Non-Newtonian Validation and Verification in HEC-RAS

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US Army Corps of Engineers®

FLOOD RISK MANAGEMENT RESEARCH & DEVELOPMENT

POST-WILDFIRE FLOOD RISK MANAGEMENT

Santa Barbara Mud-and-Debris Flow

Local News

A Year Ago, Montecito Debris Flows Brought 'Unfathomable Destruction' to Coastal Community

Residents and first responders recall and reflect on the fateful Jan. 9 events that reshaped their world

1 > of 11

Santa Barbara County responders launched into rescue mode in the early-morning hours of Jan. 9, 2018 after debris flows devastated Montecito. (Ray Ford / Noozhawk photo)

By Joshua Molina, Noozhawk Staff Writer | @JECMolina | January 8, 2019 | 10:02 p.m.

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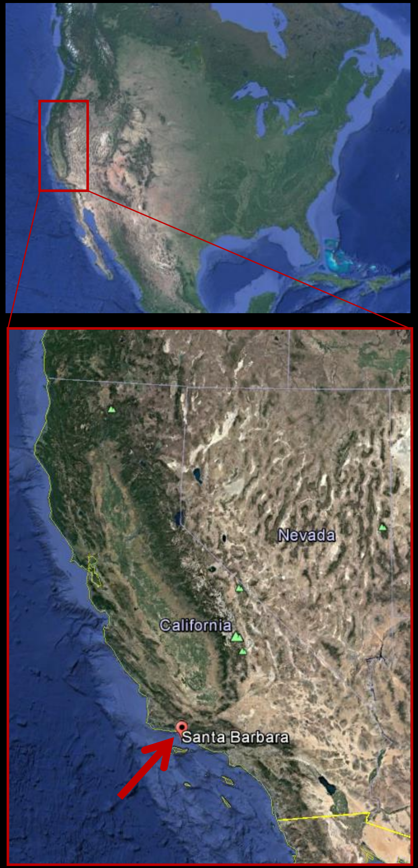
NATION & WORLD

Mudslide-stricken California town is all but emptied out as residents ordered to leave

By KRYSTA FAURIA AND BRIAN MELLEY
ASSOCIATED PRESS | JAN 12, 2018 | 11:37 PM | MONTECITO, CALIF.

A house sits among boulders and mud along Glen Oaks Drive in Montecito after a major storm hit the burn area Wednesday. (Wally Skalij / Los Angeles Times)



23 Fatalities
Damages:
$200 Million (USD)

Santa Barbara Mud-and-Debris Flow

HEC-RAS

1&2D Hydraulic and Morphdynamic Software

100,000 Downloads/Year in 200 countries

Newtonian Assumptions

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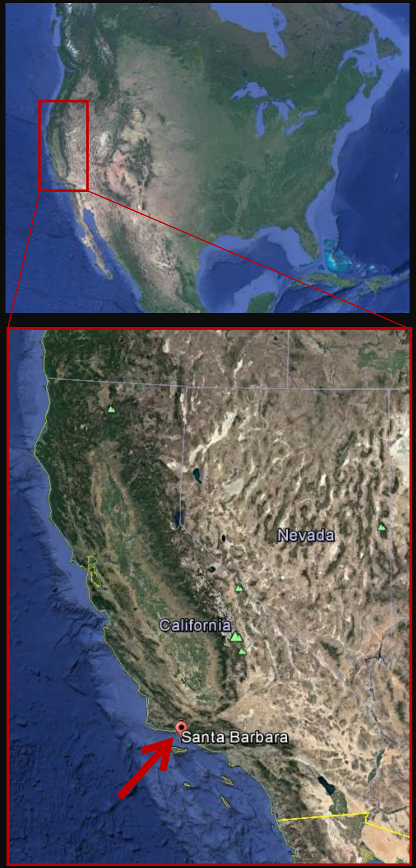

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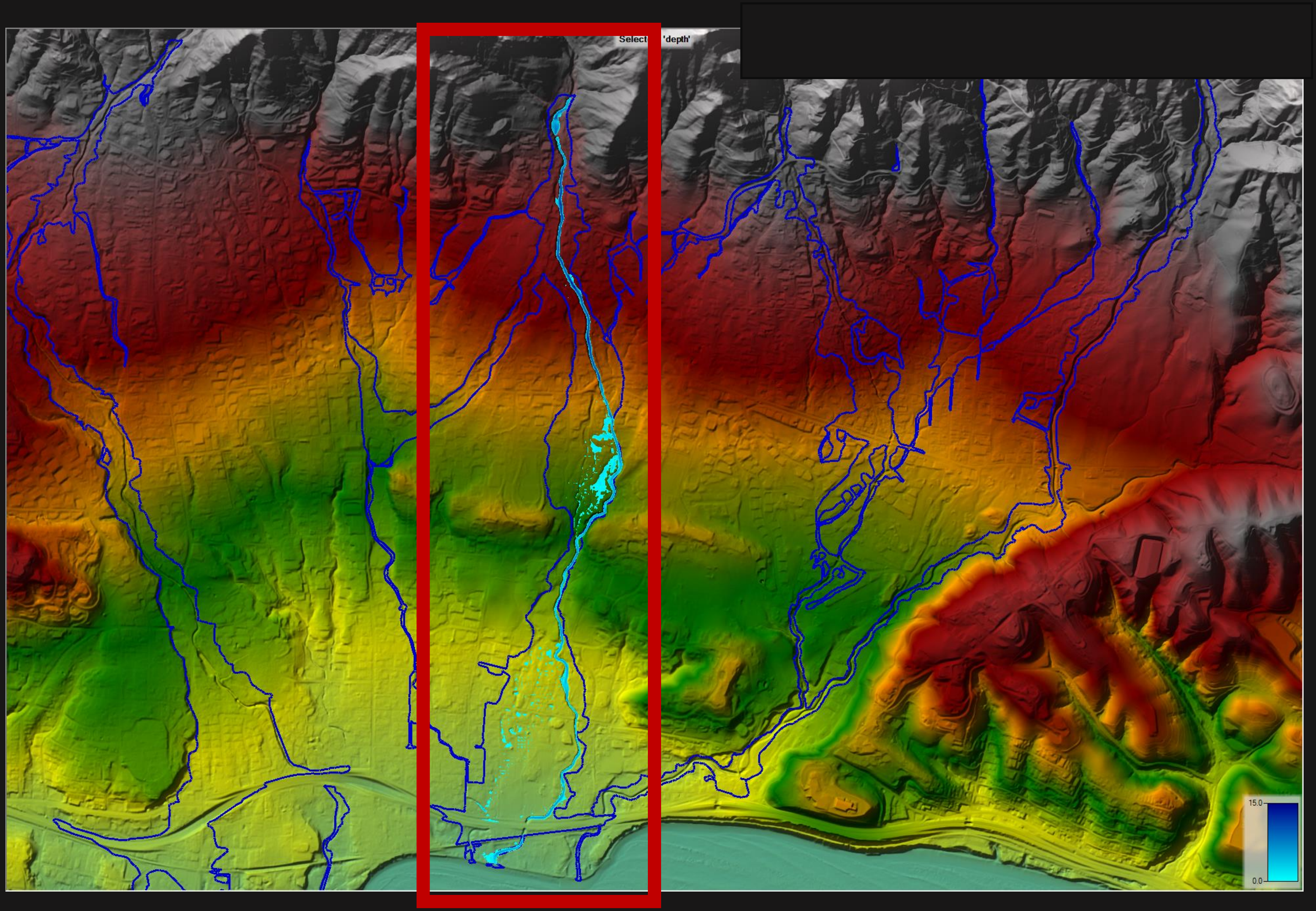

Non-Newtonian Validation and Verification in HEC-RAS

1. Non-Newtonian Closure in HEC-RAS

2. Laboratory and Meso-Scale Validation and Verification

3. Field Applications

US Army Corps of Engineers®

POST-WILDFIRE FLOOD RISK MANAGEMENT

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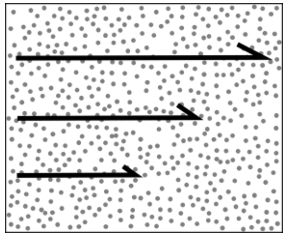
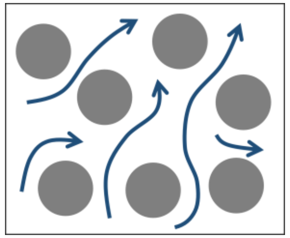
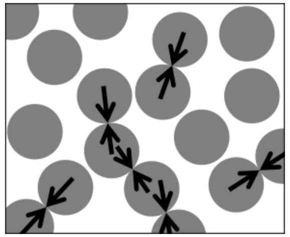
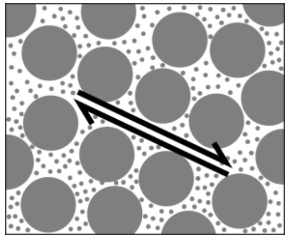
Taxonomy of Geologic Flows

Flow Type	Hyperconcentrated	Mudflow	Grain Flow Collision Dominated	Debris Flow Friction Dominated
Internal Loss Mechanism	Viscous	Turbulence	Grain Collison	Matrix Strength
Support Schematic				

Lower Concentration → Higher Concentration

Finer Sediment → Coarser Sediment

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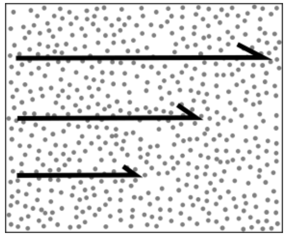
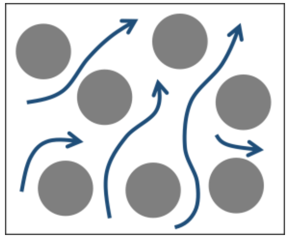
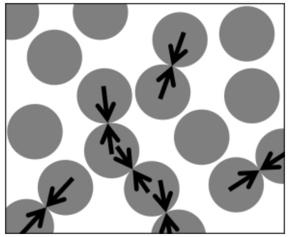
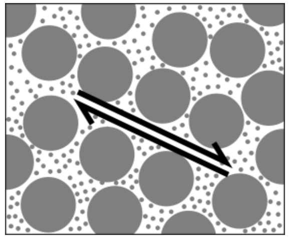
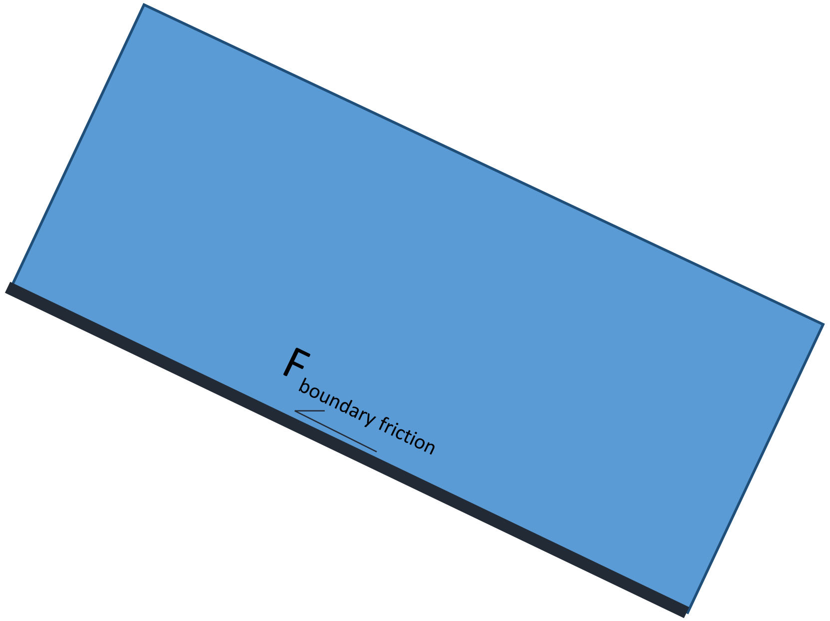
Support Schematic				



Clear Water Resisting Forces

Mud and Debris Flow Resisting Forces

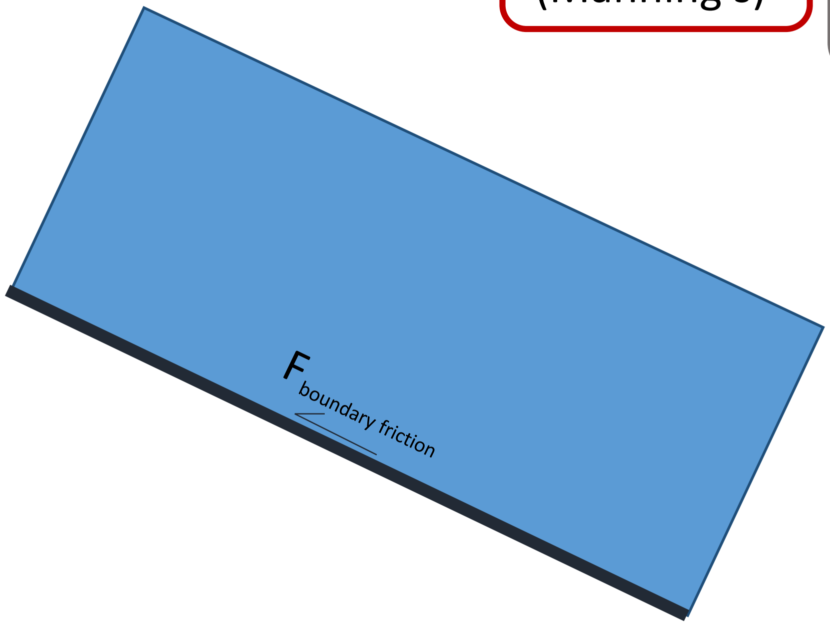
We Integrate These Effects in the Momentum Equation by Partitioning the Friction Slope

$$\frac{\partial Q}{\partial x} + \frac{\partial s_c \left(A + A_o\right)}{\partial t} - q = 0 \qquad \textbf{(Conservation of Mass)}$$

$$\frac{\partial \left(s_m Q\right)}{\partial t} + \frac{\partial \left(\beta Q^2 / A\right)}{\partial x} + gA\left(\frac{\partial h}{\partial x} + S_f + S_i\right) + L = 0 \qquad \textbf{(Conservation of Momentum)}$$

Friction Slope (Manning's)

Viscous and Inertial Internal Losses



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Friction Slope (Manning's)

Viscous and Inertial Internal Losses

Friction Slope is a Function of Shear Stress

$$\tau_b = \gamma R S_f \sim \gamma D S_f$$

$$S_f = \left(\frac{\tau_b}{\gamma D}\right)$$

We Can Also Express Internal Losses as a Stress

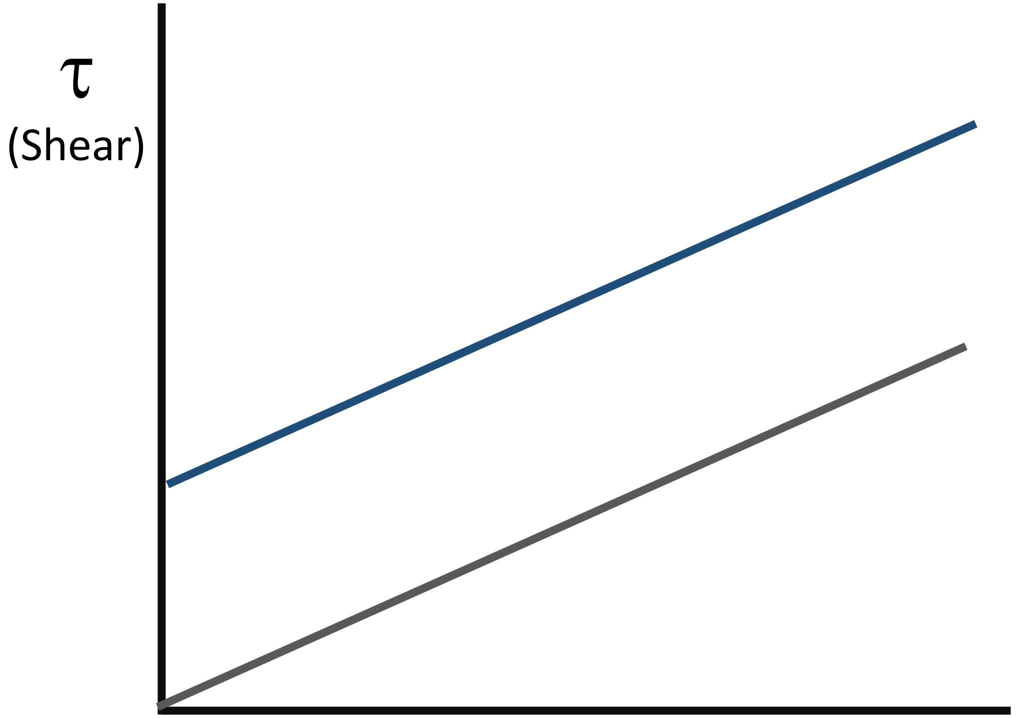
$$S_i = \left(\frac{\tau_i}{\gamma D}\right)$$

Which Allows Us To Quantify These Effects with Stress-Strain (Rheological) Models

Rheological Models

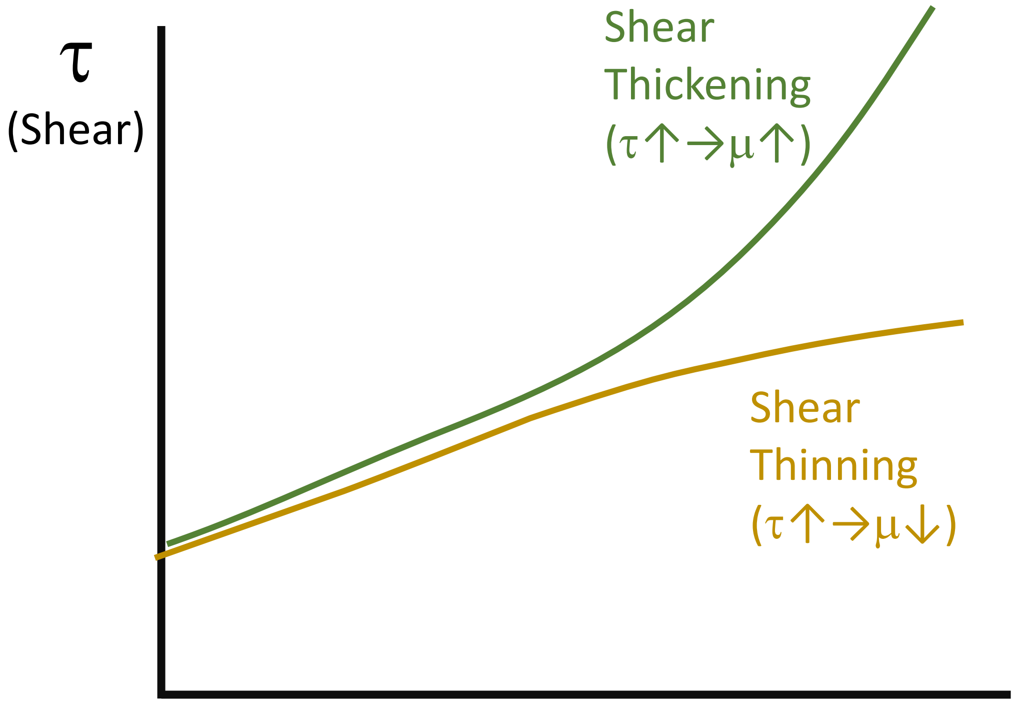
Deformational/Stress-Strain Relationships

$$\tau = \tau_y + \mu\left(\frac{dv_x}{dz}\right)$$

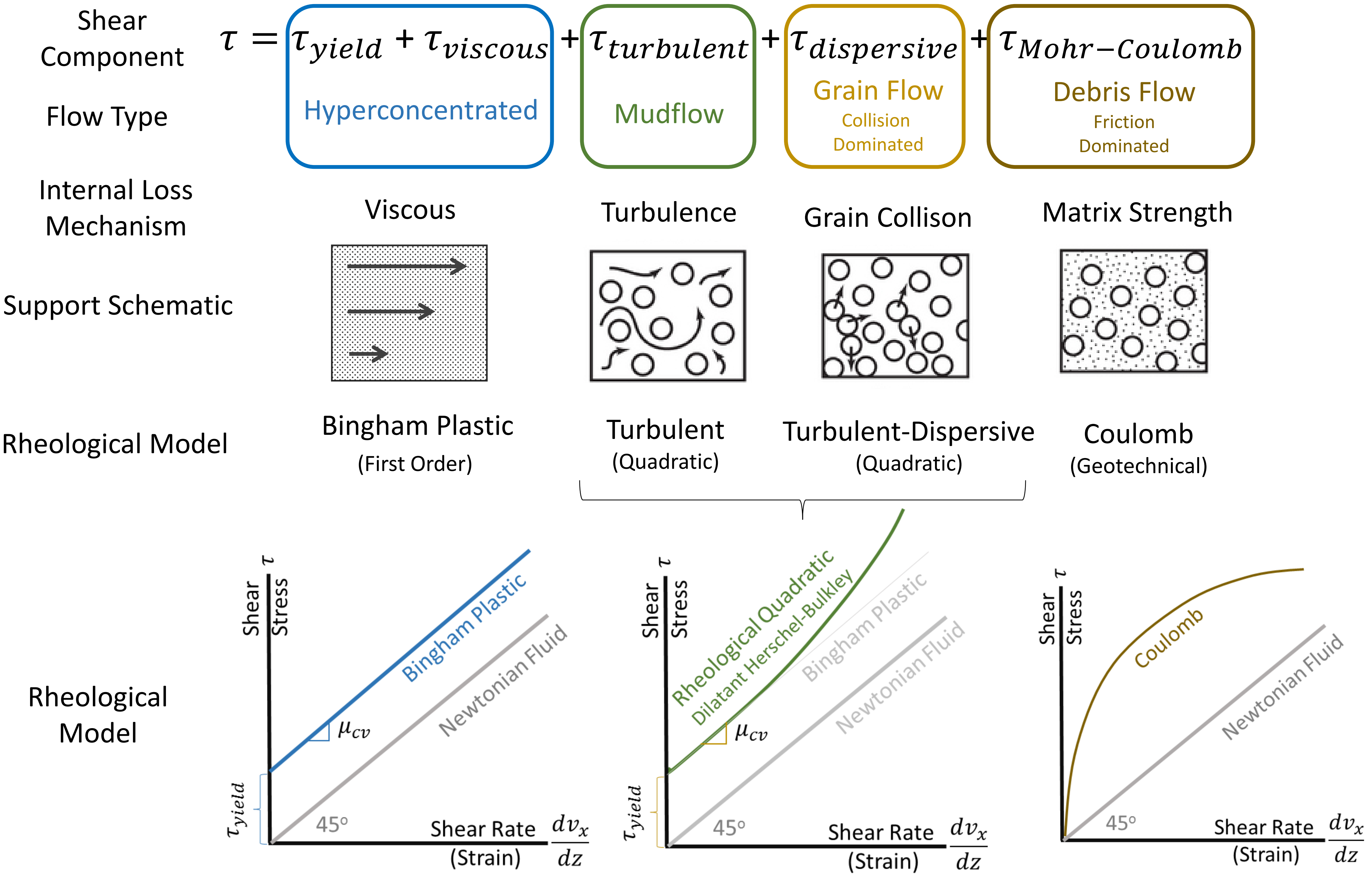


Linear: Newtonian
& Bingham Plastic

$$\tau = \tau_y + \mu\left(\frac{dv_x}{dz}\right) + \varphi\left(\frac{dv_x}{dz}\right)^2$$



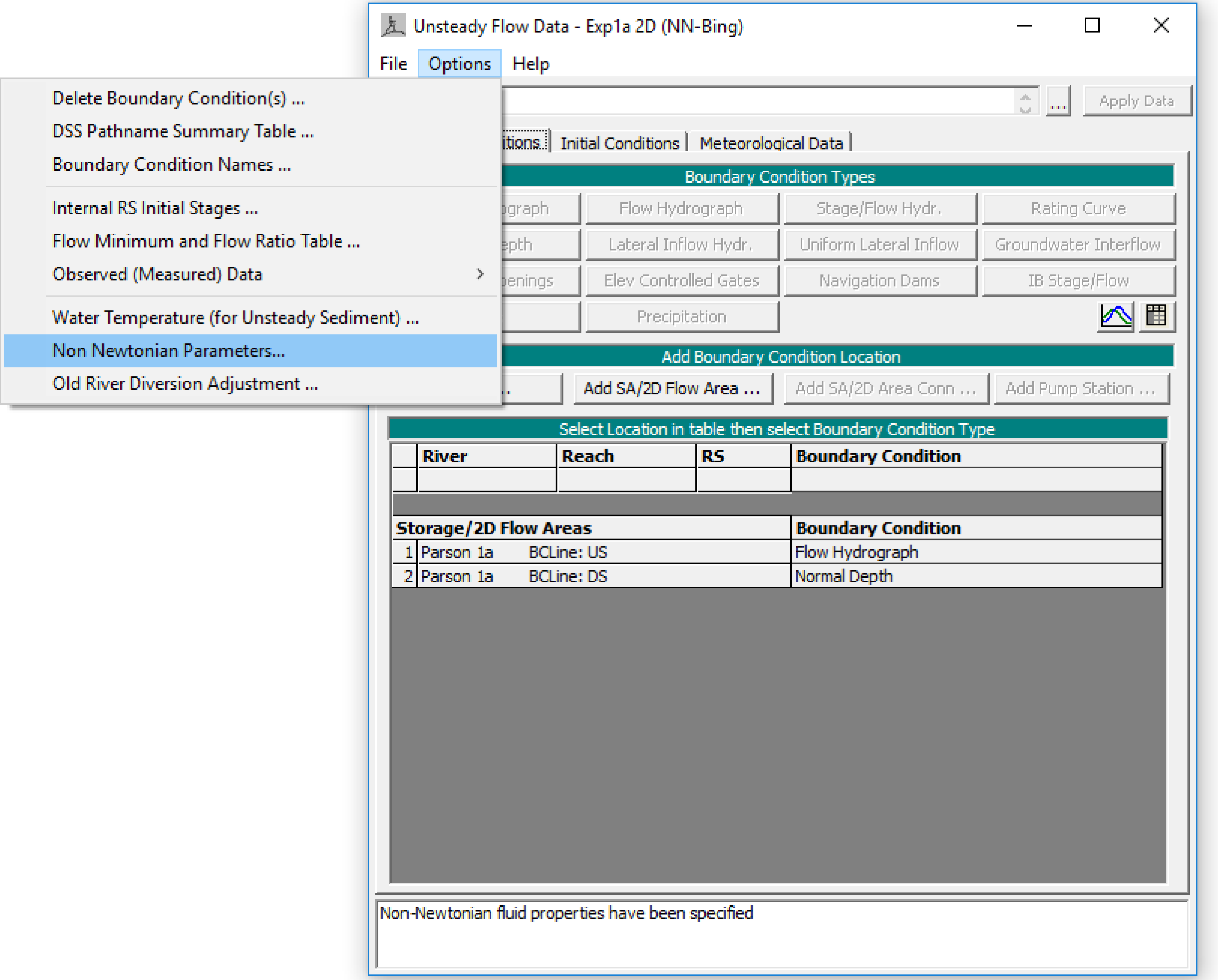
Non-Linear:
Quadratic

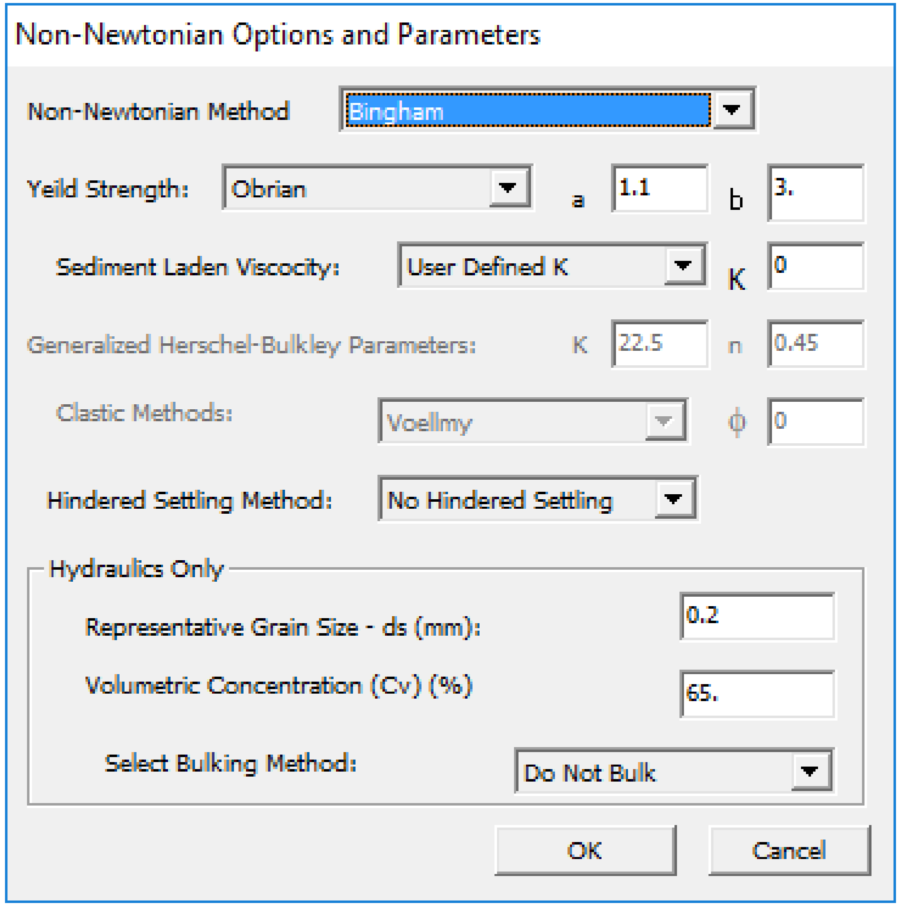


Shear Component
$\tau = \tau_{yield} + \tau_{viscous} + \tau_{turbulent} + \tau_{dispersive} + \tau_{Mohr-Coulomb}$
Flow Type
Hyperconcentrated
Mudflow
Grain Flow
Collision Dominated
Debris Flow
Friction Dominated
Internal Loss Mechanism
Viscous
Turbulence
Grain Collison
Matrix Strength
Support Schematic
Rheological Model
Bingham Plastic
(First Order)
Turbulent
(Quadratic)
Turbulent-Dispersive
(Quadratic)
Coulomb
(Geotechnical)
Rheological Model
Shear Stress τ
Bingham Plastic
Newtonian Fluid
μ_{cv}
τ_{yield}
45°
Shear Rate (Strain) $\frac{dv_x}{dz}$
Shear Stress τ
Rheological Quadratic
Dilatant Herschel-Bulkley
Bingham Plastic
Newtonian Fluid
μ_{cv}
τ_{yield}
45°
Shear Rate (Strain) $\frac{dv_x}{dz}$
Shear Stress τ
Coulomb
Newtonian Fluid
45°
Shear Rate (Strain) $\frac{dv_x}{dz}$

Selecting a Non-Newtonian Method in HEC-RAS

Non-Newtonian Parameters are Unsteady Flow Variables





1D, Unsteady, FD (Working)
2D, Unsteady, FV (Working)
1D, Unsteady, FV (coming soon)
1D/2D Mobile Bed (coming later)
-Not in Steady or Quasi-Unsteady

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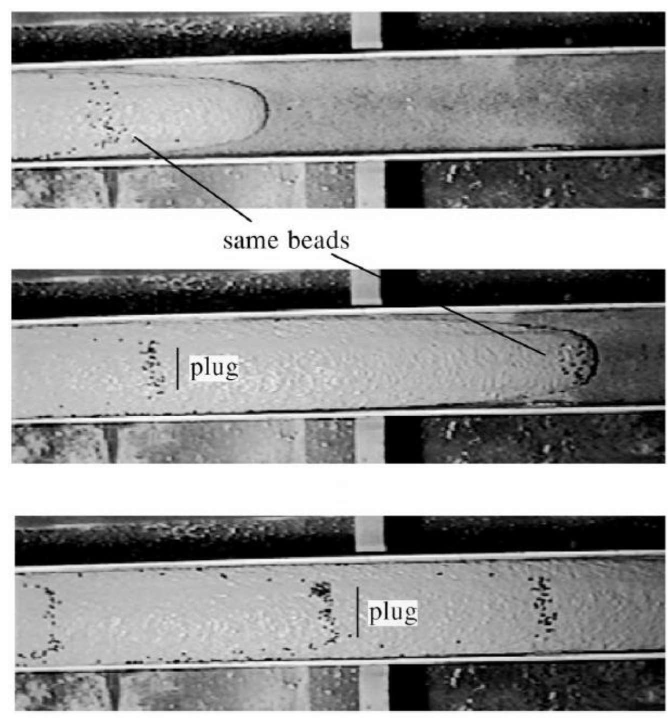
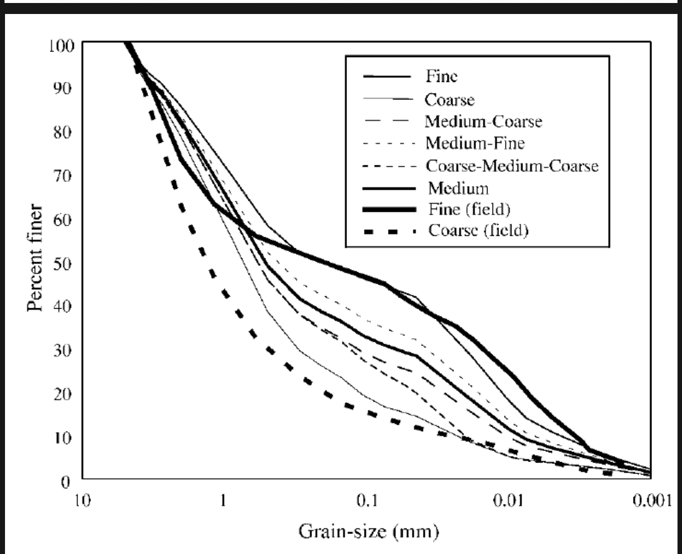
POST-WILDFIRE FLOOD RISK MANAGEMENT

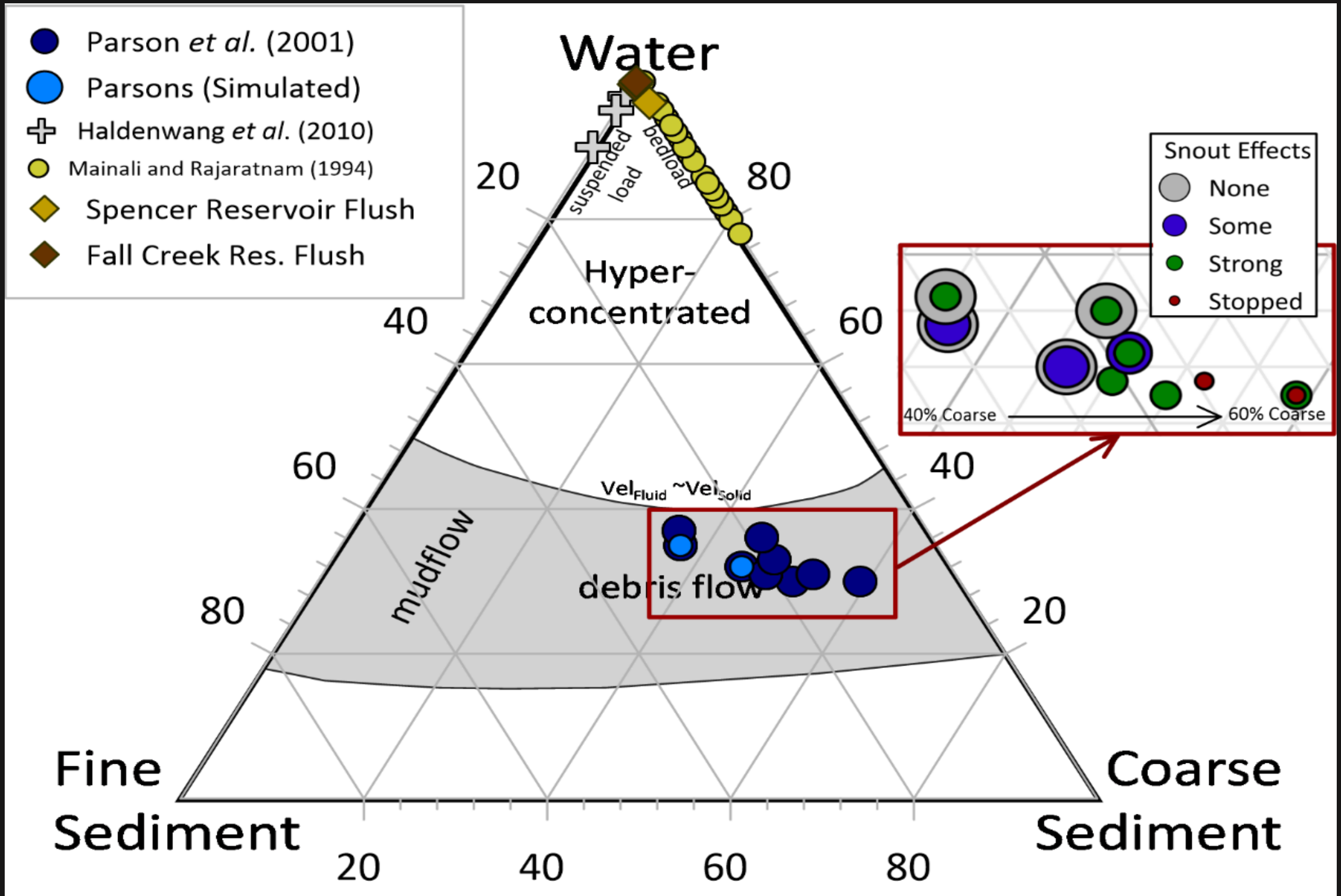
1. Parson et al – Mudflow and Debris Flow





Experimental Study of the Grain-Flow, Fluid-Mud Transition in Debris Flows

Jeffrey D. Parsons,[1] Kelin X. Whipple, and Alessandro Simoni[2]



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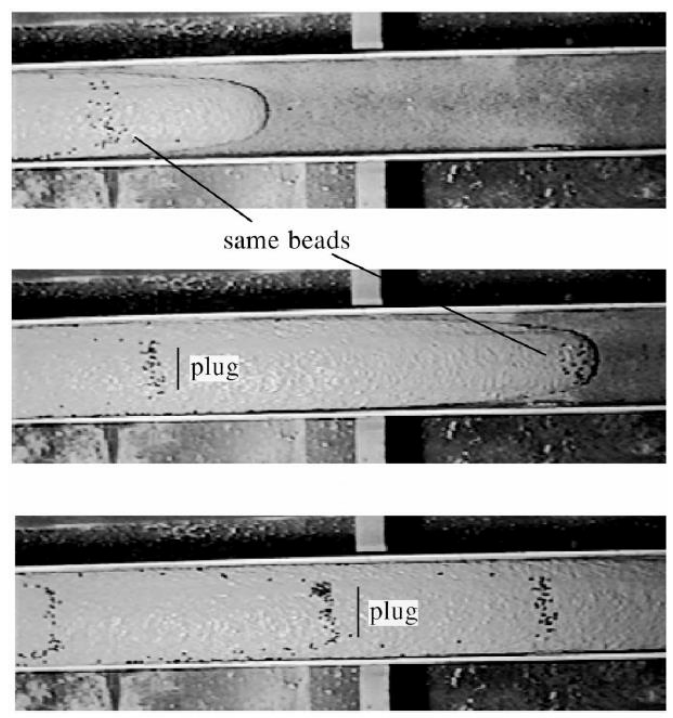
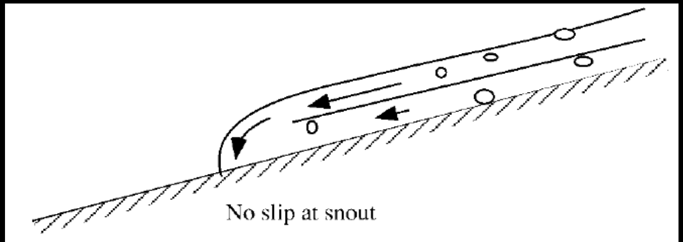
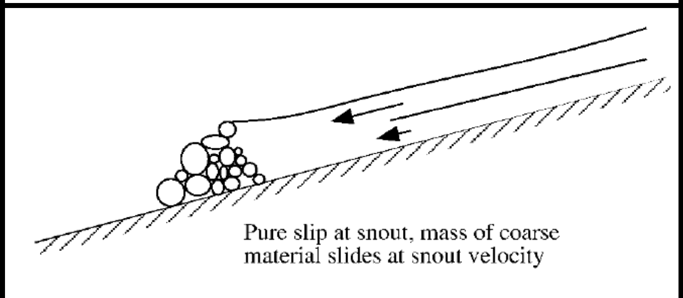


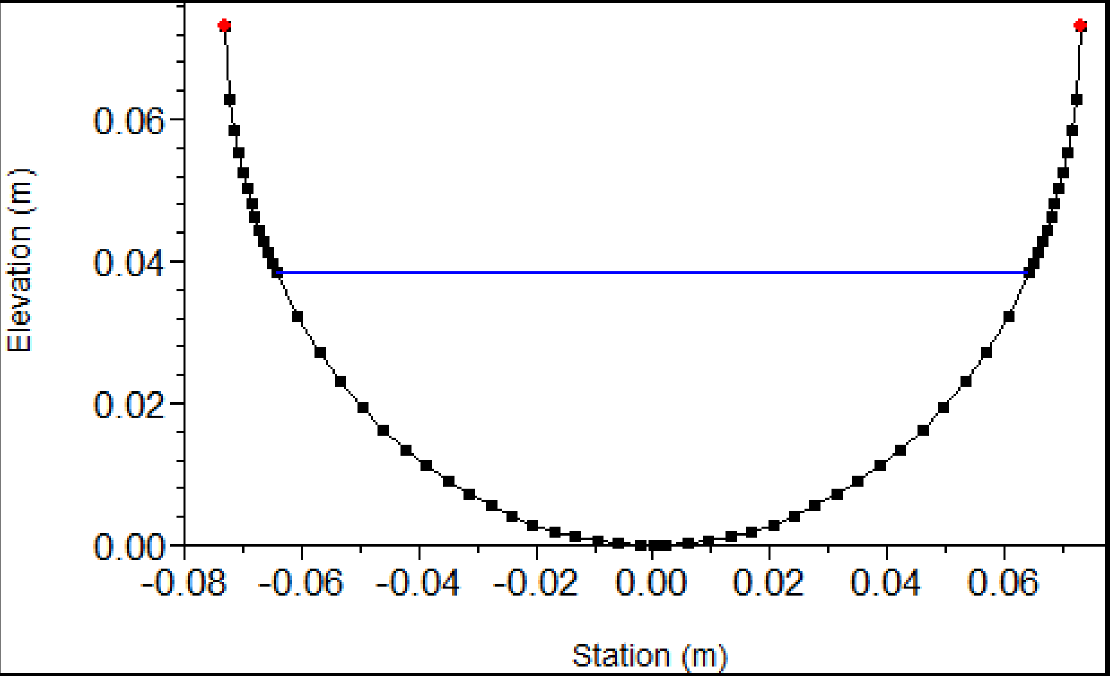
Start with non-snout effect experiments





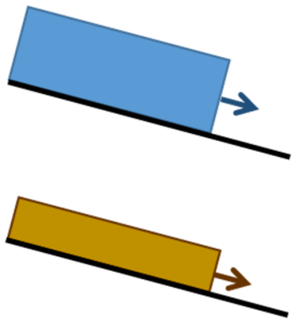
Fine 1D Simulations:

Experiment	Material	w	R	Slope (θ)	Snout effect?	U_p	U_{snout}	Q
1a	F	16.8	.073	10.7	None	.24 (8.3)	.22 (1.8)	.00189 (1.8)
1b	C_m=83.2%→C_v=65%		.073	15.2	None	1.17 (10.2)	.87 (1.0)	.00692 (1.3)
1c			.05	15.2	Some	.26 (7.8)	.16 (1.7)	.00061 (.4)
2a	MF	14.8	.073	10.7	None	.83 (4.8)	.57 (.9)	.00391 (.6)
2b	C_m=85.2%→C_v=68%		.073	13.7	None	1.69 (2.3)	1.22 (.7)	.00988 (3.7)
2c			.05	13.7	Some	.30 (8.3)	.16 (.3)	.00096 (.4)

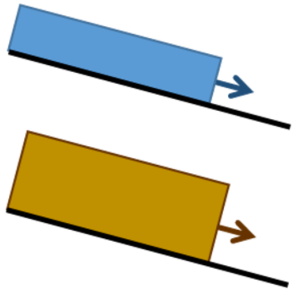


3. A steady state debris flow will be deeper/shallower than a water flow of the same volume?

a) $D_{water} > D_{debirs}$

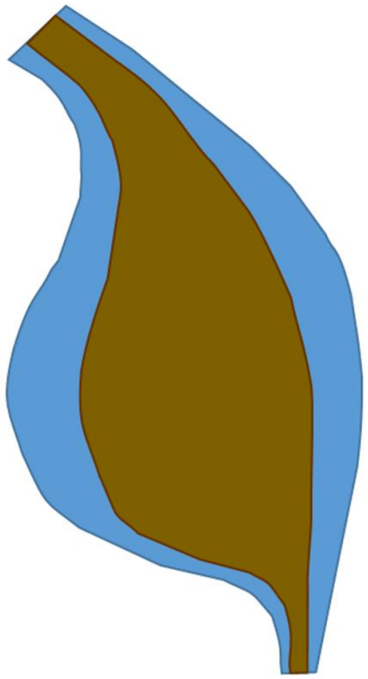


b) $D_{debris} > D_{water}$

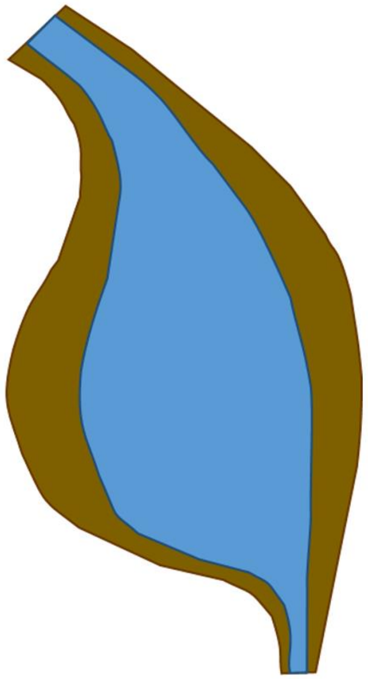


4. A debris flow will have a bigger/smaller floodplain area than a water flow of the same peak volume?

a) $A_{water} > A_{debirs}$

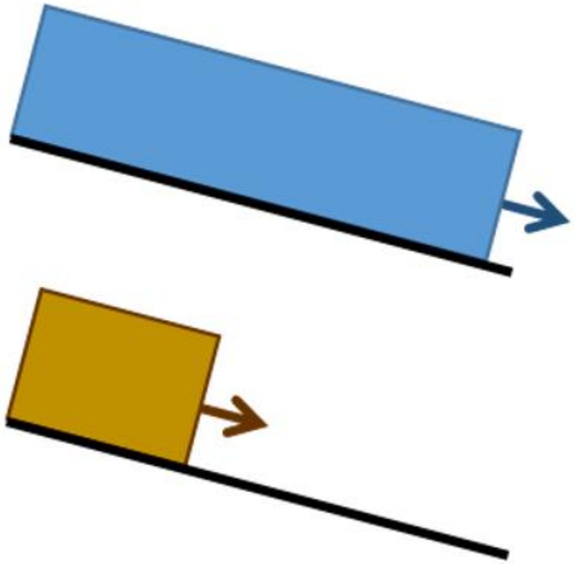


b) $A_{debris} > A_{water}$

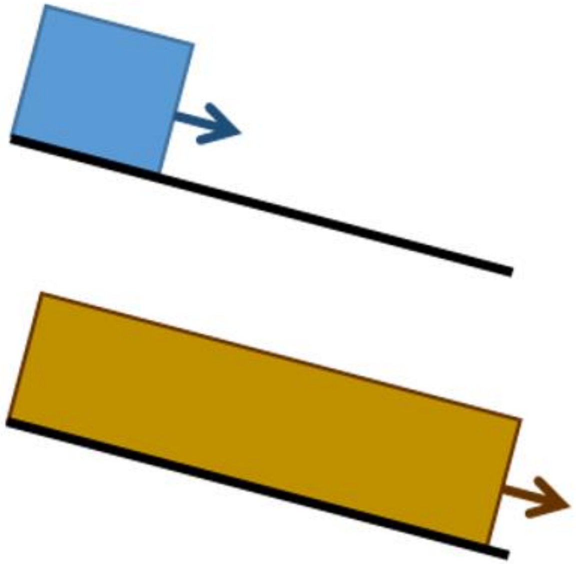


2. A debris flow will be faster or slower than a water flow of the same volume?

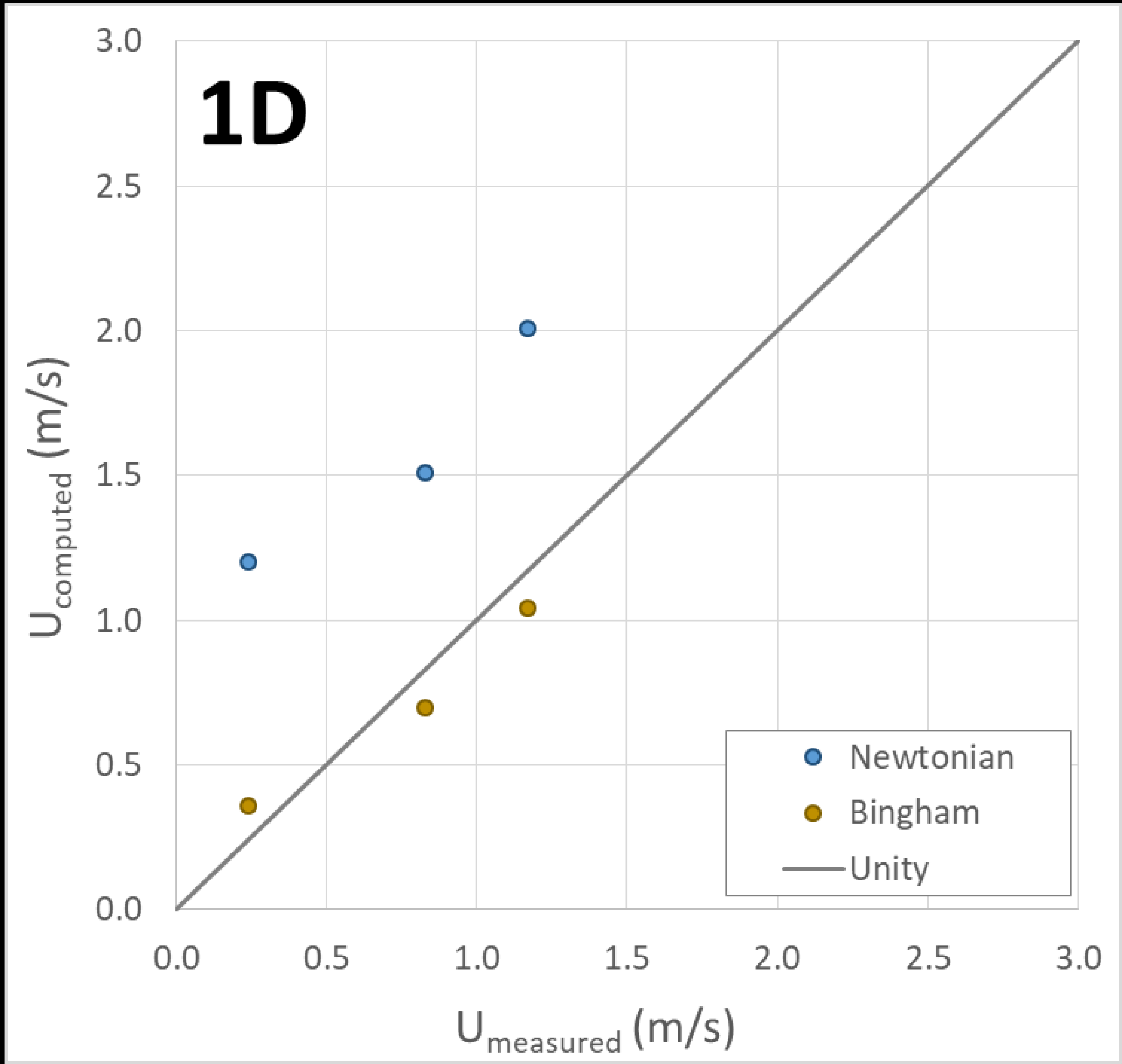
a) $V_{water} > V_{debirs}$



b) $V_{debris} > V_{water}$



2. Parson et al – Mudflow and Debris Flow



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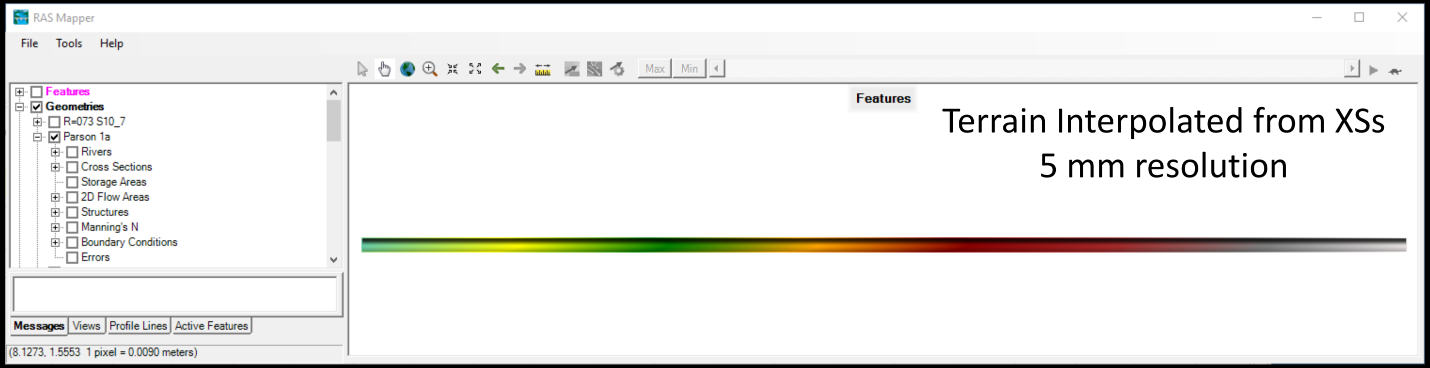
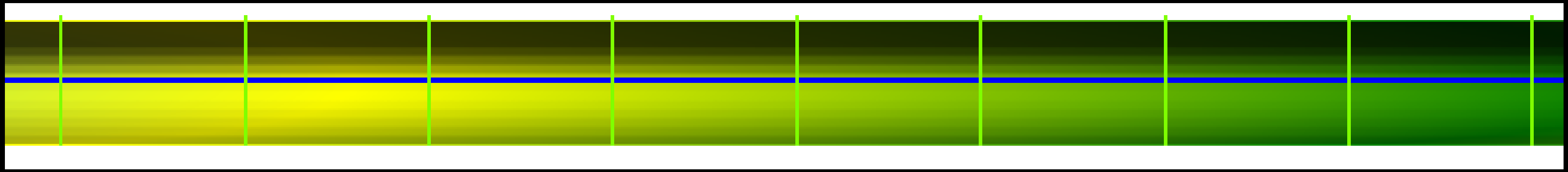
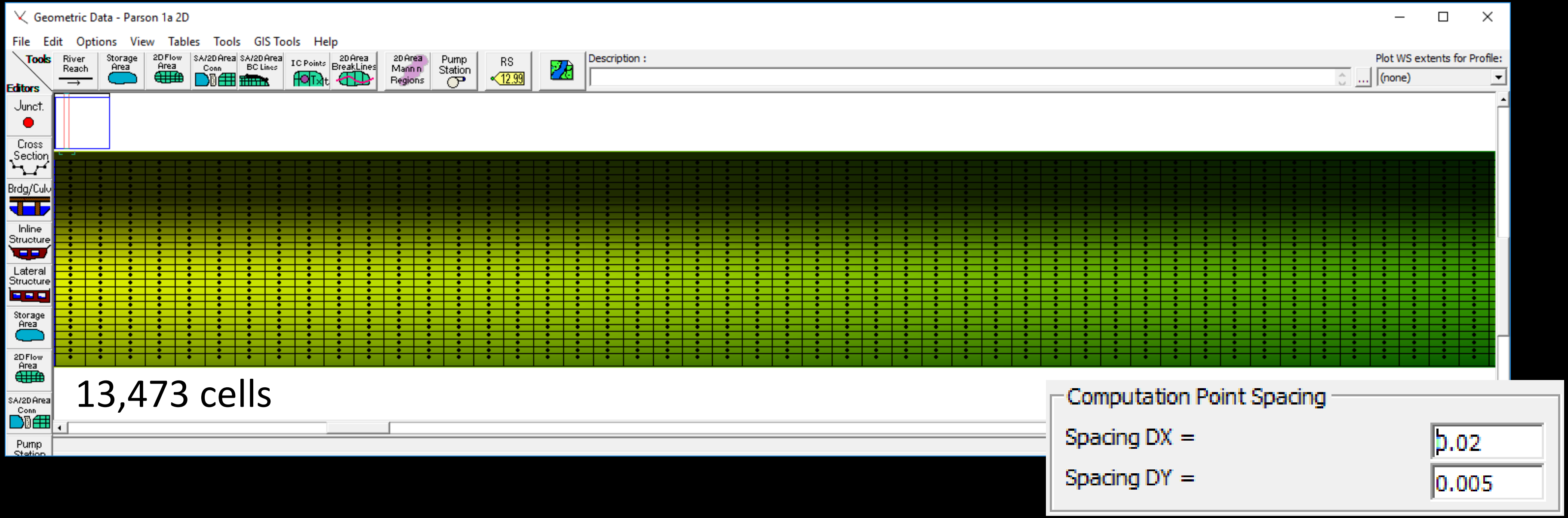
Fine 2D Simulations:



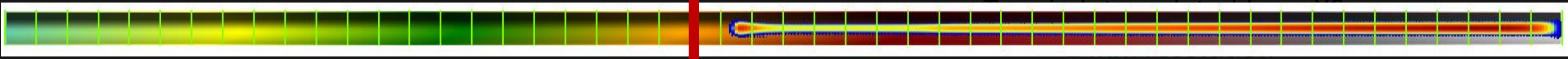




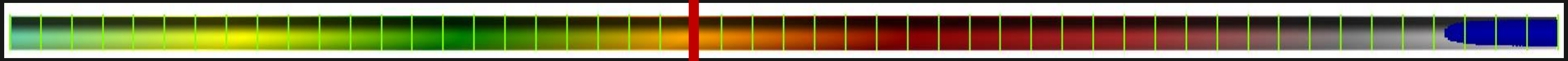
2. Parson et al – Mudflow and Debris Flow (2D)

Fine 2D Simulations:

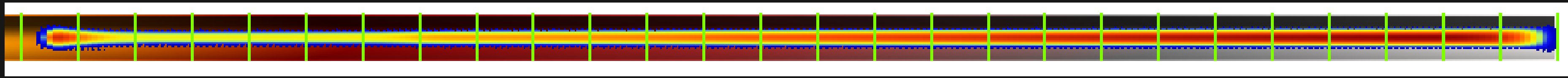
Newtonian (t=10s)



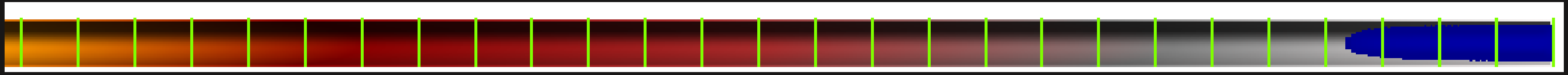
Bingham (t=10s)

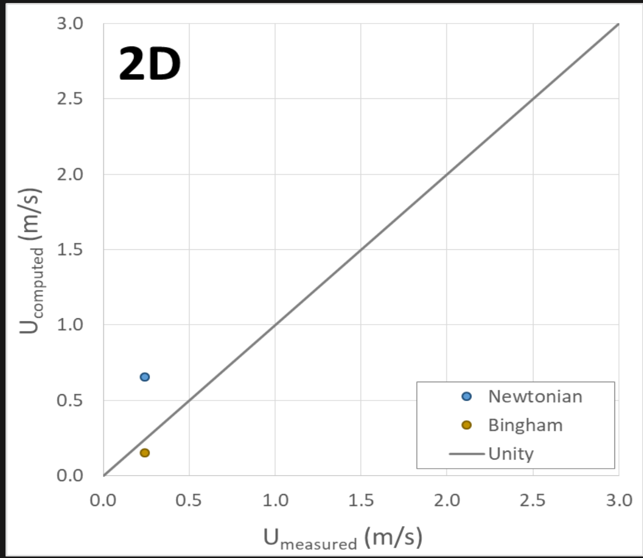


Newtonian (t=10s)



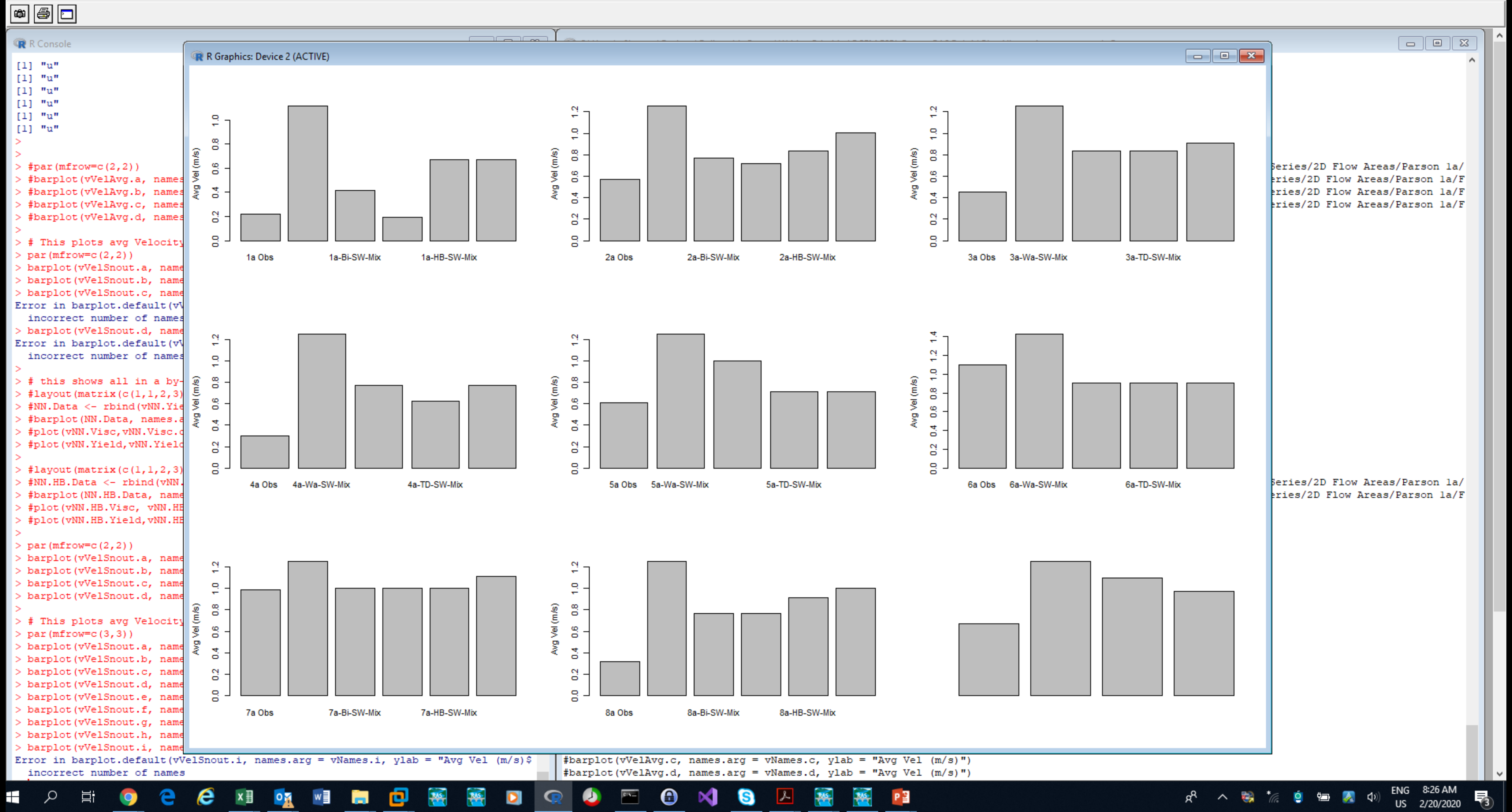
Bingham (t=10s)





13,473 cells

I'm working on a video on how to interact with the RAS HDF5 Results in R



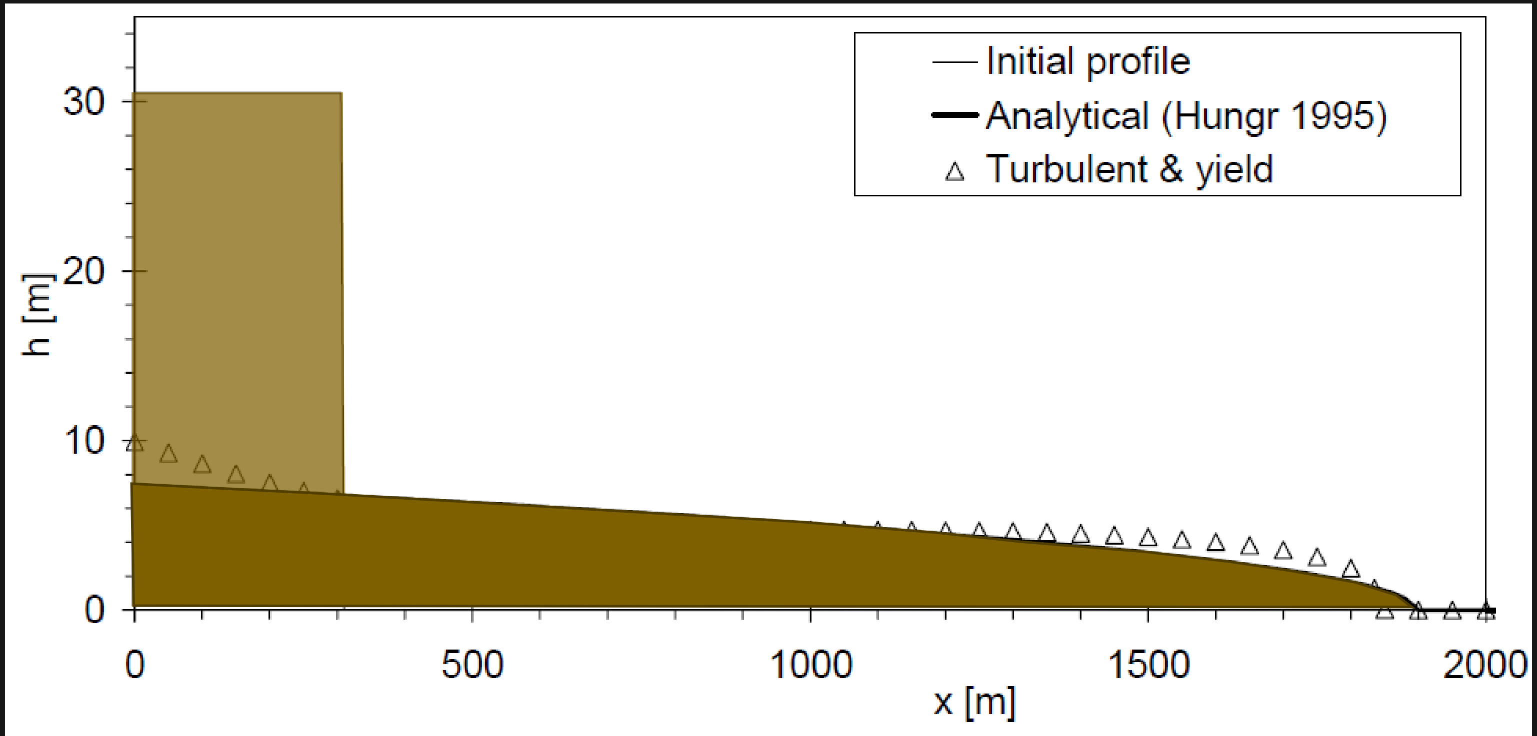
3. Hungr et al – Non-Newtonian Dam Breach

30.5 m Dam Breach
1,000+ m Runout
ρ=1,835 km/m³

Bingham:

τ_y = 1,500 N/m²
μ_B = 100 Pa-s

$$\tau = \tau_y + \mu_B \left(\frac{dv_x}{dz}\right)$$



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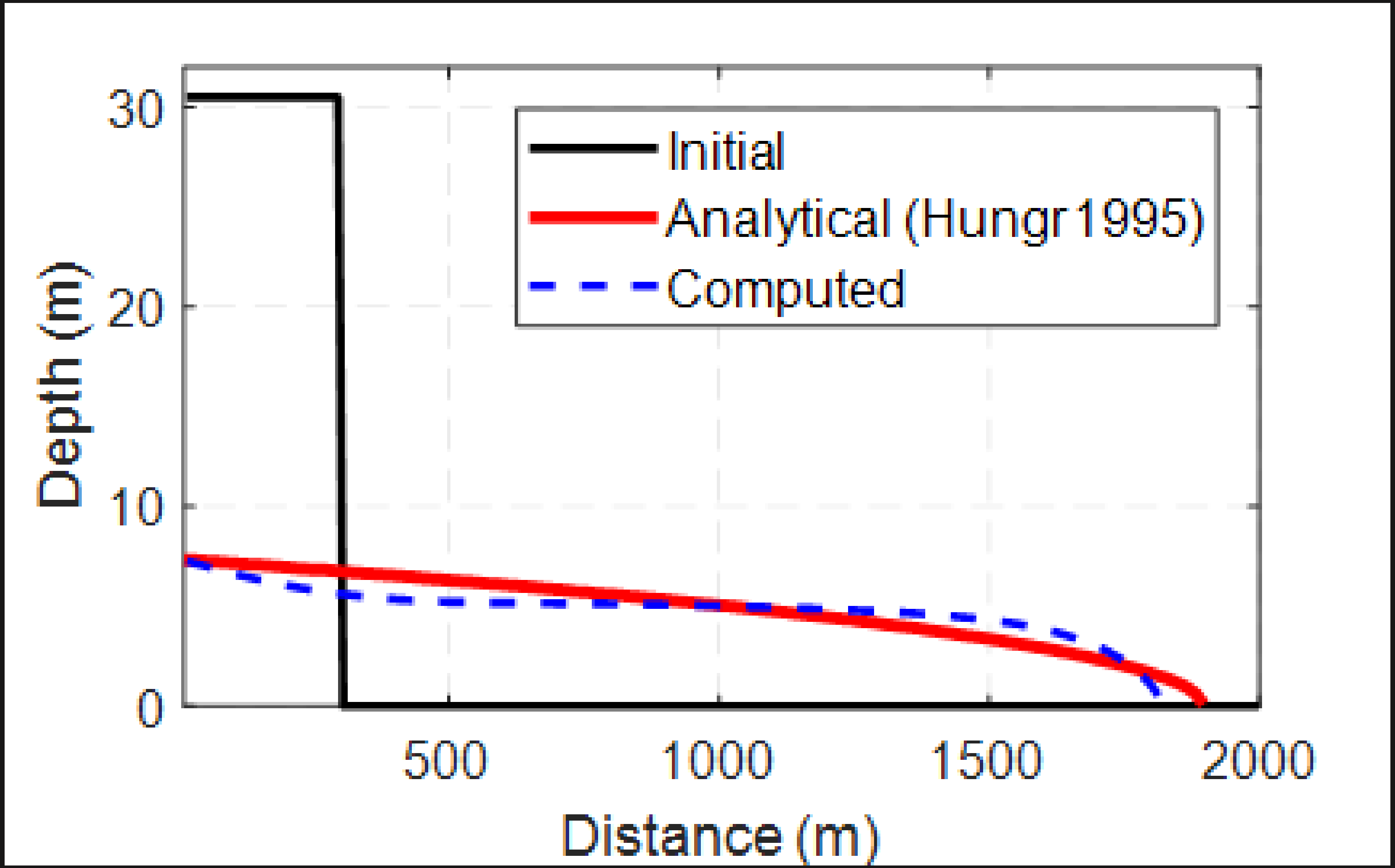


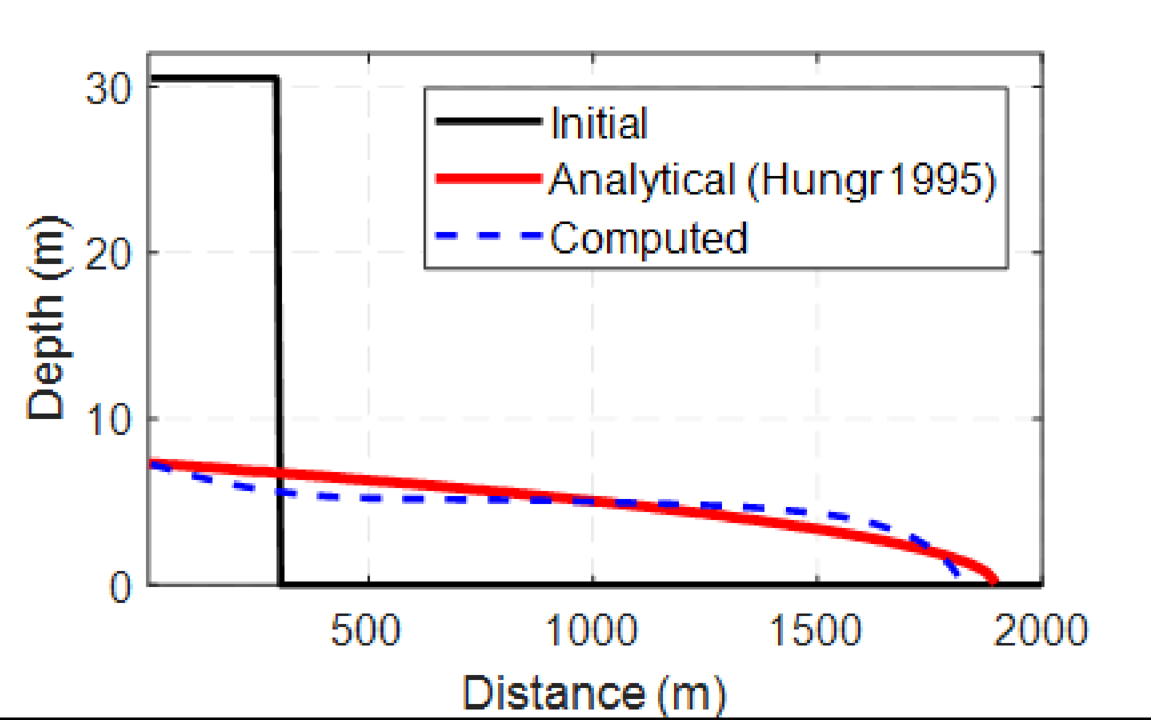
HEC-RAS
1D Finite Difference
2D Finite Volume
Fortran Code

Adaptive Hydraulics
2D Finite Area
C++ Code

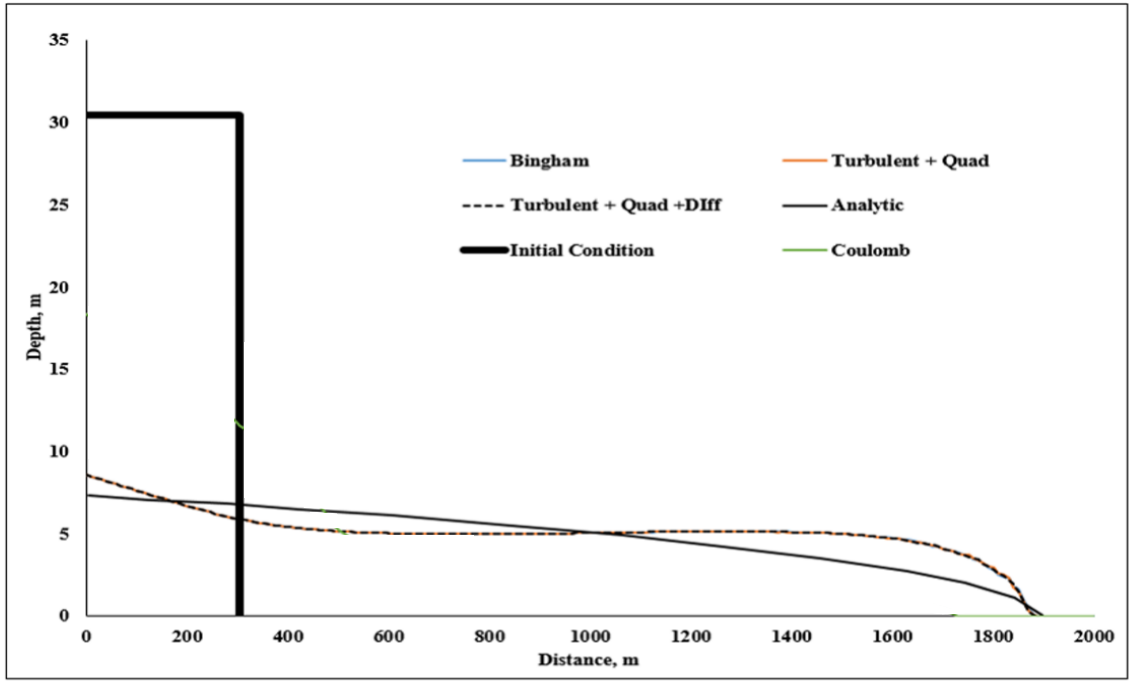
ADH

DebrisLib

ADH

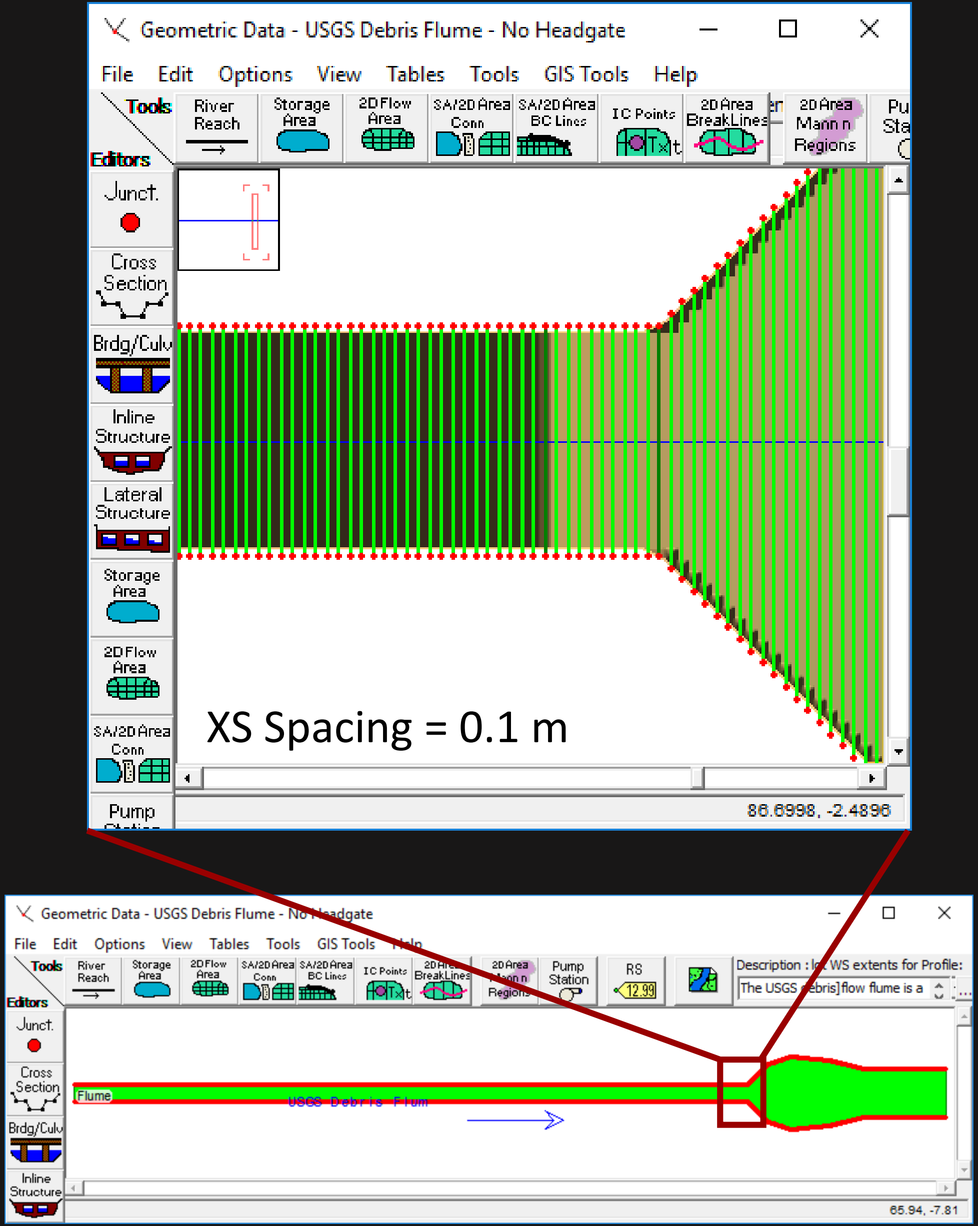


2D Adaptive Hydraulics

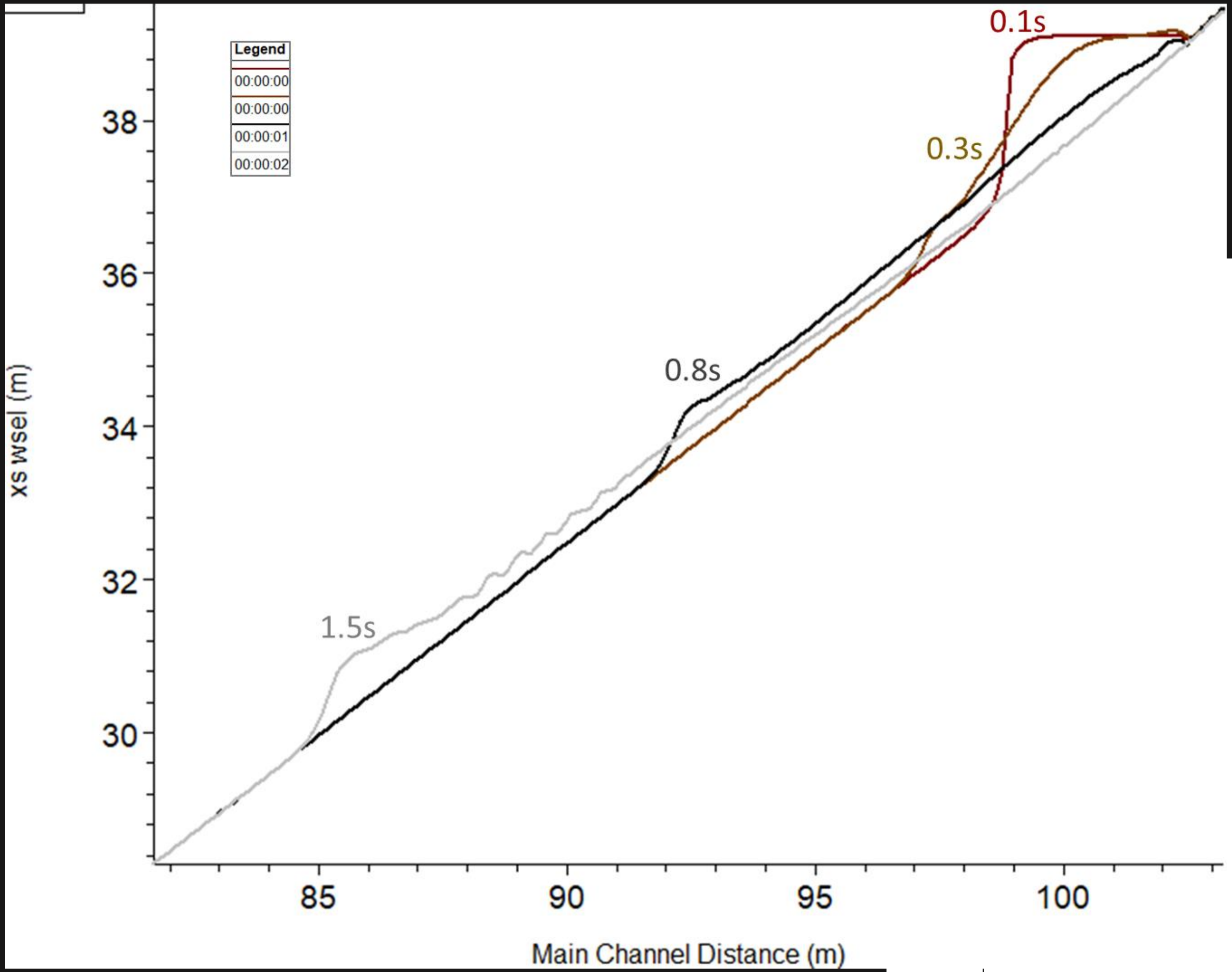


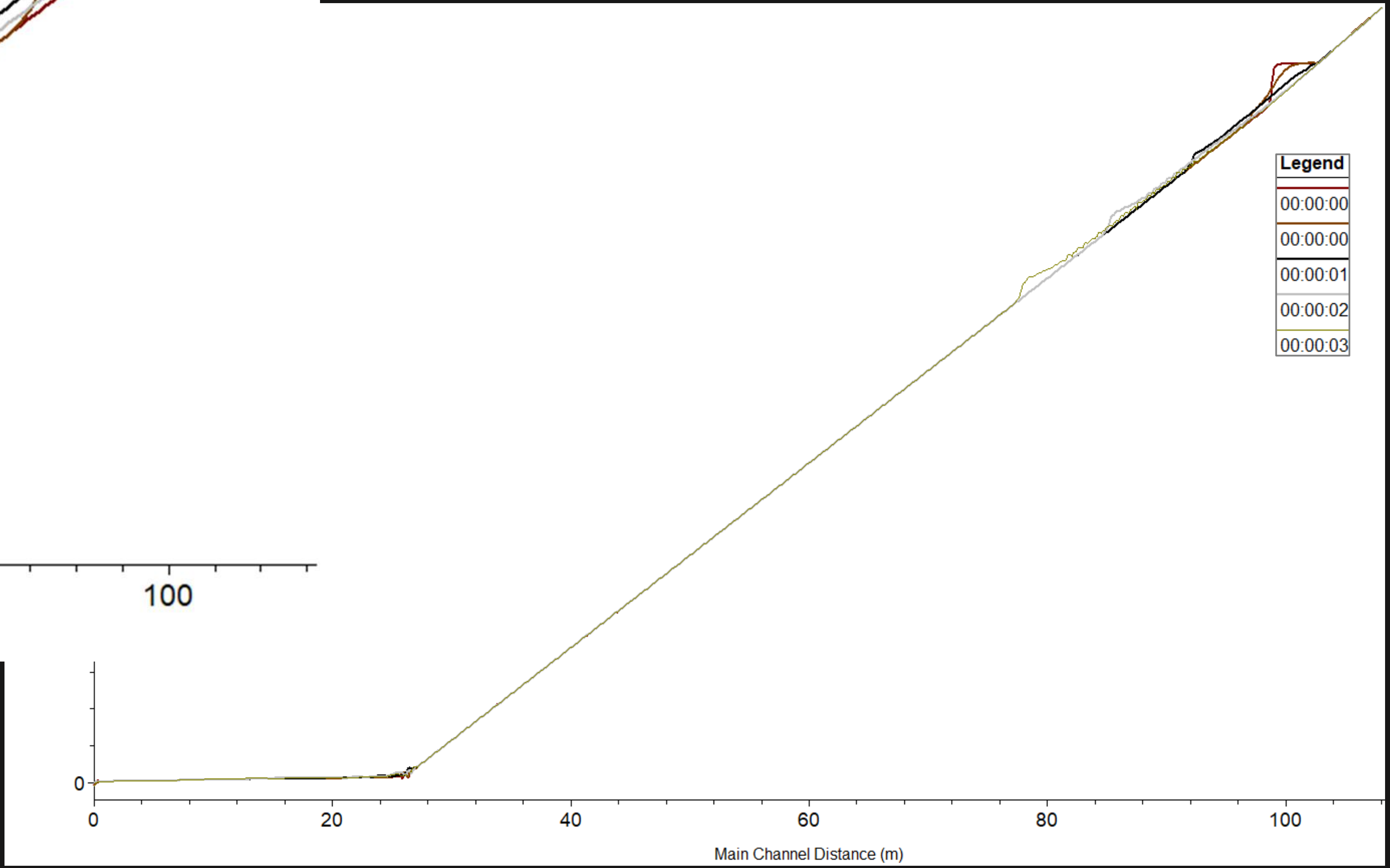

NON-NEWTONIAN
FLOWS
ADH

4. USGS Debris Flume

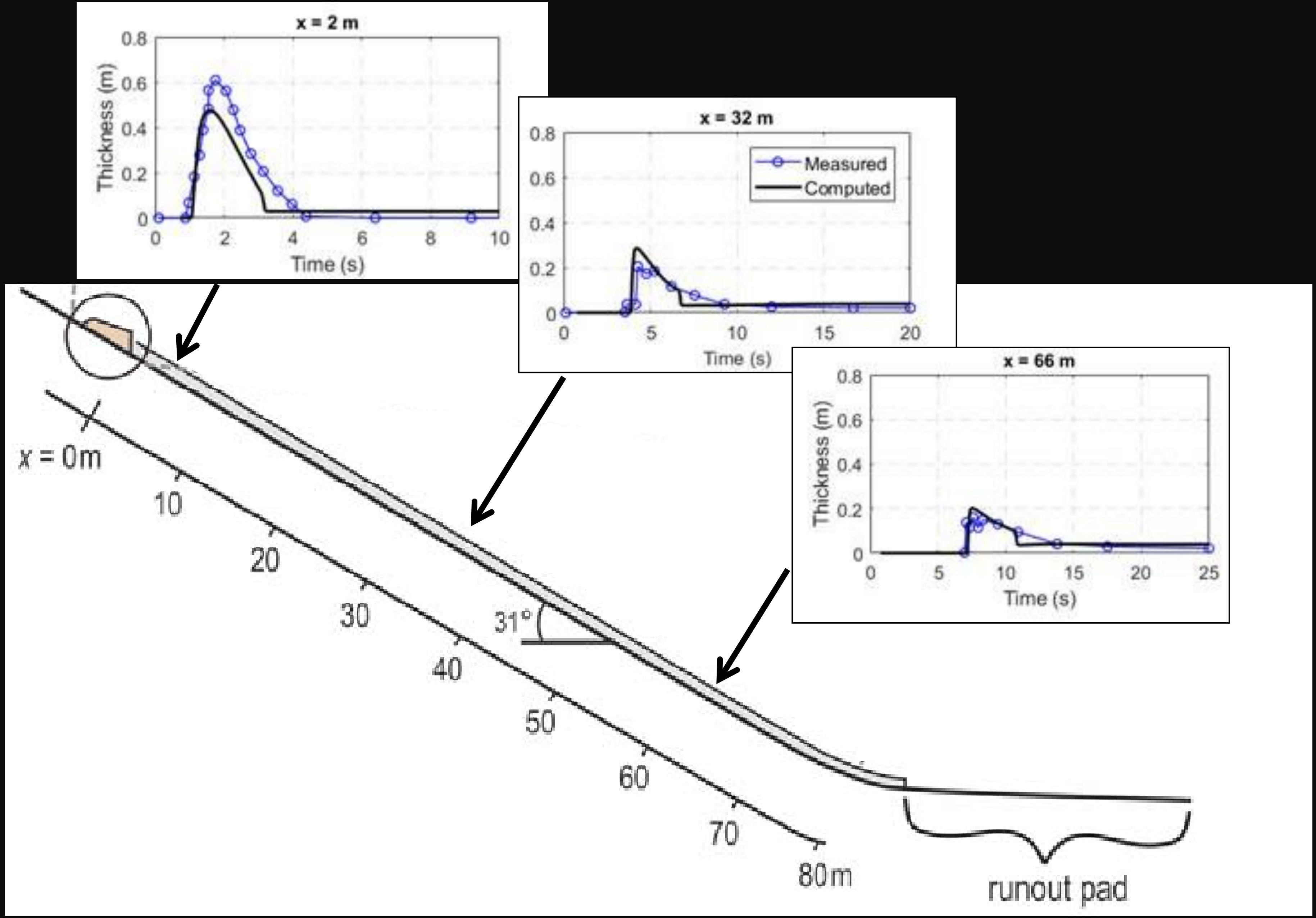


US Geological Survey - Debris Flume

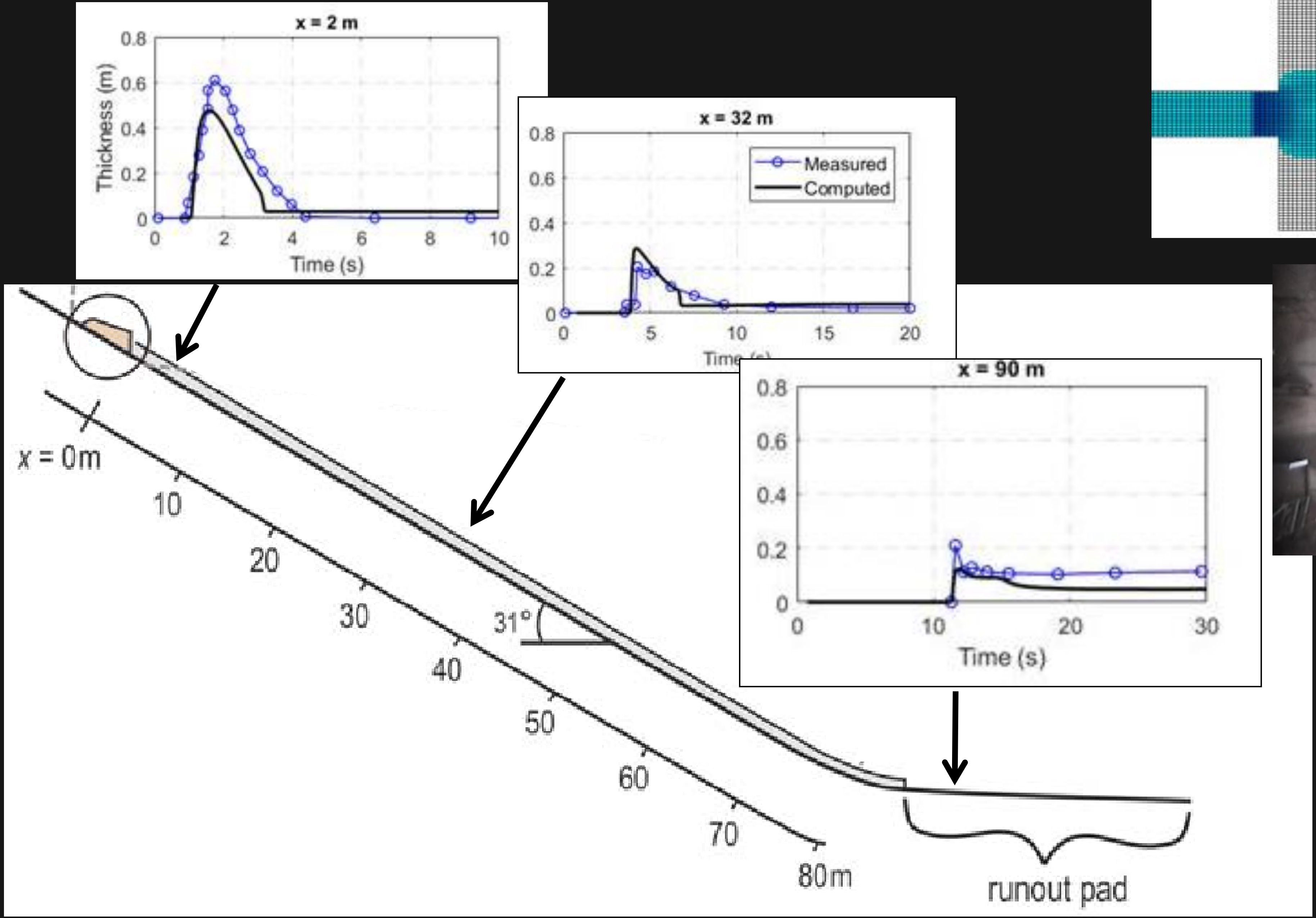


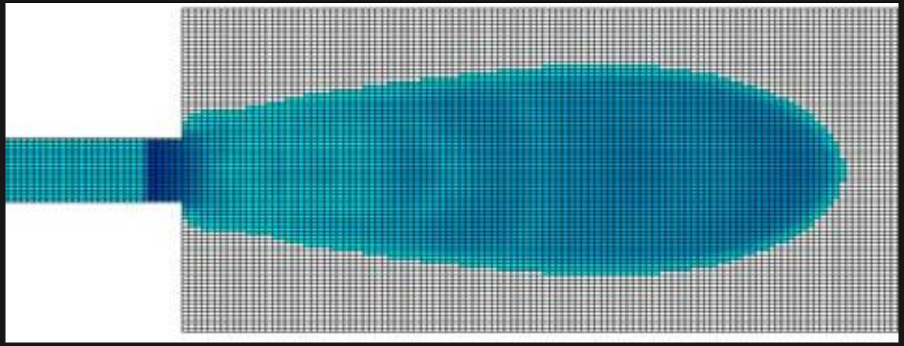


US Geological Survey - Debris Flume



US Geological Survey - Debris Flume





Non-Newtonian Validation and Verification in HEC-RAS

1. Non-Newtonian Closure in HEC-RAS
2. Laboratory and Meso-Scale Validation and Verification
3. Field Applications

US Army Corps of Engineers®

POST-WILDFIRE FLOOD RISK MANAGEMENT

Santa Barbara Mud-and-Debris Flow

HEC-RAS

1&2D Hydraulic and
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100,000 Downloads/Year
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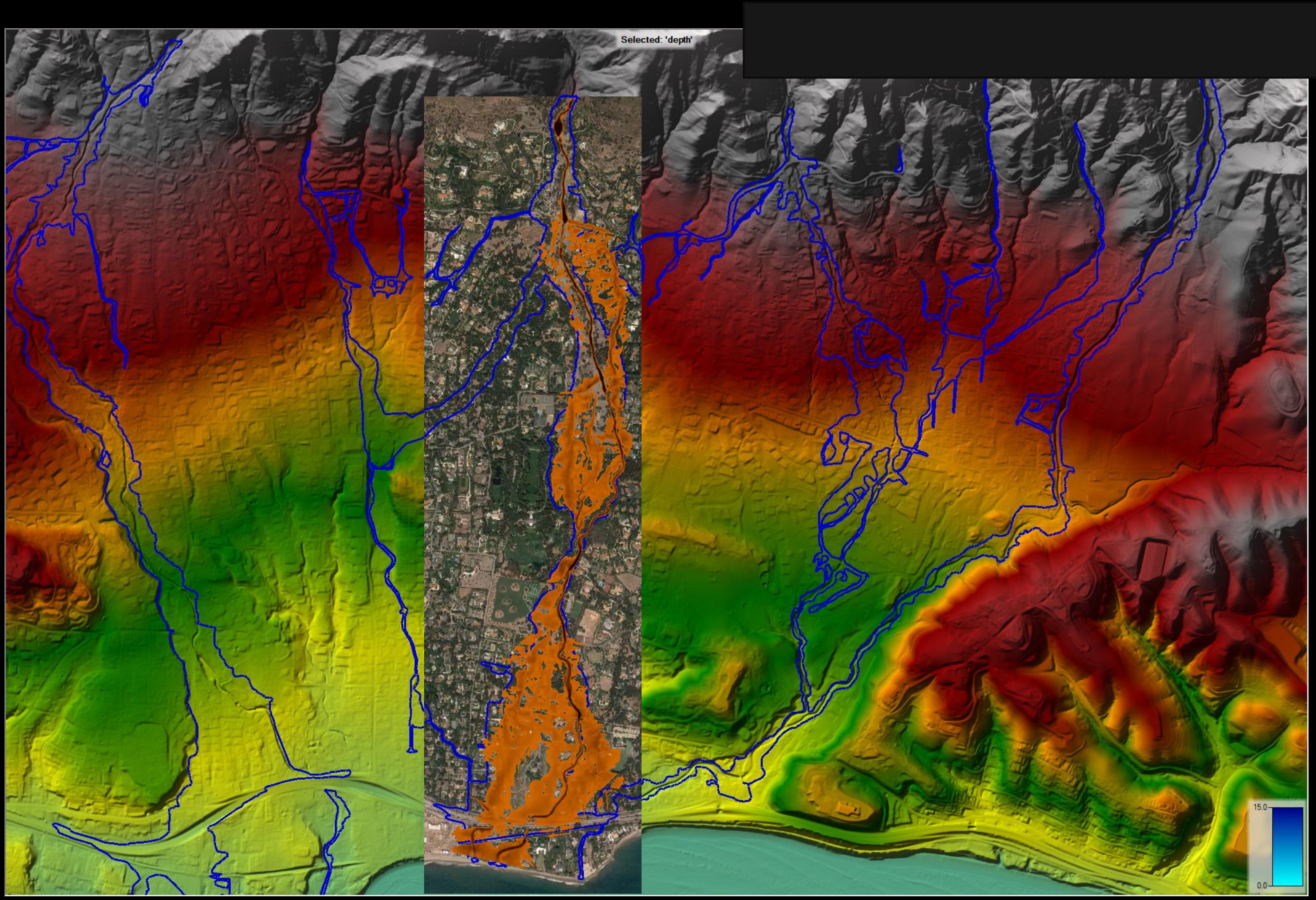
Newtonian Assumptions



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USACE Flood and Coastal R&D
Post-Wild Fire Work Unit
PI: Ian Floyd

1. Next Steps. What Non-Newtonian approaches would you like to see?

2. Non-Newtonian (and 2D sediment transport) will be available for testing in a pre-Beta that will be available shortly. Email me if you want to test:
stanford.gibson@usace.army.mil