CFD in Surface Water Forensic Investigations

1. Roadway Overflow and Influence on Vehicle
2. Water Release from an Impoundment Collapse
3. Small Scale Flow Modelling of Grate Inlet

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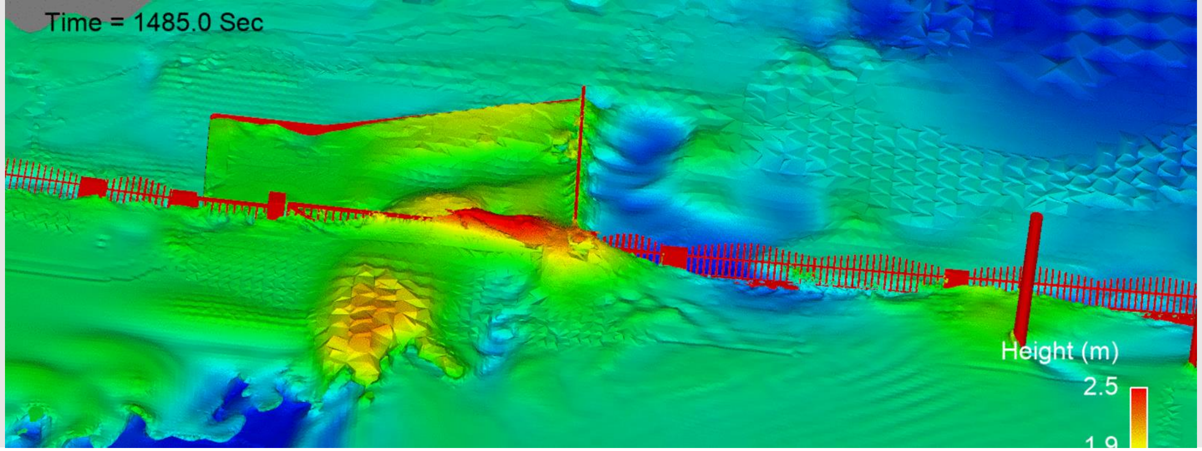
About

- Education: Biomedical Engineering at the University of Michigan

- Senior Project Manager – Hromadka & Associates
  - Providing consulting and litigation support in various fields including hydrology, water contamination, flood, landslide, etc.

What is Computational Fluid Dynamics (CFD)

- Computational Fluid Dynamics (CFD) is the science of predicting fluid flow, heat transfer, mass transfer, chemical reactions, and related phenomena by solving mathematical equations that represent physical laws, using a numerical process.
  - Conservation of mass, momentum, energy...
- The result of CFD analyses is relevant engineering data:
  - conceptual studies of new designs
  - Design optimization
  - Troubleshooting and root cause
  - Forensic Investigations
- CFD analysis complements testing and experimentation.
  - Reduces the total effort required in the laboratory.



Case Example: Roadway Overflow and Vehicle Influence

Goal: Evaluate the effects of storm runoff on a vehicle attempting to cross the flow path

CFD was used to determine the water height and velocity of storm runoff flowing down a channel and crossing a road before entering the storm drainage system.

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Why CFD?

- Complex cross sections and minor cross sectional changes are difficult to evaluate with traditional hydraulic modelling software
  - Evaluate the effect on the flow regime crossing the roadway due to the downstream infrastructure conditions (developed vs. damaged infrastructure vs. natural conditions)
- Accurately modelling at multiple scales in one simulation
  - Evaluate the flow effects on a vehicle in addition to the vehicles affect on the flow

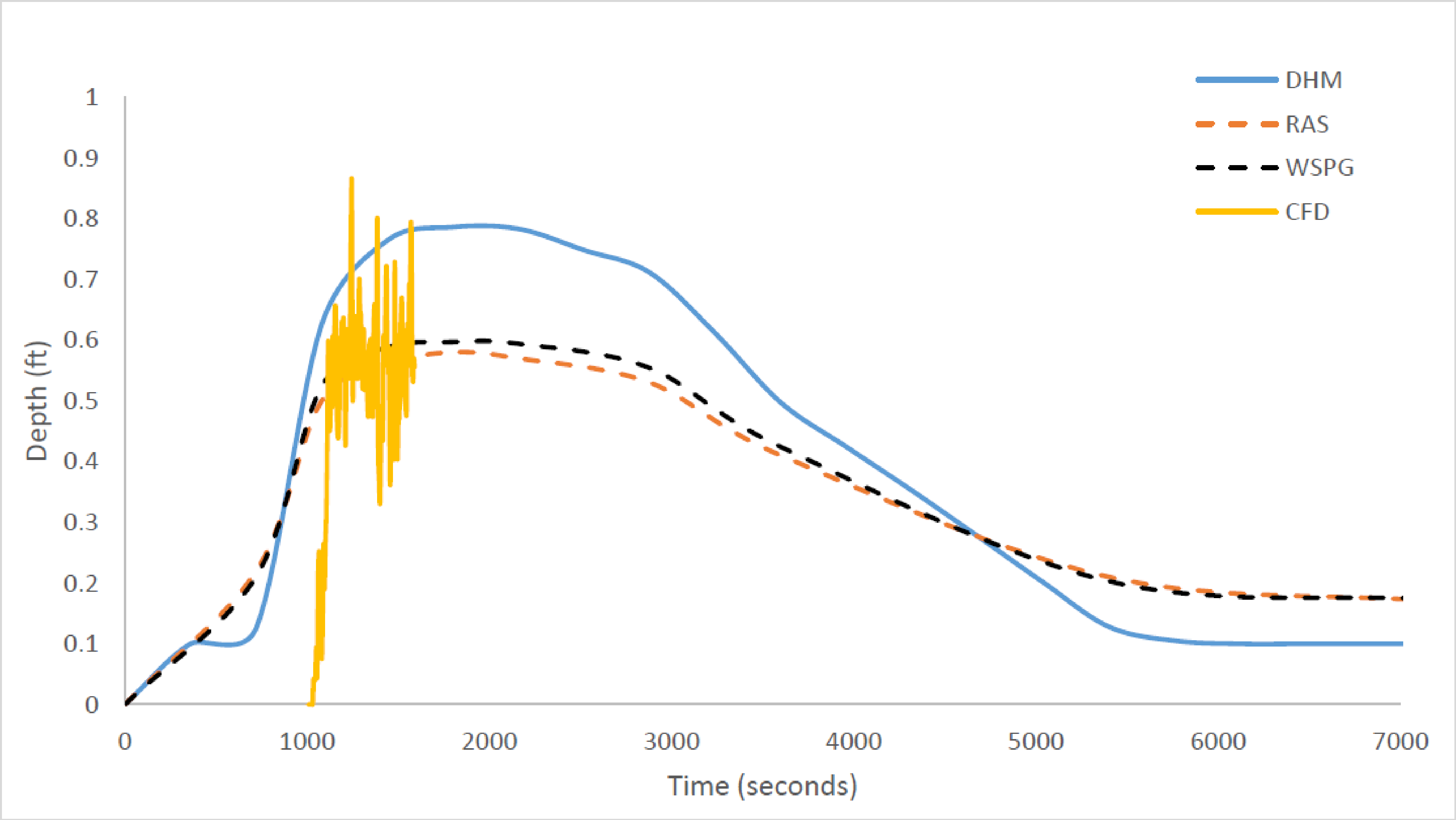
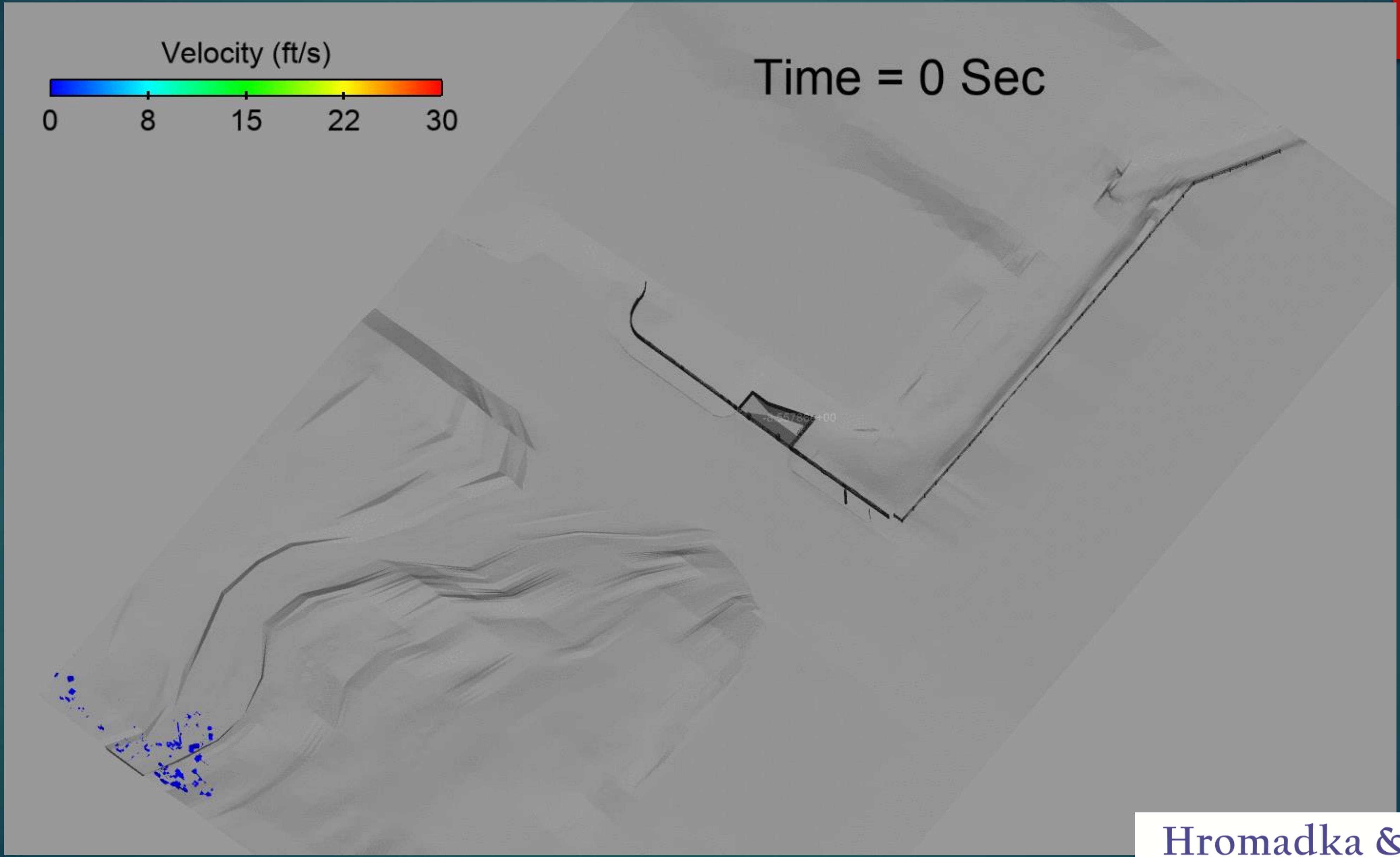


Figure 1. Comparison of results at Probe P0

Baseline Results

Animation: Water interface colored by Velocity



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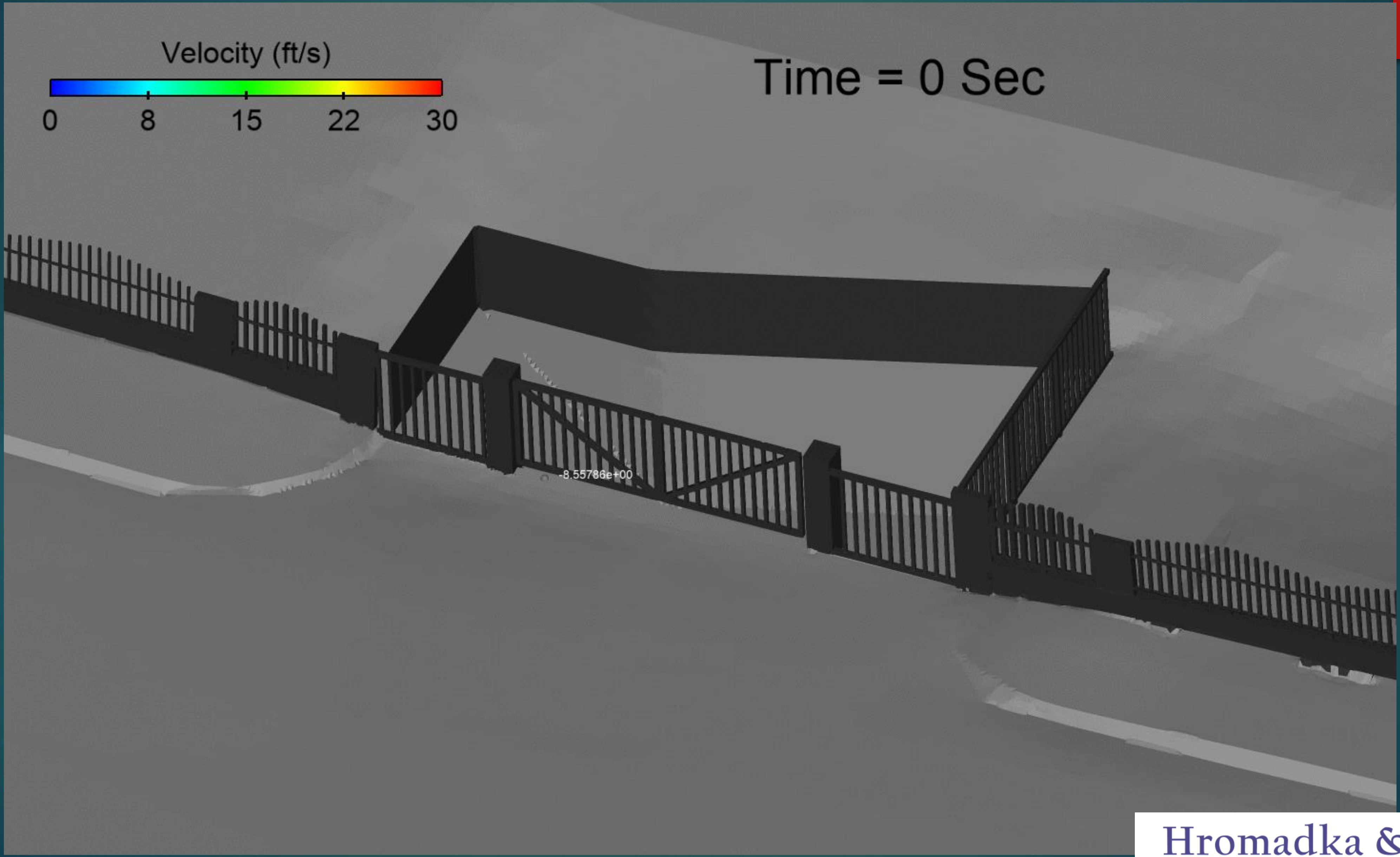
Baseline Results
Animation: Water interface colored by Velocity



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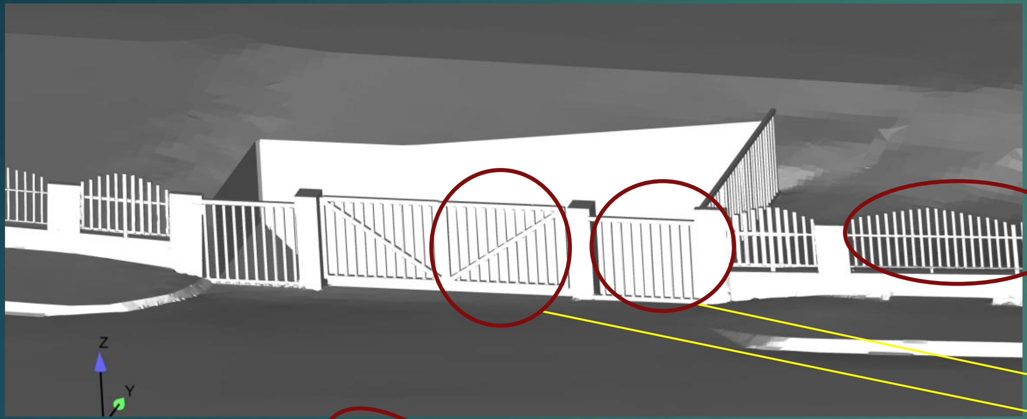
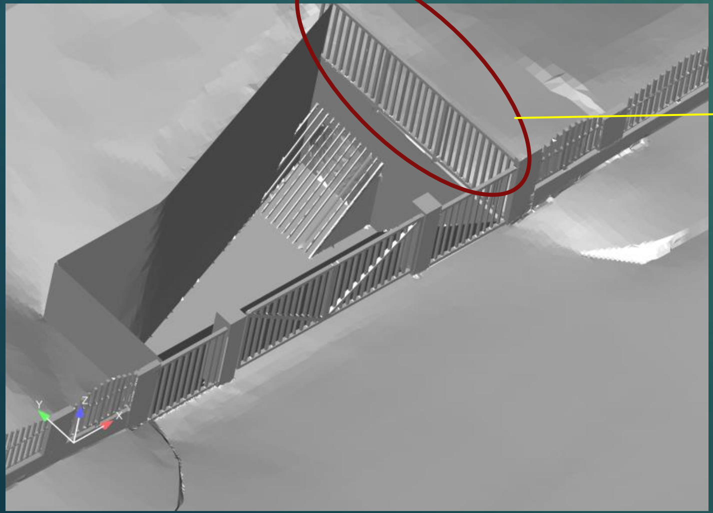
Baseline with Damaged Infrastructure: Geometry Changes

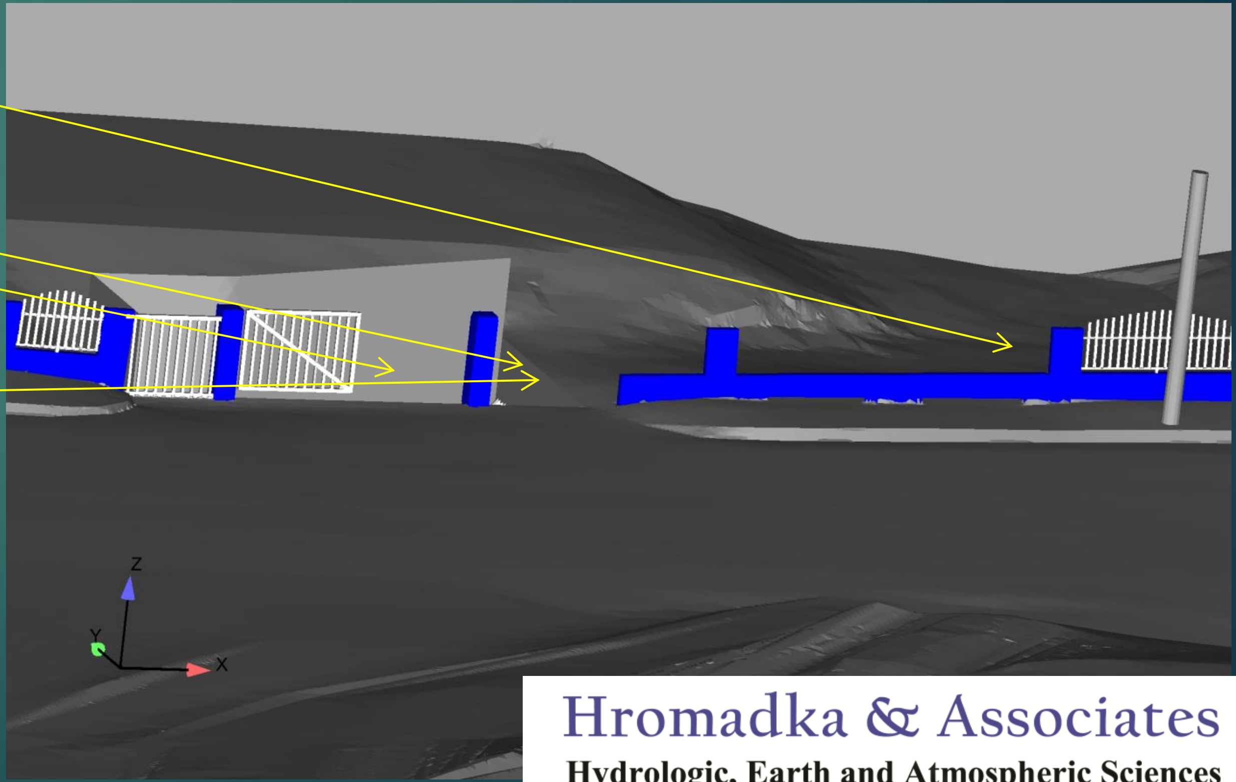
Part of gate, fence and block wall removed from base geometry.

Baseline





Baseline with Damaged Infrastructure



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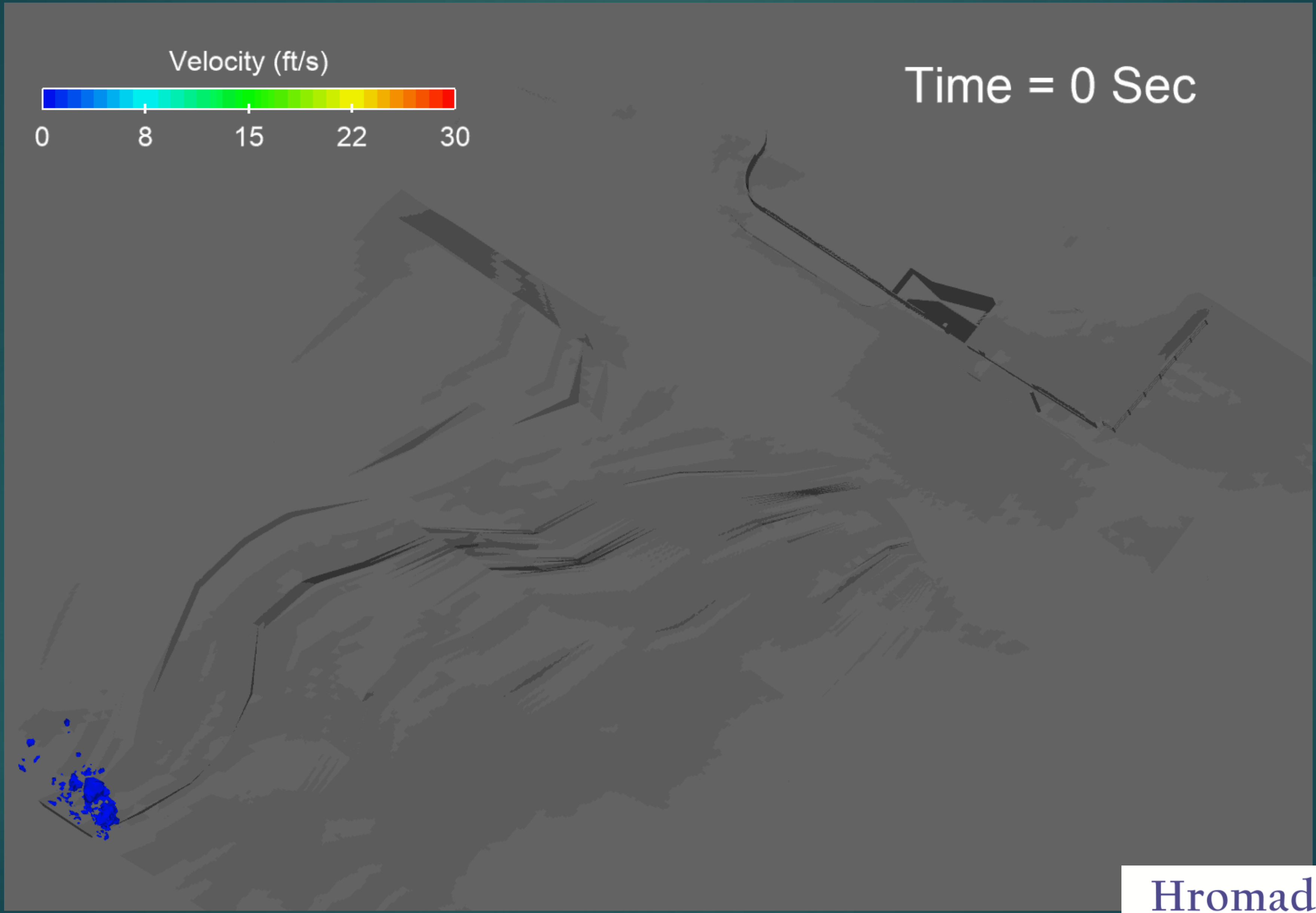
Baseline with Damaged Infrastructure
Animation: Water interface colored by Velocity



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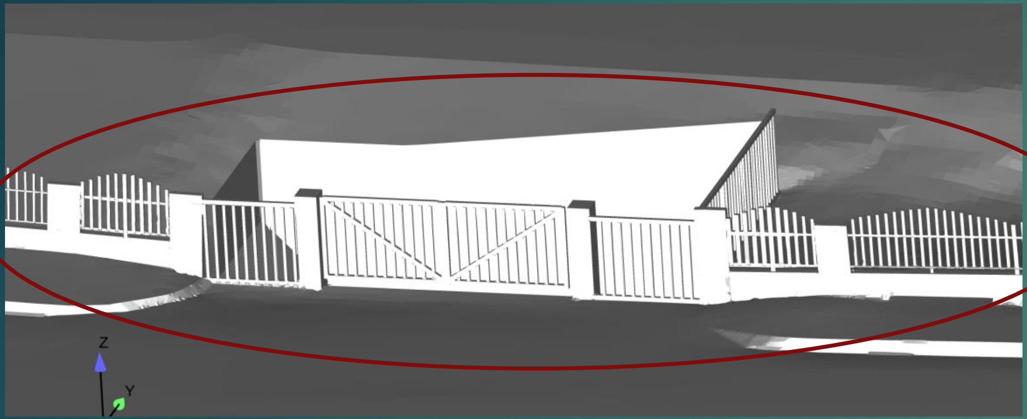
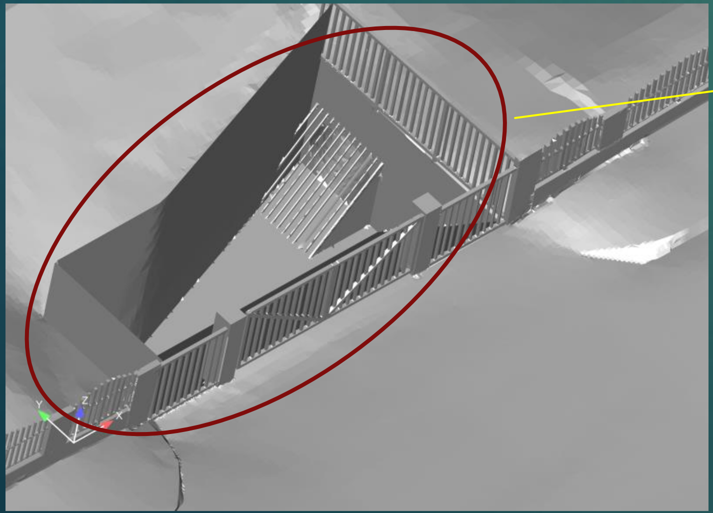
Natural Conditions: Geometry Changes

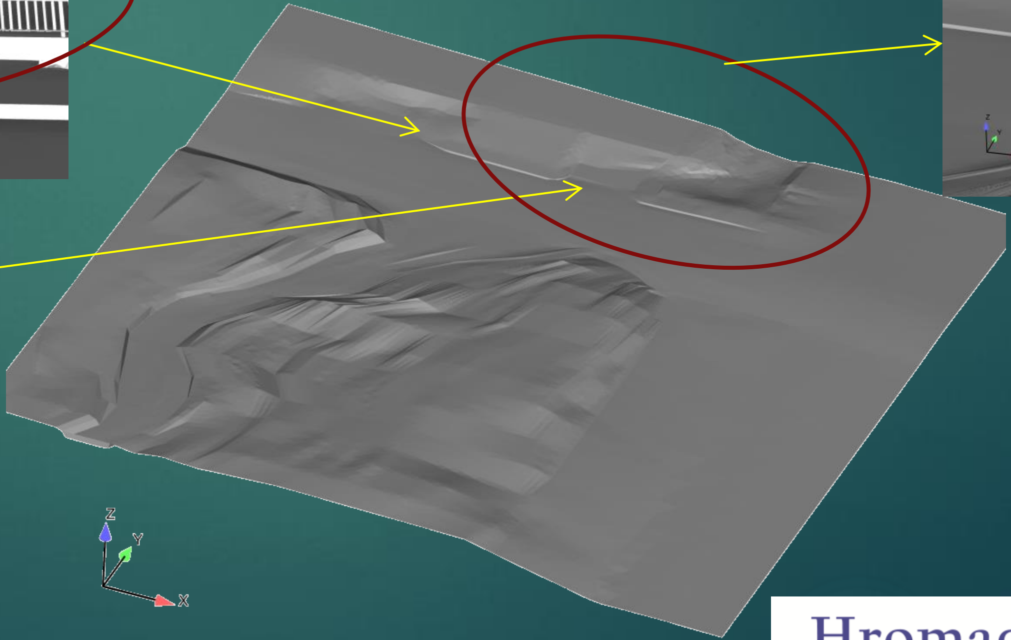
The Gate, fencing, walls and drainage ditch removed from base geometry.

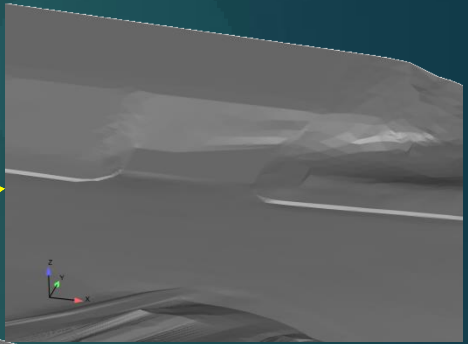
Baseline





Natural Conditions





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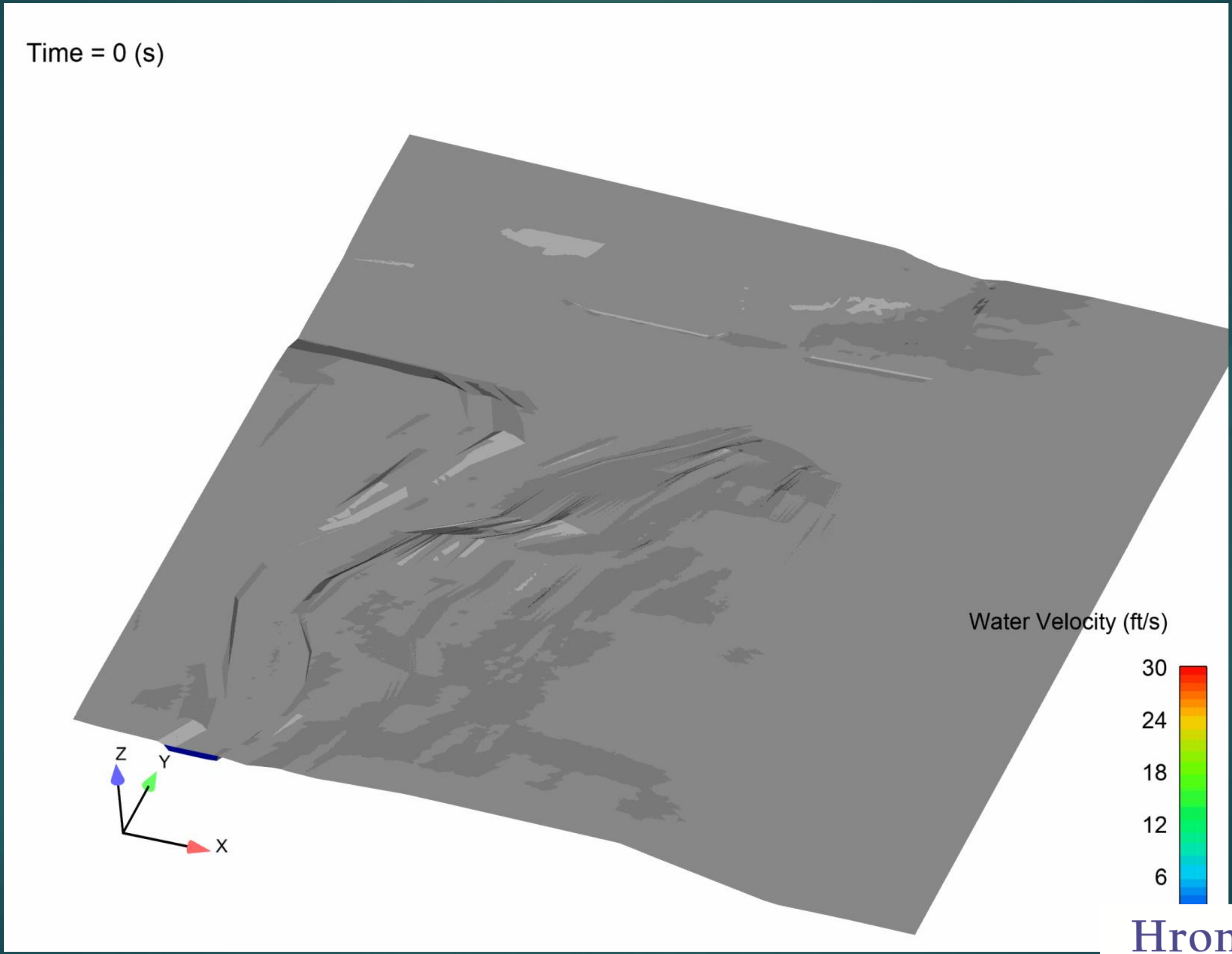
Natural Conditions

Animation: Water interface colored by Velocity



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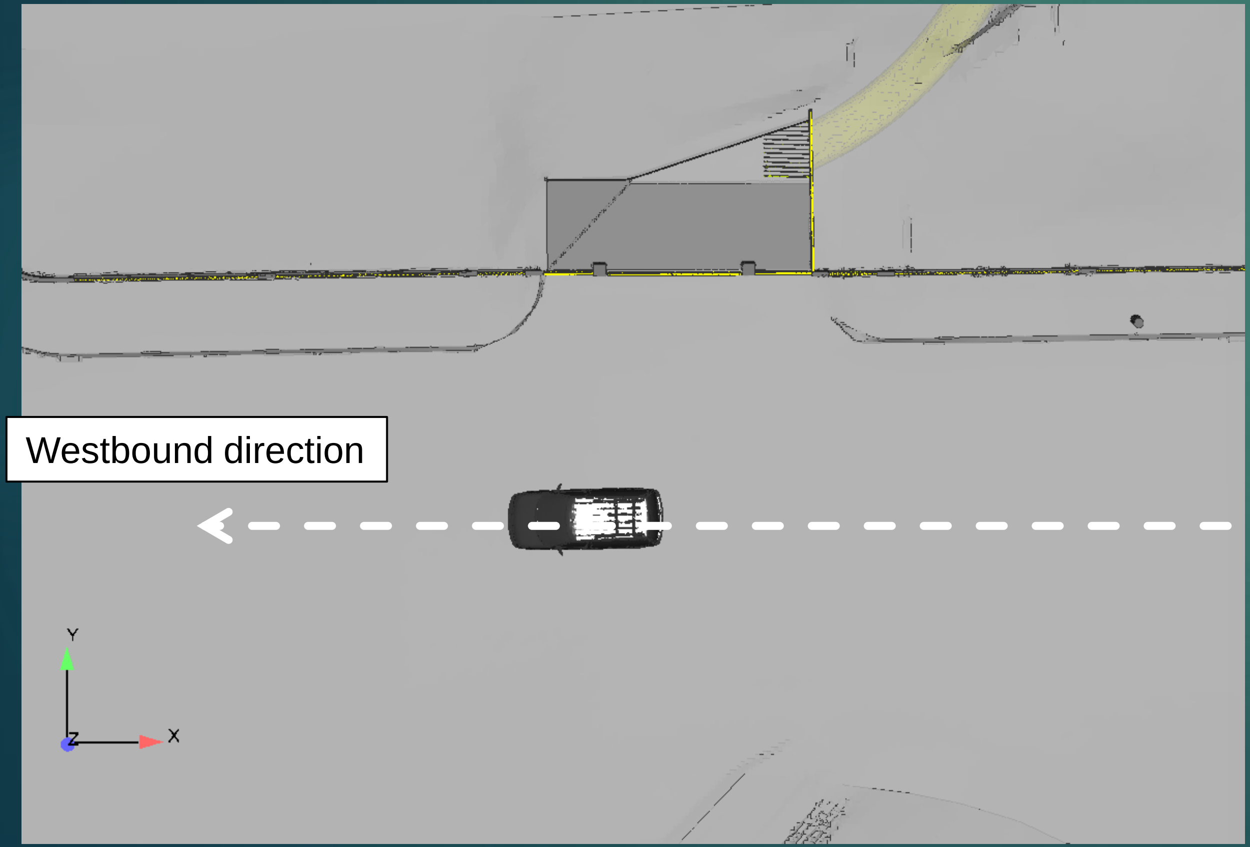
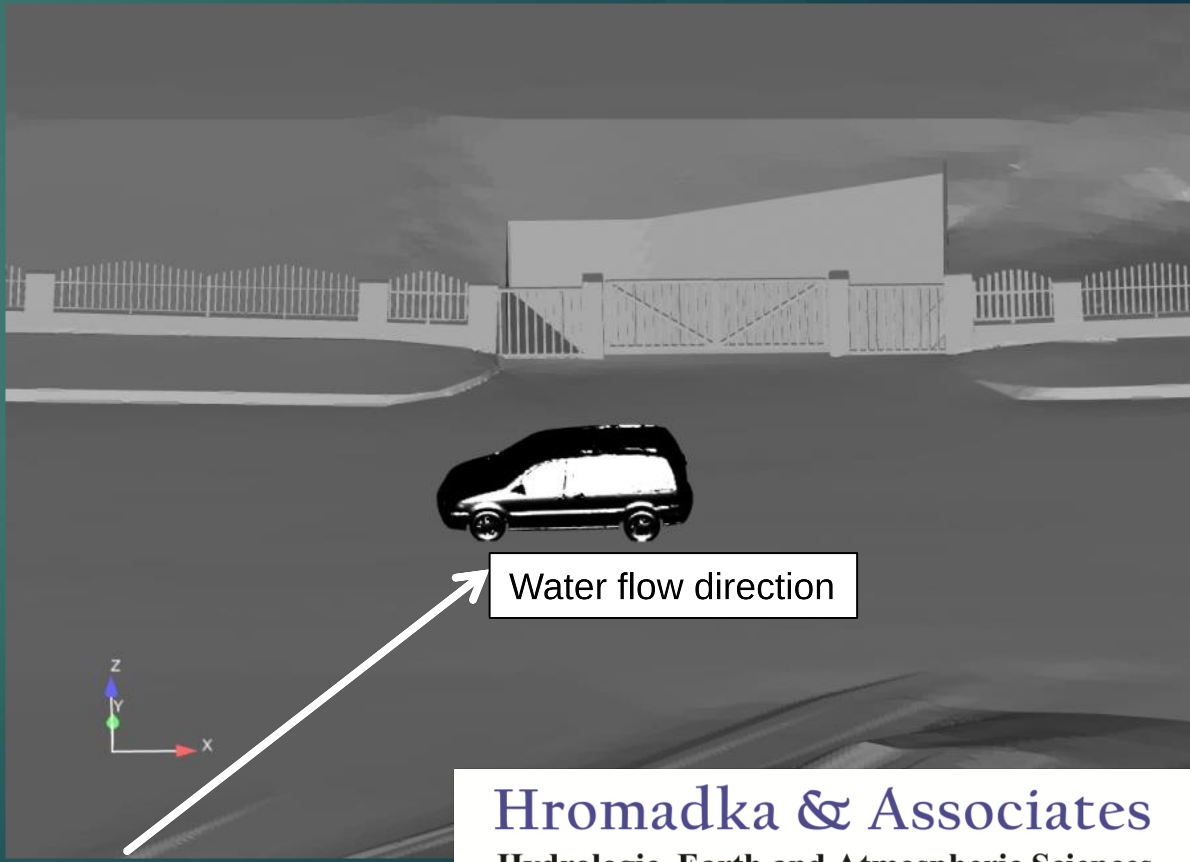
Baseline with Vehicle: Geometry Changes

- A model of a minivan was included in the model.
- Vehicle assumed to be stationary, non-movable, and non-deformable
- The center of the vehicle was located on the westbound lane, 8ft toward north from center of westbound lane
  - Google map shows the center of the westbound lane is approximately 33ft from the fence.





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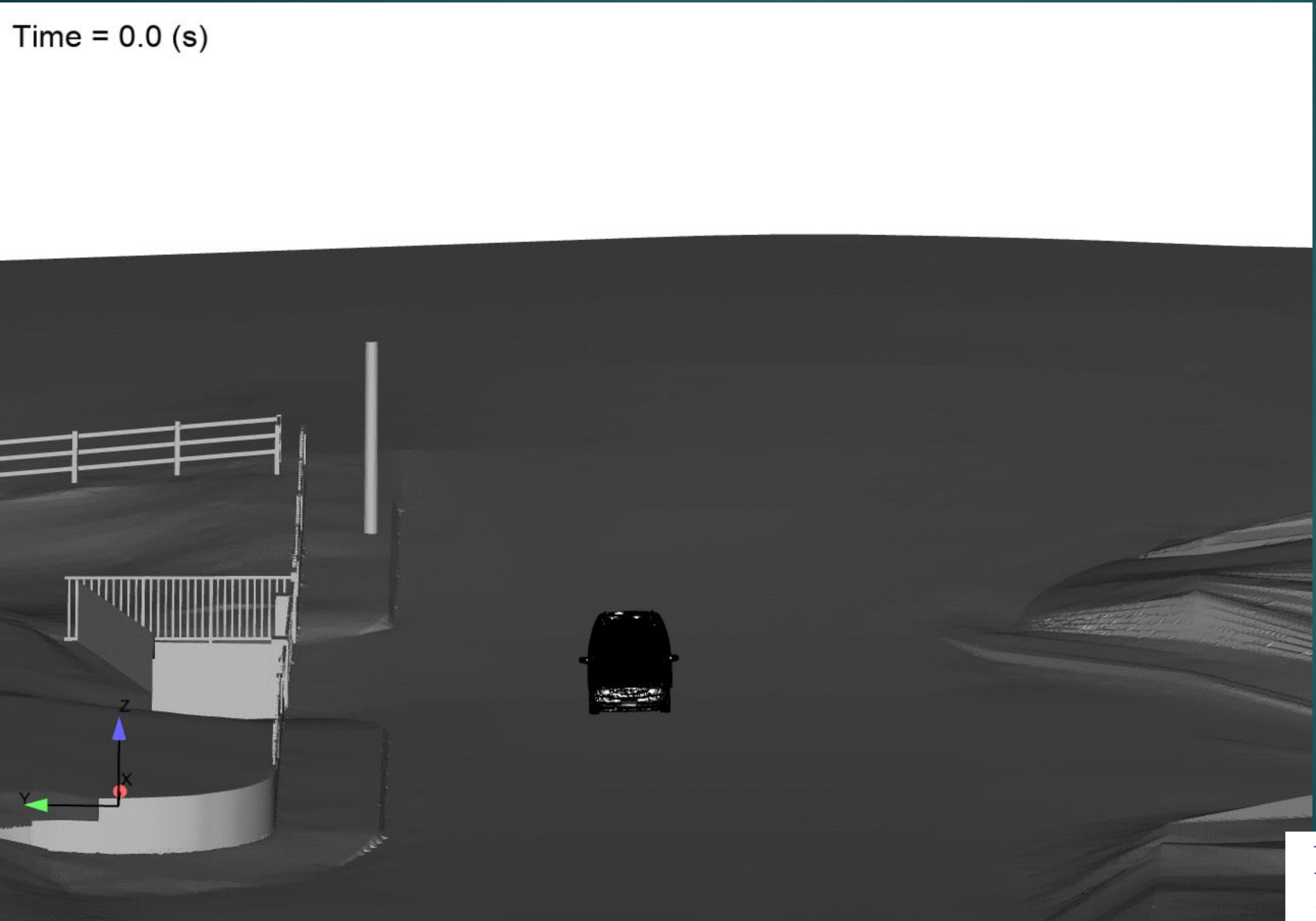
Baseline with Vehicle
Animation: Water interface

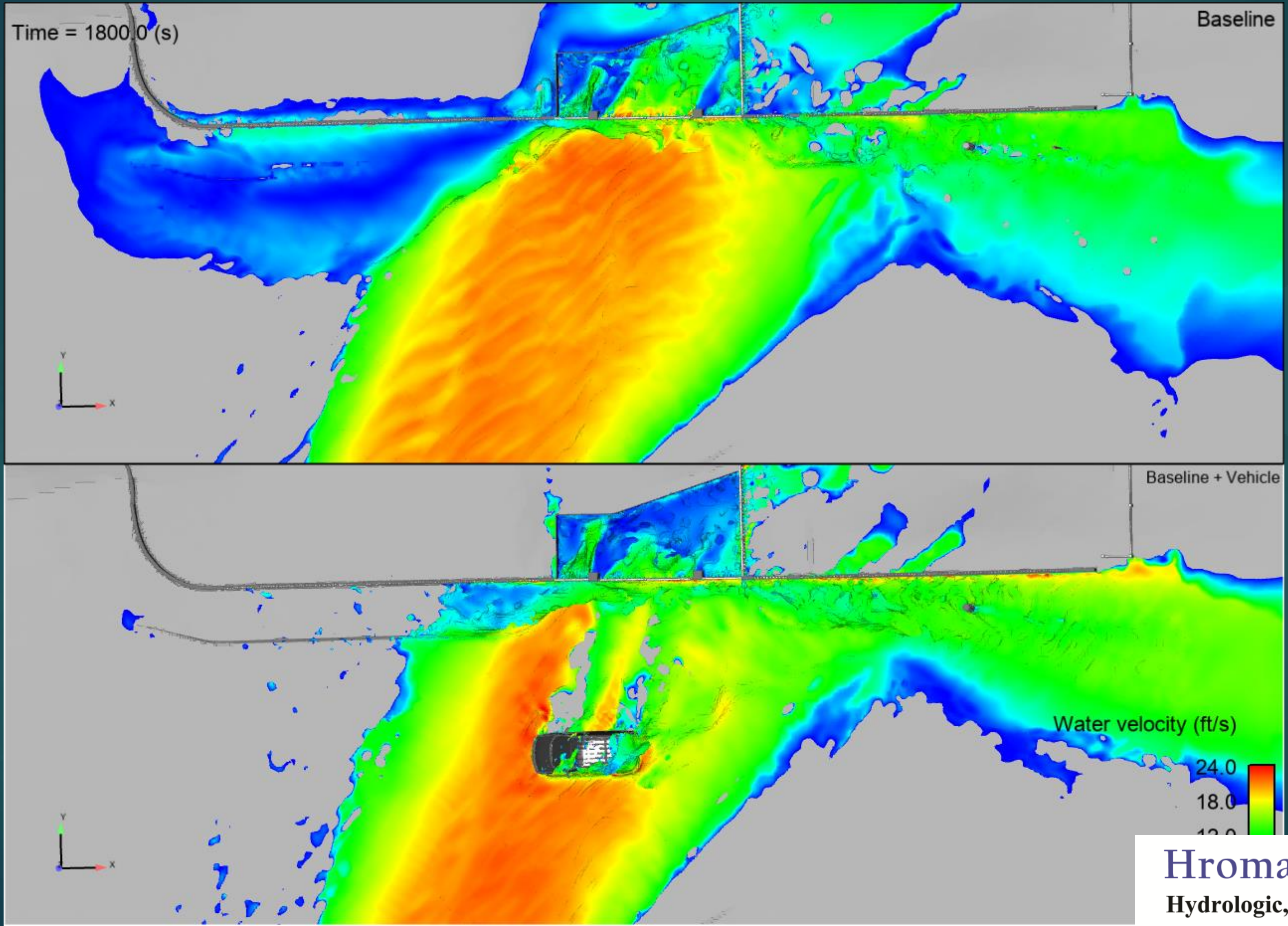
Note:
Water Interface is colored in the post-processing phase to look more realistic.
This is in contrast to the other simulations where the results are colored according to the value of some attribute (height, velocity, etc.)

Baseline with Vehicle
Animation: Water interface



Results: Comparison of Baseline vs. Baseline with Vehicle

Water interface colored by water velocity magnitude



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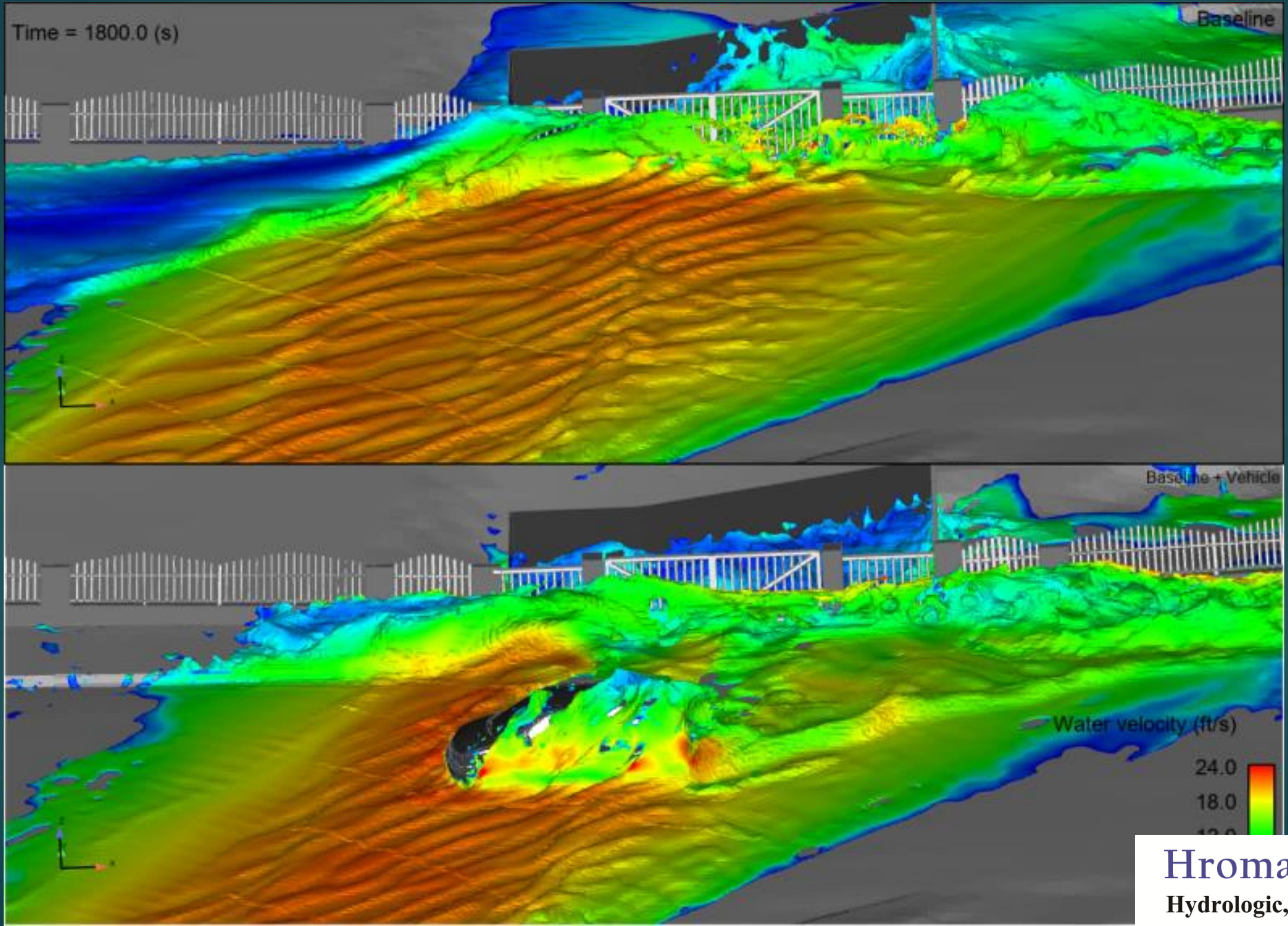
Results: Comparison of Baseline vs. Baseline with Vehicle

Water interface colored by water velocity magnitude



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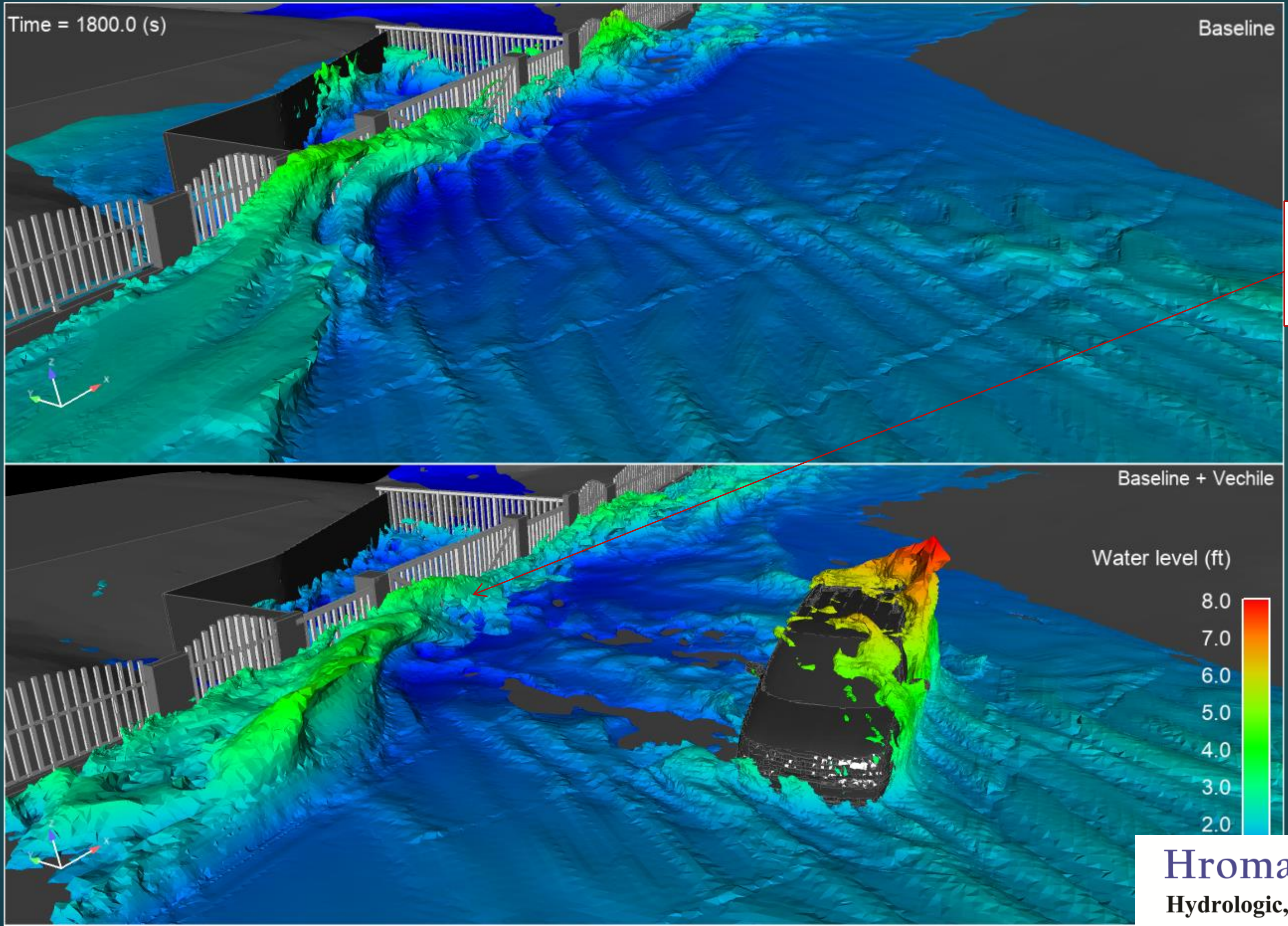
Results: Comparison of Baseline vs. Baseline with Vehicle

Water interface colored by water level



Reference location: center of gate
X = -24.8 ft
Y = 18.368 ft
Z = -28 ft

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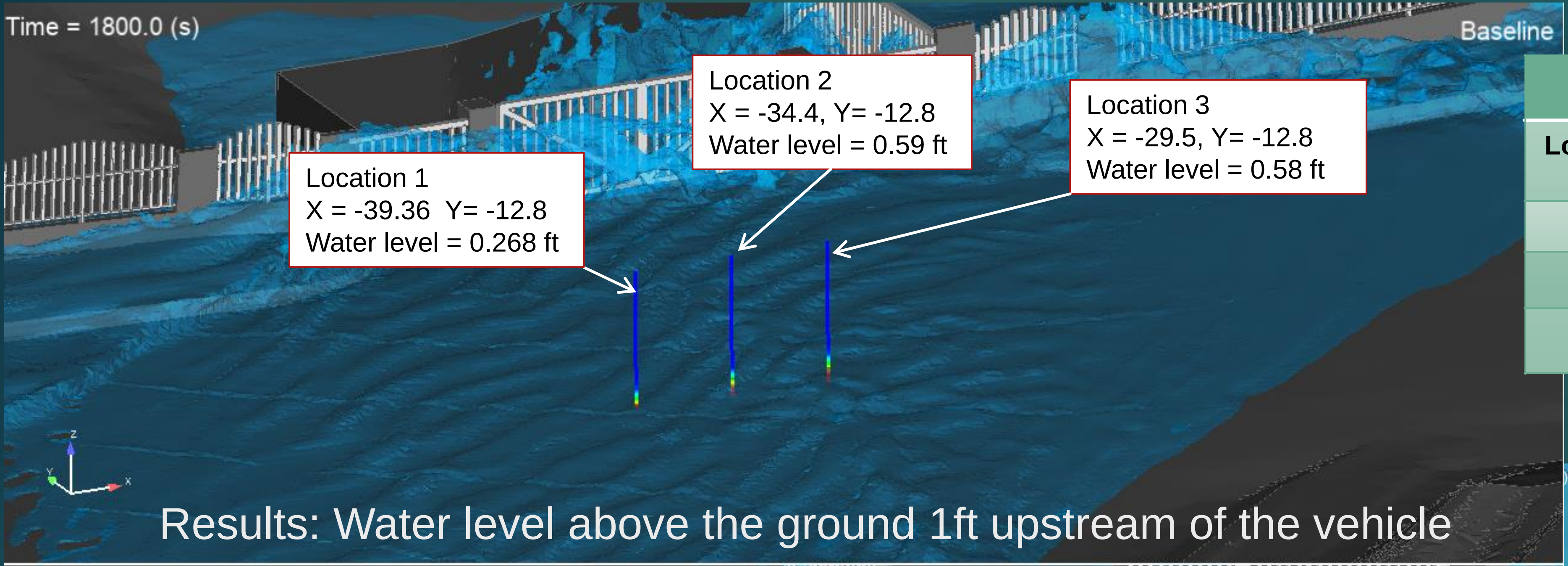
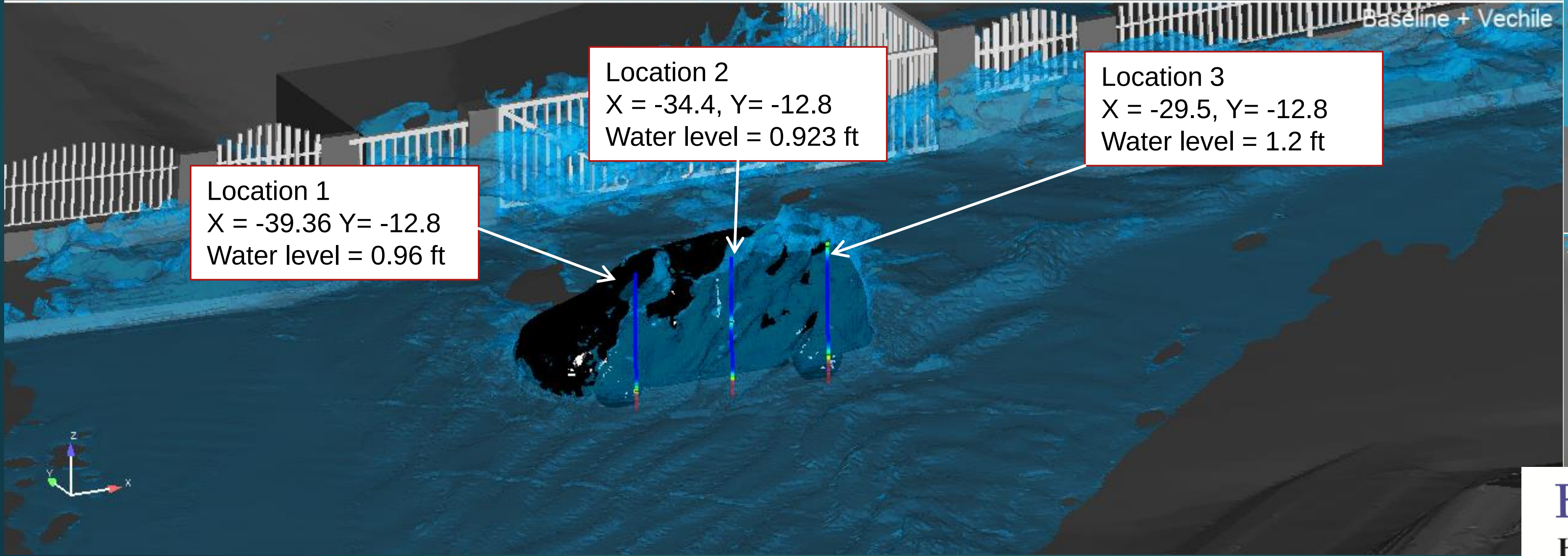
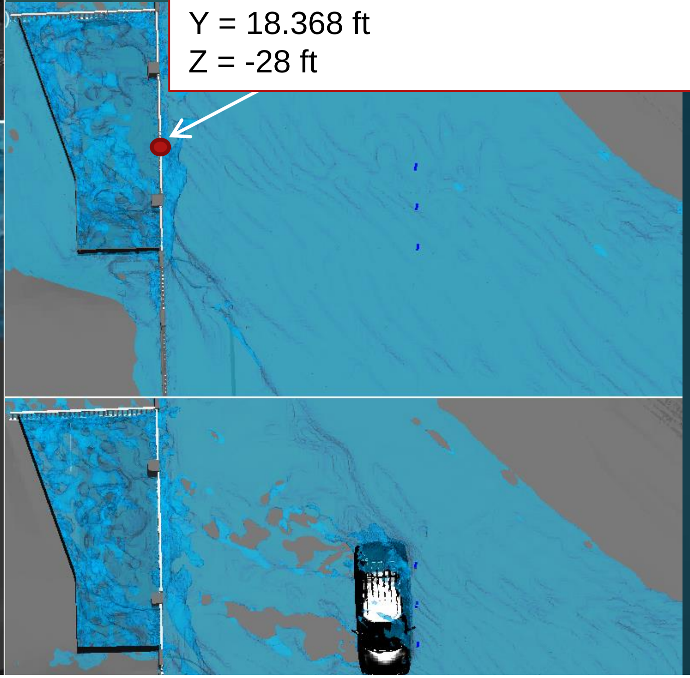
Comparison of Baseline vs. Baseline with Vehicle



Results: Water level above the ground 1ft upstream of the vehicle



Water Level (ft)			
Locations	Base line	Baseline + Vehicle	Difference
1	0.268	0.96	0.692
2	0.59	0.923	0.33
3	0.58	1.2	0.62



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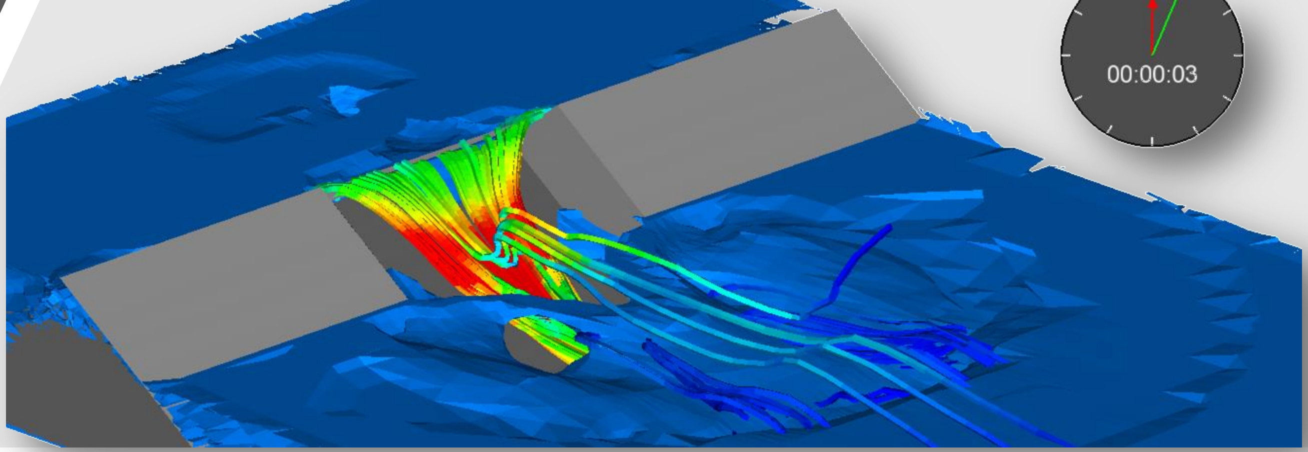

Case Example 2: Water Release from Impoundment Collapse

Goal: Determine source of flooding in a channel

CFD was used to evaluate the transient effects in the immediate aftermath of the impoundment collapse

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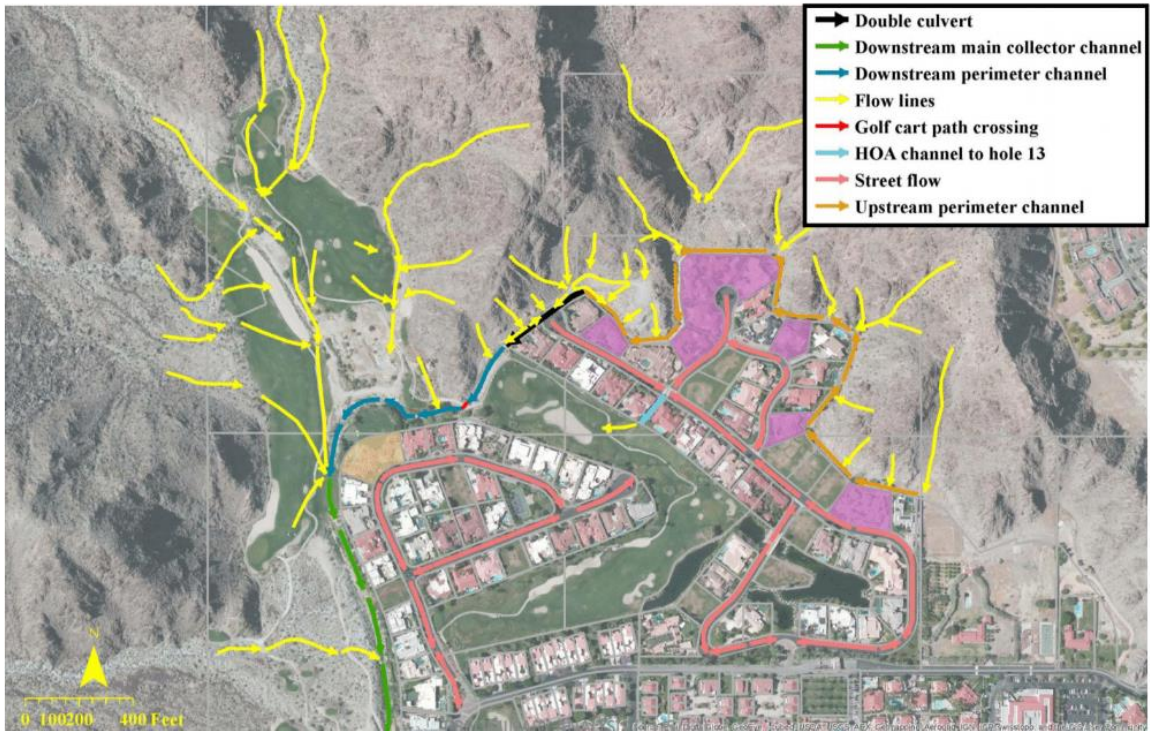
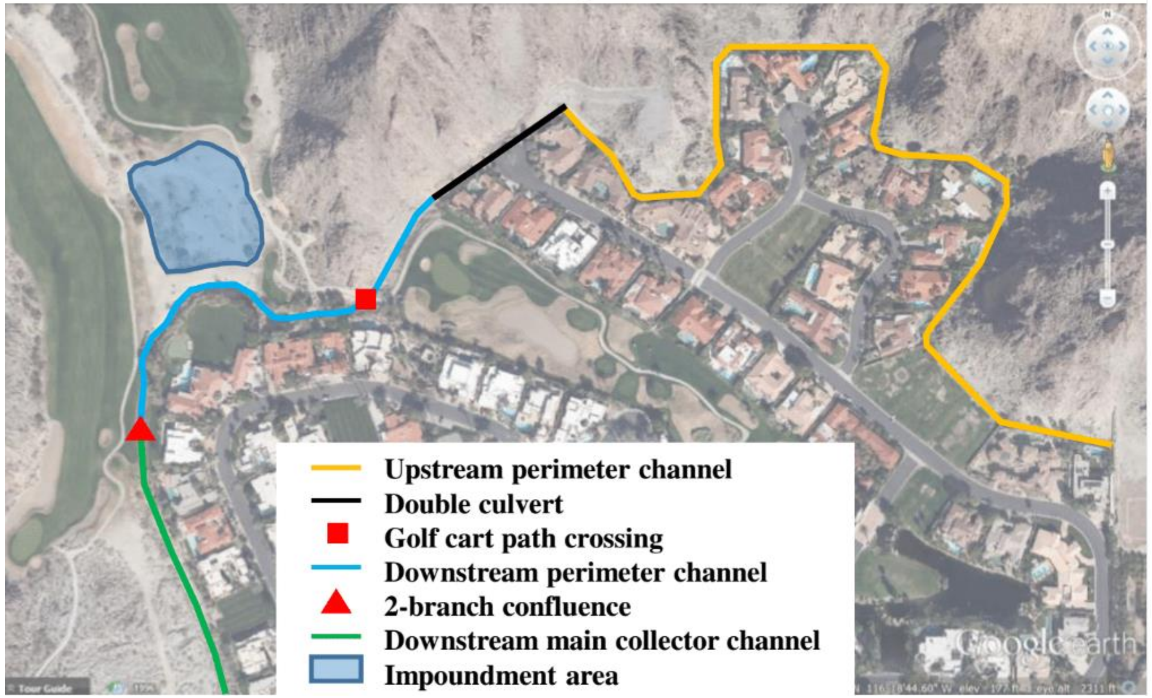
Current Flowpaths



Flood Control System Elements



Impoundment Breach and Flooding: Overview

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Breach and Flooding: Physical Mock-Up

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Breach and Flooding: Physical Mock-Up Videos

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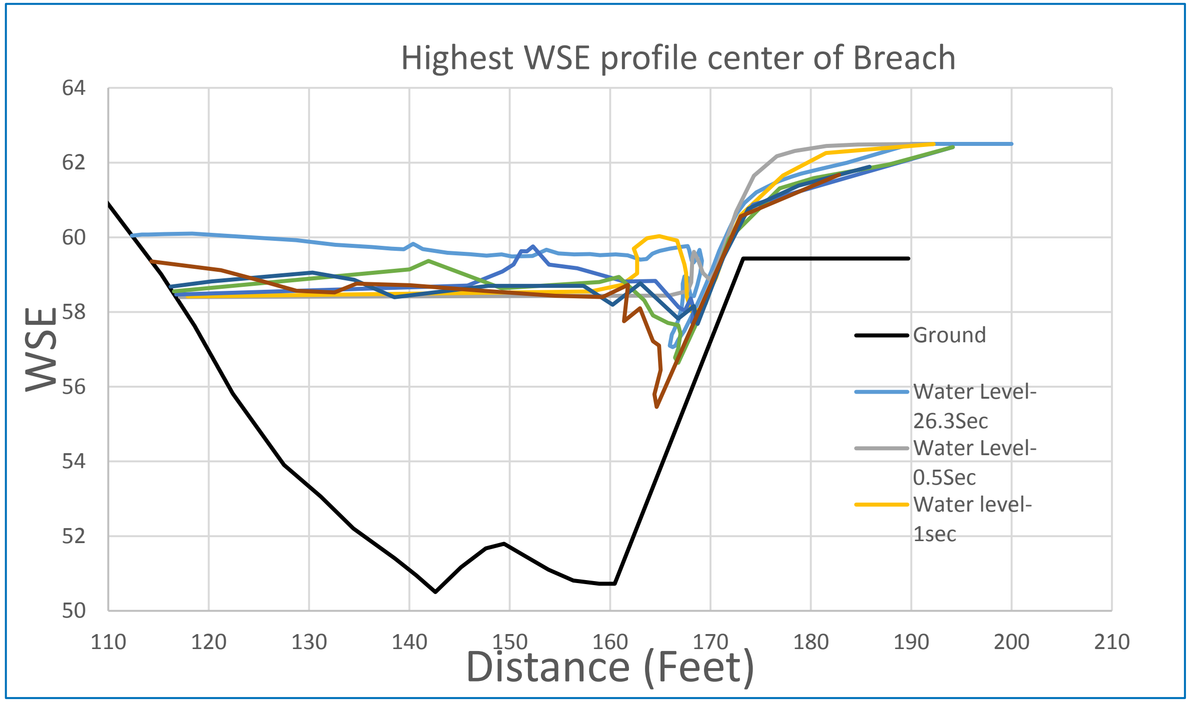
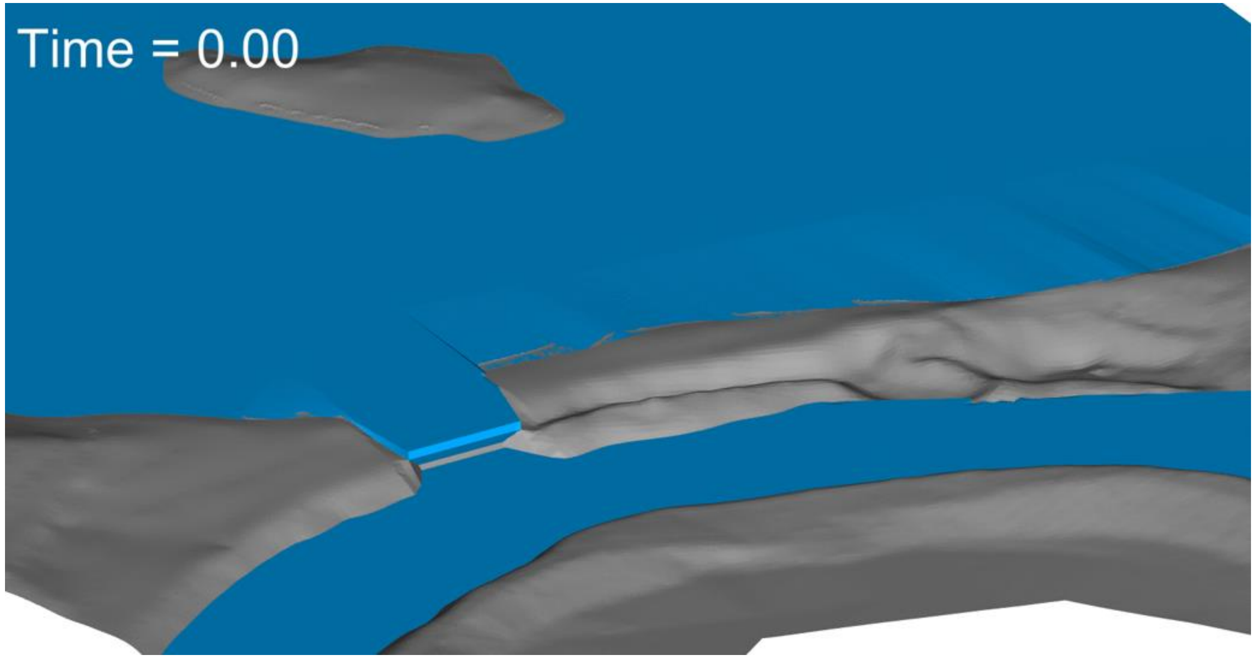
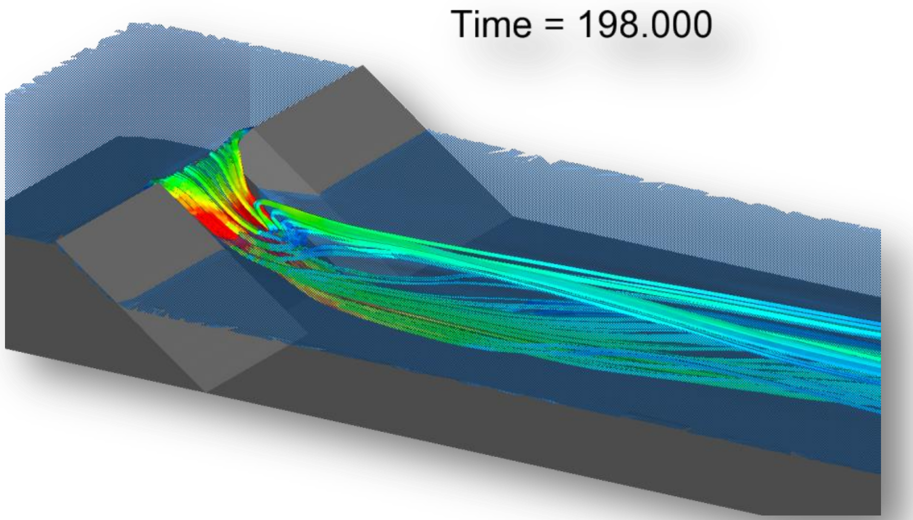
Why CFD?

- Designed to capture transient effects
  - Evaluate effects of impoundment collapse and subsequent wave action
- More accurate than a physical prototype
  - Better capture the true geometry of the channel walls







Breach and Flooding: Computational Fluid Dynamics

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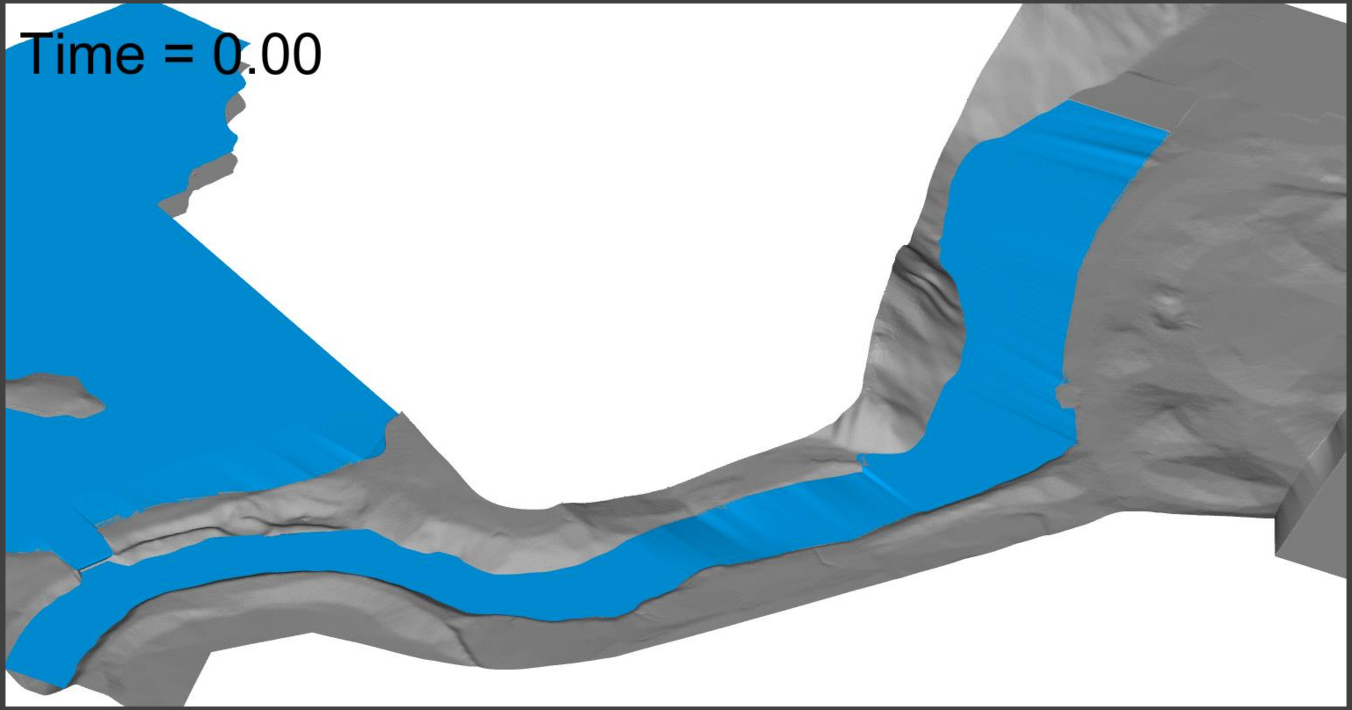
Breach and Flooding: Computational Fluid Dynamics



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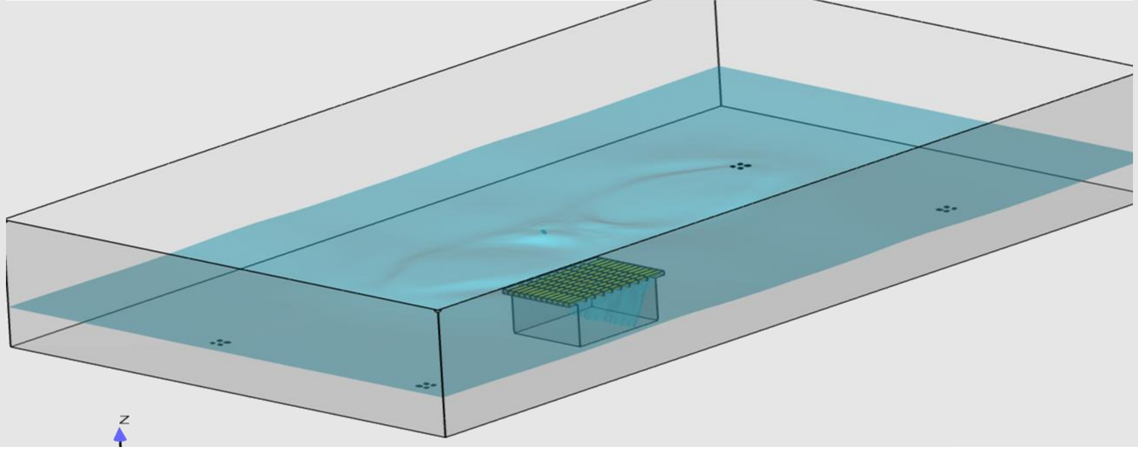

Case Example 3: Small Scale Flow Modelling of Grate Inlet

Goal: Determine if the inlet grate capacity was the limiting factor in a storm drainage system, and thus the cause of flooding downstream. CFD was used to measure Grate Capacity (cfs) as a function of water height

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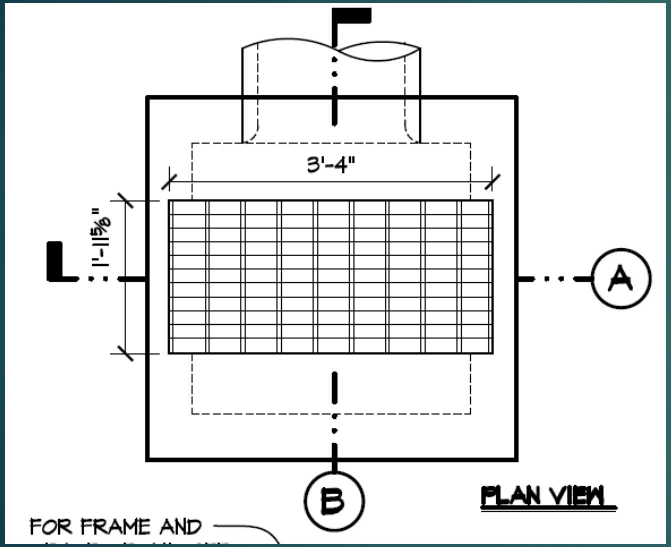
Geometry construction

- The CAD geometry was constructed based on:
  - Schematic drawing (grate Type)
  - Actual grate pictures from the site



~2"

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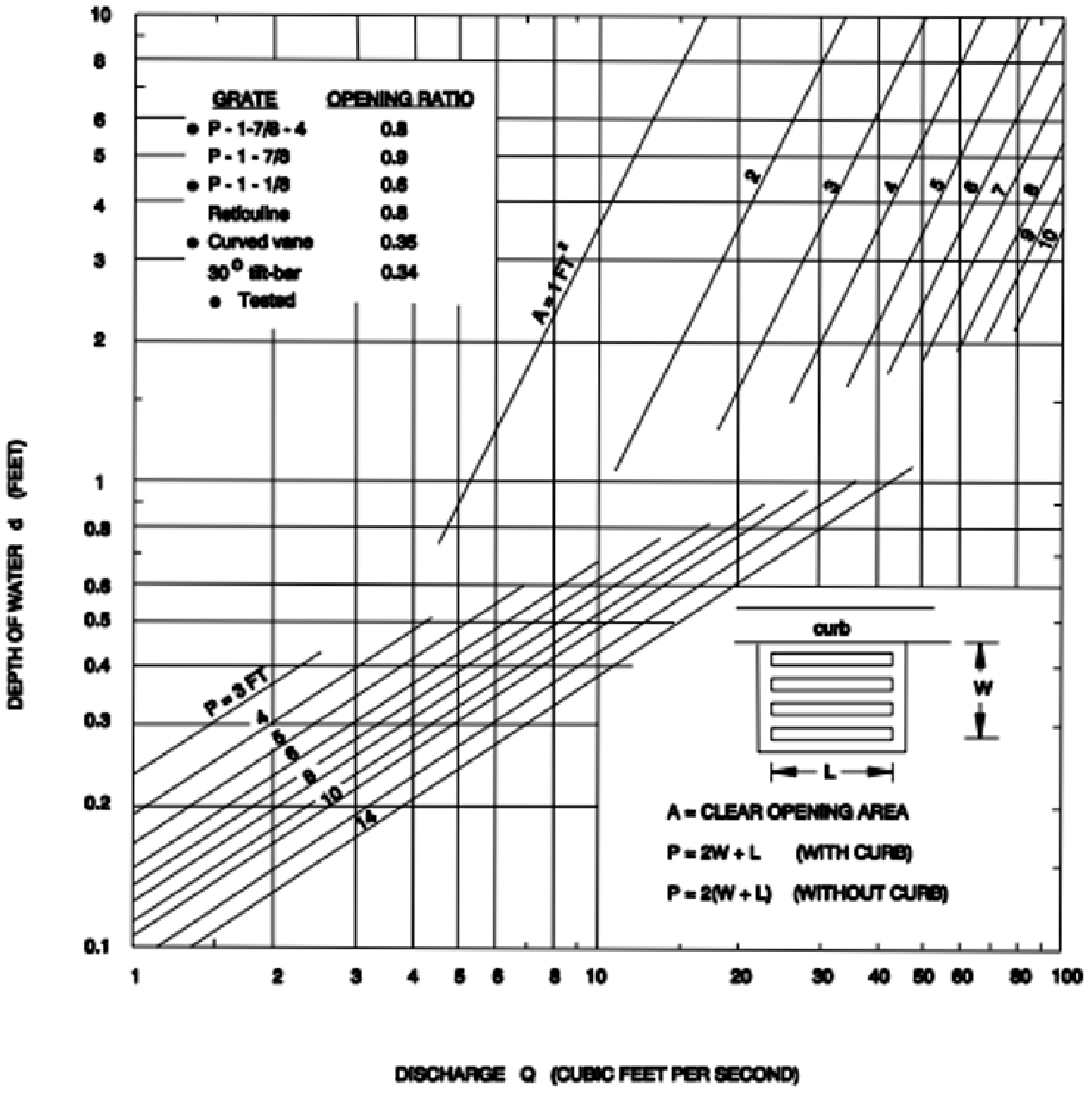


Figure 1 Grate inlet capacity in Sump Conditions

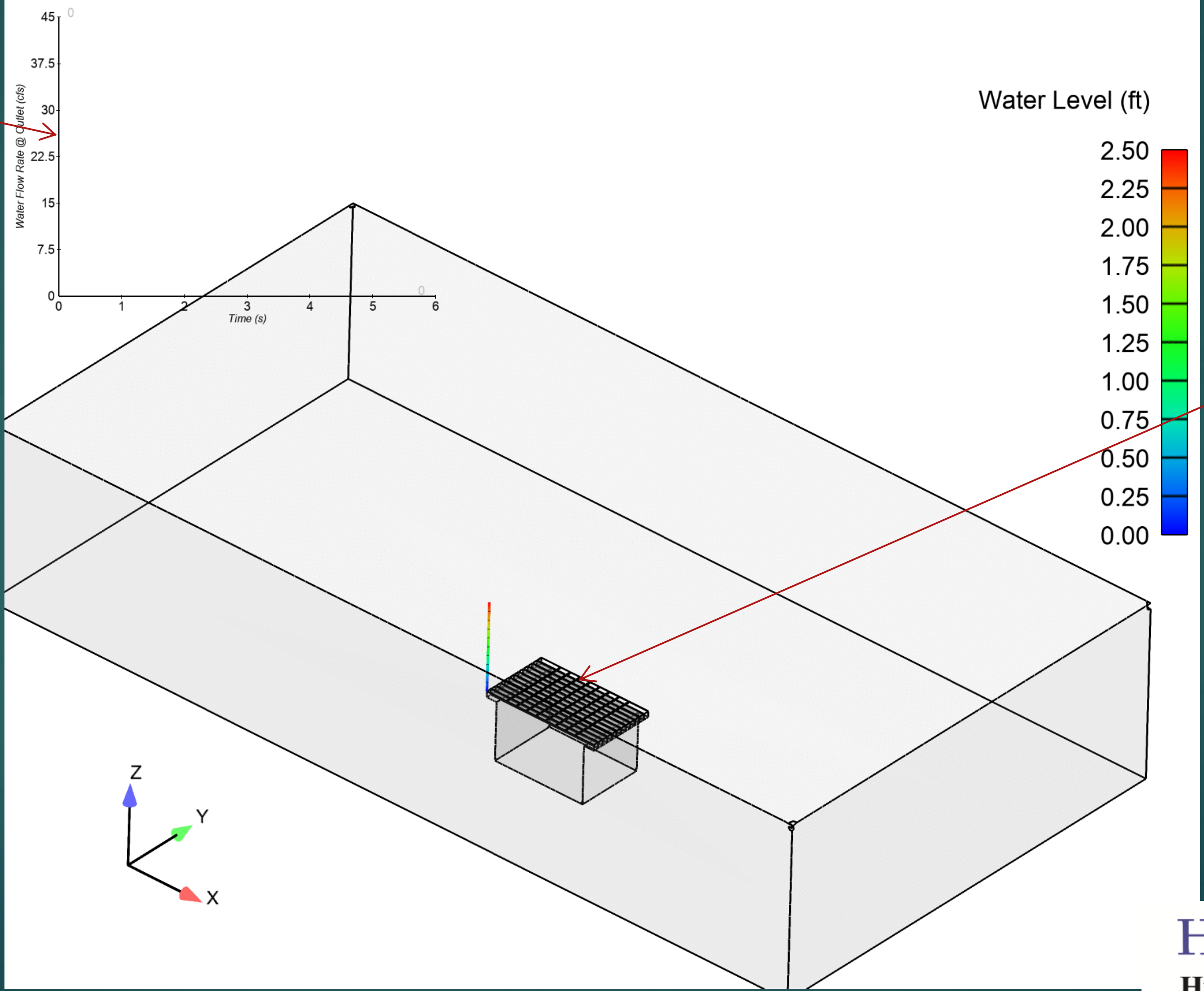
(Chart 8 in https://www.oregon.gov/ODOT/GeoEnvironmental/Docs_Hydraulics_Manual/Hydraulics-13-H.pdf)

Why CFD?

- Small-Scale Modelling with complex geometry is not typically available in hydraulic software.
  - Evaluate the as-built capacity of the storm drain inlet
- Capture all types of flow in one simulation: weir flow, mixing flow, to orifice flow

Results: Water interface colored by water level

Water flow rate through the Grate plot



Note that water depth changes from :
weir flow, through mixing flow to orifice flow. This is all captured through the underlying Navier-Stokes equations without any need to adjust the model

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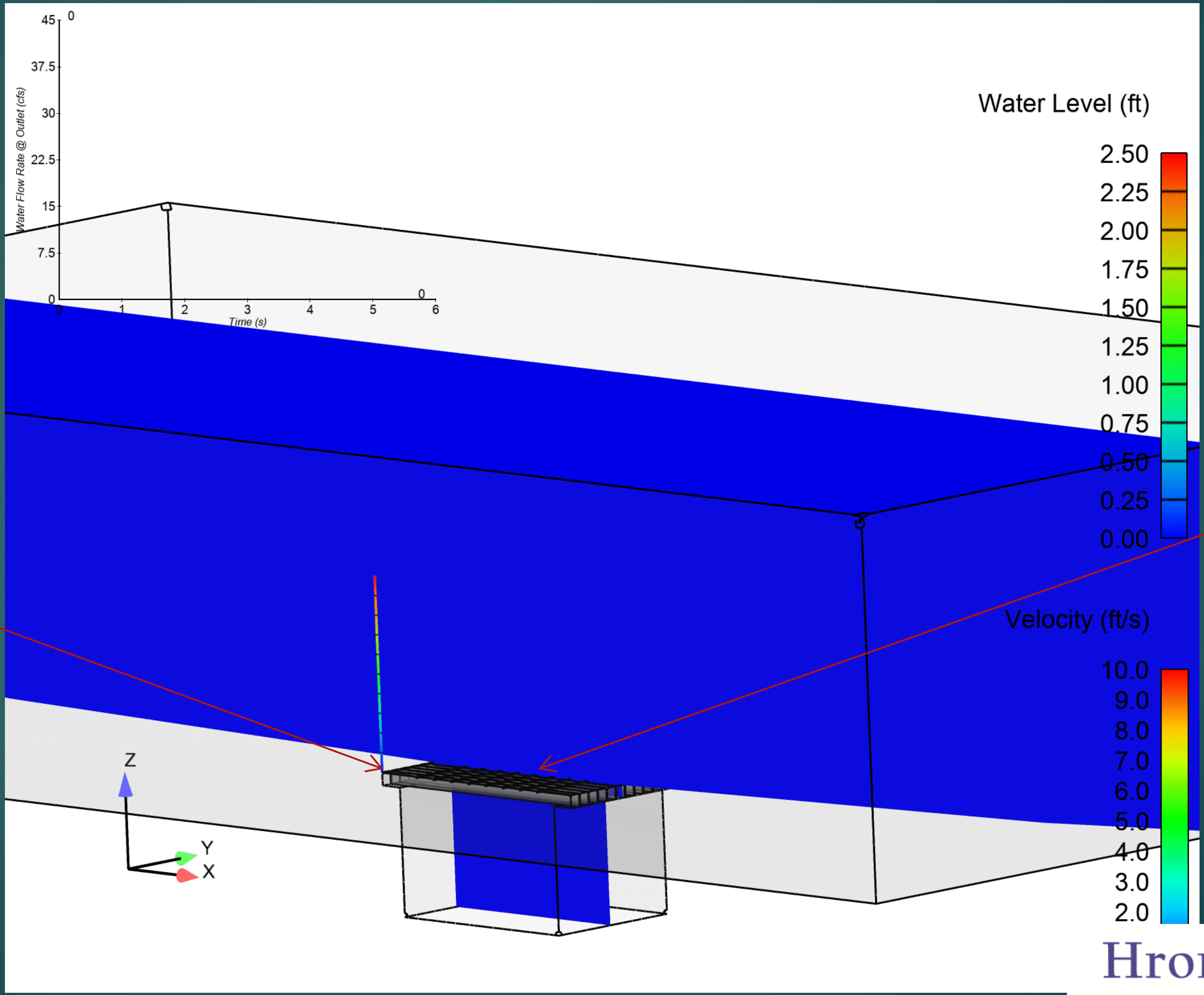
Results: Cut plane colored by water velocity

Water flow rate through the Grate plot



0,0,0 reference point @ top surface of grate

Water depth changes from : weir flow, through mixing flow to orifice flow

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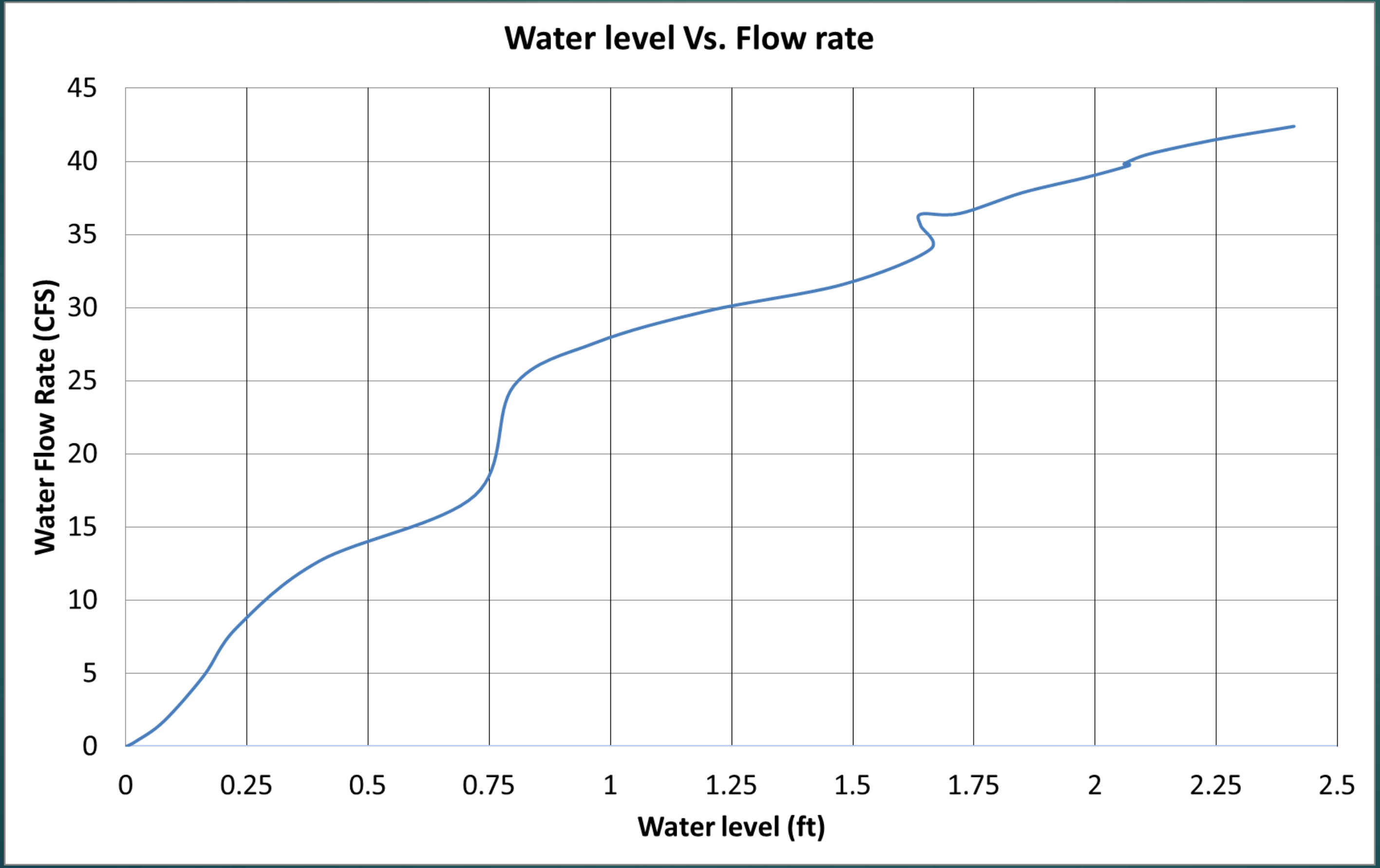
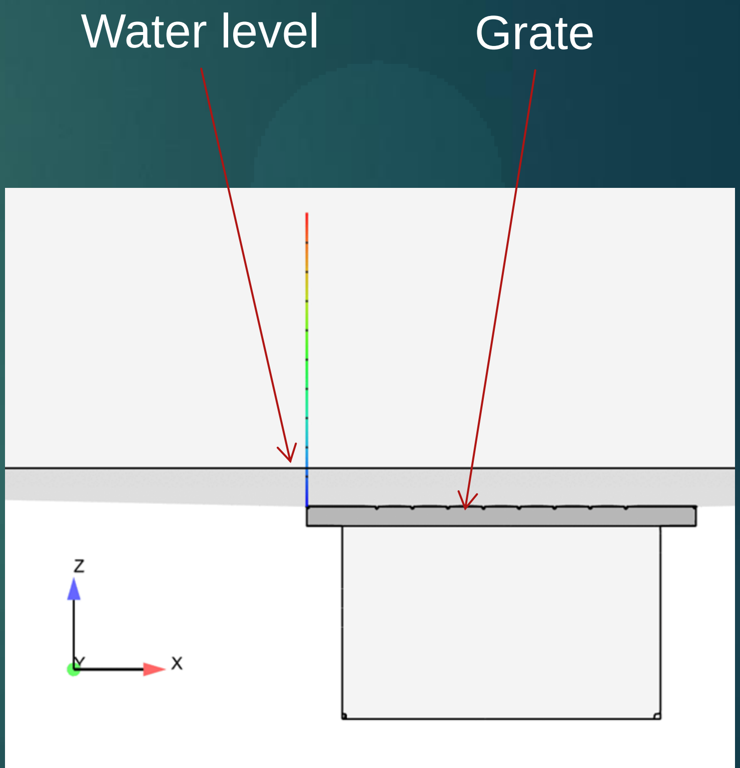
Results: Water level above the grate Vs. Flow Rate





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