



United States Department of Agriculture

Agricultural Research Service

Critical U.S. Sedimentation Issues & New Sediment Transport Model Advancements

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Oxford, Mississippi



Outline

- Critical sedimentation issues
- Technology needs & products
- HEC-RAS v5 new sediment features

Subcommittee on Sedimentation (SOS)

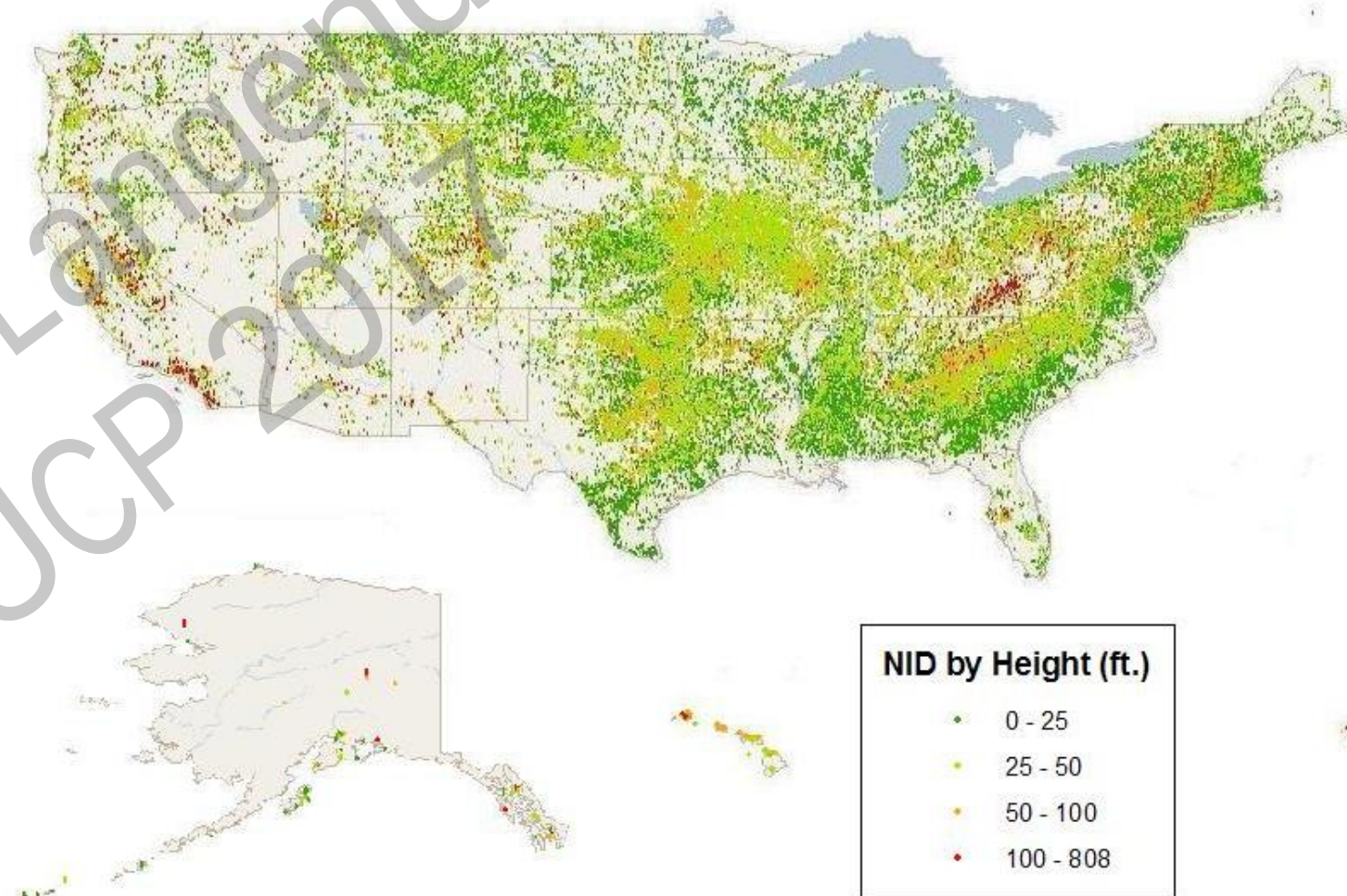
The Subcommittee **promotes and supports development and standardization of equipment, methodologies, and calibration and performance criteria for the collection, analysis, interpretation, and interchange of fluvial-sediment data and related technical information.** Information and data about sediment transport or deposition rates and the physical and chemical qualities of sediment are important to understanding current resource conditions and trends. The Subcommittee evaluates this information and other relevant issues and facts, and drafts proposed position papers or recommendations for improving the availability, reliability, and interpretation of information and data about sediment conditions. The Subcommittee forwards the draft papers and recommendations to the ACWI for deliberation and approval as advice to the Federal Government. **With such information, decisions can be made by local, State, Tribal, and Federal entities on the direction of current and future programs for solutions to identified problems related to sediment.**

SOS Working Groups

- Dam removal guidelines
- Sustainable reservoir sediment management
- National stream morphology data exchange
- Infrastructure & environment
- Climate and sediment
- Federal interagency sedimentation project (FISP)

Dams and Reservoirs

- National Inventory of Dams
(<http://nid.usace.army.mil/>)
- Lists > 90,000 dams
- Majority < 25 ft
- Majority completed between 1950-70
- Majority are earthen
- On average 1 dam/day has been constructed since the Declaration of Independence



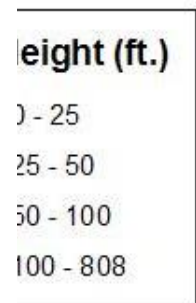
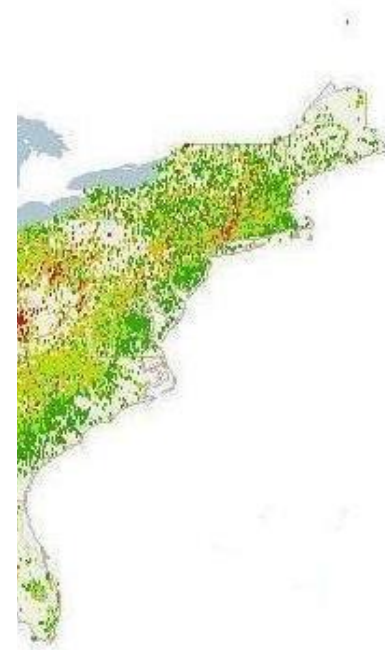
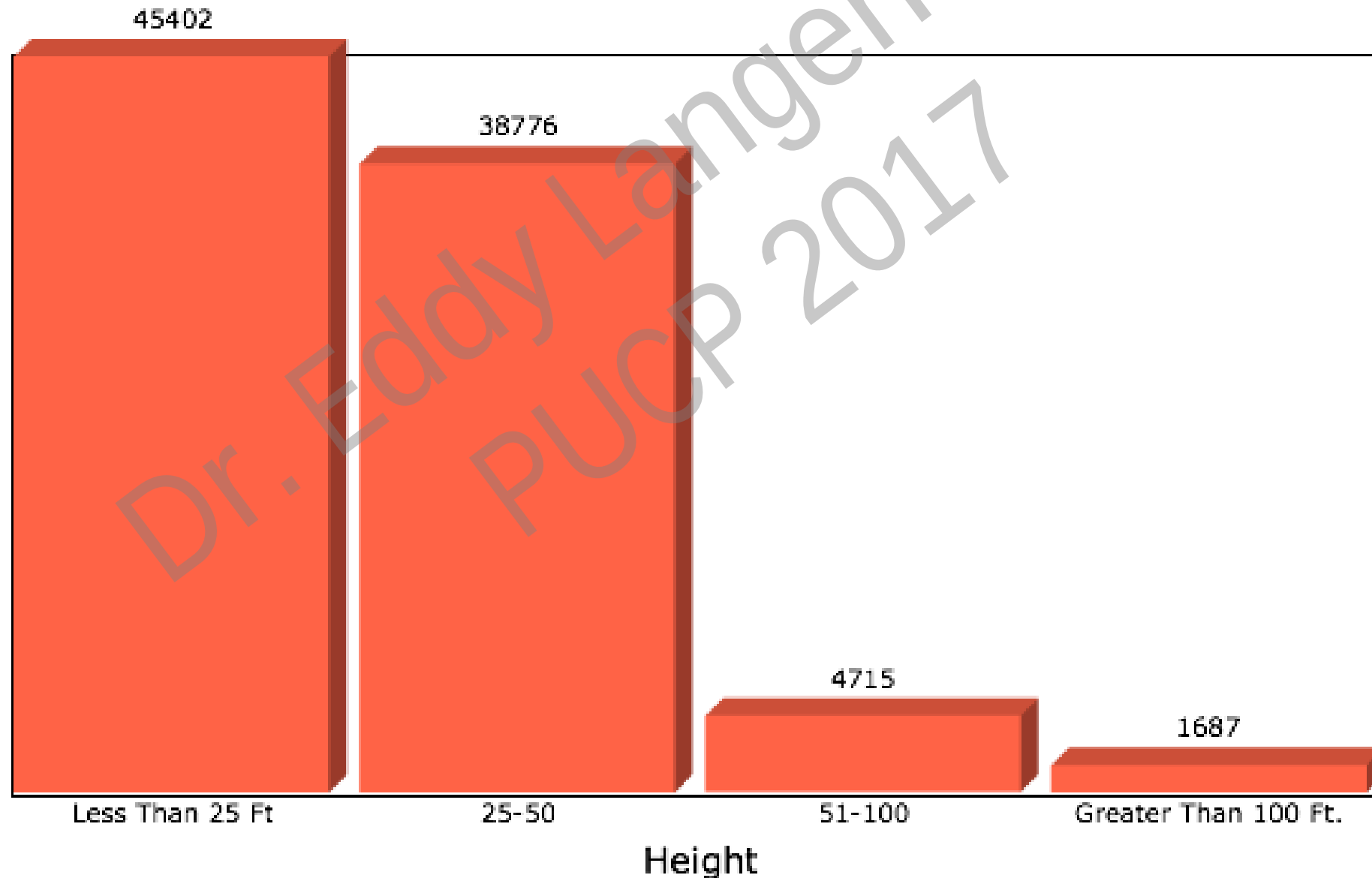
Dams and Reservoirs

- National Inventory of Dams

(<http://www.fws.gov/nis/>)

Dams by Height

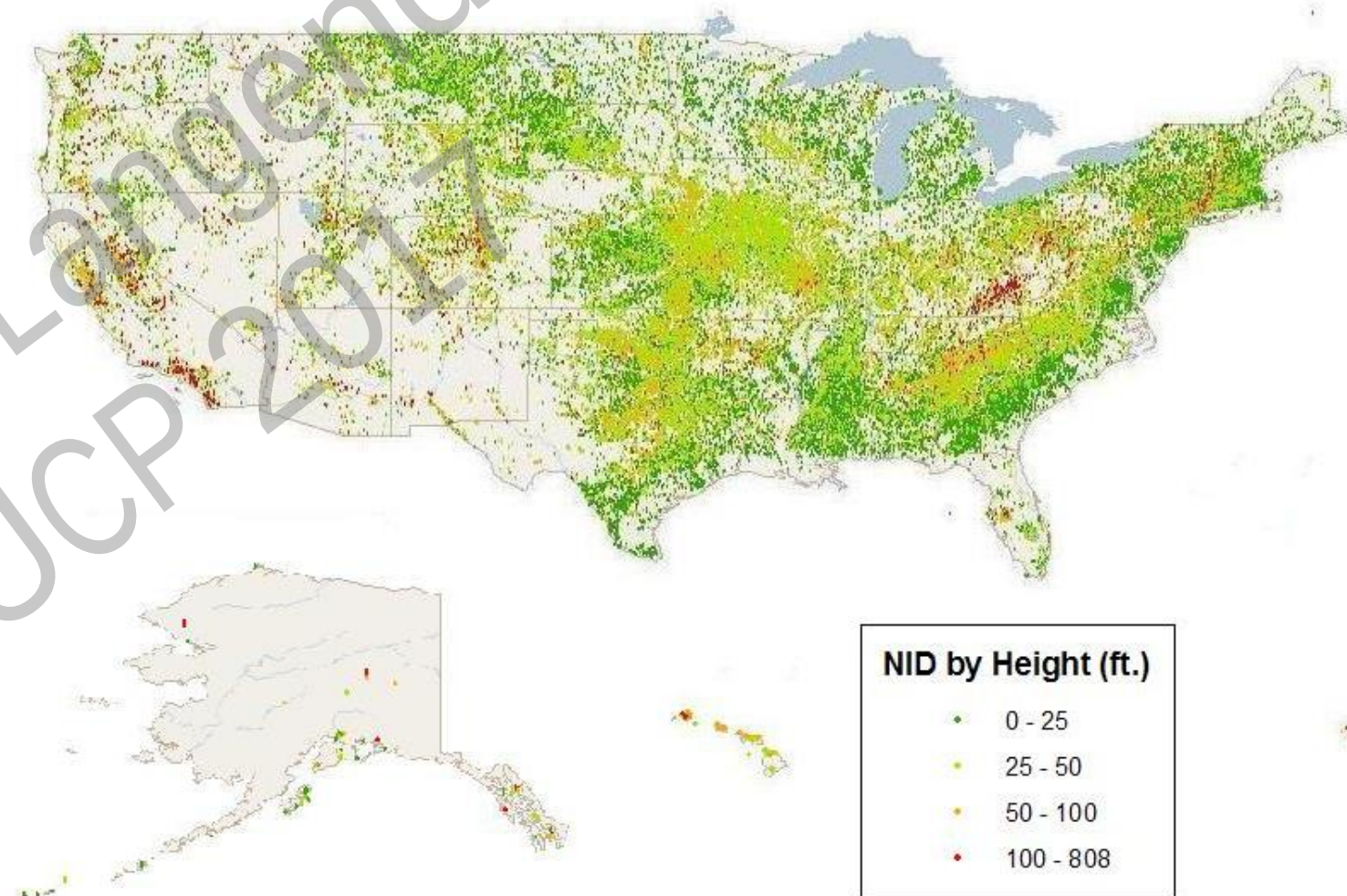
- Lists
- Major
- Major
- 1950-
- Major
- On a
- been



Declaration of independence

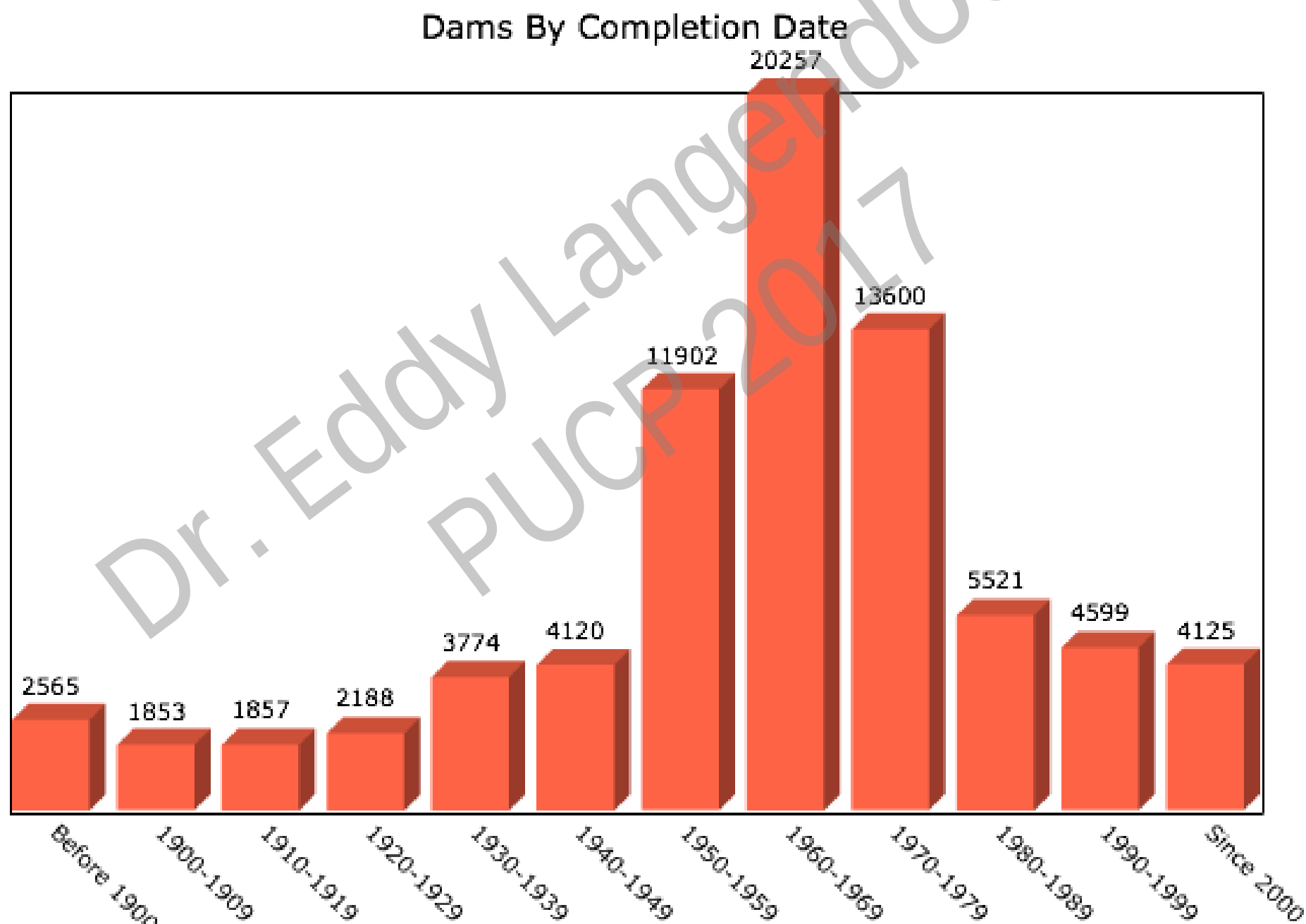
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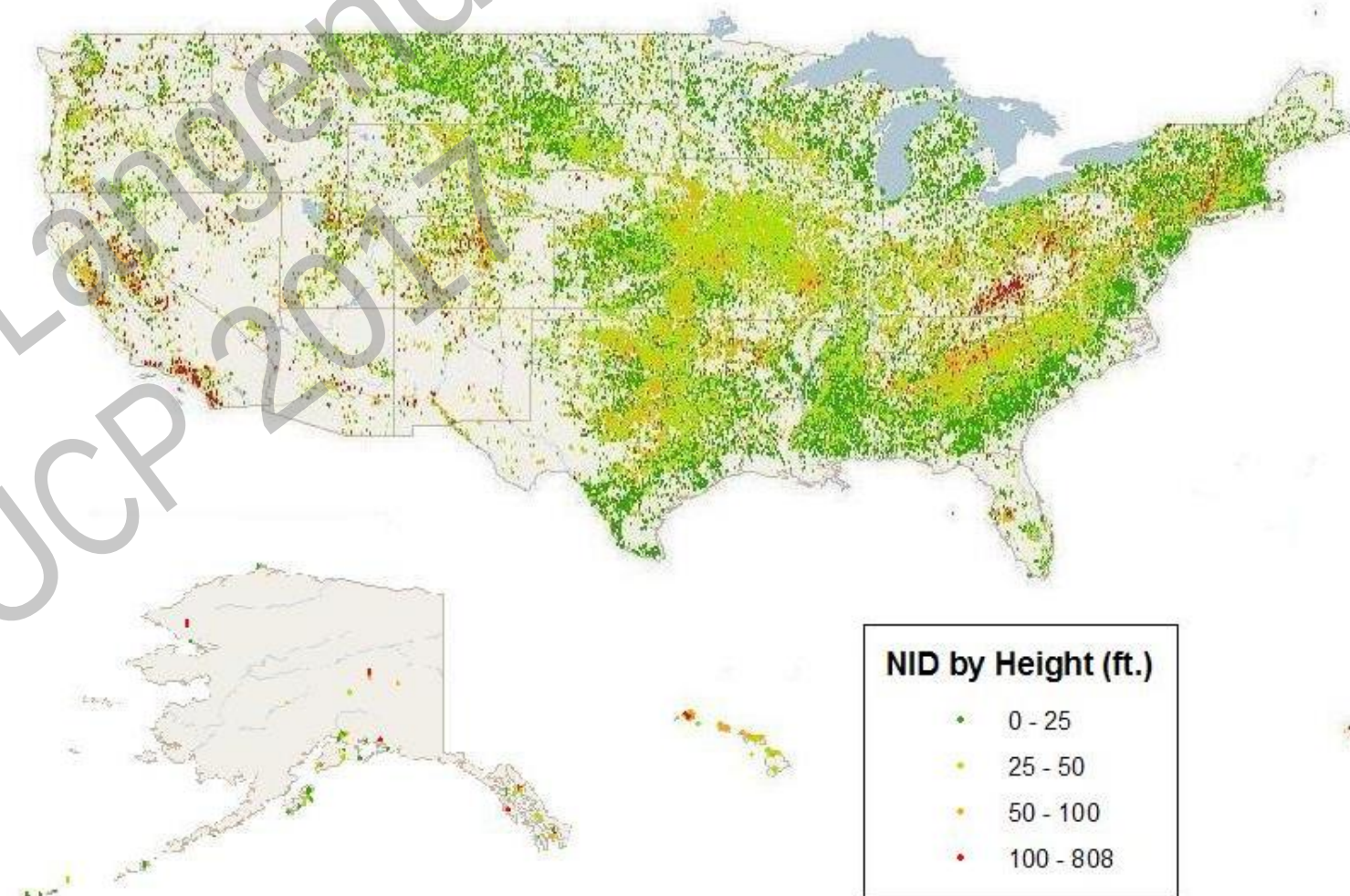
Dams and Reservoirs

- National Inventory of Dams (NID) (<http://www.fws.gov/nid/>)
- Lists of Dams and Reservoirs
- Major Dams and Reservoirs
- Major Dams and Reservoirs
- Major Dams and Reservoirs
- Major Dams and Reservoirs
- On a National Scale
- Decline in Dams and Reservoirs



Dams and Reservoirs

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Dams and Reservoirs

- Nation

(<http://www.usbr.gov/dams/>)

- Lists >

- Majori

- Majori

1950-

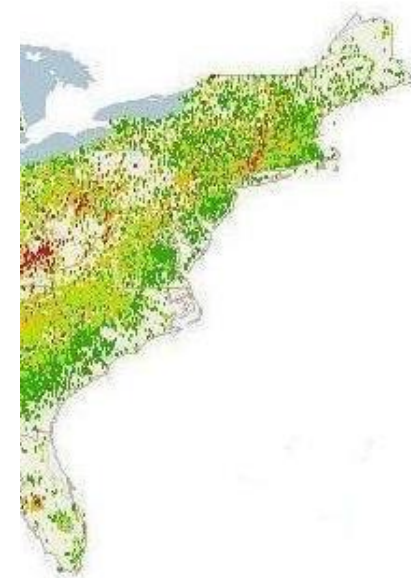
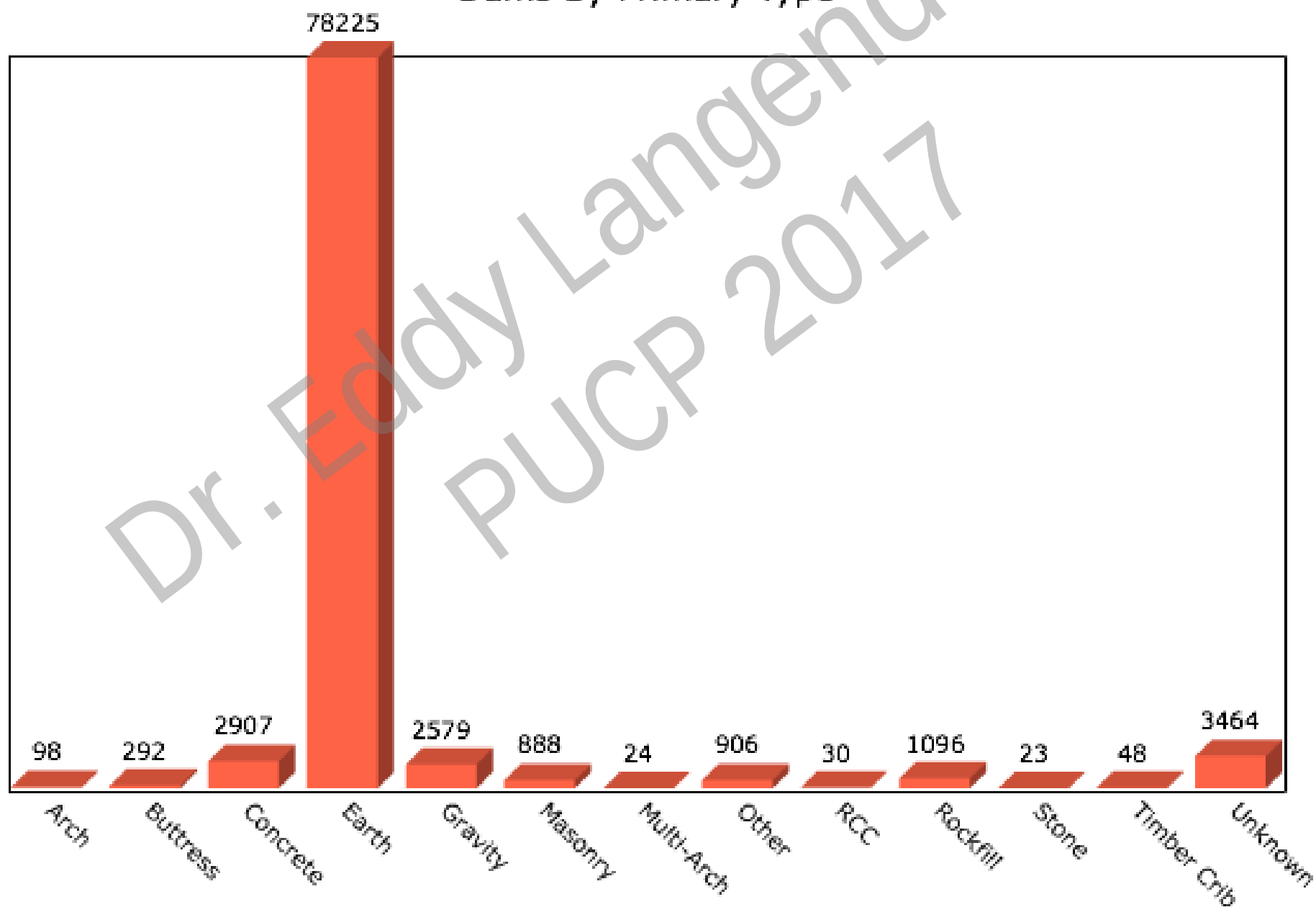
- Majori

- On av

been c

Decla

Dams By Primary Type

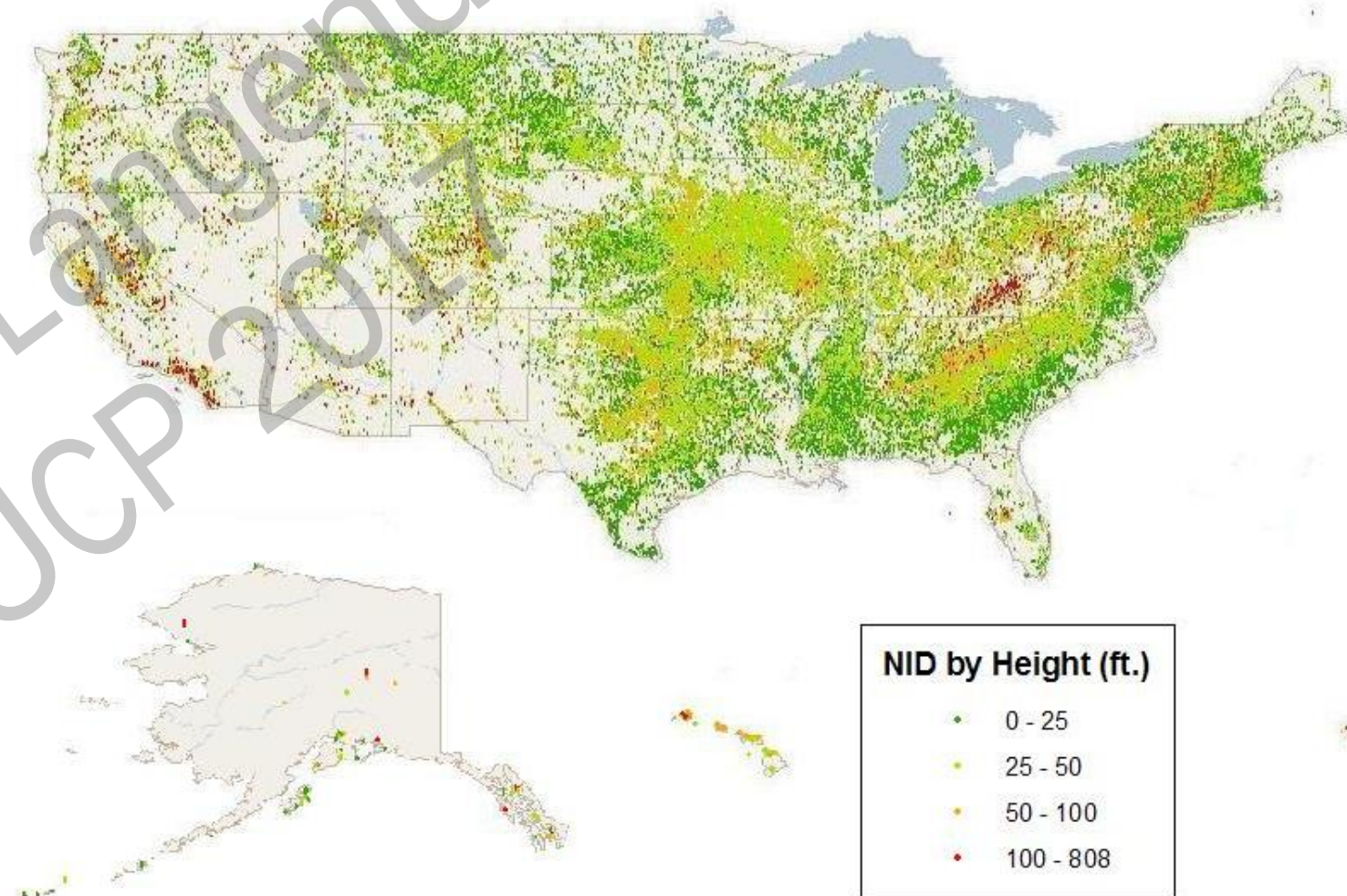


Height (ft.)

0 - 25
25 - 50
50 - 100
100 - 808

Dams and Reservoirs

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(<http://nid.usace.army.mil/>)
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Dams and Reservoirs

- Earthen embankments have 50-yr (before 1960) or 100-yr design life (after 1960)
- U.S. Department of Agriculture dams
 - \$14 billion infrastructure with \$1 billion in benefits (1997 dollars)
 - ~2000 at end of design life
 - yr 2000 rehabilitation estimates > \$550 million



Dams and Reservoirs – Critical Issues

- Remaining storage capacity
- Hazard reclassification
- Increased environmental awareness
- Embankment integrity





United States Department of Agriculture

Oroville Dam, California





United States Department of Agriculture

Oroville Dam, California





United States Department of Agriculture



Embankments Incl. Levees

WALNUT GROVE, CALIF.

JUDAH GROSSMAN/THE NATURE CONSERVANCY



Flood Control Reservoir Sedimentation Rates

- Extensively surveyed between 1950 and 1970 by ARS, National Sedimentation Laboratory under the auspices of Subcommittee on Sedimentation
- These data are the foundation of the RESSED database (<https://water.usgs.gov/osw/ressed/>) and its successor RSI (U.S. Army Corps of Engineers)

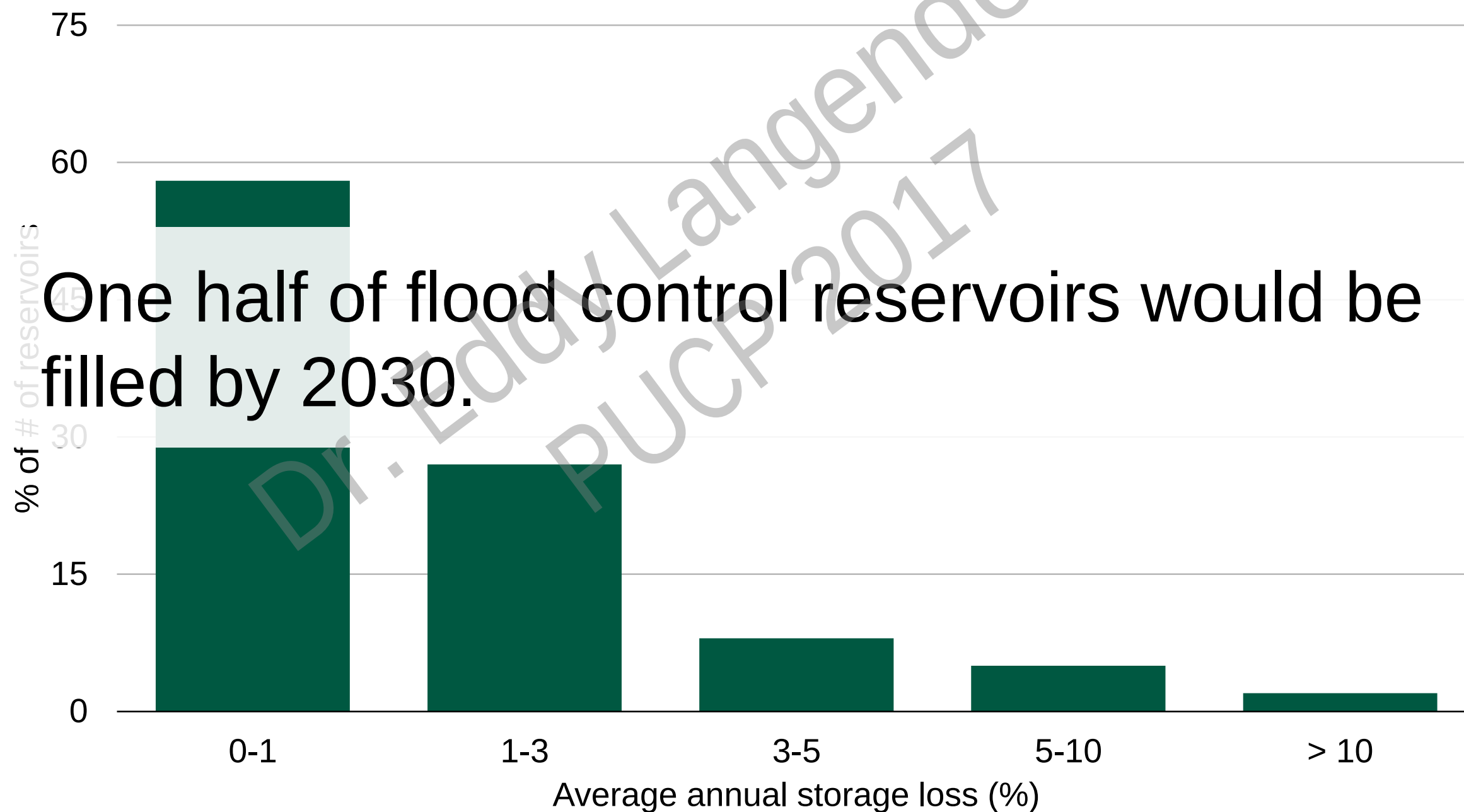
Reservoir Storage Depletion Rates

Reservoir capacity (acre-ft)	# of reservoirs	Annual depletion rate (%)		Mean depletion in 1967 (%)
		Mean	Median	
0 - 10	161	3.41	2.20	25.0
10 - 100	228	3.17	1.32	21.2
100 - 1000	251	1.02	0.61	17.2
1000 - 10000	155	0.78	0.50	11.0
10000 - 100000	99	0.45	0.26	9.92
100000 - 1000000	56	0.26	0.13	3.72
> 1000000	18	0.16	0.10	3.35
Total	968	1.77	0.72	16.7

1 acre-ft = 1233.5 m³

From Dendy et al. (1967)

Reservoir Storage Depletion Rates





**THAT WAS 40 YEARS
AGO. WHAT ABOUT
NOW?**

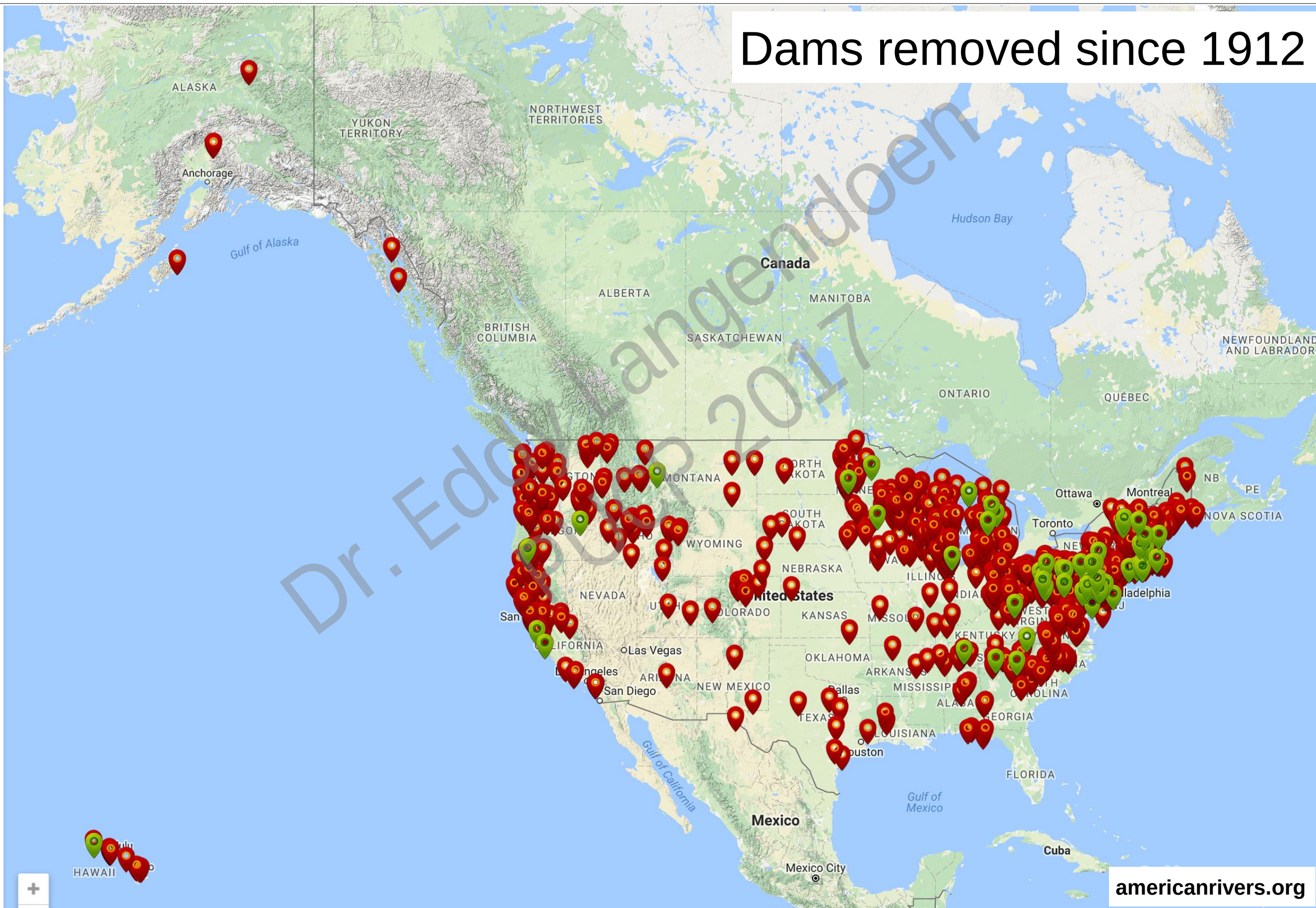
Reservoir Storage Depletion Rates Studies

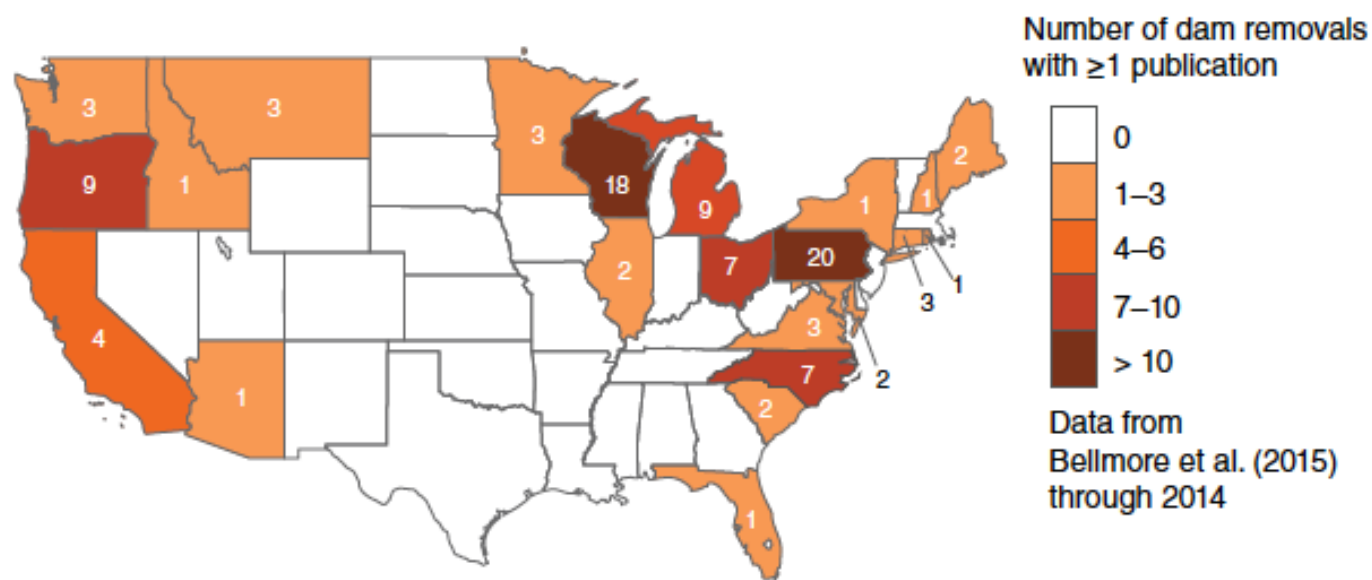
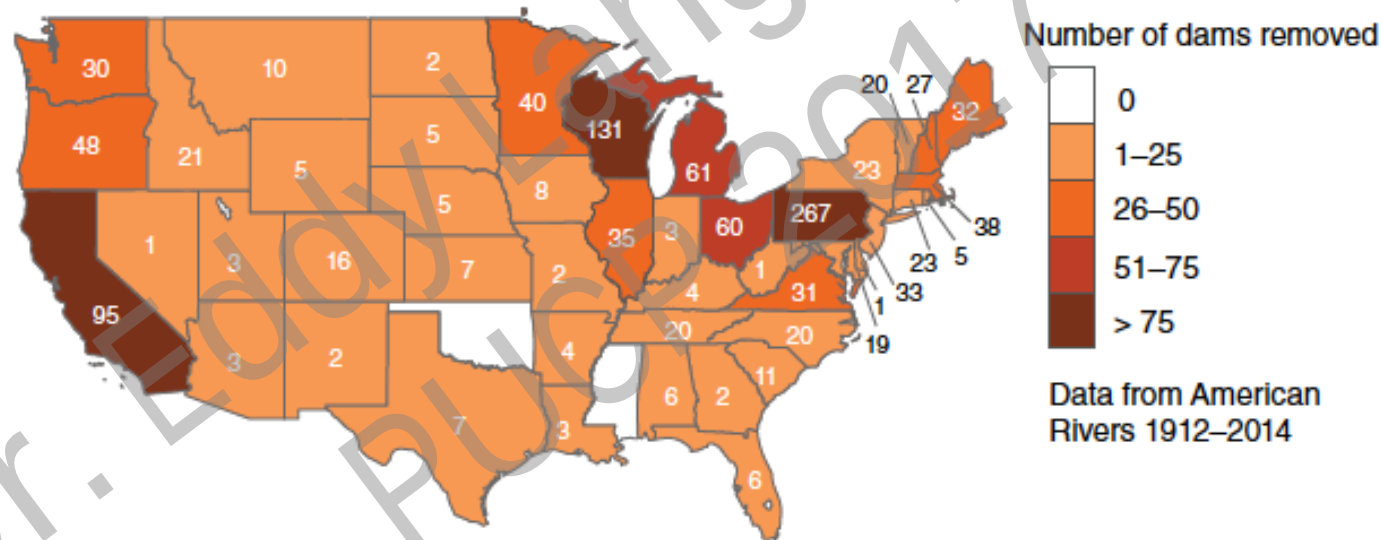
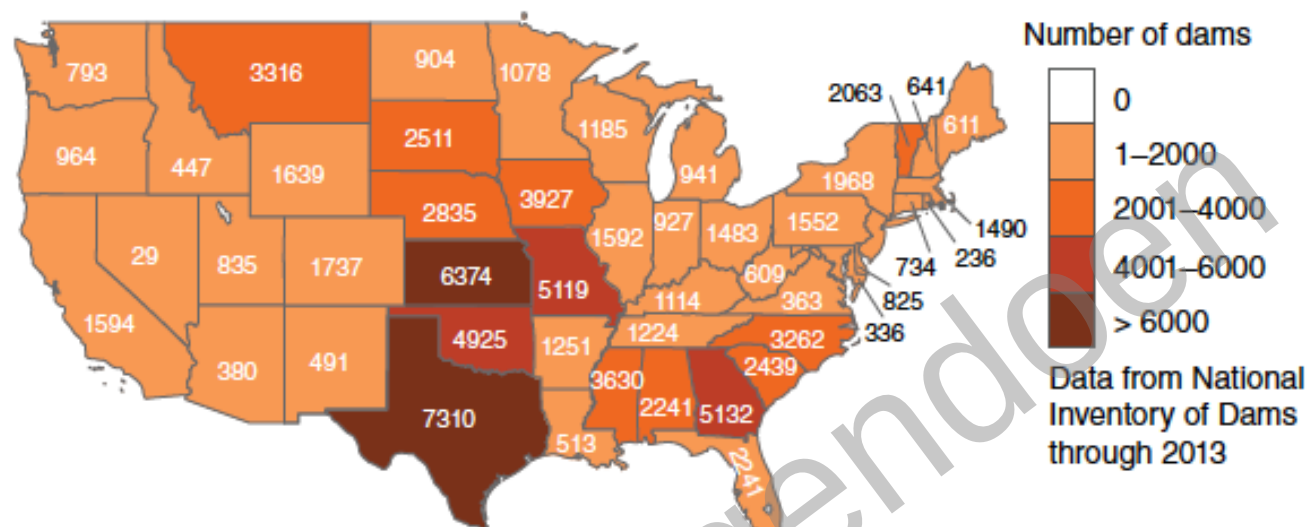
- No system-wide studies since the 1970s
- Some small studies funded by NRCS in early 2000s in Mississippi, Texas, Oklahoma, and Wisconsin (Baylor University and National Sedimentation Laboratory)
- State of Kansas a more systemwide study in 2011
- USBR and USACE are increasing their efforts to more frequently survey their reservoirs

Dams & Reservoirs - Summary

- Embankment integrity
 - Dam strengthening
 - Dam removal
- Reservoir storage depletion
 - Dam removal
 - Sustainable reservoir sediment management

Dams removed since 1912





Brewster Creek, Illinois



(a) Stream-channel evolution as of November 4, 2003



(b) After Notch 4 – November 20, 2003



(c) Stream-channel evolution as of December 29, 2003



(d) 2 weeks after Notch 5 – March 5, 2004



(e) Stream-channel evolution as of March 8, 2004



(f) Stream-channel evolution as of March 30, 2004

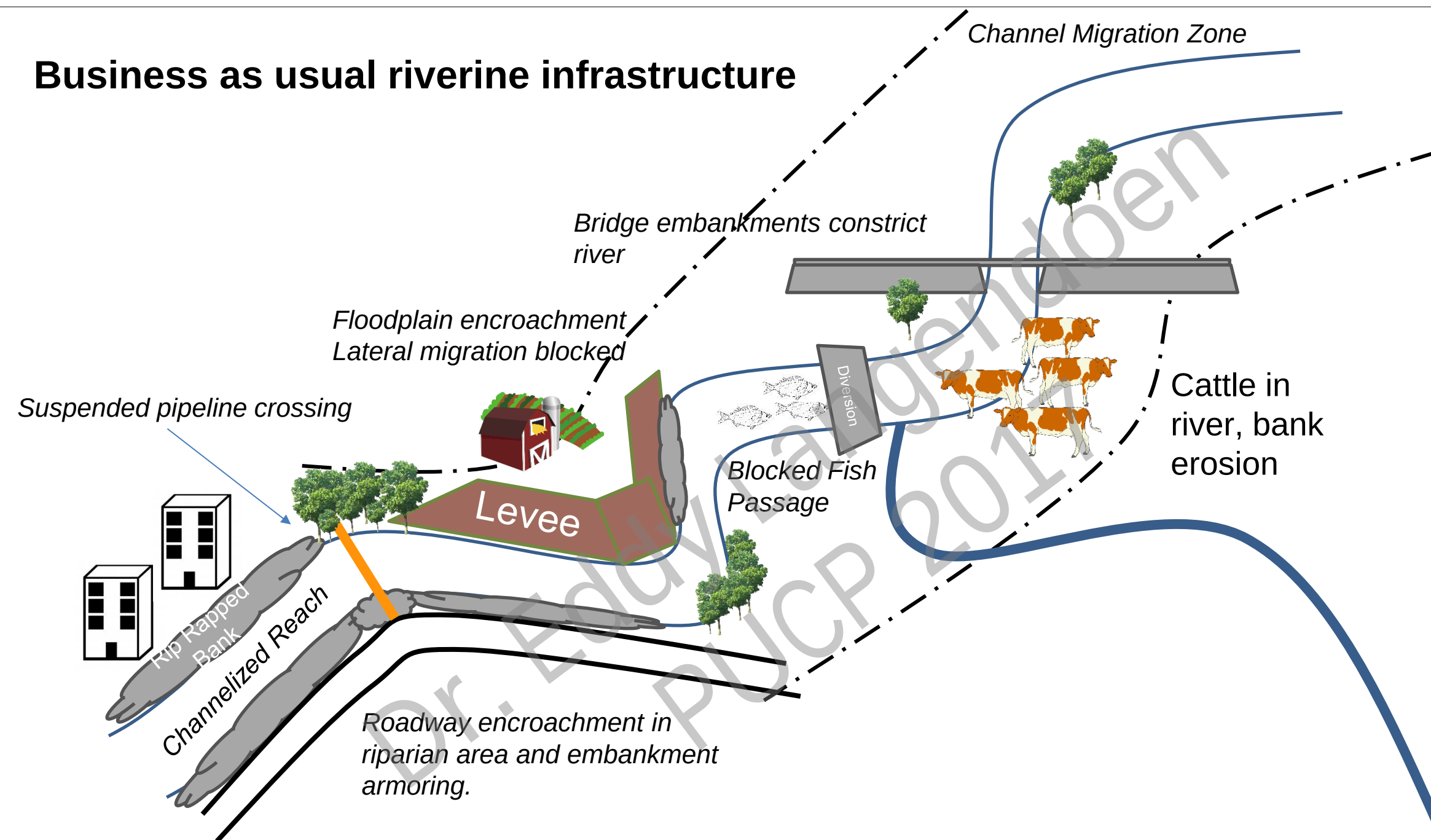
Evacuation of Reservoir Sediment?



Lateral adjustment >> Vertical adjustment
&
Significant planform adjustment



Business as usual riverine infrastructure



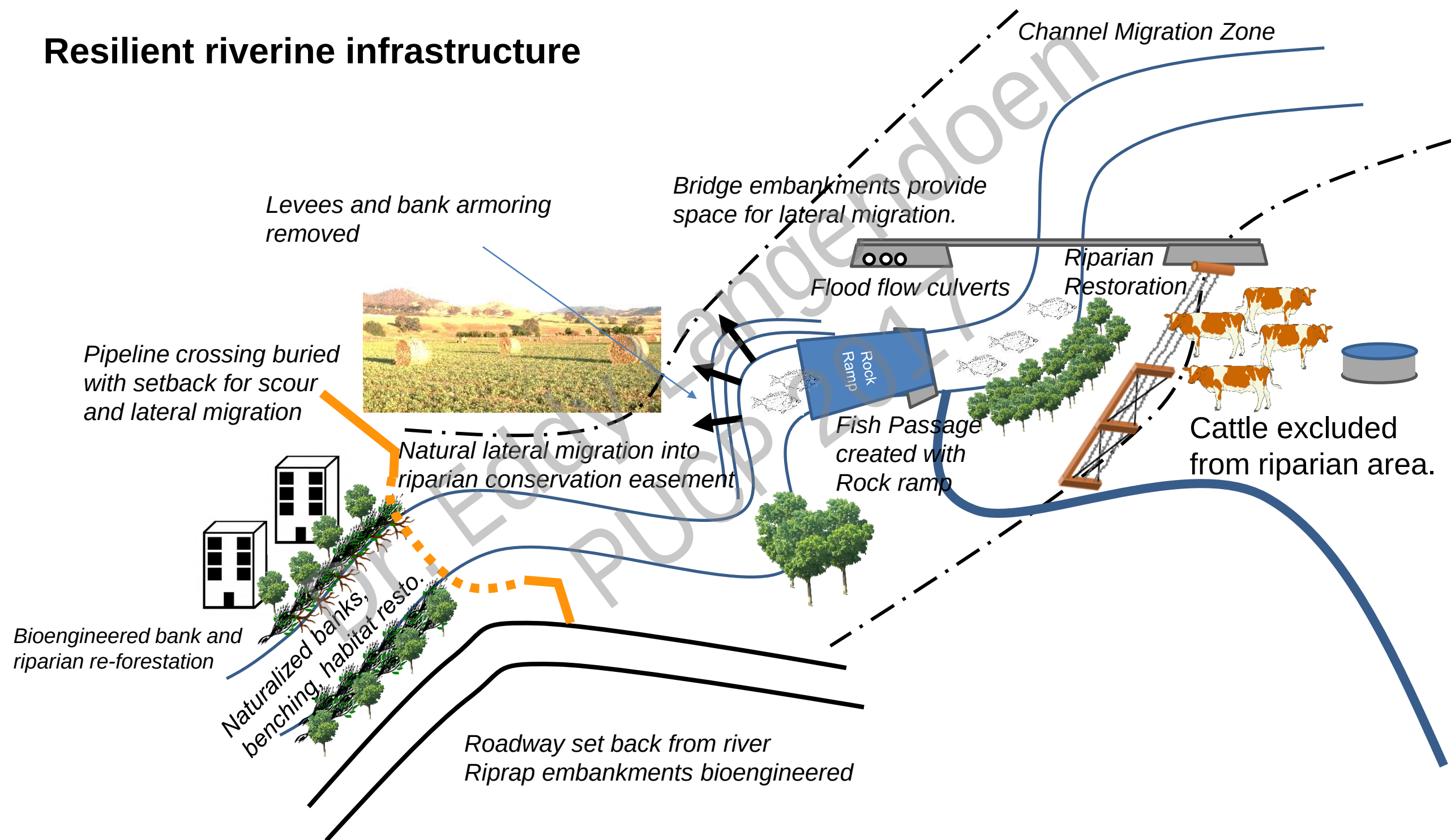
Infrastructure Features:

- Bridge
- Diversion Structure
- Levee
- Parallel Roadway with riprap embankment
- Cattle/fencing
- Pipeline crossing

Processes / Habitat Features:

- Riparian Habitat
- Lateral Migration
- Longitudinal connectivity
- Sediment continuity
- Bank bioengineering

Resilient riverine infrastructure



SOS Product Development

- Dam removal guidelines
- Workshops and FAQ on Reservoir Sedimentation and Sustainability
- White, briefing, & guidance papers
 - Infrastructure and the stream environment
 - Impact of climate change and extreme events on sediment delivery and landscape geomorphology
- Databases:
 - Reservoir sedimentation
 - Stream morphology data exchange

RECLAMATION
Managing Water in the West
DRAFT

Dam Removal Analysis Guidelines for Sediment - Version 3

Prepared for Subcommittee on Sedimentation
 Federal Advisory Committee on Water Information



U.S. Government 1D/2D/3D Sediment Transport Models^{*}

- U.S. Army Corps of Engineers
 - HEC-RAS (1D/2D): <http://www.hec.usace.army.mil/software/hec-ras/>
 - ADH (2D/3D): <https://chl.erdc.dren.mil/adh/main/index.html>
- U.S. Bureau of Reclamation
 - SRH-1D (1D): <https://www.usbr.gov/tsc/techreferences/computer%20software/models/srh1d/index.html>
 - SRH-2D (2D): <https://www.usbr.gov/tsc/techreferences/computer%20software/models/srh2d/index.html>
 - U²RANS (3D): <https://www.usbr.gov/tsc/techreferences/computer%20software/models/u2rans/index.html>
- U.S. Department of Agriculture
 - CONCEPTS (1D): <https://drive.google.com/open?id=0B1sIOPn4amxWNFFUb2N5ZE9QTUk>

^{*} Limited to physically- and process-based models only.

U.S. Government 1D/2D/3D Sediment Transport Models^{*}

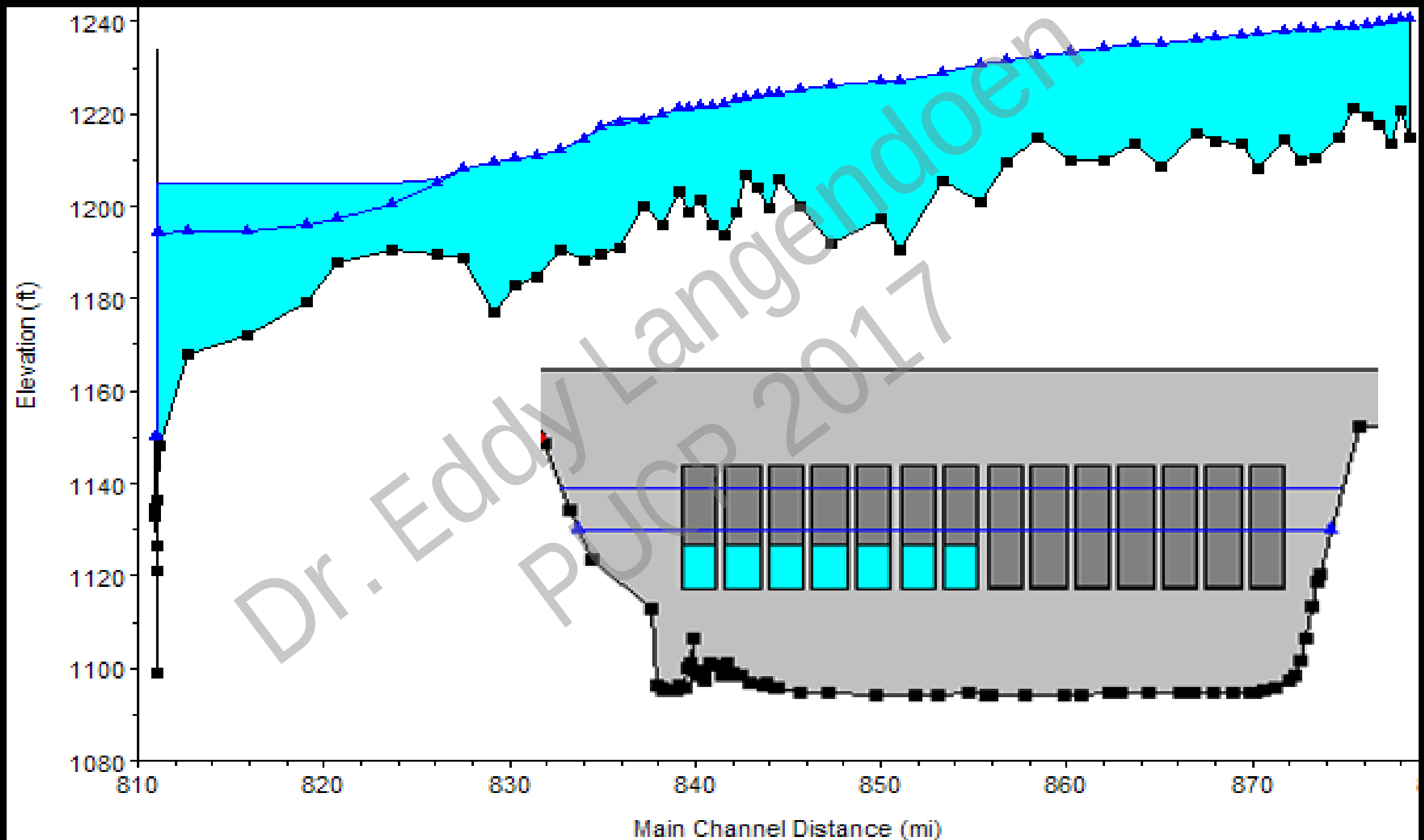
- U.S. Army Corps of Engineers
 - **HEC-RAS (1D/2D):** <http://www.hec.usace.army.mil/software/hec-ras/>
 - **ADH (2D/3D):** <https://chl.erdc.dren.mil/adh/main/index.html>
- U.S. Bureau of Reclamation
 - **SRH-1D (1D):** <https://www.usbr.gov/tsc/techreferences/computer%20software/models/srh1d/index.html>
 - **SRH-2D (2D):** <https://www.usbr.gov/tsc/techreferences/computer%20software/models/srh2d/index.html>
 - **U²RANS (3D):** <https://www.usbr.gov/tsc/techreferences/computer%20software/models/u2rans/index.html>
- U.S. Department of Agriculture
 - **CONCEPTS (1D):** <https://drive.google.com/open?id=0B1sIOPn4amxWNFFUb2N5ZE9QTUk>

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HEC-RAS v5 New Features

- Hydraulics
 - Two-dimensional and combined 1D/2D unsteady flow modeling
 - Mixed flow
 - Dam/levee breach analysis
- Sediment transport
 - Unsteady sediment transport
 - Reservoir sluicing and flushing (sustainable reservoir sediment management)
 - Bank erosion
- RAS Mapper

Advanced Reservoir Modeling and Unsteady Sediment Analysis with HEC-RAS



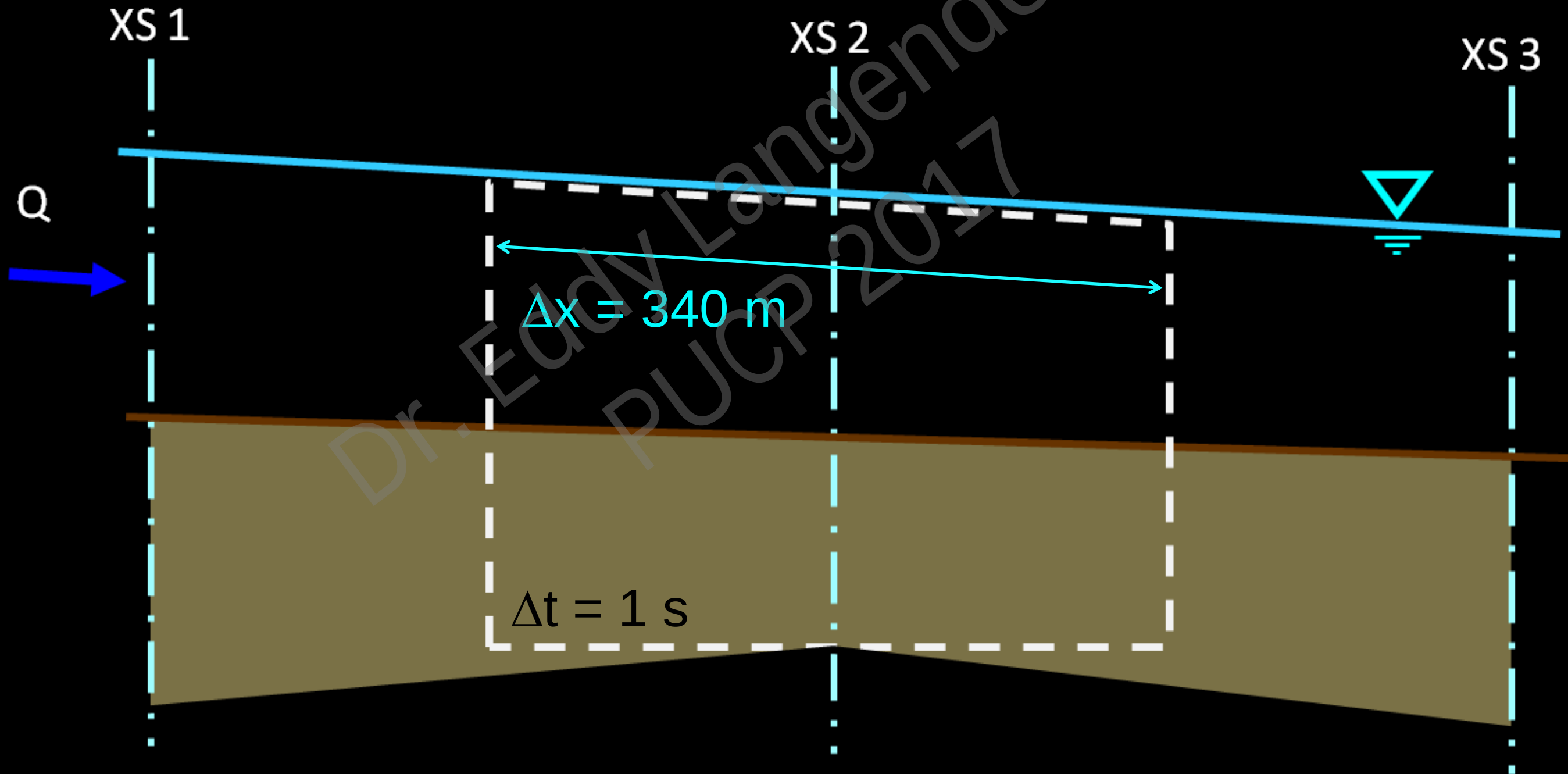
- Stanford Gibson, Phd
- Hydrologic Engineering Center, USACE

Advanced Reservoir Modeling and Unsteady Sediment Analysis with HEC-RAS

1. Principles of Reservoir Sedimentation
2. New Features for Reservoir Sediment Modeling
3. Limitations of the Quasi-Unsteady Assumption for Reservoir Sediment Analysis
4. Unsteady Sediment Transport Analysis

1. Continuity (Exner) Equation

$$V_{\text{sed}} = \frac{\Delta x}{\Delta t}$$



Temporal Deposition Limiter

Deposition efficiency coefficient =

$$\frac{\omega_{s,i} \Delta t}{H_{e,i}}$$

In a reservoir H_e is large

Therefore $H_e \gg \omega_s \Delta t$ if Δt is small

This will make the deposition efficiency coefficient very small for small time steps

If Δt does not reflect the travel time of the sediment, tying fall velocity to the time step rather than a residence time will over or under predict deposition.

Sediment Transport Analysis

File Options Help

Plan Flow Distribution Locations ... t ID Deposition

Sediment Computation Options and Tolerances ...

Sediment Output Options ...

Predefined Events

HEC-RAS Sediment Computation Options and Tolerances

Cross Section Weighting Factors

☒ Set Global Weighting Factors

Internal Cross Section

Number of US XS's to use for averaging hydraulic properties: 1

Number of DS XS's to use for averaging hydraulic properties: 1

Weight fraction (0.0-1.0) assigned to the hydraulic properties at:

Upstream Cross Section(s): 0.25

Main Cross Section: 0.5

Downstream Cross Section(s): 0.25

Upstream Boundaries:

Number of averaging XS's to use DS of the US boundary: 1

Weight fraction (0.0-1.0) assigned to the hydraulic properties at:

Upstream Boundary Condition: 1

Downstream Cross Section(s): 0

Downstream Boundaries:

Number of averaging XS's to use US of the DS boundary: 1

Weight fraction (0.0-1.0) assigned to the hydraulic properties at:

Downstream Boundary Condition: 0.5

Upstream Cross Section(s): 0.5

Computational Options

Bed exchange iterations per time step (SPI): 10

Min bed change before updating Cross Section (ft): 0.02

Min XS change before recomputation of hydraulics (ft): 0.02

☐ Perform Volume Error Check/Carry Over:

Route Sediment With:

Continuity

Bed Roughness Predictor:

Continuity
Limit to Water Velocity
Solve Advection-Dispersion

Select Reaches to
Average Bed
Roughness Predictors

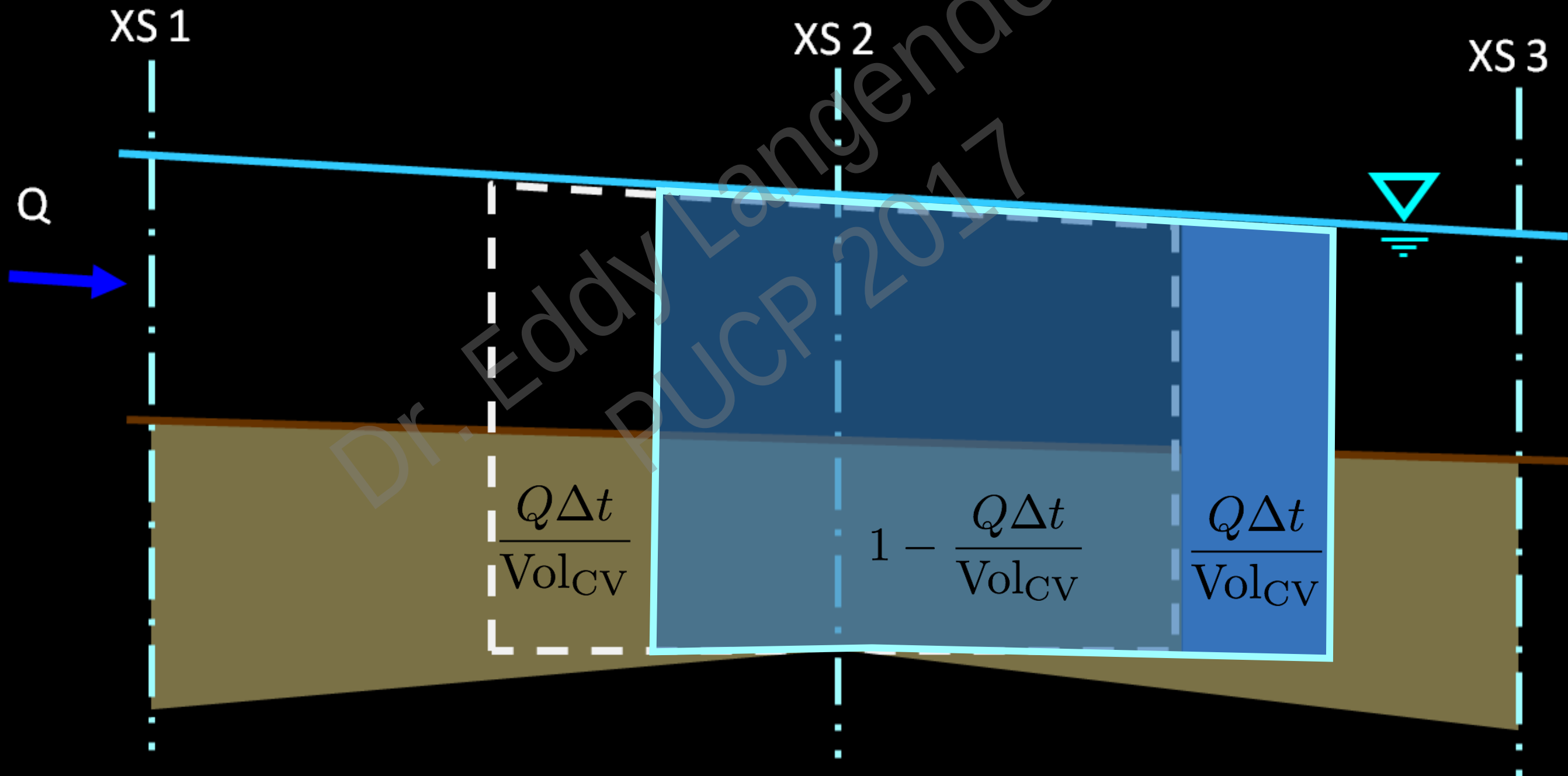
OK

Cancel

Defaults ...

$$\text{retention ratio} = 1 - \frac{Q\Delta t}{\text{Vol}_{CV}}$$

- $\text{Vel}_{\text{sediment}} = \text{Vel}_{\text{water}}$
- Limits sediment velocity to water velocity
- Increases residence time and deposition



3. Advection Dispersion

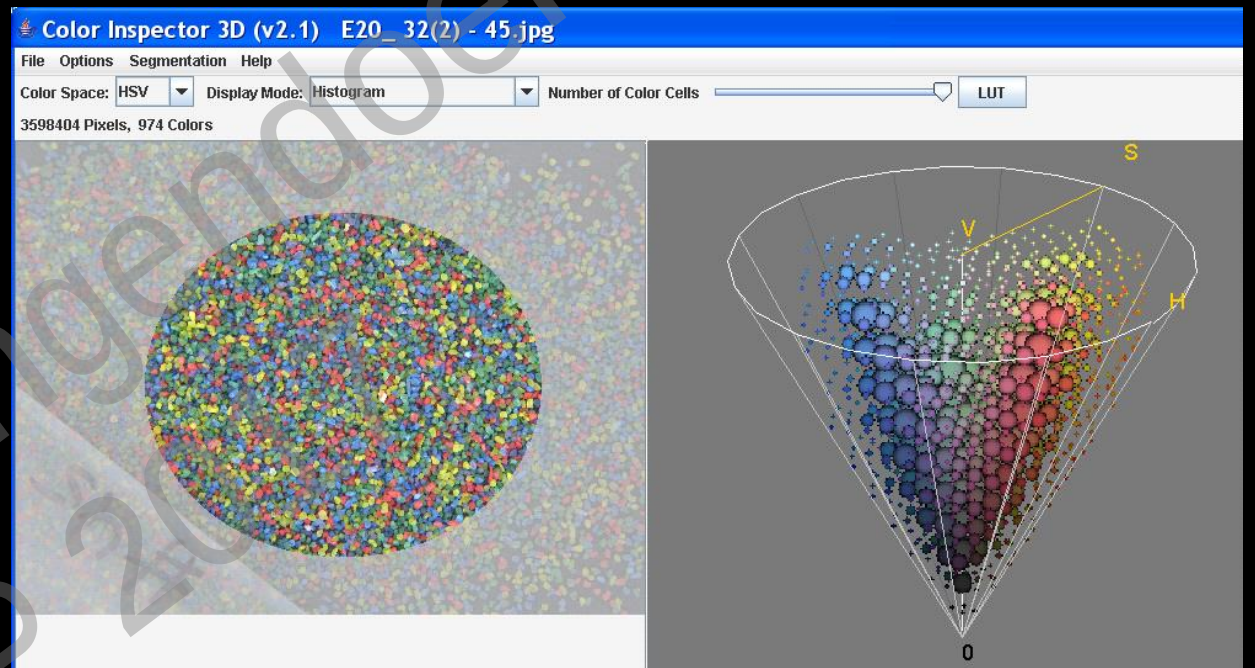
$$\frac{\partial C}{\partial t} = D \frac{\partial^2 C}{\partial x^2} - \frac{\partial uC}{\partial x}$$

- Tracks the movement of sediment longitudinally
- We used the UNET Skyline solver
- Upwind first order for advection (1st derivative)
- Central difference scheme for dispersion (2nd derivative)

3. Advection Dispersion



$$C(X_2, t) = \int_{-\infty}^{\infty} C(X_1, \tau) \frac{\exp \left[\frac{-\{\bar{u}(\bar{t}_2 - \bar{t}_1 - t + \tau)\}^2}{4K(\bar{t}_2 - \bar{t}_1)} \right]}{\sqrt{4\pi K(\bar{t}_2 - \bar{t}_1)}} \bar{u} d\tau$$



Flume



100%

0%

% Blue

Expected location of blue pulse based on time of introduction and average bed form celerity.

Actual expected spatial distribution of the blue sediment.

Advanced Reservoir Modeling and Unsteady Sediment Analysis with HEC-RAS

1. Principles of Reservoir Sedimentation
2. New Features for Reservoir Sediment Modeling
3. Quasi-Unsteady Reservoir Analysis and Limitations
4. Unsteady Sediment Transport Analysis

Quasi-Unsteady Gate Operations

Gate Time Series for Missouri River Missouri 811.065

Define openings for every gate group → Gate Group: Gates

Select/Enter the Data's Starting Time Reference

☒ Use Simulation Time: Date: 01Oct1995 Time: 0000

☐ Fixed Start Time: Date: Time:

Hydrograph Data

No. Ordinates Interpolate Values Del Row Ins Row

	Simulation Time	Elapsed Time (hours)	Duration (hours)	Gate Opening (ft)
1	01Oct1995 0000	24	24	3.6
2	02Oct1995 0000	48	24	3.58
3	03Oct1995 0000	72	24	3.52
4	04Oct1995 0000	96	24	3.44
5	05Oct1995 0000	120	24	3.35
6	06Oct1995 0000	144	24	3.5
7	07Oct1995 0000	168	24	3.41
8	08Oct1995 0000	192	24	3.49
9	09Oct1995 0000	216	24	3.49
10	10Oct1995 0000	240	24	3.44
11	11Oct1995 0000	264	24	3.45
12	12Oct1995 0000	288	24	3.55
13	13Oct1995 0000	312	24	3.55
14	14Oct1995 0000	336	24	3.55
15	15Oct1995 0000	360	24	3.58
16	16Oct1995 0000	384	24	3.61
17	17Oct1995 0000	408	24	3.53
18	18Oct1995 0000	432	24	3.51
19	19Oct1995 0000	456	24	3.48

Gate Closure Elevation

Plot ... OK Cancel

Quasi Unsteady Flow Editor

File Help

Boundary Condition Types

Flow Series Lateral Flow Series Uniform Lateral Flow

Normal Depth Stage Series Rating Curve

T.S. Gate Openings

Select Location for Boundary Condition

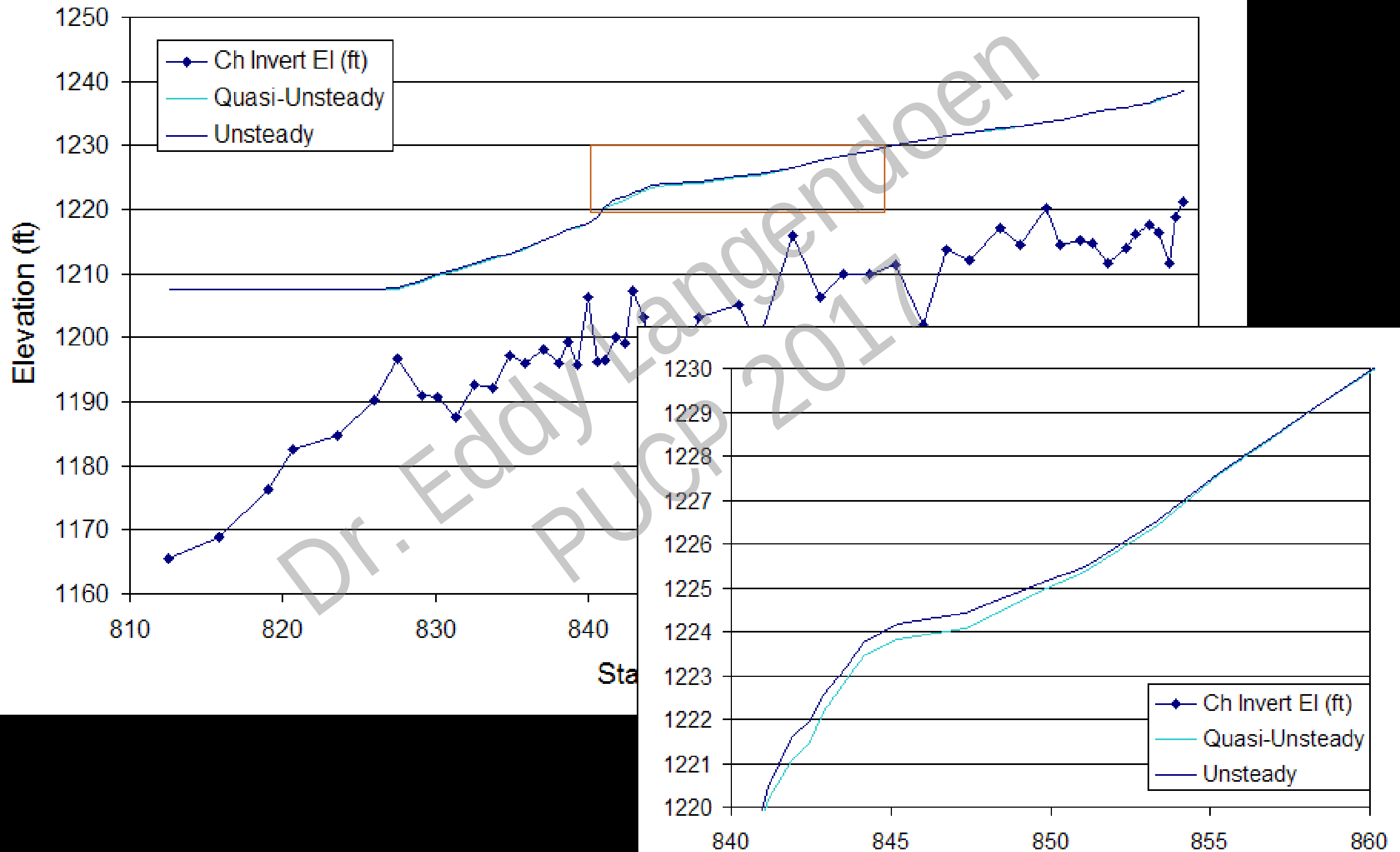
Add Flow Change Location(s) Delete Current Row

	River	Reach	RS	Boundary Condition Type
1	Missouri River	Missouri	879.01	Flow Series
2	Missouri River	Missouri	811.065	T.S. Gate Openings
3	Missouri River	Missouri	810.901	Normal Depth
4	Missouri River	Missouri	849.9	Lateral Flow Series

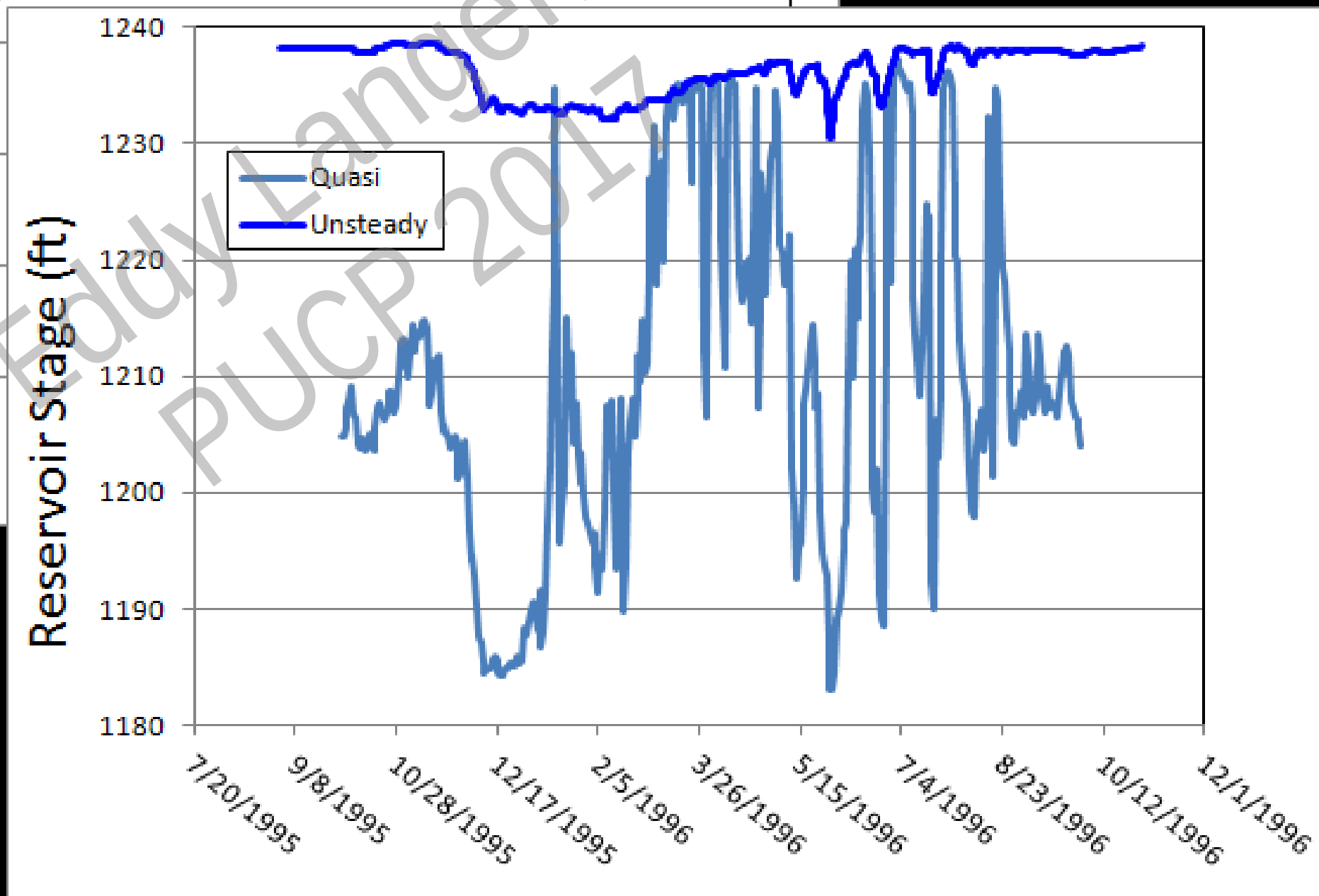
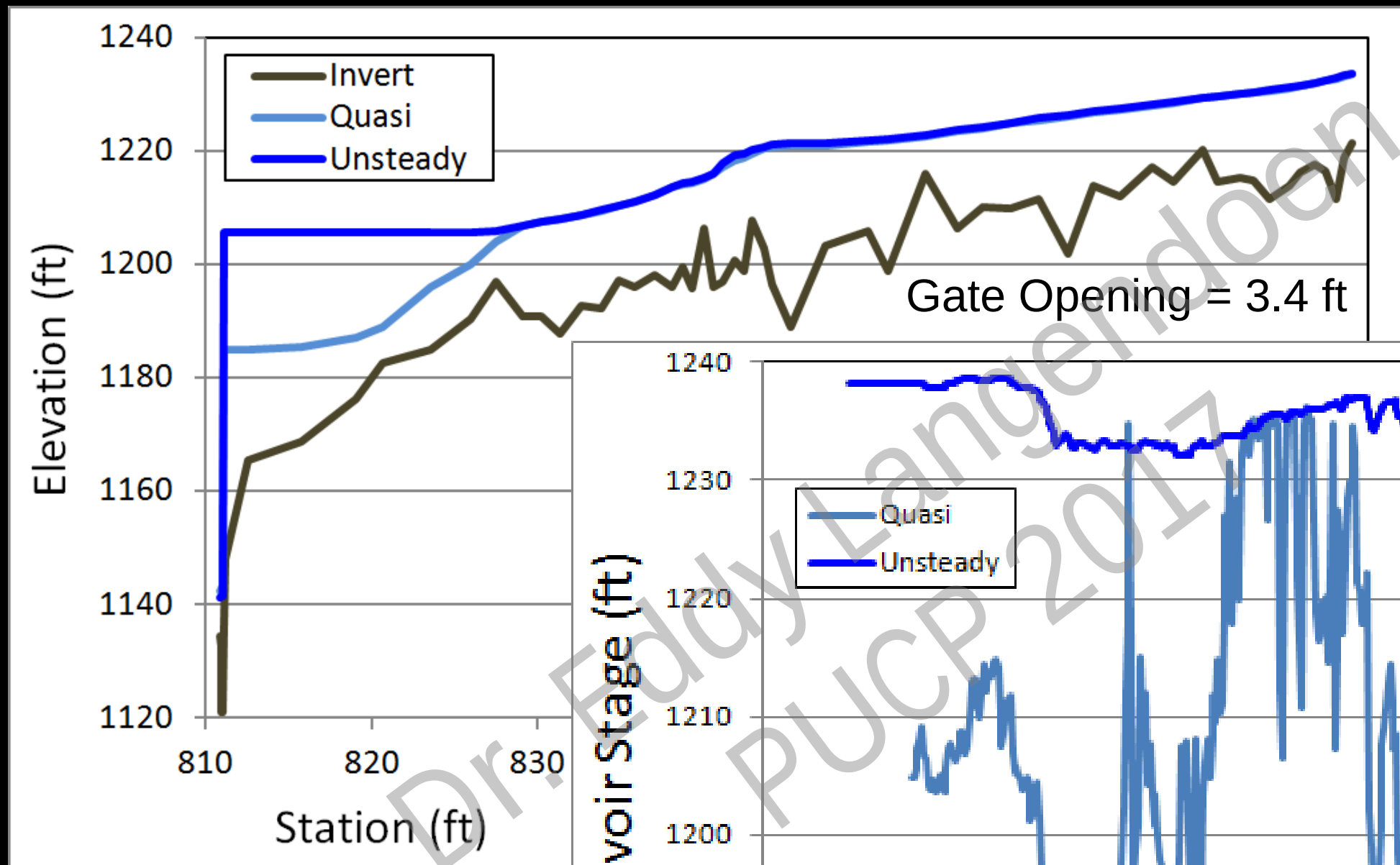
Set Temperature ... Histogram Generator...

The only gate option in the quasi-unsteady version is the Time Series of Gate Openings.

Unsteady vs Quasi-Unsteady (DS Stage BC)



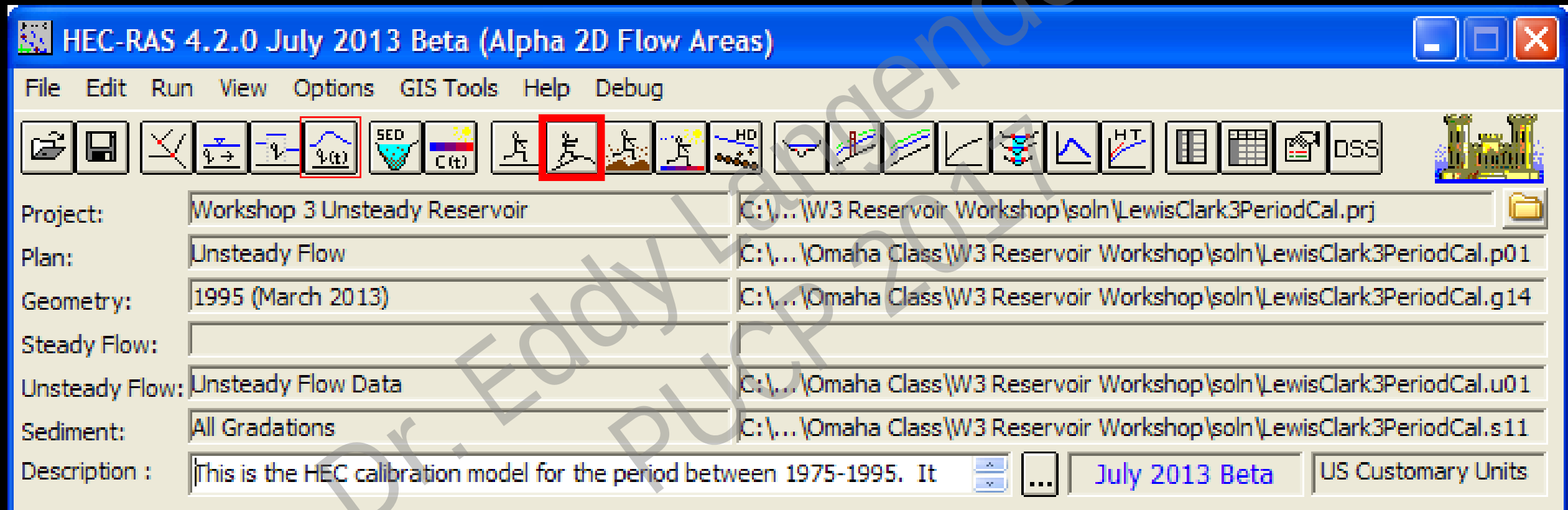
Unsteady vs Quasi-Unsteady (TS Gate BC)



Advanced Reservoir Modeling and Unsteady Sediment Analysis with HEC-RAS

1. Principles of Reservoir Sedimentation
2. New Features for Reservoir Sediment Modeling
3. Quasi-Unsteady Reservoir Analysis and Limitations
4. Unsteady Sediment Transport Analysis

Unsteady Sediment Transport



Unsteady Sediment Transport

Unsteady Flow Data - Unsteady Flow Data

File Options Help

Boundary Conditions | Initial Conditions | Apply Data

Boundary Condition Types

Stage Hydrograph	Flow Hydrograph	Stage/Flow Hydr.	Rating Curve
Normal Depth	Lateral Inflow Hydr.	Uniform Lateral Inflow	Groundwater Interflow
T.S. Gate Openings	Elev Controlled Gates	Navigation Dams	IB Stage/Flow
Rules			

Add Boundary Condition Location

Add RS ... Add Storage Area ... Add SA Connection ... Add Pump Station ...

Select Location in table then select Boundary Condition Type

	River	Reach	RS	Boundary Condition
1	Missouri River	Missouri	879.01	Flow Hydrograph
2	Missouri River	Missouri	849.9	Lateral Inflow Hydr.
3	Missouri River	Missouri	812.54	Stage Hydrograph

Flow Hydrograph

River: Missouri River Reach: Missouri RS: 879.01

☐ Read from DSS before simulation Select DSS file and Path

File:
Path:

☒ Enter Table Data time interval: 1 Day

Select/Enter the Data's Starting Time Reference

☐ Use Simulation Time: Date: 01Oct1995 Time: 0000
☒ Fixed Start Time: Date: 02Jan1955 Time: 0000

No. Ordinates Interpolate Missing Values Del Row Ins Row

Hydrograph Data

	Date	Simulation Time (hours)	Flow (cfs)
1	01Jan1955 2400	00:00	7329.
2	02Jan1955 2400	24:00	7096.
3	03Jan1955 2400	48:00	7992.
4	04Jan1955 2400	72:00	7757.
5	05Jan1955 2400	96:00	7621.
6	06Jan1955 2400	120:00	7649.
7	07Jan1955 2400	144:00	7596.
8	08Jan1955 2400	168:00	7720.
9	09Jan1955 2400	192:00	6731.
10	10Jan1955 2400	216:00	8138.
11	11Jan1955 2400	240:00	7974.
12	12Jan1955 2400	264:00	8026.
13	13Jan1955 2400	288:00	7880.

Time Step Adjustment Options ("Critical" boundary conditions)

☐ Monitor this hydrograph for adjustments to computational time step

Max Change in Flow (without changing time step):

Min Flow: Multiplier:

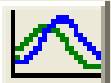
Plot Data OK Cancel

Unsteady Sediment Transport

Boundary Conditions | Initial Conditions | Apply Data

Boundary Condition Types

Stage Hydrograph	Flow Hydrograph	Stage/Flow Hydr.	Rating Curve
Normal Depth	Lateral Inflow Hydr.	Uniform Lateral Inflow	Groundwater Interflow
T.S. Gate Openings	Elev Controlled Gates	Navigation Dams	IB Stage/Flow

Rules  

Add Boundary Condition Location

Add RS ...
Add Storage Area ...
Add SA Connection ...
Add Pump Station ...

Select Location in table then select Boundary Condition Type

	River	Reach	RS	Boundary Condition
1	Missouri River	Missouri	879.01	Flow Hydrograph
2	Missouri River	Missouri	811.065 IS	
3	Missouri River	Missouri	810.901	Normal Depth

-Structures in an unsteady sediment transport model have more simulation options

Internal Boundary Stage/Flow

IB Stage/Flow

Internal Boundary Stage and Flow Hydrograph

River: Missouri River Reach: Missouri RS: 811.076

☐ Read from DSS before simulation Select DSS file and Path

File:

Stage

Flow

☒ Enter Table Data time interval: 1 Day

Select/Enter the Data's Starting Time Reference

☐ Use Simulation Time: Date: 01Sep1995 Time: 0000

☒ Fixed Start Time: Date: 01Jul1956 Time: 0000

No. Ordinates Interpolate Missing Values Del Row Ins Row

Hydrograph Data				
	Date	Simulation Time (hours)	Stage (ft)	Flow (cfs)
1	30Jun1956 2400	00:00	1203.6	
2	01Jul1956 2400	24:00	1204.2	
3	02Jul1956 2400	48:00	1204.7	
4	03Jul1956 2400	72:00	1204.8	
5	04Jul1956 2400	96:00	1205.	
6	05Jul1956 2400	120:00	1205.1	
7	06Jul1956 2400	144:00	1204.7	
8	07Jul1956 2400	168:00	1204.1	
9	08Jul1956 2400	192:00	1204	

Time Step Adjustment Options ("Critical" boundary conditions)

☐ Monitor this hydrograph for adjustments to computational time step

Max Change in Flow (without changing time step):

Plot Data OK Cancel

-Automatically opens gates to achieve either an upstream stage or a flow through the gates

-Define gate BCs which will be used in the first time step.

-Add the IB Stage/Flow BC to the XS upstream of the Inline Structure

811.076

IB Stage/Flow

811.065 IS

T.S. Gate Openings

Unsteady Sediment Transport

Unsteady Flow Analysis

File Options Help

Plan : Unsteadyi-Flush (no Dam) Short ID : Unsteady-Flush

Geometry File : 2011 Geometry

Unsteady Flow File : Flush Unsteady no_Dam

Sediment File : Flush Sediment (no Dam)

Plan Description :

Programs to Run

- ☒ Geometry Preprocessor
- ☒ Unsteady Flow Simulation
- ☒ Sediment
- ☒ Post Processor
- ☐ Floodplain Mapping

Simulation Time Window

Starting Date: 01Oct2012 Starting Time: 0000

Ending Date: 25Oct2012 Ending Time: 2400

Computation Settings

Computation Interval: 30 Minute Hydrograph Output Interval: 1 Hour

Mapping Output Interval: 1 Hour Detailed Output Interval: 1 Hour

☐ Computation Level Output

DSS Output Filename: C:\Documents and Settings\HEC User\My Documents\OmahaM

☐ Mixed Flow Regime (see menu: "Options/Mixed Flow Options ...") debug parameters

Compute

Reservoir Operation Situations

1. Know reservoir stage *a priori*?
 - Quasi-Unsteady Flow
2. Know Gate Operations *a priori*?
 - Unsteady Flow with Gate Operations
3. Know reservoir stage but want to compute gate flow?
 - Unsteady/IB Stage Flow
4. Don't know gate ops. or reservoir stage but want to set flow through gates?
 - Unsteady with Rules

Reservoir Flushing and Unsteady Sediment Analysis with Operational Rules



Crosa *et al.* 2010

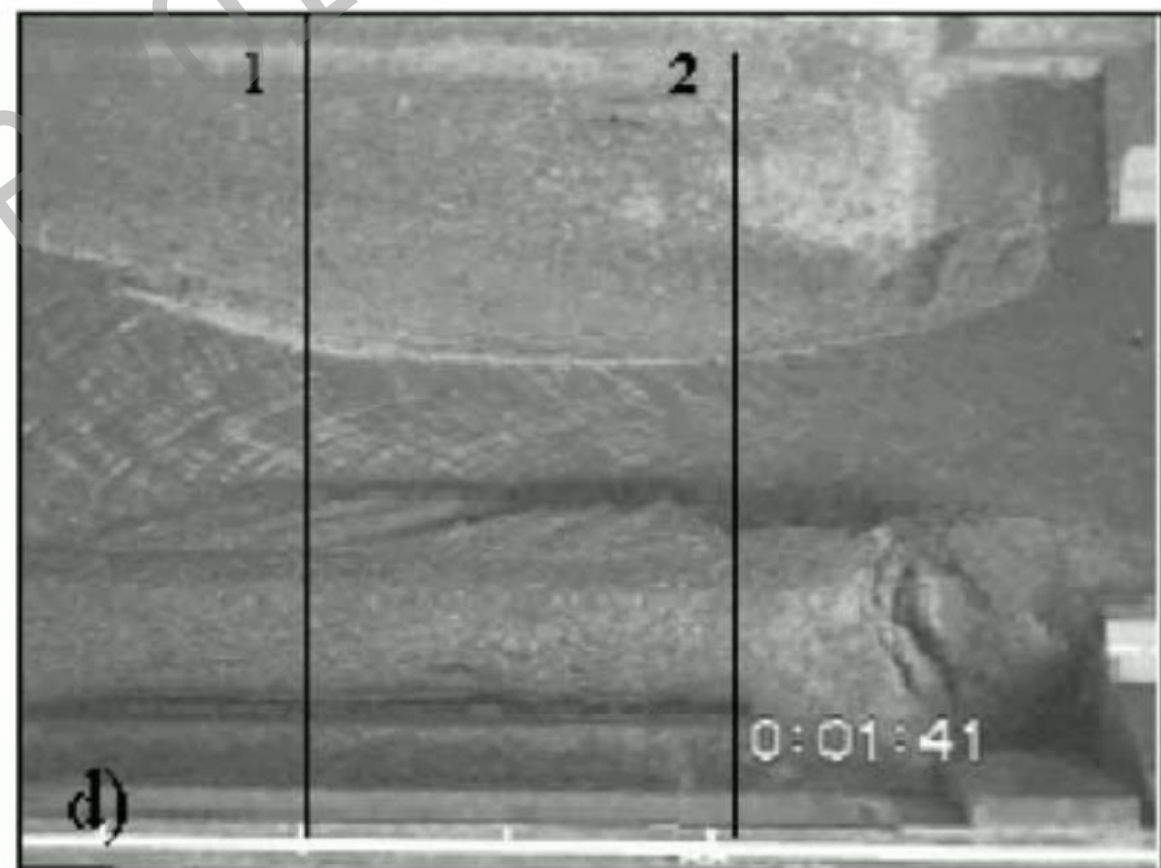
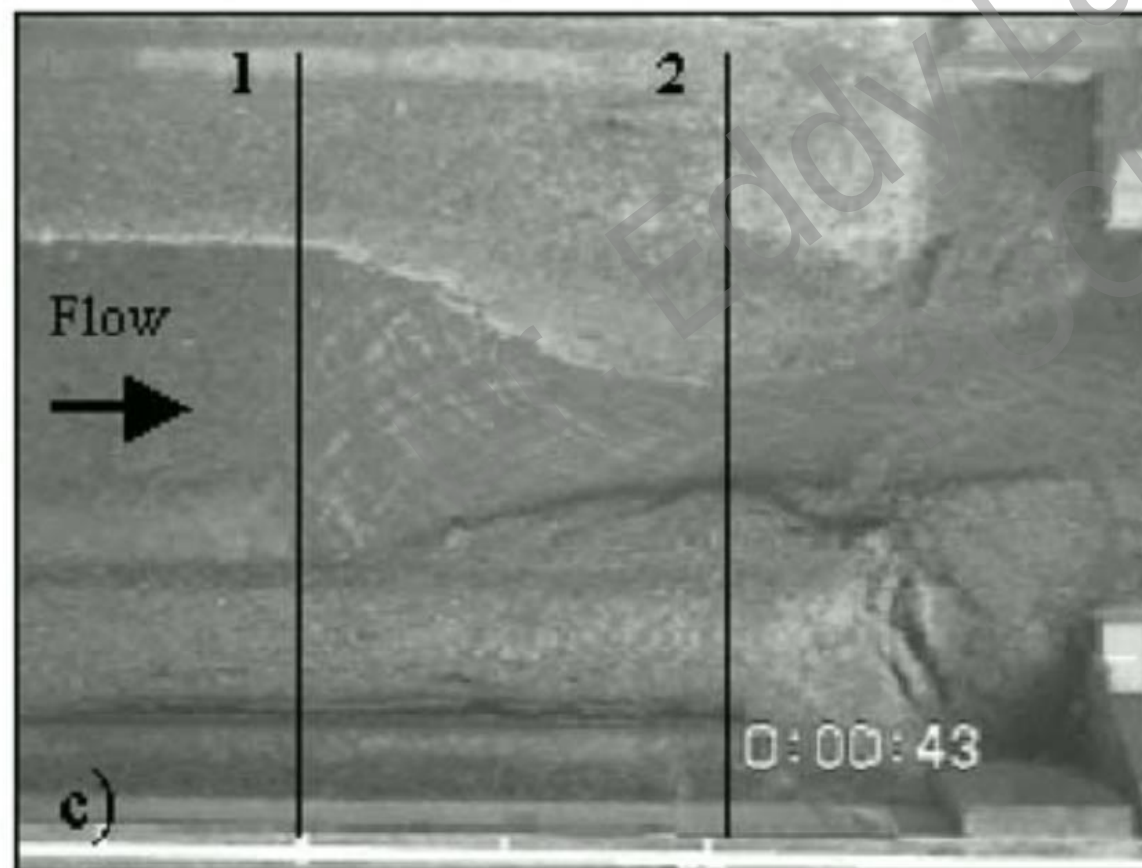
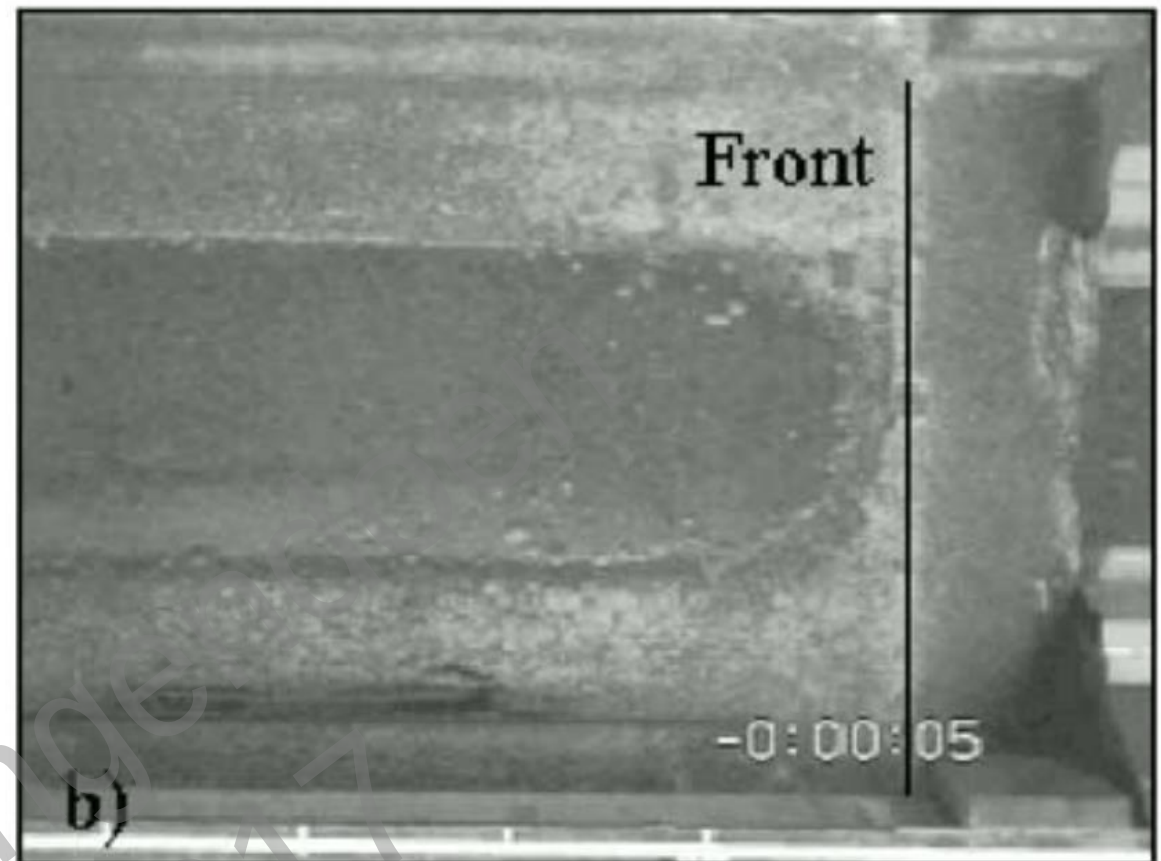
Stanford Gibson, Phd
Hydrologic Engineering Center

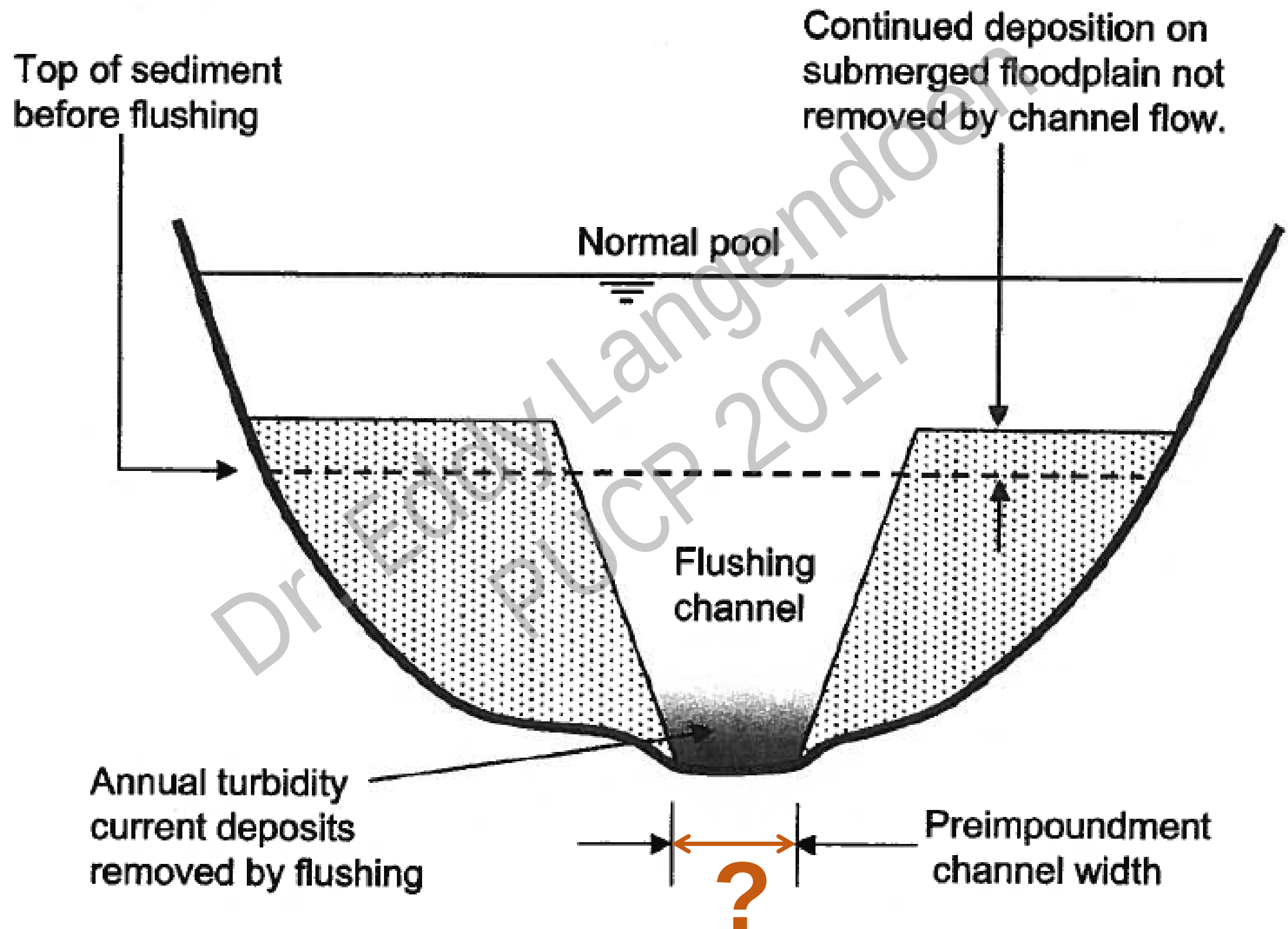
Advanced Reservoir Modeling and Unsteady Sediment Analysis with HEC-RAS

1. Principles of Reservoir Flushing and Sluicing
2. New Features for Sustainable Sediment Management Modeling
3. Modeling Sustainable Sediment Reservoir Operations with Unsteady Analysis and Rules

2. New Features for Sustainable Sediment Management Modeling

- Simplified Channel Evolution
 - Atkinson Width Calculator
- Multiple Erovable Channels
- Alternate Cohesive Erosion Methods
- Bed Stratigraphy
- Flocculation/Clod Erosion





'Channel Evolution' Erosion Model

Bed Change Options

Deposition

☒ No Bed Change Allowed Outside of the Movable Bed Limits

☐ Allow Deposition Outside of the Movable Bed Limits

Erosion

Erode Reservoir Sediments Using a Simplified Channel Evolution Model

Note: Standard bed change algorithms will be used for any XS left blank.

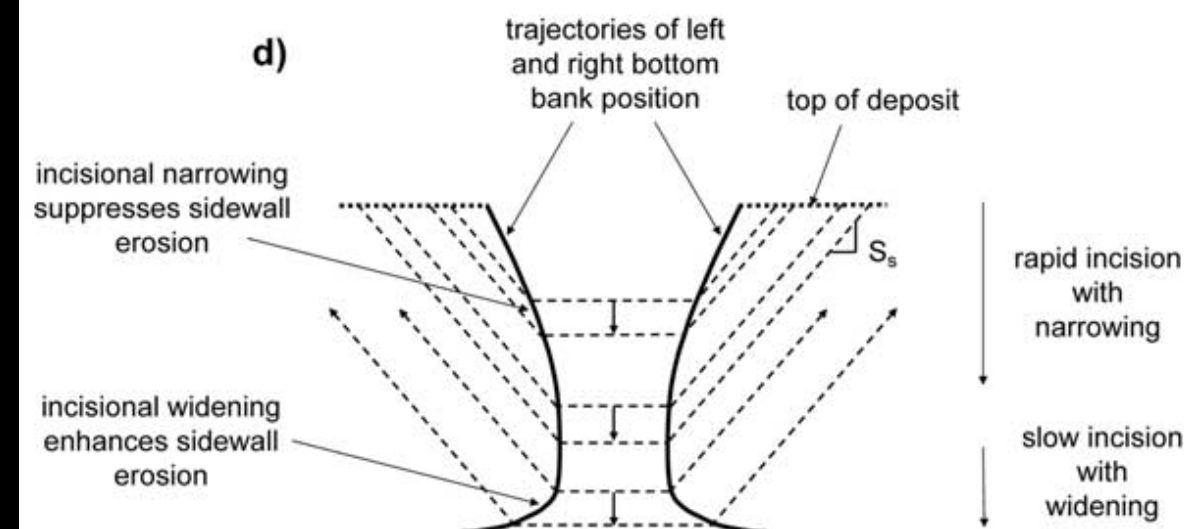
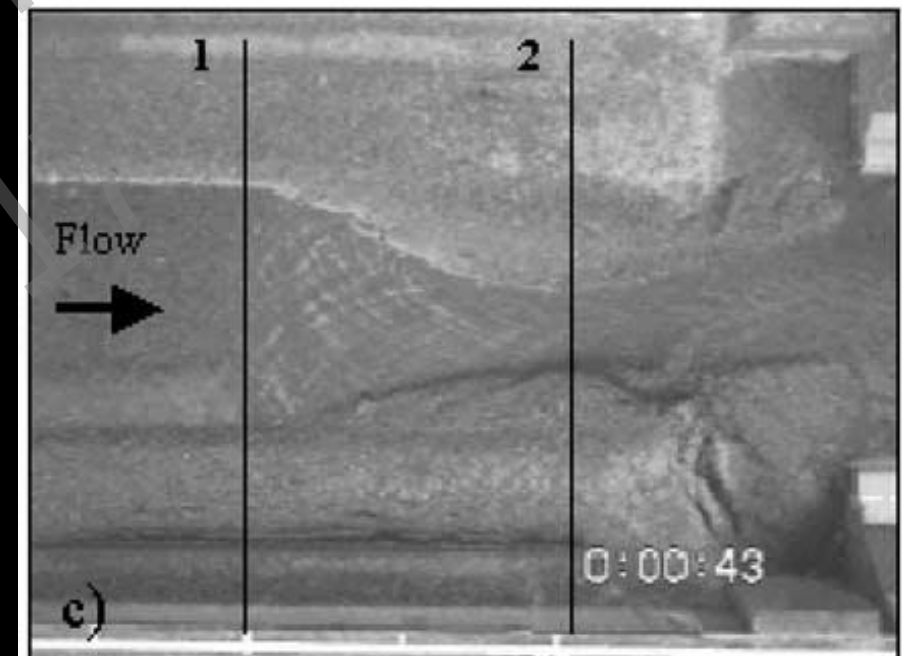
River: (All Rivers) Reset Trigger: Width Calculator...

	River	Reach	RS	Max Width	Side Slope
1	Yang Flume	Yang Flume	1000	2000	0.5
2	Yang Flume	Yang Flume	980.*	2000	0.5
3	Yang Flume	Yang Flume	960.*	2000	0.5
4	Yang Flume	Yang Flume	940.*	2000	0.5
5	Yang Flume	Yang Flume	920.*	2000	0.5
6	Yang Flume	Yang Flume	900.*	2000	0.5
7	Yang Flume	Yang Flume	880.*	2000	0.5
8	Yang Flume	Yang Flume	860.*	2000	0.5
9	Yang Flume	Yang Flume	840.*	2000	0.5

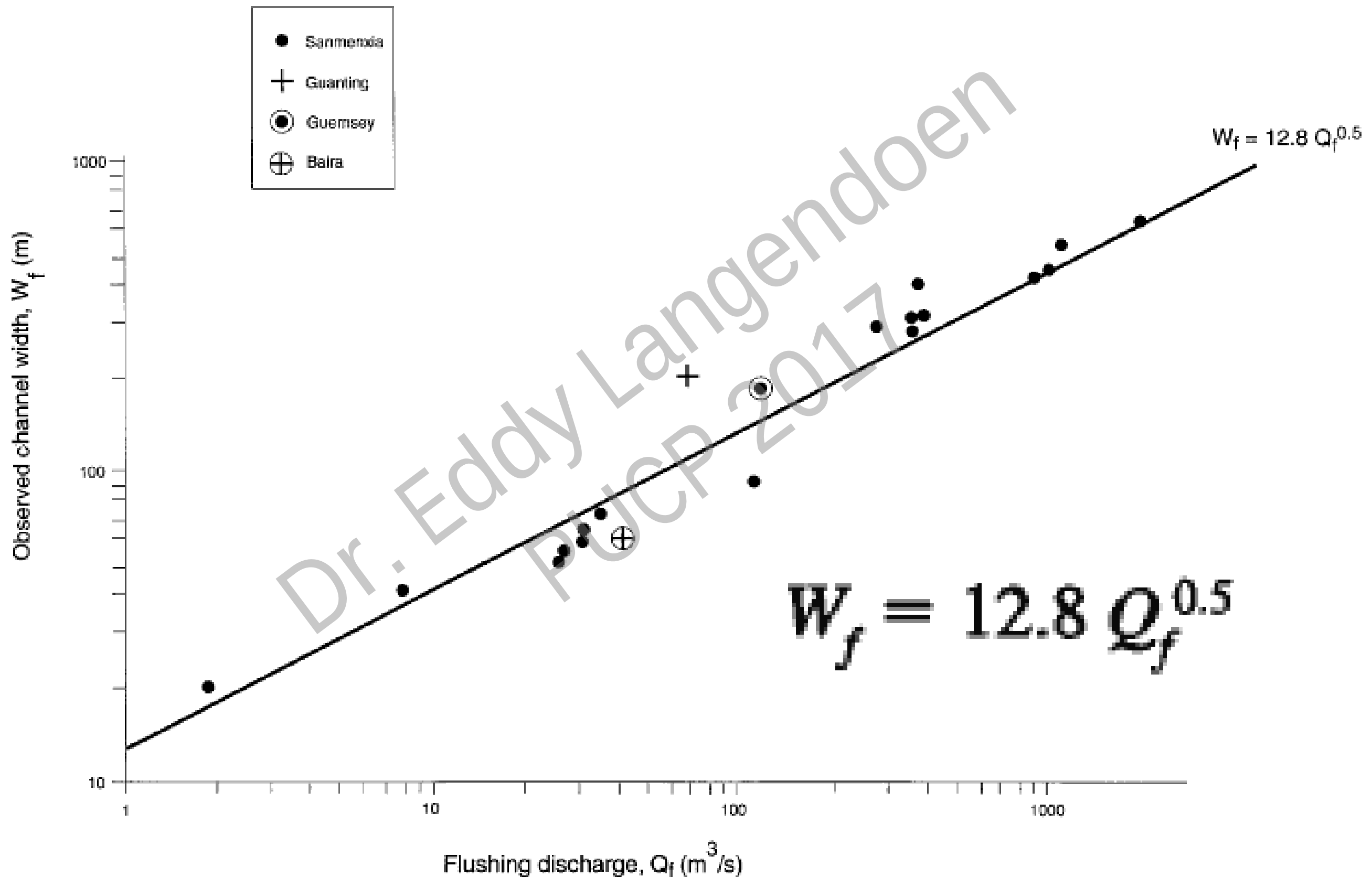
Bed Rock XSs geometry file:

OK

Cancel



Atkinson (1996)



Width Calculator

Erosion

Erode Reservoir Sediments Using a Simplified Channel Evolution Model

Note: Standard bed change algorithms will be used for any XS left blank.

River: (All Rivers) ▼

Reset Trigger: ▼

Reach: ▼

Width Calculator...

	River	Reach	RS	Max Width	Side Slope
6	Cattaraugus Ck	1	204398.7	2000	0.5
7	Cattaraugus Ck	1	204000	2000	0.5
8	Cattaraugus Ck	1	203000		
9	Cattaraugus Ck	1	202000		
10	Cattaraugus Ck	1	201467		
11	Cattaraugus Ck	1	201166		
12	Cattaraugus Ck	1	200611		
13	Cattaraugus Ck	1	200000		
14	Cattaraugus Ck	1	199463		
15	Cattaraugus Ck	1	198994		
16	Cattaraugus Ck	1	198325		
17	Cattaraugus Ck	1	197977.6	2000	0.5

Bed Rock XSs geometry file: ▼

OK

Cancel

Width Calculator

This calculator computes a channel bottom width for a channel formed by a flushing flow according to the equation Atkinson (1996) fit through data from several reservoir flushing studies.

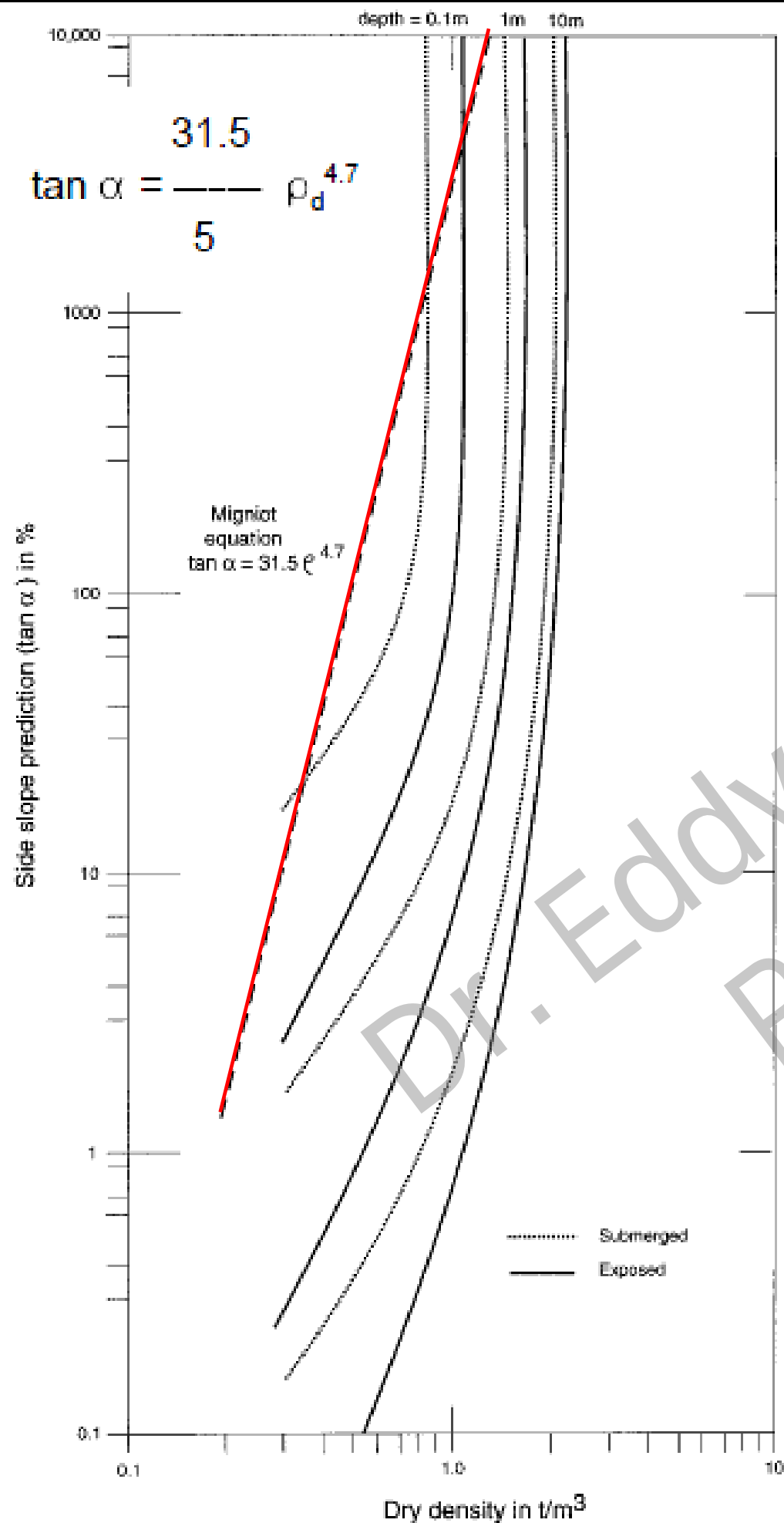
Flow (cfs)

200

Width (ft)

3529.292

Compute Width

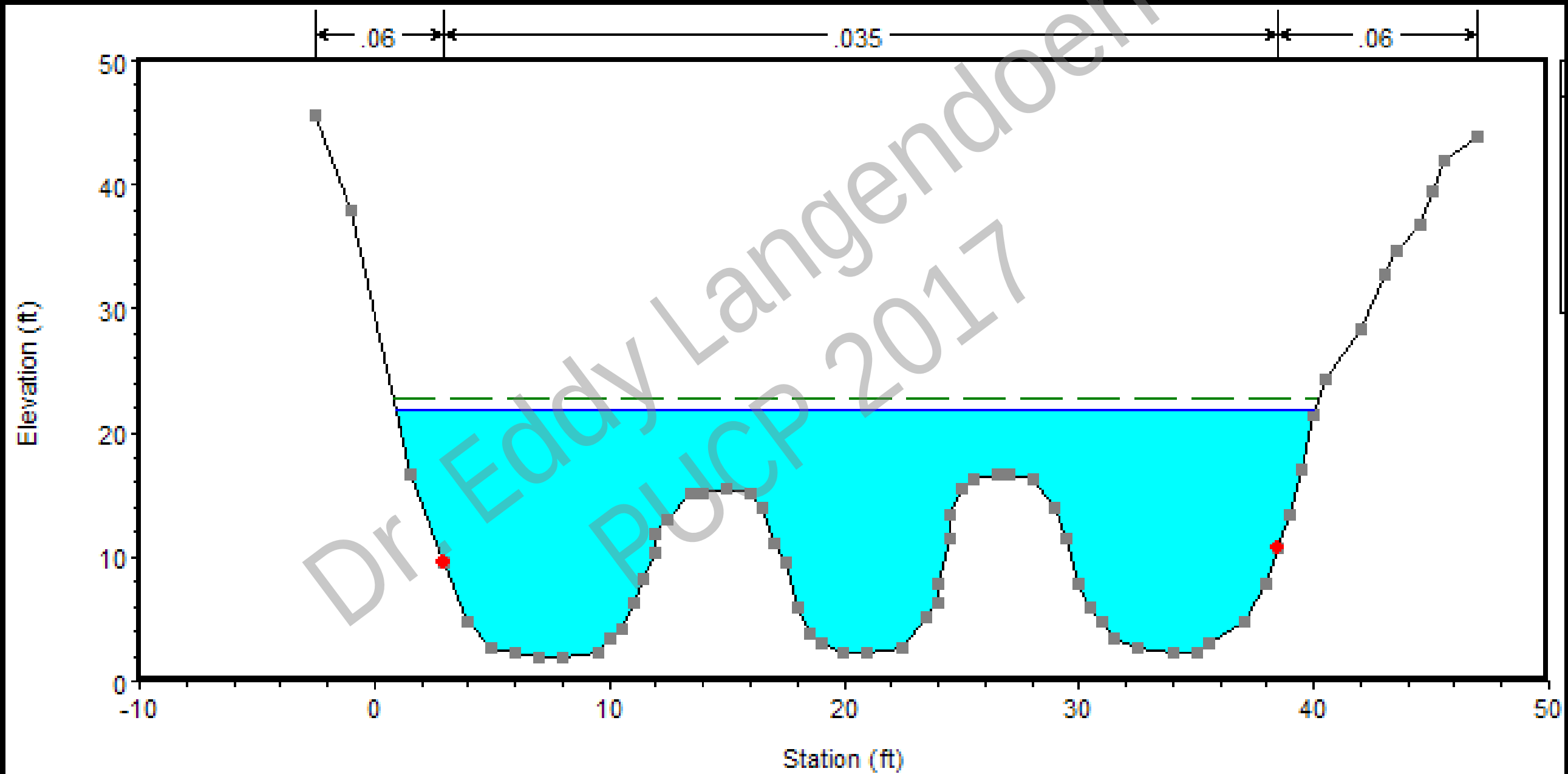


“No reasonably reliable general purpose relationship could be found for predicting flushing channel side slopes.” -Atkinson (1996)

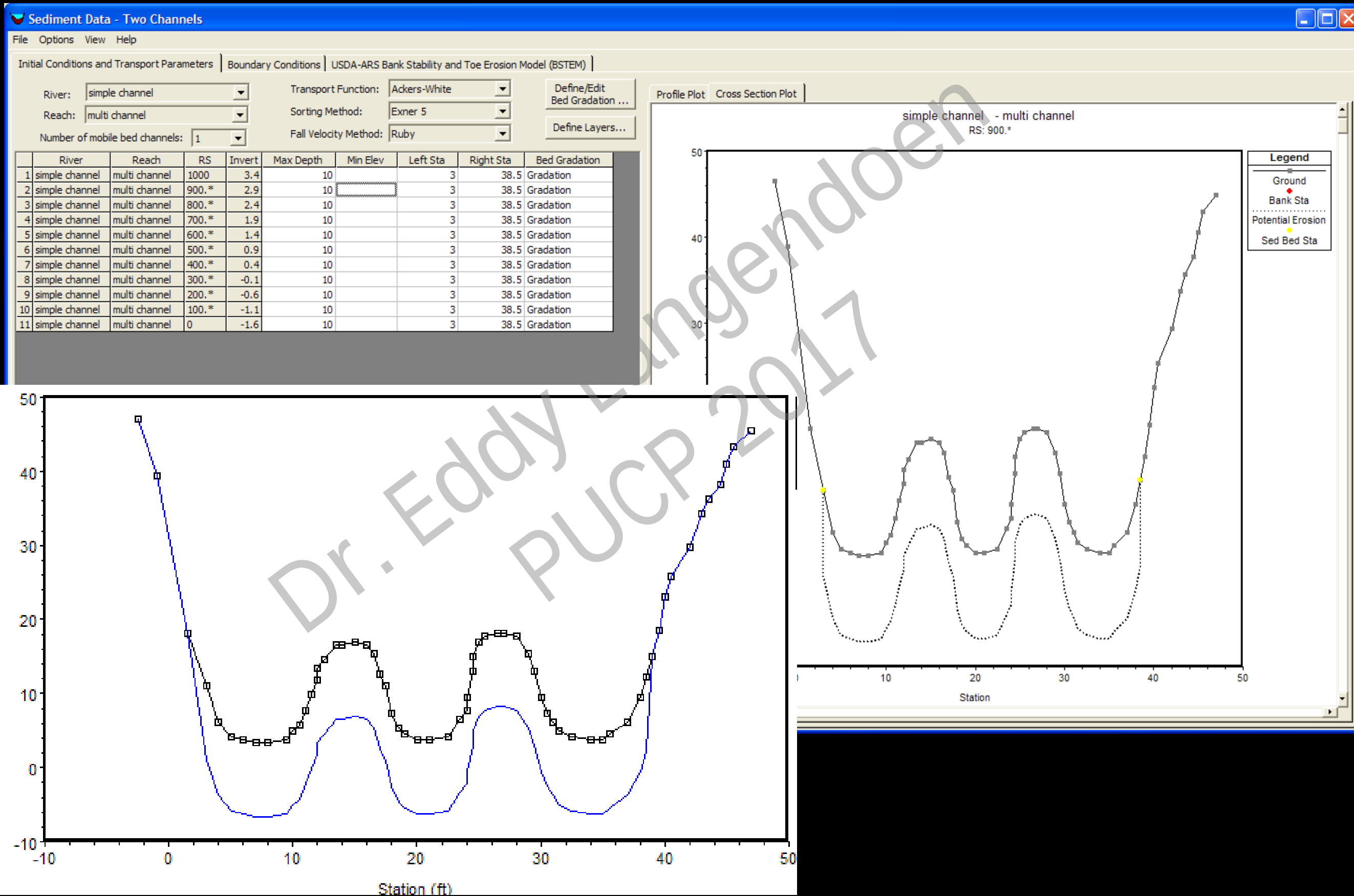
2. New Features for Sustainable Sediment Management Modeling

- Simplified Channel Evolution
 - Atkinson Width Calculator
- Multiple Erovable Channels
- Alternate Cohesive Erosion Methods
- Bed Stratigraphy
- Flocculation/Clod Erosion

Multiple Erovable Channels



Multiple Erovable Channels

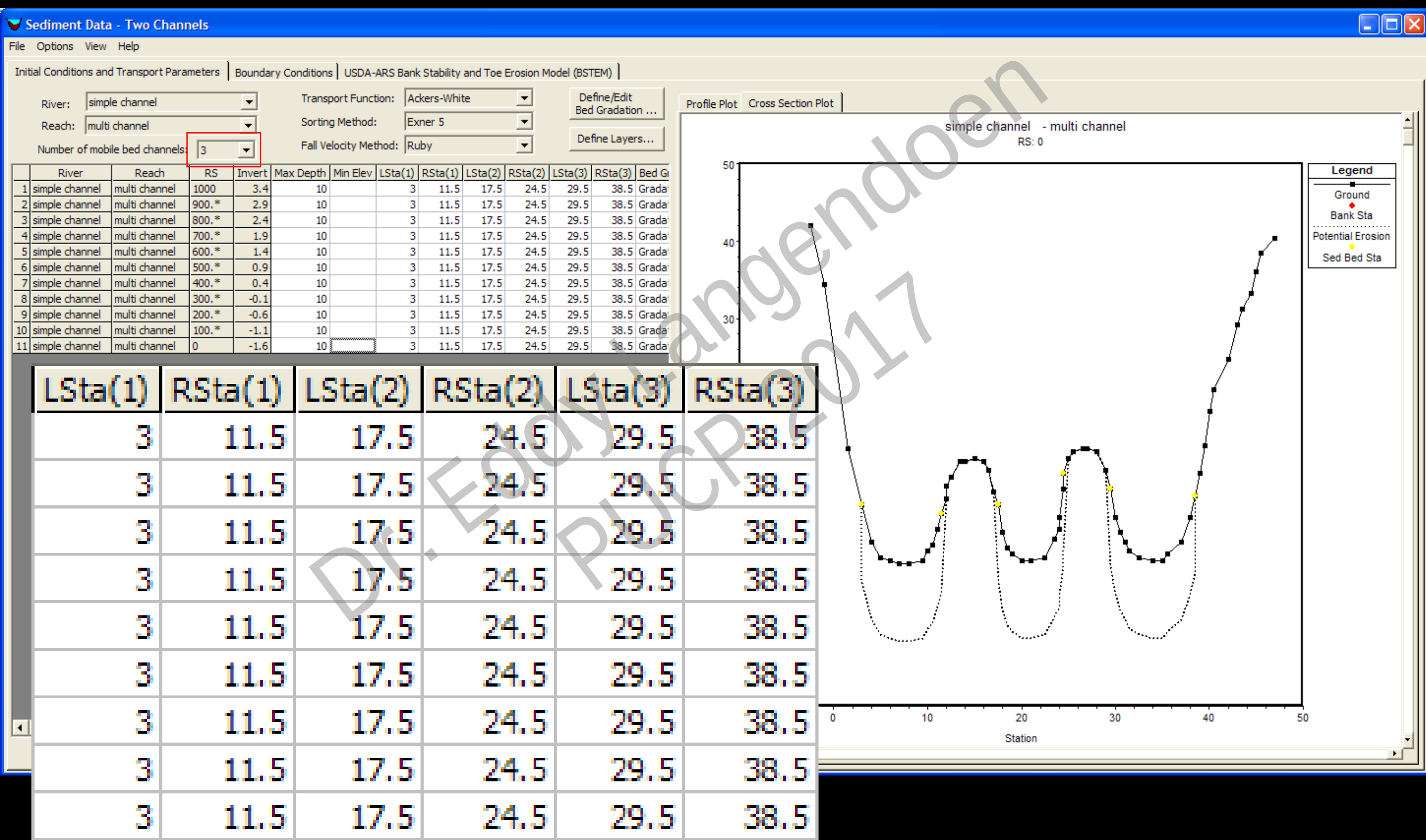


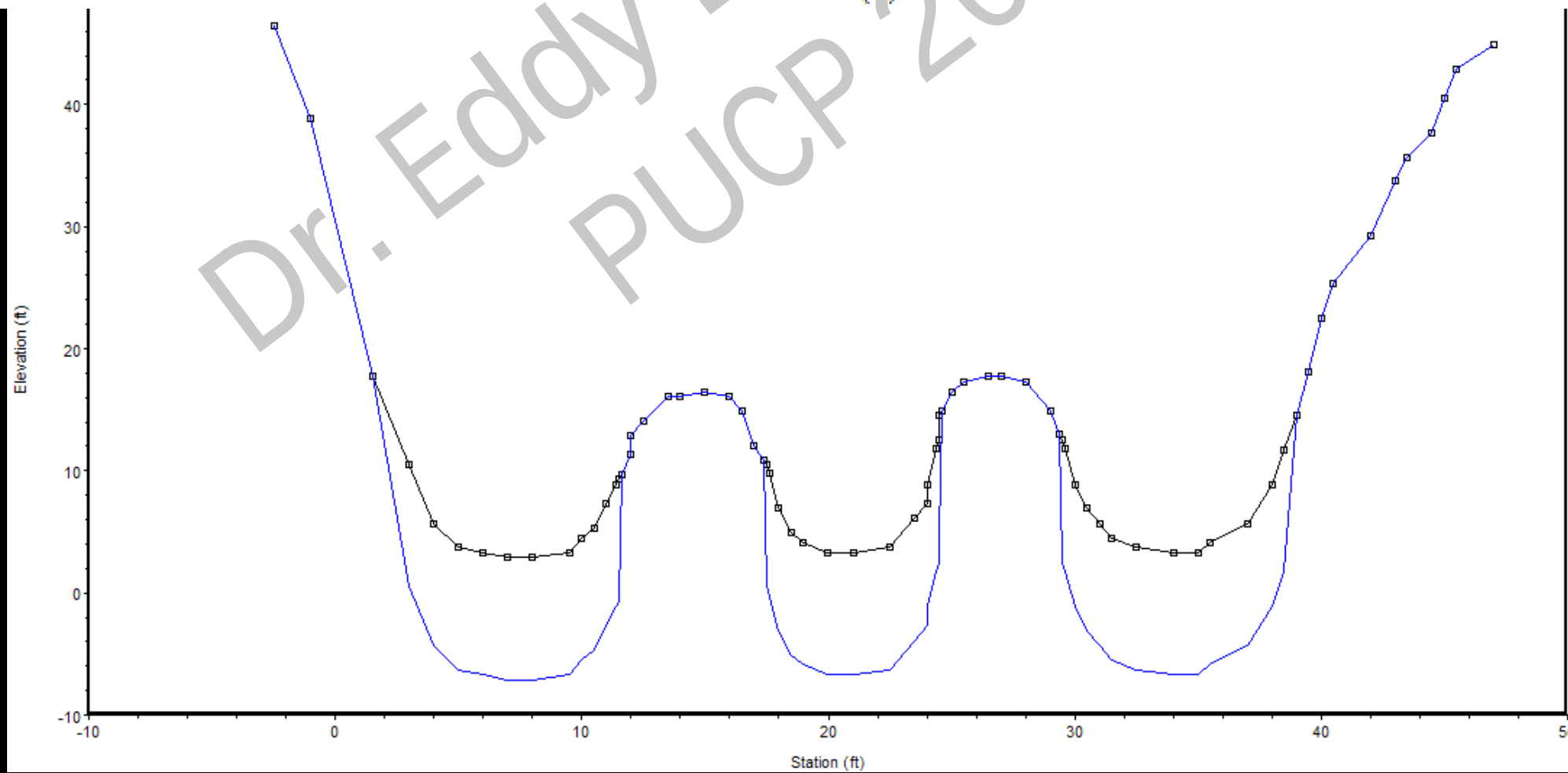
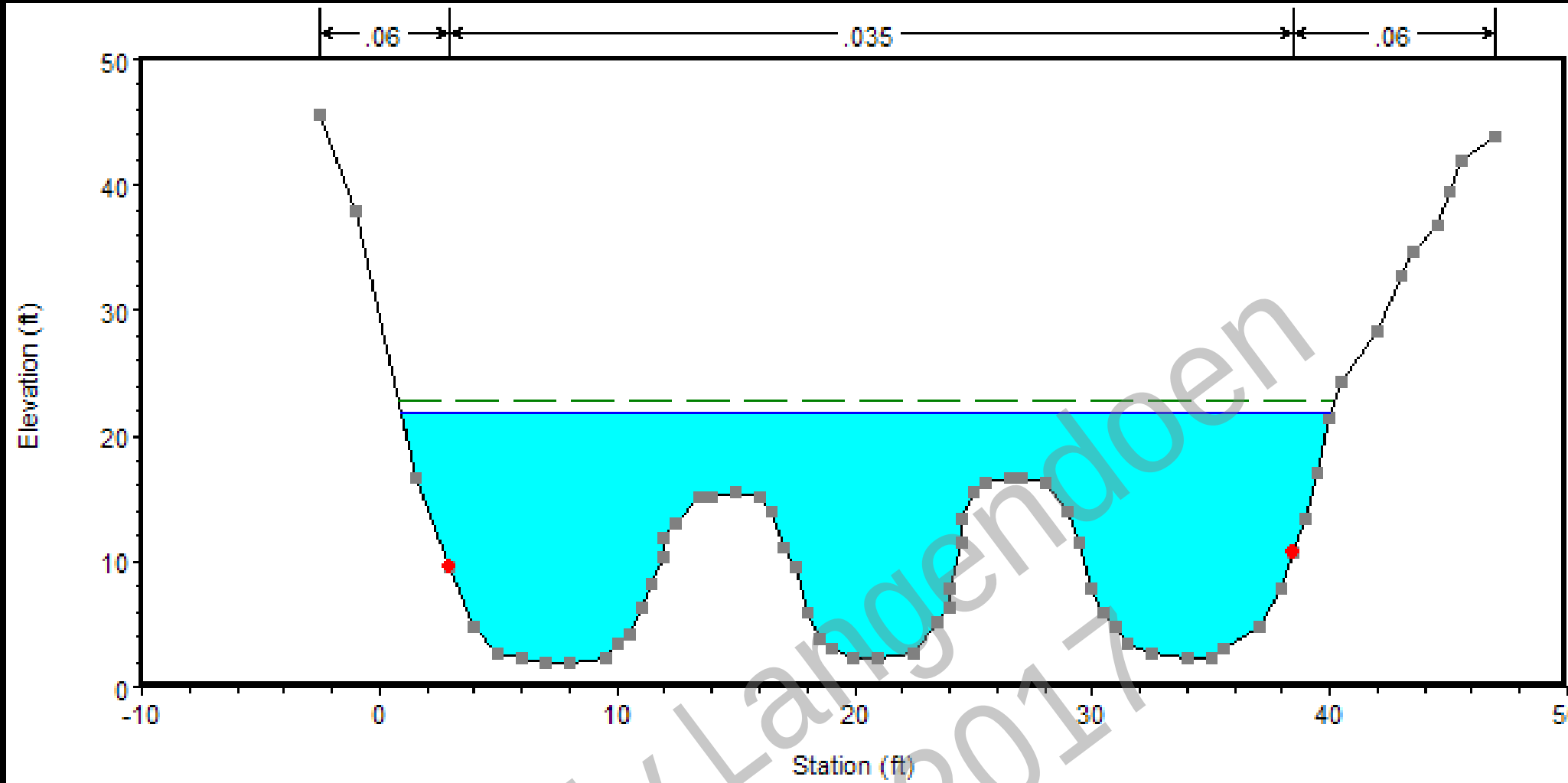
Multiple Erovable Channels



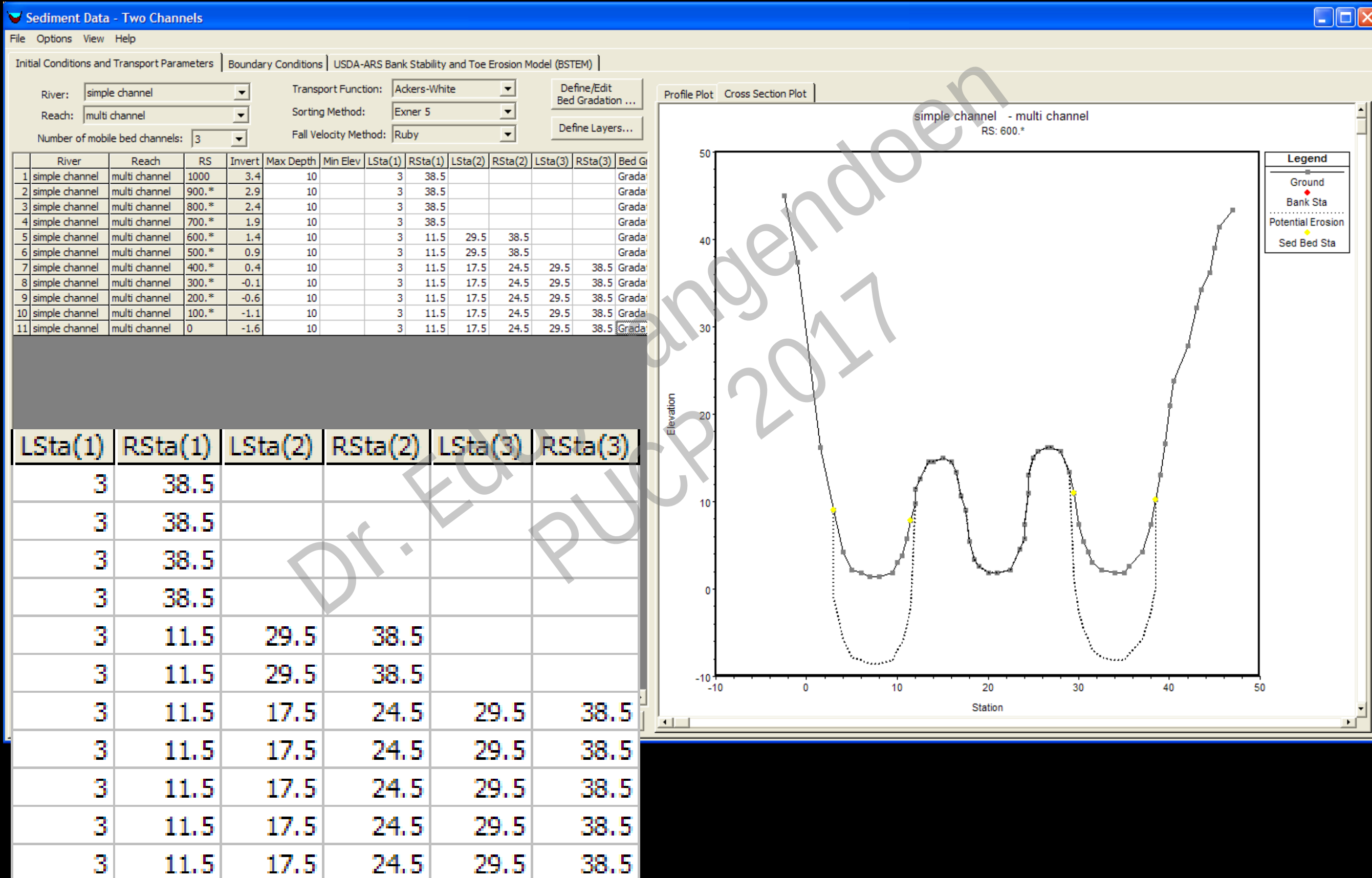
Figure 1.4 Bars due to deposition (vegetated – previous deposition)

Multiple Erovable Channels





Multiple Erovable Channels



2. New Features for Sustainable Sediment Management Modeling

- Simplified Channel Evolution
 - Atkinson Width Calculator
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- Alternate Cohesive Erosion Methods
- Bed Stratigraphy
- Flocculation/Clod Erosion

Cohesive Erosion Methods

HEC-RAS KP Method

- Apportions M between available fine grain classes in bed.
- Assumes infinite wash load –
If fine sediment can be scoured it can be transported

HEC 6T KP Method

- Considers fine capacity – Inflowing fines decrease the amount of fines that can be scoured.
- Removes Total M (reduced by inflowing sediment) from each grain class

Cohesive Options

☐ Use Selected Transport Functions for All Grain Sizes

☐ Use Krone/Parthenaides for Clay and Silt Size Fractions

☒ Use Krone/Parthenaides (HEC 6T Capacity Method)

Particle Erosion		Mass Wasting Erosion	
Threshold (tc)	0.02 (lb/ft ²)	(tmw)	5 (lb/ft ²)
Slope of the Erosion Rate Curve (M)	0.06 (lb/ft ² /hr) / (lb/ft ²)	(Mmw)	0 (lb/ft ² /hr) / (lb/ft ²)

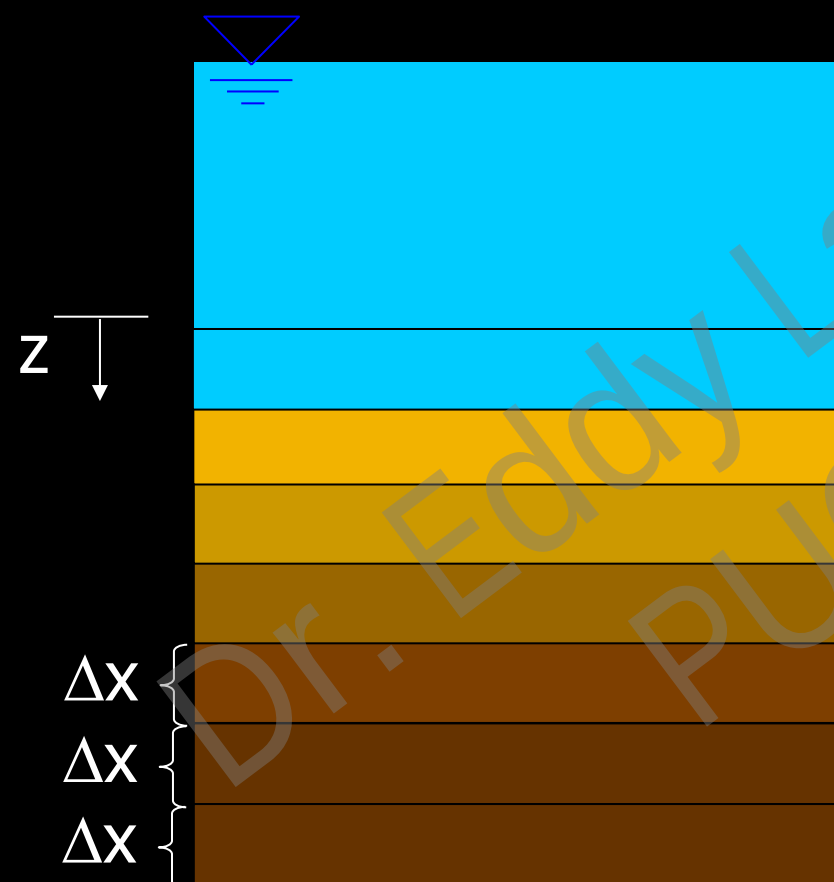
OK Cancel

2. New Features for Sustainable Sediment Management Modeling

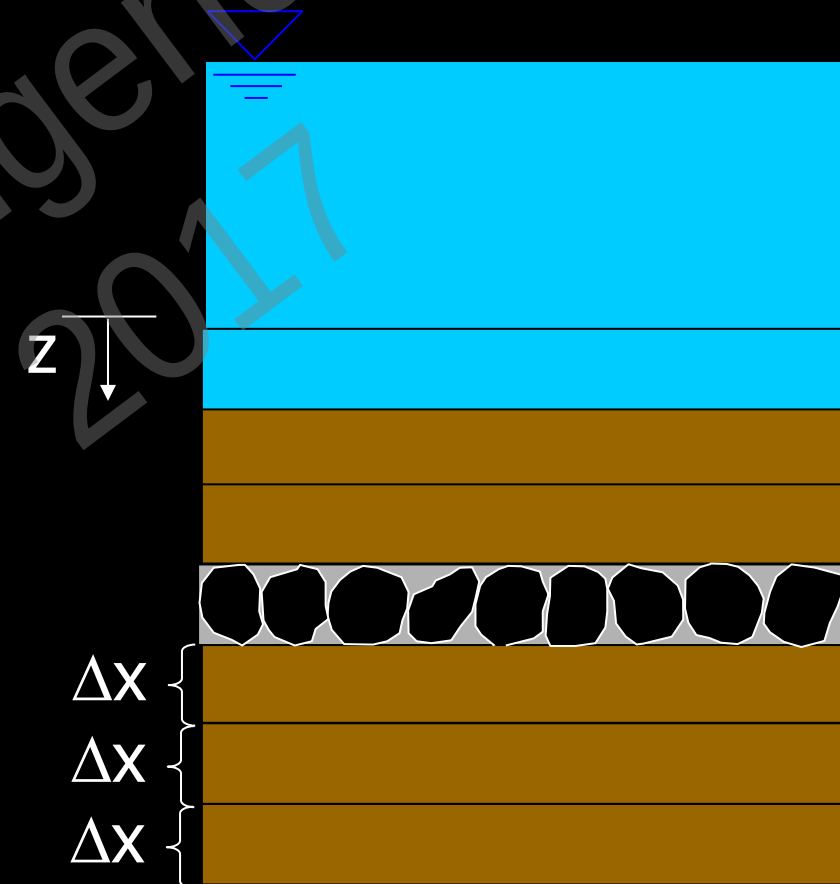
- Simplified Channel Evolution
 - Atkinson Width Calculator
- Multiple Erovable Channels
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Eulerian Multi-Layer Bed Accounting

Advantageous for: Reservoir Flushing, Dam Removal, Glacial Lacustrine or Outwash Substrates, Cohesive Substrates with Depth/ Density Dependent Erodibility

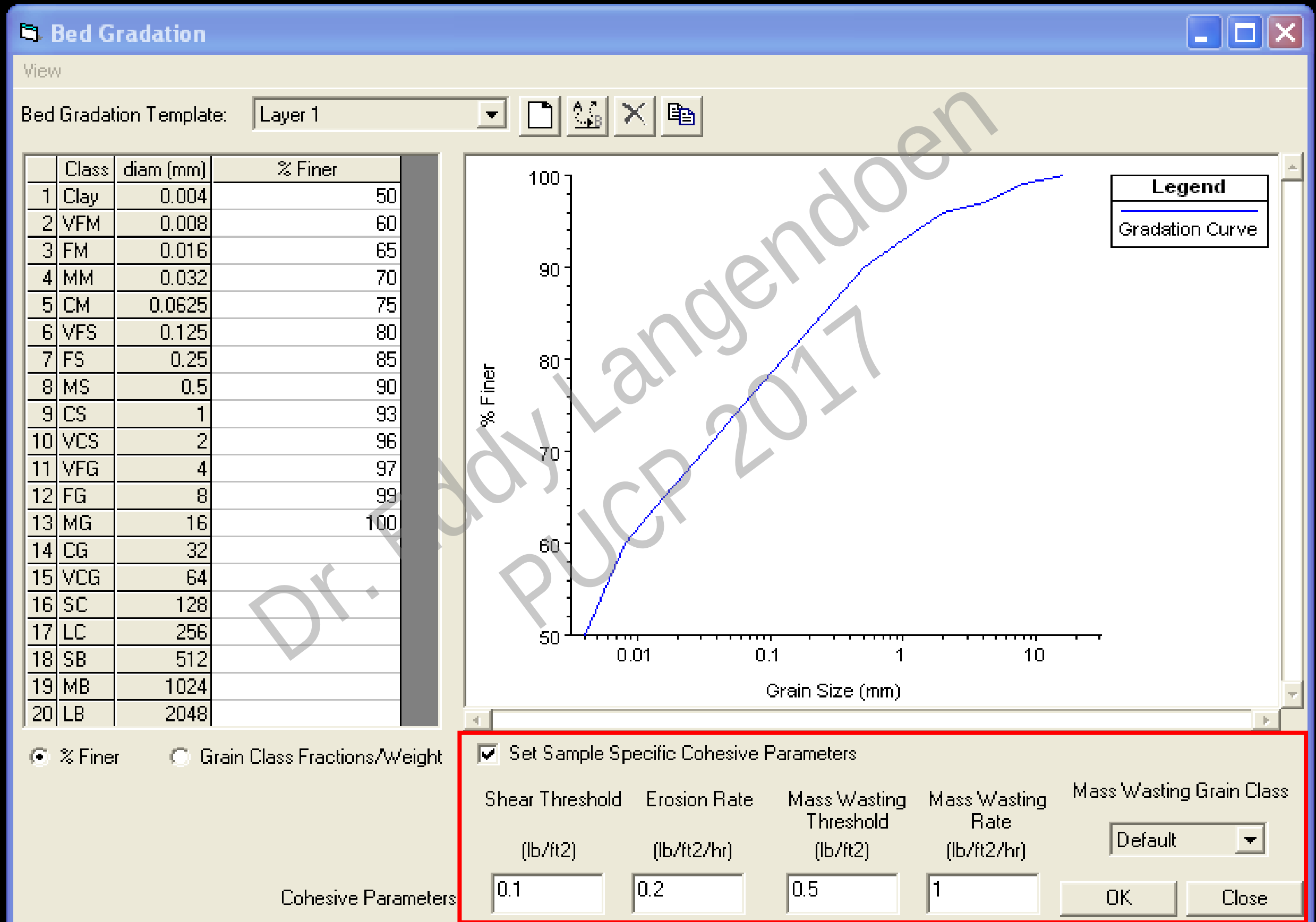


Erodibility= f (Density)
Density= f (Depth)



Resistant Reservoir Layer
Lacustrine Glacial Strata
Glacial Outwash Strata

Eulerian Multi-Layer Bed Accounting



Eulerian Multi-Layer Bed Accounting

Sediment Data - Three Layer Erosion

File Options View Help

Initial Conditions and Transport Parameters | Boundary Conditions

River: (All Rivers) Transport Function: Ackers-White
Reach: Sorting Method: Active Layer
Fall Velocity Method: Ruby

Define/Edit Bed Gradation...
Define Layers...

Define Gradation Layers

Layer Groups: Group 1

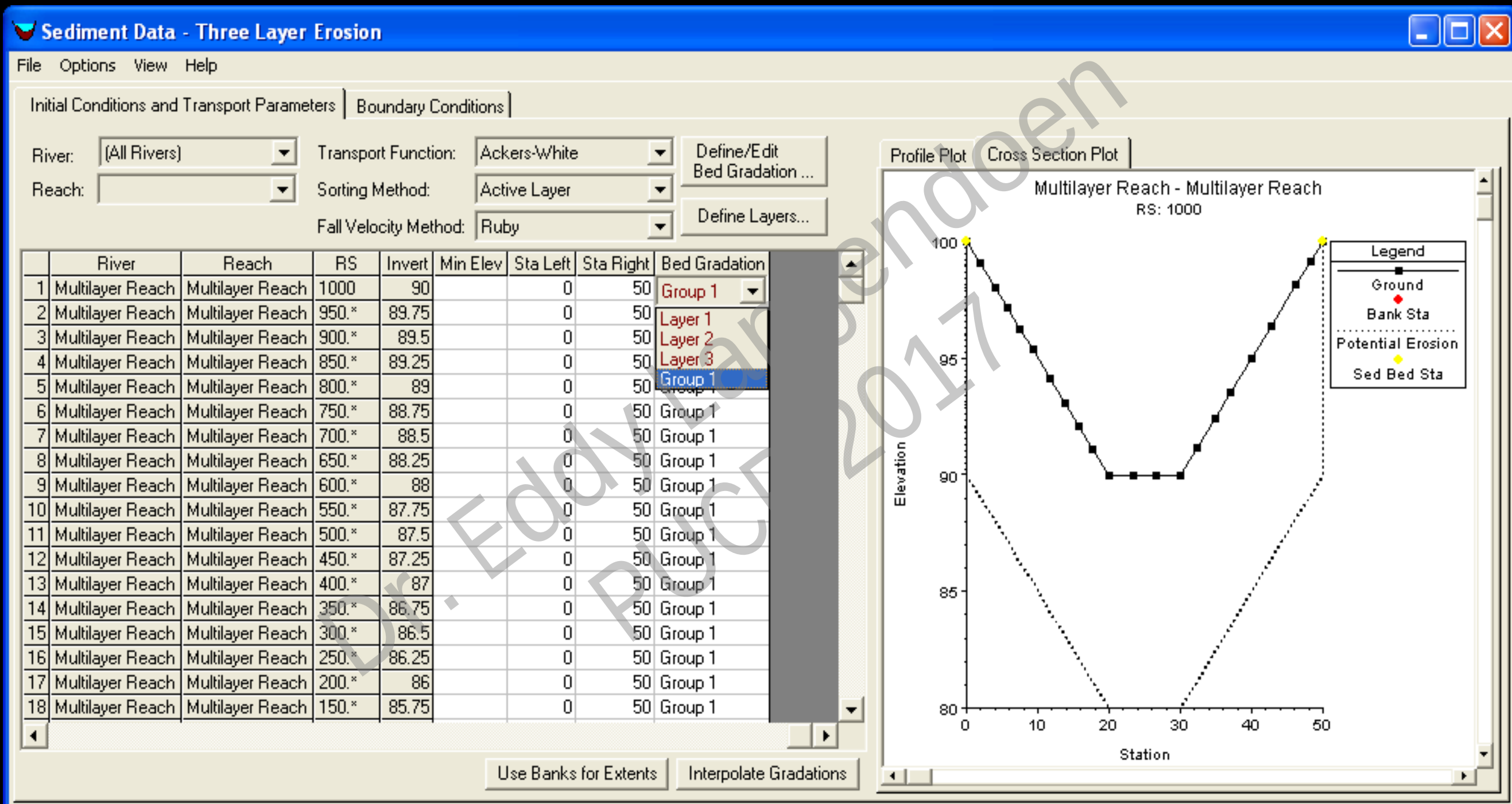
of Layers: 8 Depositional Layer thickness (ft): 1

	Layer Thickness (ft)	Layer Gradation Template
1	1	Layer 1 ← Select Gradation
2	1	Layer 2
3	1	Layer 2
4	1	Layer 2
5	1	Layer 3
6	1	Layer 3
7	1	Layer 3
8	1	Layer 3

OK Cancel

Layer groups are collections of gradations

Eulerian Multi-Layer Bed Accounting



Groups show up at the bottom of the list of gradations. If a layer group is selected, the multi-layer method is used.

2. New Features for Sustainable Sediment Management Modeling

- Simplified Channel Evolution
 - Atkinson Width Calculator
- Multiple Erovable Channels
- Alternate Cohesive Erosion Methods
- Bed Stratigraphy
- Flocculation/Clod Erosion

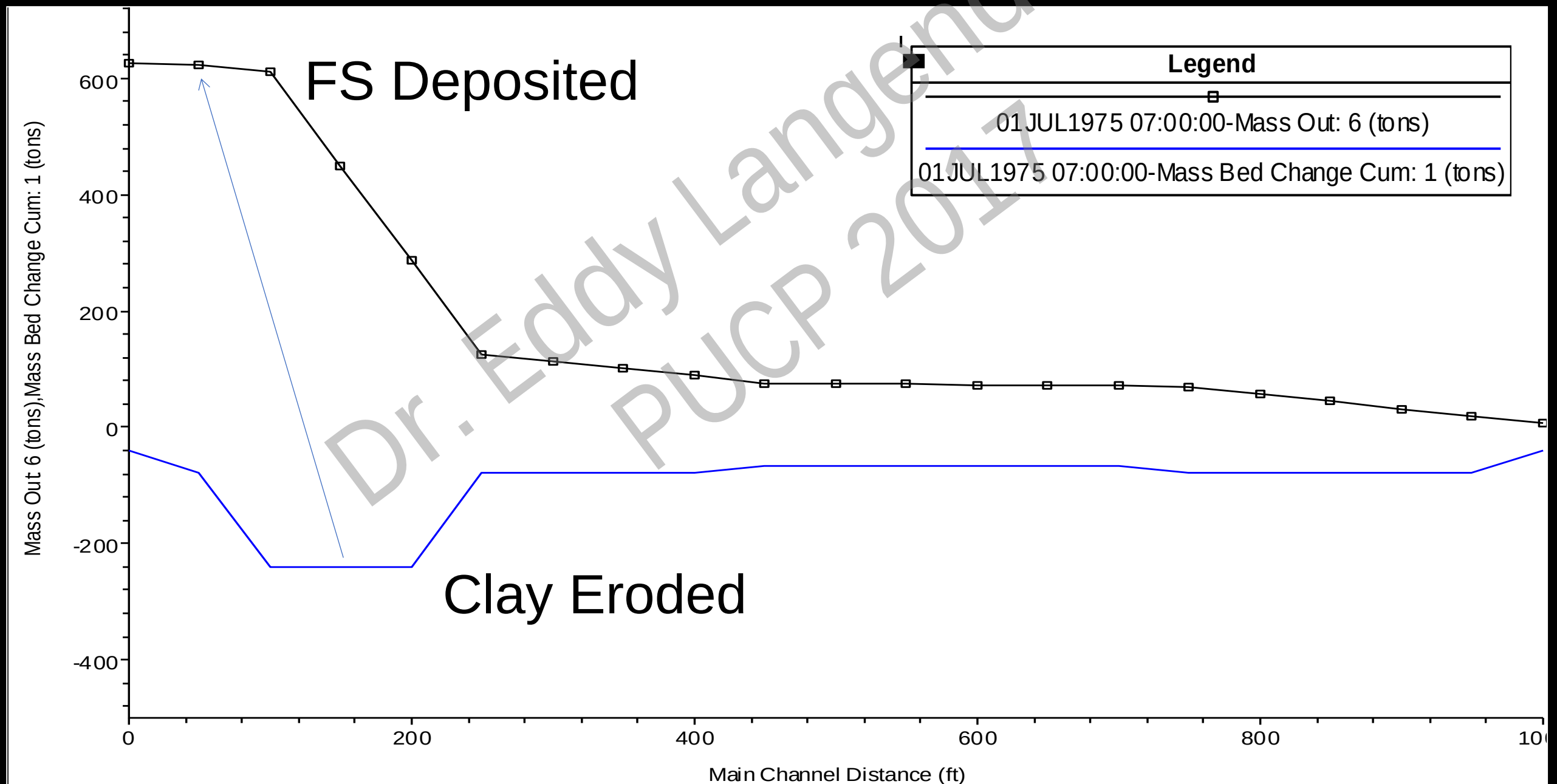
Clod Erosion and Flocculation

☒ Set Sample Specific Cohesive Parameters

Shear Threshold	Erosion Rate	Mass Wasting Threshold	Mass Wasting Rate	Mass Wasting Grain Class
(lb/ft ²)	(lb/ft ² /hr)	(lb/ft ²)	(lb/ft ² /hr)	
0.1	0.1	0.2	1	VFS

Cohesive Parameters

OK Close



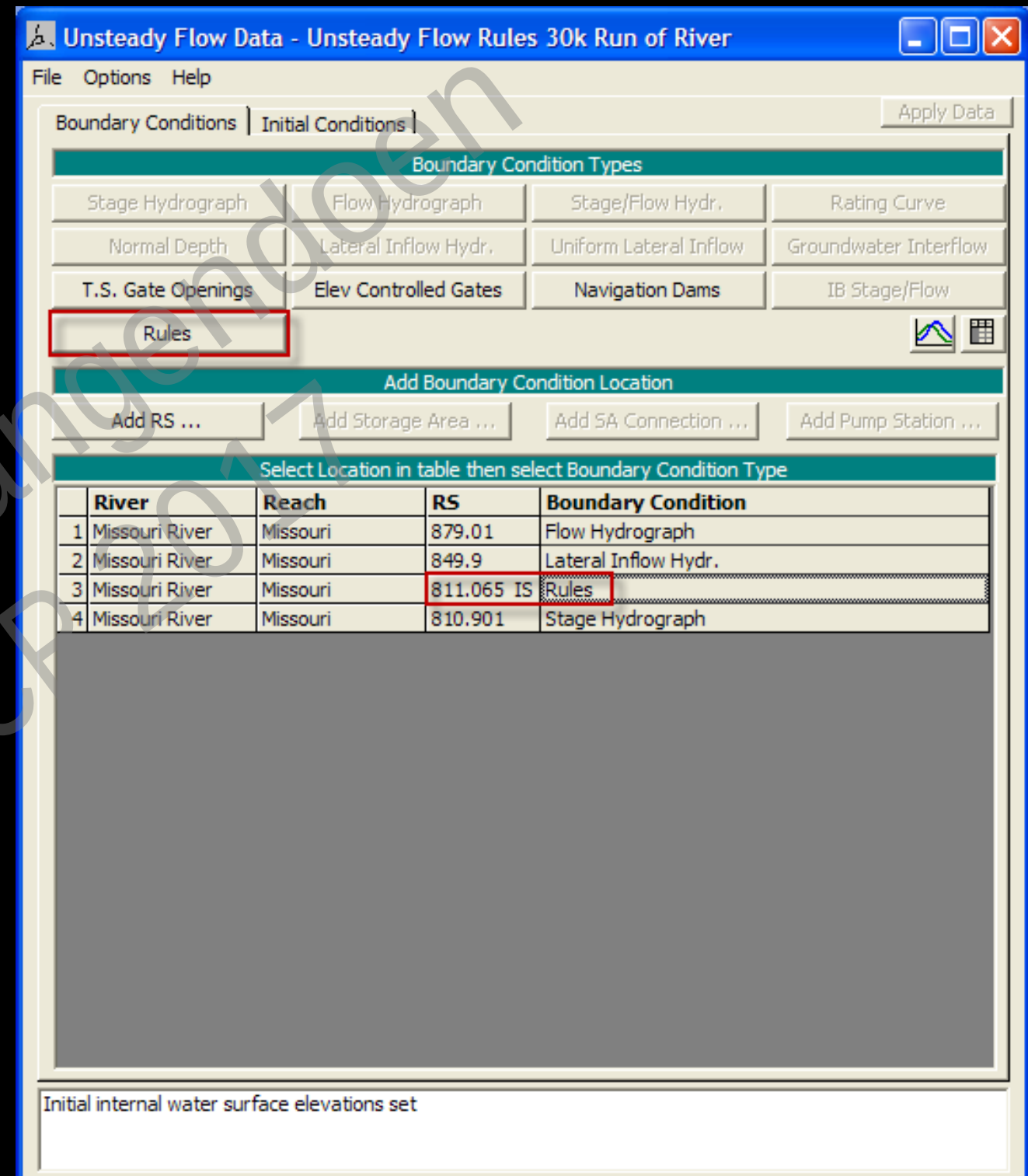
Advanced Reservoir Modeling and Unsteady Sediment Analysis with HEC-RAS

1. Principles of Reservoir Flushing and Sluicing
2. New Features for Sustainable Sediment Management Modeling
 - Multiple Erodible Channels
 - Simplified Channel Evolution (and width calc)
 - Bed Stratigraphy
3. Modeling Sustainable Sediment Reservoir Operations with Unsteady Analysis and Rules

Rules

The advanced rules allow sophisticated **automated control of hydraulic structures** (e.g. inline structures, lateral structures, storage area connectors, and, pumps).

Fully **integrated with unsteady sediment transport** (i.e. gates can be operated with rules as sediment is routed through the model and aggradation and degradation are computed).



Rules

Boundary Conditions | Initial Conditions

Stage Hydrograph | Flow Hydrograph

Normal Depth | Lateral Inflow

T.S. Gate Openings | Elev Control

Rules

Add RS ... Add Storage

Select Location in

	River	Reach
1	Missouri River	Missouri
2	Missouri River	Missouri
3	Missouri River	Missouri
4	Missouri River	Missouri

Rule Operations

Description:

Gate Parameters						
	Location	Open Rate (ft/min)	Close Rate (ft/min)	Max Opening	Min Opening	Initial Opening
1	Gates	0.5	0.5	30	0	1

Summary of Variable Initializations:

	User Variable	Description	Initial Value
1			

Rule Operations

row	Operation
1	'Pool Stage' = Cross Sections:WS Elevation(Missouri River,Missouri,811.076,Value at curren...
2	'RunTime' = Time:Hour of Simulation(Beginning of time step)
3	!
4	!
5	Structure.Total Flow (Desired) = 60000
6	!
7	! Start to fill after 11 total days of run time
8	If ('RunTime' > 246) And ('Pool Stage' < 1205) Then
9	Structure.Total Flow (Desired) = 5000
10	ElseIf ('RunTime' > 246) And ('Pool Stage' >= 1205) Then
11	Structure.Total Flow (Desired) = 30000
12	End If

Enter/Edit Rule Operations... OK Cancel

Rules

Operation Rules

Rule Based Operations Rule Font Size: 10 Bold Font

row	Operation
1	'Pool Stage' = Cross Sections:WS Elevation(Missouri River,Missouri,811.076,Value at current time step)
2	'RunTime' = Time:Hour of Simulation(Beginning of time step)
3	!
4	!
5	Structure.Total Flow (Desired) = 60000
6	!
7	! Start to fill after 11 total days of run time
8	If ('RunTime' > 246) And ('Pool Stage' < 1205) Then
9	Structure.Total Flow (Desired) = 5000
10	Elself ('RunTime' > 246) And ('Pool Stage' >= 1205) Then
11	Structure.Total Flow (Desired) = 30000
12	End If

Insert New Operation

Comment New Variable Get Sim Value Set Operational Param Branch (If/Else) Math Table

Current Selection Changes

Copy descriptions to Clipboard ...

Get Simulation Value

Assign Result

☐ Existing Variable

☒ New Variable

Pool Stage

Simulation Variables

- Time
- Solution
- Cross Sections
 - WS Elevation
 - Flow
 - WS Change
 - Flow Change
 - WS Error
 - Flow Error
- Inline Structures

Set Node Location

River: Missouri River

Reach: Missouri

RS: 811.076

Value at current time step

(Simulation variables in bold are only available for the current structure)

Check Rule Set ...

OK Cancel

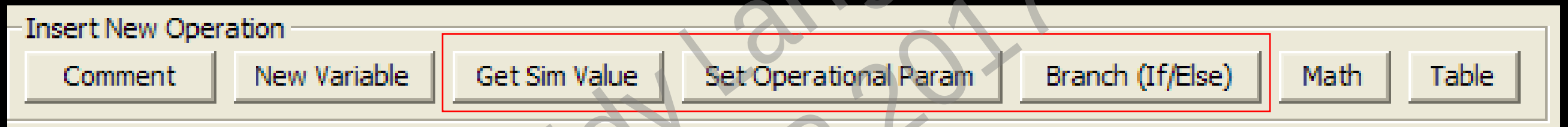
Rules

“HEC-RAS Output”
WSE/Q/Time

If/Then/Else
And/Or

Turn Simulation Results
into a Variable

Programming
Logic



Set a Target to
Base Operations on

“Target Variable”
“Operational Goal”
“Specified Parameter”

Get Simulation Value

Assign Result

☐ Existing Variable

☒ New Variable

Pool Stage

Simulation Variables

- Time
- Solution
- Cross Sections
 - WS Elevation**
 - Flow
 - WS Change
 - Flow Change
 - WS Error
 - Flow Error
- Toline Structures

Set Node Location

River: Missouri River

Reach: Missouri

RS: 811.076

(Simulation variables in bold are only a

Document
Document

Turn Simulation Results
into a Variable

Insert New Operation

Comment New Variable Get Sim Value Set Operational Param Branch (If/Else) Math Table

Set a Target to
Base Operations on

Programming
Logic

Complex
Equations

Set Operational Parameter (i.e. gate opening)

Structure.Total Flow (Desired)

Structure.Flow Additional

Structure.Flow Maximum

Structure.Flow Minimum

Structure.Total Gate Flow

Structure.Total Gate Flow Maximum

Structure.Total Gate Flow Minimum

Weir.Flow

Weir.Flow Maximum

Expression

Edit ... X

60000

Branching Operation (If/Else/ElseIf/Else/Endif)

Branching Line Type:

☐ If () Then

☒ If () And/Or () Then

☐ ElseIf () Then

☐ ElseIf () And/Or () Then

☐ Else

☐ End If

Expression

Edit ... X

'RunTime'

>

Expression

Edit ... X

246

Rules

```
2 'Pool Stage' = Cross Sections:WS Elevation(Missouri River,Missouri,811.076
3 'RunTime' = Time:Hour of Simulation(Beginning of time step)
4 !
5 !
6 Structure.Total Flow (Desired) = 60000
7 !
8 ! Start to fill after 11 total days of run time
9 If ('RunTime' > 246) And ('Pool Stage' < 1205) Then
10     Structure.Total Flow (Desired) = 5000
11 Elself ('RunTime' > 246) And ('Pool Stage' >= 1205) Then
12     Structure.Total Flow (Desired) = 30000
13 End If
```

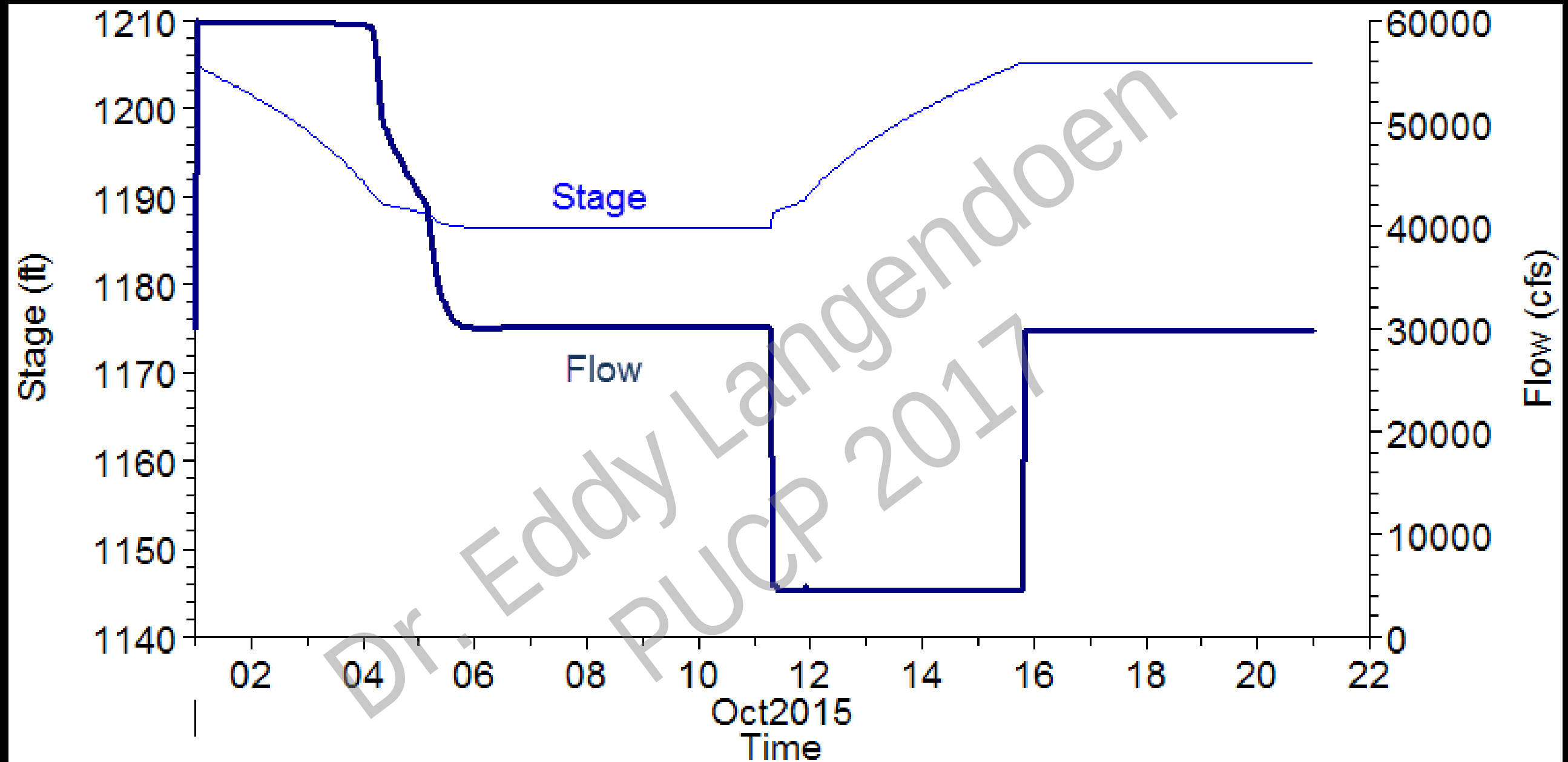
Get Sim Value

Set Operational Param

Comment

Branch (If/Else)

Rules



-The relatively simple rule set in the previous slide generated this draining/flushing/refilling hydrograph.

Rules: What's Next

Get Sim Value

= Sediment Variables

Sediment output as Simulation Variables will allow automated gate operation based on:

- Release Concentrations
- Delta aggradation or advancement
- Inflowing sediment concentrations
(e.g. for sluicing/pass through analysis)

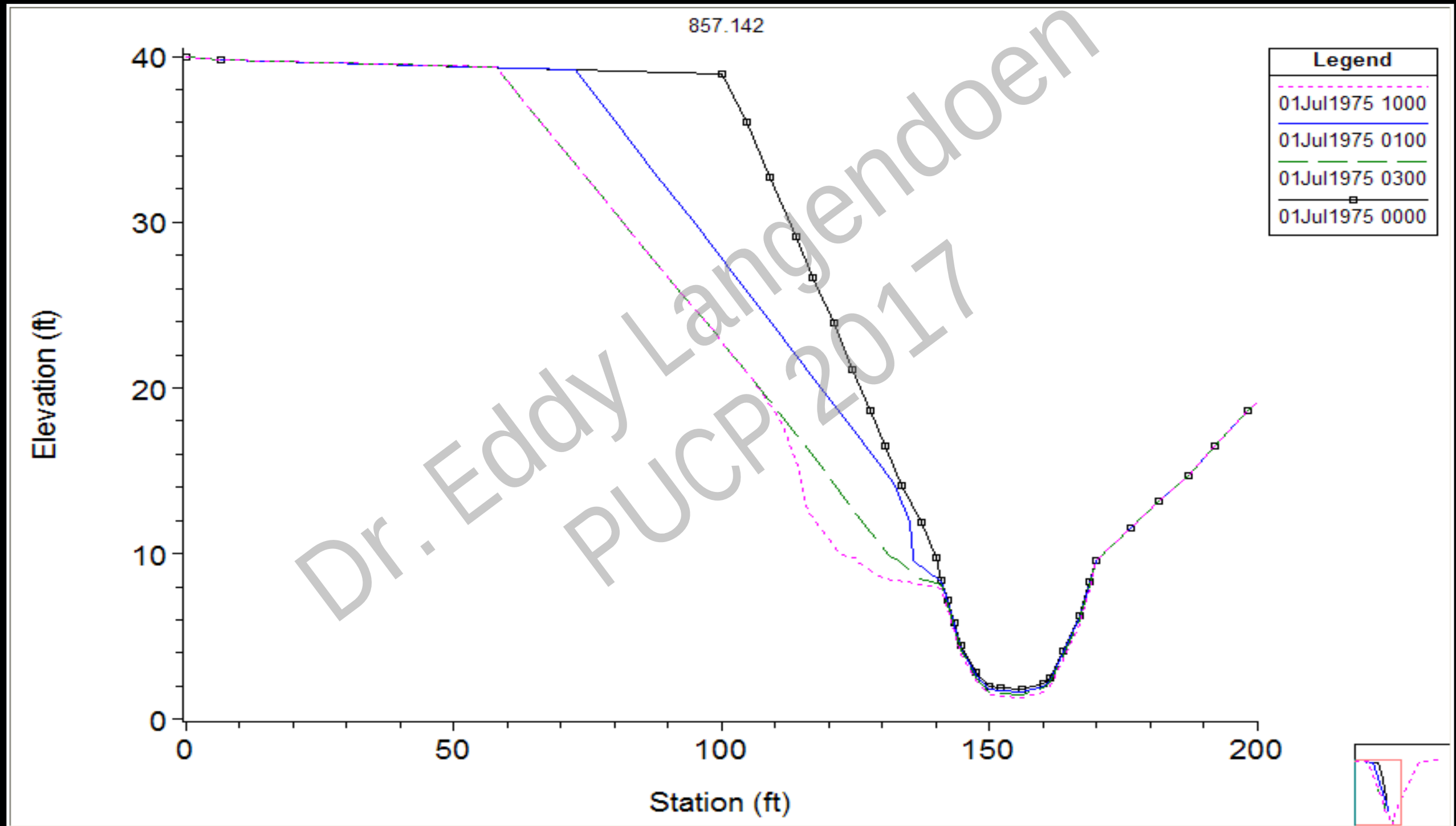
Set Operational Param

= Dredging Schedules

Will target dredging operations to bed changes

- (e.g. if Mass Δ at XS 849 > +100,000 tons → Dredge)

Using the USDA-ARS Bank Failure and Toe Scour (BSTEM) Routines in HEC-RAS



Stanford Gibson, PhD
Hydrologic Engineering Center

USDA-ARS BSTEM Interface

Sediment Data - Sediment Data

File Options View Help

Initial Conditions and Transport Parameters | Boundary Conditions | **USDA-ARS Bank Stability and Toe Erosion Model (BSTEM)**

River: (All Rivers) Bank Failure Method: Layer Method Define/Edit BSTEM Sample Parameters

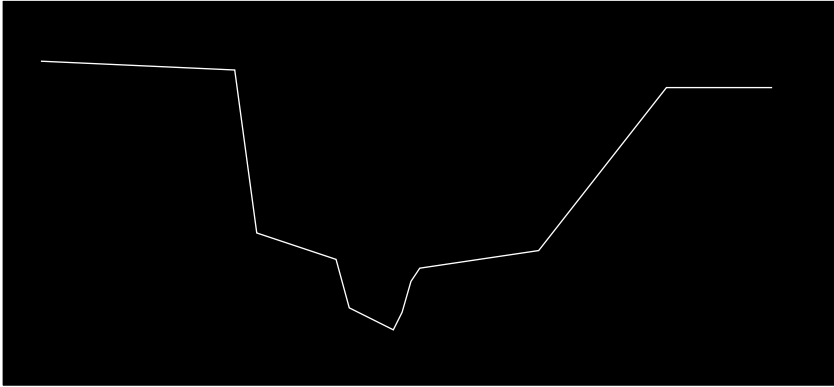
Reach:

	River	Reach	RS	Left Bank Edge Station	Left Bank Toe Station	Left Bank Material	Right Bank Toe Station	Right Bank Edge Station	Right Bank Material	GW Elev
1	8XS	8XS	1000	100	140.1	Erodible Silt				36
2	8XS	8XS	857.142							
3	8XS	8XS	714.285							
4	8XS	8XS	571.428	100.000	140.100	Loam				35.8
5	8XS	8XS	428.571	100.000	200.1	DEFINE LAYER				35.3
6	8XS	8XS	285.714							
7	8XS	8XS	142.857							
8	8XS	8XS	0							

Left Bank Layers

	Bottom Elev	Material
1	0	Erodible Silt
2	16	E Soft Clay
3	25	C Round San
4		
5		
6		
7		
8		
9		
10		

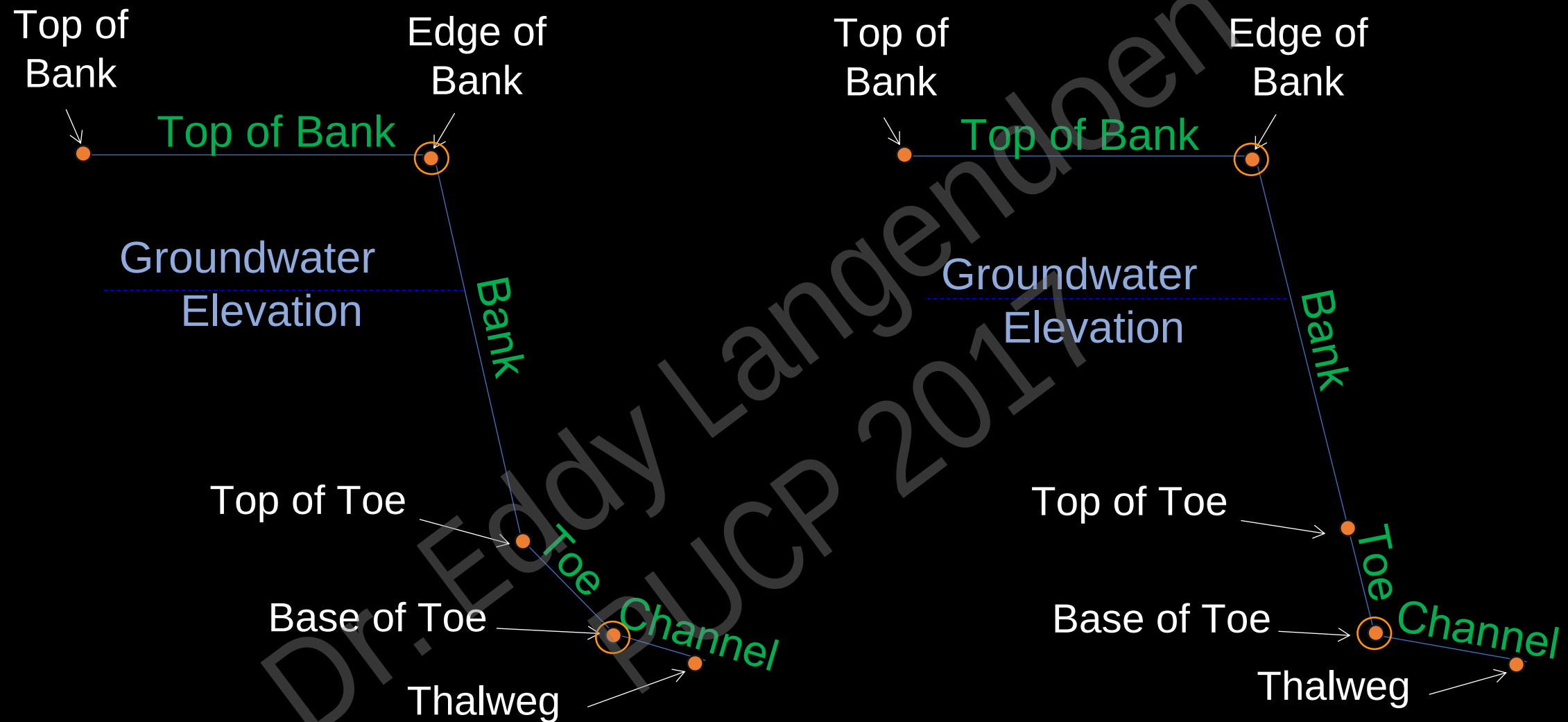
Right Bank Material



Set Toe Station to Bank Stations

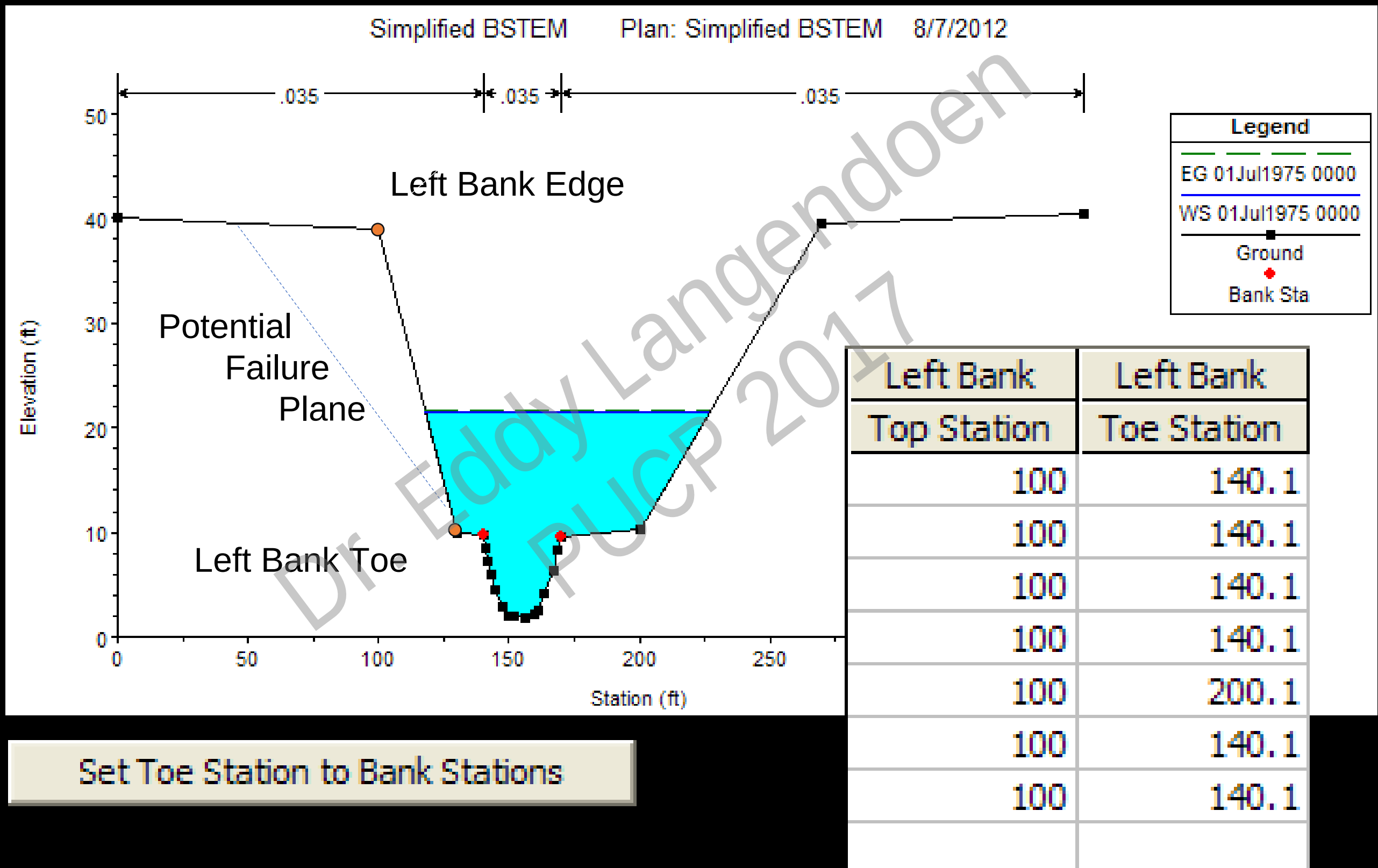
-A third optional tab in the Sediment Data Editor

BSTEM Bank Schematic



HEC-RAS simplifies this to two important points: Edge of Bank and Toe

Defining top of Bank and Toe



Defining Bank Material

Three Methods:

1. Pre-Defined Default Parameters
2. Single Set of User Defined Material
3. Layers of Unique Material at a Bank

				Left Bank	Left Bank	Left Bank
	River	Reach	RS	Edge Station	Toe Station	Material
1	8XS	8XS	1000	100	140.1	Erodible Silt
2	8XS	8XS	857.142			
3	8XS	8XS	714.285	100	140.1	Loam
4	8XS	8XS	571.428			
5	8XS	8XS	428.571	100.000	200.1	
6	8XS	8XS	285.714			
7	8XS	8XS	142.857			
8	8XS	8XS	0			

Loam

Boulders

Cobbles

Gravel

C Angular

C Round S

F Angular

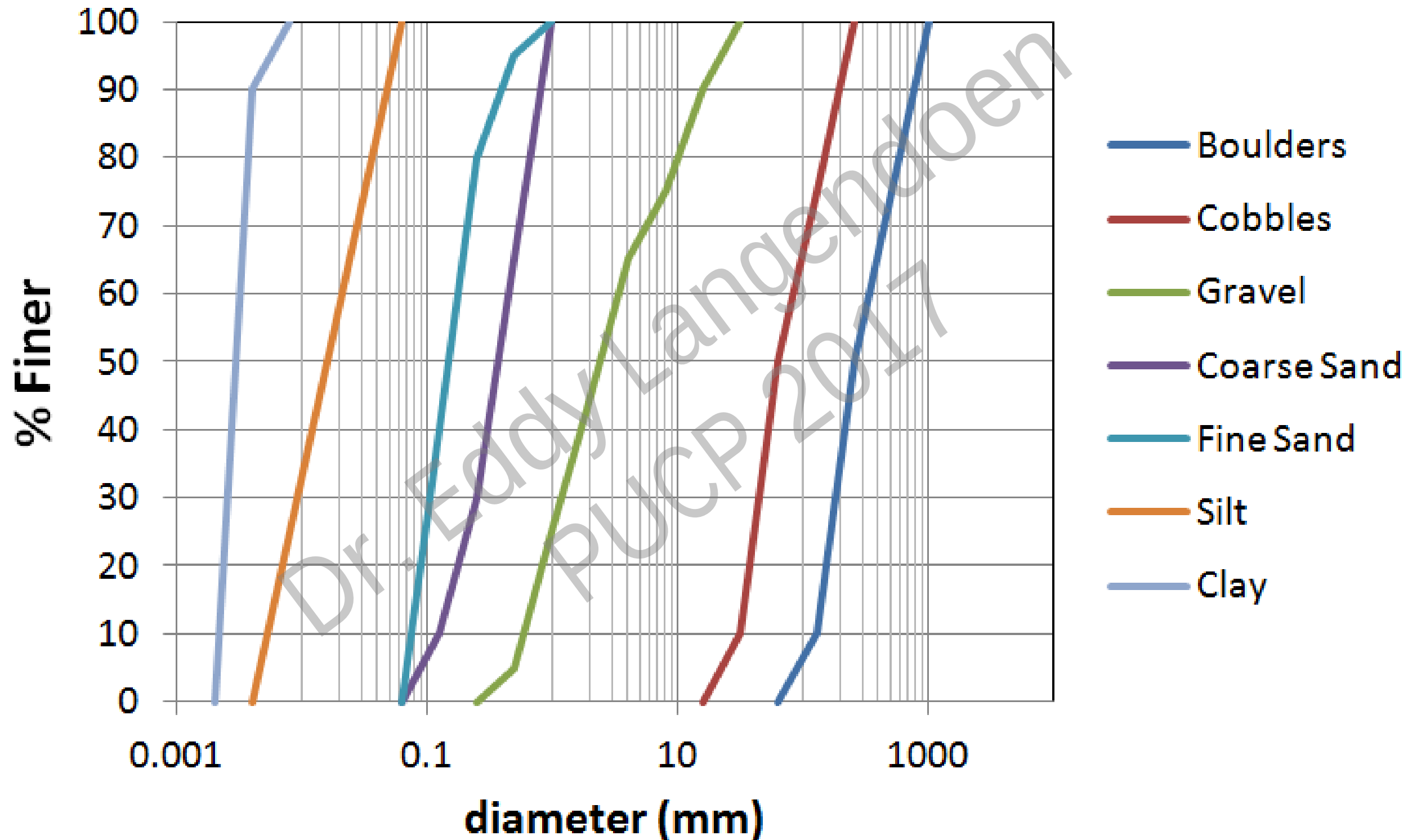
F Round S

Erodible Sil

Default Material Parameters

Default Material Type	Saturated Unit Weight (lb/ft ³)	Friction Angle (ϕ')	Cohesion (lb/ft ²)	ϕ^b	Critical Shear (lb/ft ²)	Erodibility (ft ³ /lb-f-s)
Boulders	127.3	42	0	15	10.4	7.04E-07
Cobbles	127.3	42	0	15	2.59	1.41E-06
Gravel	127.3	36	0	15	0.23	4.74E-06
Coarse Angular Sand	117.8	32.3	8.354	15	0.0106	2.21E-05
Coarse Round Sand	117.8	28.3	8.354	15	0.0106	2.21E-05
Fine Angular Sand	117.8	32.3	8.354	15	0.00267	4.40E-05
Fine Round Sand	117.8	28.3	8.354	15	0.00267	4.40E-05
Erodible Silt	114.6	26.6	89.81	15	0.00209	4.94E-05
Moderate Silt	114.6	26.6	89.81	15	0.1044	7.07E-06
Resistant Silt	114.6	26.6	89.81	15	1.0443	2.20E-06
Erodible Soft Clay	112.7	26.4	171.26	15	0.00209	4.94E-05
Moderate Soft Clay	112.7	26.4	171.26	15	0.1044	7.07E-06
Resistant Soft Clay	112.7	26.4	171.26	15	1.0443	4.94E-05
Erodible Stiff Clay	112.7	21.1	263.16	15	14.6	4.94E-05
Moderate Stiff Clay	112.7	21.1	263.16	15	0.1044	7.07E-06
Resistant Stiff Clay	112.7	21.1	263.16	15	1.0443	4.94E-05

Default Material Gradations



Defining Bank Material

Three Methods:

1. Pre-Defined Default Parameters
2. Single Set of User Defined Material
3. Layers of Unique Material at a Bank

User defined materials will appear between the “DEFINE LAYERS” method and the default materials

Sediment Data - Sediment Data

File Options View Help

Initial Conditions and Transport Parameters | Boundary Conditions | USDA-ARS Bank

River: (All Rivers) Bank Failure Method: Layer Method

Reach:

	River	Reach	RS	Left Bank Edge Station	Left Bank Toe Station	Left Bank Material
1	8XS	8XS	1000	100	140.1	Erodible Silt
2	8XS	8XS	857.142			
3	8XS	8XS	714.285	100	140.1	Loam
4	8XS	8XS	571.428			
5	8XS	8XS	428.571	100.000		Loam
6	8XS	8XS	285.714			
7	8XS	8XS	142.857			
8	8XS	8XS	0			

DEFINE LAYERS

Loam

Boulders

Cobbles

Gravel

C Angular

C Round S

F Angular

Defining Bank Material

Three Methods:

1. Pre-Defined Default Parameters
2. Single Set of User Defined Material
3. Layers of Unique Material at a Bank

Sediment Data - Sediment Data

File Options View Help

Initial Conditions and Transport Parameters | Boundary Conditions | **USDA-ARS Bank Stability and Toe Erosion Model (BSTEM)**

River: (All Rivers) Bank Failure Method: Layer Method

Reach:

Define/Edit BSTEM Sample Parameters

	River	Reach	RS	Left Bank Edge Station	Left Bank Toe Station	Left Bank Material	Right Bank Toe Station	Right Bank Edge Station	Right Bank Material	GW
1	8XS	8XS	1000	100	140.1	Erodible Silt				
2	8XS	8XS	857.142							
3	8XS	8XS	714.285	100	140.1	Loam				
4	8XS	8XS	571.428							
5	8XS	8XS	428.571	100.000	200.1	DEFINE LAYER				
6	8XS	8XS	285.714							
7	8XS	8XS	142.857							
8	8XS	8XS	0							

Set Toe Station to Bank Stations

BSTEM Material Parameters

BSTEM Layer Parameters: Loam

Saturated

Unit Weight: 125 lb/ft³

Friction Angle: 29 degrees

Cohesion: 15 lb/ft²

Phi b: 16 degrees

Gradation Sample: Sand

Critical Shear Stress: 0.02 lb/ft²

Erodibility: 0.0000005 ft³/lb-ft-s

Estimate Parameters

Pore Water Pressure: lb/ft² (optional)

OK Cancel

Gradation of the Failure Material

- The gradation drop down is populated with the gradations from the main menu.
- Affects the toe scour method and results.

BSTEM Material Parameters

BSTEM Layer Parameters: **Loam**

Unit Weight: **125** lbf/ft³

Friction Angle: **29** degrees

Cohesion: **15** lbf/ft²

Phi b: **16** degrees

Gradation Sample: **Sand**

Critical Shear Stress: **0.02** lbf/ft²

Erodibility: **0.0000005** ft³/lbf-s

Estimate Parameters

Pore Water Pressure: lbf/ft² (optional)

OK Cancel

Sediment Data - Sediment Data

File Options View Help

Initial Conditions and Transport Parameters | Boundary Conditions | USDA-ARS Bank Stability and Toe Erosion Model (BSTEM)

River: **(All Rivers)** Transport Function: **Laursen (Copeland)**

Reach: Sorting Method: **Active Layer**

Number of mobile bed channels: **1** Fall Velocity Method: **Ruby**

Define/Edit Bed Gradation ...

Define Layers...

	River	Reach	RS	Invert	Max Depth	Min Elev	Left Sta	Right Sta	Bed Gradation
1	8XS	8XS	1000	1.84	15		140	170	Sand
2	8XS	8XS	857.142	1.8	10		140	170	Sand
3	8XS	8XS	714.285	1.75	15		140	170	Sand
4	8XS	8XS	571.428	1.71	15		140	170	Sand

Bed Gradation

View

Bed Gradation Template: **Sand**

Class	diam (mm)	% Finer
1 Clay	0.002-0.004	
2 VFM	0.004-0.008	
3 FM	0.008-0.016	
4 MM	0.016-0.032	
5 CM	0.032-0.0625	0
6 VFS	0.0625-0.125	5
7 FS	0.125-0.25	15
8 MS	0.25-0.5	35
9 CS	0.5-1	60
10 VCS	1-2	85
11 VFG	2-4	95
12 FG	4-8	100
13 MG	8-16	
14 CG	16-32	
15 VCG	32-64	
16 SC	64-128	
17 LC	128-256	
18 SB	256-512	
19 MB	512-1024	
20 LB	1024-2048	

% Finer

Grain Class Fractions/Weight

Set Sample Specific Cohesive Parameters

OK Close

Legend

Gradation Curve

Erodibility

Bank Erosion Parameter Calculator

Non-cohesive Particle Diameter: (mm)

Critical Shear:

Critical Shear:

Erodibility Coefficient:

BSTEM Material Parameters

BSTEM Layer Parameters:

Unit Weight: lbf/ft³

Friction Angle: degrees

Cohesion: lbf/ft²

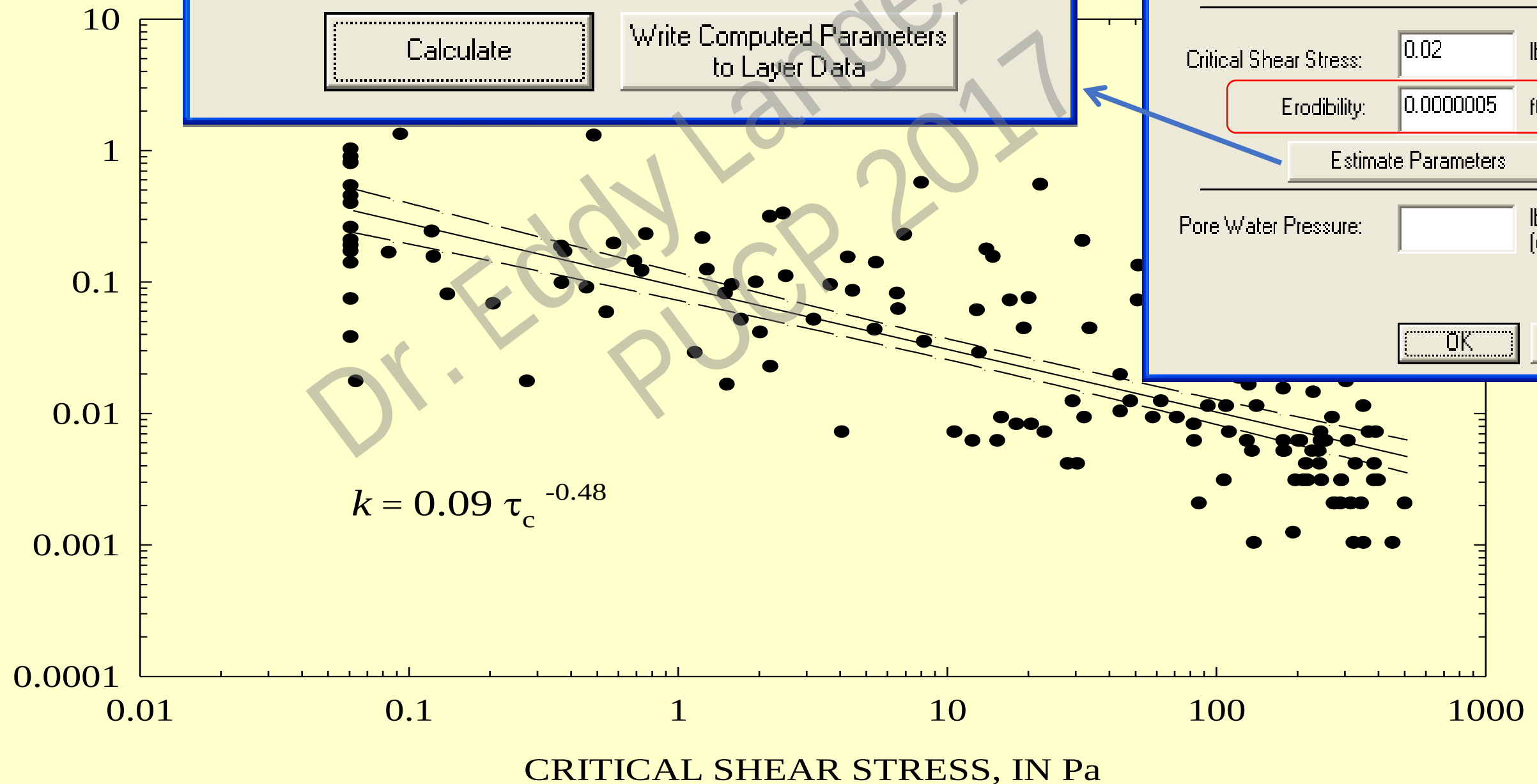
Phi b: degrees

Gradation Sample:

Critical Shear Stress: lbf/ft²

Erodibility: ft³/lbf-s

Pore Water Pressure: lbf/ft² (optional)



Defining Bank Material

Three Methods:

1. Pre-Defined Default Parameters
2. Single Set of User Defined Material
3. Layers of Unique Material at a Bank

			Left Bank	Left Bank	Left Bank
River	Reach	RS	Edge Station	Toe Station	Material
8XS	8XS	1000	100	140.1	Erodible Silt
8XS	8XS	857.142			
8XS	8XS	714.285	100	140.1	Loam
8XS	8XS	571.428			
8XS	8XS	428.571	100	200.1	DEFINE LA
8XS	8XS	285.714			DEFINE LA
8XS	8XS	142.857			Loam
8XS	8XS	0			Boulders
					Cobbles
					Gravel
					C Angular
					C Round S
					F Angular

Sediment Data - Sediment Data

File Options View Help

Initial Conditions and Transport Parameters | Boundary Conditions | USDA-ARS Bank Stability and Toe Erosion Model (BSTEM)

River: (All Rivers) Bank Failure Method: Layer Method

Reach:

Define/Edit BSTEM
Sample Parameters

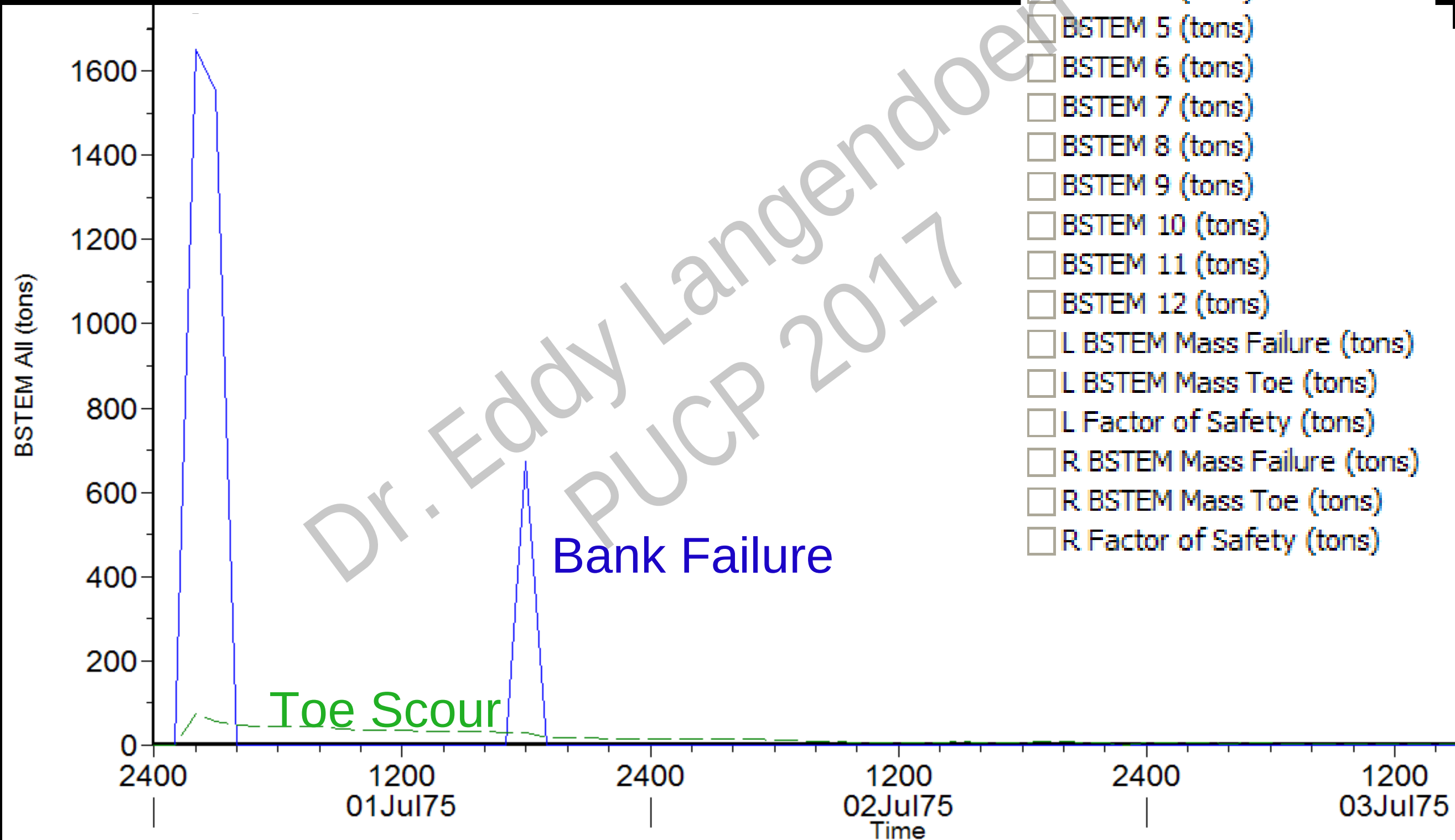
				Left Bank	Left Bank	Left Bank	Right Bank	Right Bank	Right Bank	GW Elev
	River	Reach	RS	Edge Station	Toe Station	Material	Toe Station	Edge Station	Material	
1	8XS	8XS	1000	100	140.1	Erodible Silt				36
2	8XS	8XS	857.142							
3	8XS	8XS	714.285	100	140.1	Loam				35.8
4	8XS	8XS	571.428							
5	8XS	8XS	428.571	100	200.1	DEFINE LAYEF	230	370	E Soft Clay	35.3
6	8XS	8XS	285.714							
7	8XS	8XS	142.857							
8	8XS	8XS	0							

Low to High

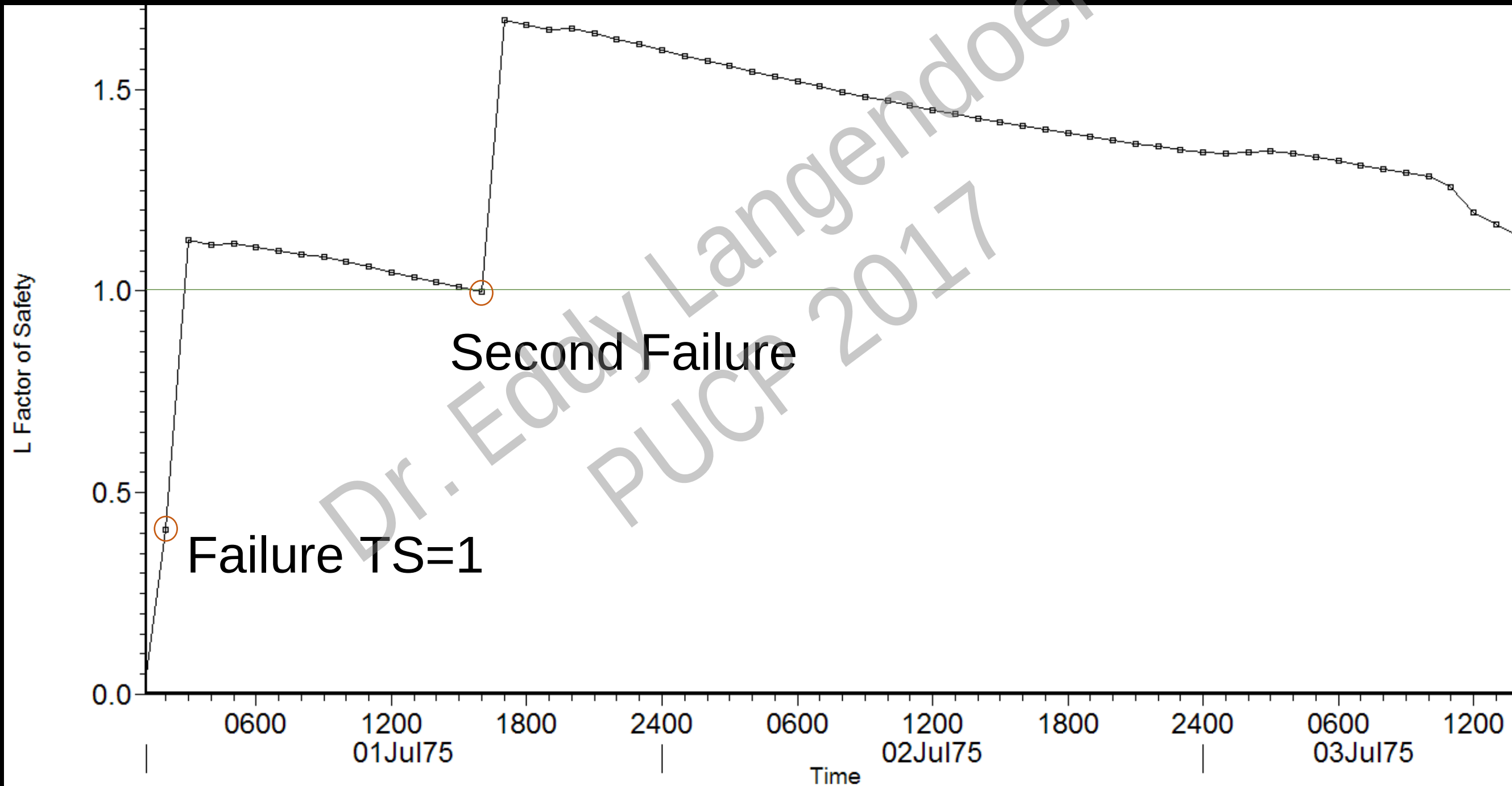
Left Bank Layers

	Bottom Elev	Material
1	0.5	Resistant Silt
2	2.8	Moderate Silt
3	5.1	Erodible Silt
4	7.4	Loam
5	9.62	
6		Loam
7		Boulders
8		Cobbles
9		Gravel
10		C Angular
		C Round
		F Angular
		F Round

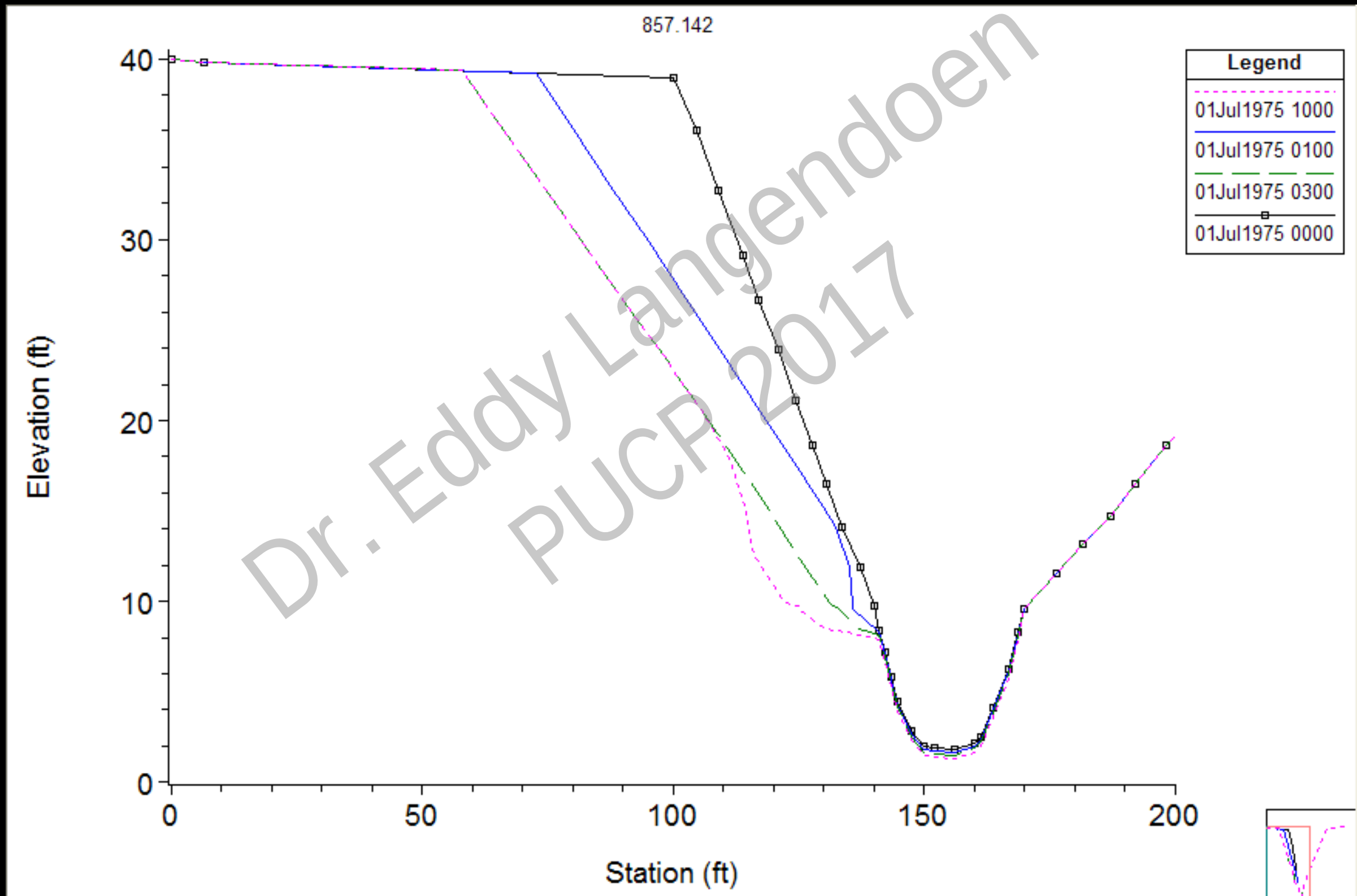
Output: Failure Mass



Output: Factor of Safety



Output: Cross Section





THANK YOU.
QUESTIONS?