Black Butte Dam Erosion Repairs

3D Model and Analysis

April 12, 2016

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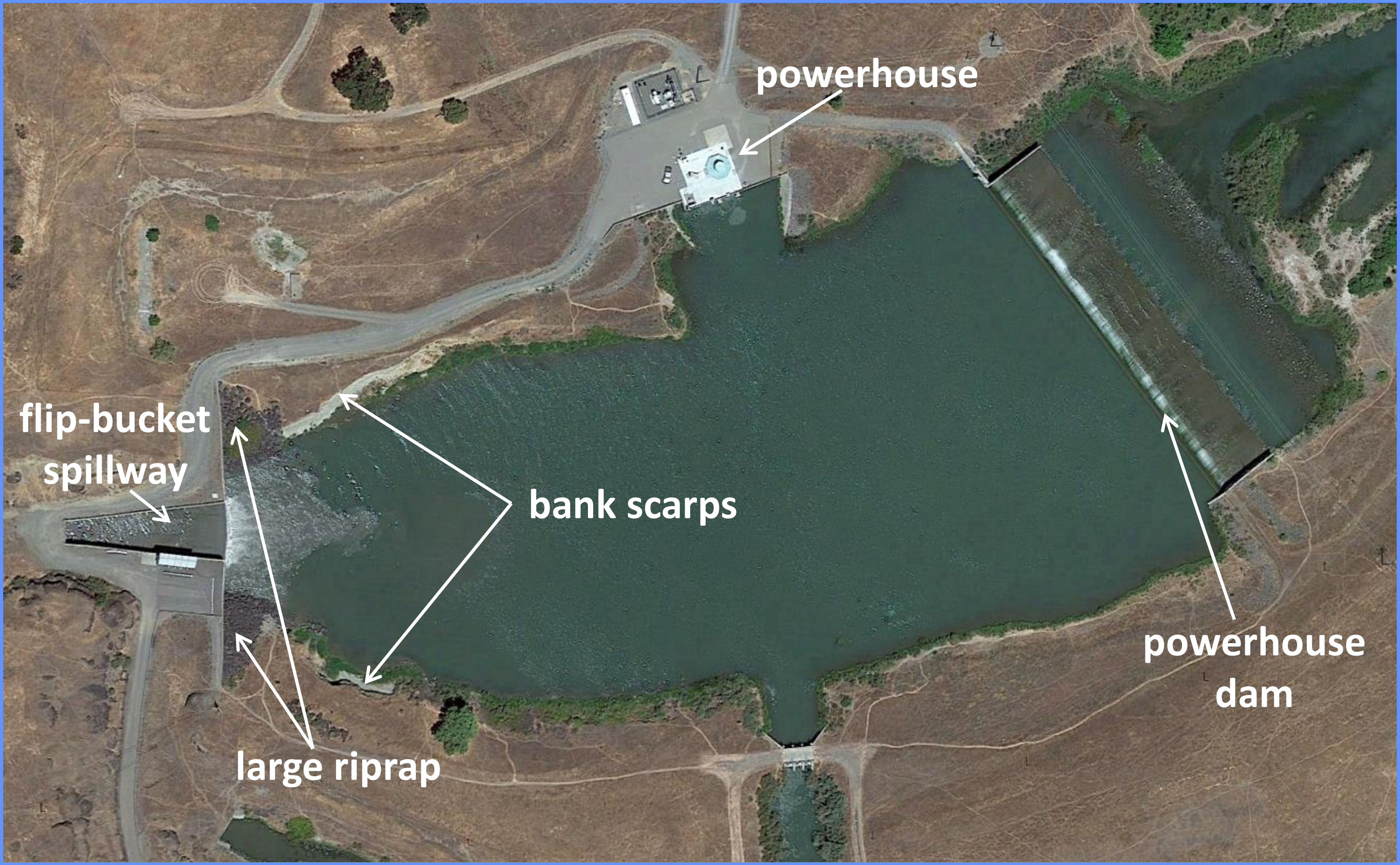
City of Santa Clara
The Center of What's Possible

Site Overview



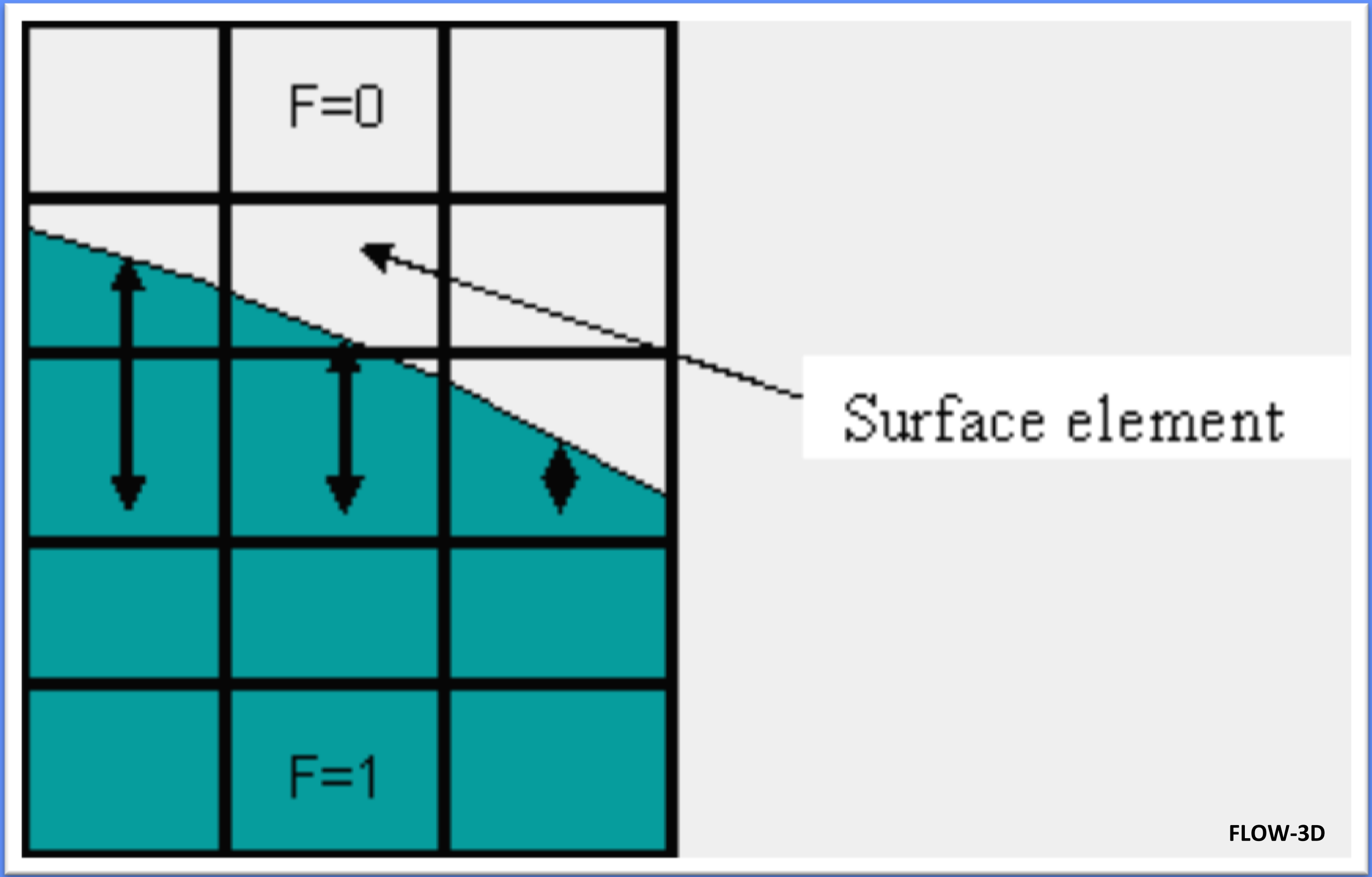
North Bank Scarp

What is a flip-bucket?

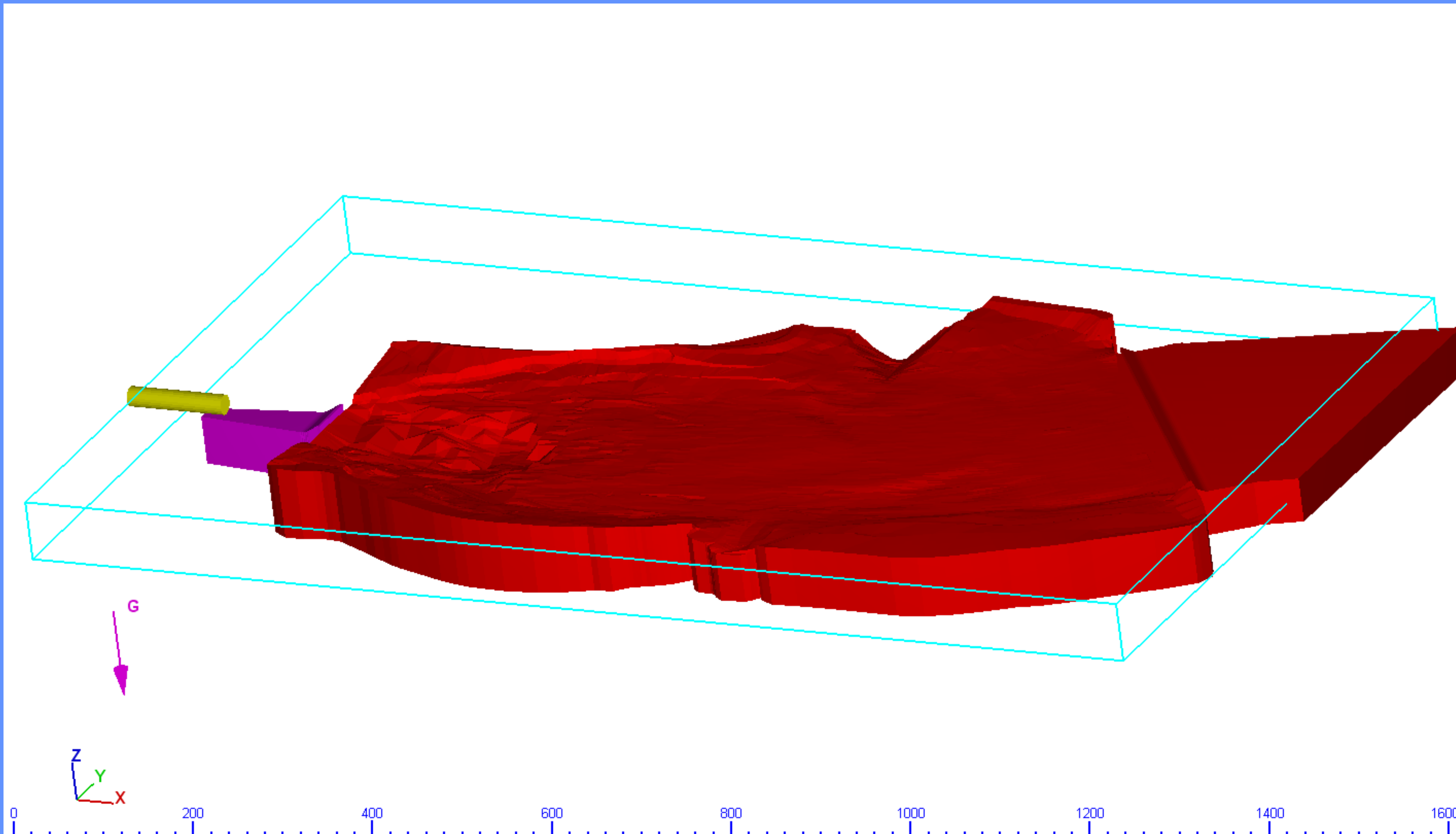
What is a flip-bucket?

VOF

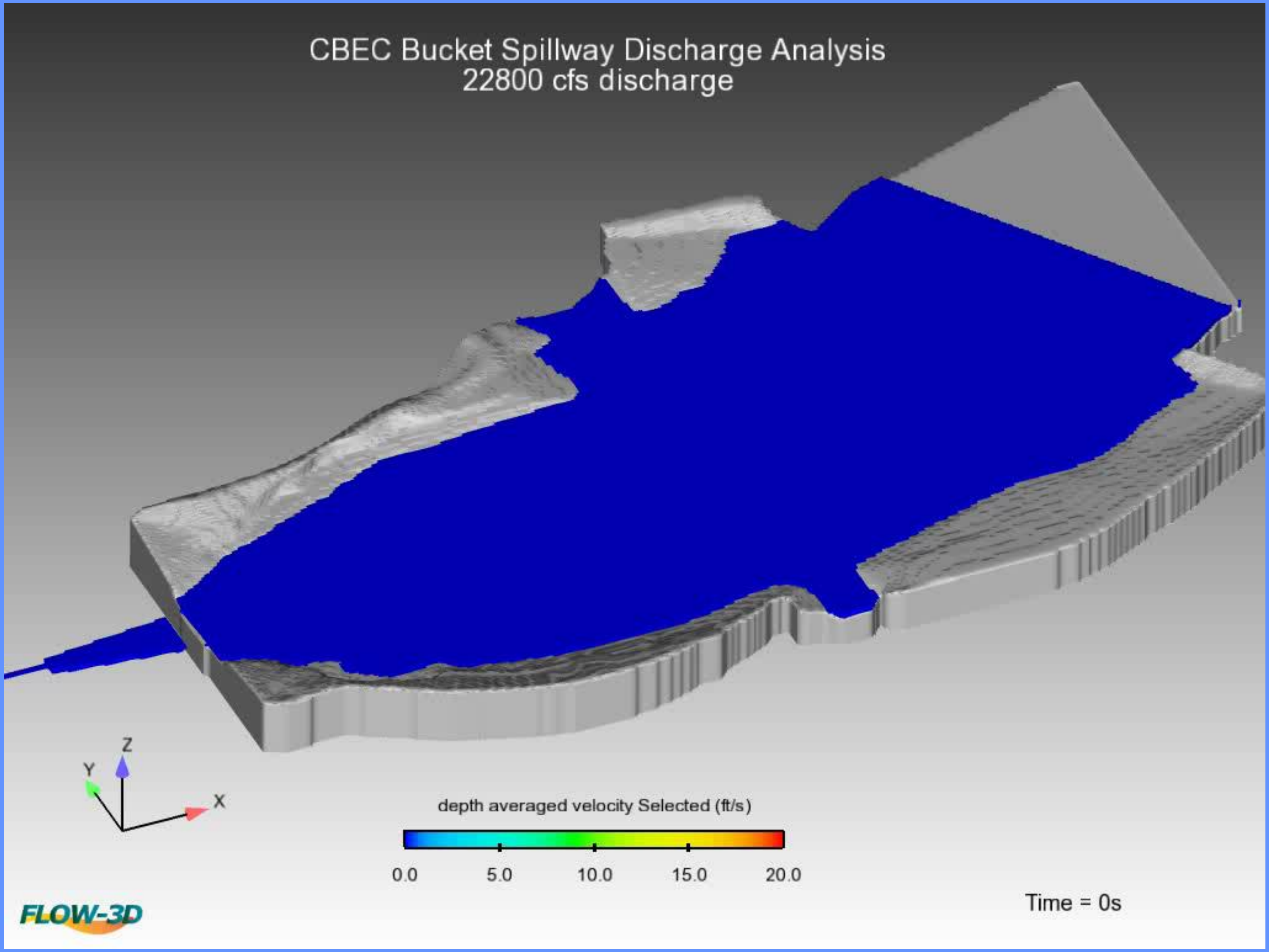
(Volume of Fluid)



Model Geometry



Simulation Results



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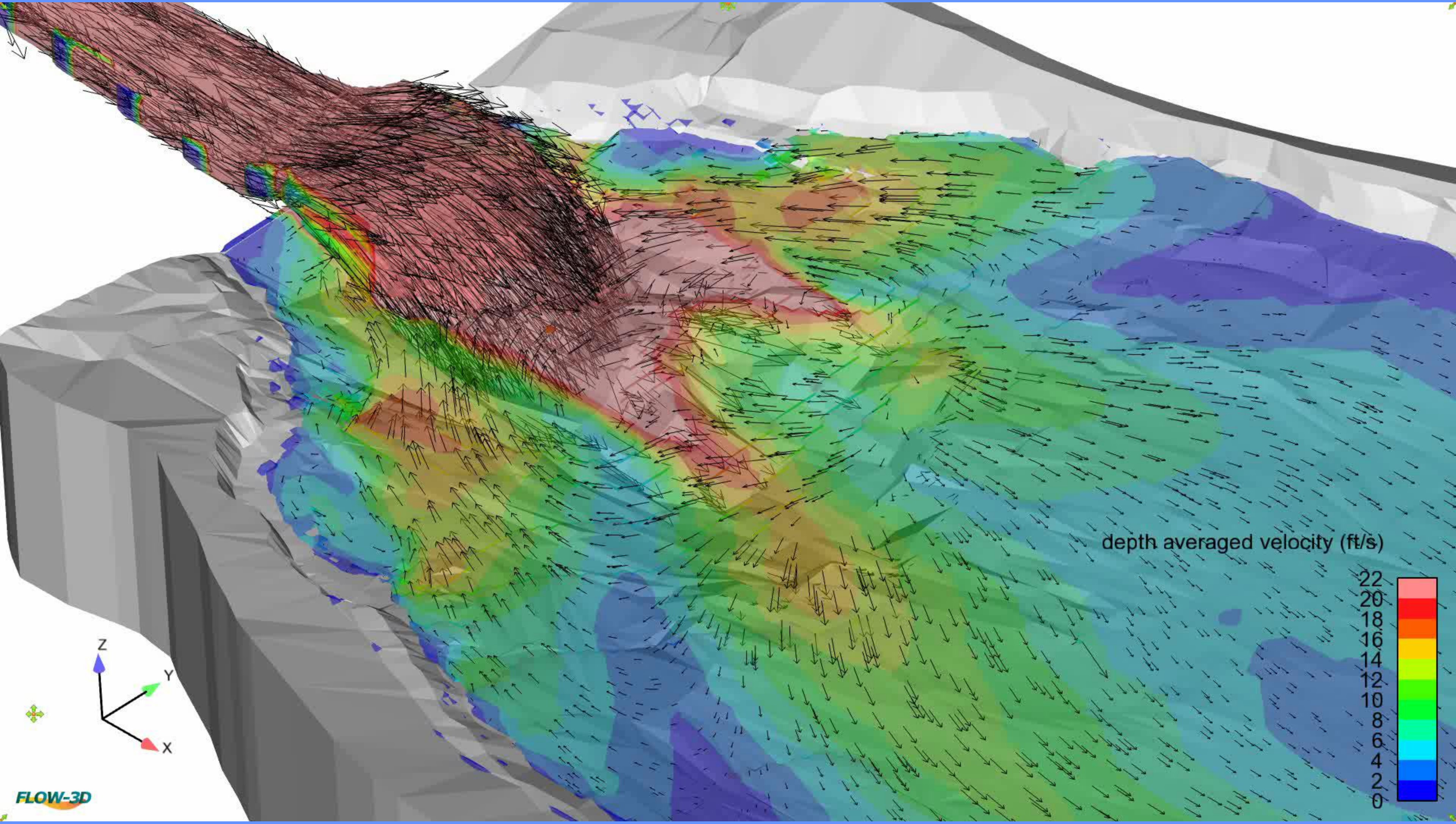
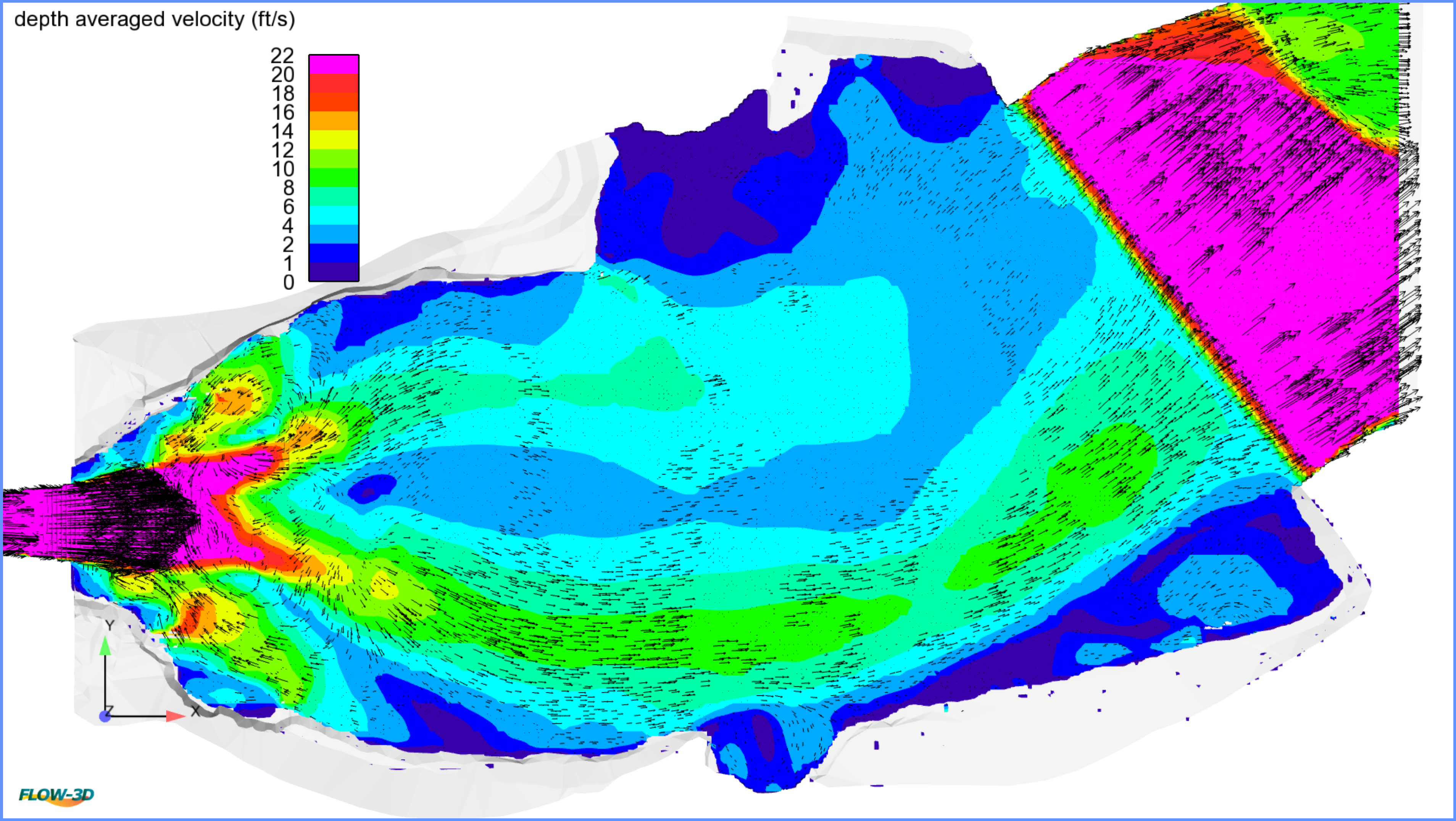
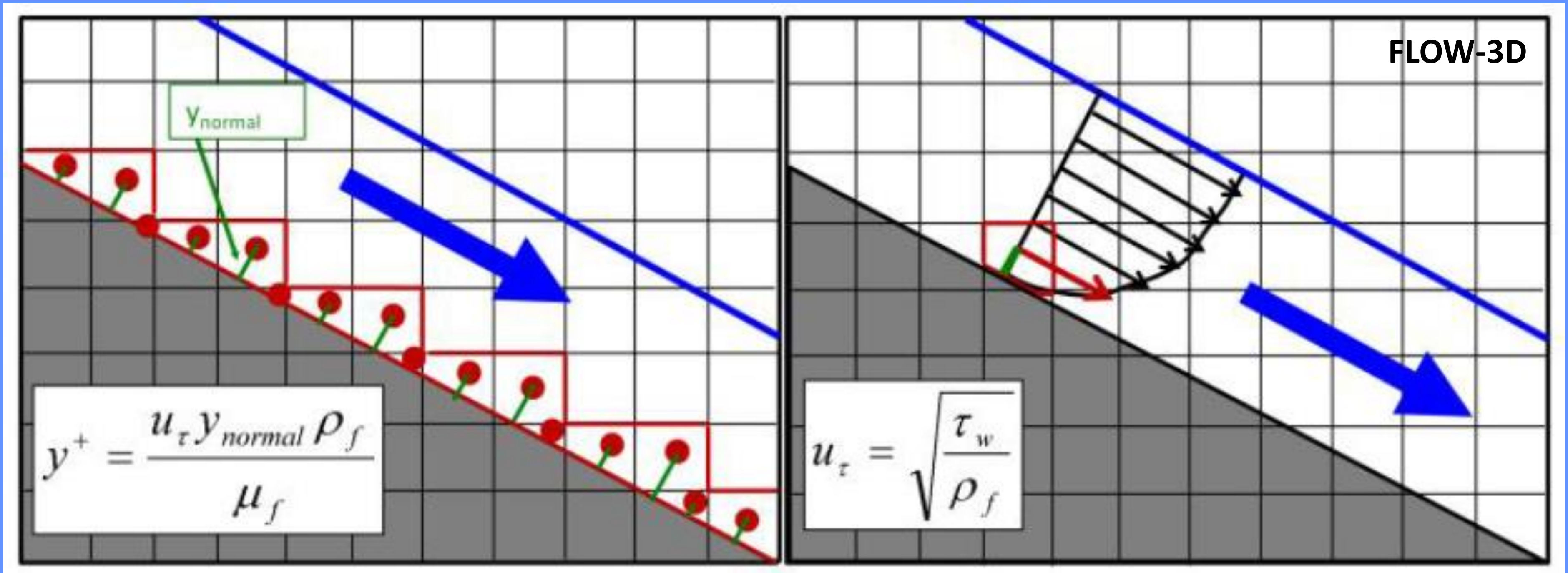


Simulation Results



Challenge #1: Mesh Resolution



Solution: use depth averaged velocity with coarse model resolution

Challenge #2: Which equation is right for me?

Need to size riprap to resist erosion:

1. Eddies
   a) **Shear Stress** – Shield’s Equation w/ bed shear stress from depth averaged velocity
   b) **Empirical** – USACE and HEC-11 velocity based
2. Waves
   a) **Empirical** – USACE and HEC-11 wave-height based

Challenge #2a: How do we calculate Cd?

- In order to calculate bed shear we need to have drag coefficient

$$\tau_b = \rho C_d \bar{v}^2$$

$$d_{50} = \frac{\tau_b}{\tau^*(\gamma_s - \gamma_w)}$$

  - Large depth range
    - FLOW-3D sediment transport Cd = f(d,Ks)

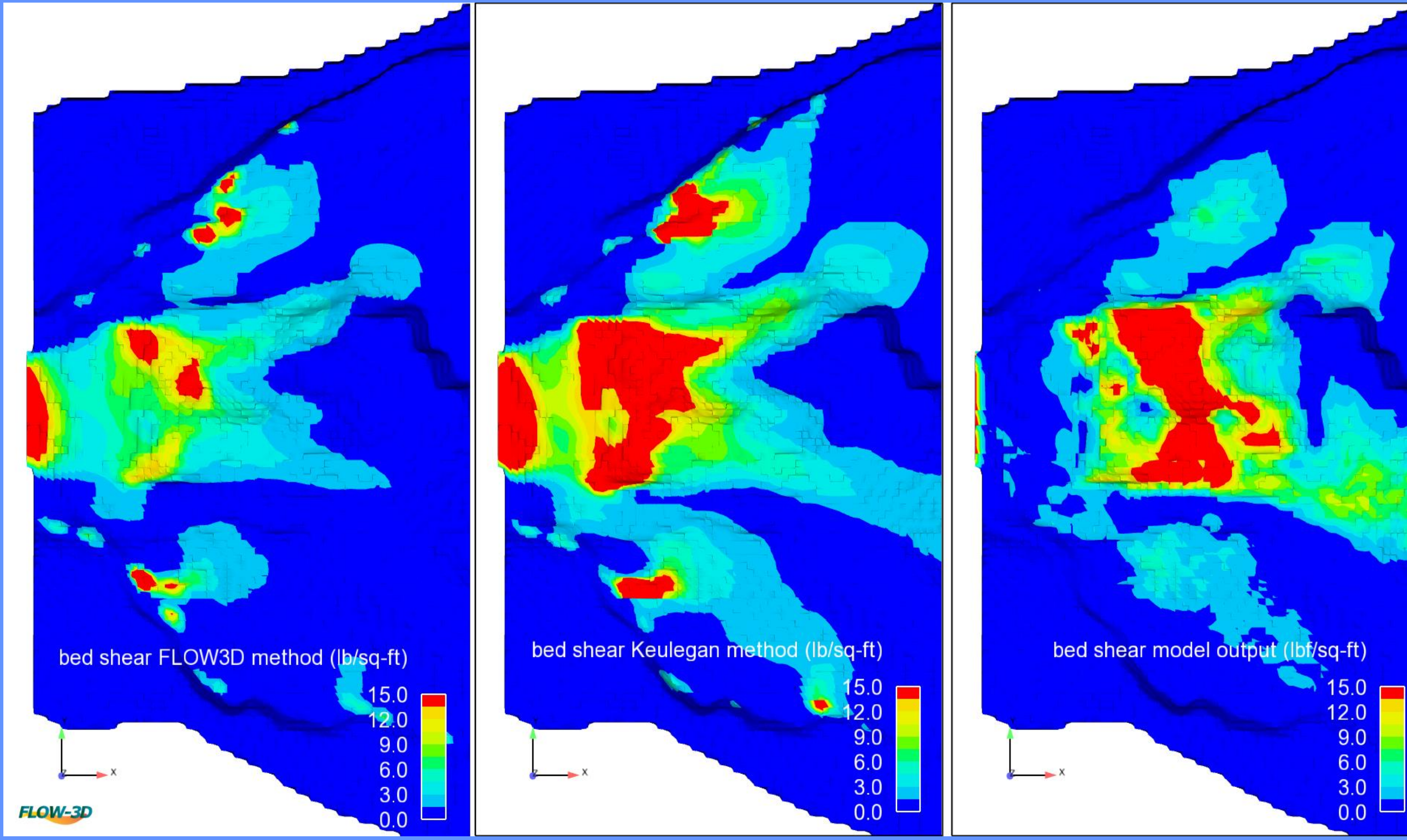
$$C_d = \left(\frac{k}{\beta + \ln\left(\frac{k_s/30}{h} \right)} \right)^2$$

    - Keulegan equation Cd = f(d,Ks,F)

$$C = 32.6 * \log_{10}\left[10^{\frac{A_r\sqrt{g}}{32.6}} \frac{R}{k_s} \right] \qquad n = \frac{1.486}{C} R^{1/6} \qquad C_d = g \frac{n^2}{h^{1/3}}$$

    - Both **fail** at low depth to substrate height ratios

Bed Shear – Comparison



Challenge #2b Safety/Adjustment Factors

- Empirical equations developed to calculate rock size using 1D model results of main channel depth and velocity
- We used a 3D model so we should have much more accurate near bank values

HEC-11

$$d_{50} = C_{sg} C_{sf} \frac{0.001 V^3}{h^{1/2} {k_1}^{3/2}}$$

USACE

$$d_{30} = S_f C_s C_v C_t d \left[\left(\frac{\gamma_w}{\gamma_s - \gamma_w} \right)^{1/2} \frac{V}{\sqrt{k_1 g d}} \right]^{5/2}$$

Challenge #2c: Waves

- Model likely not turbulent enough to fully characterize standing waves
  - To capture standing waves need LES
- **Solution:** estimated wave height and period from video and corroborate with model observations

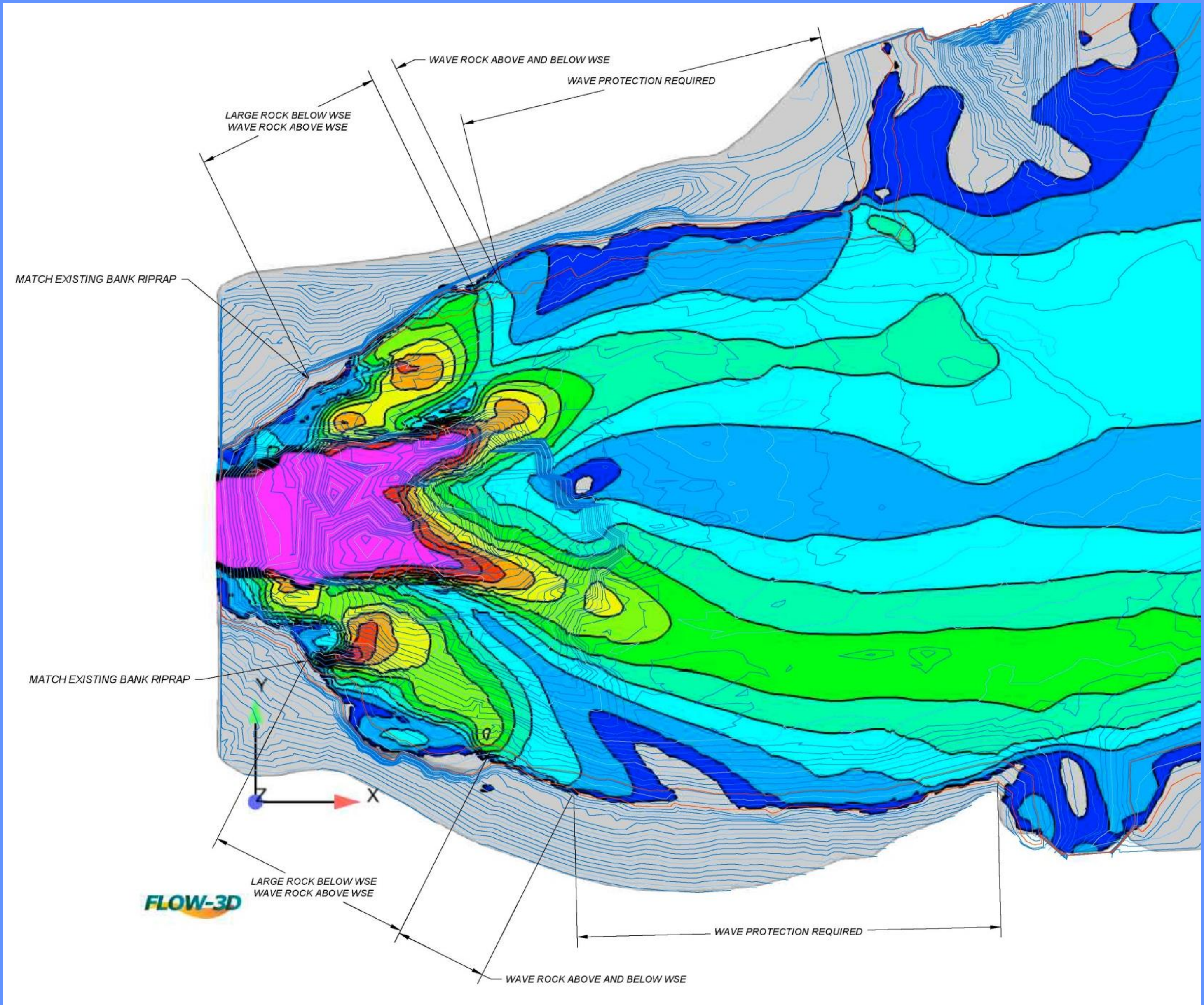
rock size

$$W_{50} = \frac{H^3 \gamma_r}{k_D \left(\frac{\gamma_r}{\gamma_w} - 1\right)^3 cot\theta} \longrightarrow d_{50} = \left(\frac{6W_{50}}{\gamma_r \pi}\right)^{1/3}$$

run up height

$$\varepsilon = \frac{tan\theta}{\left(\frac{2\pi H}{g{T_p}^2}\right)^{1/2}} \longrightarrow R_{max} = H * \frac{a\varepsilon}{1 + b\varepsilon}$$

Rock Recommendations



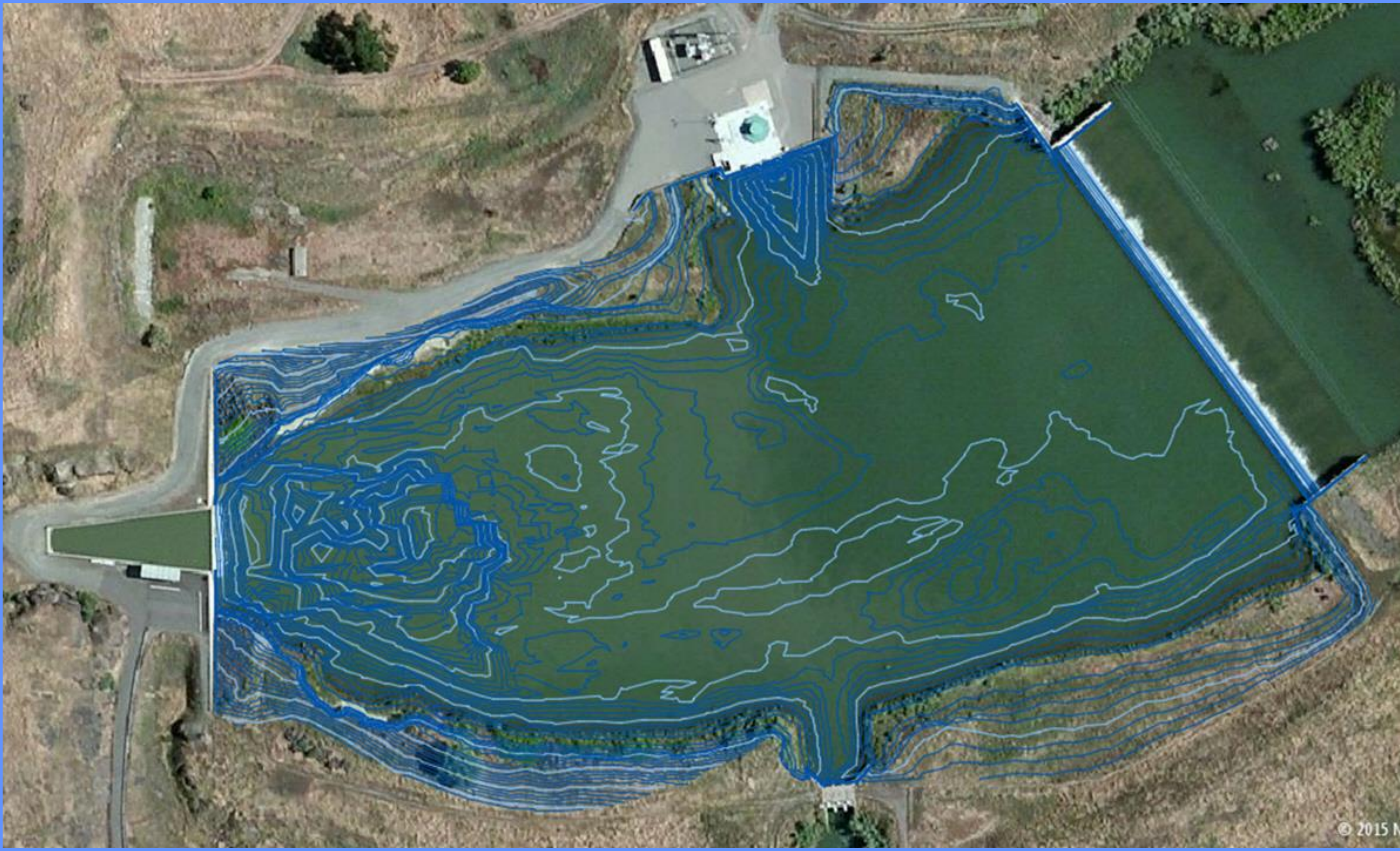
Riprap Size Comparison

Method	Average D50 Absolute (ft)	Average D50 Relative
FLOW-3D Cd - Shear	1.0	0.6
HEC-11 - Wave	1.4	0.8
USACE - Wave	**1.7**	**0.9**
Model Output – Shear*	1.8	1.0
Keulegan Cd - Shear	2.4	1.3
HEC-11 - Velocity	3.3	1.9
USACE - Velocity	**3.4**	**1.9**

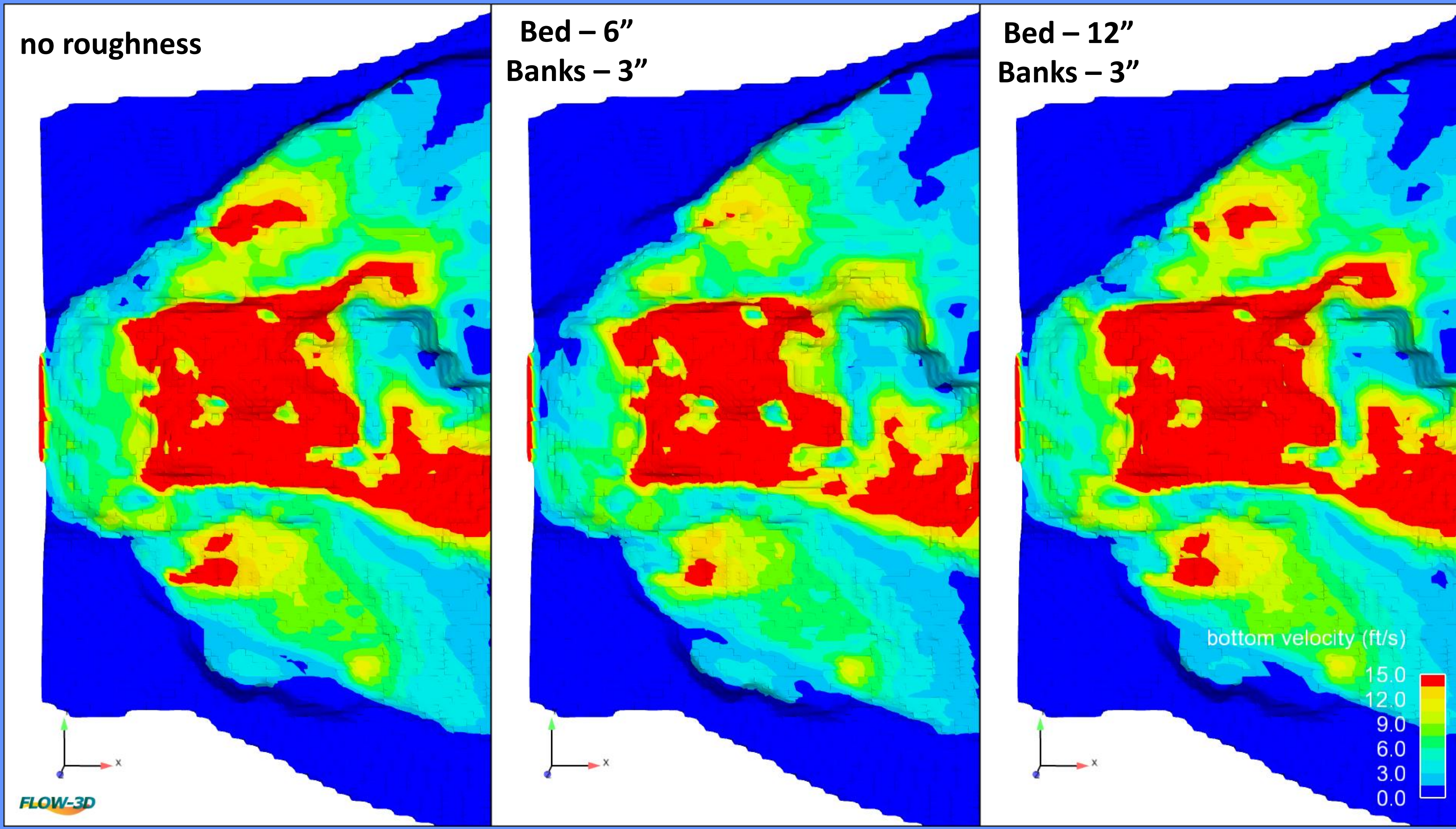
Acknowledgments

- Sam Diaz (cbec eco engineering)
- Matt Powers (GEI Consultants)
- City of Santa Clara

Questions?



Roughness Sensitivity Testing



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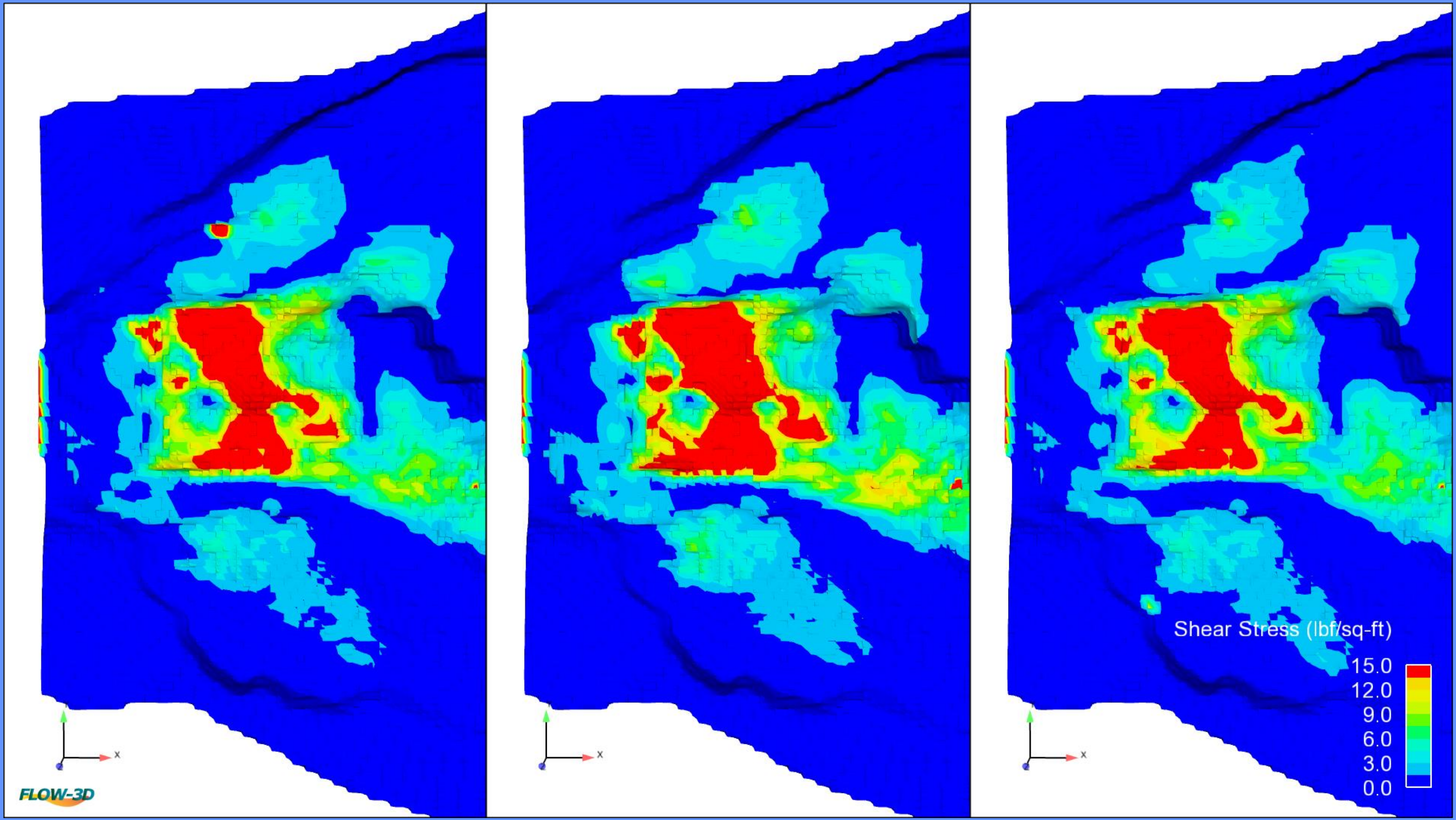

Picking Representative Values