The Science of Mixing and Improving Water Quality in Water Storage Tanks

2015 Pacific Northwest AWWA Conference
April 29 – May 1
Bellevue, WA

Presented by:

Michael Duer, P.E., Chief Engineer
Red Valve Co., *Tideflex Technologies Division*

Tideflex® Technologies

Common Types of Water Storage Tanks

- Ground Level Tanks (Rectangular)
- Ground Level Tanks (Circular)
- Elevated Tanks
- Standpipes

All Have Unique Challenges with Short-Circuiting and Mixing Solely based on Volume, Geometry, and Inlet/Outlet Pipe Configuration

How to Improve Water Quality in Water Storage Tanks

- Correct Structural, Sanitary, Security Defects
- Periodic Cleaning
- (not the focus of today's seminar)

1) Maximize Volume Turnover to Minimize Water Age (Operation of Distribution System)
2) Achieve Complete Mixing (eliminate Short-Circuiting (Design of tank, inlet/outlet, mixing system)

➢ Have to do Both

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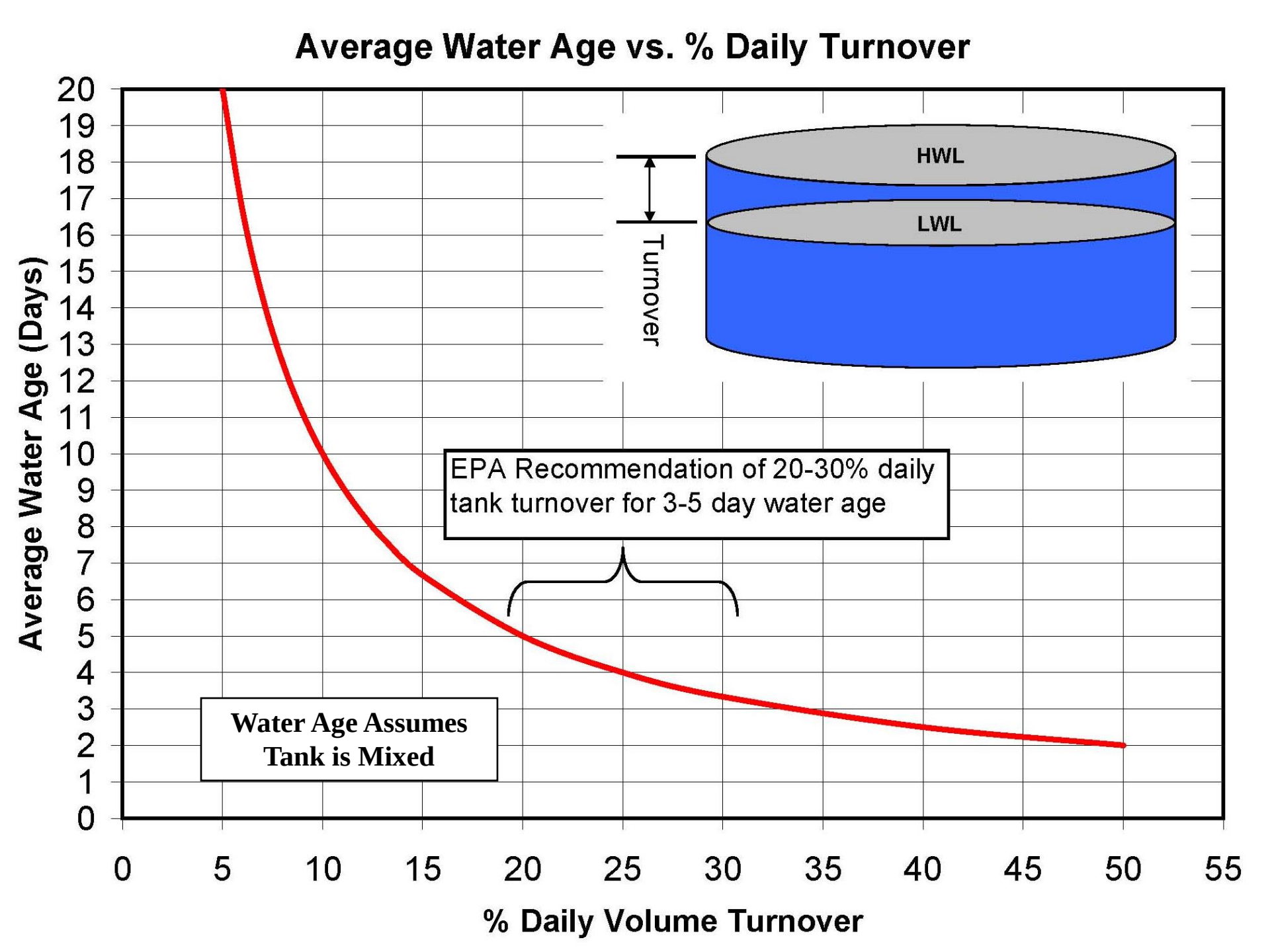
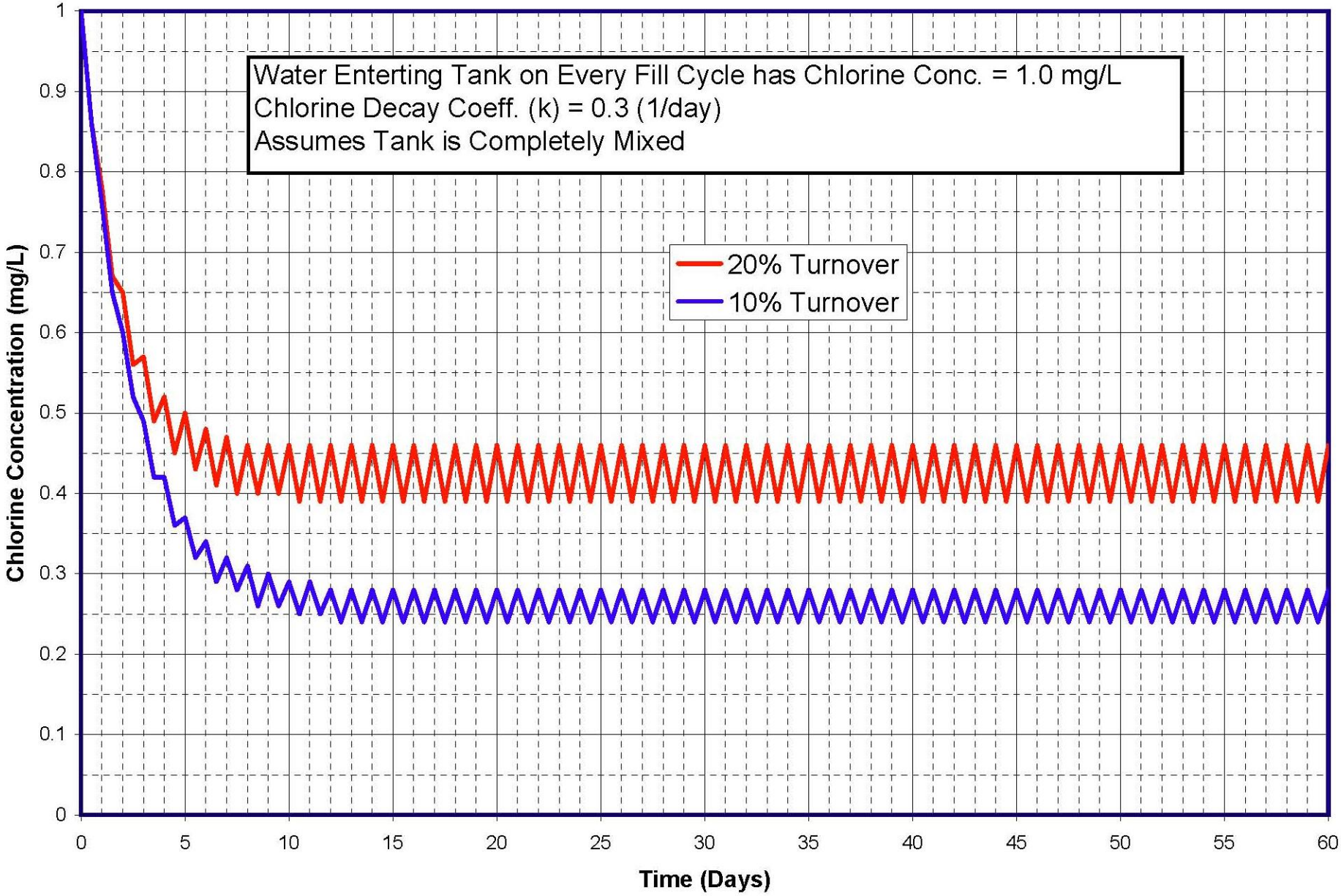
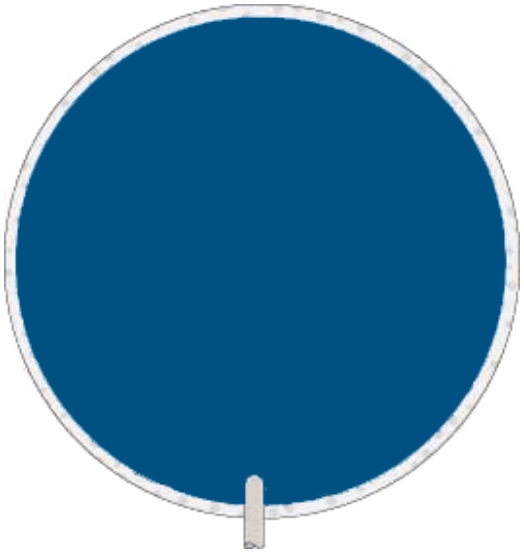

Average Water Age vs. % Daily Turnover
Average Water Age (Days)
% Daily Volume Turnover
HWL
LWL
Turnover
EPA Recommendation of 20-30% daily tank turnover for 3-5 day water age
Water Age Assumes Tank is Mixed


1.0MG Tank, 12 hour fill, 12 hour draw, 10% and 20% Turnover
Chlorine Concentration vs. Time
Water Entering Tank on Every Fill Cycle has Chlorine Conc. = 1.0 mg/L
Chlorine Decay Coeff. (k) = 0.3 (1/day)
Assumes Tank is Completely Mixed
20% Turnover
10% Turnover
Chlorine Concentration (mg/L)
Time (Days)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
5
10
15
20
25
30
35
40
45
50
55
60

Short Circuiting

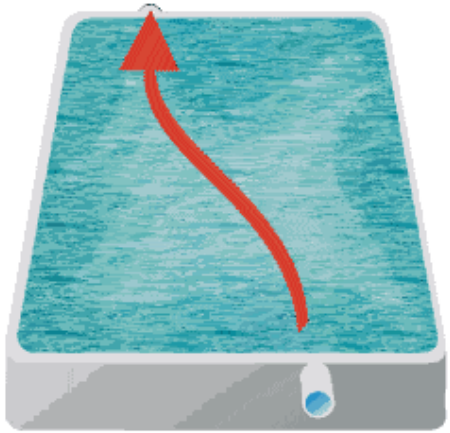
- First In, Last Out (Last in, First Out)
- Water in Close Proximity to Inlet/Outlet is Continually Turned Over. Water away from Inlet/Outlet stagnates.
- Some States Now Mandate Separate Inlet/Outlet Pipes

Common Inlet / Outlet

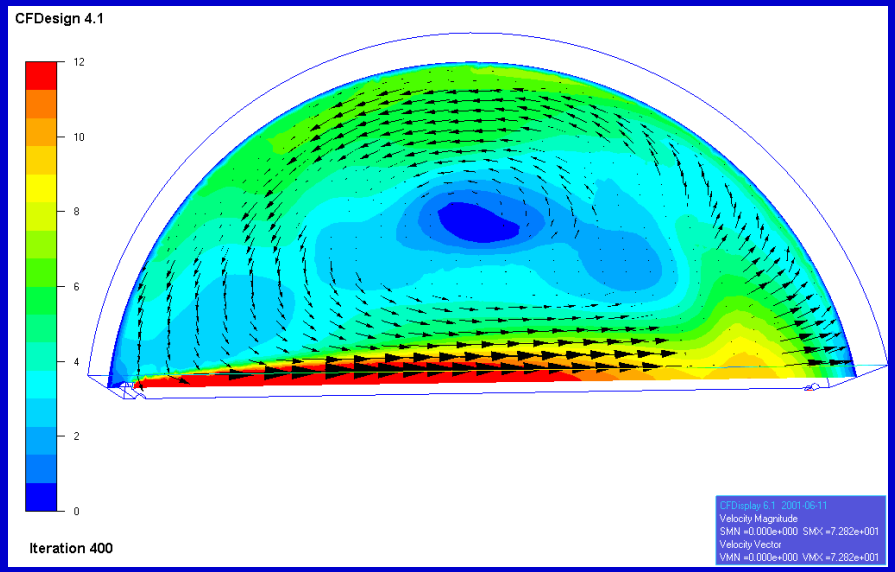


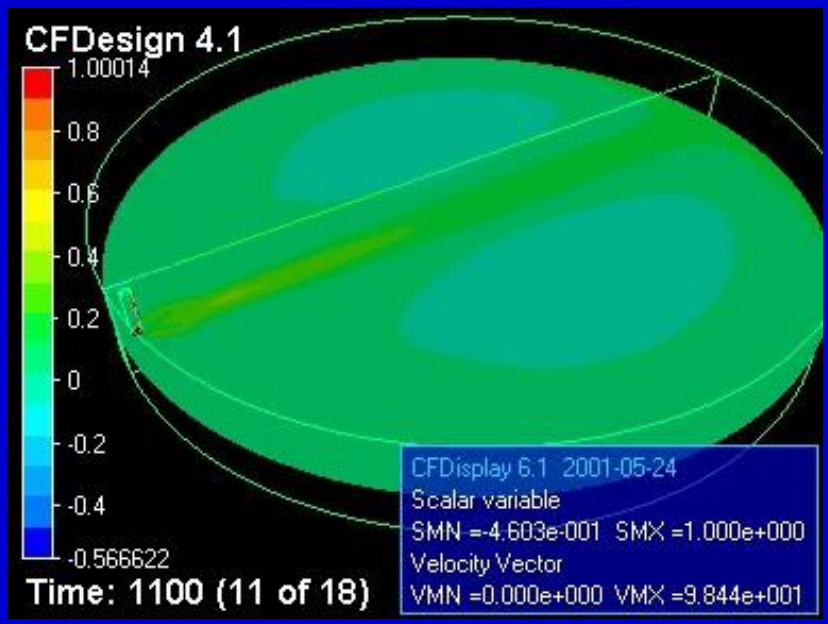
DAY AFTER DAY, WEEK AFTER WEEK OPERATION OF TANK WITH INCOMPLETE MIXING AND SHORT-CIRCUITING IS WHAT LEADS TO WATER QUALITY DEGRADATION

Separate Inlet / Outlet



CAUTION When Separating Inlet and Outlet

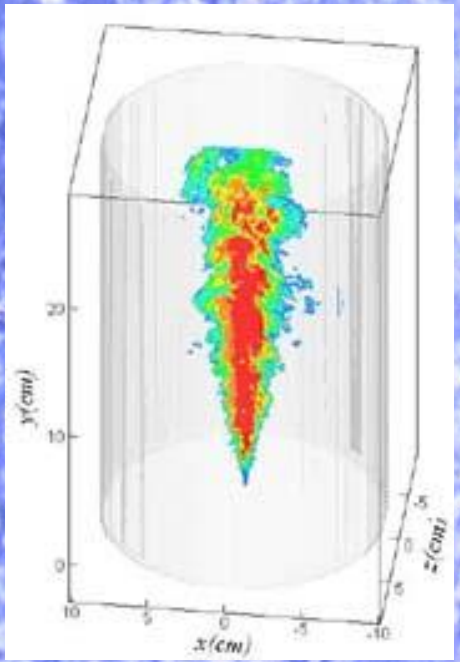


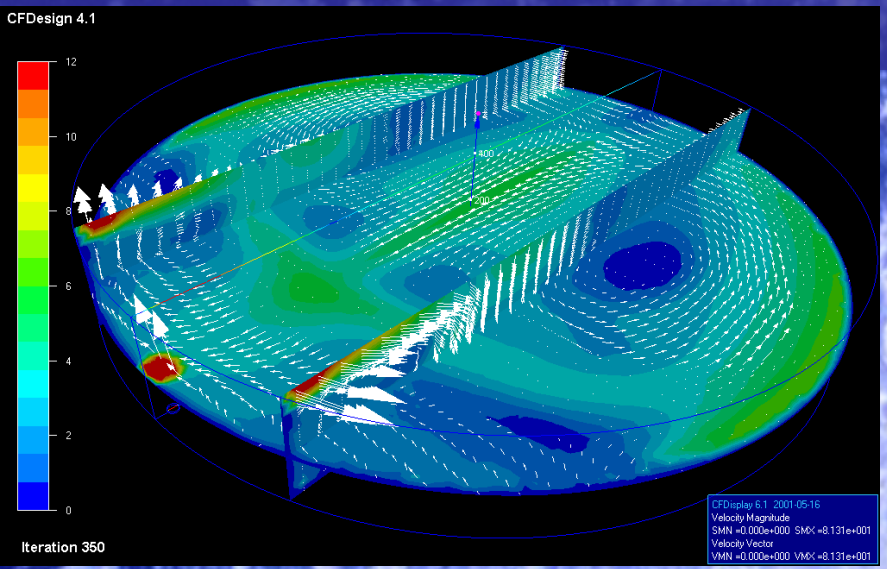


- Must Understand the Circulation Patterns in Order to Know Where Mixing Happens Last. Outlet(s) Would Go in Those Locations
- Getting Inlet and Outlet "As Far Apart As Possible" is Often the Wrong Assumption
- Circulation Patterns Change with Temperature Differences Between Inlet and Tank Water

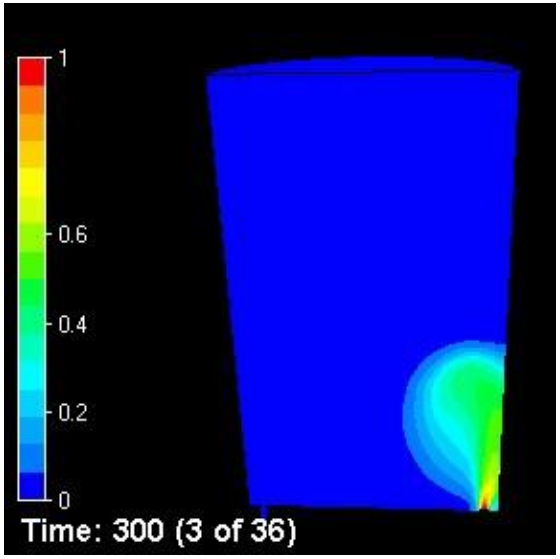
Hydrodynamic Mixing

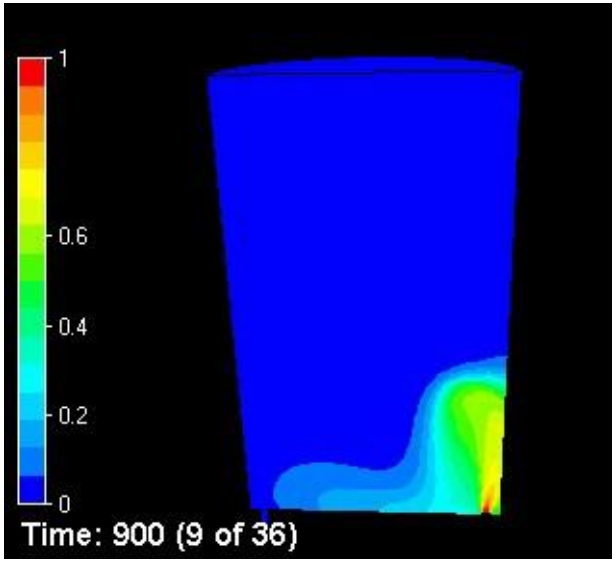
- Turbulent Inlet Jet (Only source of Energy) into Large Waterbody
- Velocity Discontinuity between Inlet and Ambient yields Entrainment
- Circulation Patterns form due to Conservation of Momentum
- Can be Strongly Dampened by Temperature Differentials (+ and - Buoyancy)

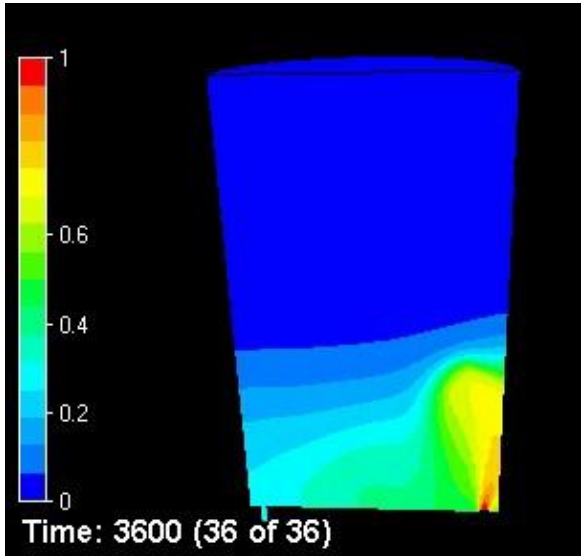




Effect of Colder Inlet Water (Summer Conditions) on Mixing



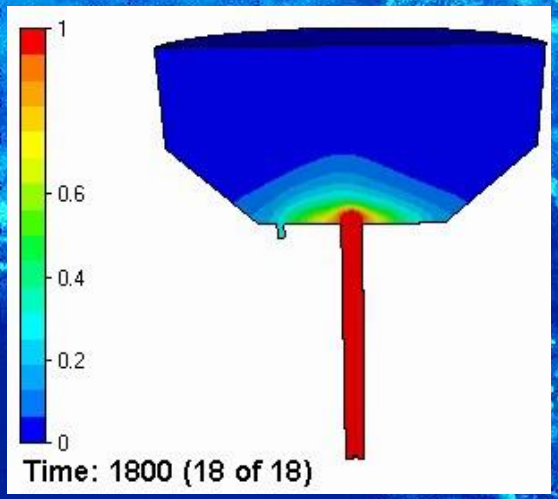




2°F Colder Inlet Water

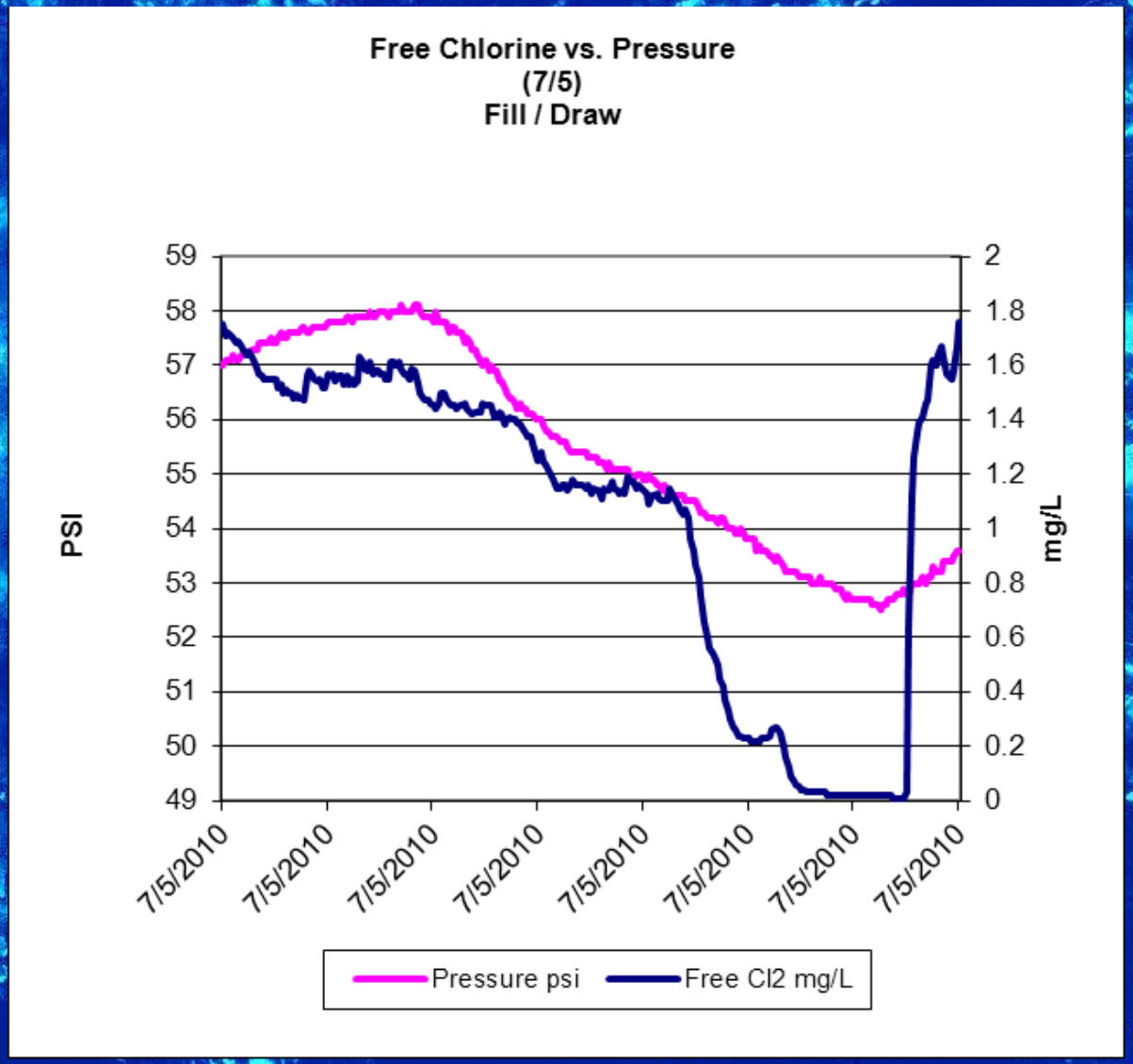
- Mixing Time Equation May Grossly Underestimate Fill Time Required to Mix
- Jet Must Reach Water Surface to Mix Tank
- Mixing Will Only Occur to Terminal Rise Height (TRH) of Jet
- Below TRH - Adequate Mixing, Temperature, and Residual
- Above TRH – No Mixing, Water Age Continually Increases With Each Fill & Draw Cycle, Lose Residual
- Have No Idea of Potential Problem Even if Sampling Outside of Tank

Example of Water Quality Decay Continuous Monitoring of I/O Pipe – 0.5MG Hydropillar



Courtesy

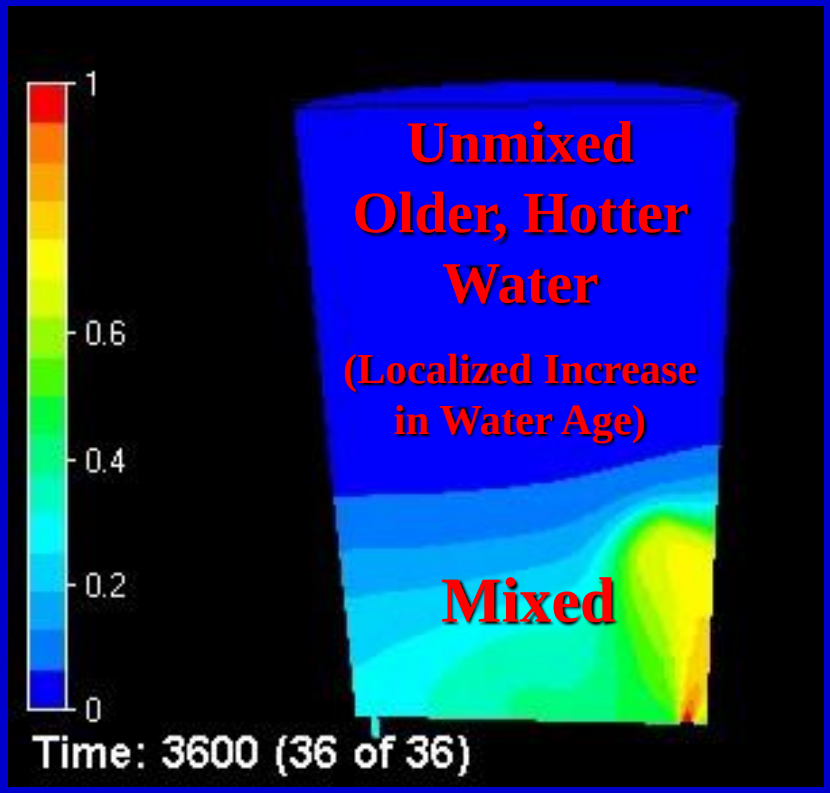
Paul Handke, PA DEP



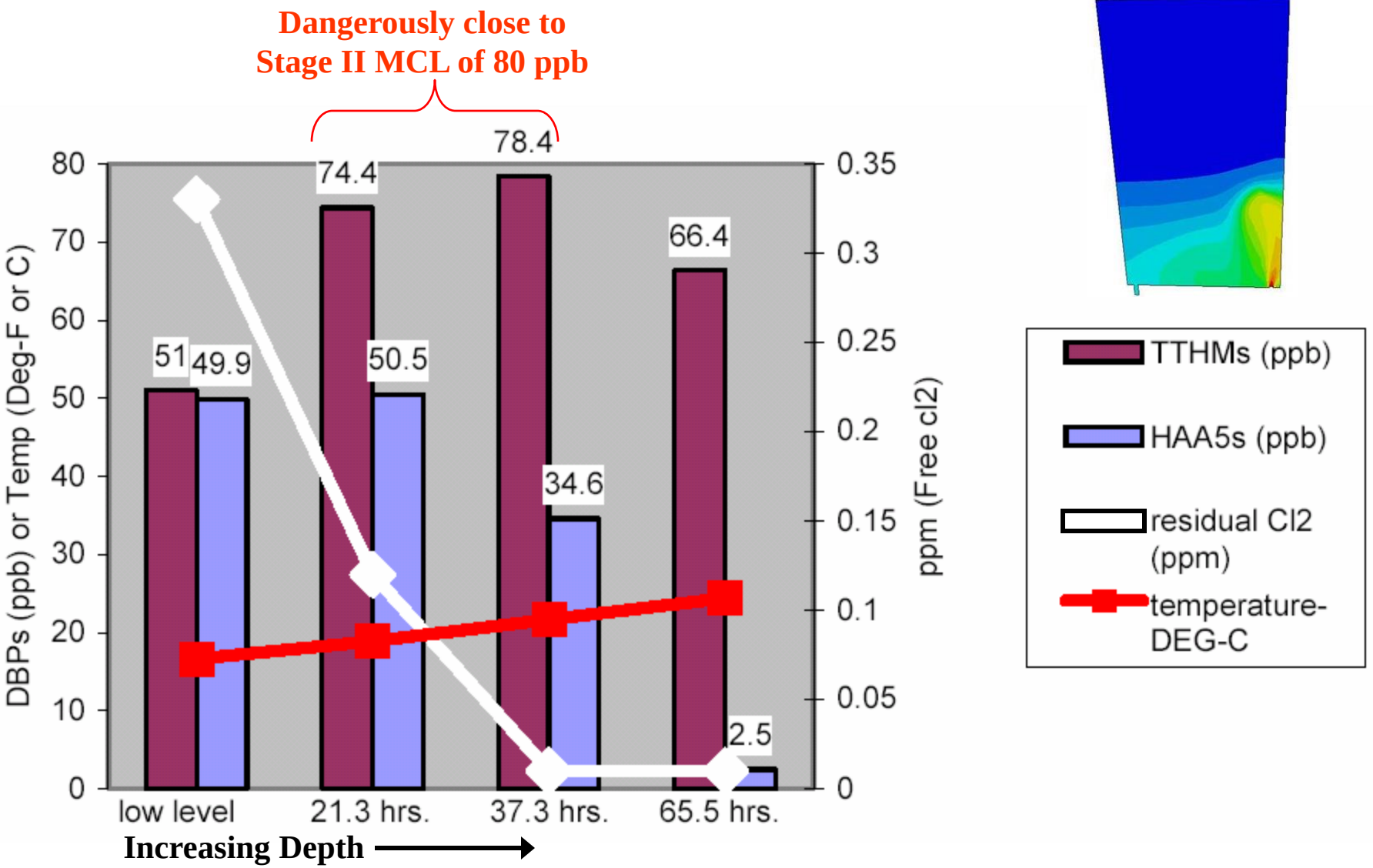
Water Quality Problems Associated with Short-Circuiting and Incomplete Mixing In Storage Tanks

A Localized Increase in Water Age and Hotter Water Responsible for:

- **LOSS OF DISINFECTANT RESIDUAL**
- **DBP SPIKES (THM AND HAA5)**
- **BACTERIA FORMATION**
- **NITRIFICATION (CHLORAMINES)**
- **VARIANCE IN pH and DISSOLVED OXYGEN**
- **HPC SPIKES**
- **TASTE & ODOR**
- **BIOFILM GROWTH**



TTHM, HAA5,Temperature and Cl_2 Residual Data 1.5MG Standpipe – Champlain W.D., VT



"Methods" and Mixing System Alternatives

- Baffles (not recommended)
- Simple Inlet/Outlet Separation
- Passive Mixing Systems
  - Complex Piping Systems
  - Passive Tideflex Mixing System (TMS)
- Active Mixing Systems
  - Active Tideflex Mixing System (TMS)
  - Submersible Mixers
  - Solar Powered and Electrically Powered Mechanical Mixers
  - Air Bubblers

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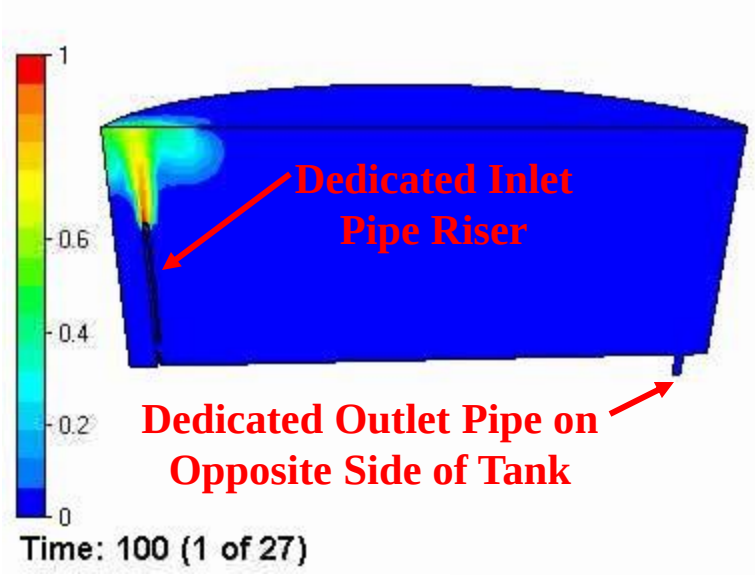
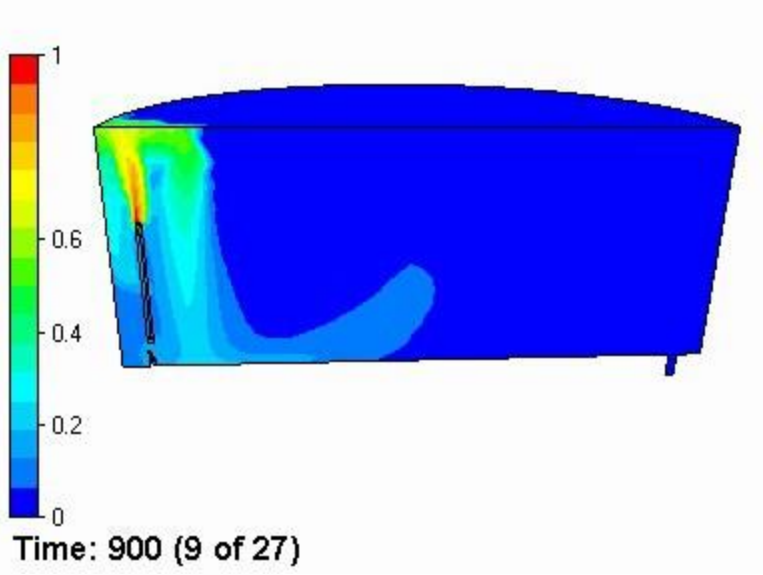
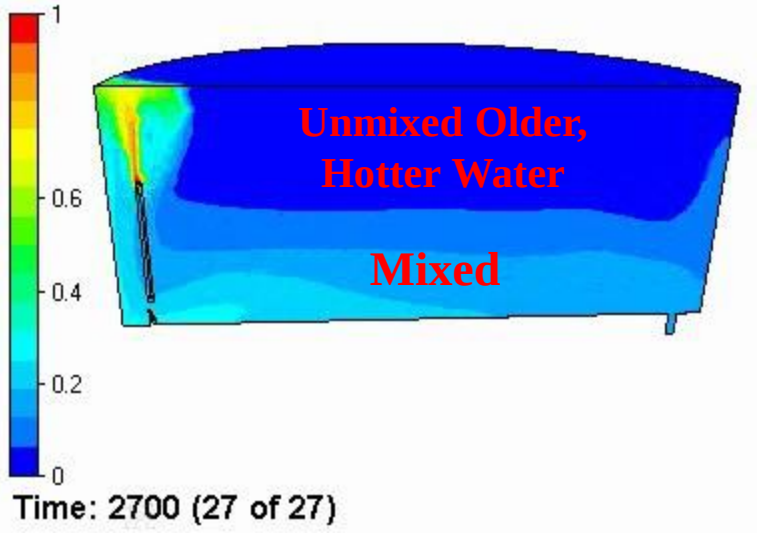
Effect of Colder Inlet Water (Summer Conditions) on Mixing

Inlet Riser Still Results in Incomplete Mixing and Stratification



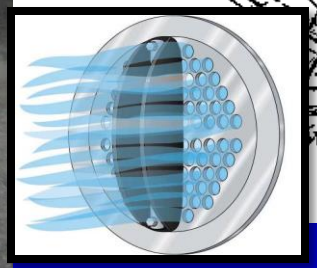




Tideflex Mixing System (TMS)–Original Design Concept

TIDEFLEX INLET NOZZLES

WATERFLEX OUTLET CHECK VALVES



TIDEFLEX INLETS

TMS MANIFOLD PIPE

WATERFLEX OUTLETS

OLD 2-PIPE SYSTEM

907 ZONE
1.6 MG POTABLE WATER
RESERVOIR

HWL = 910.3
F.F. = 879.3

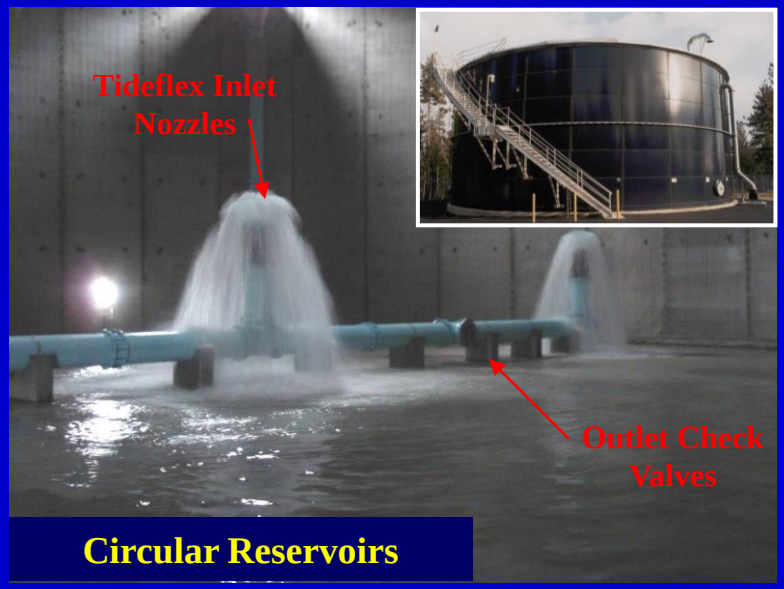
ELECTRICAL PANEL: METER, TRANSFORMER ON CONC. SLAB. SEE ELECTRICAL PLAN ON SHEET 9.

TANK AREA LIGHTING SWITCH BOX SEE ELECTRICAL PLAN ON SHEET 9.

42" MIN. DIAMETER

N.90°00'00"E REFERENCE LINE

Tideflex Mixing System (TMS)



Circular Reservoirs

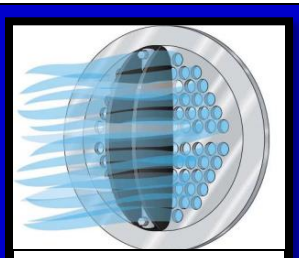
Rectangular Reservoirs

Standpipes

Dry Riser Elevated

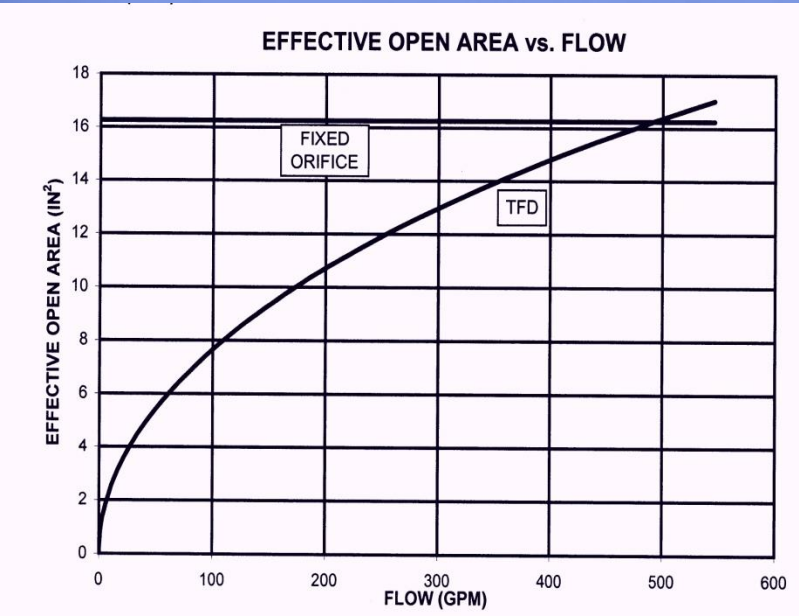
Wet Riser Elevated

Tideflex Inlet Nozzles optimize jet velocity at all flow rates



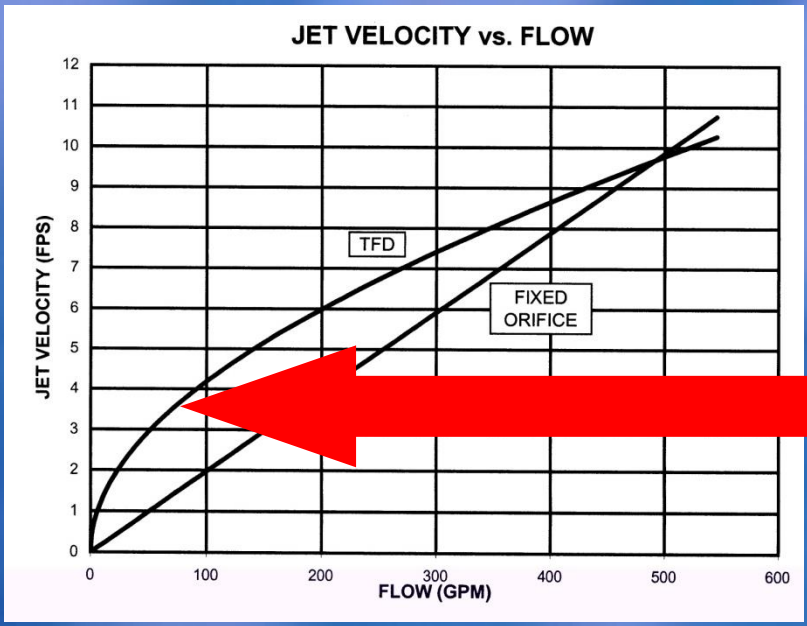
Waterflex Outlet Check Valves

Optimized Jet Velocity of Tideflex Inlet Nozzles



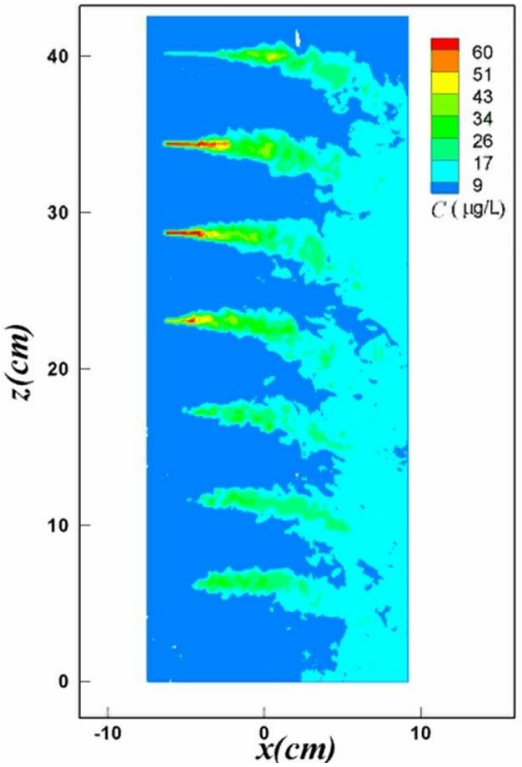
Fixed-Diameter pipes cannot optimize jet velocity

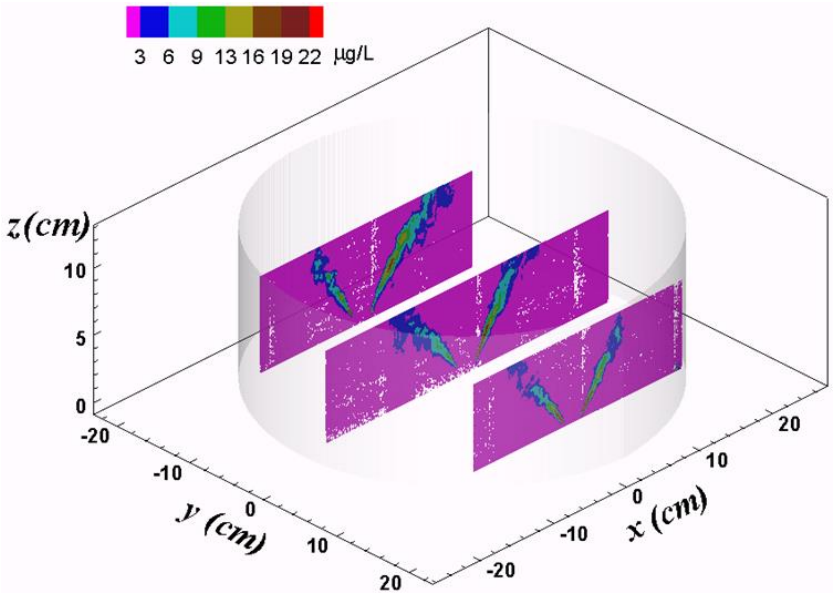
Tideflex Inlet Nozzles optimize jet velocity at all flow rates



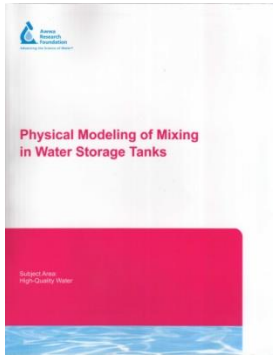
Tideflex Inlet Nozzles Maximize Jet Velocity at ALL Flow Rates Compared to Fixed-Diameter Pipe

Properly Designed Multiple Port Manifolds Result in Up to 50% Faster Mixing Compared to a Single Inlet Pipe



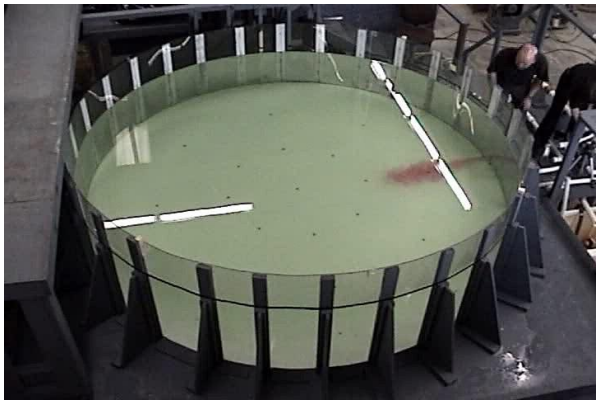


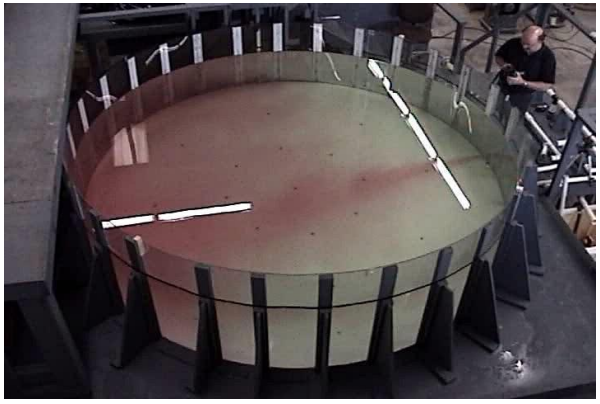
Multiple Inlet Ports Distribute Inlet Flow Momentum Thru Tank Similar to Large Public Swimming Pools. Results in Faster Mixing

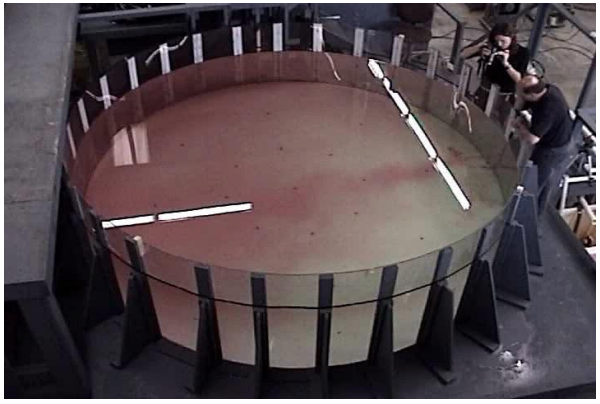


Scale Modeling of 1MG Reservoir

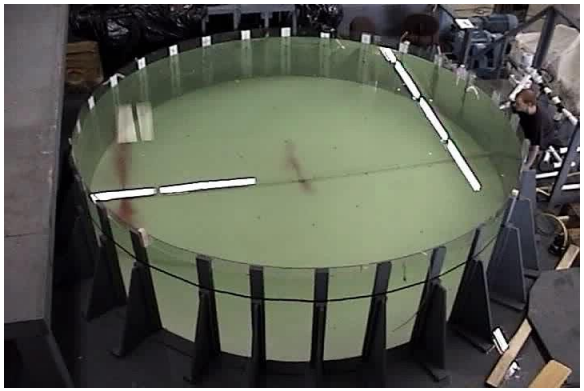
Single Inlet Pipe

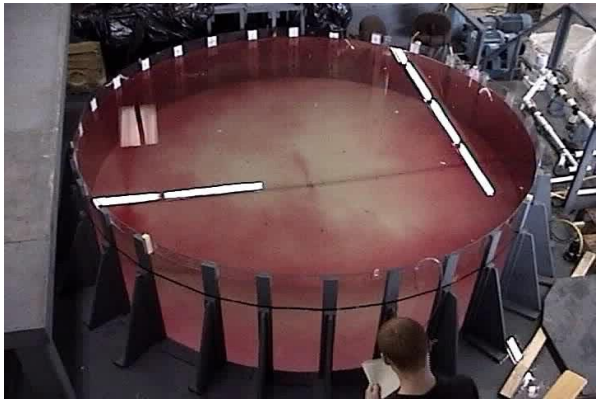






5-Port Tideflex Mixing System

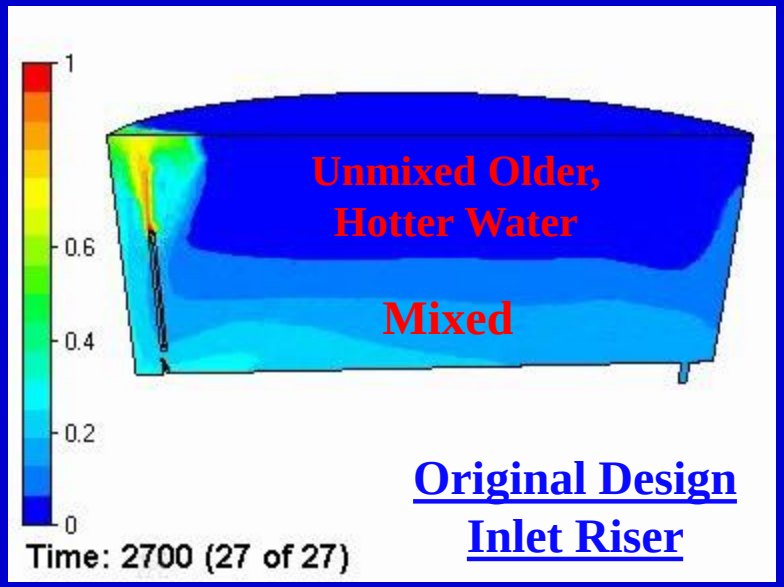




Properly Designed Multiport System Result in 50% Faster Mixing

Images courtesy of: Los Angeles Department of Water & Power and Northwest Hydraulic Consultants

Mt. View-Edgewood Water Company, WA
1.0MG Reservoir - Inlet Riser Modification



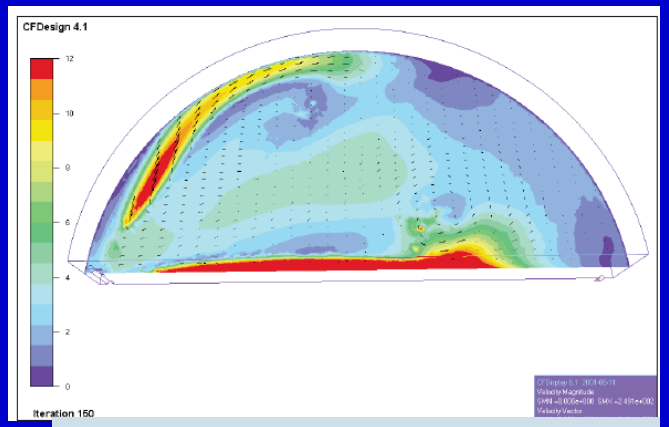
Original Design
Inlet Riser

Original Design – Inlet Riser

Total Coliform Hit

HPC System Average = 0-8 cfu/ml

HPC in Top of Tank = *30,000 cfu/ml*



CFD Modeling of TMS

TMS Retrofit to
Inlet Riser

After Retrofit

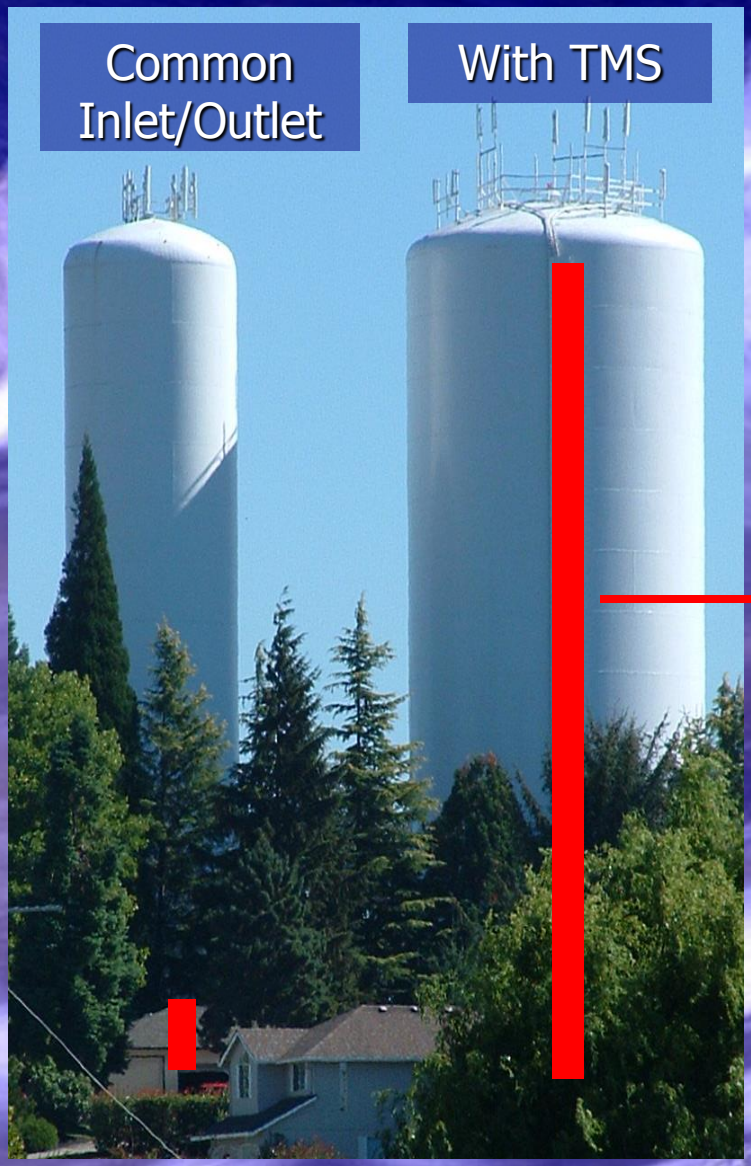
Coliform Eliminated

HPC in Top of Tank = 7.1 cfu/ml

Clark Public Utilities, WA Temperature Profiling

Adjacent Standpipes, 0.5 MG and 1.5MG (125’ Deep)

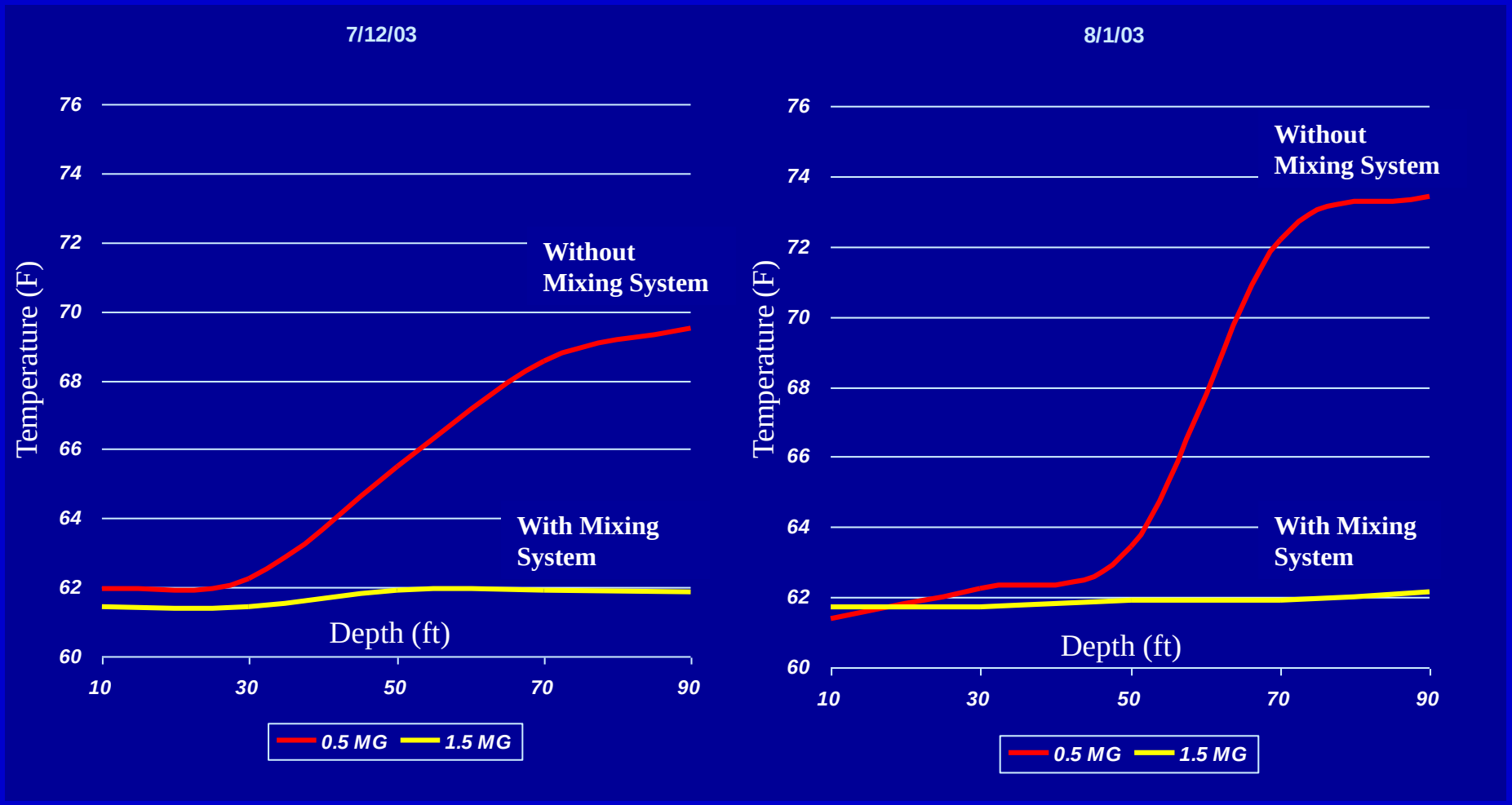
Temp. Data Loggers Installed Every 20’ Thru Depth. Logged Temp’s Every 30 minutes for Over 1 Year



Clark Public Utilities
Customer-owned, customer-focused

Temperature vs. Depth Data

- **Stratification Gets Worse in Smaller Tank from July to August**
- **Stratification Eliminated in Larger Tank with Mixing System**



Water Quality Monitoring of 2.0 MG Reservoir to Evaluate Mixing System and Volume Turnover

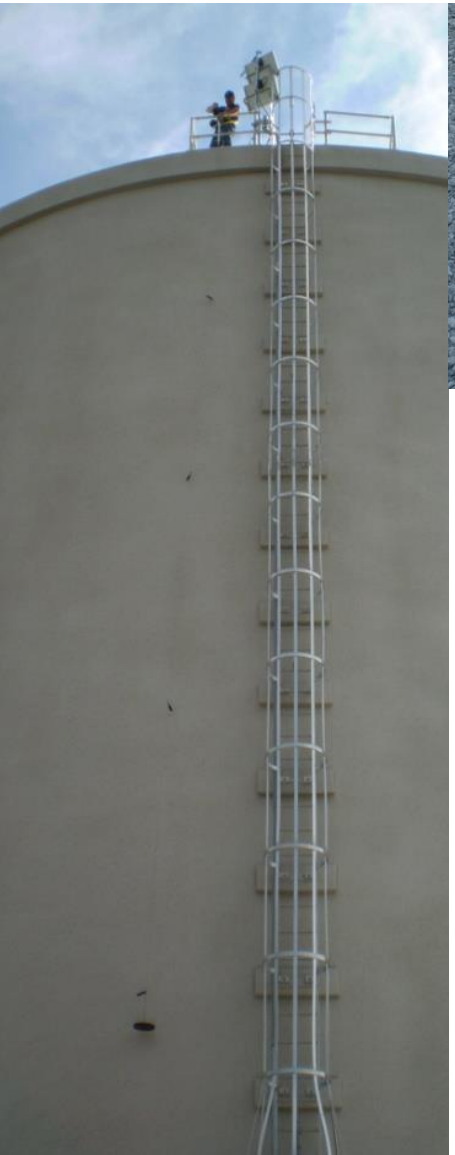
- 2MG Prestressed Concrete Reservoir
- 72.3’ Dia. x 64.25’
- Tideflex Mixing System

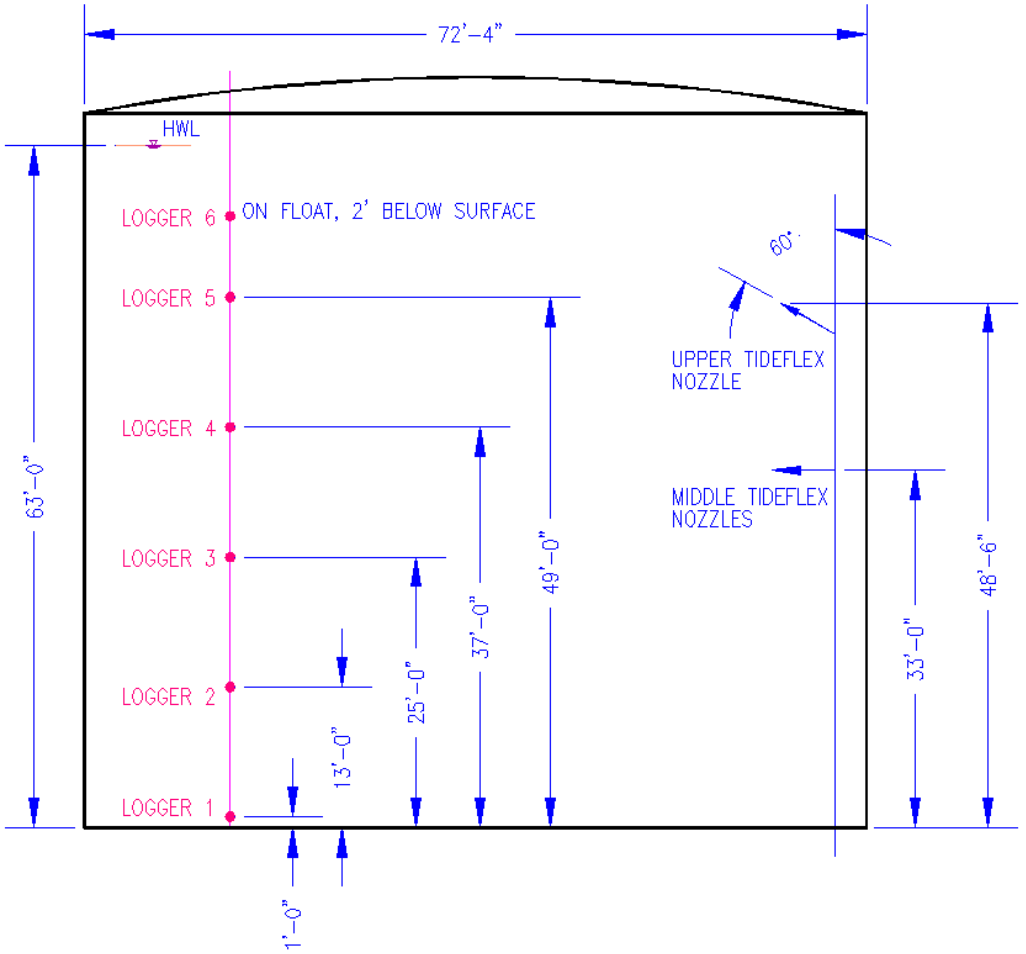
Paul Handke – Pennsylvania DEP

Mike Duer, P.E. – Tideflex Technologies

Mixing System and Turnover Study

Monitoring-Temperature Data Loggers

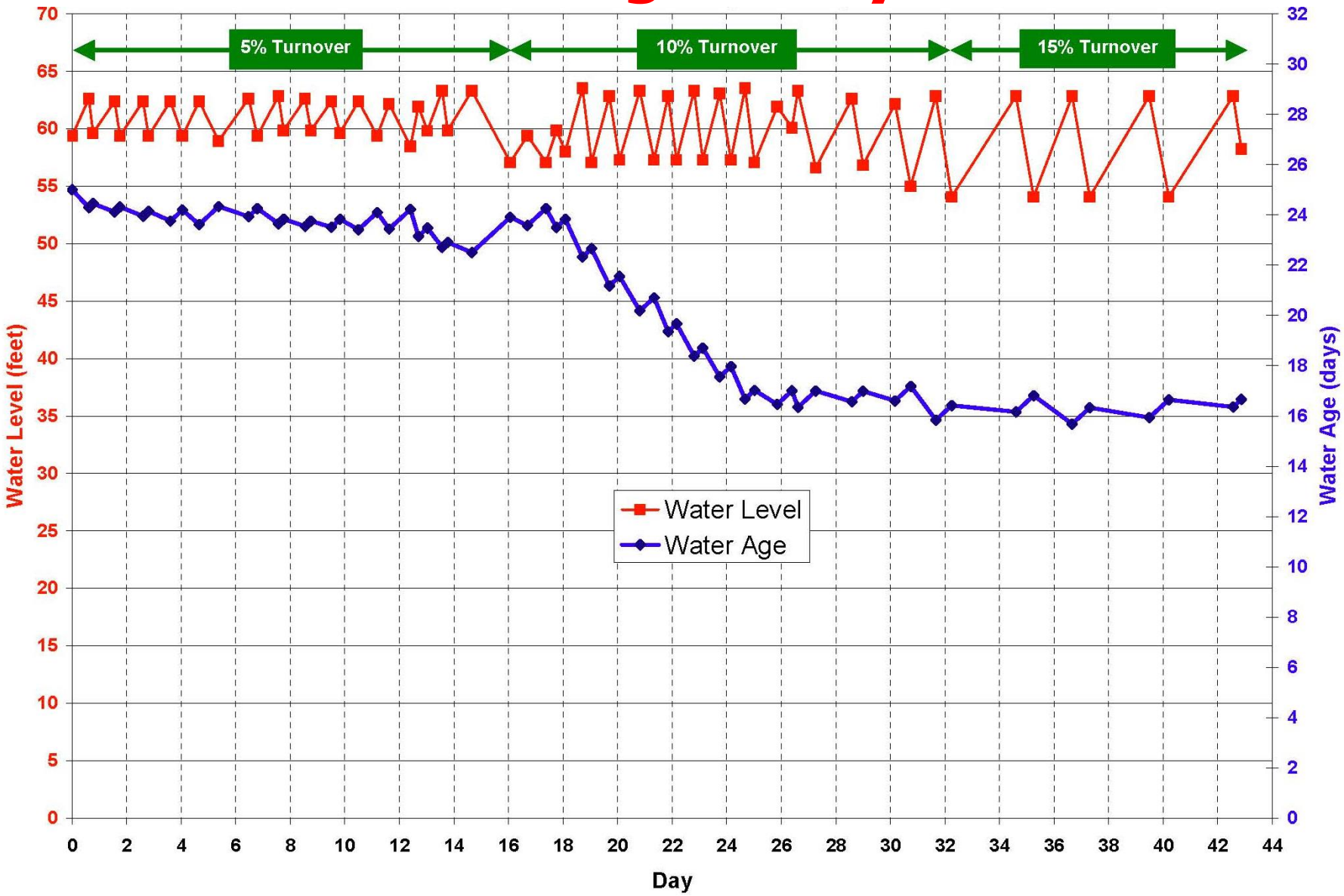




6 Loggers Stored Data Every 15 Minutes, 4700+ data points each logger, 28,200+ data points total

Mixing System and Turnover Study

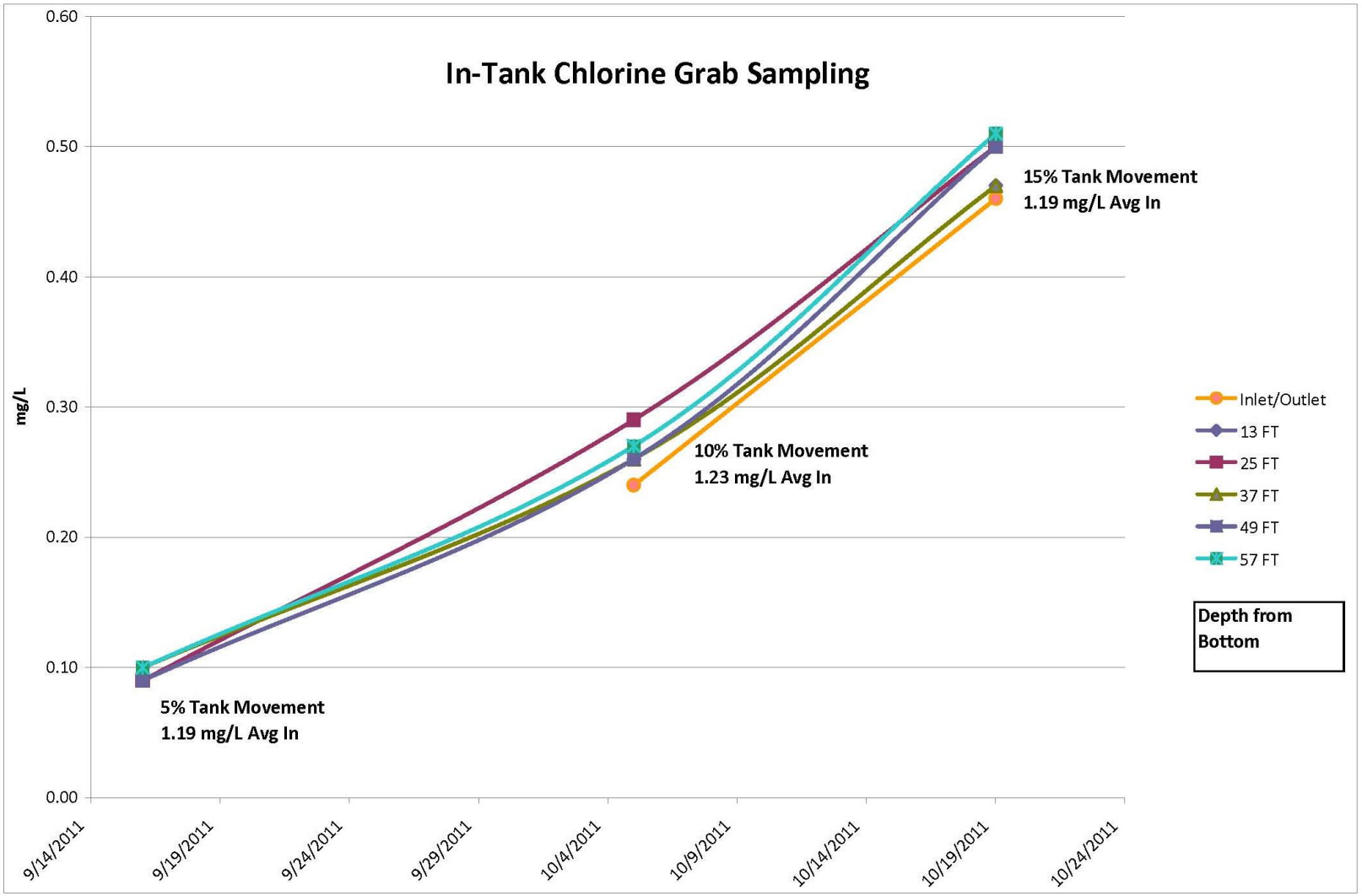
Water Age Analysis



Distribution System Water Quality

Monitoring

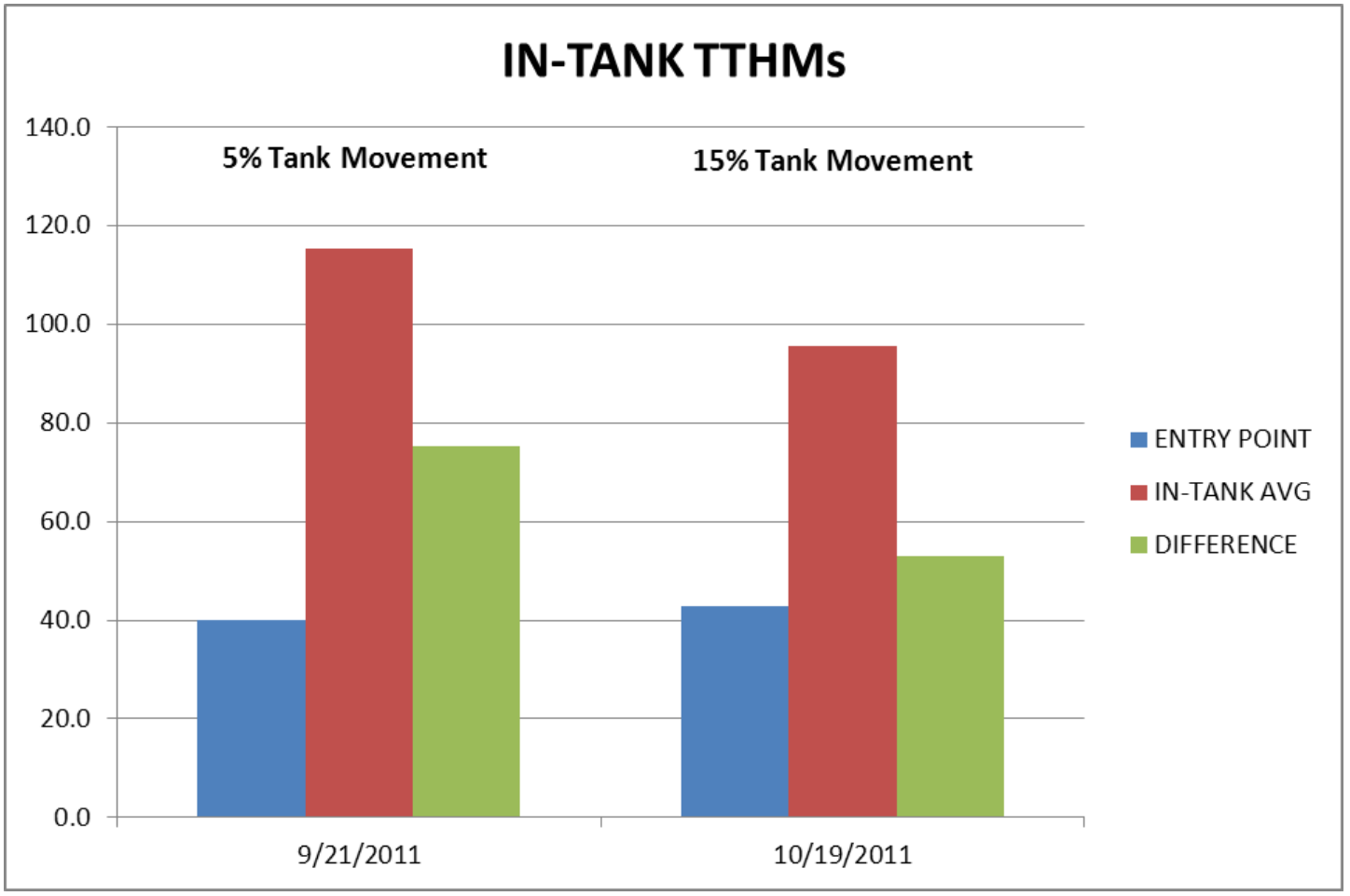
Water Quality Impacts



Distribution System Water Quality

Monitoring

Water Quality Impacts



Tideflex Mixing System (TMS)

Pros

- **Green**. Uses Energy Already in Distribution System - Pressure
- Separates Inlet and Outlet on a Single Manifold Pipe
- **Achieves Complete Mixing Using Existing Energy Source**
- CFD Modeled, Scale Modeled, Field Validated in Every Tank Style (3,500+ Installations)
- **No Maintenance - No Mechanical Parts**
- 30 Year Life
- NSF61 Certified Valves
- Rubber Tested for Chlorine and Chloramine Exposure – No Degradation

Cons

- Fitting Components thru Roof and Shell Hatches (Retrofits)
- Cannot Install "in the wet" in Steel Tanks (can in Concrete tanks)

RESERVOIR MIXING ANALYSIS (TMS)

Tideflex Technologies — A Division of Red Valve Company, Inc.

24-Jun-2011

RESERVOIR / TANK NAME: 1MG Storage Reservoir

CONSULTANT: Consulting Engineer
Contact:
Address:
phone
fax
email

UTILITY / OWNER: Water Utility
Contact:
Address:
phone
fax
email

RED VALVE REP.:
Contact:

ANALYSIS BY: Michael Dyer, P.E.

FILL

INLET FLOW RATES (gpm)

min	100.0
ave	750.0
peak	1500.0
future	2000.0

GUIDE TO TANK FLUCTUATION AND TURNOVER

Theoretical Mixing Time (Fill Time Req'd for Complete Mixing) MT = K * V^(2/3) / M^(1/2) (Minutes)	(Hours)	Req'd Drawdown on Previous Draw to Mix on Next Fill (feet)	% Turnover Required (%)	Volume Exchange Required (gallons)
		(SEE NOTE 2)	(SEE NOTE 2)	(SEE NOTE 2)
485.4	8.1	1.6	5.5	48,216
106.4	1.8	2.5	9.1	79,775
62.7	1.0	3.0	10.7	93,801
50.3	0.8	3.2	11.5	100,815

SEE NOTE 2

MINIMUM TANK FLUCTUATION TARGET

FILL

GUIDE TO TANK FLUCTUATION AND TURNOVER

INLET FLOW RATES (gpm)		Jet Velocity (fps)	JV^2 / 2g (feet)	Reynold's Number	Inlet Momentum (ft^4 / min^2)	Velocity Gradient, G (1/sec)
min	100.0	2.04	0.06	94,086	1,634	0.57
ave	750.0	5.66	0.50	429,443	34,039	4.33
peak	1500.0	8.13	1.03	727,982	97,815	8.80
future	2000.0	9.48	1.40	907,946	152,155	11.86

Theoretical Mixing Time (Fill Time Req'd for Complete Mixing) MT = K * V^(2/3) / M^(1/2) (Minutes)	(Hours)	Req'd Drawdown on Previous Draw to Mix on Next Fill (feet)	% Turnover Required (%)	Volume Exchange Required (gallons)
		(SEE NOTE 2)	(SEE NOTE 2)	(SEE NOTE 2)
485.4	8.1	1.6	5.5	48,216
106.4	1.8	2.5	9.1	79,775
62.7	1.0	3.0	10.7	93,801
50.3	0.8	3.2	11.5	100,815

SEE NOTE 2

MINIMUM TANK FLUCTUATION TARGET

DRAW

OUTLET FLOW RATES (gpm)		TIME TO DRAW TANK FROM FULL TO EMPTY (Hours)	(Days)	Time to Draw Down 1' Depth (Minutes)	(Hours)	Pipe Velocity (fps)
min	100	146.11	6.09	313.09	5.22	0.28
ave	750	19.48	0.81	41.75	0.70	2.13
fire	1500	9.74	0.41	20.87	0.35	4.25
future	2000	7.31	0.30	15.65	0.26	5.67

Volume Exchange Required (gallons)	Draw Time Required (Hours)	
100,815 →	16.8 @	100 gpm Draw Rate
100,815 →	2.2 @	750 gpm Draw Rate
100,815 →	1.1 @	1500 gpm Draw Rate
100,815 →	0.8 @	2000 gpm Draw Rate

*** NOTE:** 1. TIDEFLEX VALVES ARE INHERENTLY A VARIABLE ORIFICE SO THE TMS EFFECTIVE DIAMETER VARIES WITH FLOW RATE
2. MIXING TIME EQUATIONS DO NOT ACCOUNT FOR DIFFERENCES IN TEMPERATURE BETWEEN INLET WATER AND TANK (BUOYANT JETS) THESE CALCULATIONS MAY UNDERESTIMATE THE FILL TIME REQUIRED FOR MIXING.

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WATER AGE ANALYSIS

TIDEFLEX MIXING SYSTEM (TMS)

Actual/Predicted Daily Turnover and Water Age

High Water Level (HWL) =	28	ft	**Turnover =**	4.0	feet	**Ave. Water Age =** 7.0 days
Low Water Level (LWL) =	24	ft		14.3	%	*(Assumes tank is mixed. CAUTION: A single inlet pipe often does not mix. Water age could be much higher*

Turnover Required for TMS to Achieve Complete Mixing

(GOAL: For Required Turnover for Complete Mixing to be Less Than Actual/Predicted Turnover)

The TMS will mix the tank with **Turnover =**	3.2	feet	**Ave. Water Age =** 8.7 days
(see Mixing Analysis)	11.5	%	*(Water age if tank turnover was the minimum required to achieve complete mixing)*

RESULT

Is Actual Turnover Greater than Required Turnover to Mix with TMS? YES

If Yes, the TMS will Completely Mix the Tank. Applicable Water Age is from Actual/Predicted Turnover

If No, Tank May not be Completely Mixed. A localized increase in Water Age Could Result. Investigate Methods to Increase Turnover.

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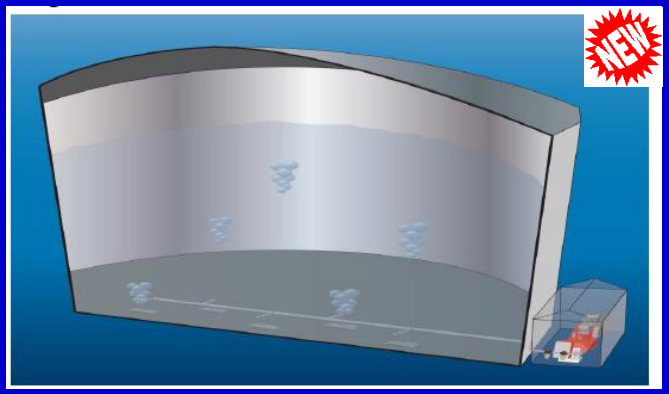
Active (Mechanical) Mixing (Rarely *Required*)

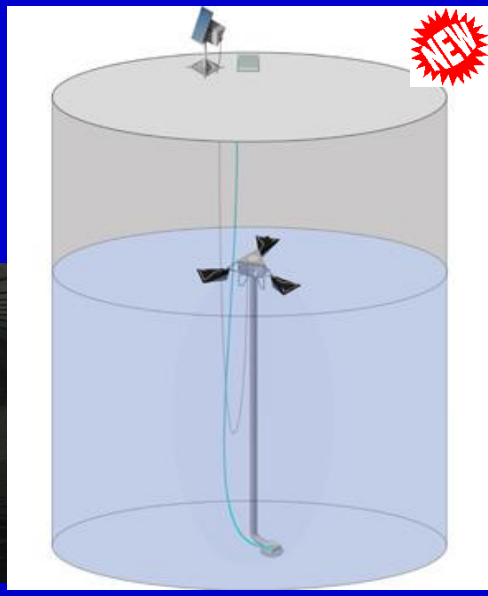
No In-Tank Maintenance

Passive TMS + Recirculation Pump
(Mechanical Components Outside of Tank, Passive TMS Inside of Tank)

Submersible Mixers



Air Bubblers



PAX Mechanical Mixer

Solarbee Mechanical Mixer

Active (Mechanical) Mixers

Pros

- Effective if Have Sufficient Quantity, Horsepower, RPM
- Some Can be Used for Disinfectant Injection

Cons

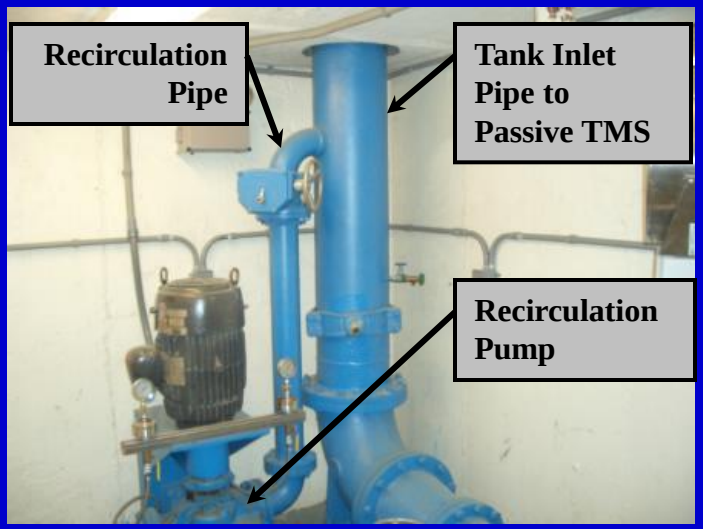
- Add Another Energy Source to Tank
  - Already have an energy source. Owner paying for energy twice
- No Mixing and Water Age Calculations for Specific Tank
  - The same mixer used in a 0.5 as a 5.0MG tank?
- Specs say takes 2-3 Days to Mix?
  - (there are multiple fill/draw cycles within 3 days. How does tank not short circuit)?
- May Need Multiple Mixers for Tanks with Higher Flow Rates and Turnover
  - Mixers "fight" the normal circulation patterns created by inlet momentum
- Maintenance/Replacement Costs Every 3-5 Years (Maintenance contracts)
- Fairly New to Market. Long term track record?
- Additional Tank Penetration, Roof Mounts, etc.
- Training Required

Active Tideflex Mixing System (ATMS)

IF active mixing is required:

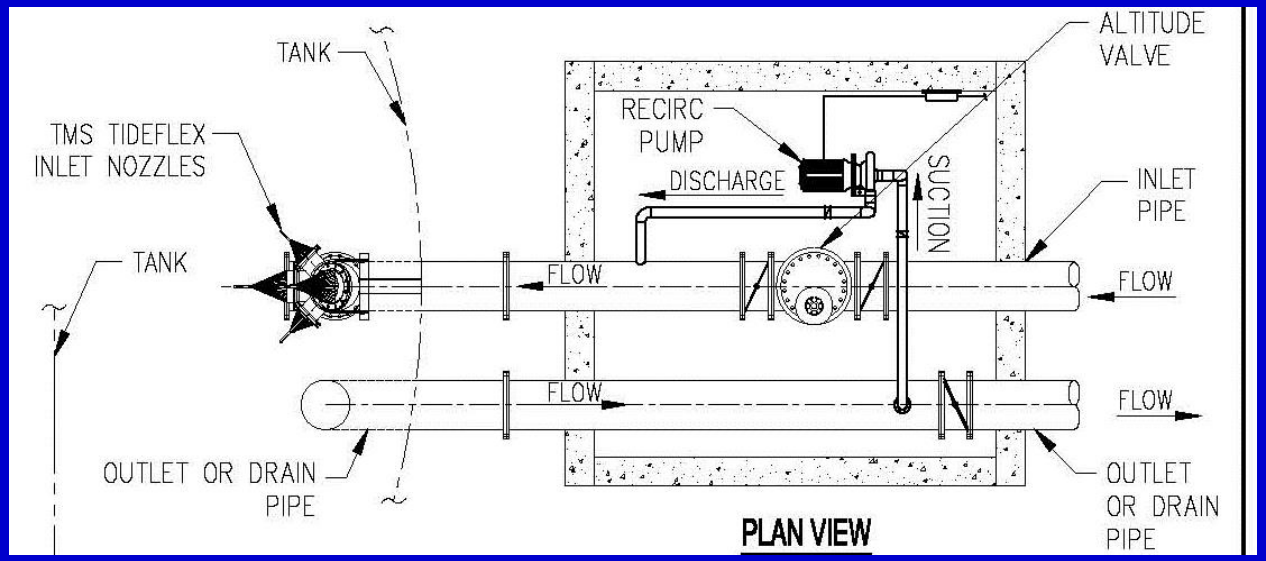
- Passive TMS installed INSIDE of Tank (No maintenance)
- Recirculation Pump in Vault OUTSIDE of tank (easily accessed in vault/structure for inspection and maintenance)
- Recirculation pump is low flow, low head, low energy
- Can perform continuous mixing
- Can perform forced-draw down to minimize water age
- Can perform chemical injection for rechlorination, forming chloramines, or performing breakpoint chlorination
- Can turn recirculation pump off when not needed and let passive TMS mix tank

Passive TMS installed in tank



Chemical Injection Alternatives

Into Tideflex
Jet In Tank



Into Inlet or Outlet Pipe

QUESTIONS ?

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