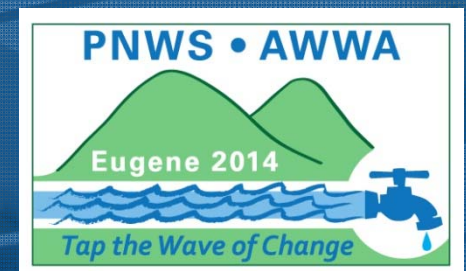


CH2MHILL®

Computational Fluid Dynamics (CFD) The Solution to Complex Fluid Flow Problems

*2014 PNWS-AWWA Conference
Eugene, Oregon*

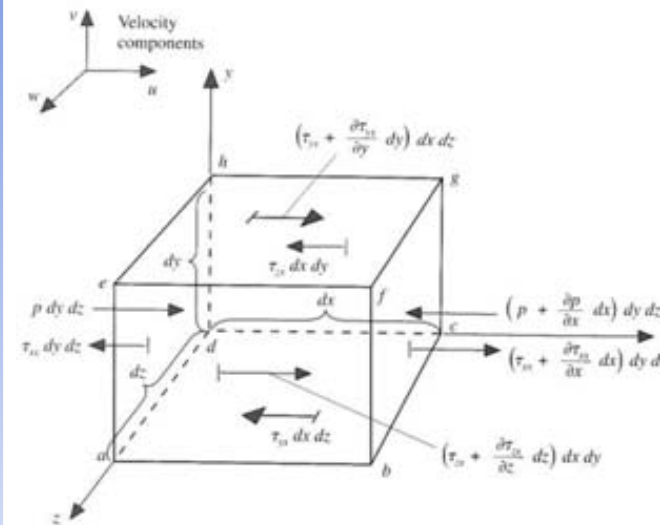
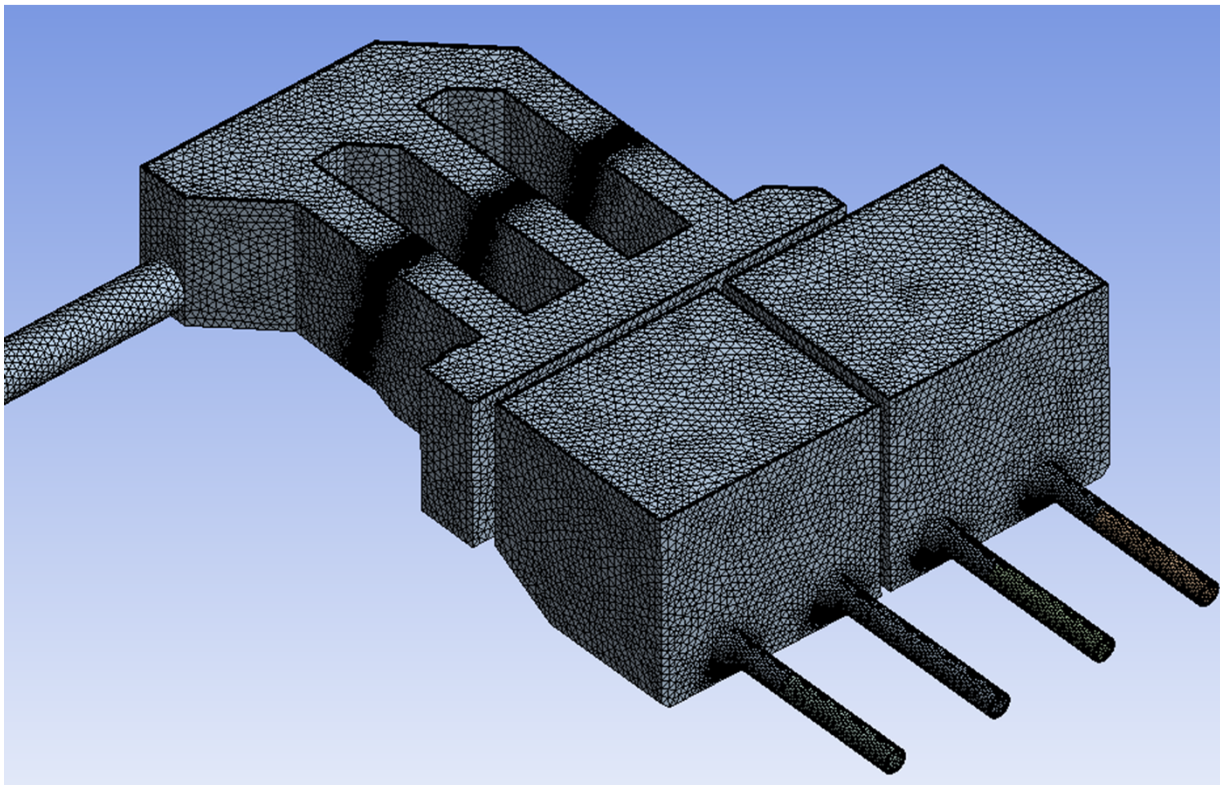
*Kevin D Nielsen, Ph.D., P.E.,
CH2M HILL*



Learning Objectives and Presentation Method

- Gain a basic understanding of Computational Fluid Dynamics (CFD)
- Recognize how CFD can assist in solving complex fluid flow problems
- Provide several example projects to illustrate the capabilities of CFD
 - Each example will be brief with only one or two slides
- Provide example projects to illustrate the capabilities of CFD to evaluate water storage reservoirs

CFD is the finite-volume solution of the governing equations for fluid flow



When can you use CFD?

- Essentially any fluid flow phenomena
 - Closed conduit or open channel
 - Subcritical or supercritical flow
 - Steady-state or transient
 - Newtonian or non-Newtonian fluids
 - Laminar or turbulent flow
 - Single or multi-phase (air-water, sediment-water)
 - Complex combinations of above conditions

CFD results provide powerful visualization of flow characteristics

- 3D solutions (x, y, & z components) at each finite volume element
 - Velocity and acceleration
 - Pressure (or water surface elevation)
 - Volume fraction of air
 - Concentration of tracer
 - Particle flow path
 - Several other parameters including user defined parameters

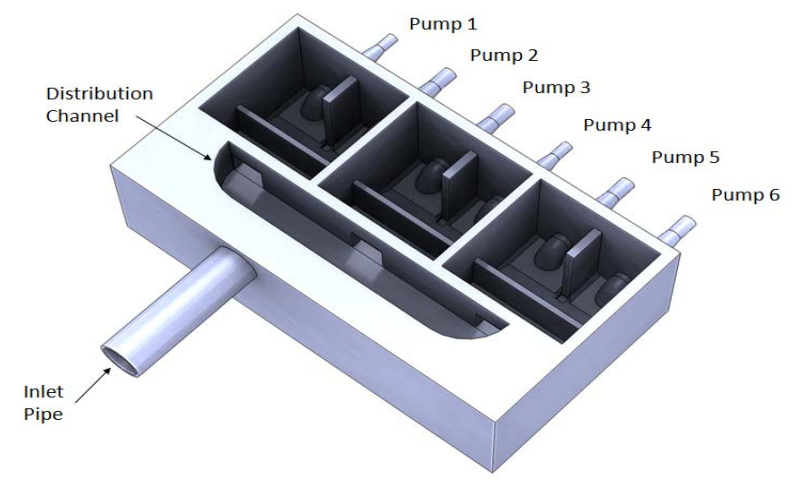
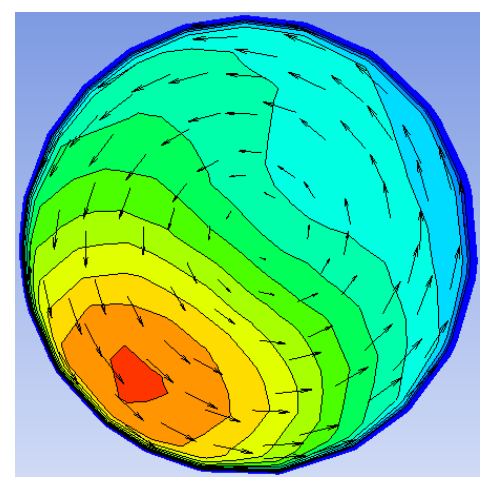
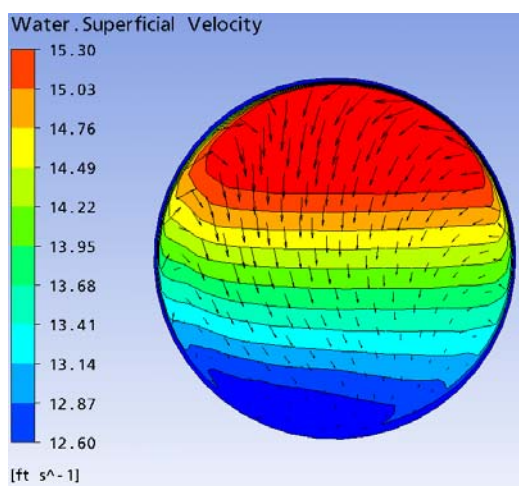
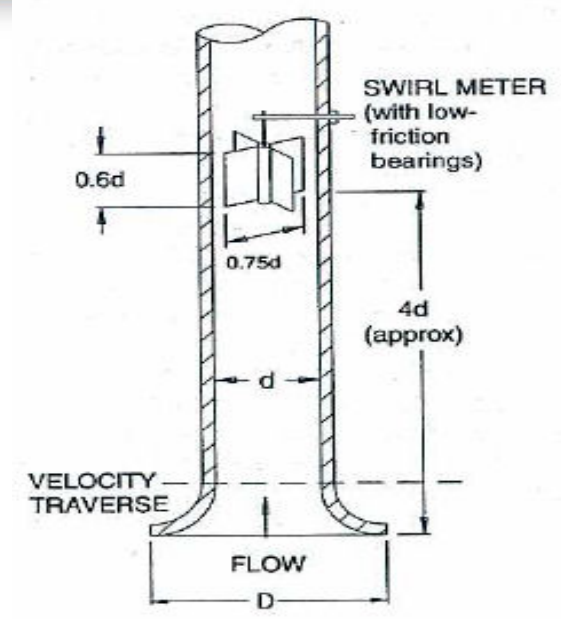
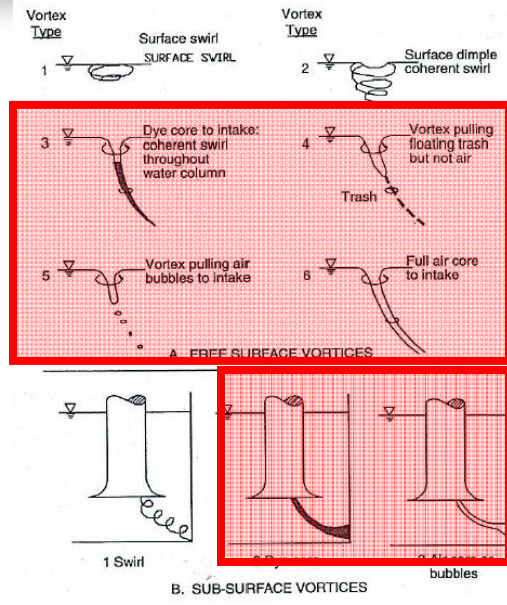
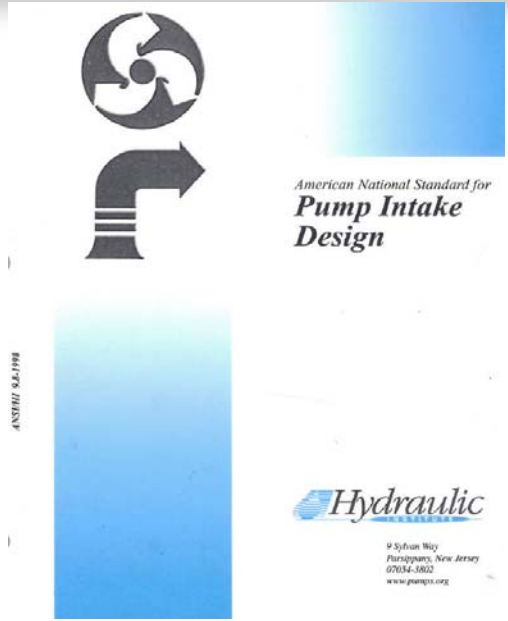
CFD Evaluation Process

- Define the problem
- Develop a 3D solids model
- Mesh the model (create each finite volume)
- Problem setup
 - Boundary conditions
 - Fluid properties
 - Solver parameters
- Computer solution
- Post processing to extract and visualize results

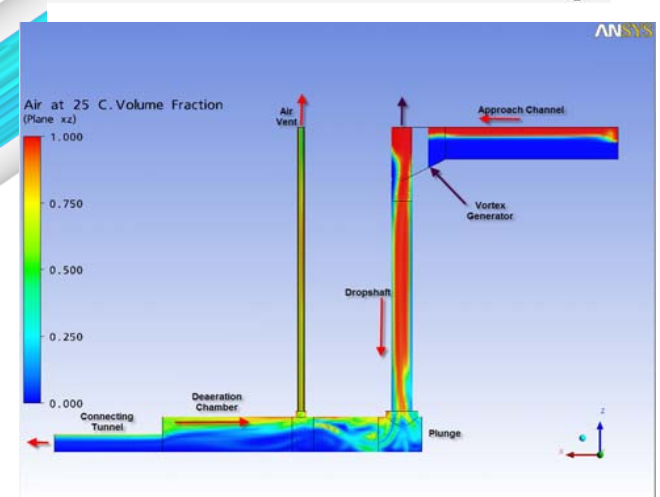
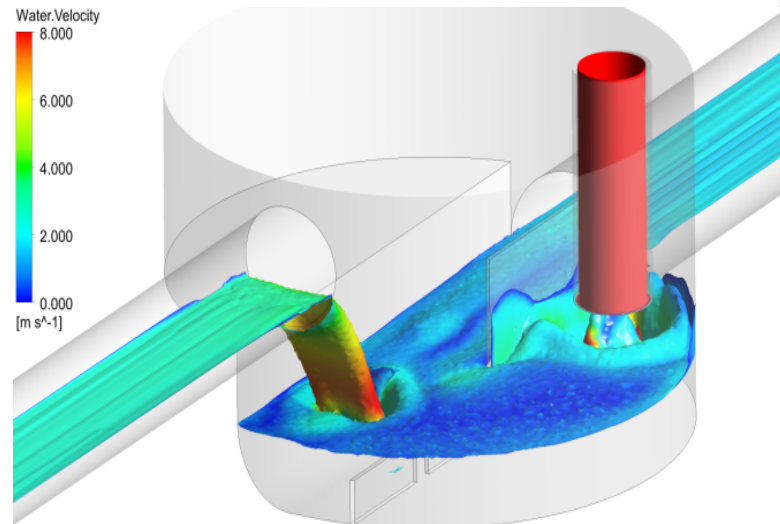
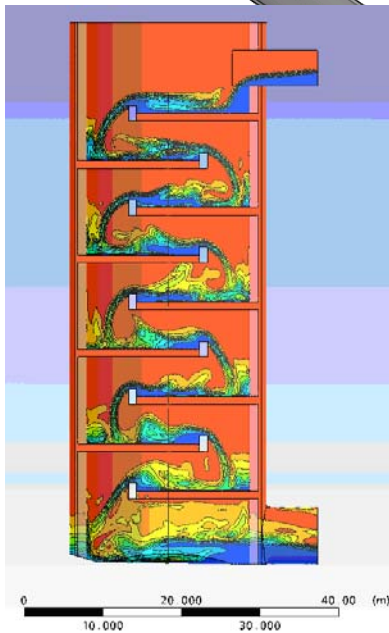
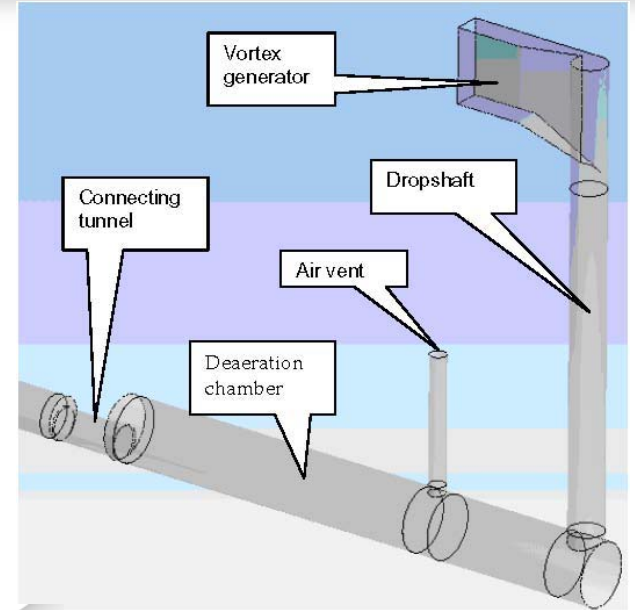
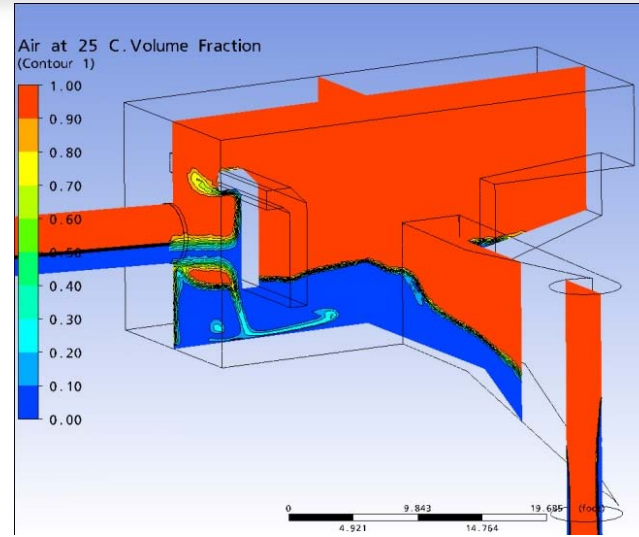
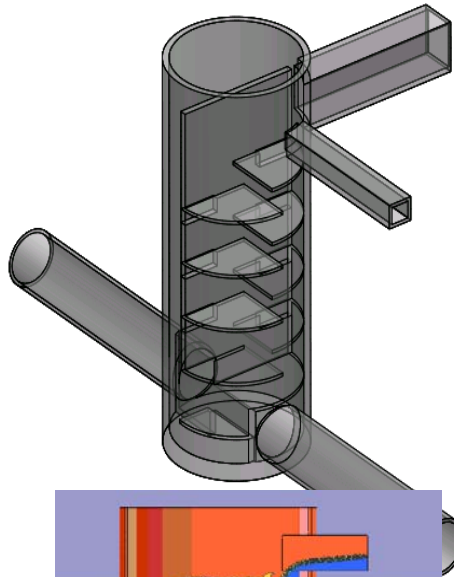
CFD Example Projects

- Diffusers, outfalls, plumes
- Digesters, clarifiers, grit chambers, mixing tanks
- Water storage tank performance (T_{10} , water-age, baffling factor, efficiency)
- Pump intake hydraulics
- Flow control structures
- Lake water quality
- Hydropower, penstocks
- UV train hydraulics
- Flow distribution and equalization
- Screening structures, intakes, fish passage
- Coalescing and bubble movement
- Dropshafts and CSO diversion structures
- Spillways/stilling basins

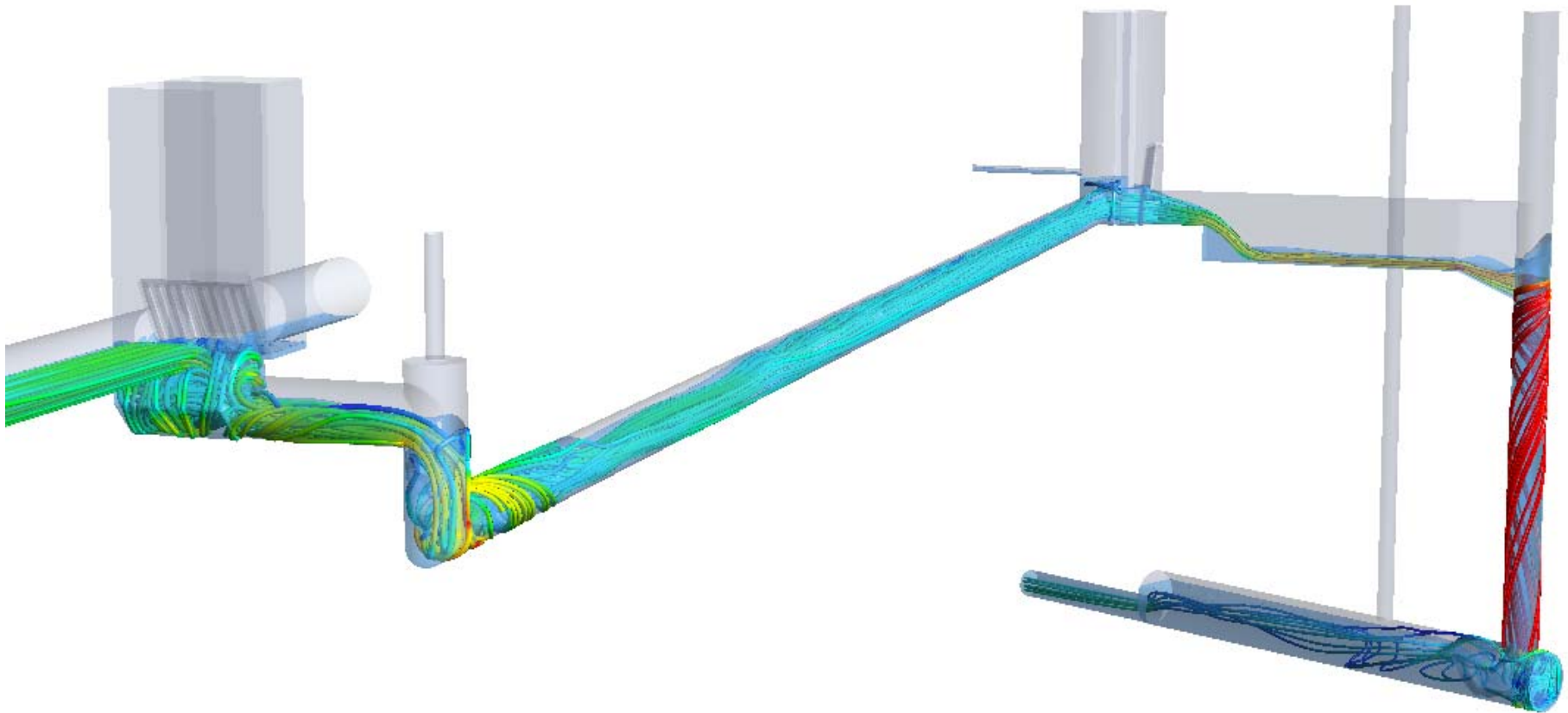
Pump Intake Evaluation of Vortices, Swirl Angle, and Velocity Distribution



CSO Diversion Structures, Dropshafts, and Deaeration Chambers

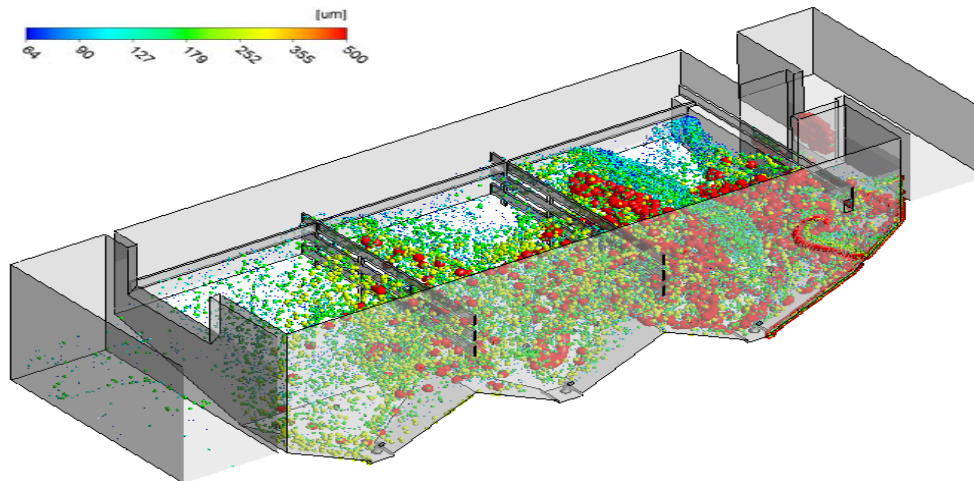
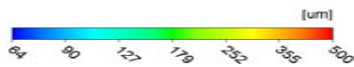
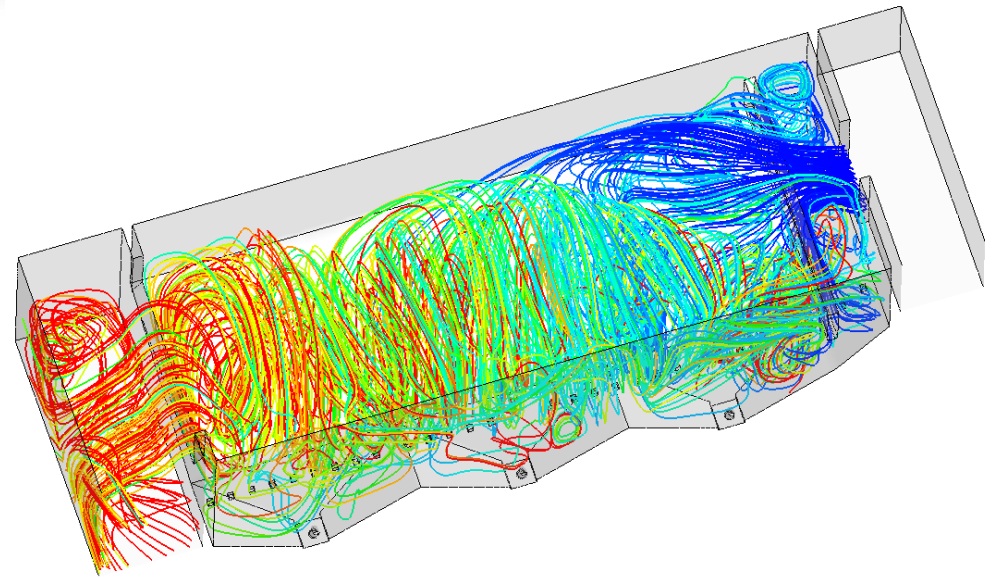
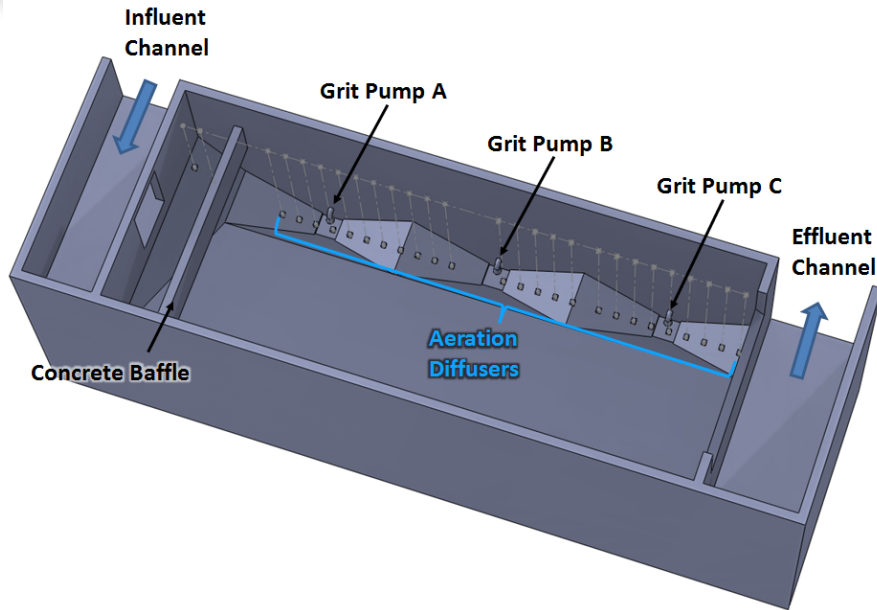


CSO Diversion Structure, Dropshaft, and Tunnel System

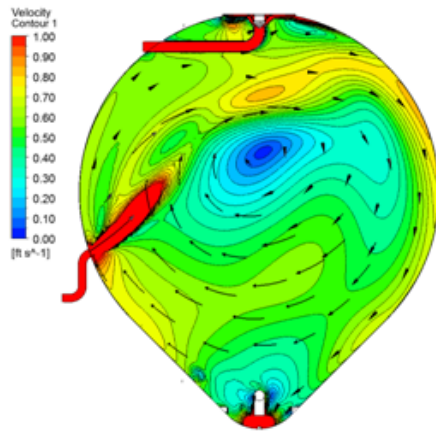


System schematic and water velocity streamlines

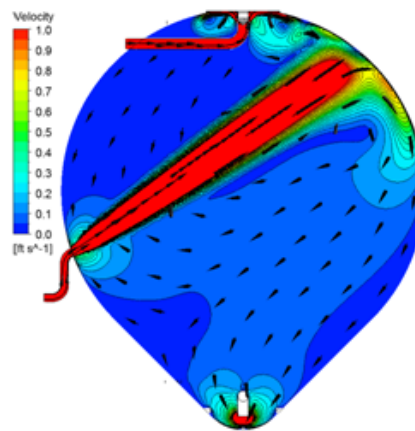
Grit Chambers (water-solids example)



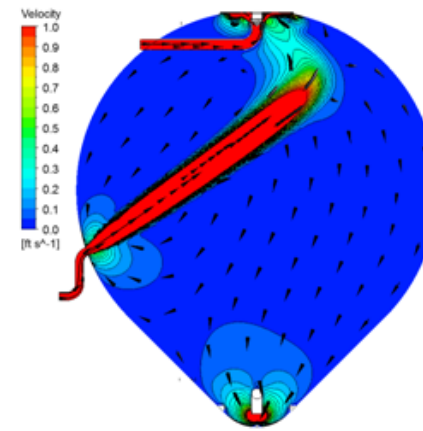
Digester Example – Non-Newtonian fluid (sludge)



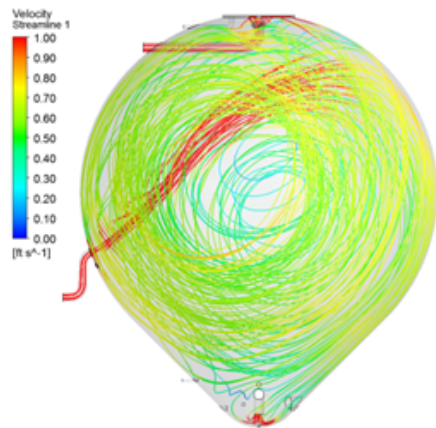
Water, 2 pumps



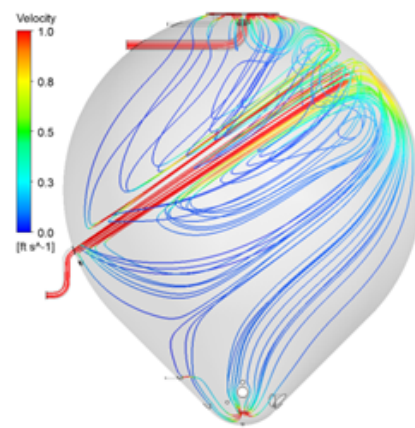
2% Solids, 2 pumps



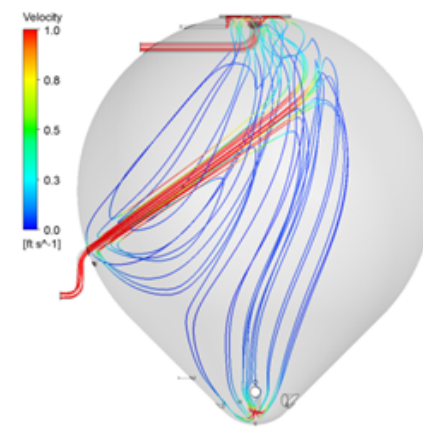
4% Solids, 2 pumps



Water, 2 pumps

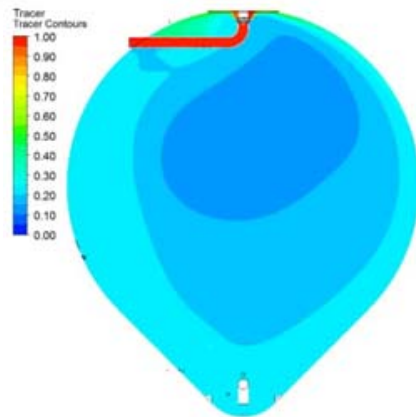


2% Solids, 2 pumps

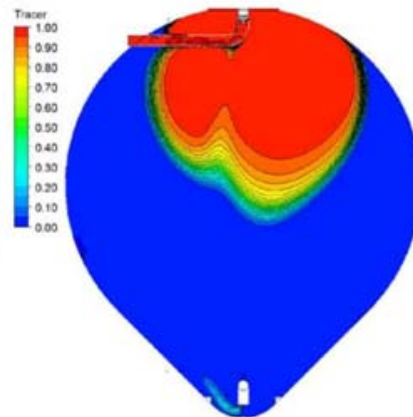


4% Solids, 2 pumps

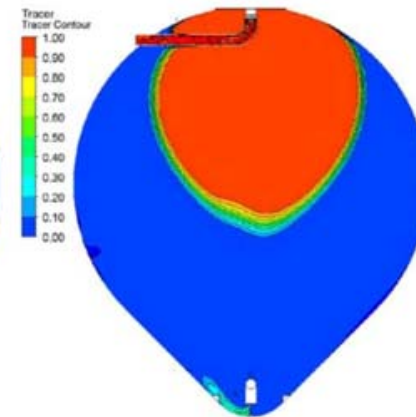
Digester Mixing Tracer Distribution vs. Time



Water, 1 pump

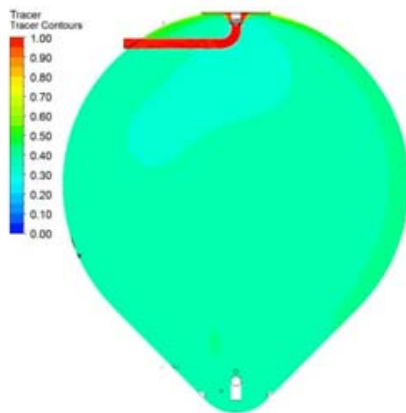


2% Sludge, 1 pump

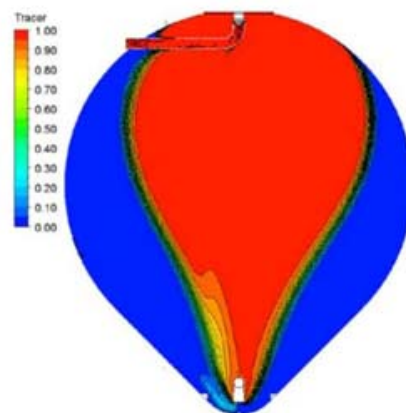


4% Sludge, 1 pump

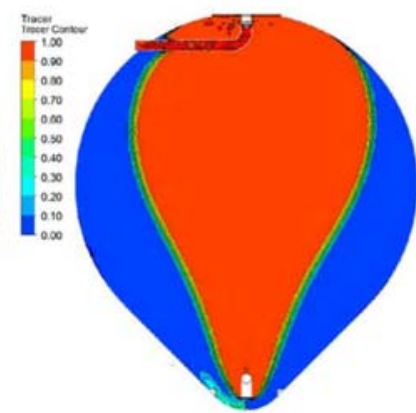
Tracer Concentrations after 1 Hour



Water, 1 pump



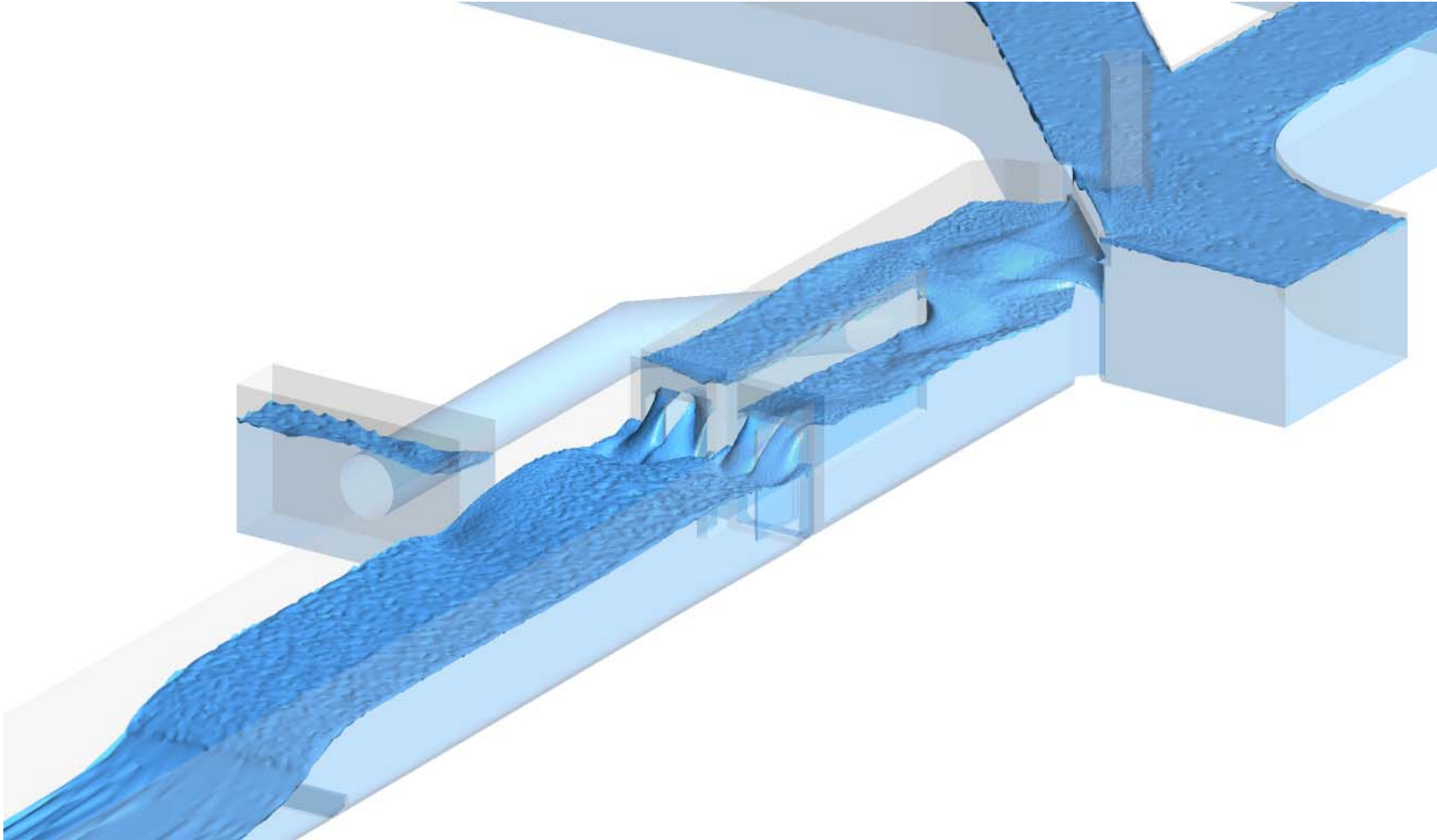
2% Sludge, 1 pump



4% Sludge, 1 pump

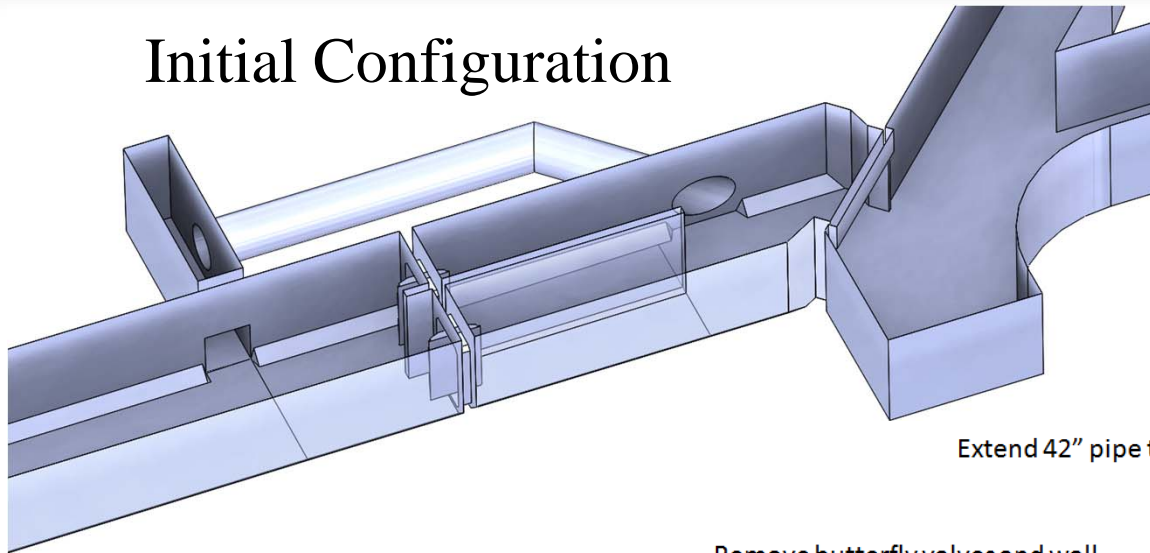
Tracer Concentrations after 2 Hours

Headloss in complex flow control structure



Initial Configuration vs. Proposed Modification

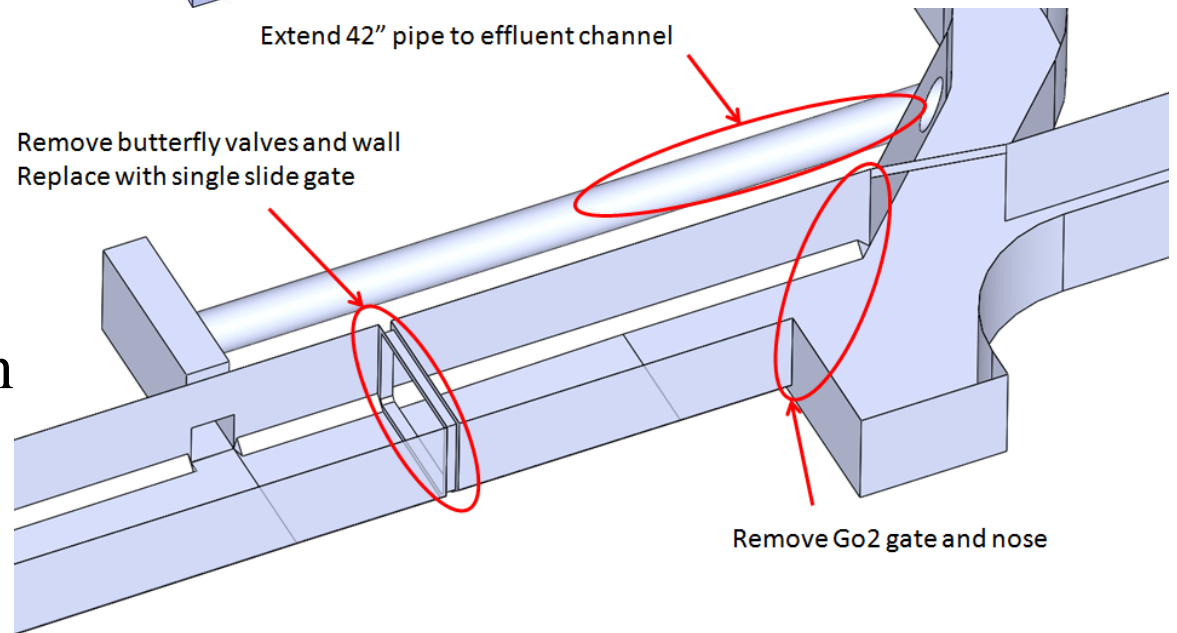
Initial Configuration



Extend 42" pipe to effluent channel

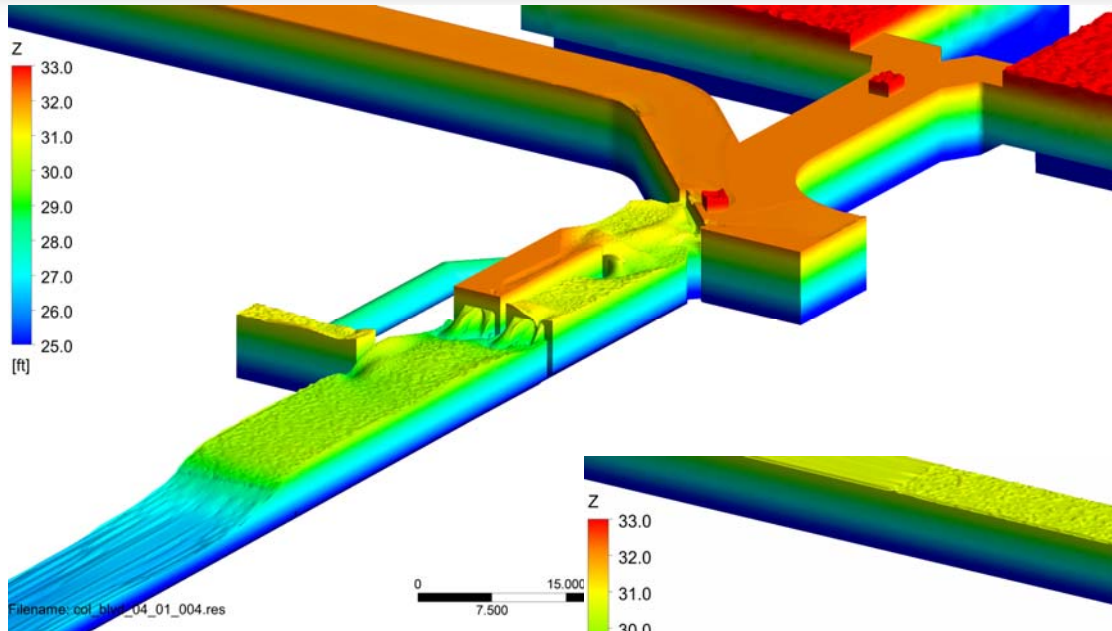
Remove butterfly valves and wall
Replace with single slide gate

Proposed Modification

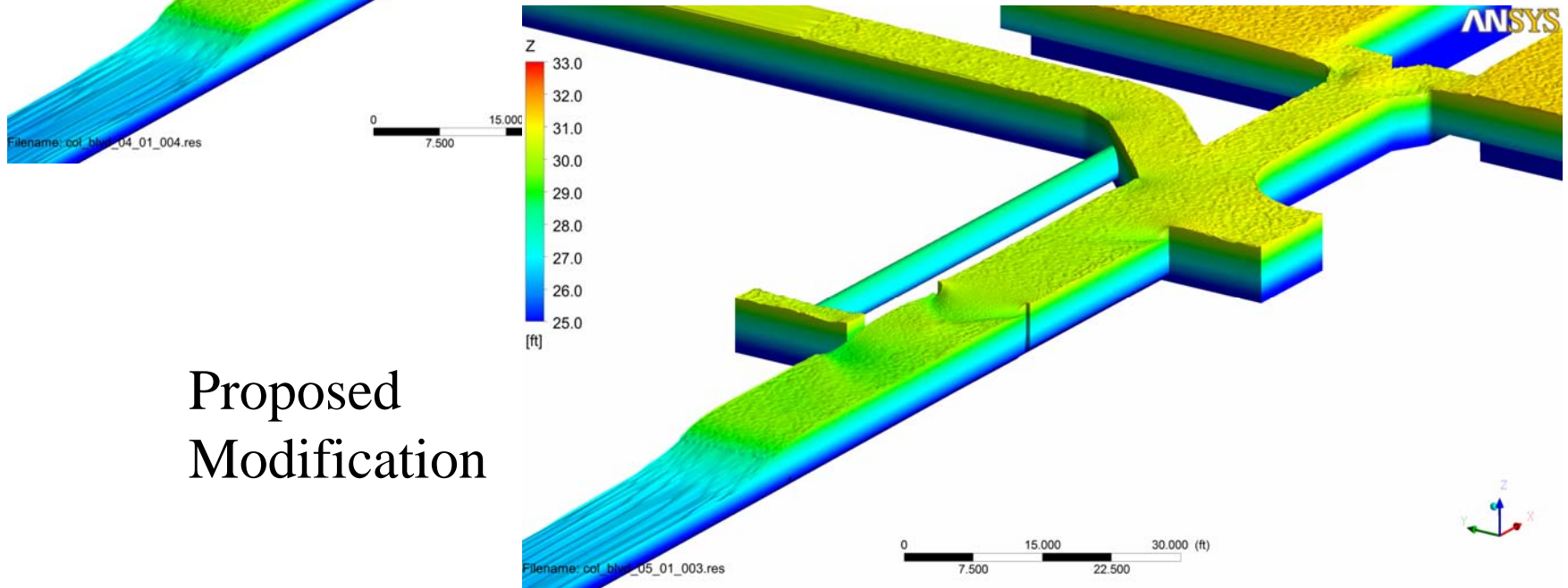


Remove Go2 gate and nose

Water Surface Elevation Comparison

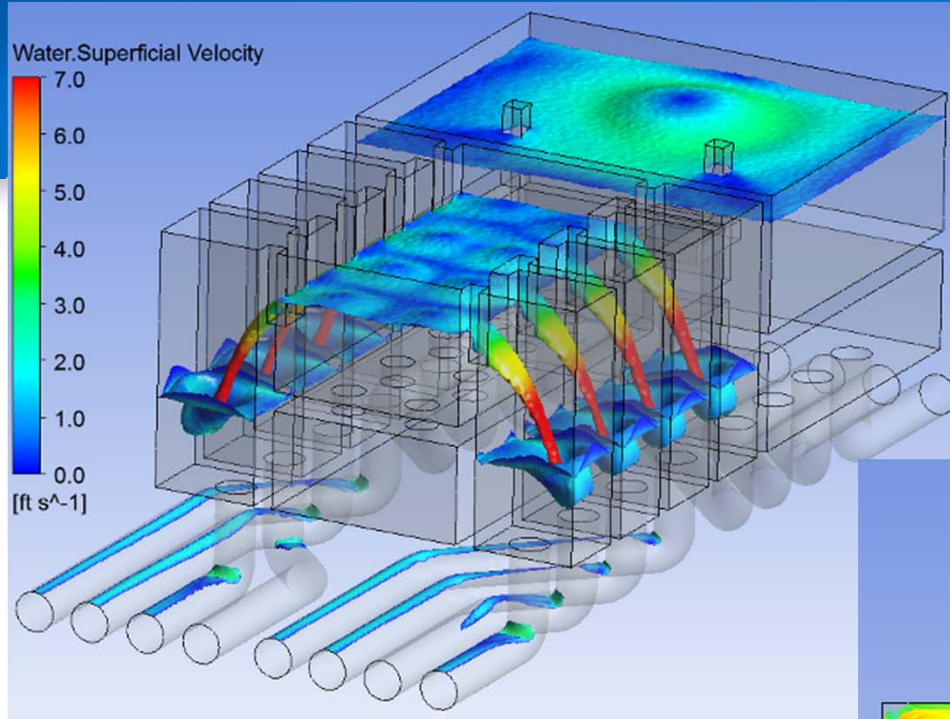


Initial Configuration

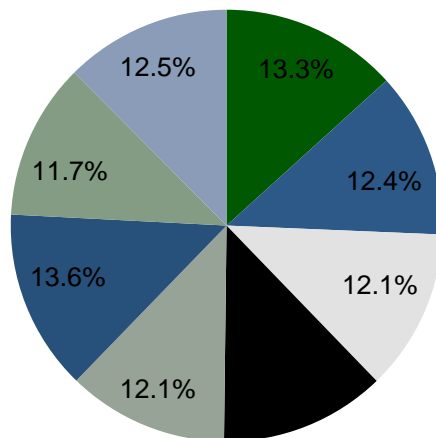


Proposed Modification

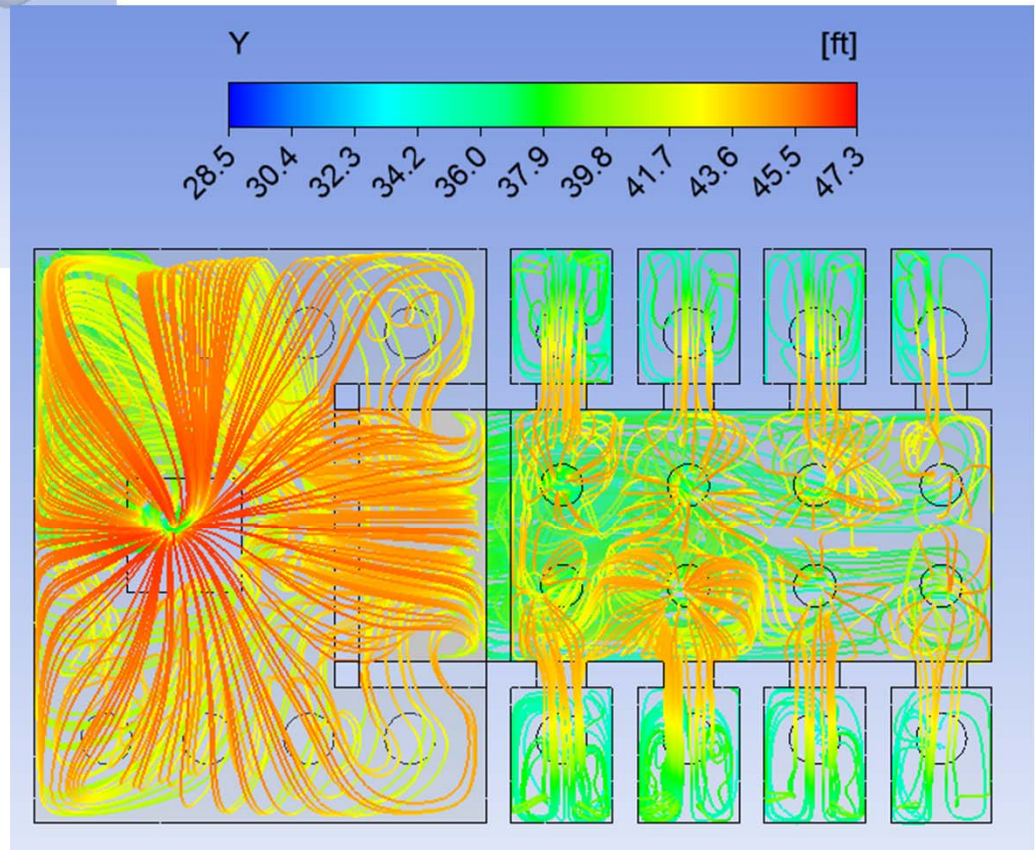
Mixing Box Characteristics



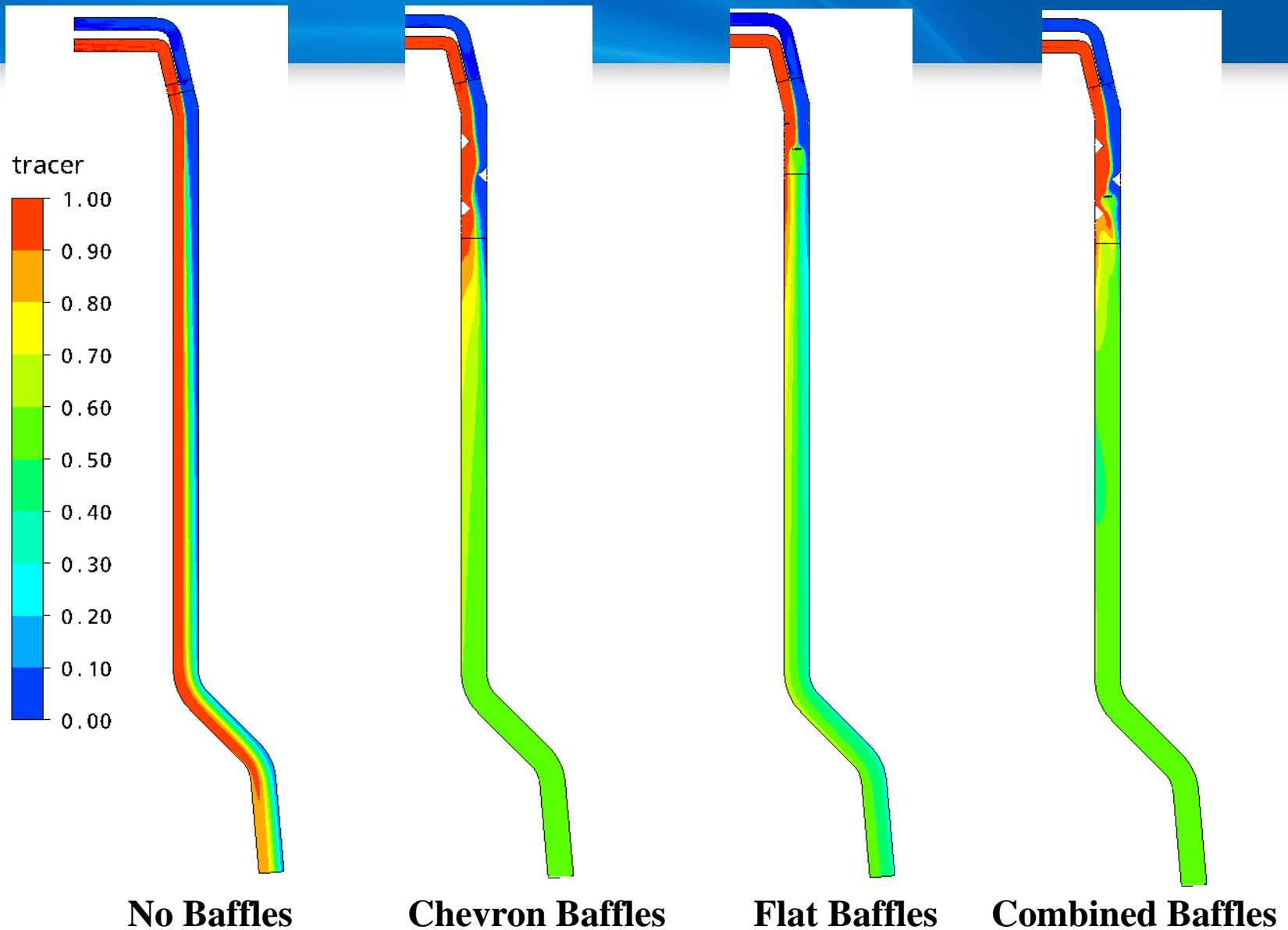
Overall Flow Distribution



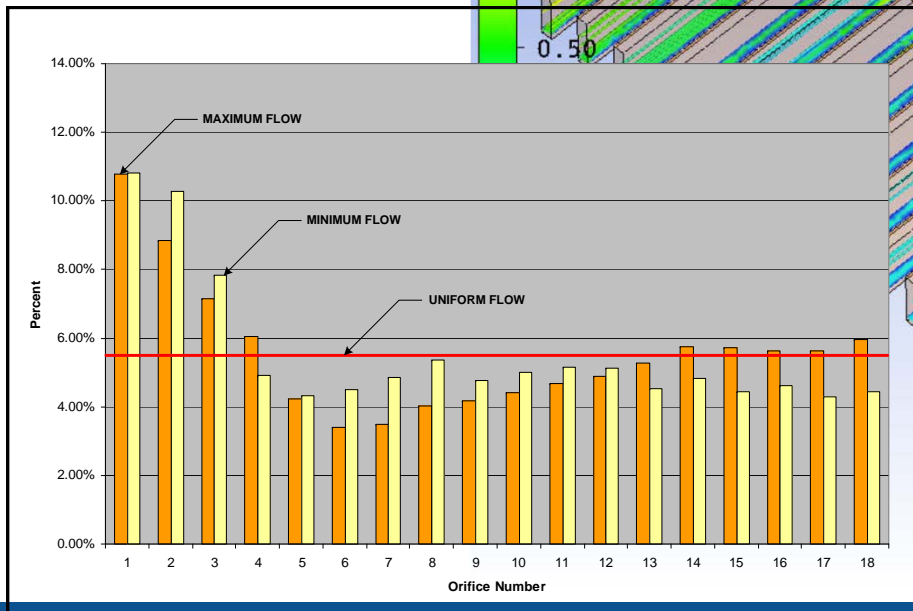
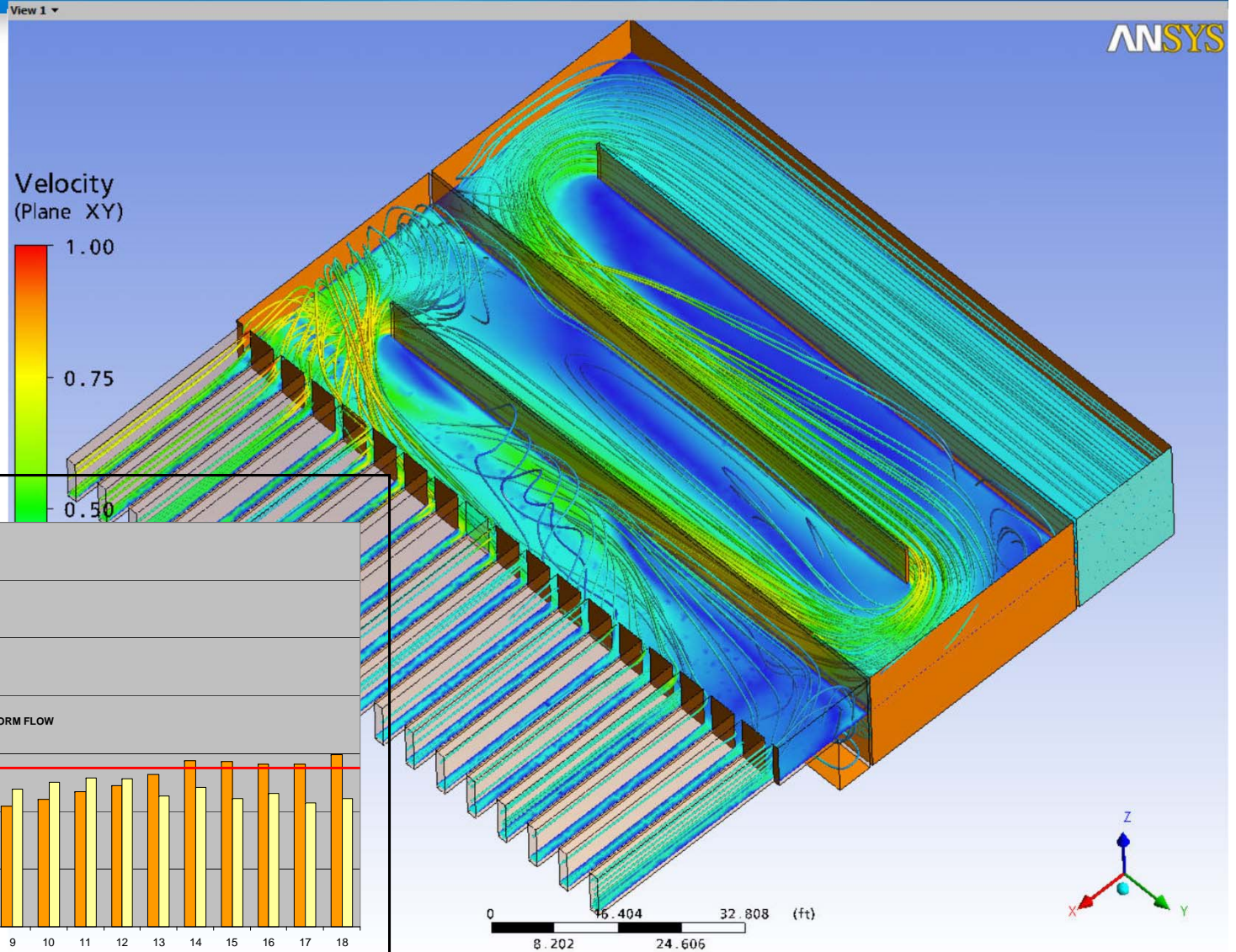
- Outlet 1
- Outlet 2
- Outlet 3
- Outlet 4
- Outlet 5
- Outlet 6
- Outlet 7
- Outlet 8



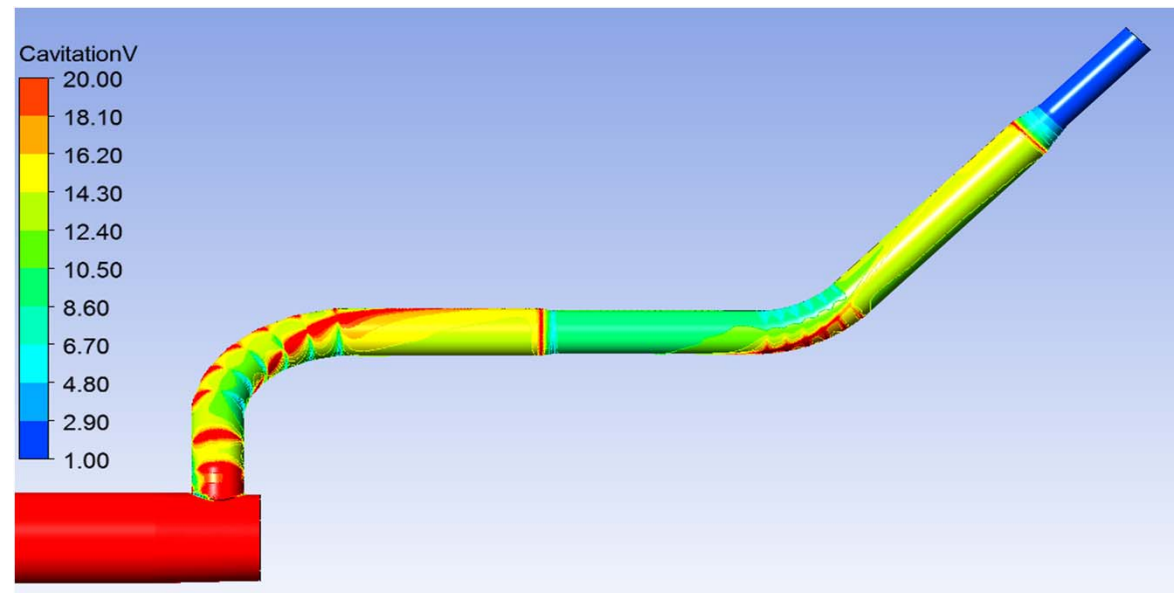
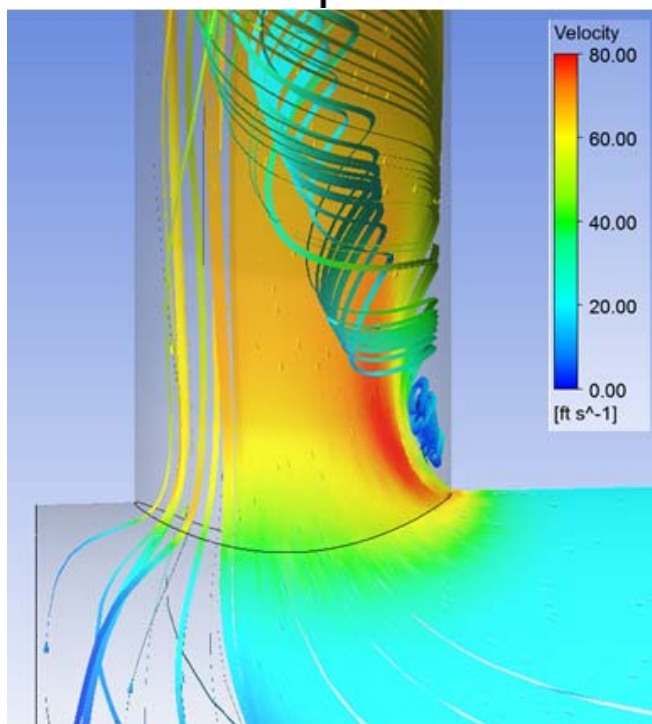
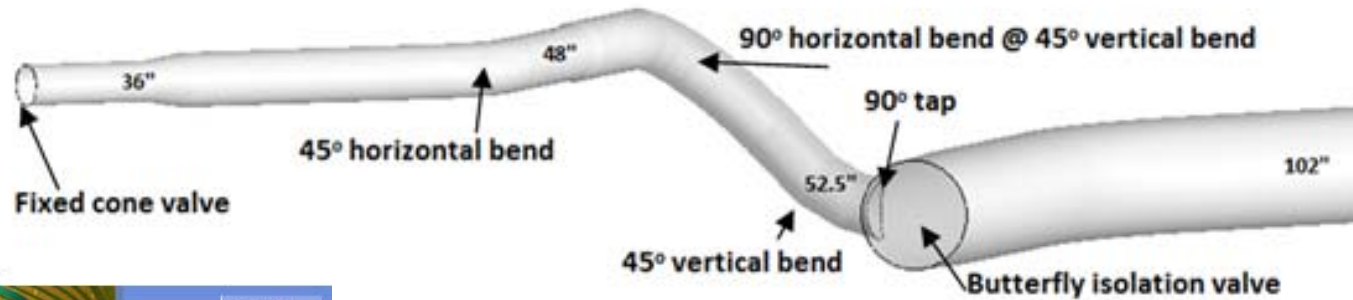
Color Contours of Mixing Characteristics



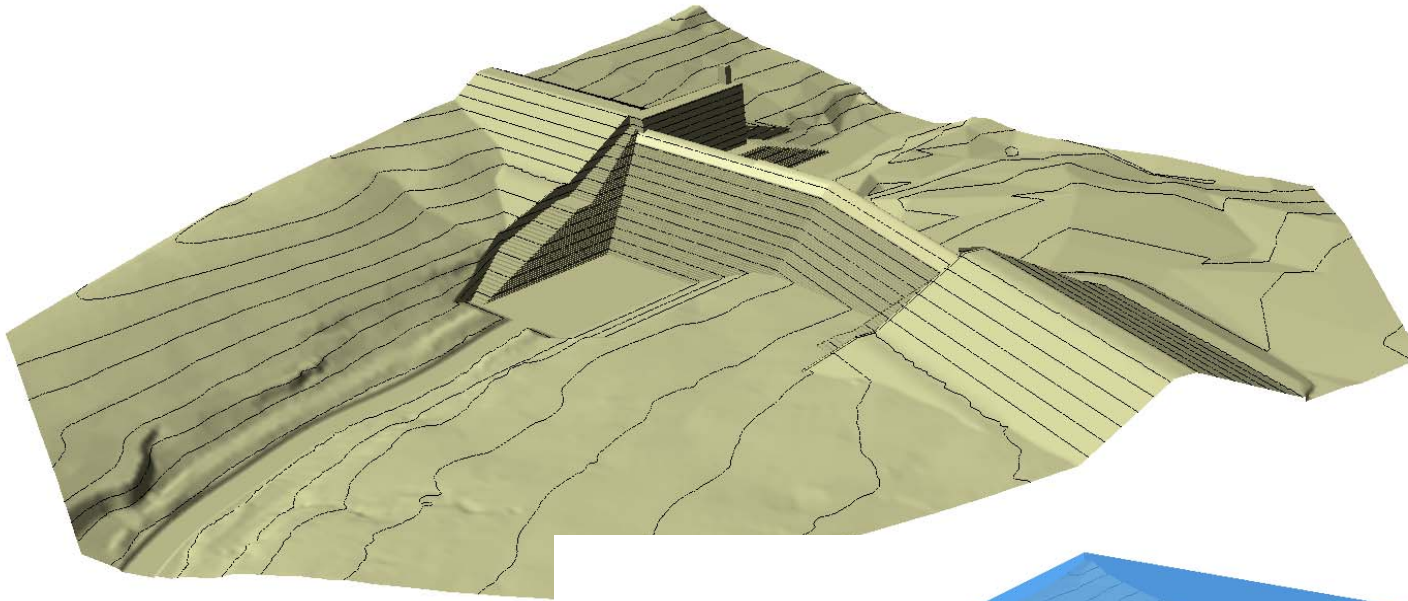
Flow Equalization Problems



Penstock Hydraulics and Cavitation

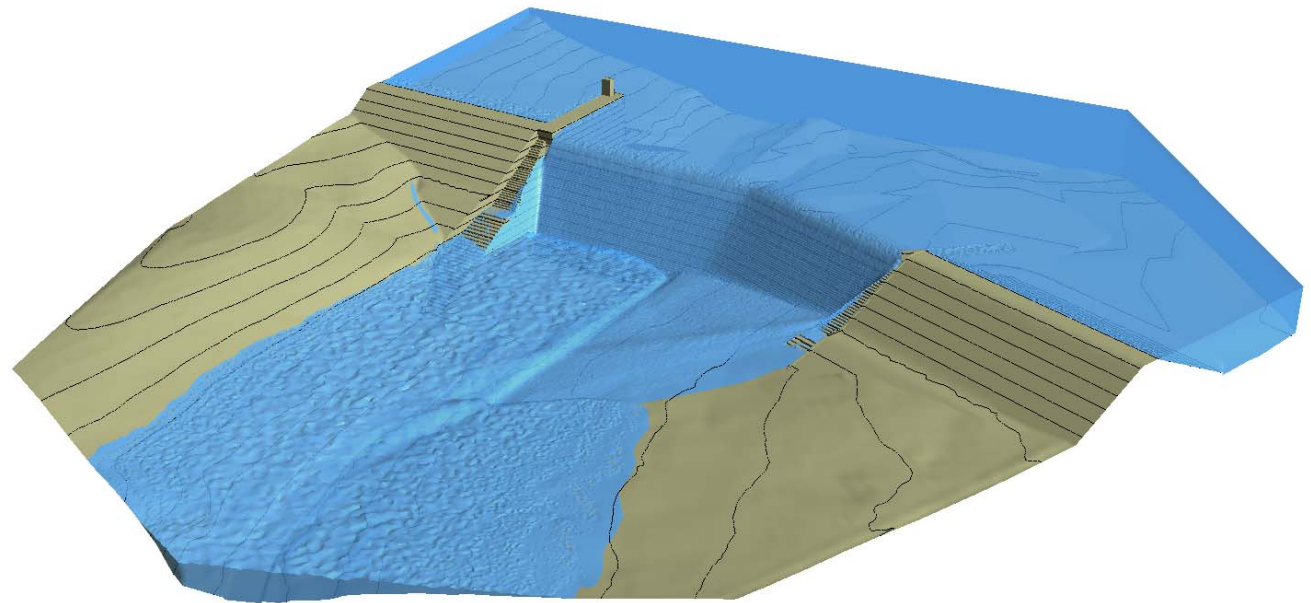


Reservoir Spillway and Stilling Basin

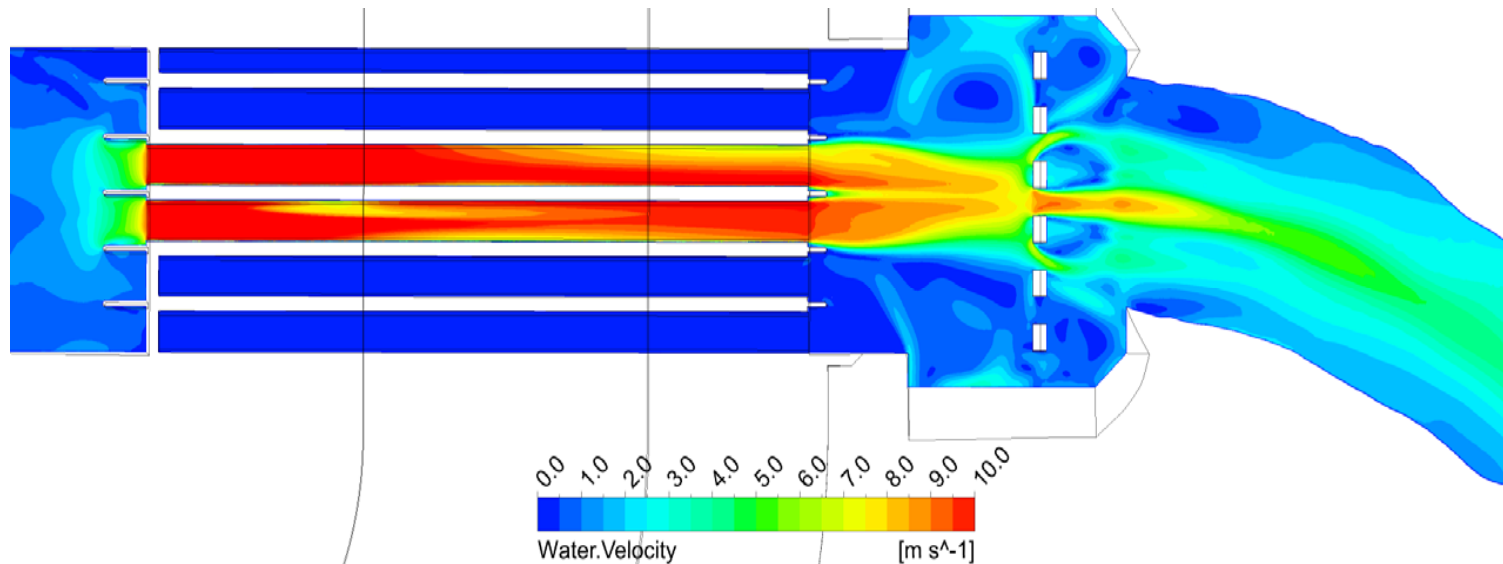
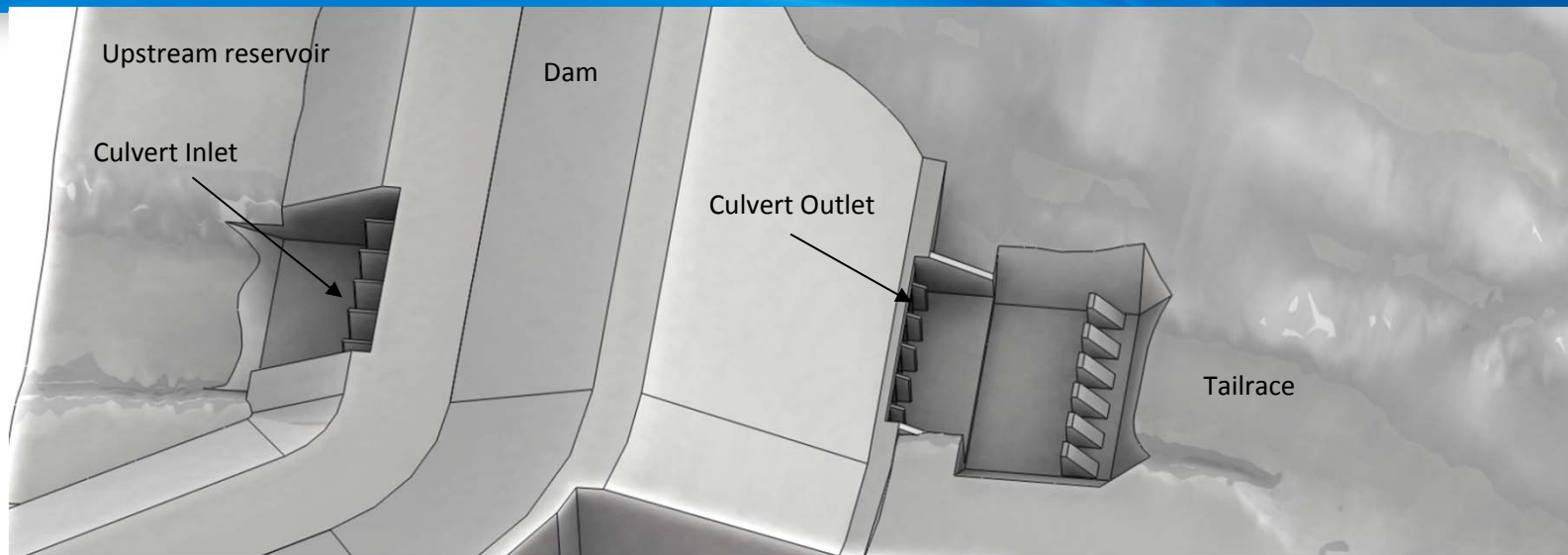


Dam and
topography

Water surface
during PMF

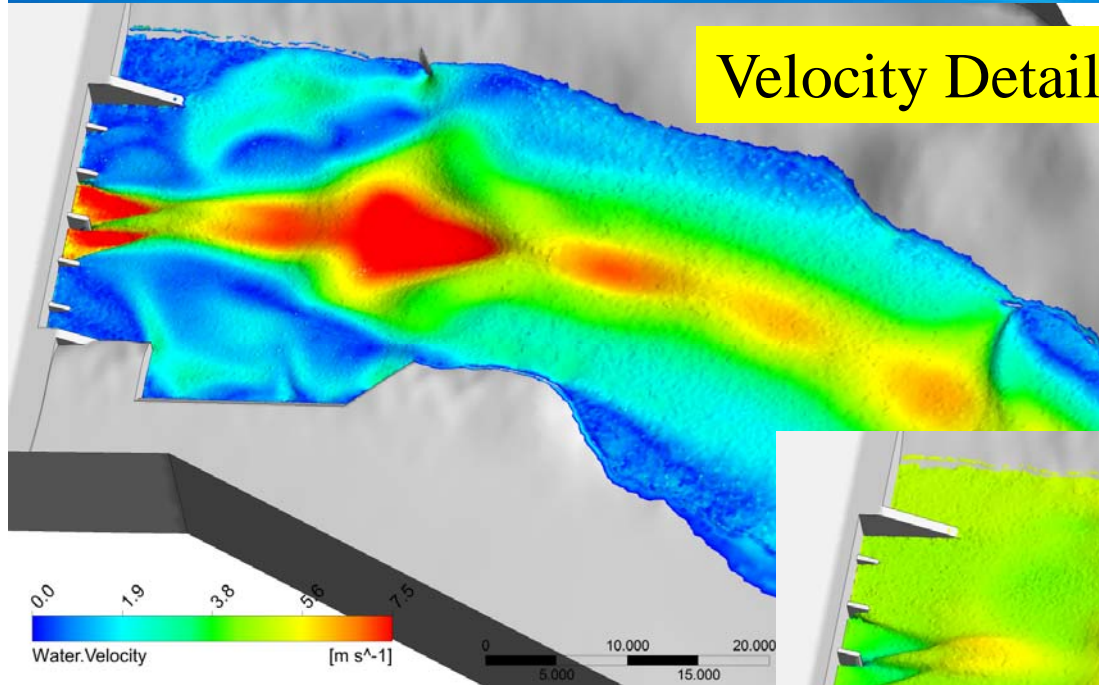


Reservoir Outlet Stilling Basin

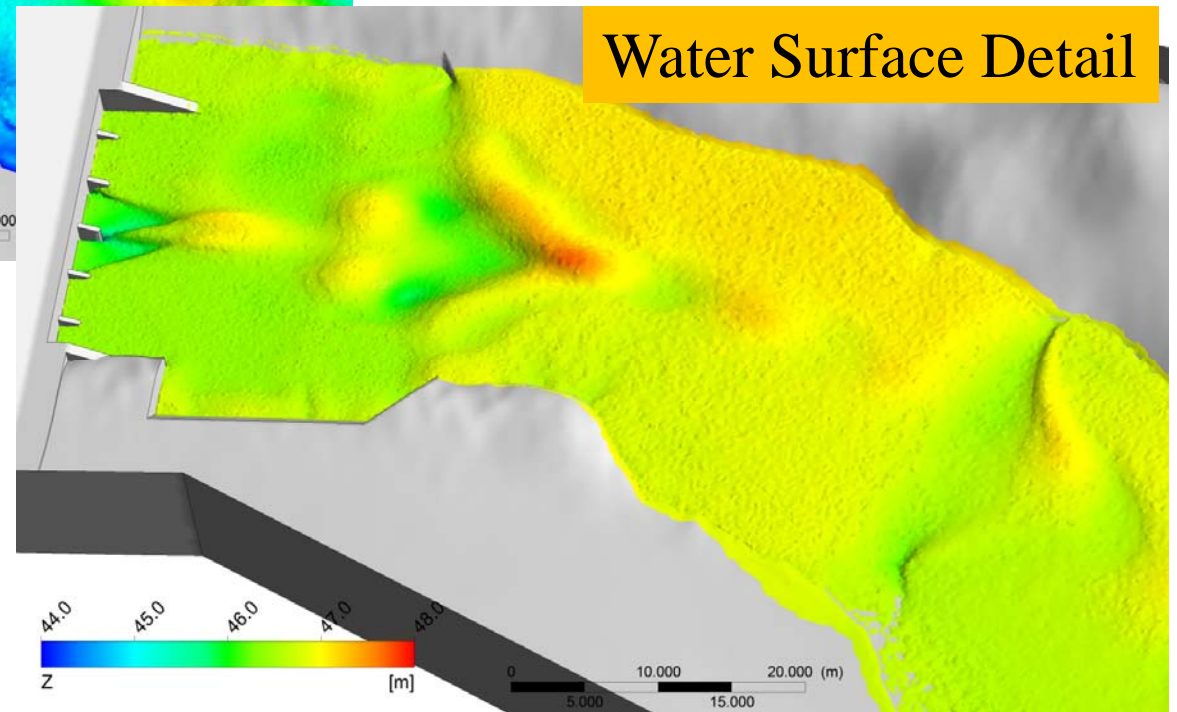


Reservoir Outlet Stilling Basin (Velocity and Water Surface Detail)

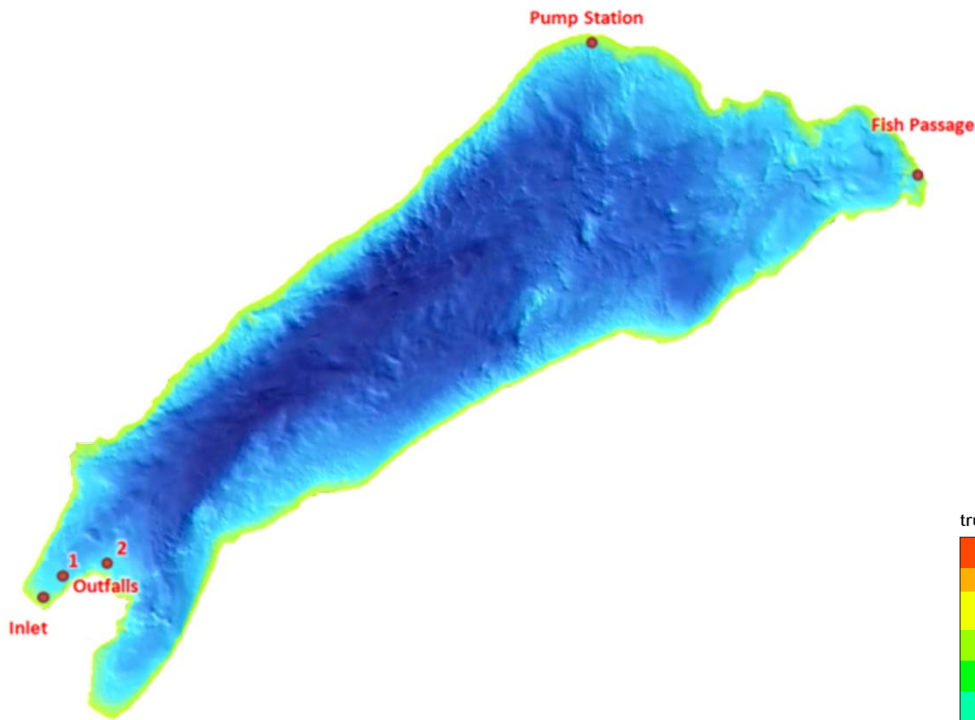
Velocity Detail



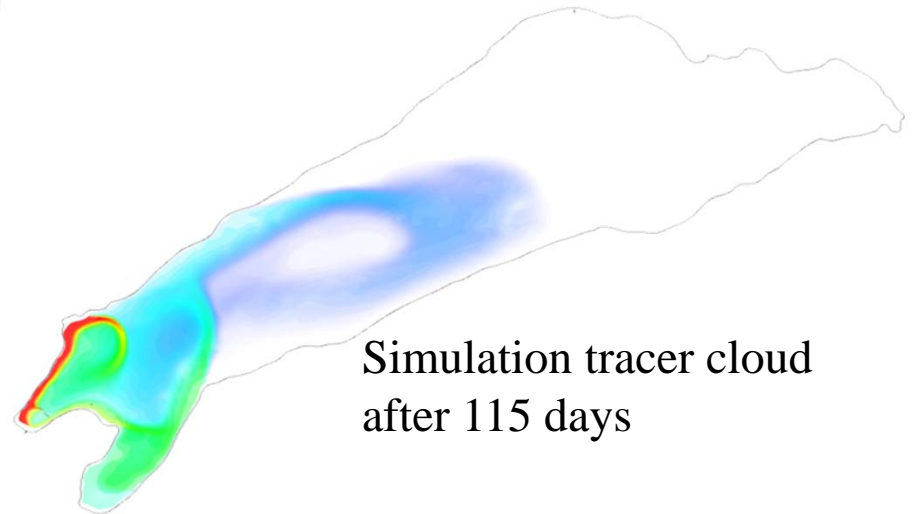
Water Surface Detail



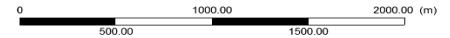
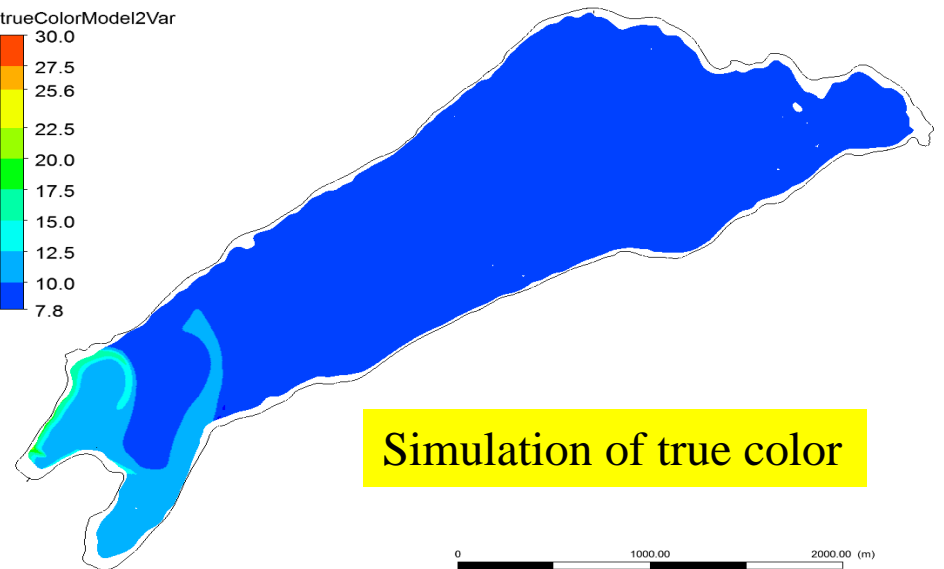
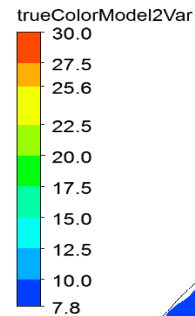
Lake Water Quality Study



Lake schematic flow boundaries.

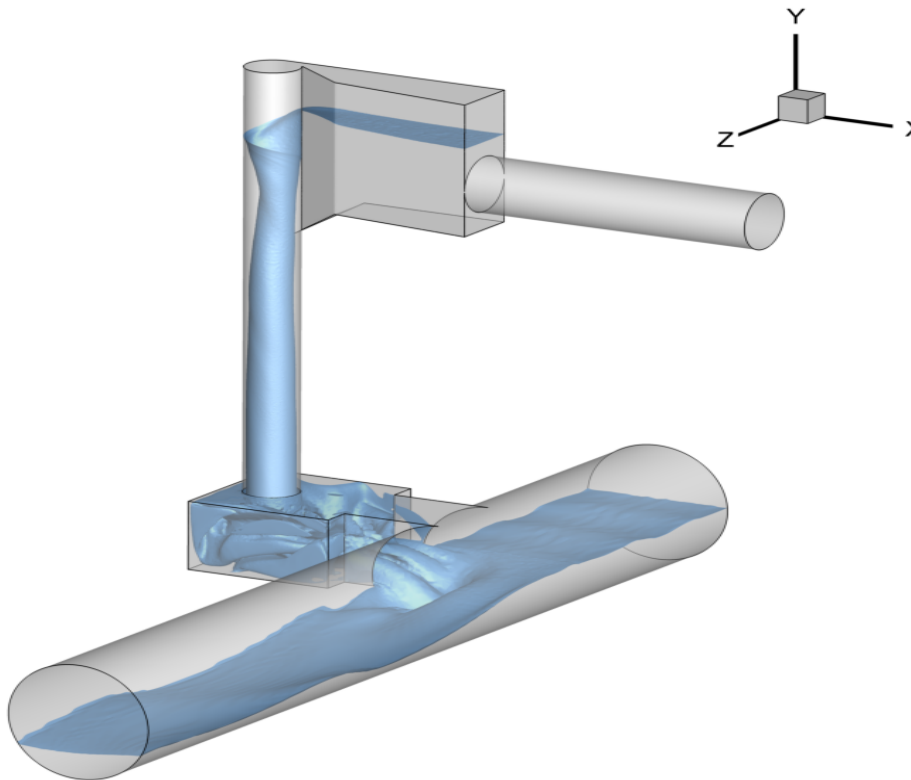


Simulation tracer cloud after 115 days



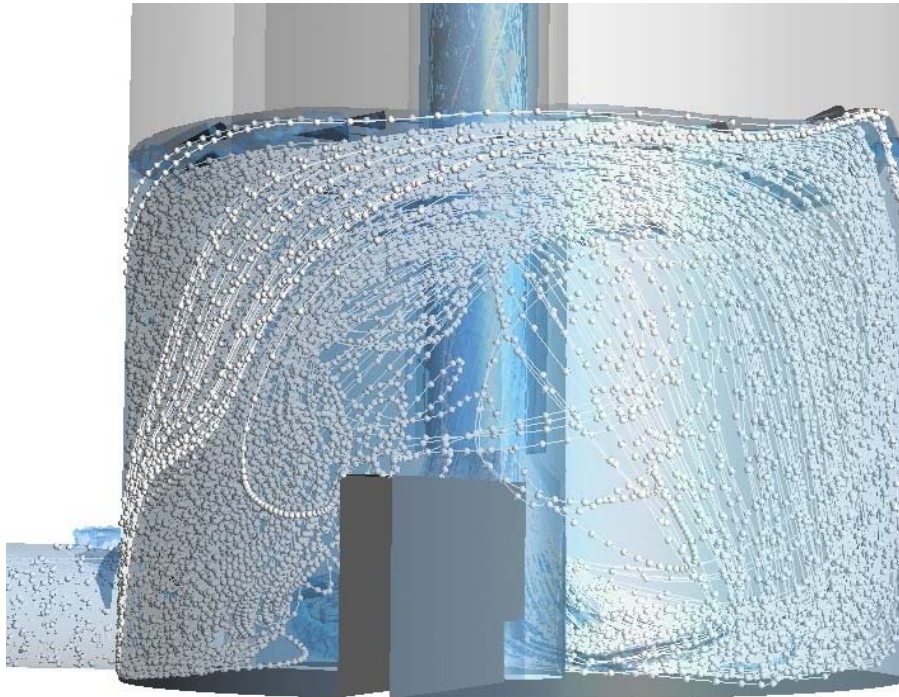
CFD as Physical Model Support

Initial Configuration with undesirable jet entering the tunnel



Revised Configuration based on CFD results

Bubble Tracking Comparison to Physical Model



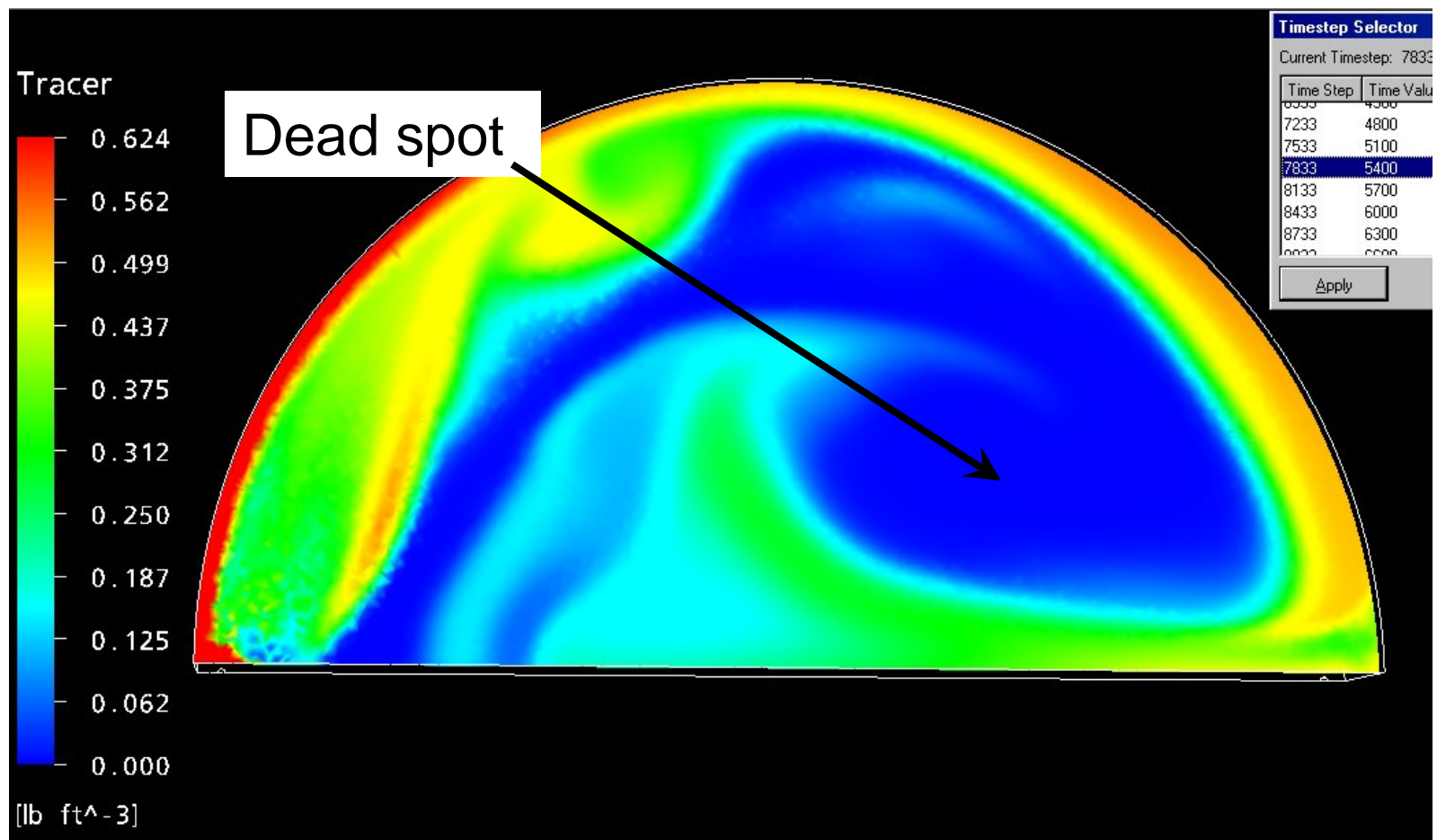
CFD



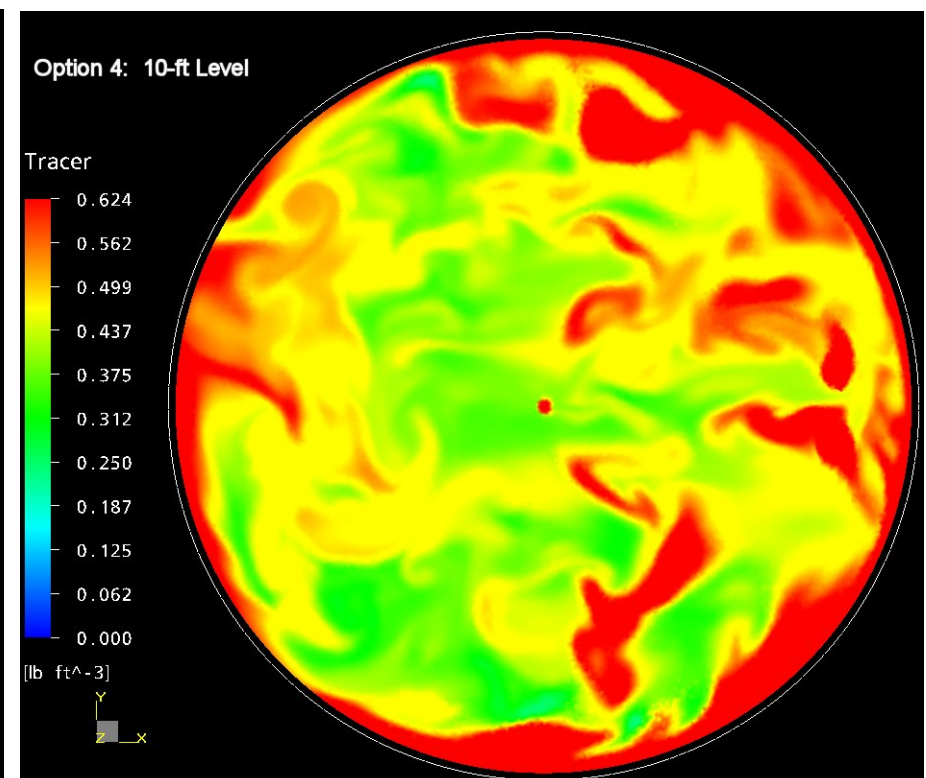
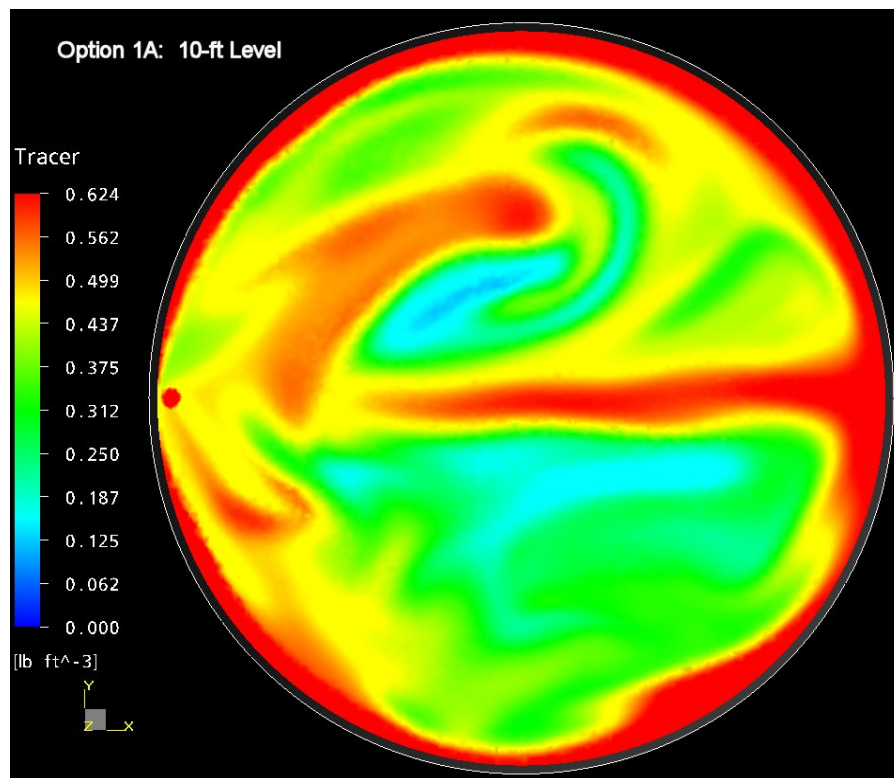
Physical Model

Storage Tank Hydraulics

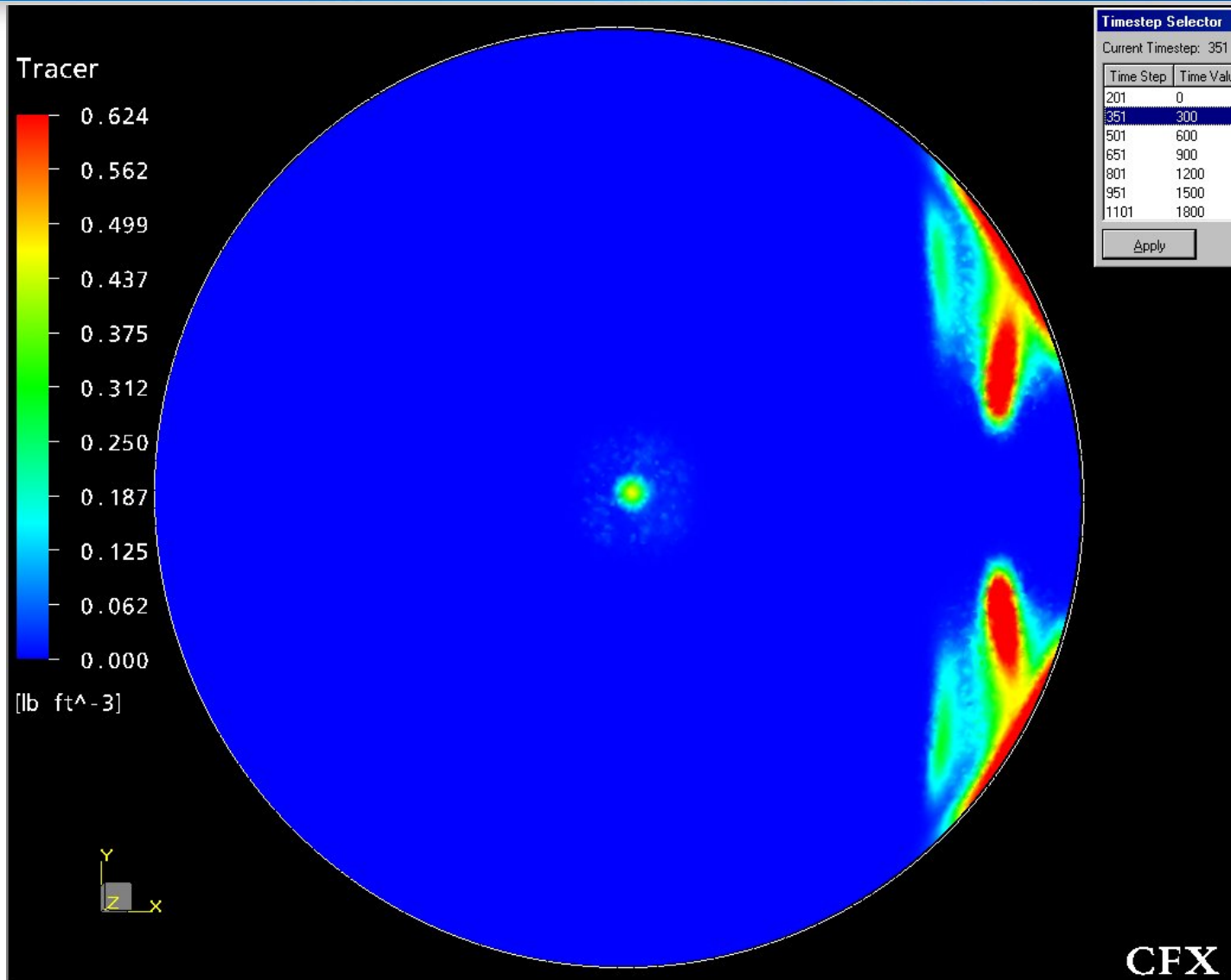
Promote good mixing and avoid dead zones
(T_{10} , water-age, baffling factor, efficiency)



Single Inlet vs. Multi Valve Inlet Option



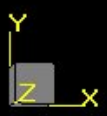
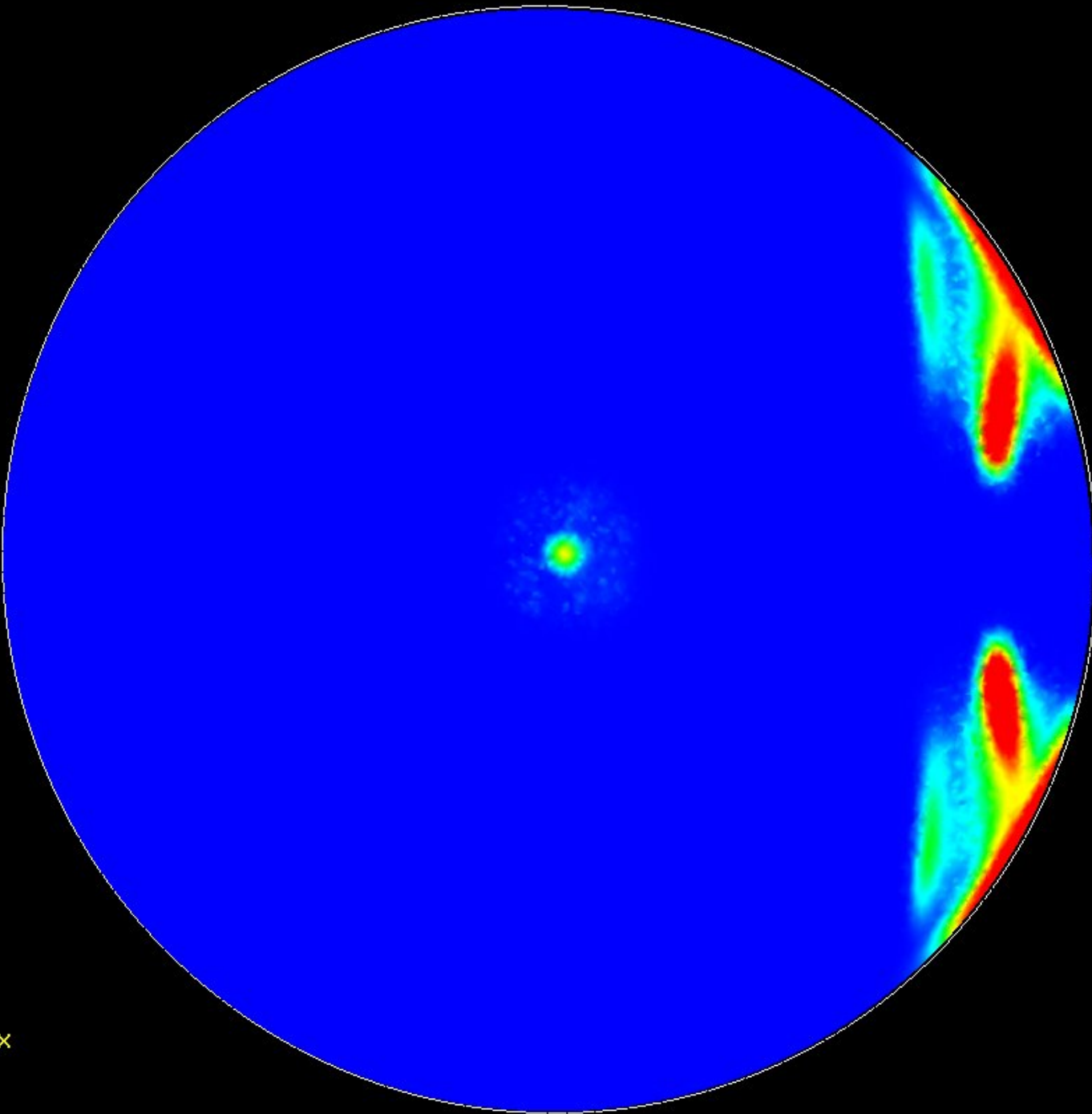
Time Sequence Slices for Multi Valve Option



Tracer



[lb ft⁻³]



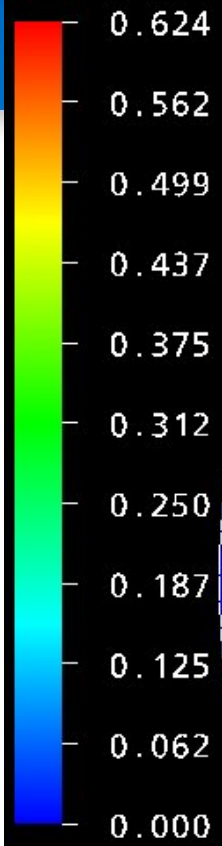
Timestep Selector

Current Timestep: 351

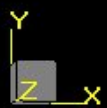
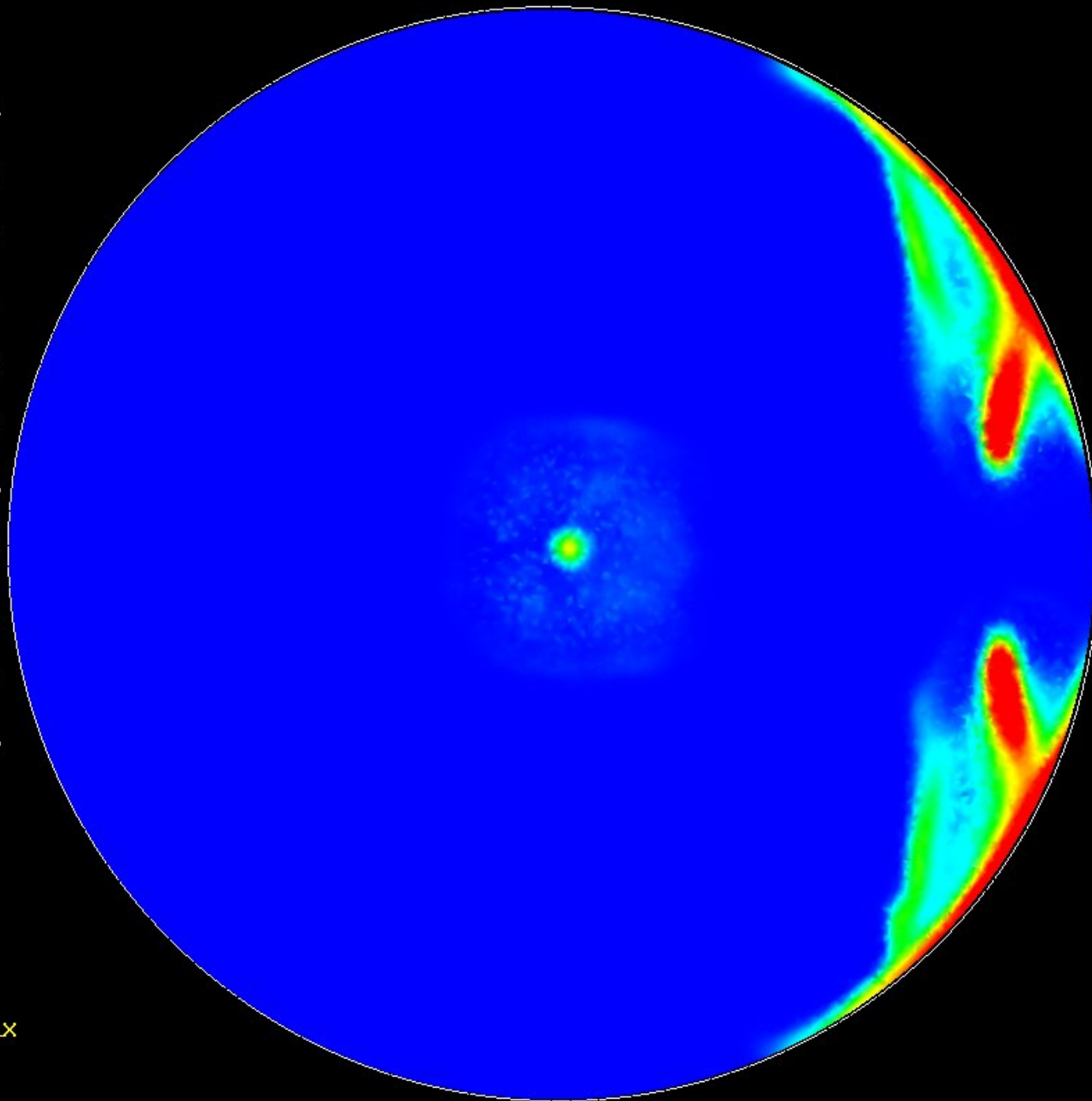
| Time Step | Time Value |
|-----------|------------|
| 201 | 0 |
| 351 | 300 |
| 501 | 600 |
| 651 | 900 |
| 801 | 1200 |
| 951 | 1500 |
| 1101 | 1800 |

Apply

Tracer



[lb ft⁻³]



Timestep Selector

Current Timestep: 501

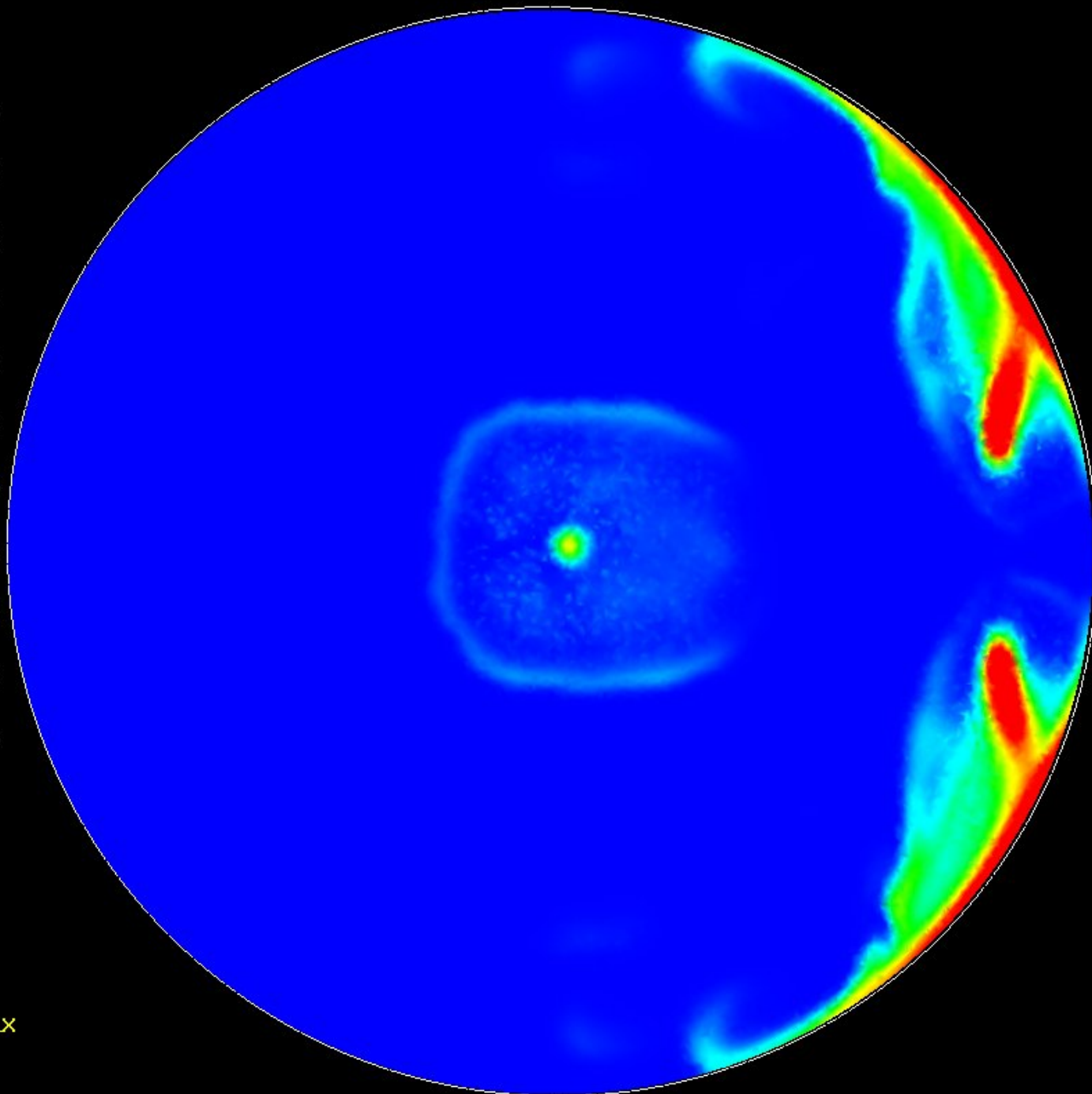
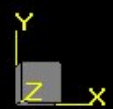
| Time Step | Time Value |
|-----------|------------|
| 201 | 0 |
| 351 | 300 |
| 501 | 600 |
| 651 | 900 |
| 801 | 1200 |
| 951 | 1500 |
| 1101 | 1800 |

Apply

Tracer



[lb ft⁻³]



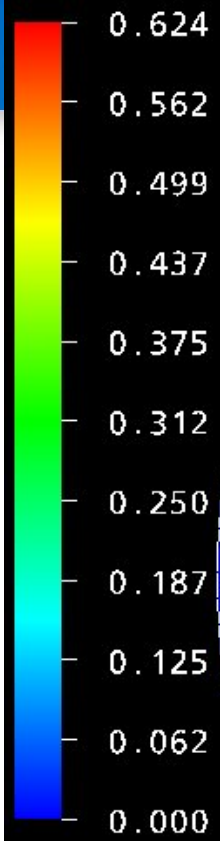
Timestep Selector

Current Timestep: 651

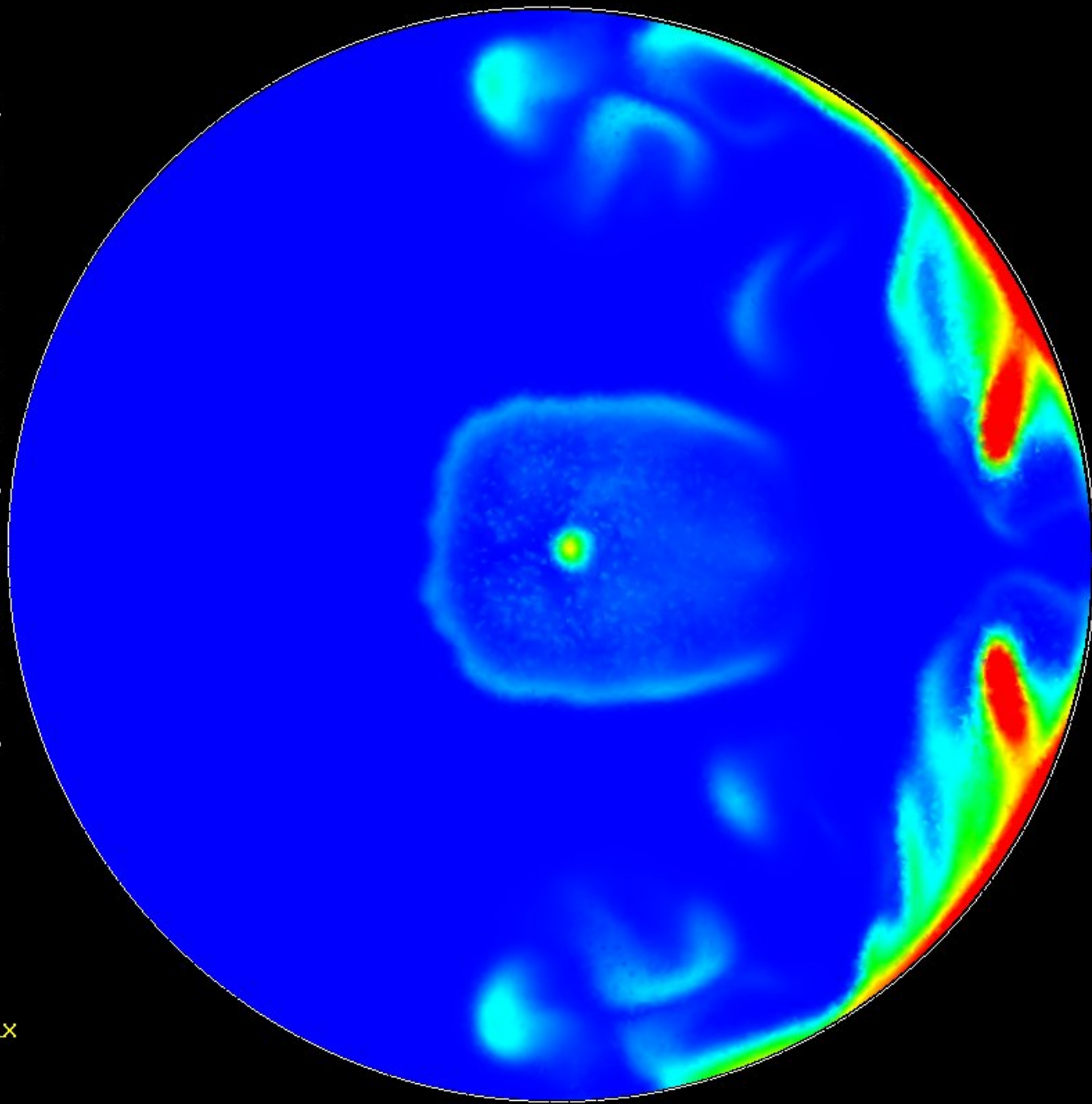
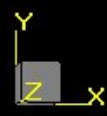
| Time Step | Time Value |
|-----------|------------|
| 201 | 0 |
| 351 | 300 |
| 501 | 600 |
| 651 | 900 |
| 801 | 1200 |
| 951 | 1500 |
| 1101 | 1800 |

Apply

Tracer



[lb ft⁻³]



Timestep Selector

Current Timestep: 801

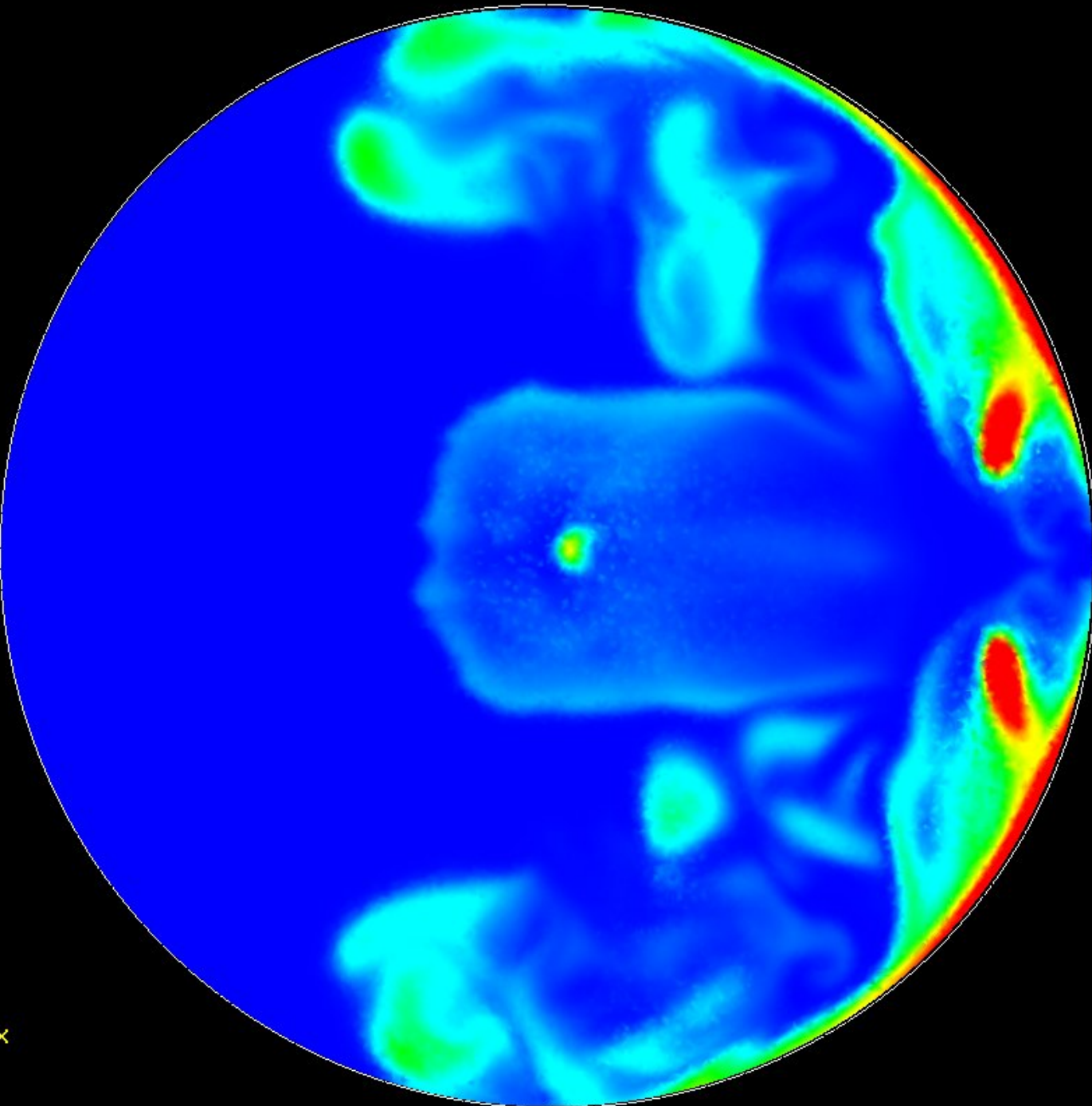
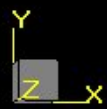
| Time Step | Time Value |
|-----------|------------|
| 201 | 0 |
| 351 | 300 |
| 501 | 600 |
| 651 | 900 |
| 801 | 1200 |
| 951 | 1500 |
| 1101 | 1800 |

Apply

Tracer



[lb ft⁻³]



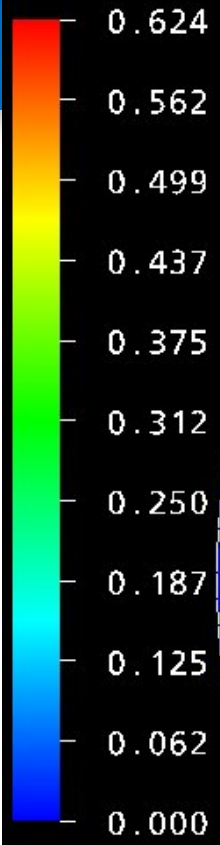
Timestep Selector

Current Timestep: 1107

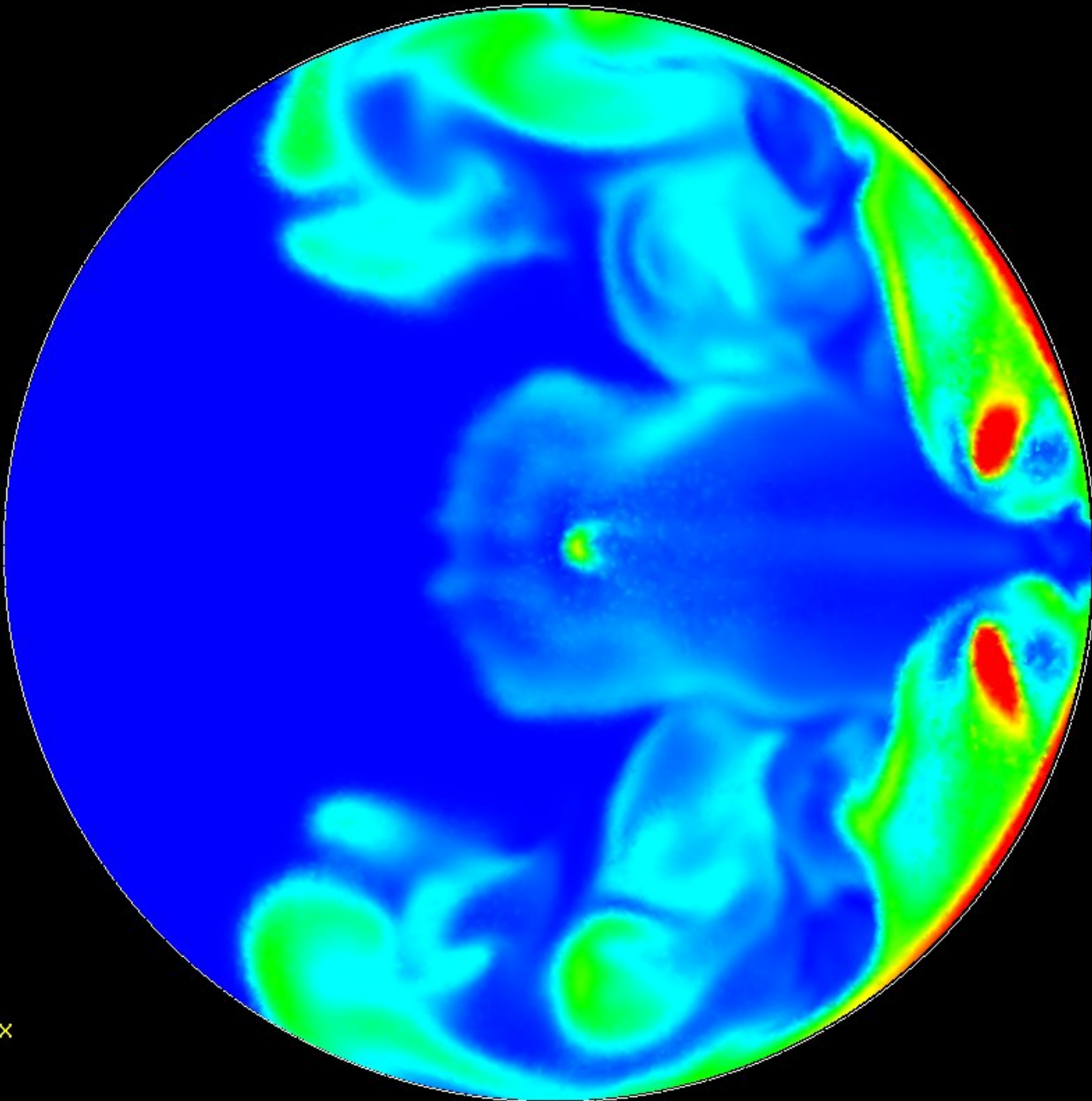
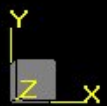
| Time Step | Time Value |
|-----------|------------|
| 951 | 1500 |
| 1101 | 1800 |
| 1251 | 2100 |
| 1401 | 2400 |
| 1551 | 2700 |
| 1701 | 3000 |
| 1704 | 3006 |

Apply

Tracer



[lb ft⁻³]



Timestep Selector

Current Timestep: 1401

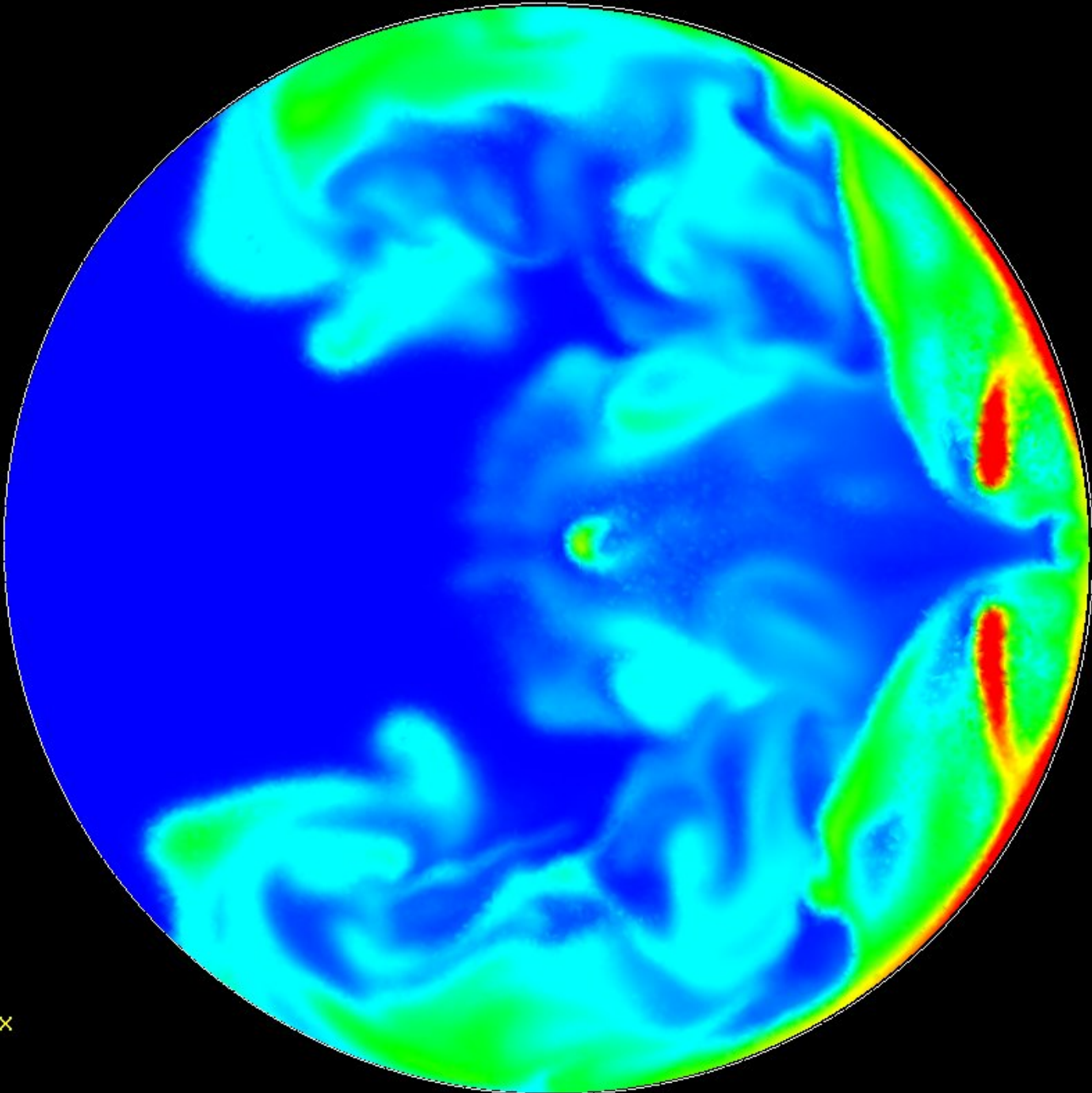
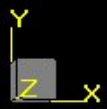
| Time Step | Time Value |
|-----------|------------|
| 951 | 1500 |
| 1101 | 1800 |
| 1251 | 2100 |
| 1401 | 2400 |
| 1551 | 2700 |
| 1701 | 3000 |
| 1704 | 3006 |

Apply

Tracer



[lb ft⁻³]



Timestep Selector

Current Timestep: 170

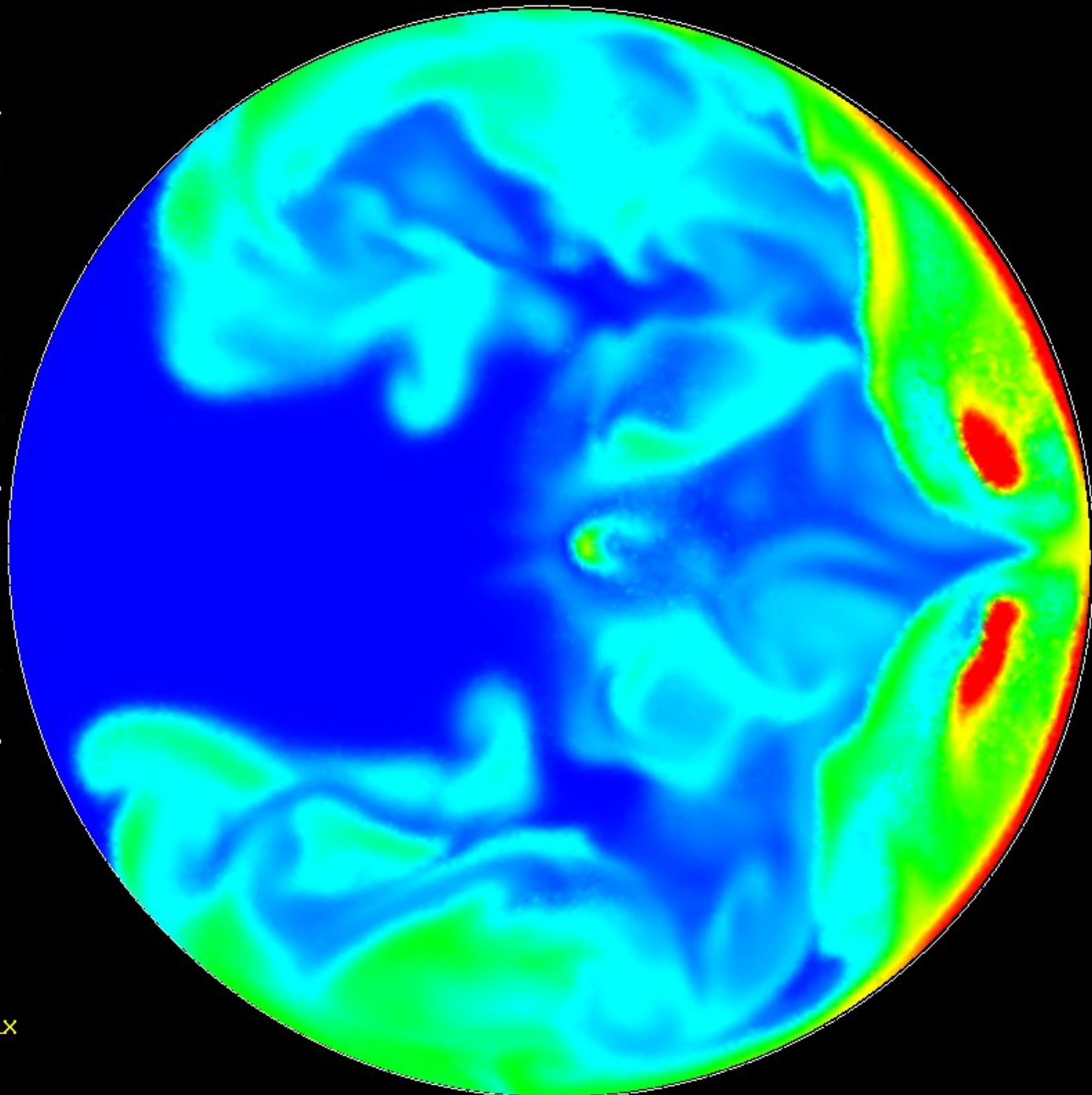
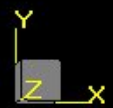
| Time Step | Time Val |
|-----------|----------|
| 1704 | 3006 |
| 1854 | 3306 |
| 2004 | 3606 |
| 2154 | 3906 |
| 2304 | 4206 |
| 2454 | 4506 |
| 2604 | 4806 |

Apply

Tracer



[lb ft⁻³]



Timestep Selector

Current Timestep: 200

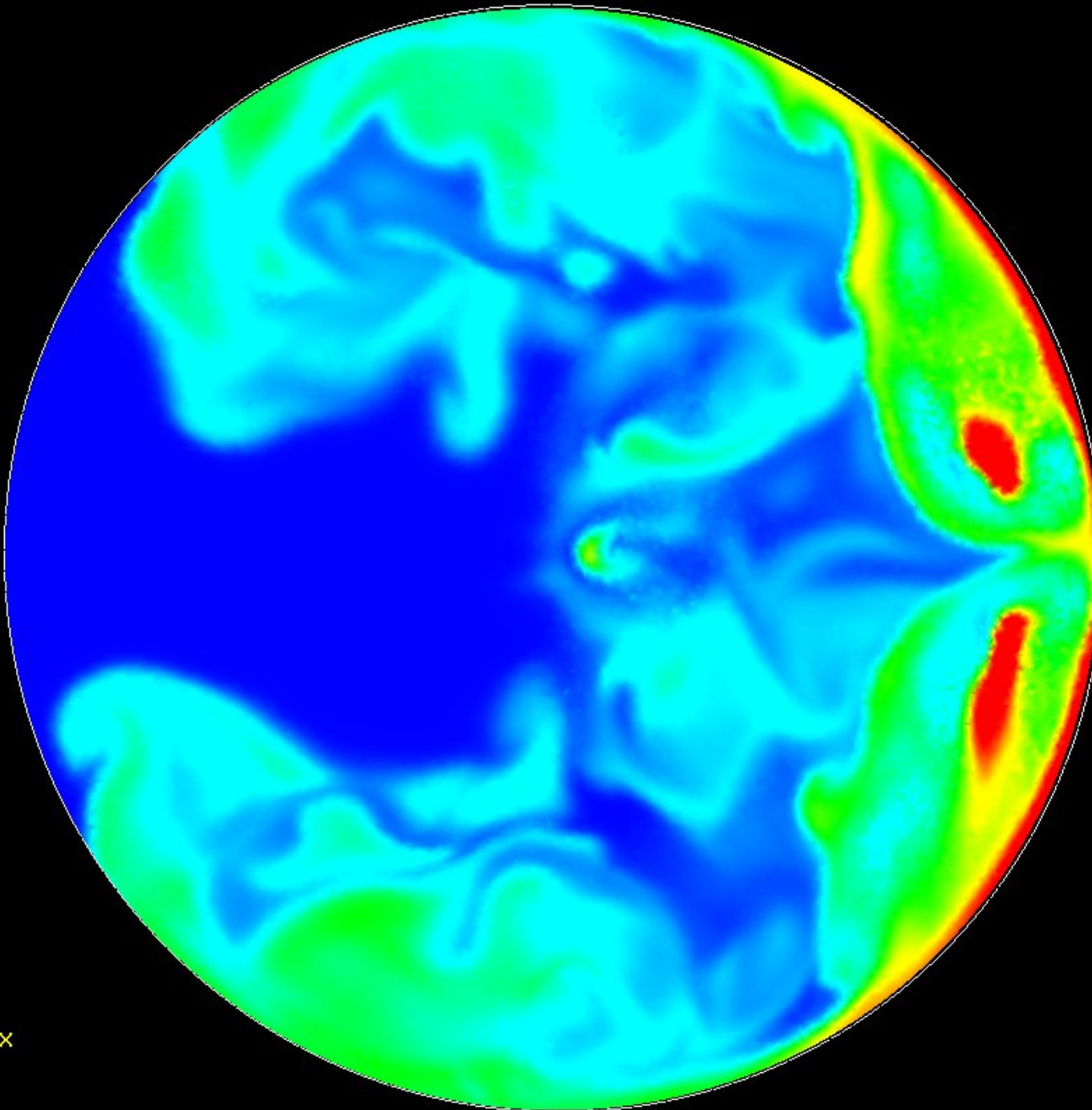
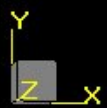
| Time Step | Time Val |
|-----------|----------|
| 1704 | 3006 |
| 1854 | 3306 |
| 2004 | 3606 |
| 2154 | 3906 |
| 2304 | 4206 |
| 2454 | 4506 |
| 2604 | 4806 |

Apply

Tracer



[lb ft⁻³]



Timestep Selector

Current Timestep: 2154

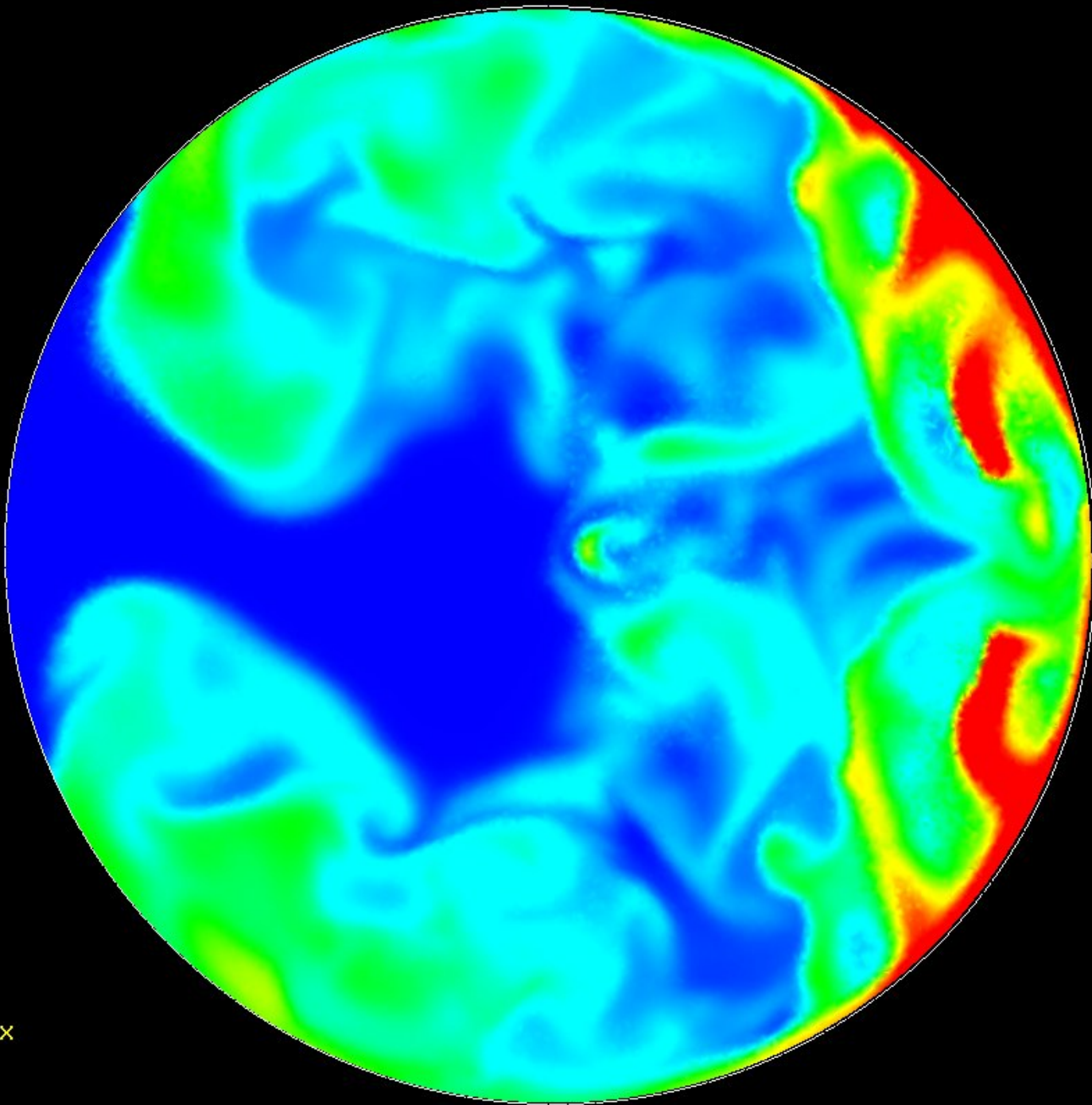
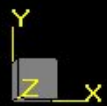
| Time Step | Time Value |
|-----------|------------|
| 2154 | 3906 |
| 2304 | 4206 |
| 2454 | 4506 |
| 2604 | 4806 |
| 2754 | 5106 |
| 2904 | 5406 |
| 2928 | 5454 |

Apply

Tracer



[lb ft⁻³]



Timestep Selector

Current Timestep: 2454

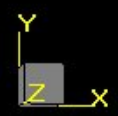
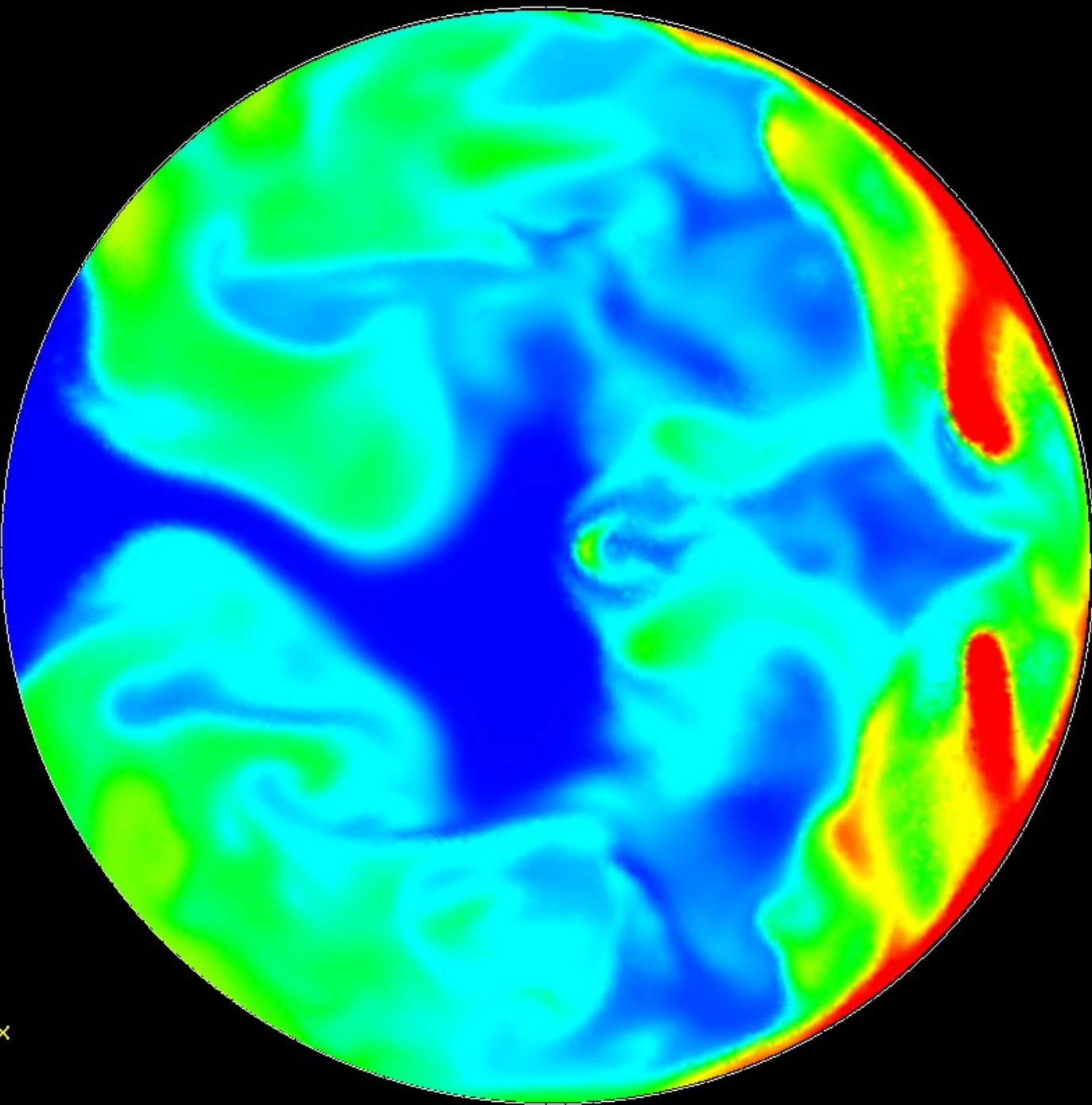
| Time Step | Time Value |
|-----------|------------|
| 2154 | 3906 |
| 2304 | 4206 |
| 2454 | 4506 |
| 2604 | 4806 |
| 2754 | 5106 |
| 2904 | 5406 |
| 2928 | 5454 |

Apply

Tracer



[lb ft⁻³]



Timestep Selector

Current Timestep: 2754

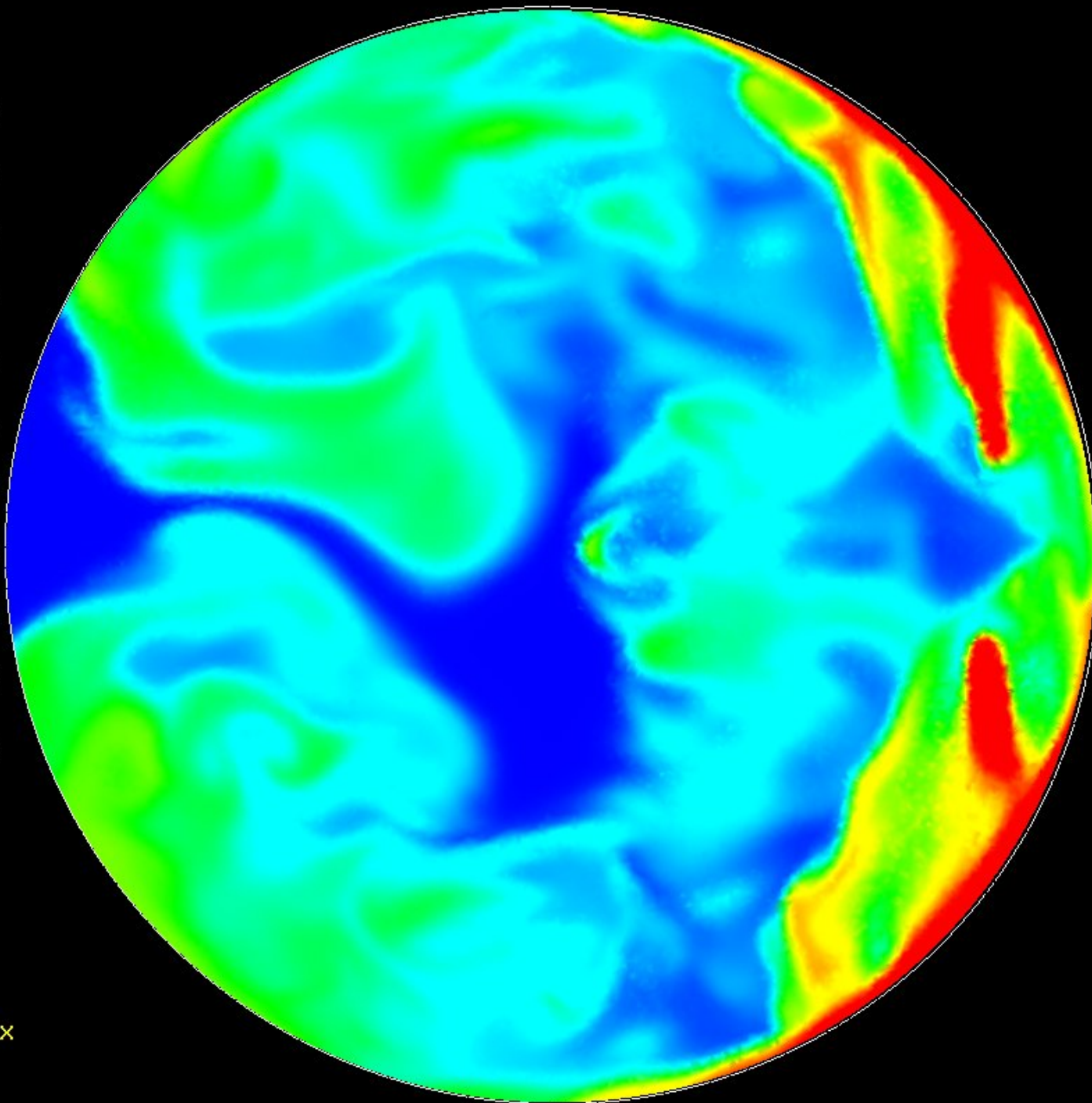
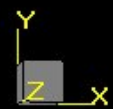
| Time Step | Time Value |
|-----------|------------|
| 2154 | 3906 |
| 2304 | 4206 |
| 2454 | 4506 |
| 2604 | 4806 |
| 2754 | 5106 |
| 2904 | 5406 |
| 2928 | 5454 |

Apply

Tracer



$[\text{lb ft}^{-3}]$



Timestep Selector

Current Timestep: 2928

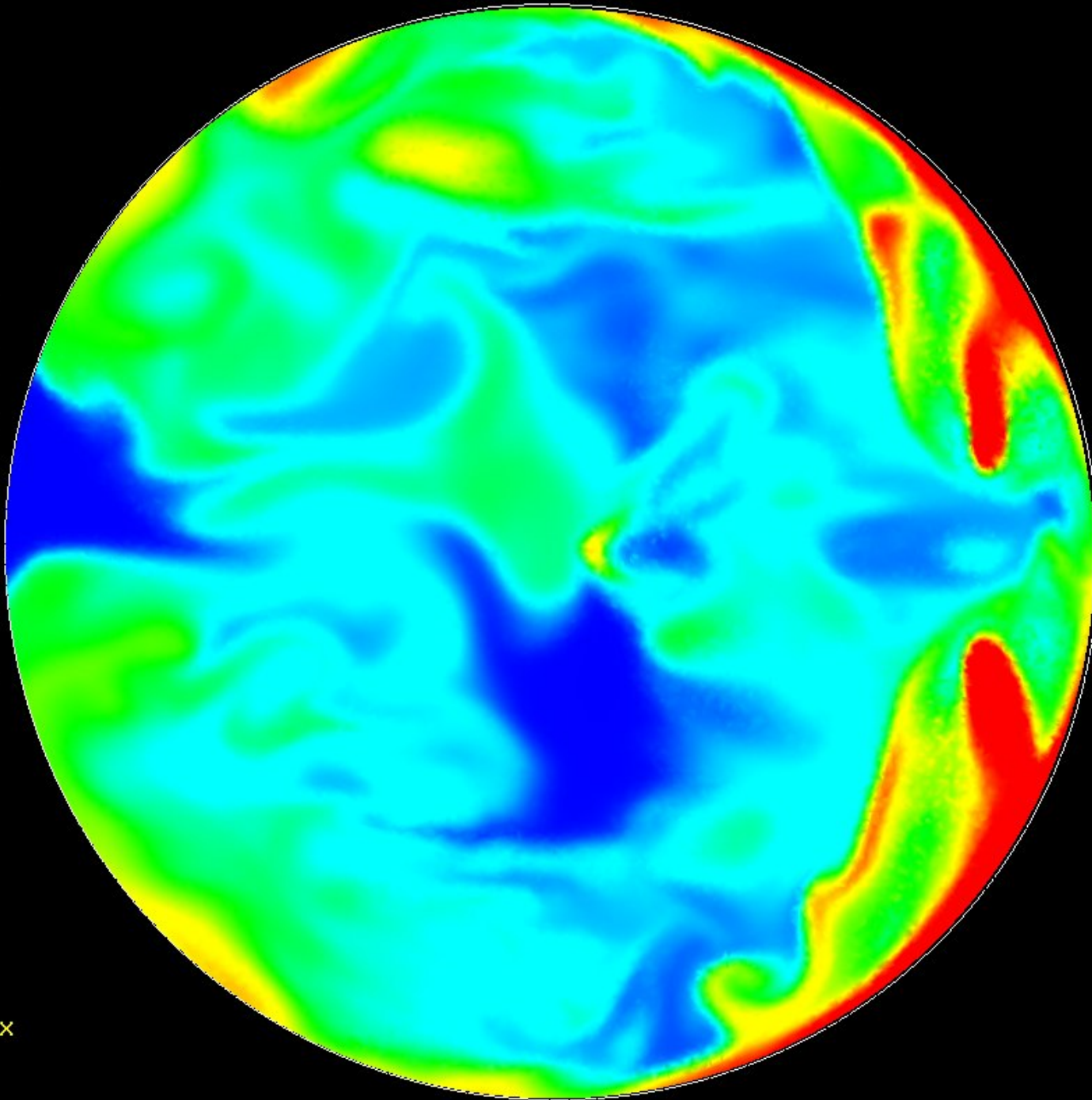
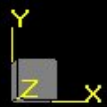
| Time Step | Time Value |
|-----------|------------|
| 2928 | 5450 |
| 3078 | 5750 |
| 3228 | 6050 |
| 3378 | 6350 |
| 3528 | 6650 |
| 3678 | 6950 |
| 3828 | 7250 |

Apply

Tracer



[lb ft⁻³]



Timestep Selector

Current Timestep: 3228

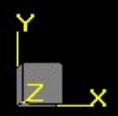
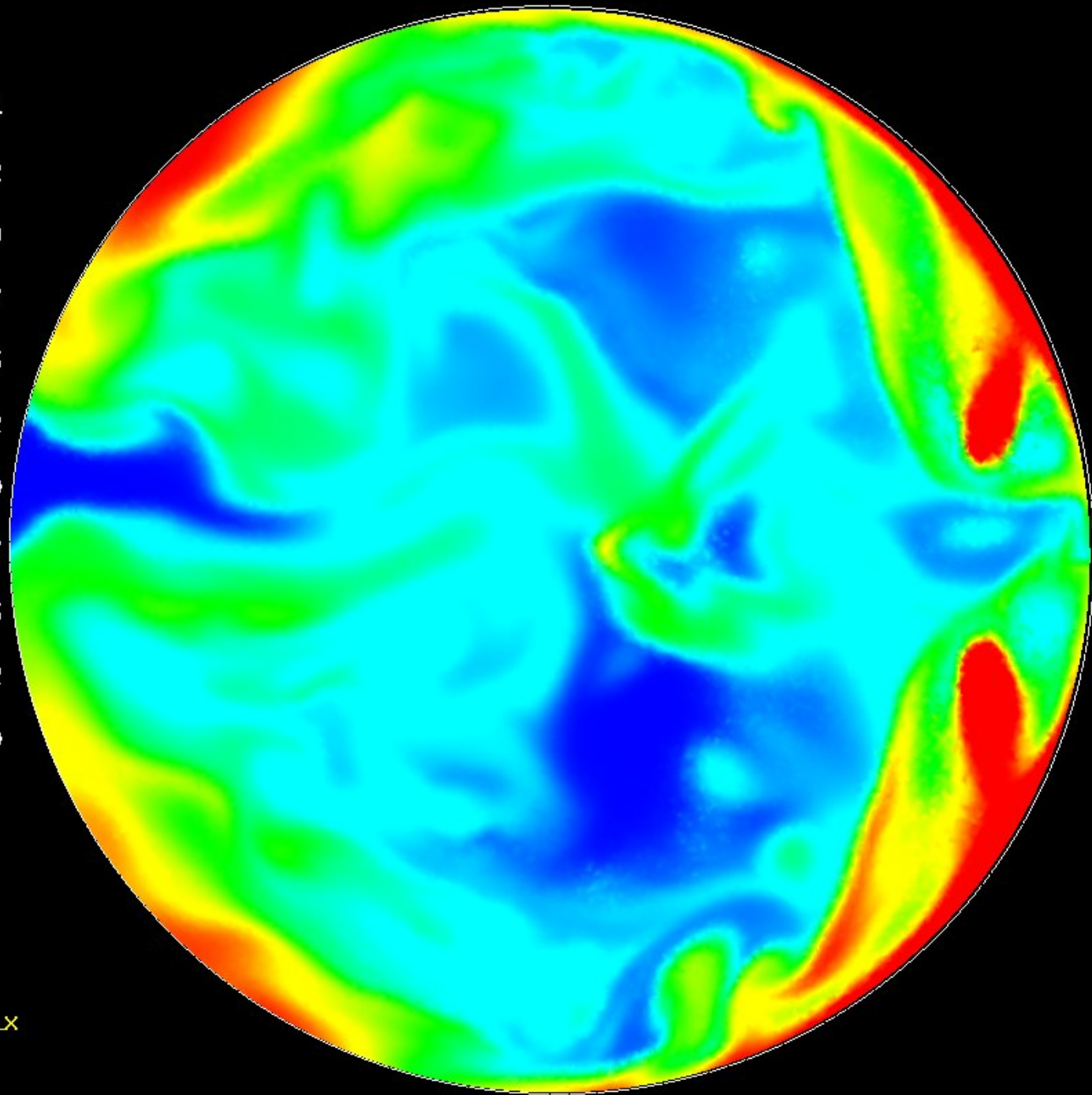
| Time Step | Time Value |
|-----------|------------|
| 2928 | 5450 |
| 3078 | 5750 |
| 3228 | 6050 |
| 3378 | 6350 |
| 3528 | 6650 |
| 3678 | 6950 |
| 3828 | 7250 |

Apply

Tracer



[lb ft⁻³]



Timestep Selector

Current Timestep: 3528

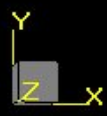
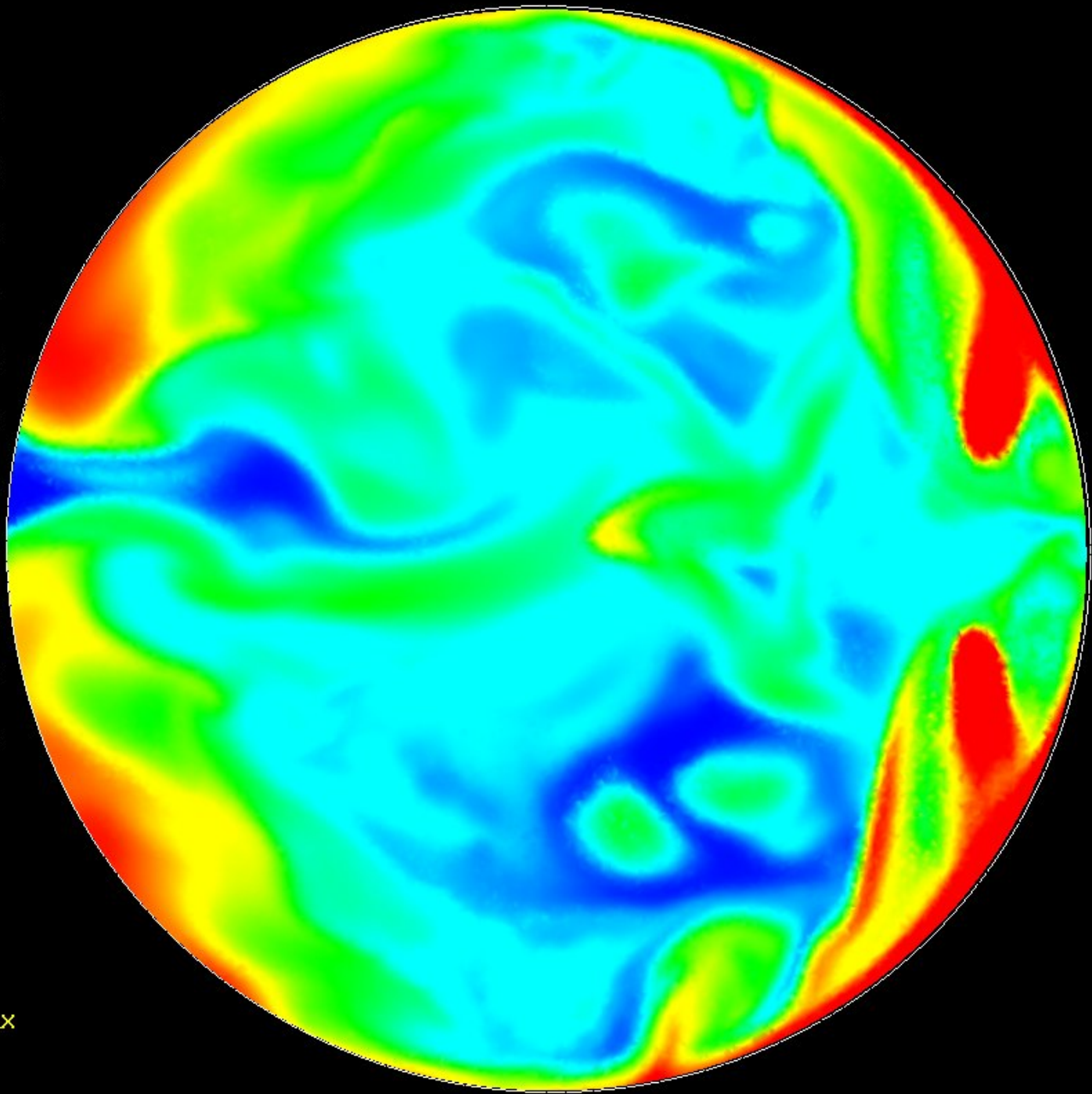
| Time Step | Time Value |
|-----------|------------|
| 2928 | 5450 |
| 3078 | 5750 |
| 3228 | 6050 |
| 3378 | 6350 |
| 3528 | 6650 |
| 3678 | 6950 |
| 3828 | 7250 |

Apply

Tracer



[lb ft⁻³]



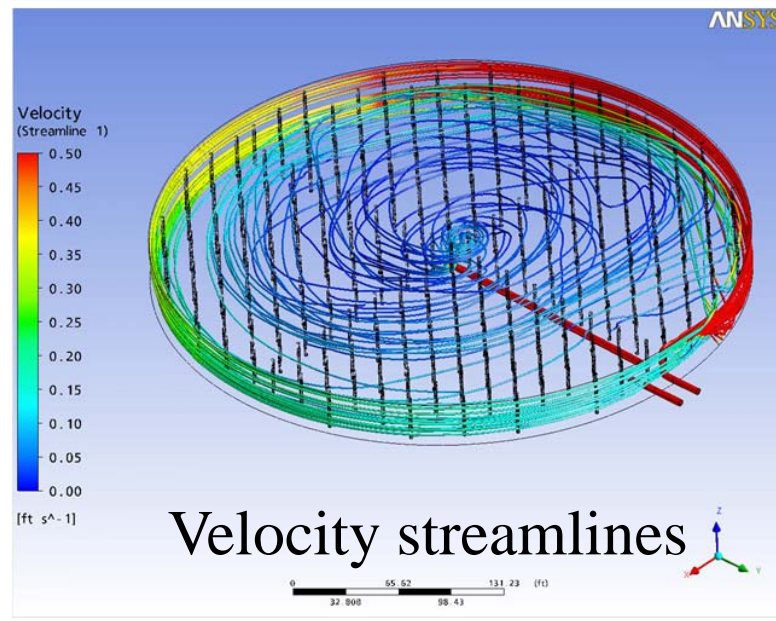
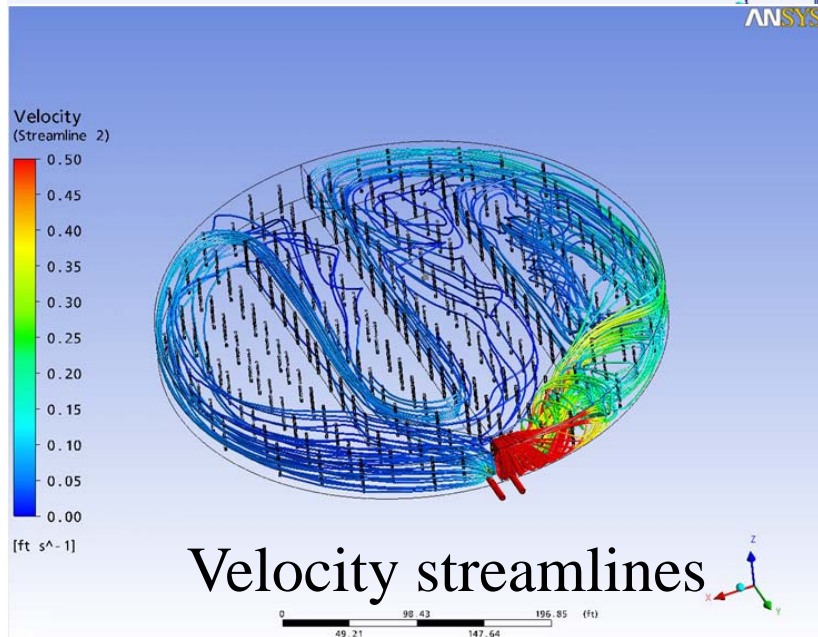
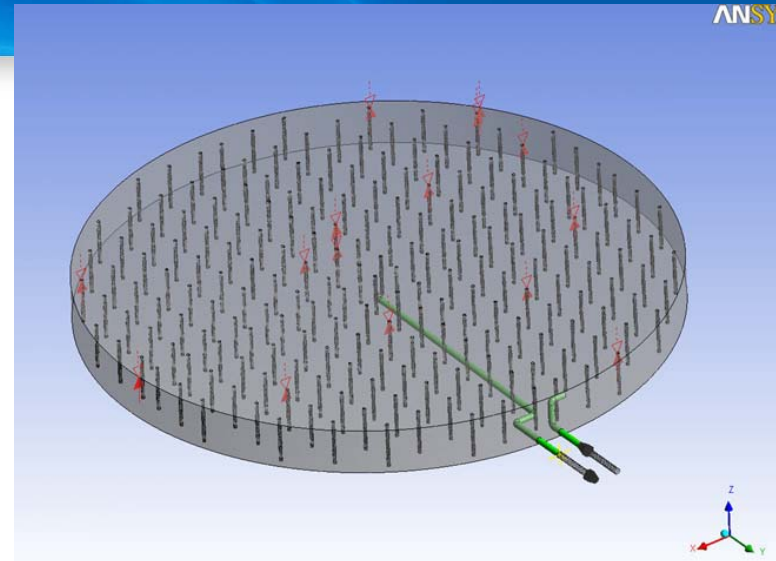
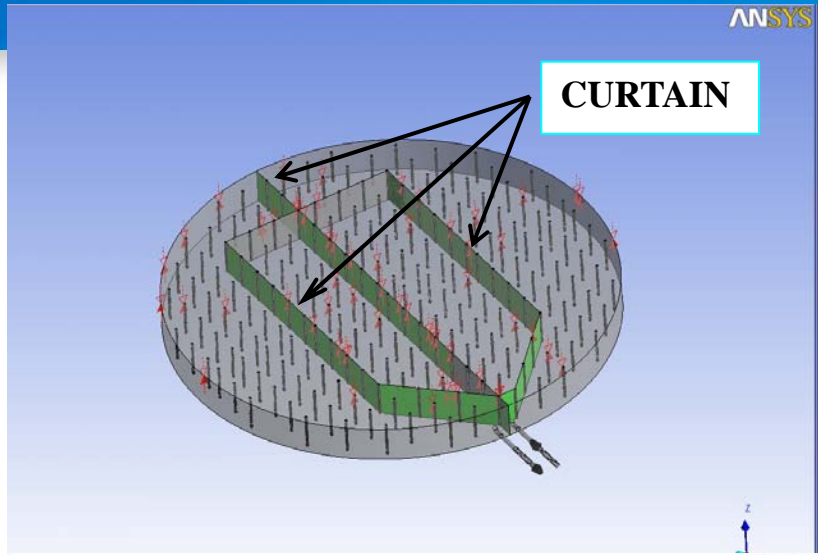
Timestep Selector

Current Timestep: 3828

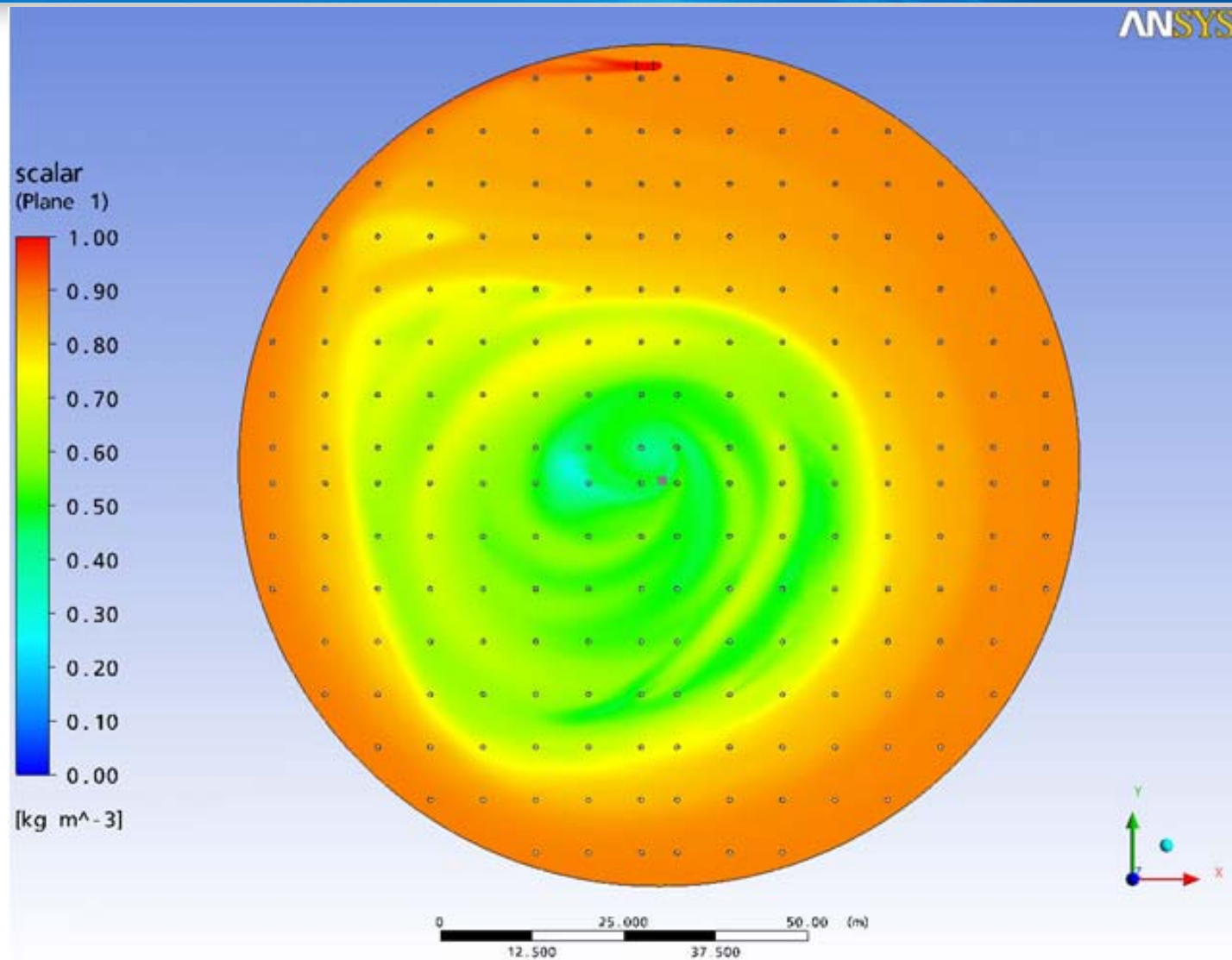
| Time Step | Time Value |
|-----------|------------|
| 2928 | 5450 |
| 3078 | 5750 |
| 3228 | 6050 |
| 3378 | 6350 |
| 3528 | 6650 |
| 3678 | 6950 |
| 3828 | 7250 |

Apply

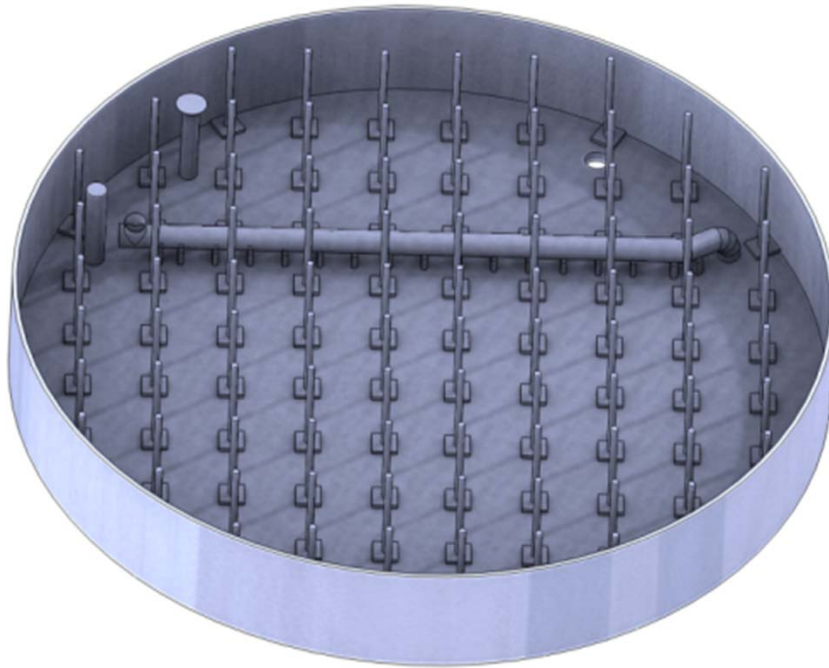
Compare Configuration Alternatives



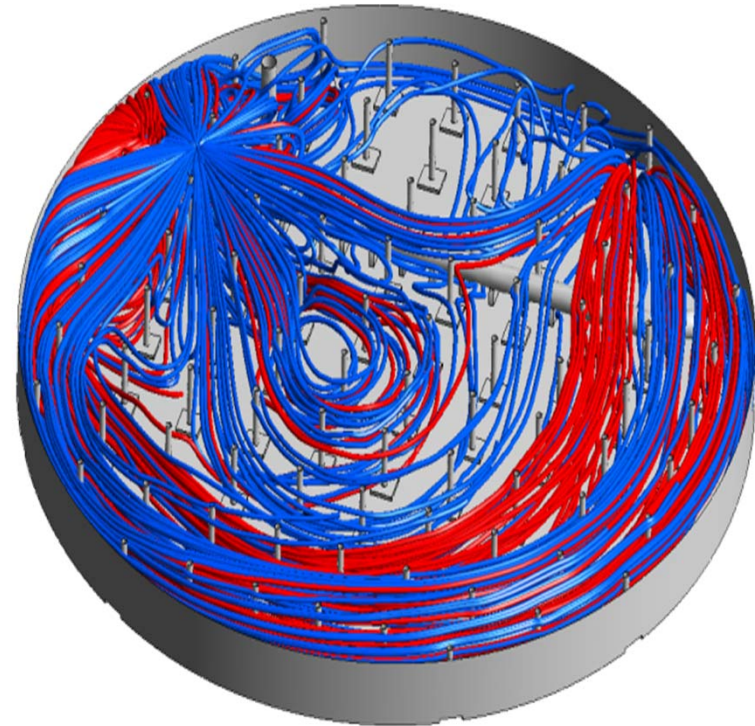
Tracer Simulation to Determine Efficiency ($T_{10}/T_{residence}$)



Dual-Source Reservoir Inlet Example



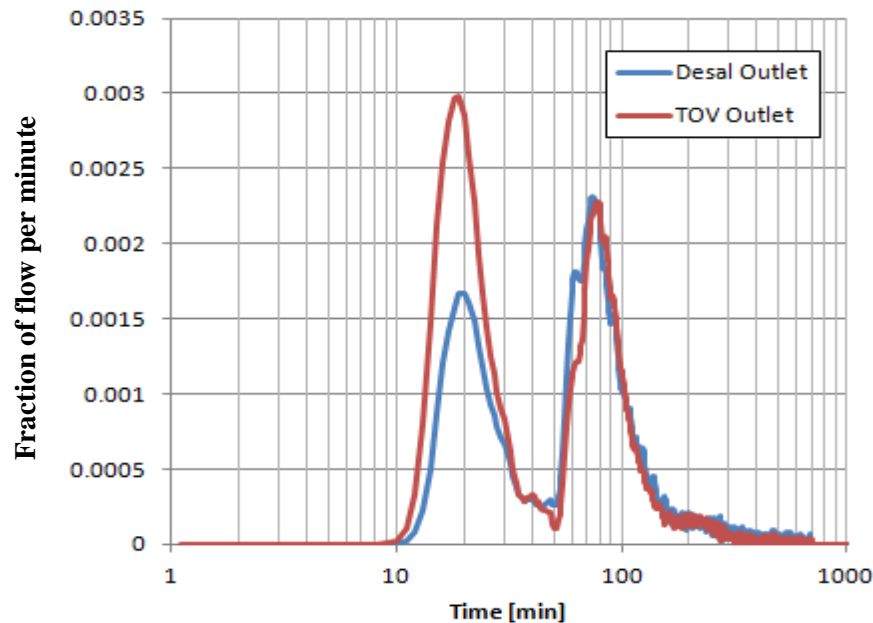
Isometric view of tank



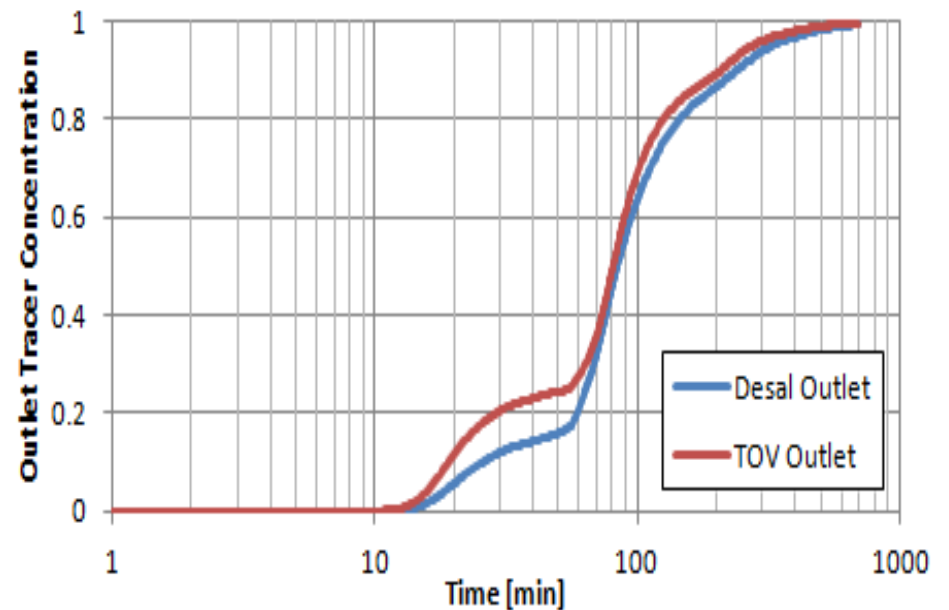
Streamlines colored by source

Water age and mixing efficiency for dual-source example

Age of Water - 1 min bins

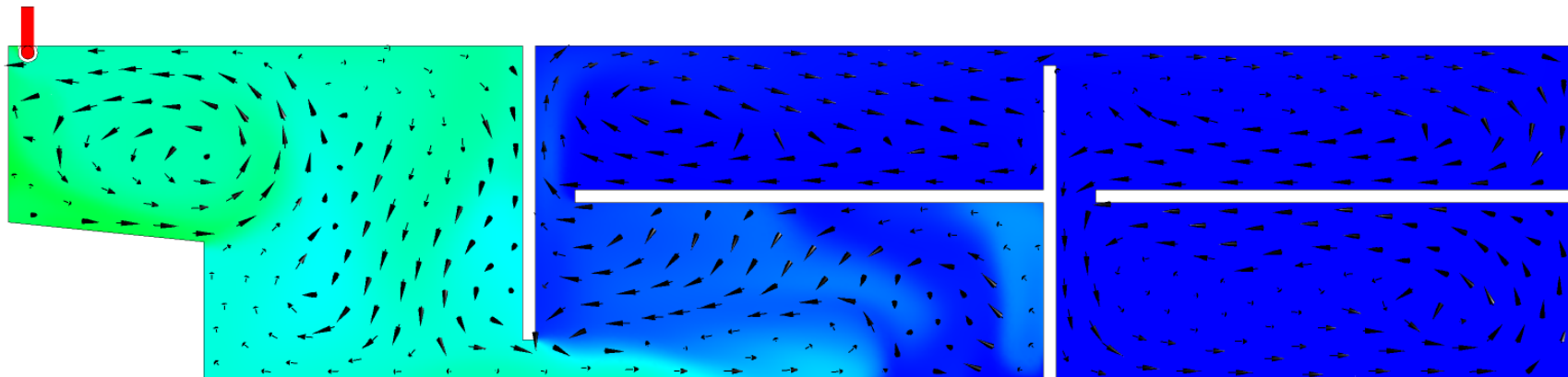
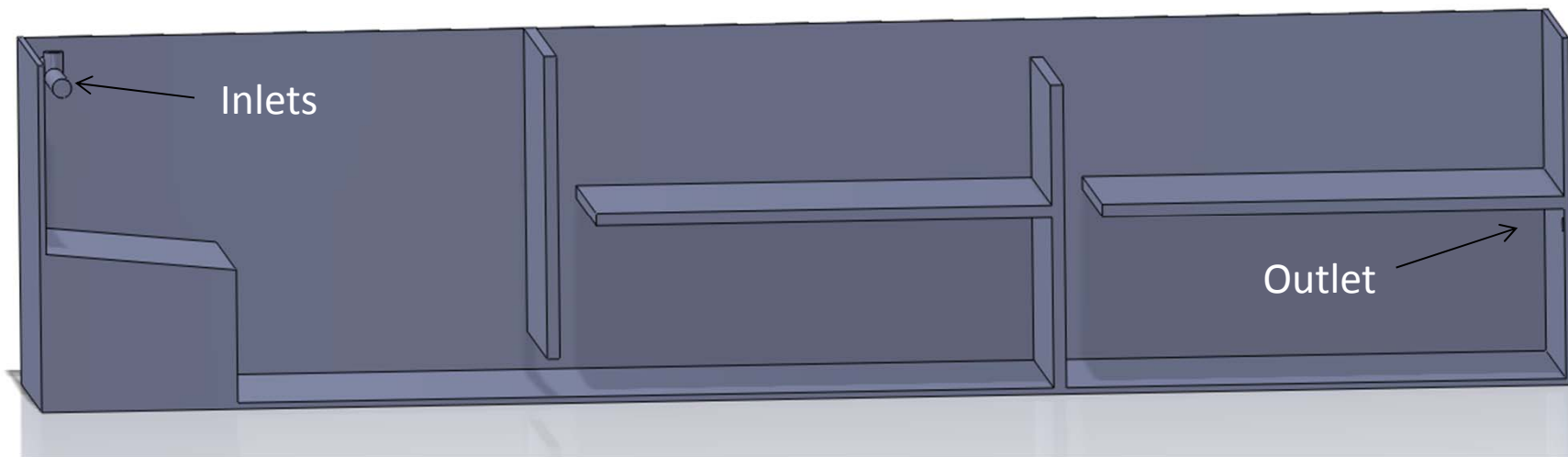


Water age frequency curve



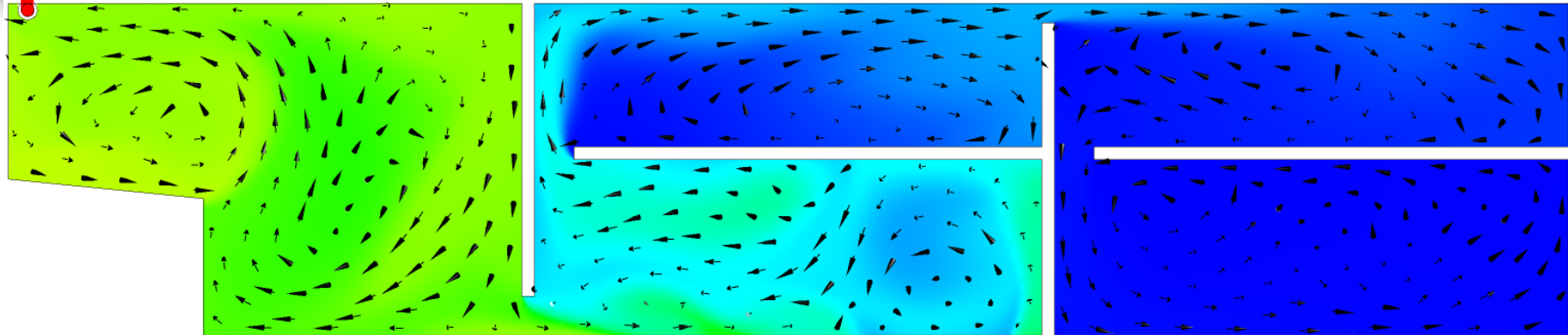
T_{10} and mixing efficiency

Pilot Study Example

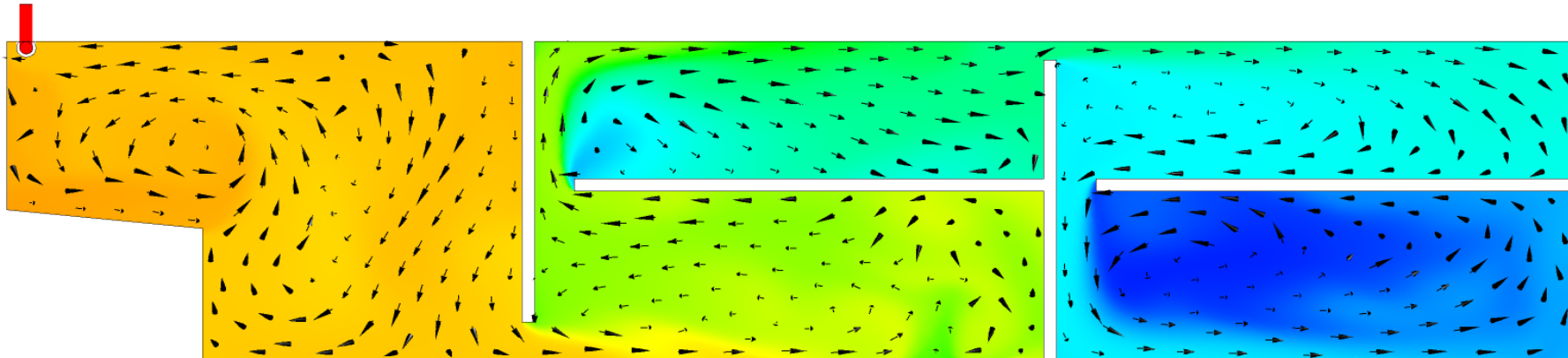


Tracer after 5 minutes

Pilot Study Example (cont)

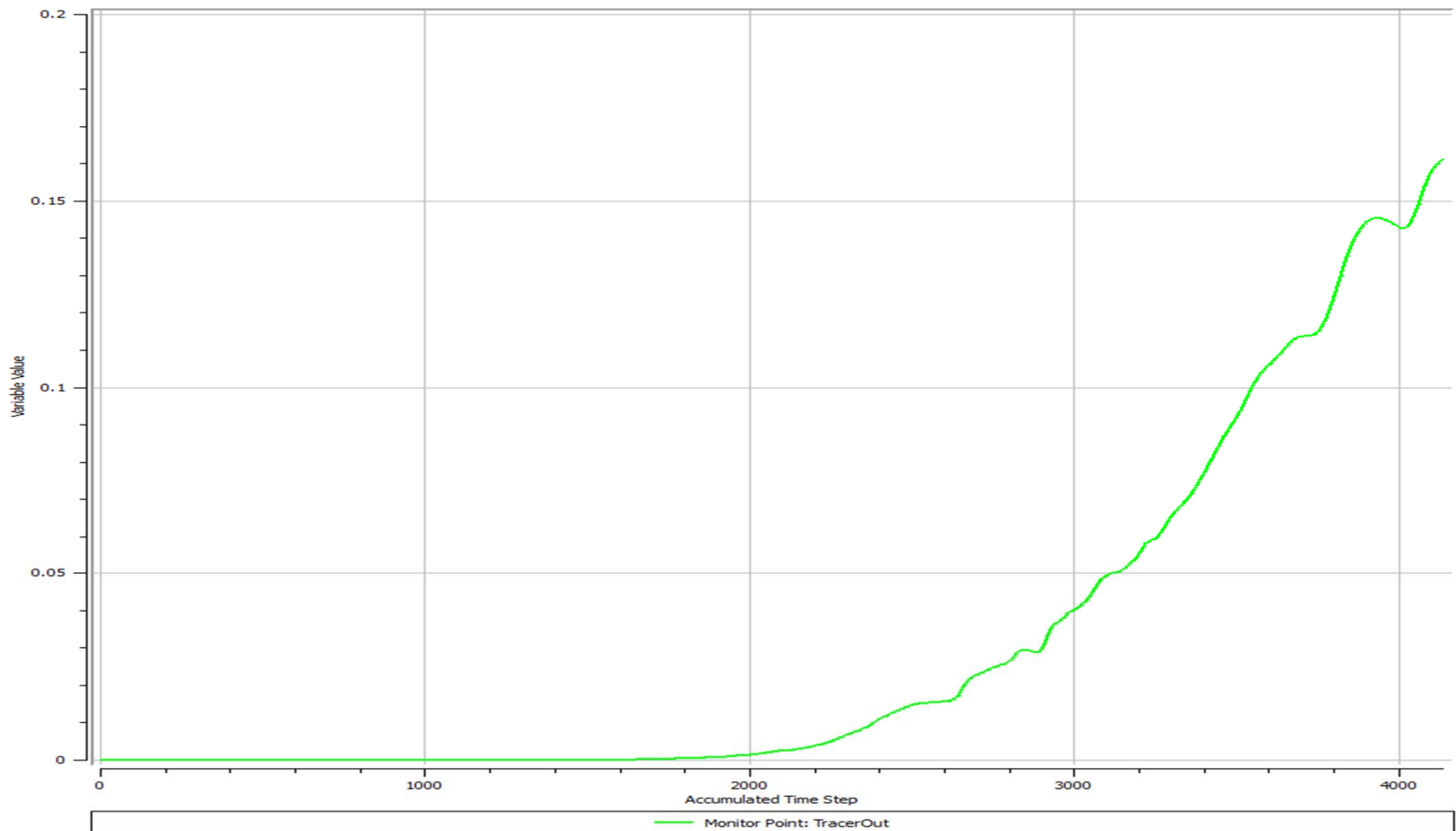


Tracer after 10 minutes

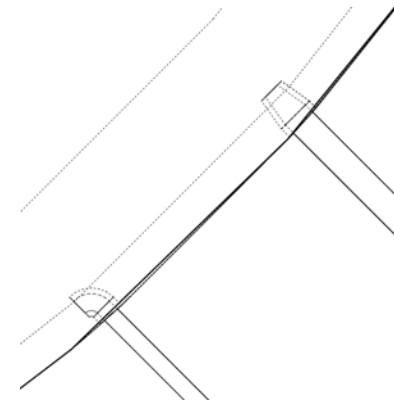
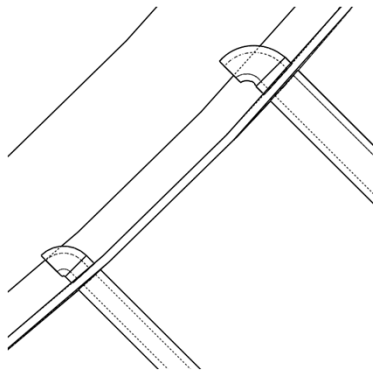
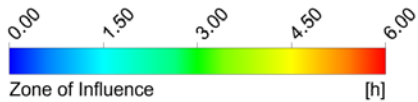
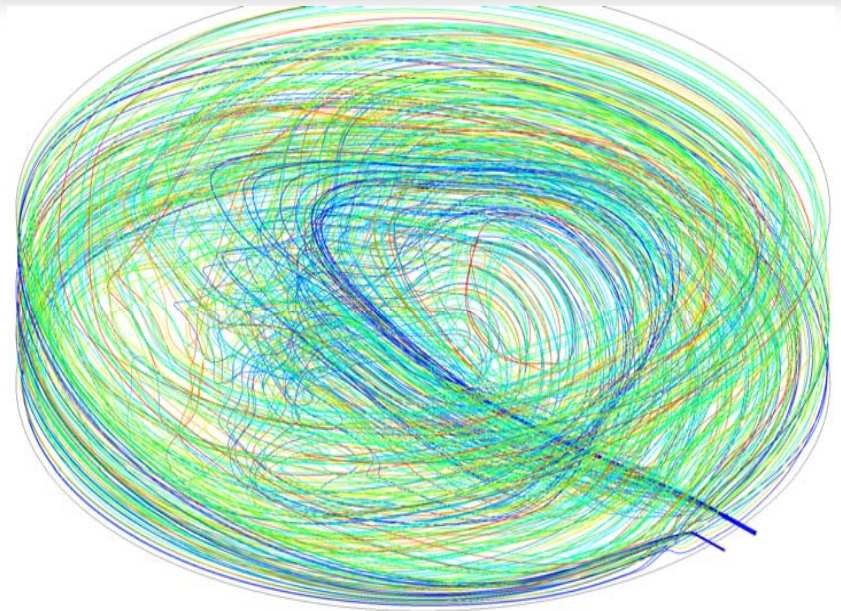
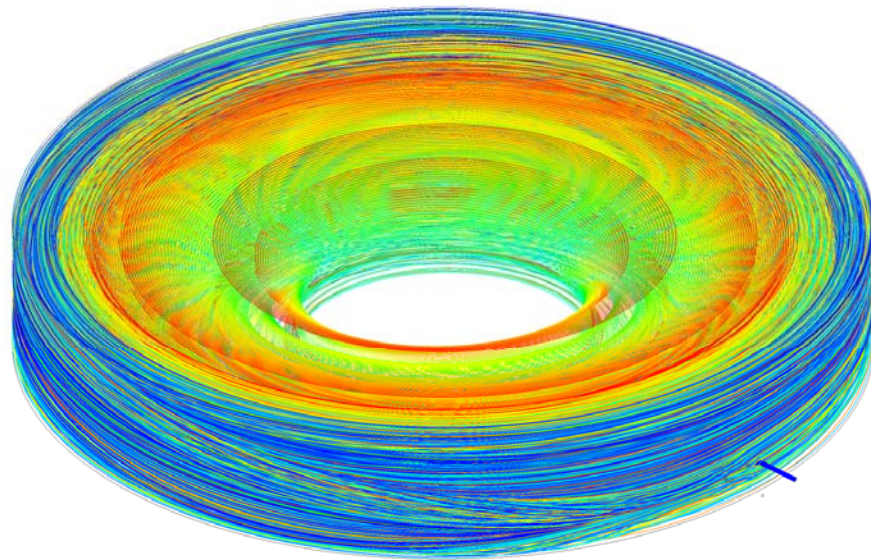


Tracer after 20 minutes

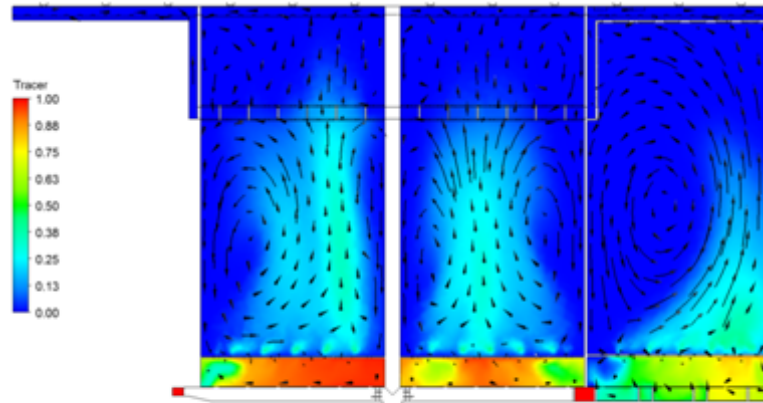
Pilot Study Example – T10, Efficiency, Baffling Factor



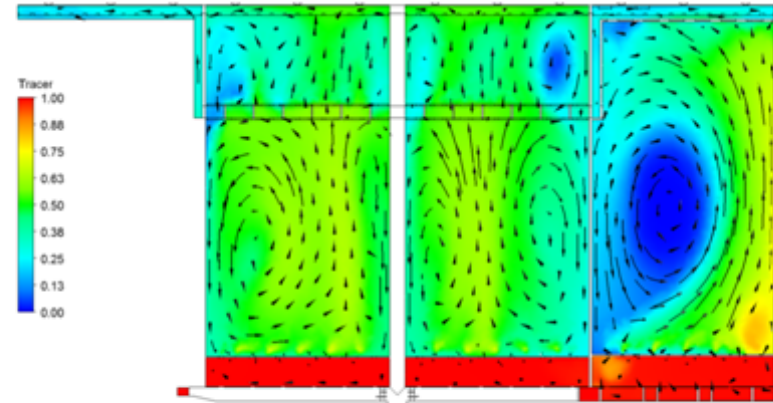
Minor Inlet Adjust Significantly Improves Mixing



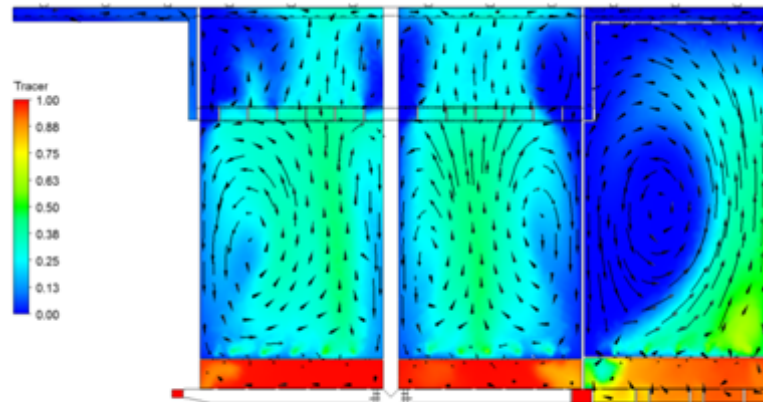
Tracer Study in Sedimentation Basins



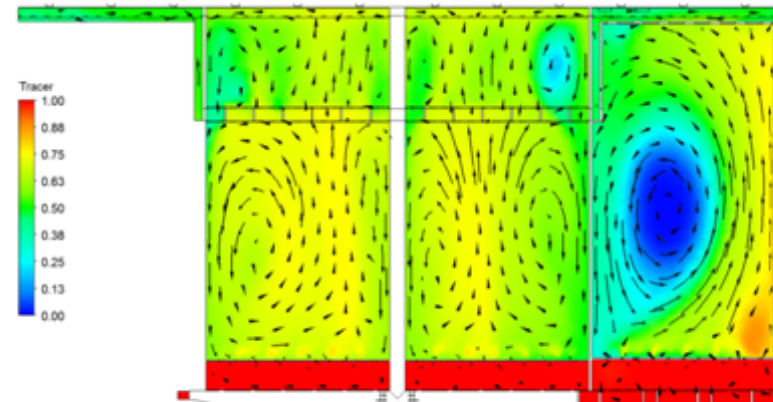
1 hour



4 hours



2 hours



6 hour

Questions?

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