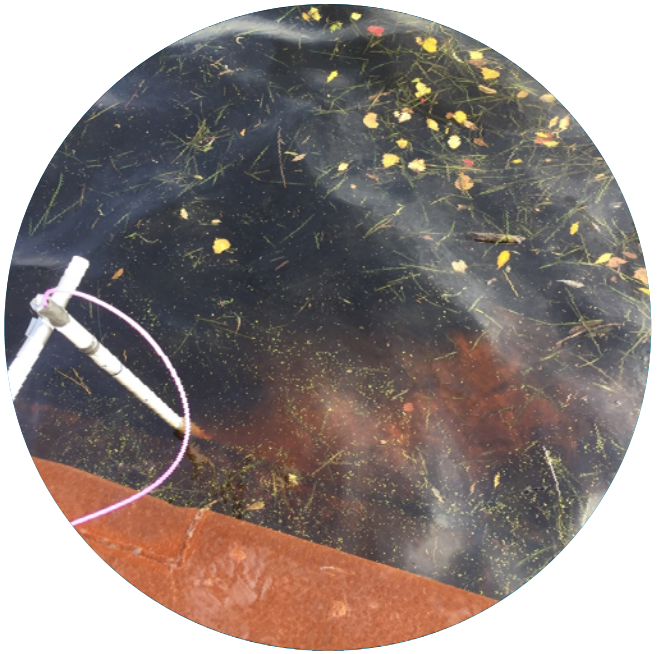
- Background
- Pilot Test Objectives
- Approach
- Field Results
- Model Results
- Implications for Full-Scale Dye Test

Background

- April 2014 - Agreement on Resolution included full-scale dye test of barrier wall performance
  - Identify if any “portions of the wall in this area are found to be visibly leaking”
- September 2015 – Proposed full-scale dye test presented in Barrier Wall Groundwater Monitoring Plan Update
  - Rely on fluorometer measurements to detect dye in river below visible limits
  - Assess representative portions of wall (not entire wall)
- May 2017 – Agreement to conduct pilot dye test to assess potential effects of dye on river
- August 2017 – Work Plan submitted
- September 9, 2017 – Work Plan approved
- September 2017 – Pilot Dye Test conducted
- November 2017 – Pilot Dye Test Technical Memorandum submitted

Pilot Test Objectives

- Measure dispersion and dilution of Rhodamine WT (RWT) dye in river
- Collect data to calibrate dilution model
- Test fluorometer equipment
- Assess background river fluorescence
- Measure river flow dynamics
- Use model to demonstrate likely downstream extents of dye concentrations
- As needed, refine full-scale test design based on pilot test results



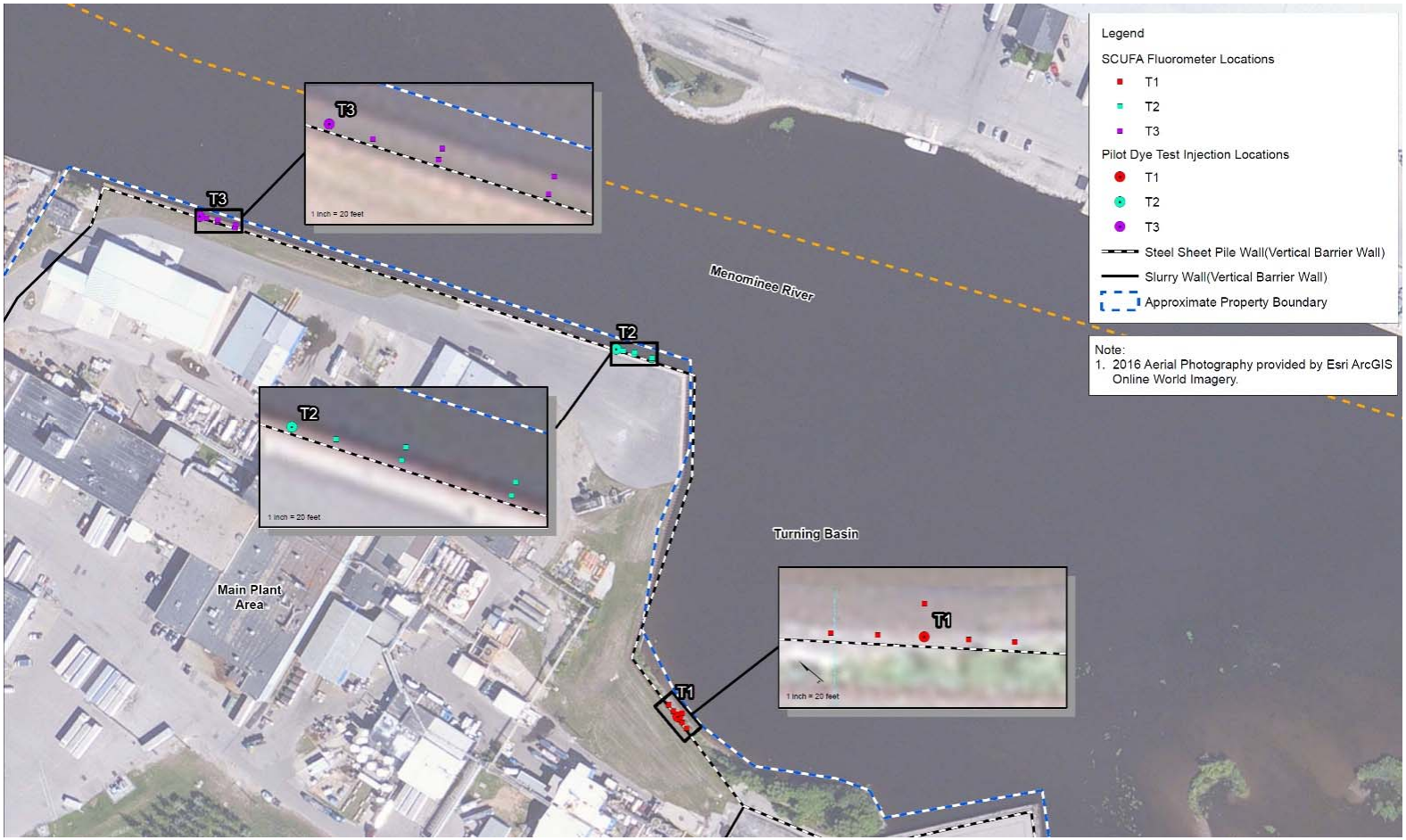
Field Approach

Add RWT at known rate and concentration at 3 locations

Continuously measure downstream concentrations using SCUFAs

Measure stream velocities and collect surface water grab samples

Pilot Test Locations

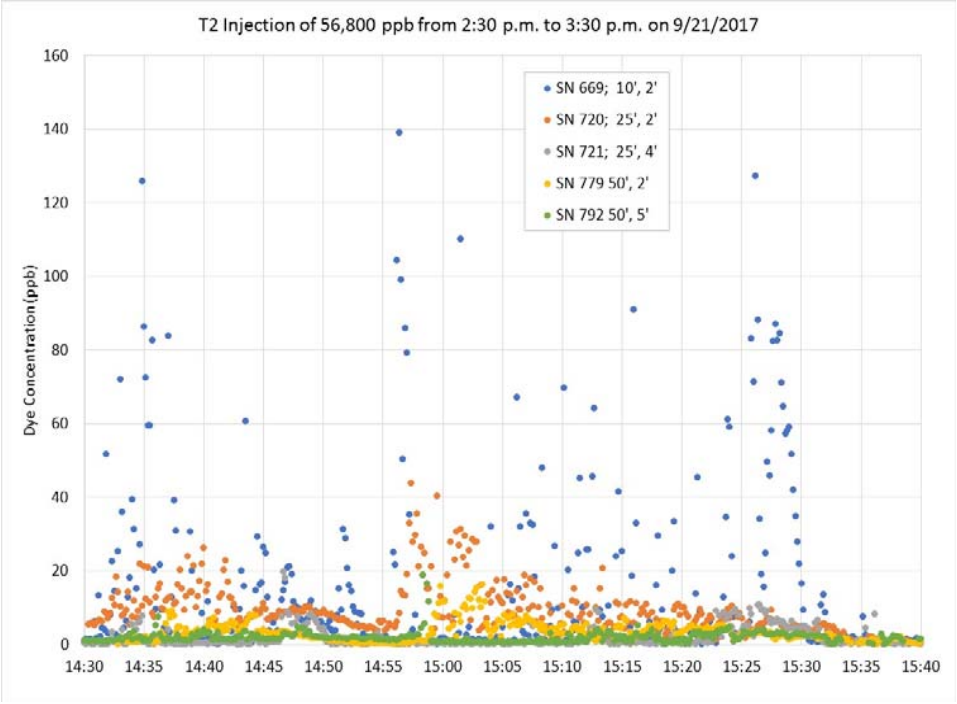


- T2 and T3 in Main Channel
  - Deep and shallow injection tests at T3
  - Shallow test only at T2
- T1 in Turning Basin
  - Fluorometers on both sides of injection
  - Shallow test

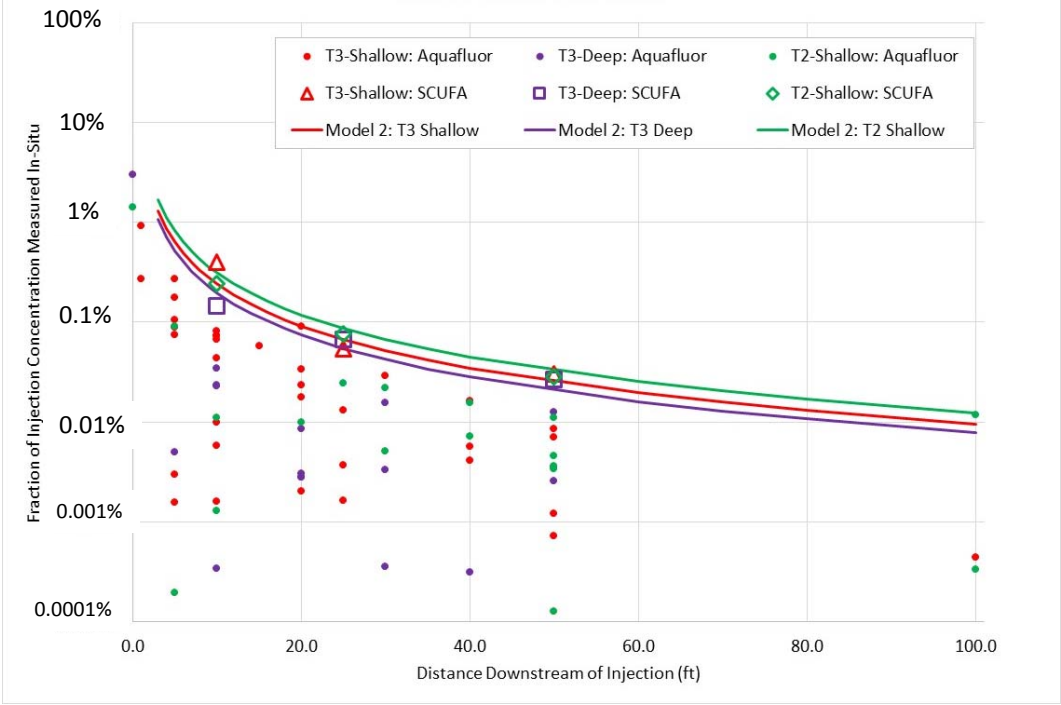
Field Adjustments

- Initial dye injections using proposed 1,000 ppb dye concentration and 100 mL/min injection rate not detectable in downstream SCUFAs
- Increased dye injection concentrations to up to 56,800 ppb
    - Below WDNR approved concentration of 64,900 ppb
    - Near concentrations originally proposed for full-scale test (40,000 to 150,000 ppb)
        - But full-scale dye has to migrate (and attenuate) through groundwater system first
- Increased dye injection rate to up to 940 mL/min
    - Near estimated low seepage rate for full-scale test calculations (0.2 gpm)
- Decreased SCUFA distances from injection point
    - 100 and 300 ft in Work Plan changed to 10, 25, and 50 ft downstream
- Decrease SCUFA distances from barrier wall
    - 5 and 20 ft in Work Plan changed to 1.5 to 10 ft (varied per test)
- Started at T3 (Main Channel) and ran shallow/deep tests because less complex than T1 (Turning Basin)

Data Analysis Approach



Use concentration data from SCUFAs to plot concentration curves

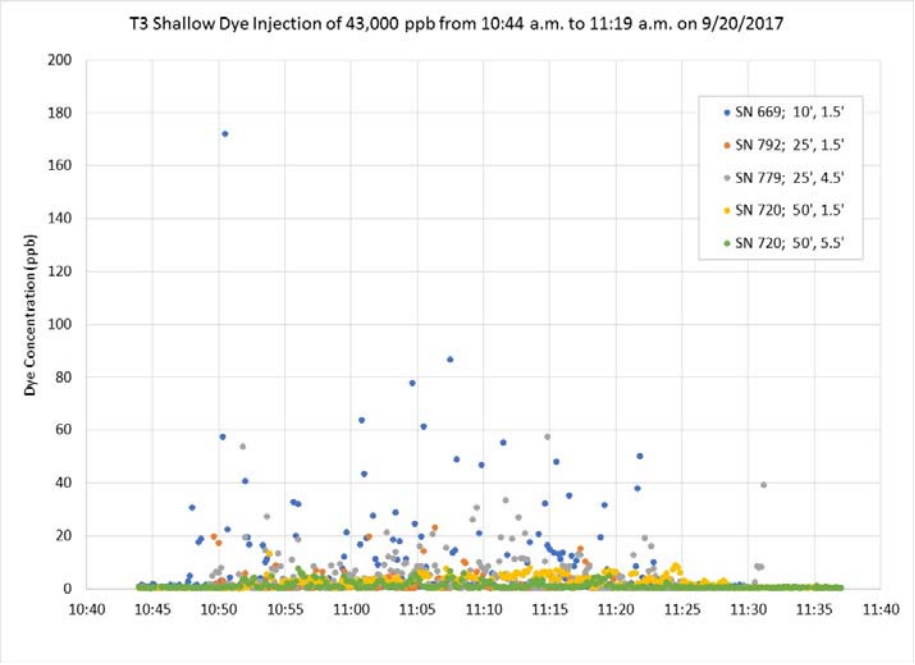


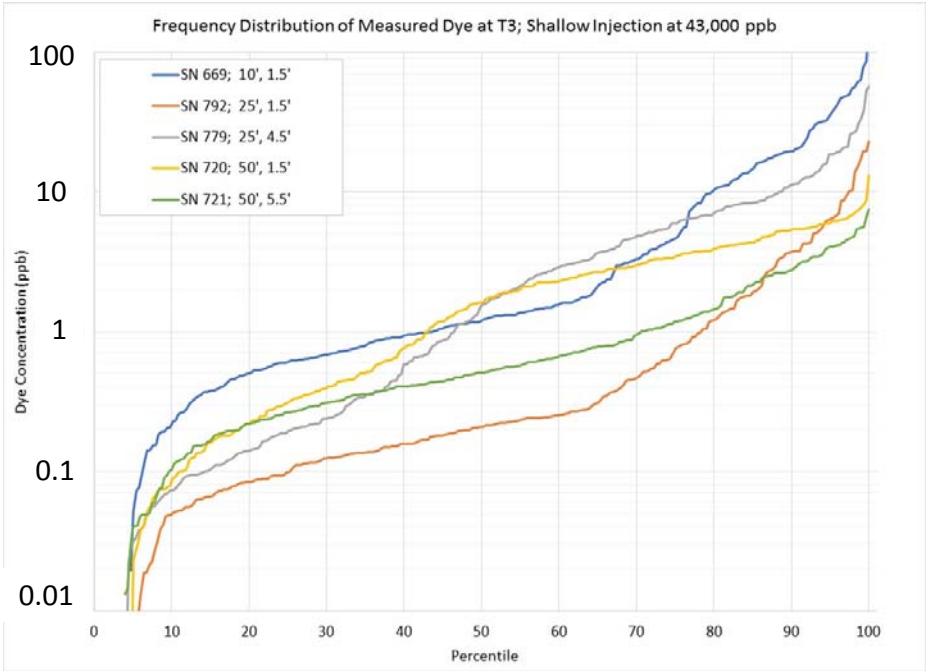
Calibrate dilution model using concentration data

Location T3 (Main Channel)-Shallow Results

- Dye only visible < 10’ from injection point
- Most dye concentrations low (<10 ppb)
- Significant scatter in dye concentrations
- Narrow, low concentration plume, moving laterally due to turbulence
- Corrugated shape of barrier wall may be inducing turbulent flow patterns

SCUFA Transect Locations (feet downstream)	Feet from Wall	Dye Injection Depth (ft)	Dye Injection Concentration (ppb)	Injection Rate (mL/min)	Maximum (Instantaneous) Dye Concentration Measured (ppb)[1]	Minimum Dilution Factor
10	1.5	2.0	43,000	880	171.8	250
25	1.5 and 4				57.4	749
50	1.5 and 5.5				13.1	3282





Results from Other Locations

T3 Deep (Main Channel)

- Dye not visible at surface
- Scatter in dye concentrations
- Narrow, low concentration plume, moving laterally due to turbulence
- Higher dilution than surface test

SCUFA Transect Locations (feet downstream)	Minimum Dilution Factor
10	683
25	1500
50	461 / 3765

T2 (Main Channel)

- Dye visible only within several feet of injection
- Dye plume hugged shoreline
- Narrow, low concentration plume

SCUFA Transect Locations (feet downstream)	Minimum Dilution Factor
10	408
25	1297
50	3005

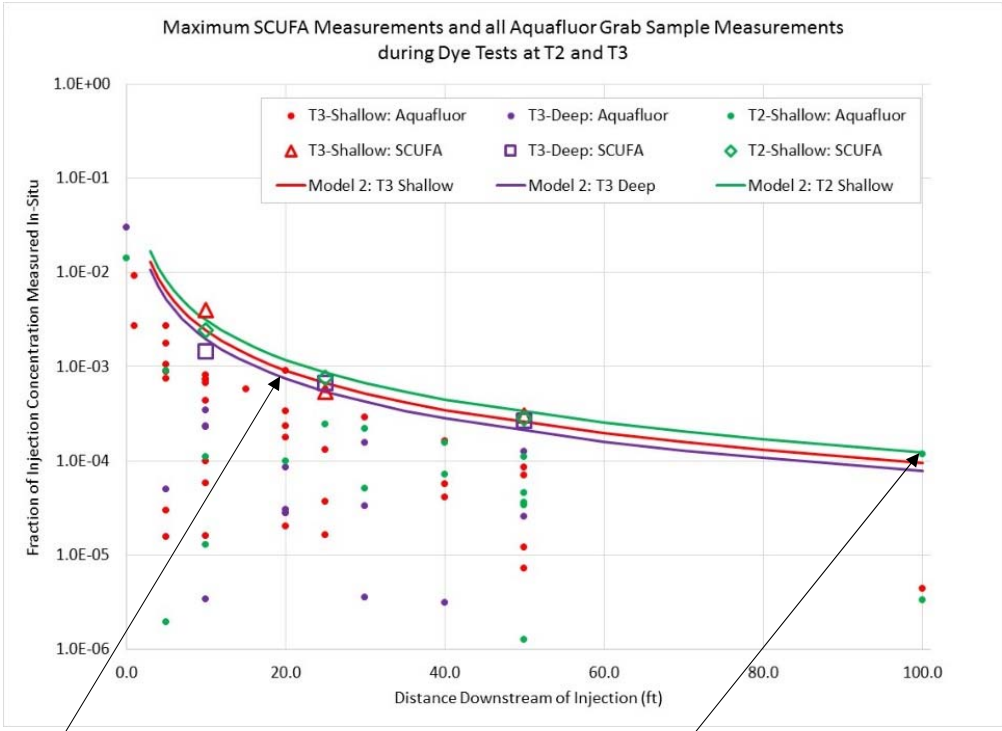
T1 (Turning Basin)

- Variable surface currents during test
- Plume more visible, pooled near injection location
- Gaussian-shaped concentration curves detected
- Lower dilution than Main Channel tests

SCUFA Transect Locations (feet up/downstream)	Minimum Dilution Factor
-20 (west)	573
-10 (west)	242
0 (injection)	403
+10 (east)	129
+20 (east)	280

Dilution Model

- Excel model based on Standard River Dispersion Equations from Fischer et al., 1979
- Adjusted with correction factor to improve model fit
- Instantaneous dilution factor of 100 added to Main Channel model
- Instantaneous dilution factor of 15 added to Turning Basin model (slower currents)
- Assumptions include:
    - Constant river depth, width, and velocity

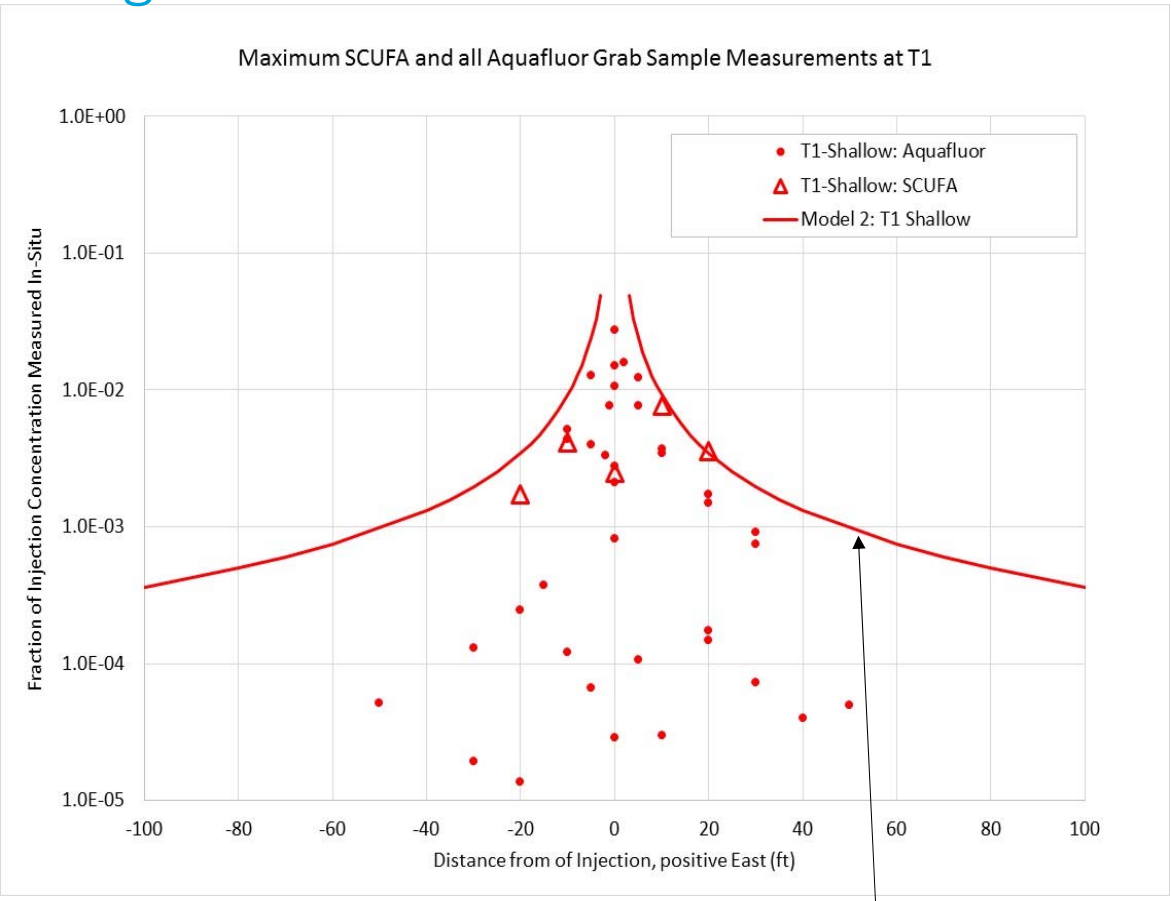


1,000x minimum dilution at 20 ft

10,000x minimum dilution at 100 ft

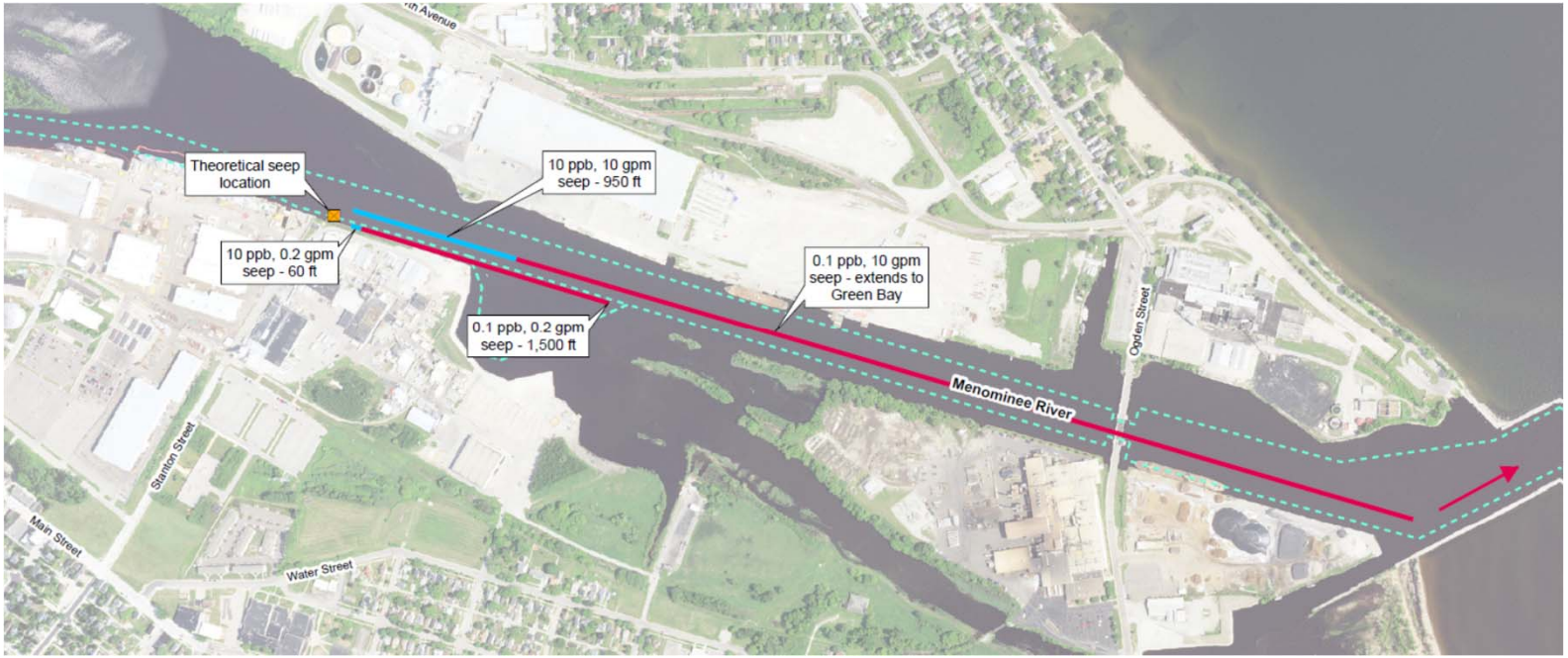
Dilution Model – Turning Basin

- Variable flow (flow in both directions)
- Less dilution than observed in Main Channel



1,000x minimum dilution at 50 ft

Modeled Downstream Extents of Dye



- Assumes constant river width, current, depth
- Based on data collected within 100 feet of injection locations
- 0.1 ppb concentration may not be achievable during lower flows (insufficient river volume to dilute to 0.1 ppb)
- Represent maximum concentration in plume core, which will be narrow

At 64,900 ppb (maximum allowable in river)

Seepage Rate (gpm)	10 ppb extent (feet)	0.1 ppb extent (feet)
0.2 gpm	60	1,500
10 gpm	950	Reaches Green Bay

10 ppb – maximum recommended RWT concentration entering drinking water plant

10 ppb – reported minimum visibility limit

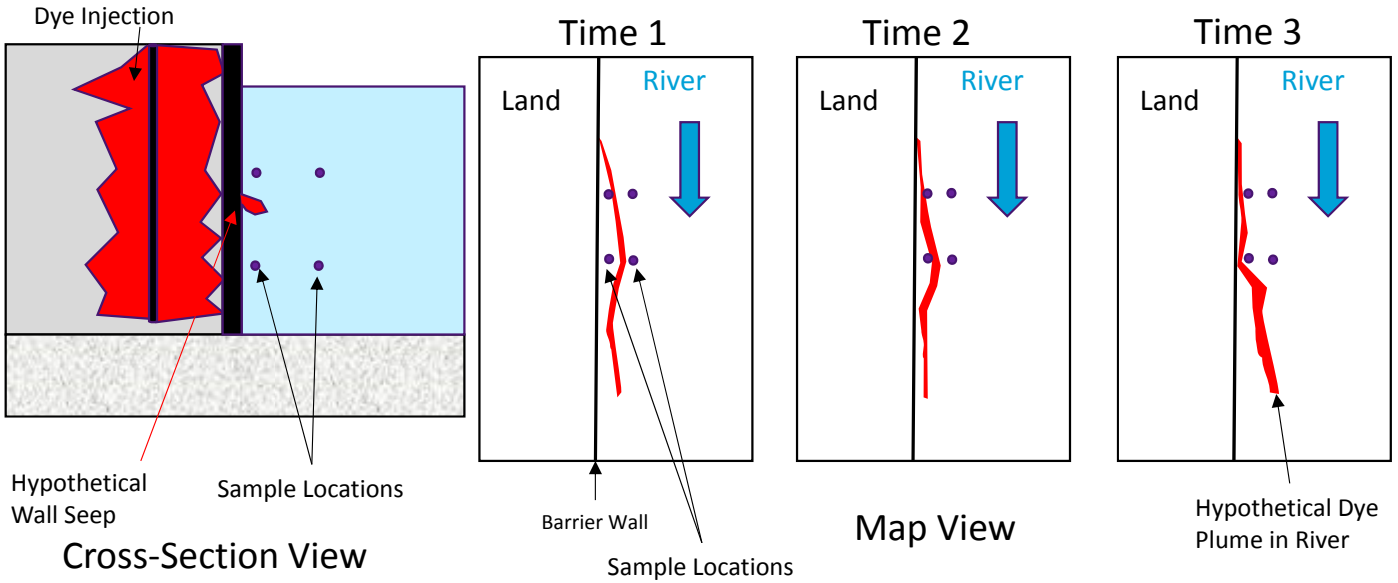
0.1 ppb – recommended maximum RWT concentration in drinking water

Detectability of Dye at Low Seepage Rate Through Wall

At 12,980 ppb (5x attenuation of 64,900 ppb in groundwater)

Seepage Rate (gpm)	10 ppb extent (feet)	0.1 ppb extent (feet)
0.2 gpm	10 - 20	270 - 500

- Dye theoretically detectable in river at low seepage rates
- However, Pilot Test demonstrated plumes narrow and shifting, making detection hit or miss
- Concentrations represent “core of plume”, would need to sample at right location (distance AND depth) AND time to detect
- Much lower concentrations (or non-detects) if sample not from “core of plume”
- Fluorometers showed considerable variation at low levels (< 1 ppb) that will make interpretation of low concentration data difficult or impossible



Key Conclusions

Pilot Test Conclusion	Implications for Full-Scale Test
High Rates of Dilution	Samples need to be located as close as possible to unknown seep location
Dye not visible > 10 feet downstream, less in Main Channel	Visual detection of seeps not likely, especially for deeper potential seeps
Dye not detected consistently downstream	Samples could “miss” dye in river, falsely conclude no seep even if seep present
Shifting, narrow plumes	Difficult to ensure that samples collected from “core of plume”; even if inches or feet off from “core” no concentrations may be detected.
Wall shape affects plume patterns	Location of dye plume difficult to predict
Worst-case scenario seep (10 gpm), 10 ppb could extend 950 feet downstream, 0.1 ppb could reach Green Bay	10 ppb represents recommended maximum concentration entering drinking water plant; no drinking water plant intakes likely to be affected. 0.1 ppb represents maximum recommended concentration in drinking water. 10 gpm seep would have limited duration (~24 hour) release of dye.
Spot sampling did not consistently detect dye	Spot sampling program may not detect dye in river, even if present
Variable readings by fluorometers at low concentrations	Accuracy/precision of fluorometers need to be demonstrated before full-scale test, otherwise interpretation of low-level detects during full-scale may be impossible or difficult to interpret
Difficult to detect dye even under controlled release conditions (known concentration, rate, location). Instruments did not detect 720 ppb injection 10 feet downstream.	More difficult to detect dye seeping at unknown location/depth/rate/concentration. Dye behavior in groundwater not known, therefore uncertain concentration at wall and uncertain concentration in surface water. ~1000x more dye per groundwater injection location as used per location in Pilot test. Recommend injecting at maximum allowable concentration (64.9 mg/L).
Variable flow patterns, less dilution in Turning Basin.	Flow directions near surface appear to be influenced by wind. Dye may be more visible if seep present, but direction of dye migration, and thus sample collection, uncertain.

Recommendation

Recommend not conducting full-scale dye test

- Consider alternative approaches (next session)
- Rely on other elements of wall integrity testing
    - Sediment sampling
    - Water level monitoring
    - Groundwater quality monitoring
    - Wall inspections

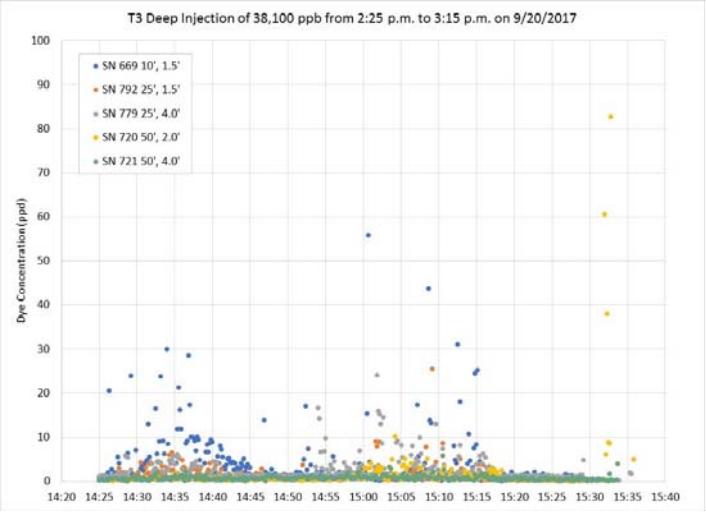
Thank You

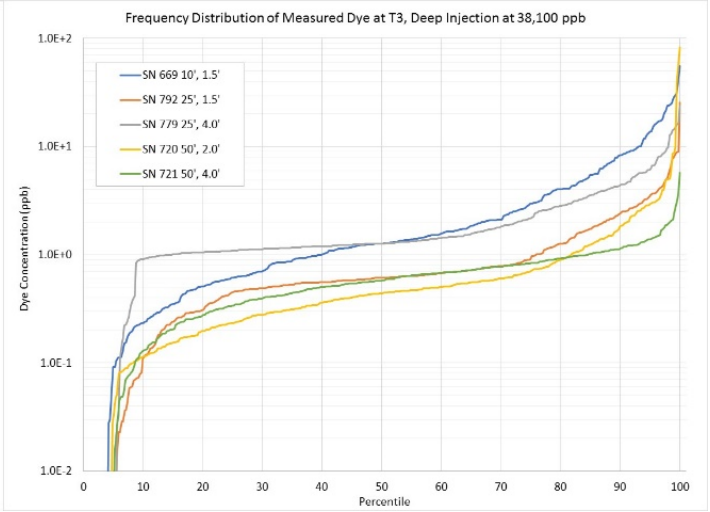
Supplemental Slides

Location T3 (Main Channel)-Deep Results

- Dye not visible at surface
- Most dye measurements < 10 ppb
- Significant scatter in dye concentrations
- Narrow, low concentration plume, moving laterally due to turbulence
- Higher dilution than surface test

SCUFA Transect Locations (feet downstream)	Feet from Wall	Dye Injection Depth (ft)	Dye Injection Concentration (ppb)	Injection Rate (mL/min)	Maximum (Instantaneous) Dye Concentration Measured (ppb)[1]	Minimum Dilution Factor
10	1.5	12.0	38,100	940	55.8	683
25	1.5 and 4				25.4	1500
50	1.5 and 5.5				82.6 / 10.1	461 / 3765

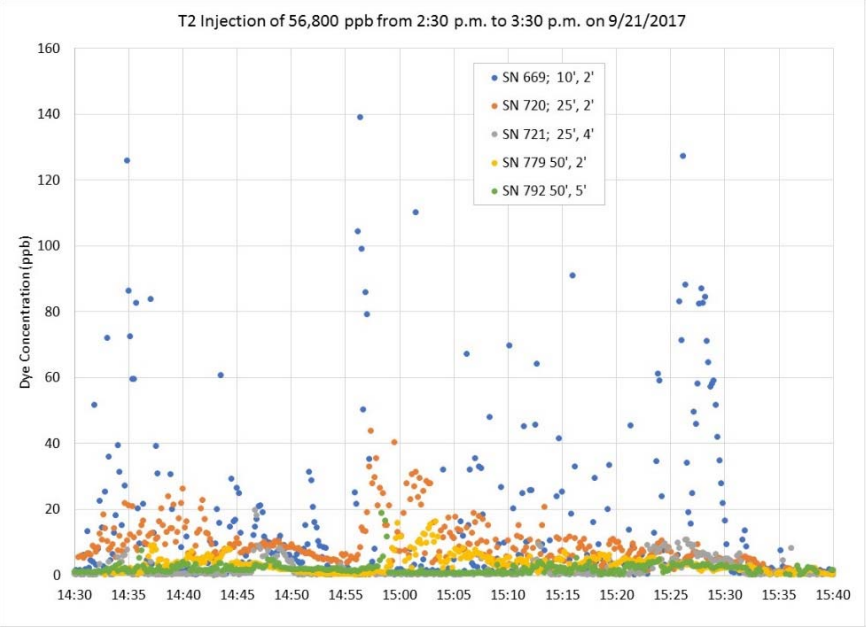


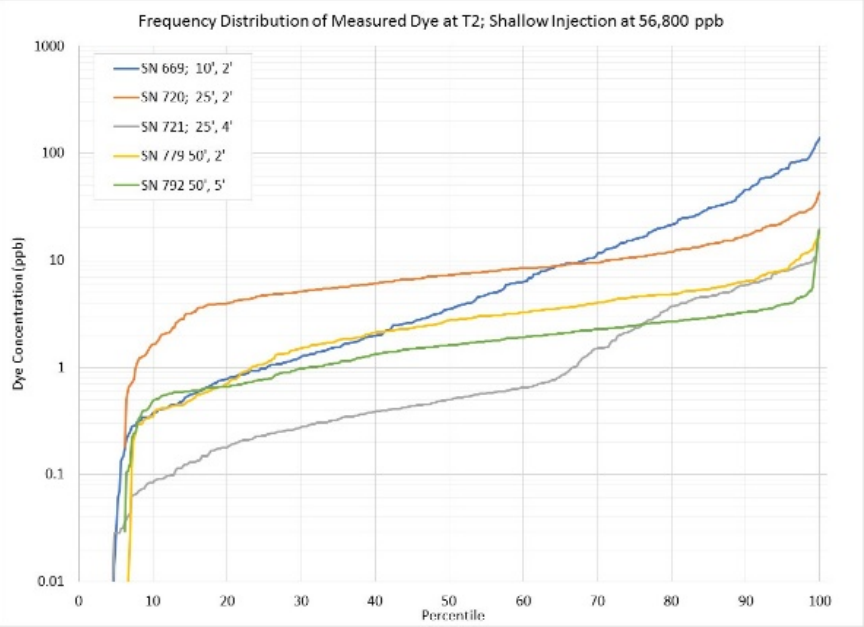


Location T2 (Main Channel) Results

- Dye visible only within several feet of injection
- Most dye measurements < 10 ppb
- Dye plume hugged shoreline
- Narrow, low concentration plume

SCUFA Transect Locations (feet downstream)	Feet from Wall	Dye Injection Depth (ft)	Dye Injection Concentration (ppb)	Injection Rate (mL/min)	Maximum (Instantaneous) Dye Concentration Measured (ppb)[1]	Minimum Dilution Factor
10	2	2.5	56,800	870	139.1	408
25	2 and 5				43.8	1297
50	2 and 5				18.9	3005

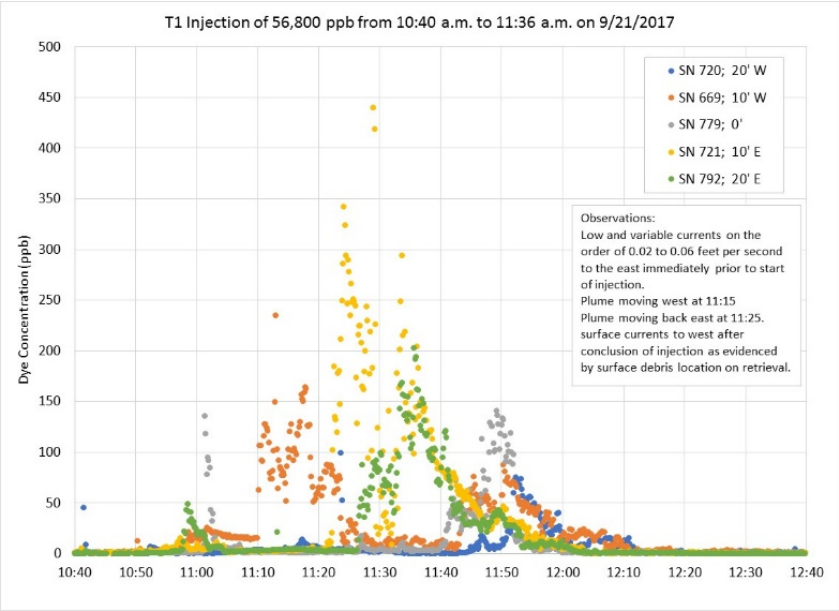


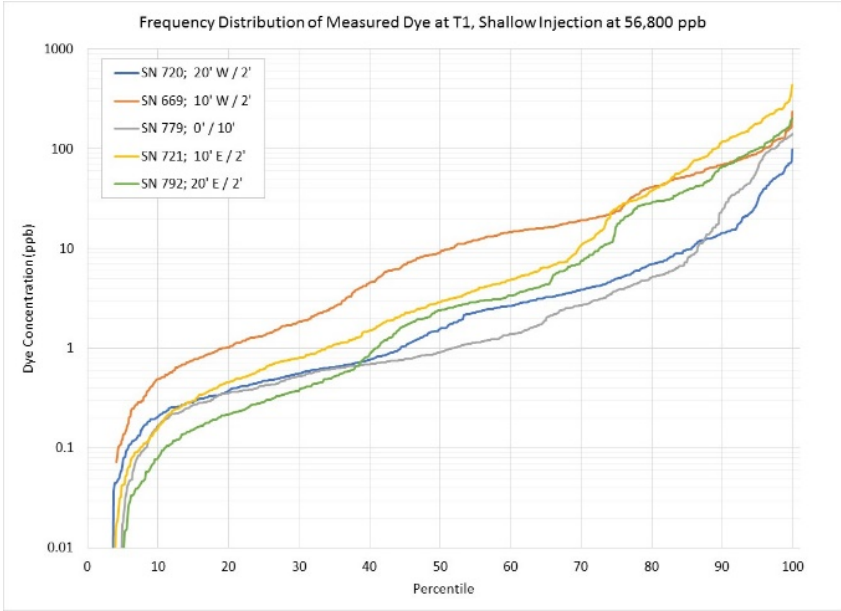


Location T1 (Turning Basin) Results

- Variable surface currents (wind) during test
- Plume more visible, pooled near injection location
- Gaussian-shaped concentration curves

SCUFA Transect Locations (feet up/downstream)	Feet from Wall	Dye Injection Depth (ft)	Dye Injection Concentration (ppb)	Injection Rate (mL/min)	Maximum (Instantaneous) Dye Concentration Measured (ppb)[1]	Minimum Dilution Factor
-20 (west)	2	2.0	56,800	940	99.1	573
-10 (west)	2				234.6	242
0 (injection)	10				141.0	403
+10 (east)	2				439.6	129
+20 (east)	2				202.8	280





Dilution Model

- Based on Standard River Dispersion Equations from Fischer et al., 1979
- Adjusted with correction factor, $\frac{a}{x^b}$, to improve model fit
- Model fit to maximum detected dye concentrations at each downstream location
- Instantaneous dilution factor of 100 added to Main Channel model
- Instantaneous dilution factor of 15 added to Turning Basin model (slower currents)
- Assumptions include:
    - Constant river depth, width, and velocity

$$C\ (y,t) = Co\frac{e^{-y^2/4\kappa t}}{2\sqrt{\pi\kappa t}}$$

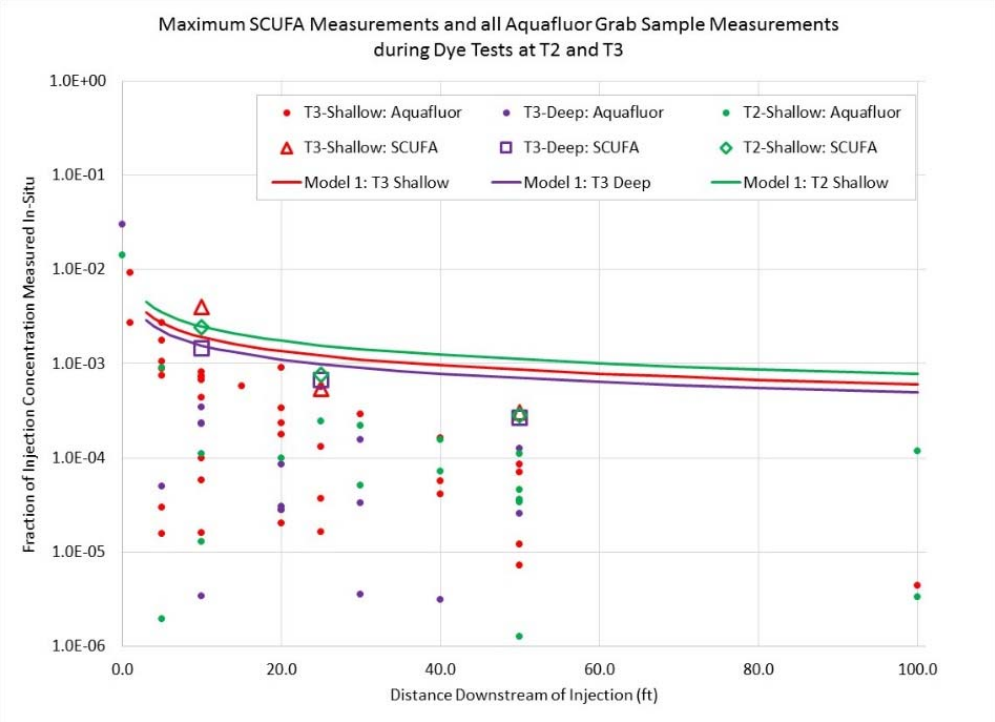
C is concentration
y = distance laterally from river bank
T = time of travel
C0 = Initial concentration
κ = lateral dispersion coefficient

$$\kappa = 0.6 * d * u$$

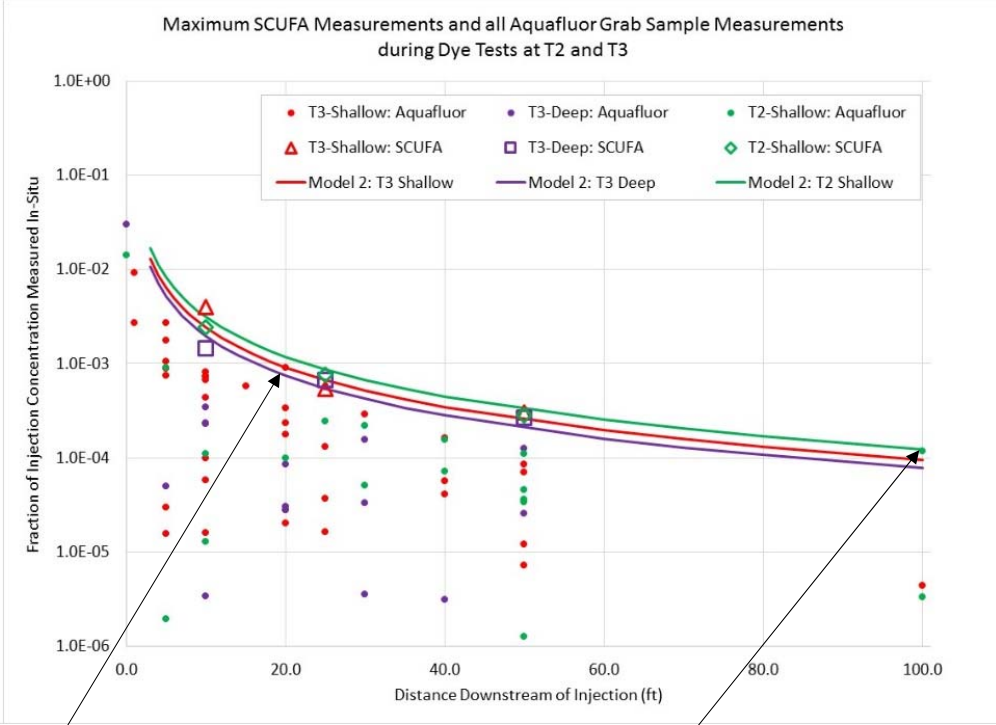
d = depth
u = shear velocity

Dilution Model – Main Channel

Without correction factor, over-estimates downstream concentrations



Better fit with correction factor



1,000x minimum dilution at 20 ft

10,000x minimum dilution at 100 ft