Predictable Turbidity Reduction in Construction Site Runoff Using Liquid Flocculant

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April 18, 2013

Project Team

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- Billy Barfield, Ph.D., P.E.
- Sam Harp, P.E.
- Neha Bhadbhade
- Aaron Mittelstet
- Alex McLemore
- Sagar Neupane
- Brad Rogers
- Lizzie Hickman
- Karl Garbrecht
- Sonal Patil
- Many othe undergraduate student helpers

Overall Objective

Develop a system to predictably reduce the turbidity of construction site runoff

Introduction

<u>Sediment Pollution</u>

- Smother benthic ecosystems
- Transport contaminants
- Reduce sunlight penetration

<u>Turbidity</u>

- Nephelometric Turbidity Units (NTU)
- Easy and quick

Turbidity

EPA Regulations

Proposed EPA Turbidity Limit

- 2008 Draft ELG – 13 NTU
- 2009 ELG – 280 NTU
- 2011 EPA stayed 280 NTU limitation

http://www.montgomerycountymd.gov/dectmpl.asp?url=/content/dep/community/sediment.asp

- 2013 Lawsuit settled
  - no plan for turbidity limit in immediate future, but some states have already passed turbidity limits

Traditional Sediment Capture strategies

Traditional Strategies

- Rely on gravity settling
- Require large volumes for sufficient retention time
- Can be ineffective, especially for smaller particles

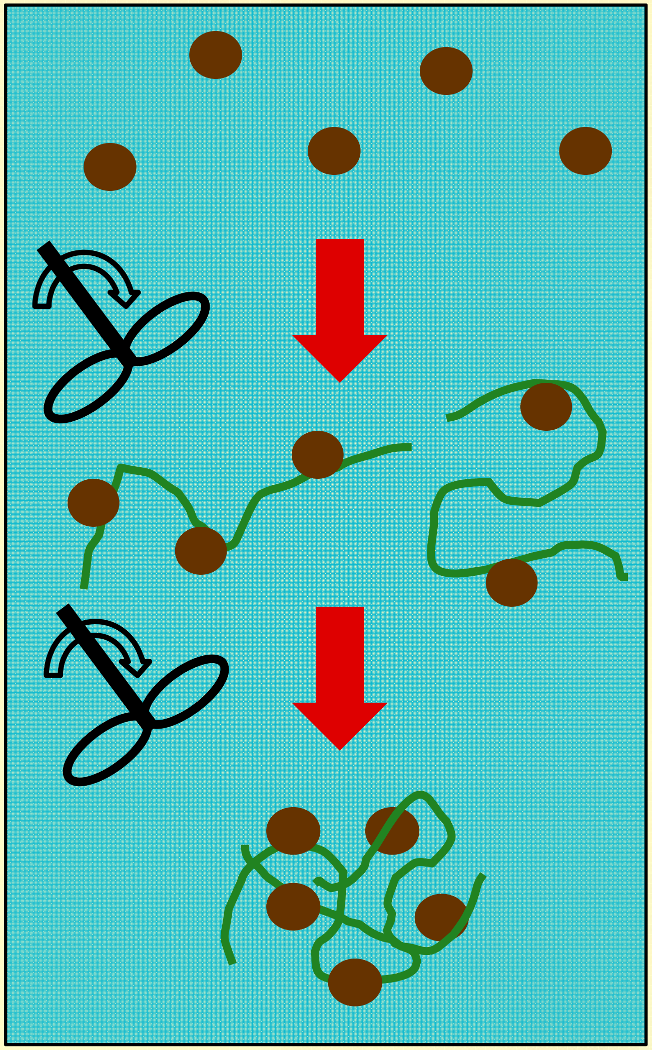
Improved Strategies

- Incorporate waste water treatment technologies to enhance sediment capture

Enhanced sediment capture via Flocculation

Flocculation

- Bridges multiple particles together to form flocs
- Polymers used as bridging agents
- Polymers sold as powders, solids, or liquid
- Flocculant concentration and mixing intensity essential for optimum flocculation



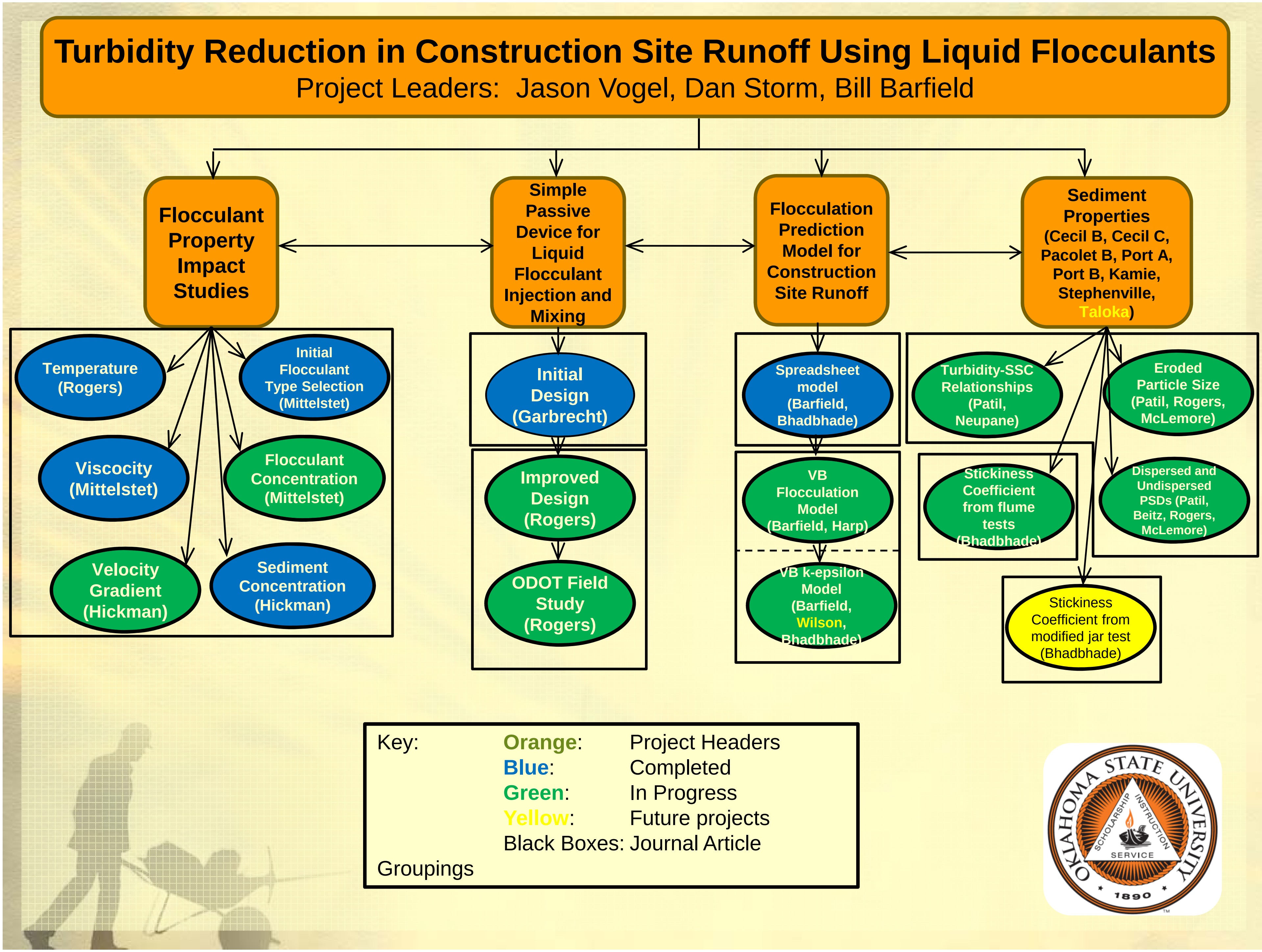
Current Passive Flocculation Techniques

Pros

- Easy installation
- Low cost
- Effective when they work

Challenges

- Limited data on dosing concentrations
- Potential to become sediment laden



Turbidity Reduction in Construction Site Runoff Using Liquid Flocculants
Project Leaders: Jason Vogel, Dan Storm, Bill Barfield
Flocculant Property Impact Studies
Simple Passive Device for Liquid Flocculant Injection and Mixing
Flocculation Prediction Model for Construction Site Runoff
Sediment Properties (Cecil B, Cecil C, Pacolet B, Port A, Port B, Kamie, Stephenville, Taloka)
Temperature (Rogers)
Initial Flocculant Type Selection (Mittelstet)
Viscocity (Mittelstet)
Flocculant Concentration (Mittelstet)
Velocity Gradient (Hickman)
Sediment Concentration (Hickman)
Initial Design (Garbrecht)
Improved Design (Rogers)
ODOT Field Study (Rogers)
Spreadsheet model (Barfield, Bhadbhade)
VB Flocculation Model (Barfield, Harp)
VB k-epsilon Model (Barfield, Wilson, Bhadbhade)
Turbidity-SSC Relationships (Patil, Neupane)
Eroded Particle Size (Patil, Rogers, McLemore)
Stickiness Coefficient from flume tests (Bhadbhade)
Dispersed and Undispersed PSDs (Patil, Beitz, Rogers, McLemore)
Stickiness Coefficient from modified jar test (Bhadbhade)
Key: Orange: Project Headers
Blue: Completed
Green: In Progress
Yellow: Future projects
Black Boxes: Journal Article Groupings
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1890

Predictable Turbidity Reduction Studies

- **Flocculation Prediction Model for Construction Site Runoff**
  - Spreadsheet and Visual Basic model
- **Flocculant Property Impact Studies**
  - Flocculant Selection
  - Temperature
  - Viscocity
  - Sediment Concentration
  - Flocculant Concentration
  - Velocity Gradient

Predictable Turbidity Reduction Studies

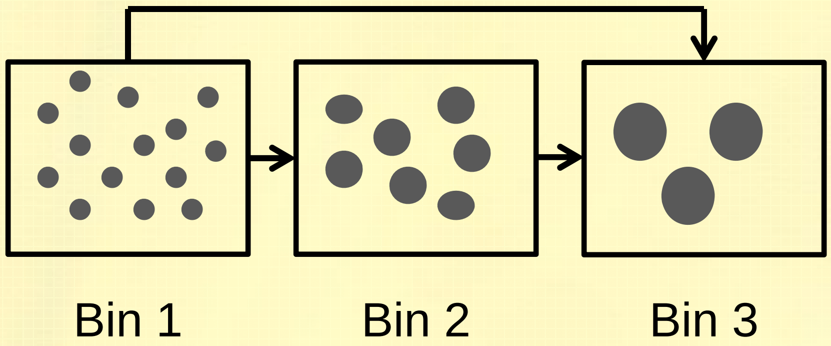
- **Simple Passive Device for Liquid Flocculant Injection and Mixing**
  - Design and testing
- **Sediment Properties Affecting Flocculation**
  - Dispersed and undispersed particle size distributions
  - Eroded particle size distribution
  - Relationship between particle size distribution and
  - Stickiness coefficient from flume studies

FLOCCULATION PREDICTION MODEL FOR CONSTRUCTION SITE RUNOFF

Flocculation Model

- Flocculation Model: Krishnappan and Marsalek (1991)
- PBE-Advection dispersion equation
- PBE: All particles are clay particles
- Flocs grow in geometric progression

$$r_f = r_i 2^{\frac{i-1}{3}}$$



Example:

Bin number	Radius (microns)	Number or particles in floc
1	2	1
2	2.52	2
3	3.17	4

Flocculation Model

$$\frac{dn_{pp,i}}{dt} = -\sum_{j=i}^{N_{\max}} 2^{i-1}\beta_j K_{ij}^{eff} n_i n_j + \sum_{j=1}^{i} 2^{j-1}\beta_i f_{ij} K_{ij}^{eff} n_i n_j + \sum_{j=1}^{i-1} 2^{j-1}\left(1 - f_{i-1,j}\right)\beta_{i-1} K_{i-1,j}^{eff} n_{i-1} n_j$$

β : Coagulation coefficient

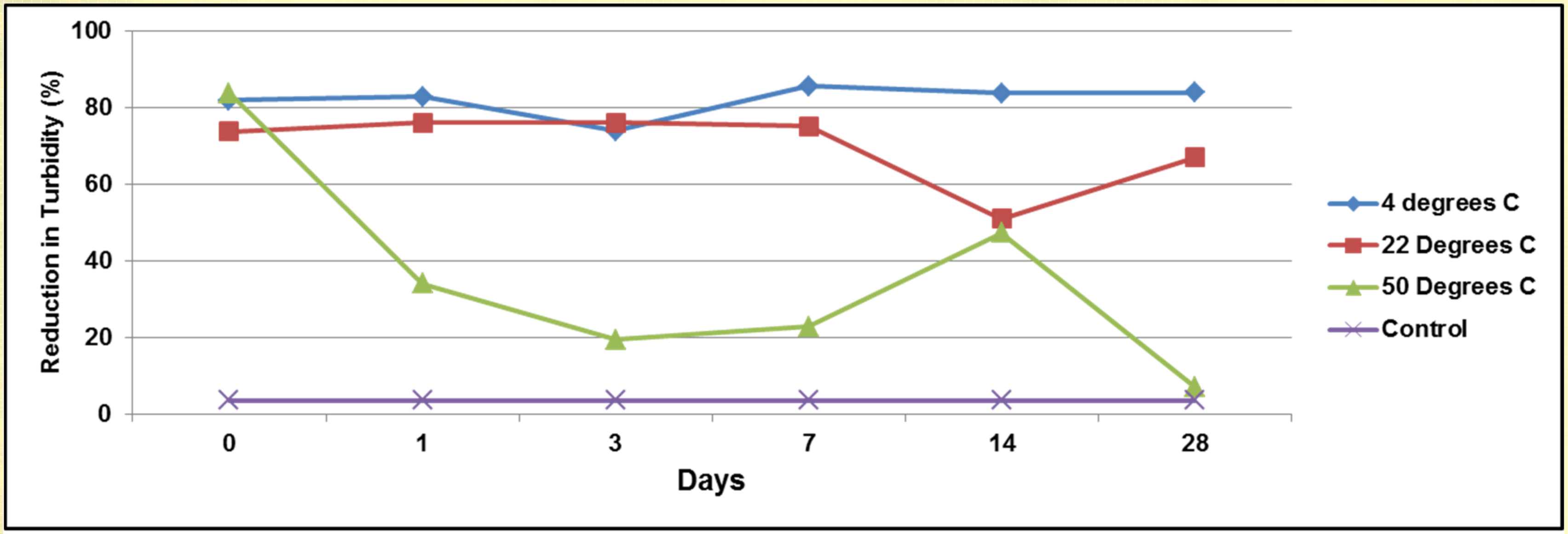
K_{ij}^{eff}: Effective collision coefficient

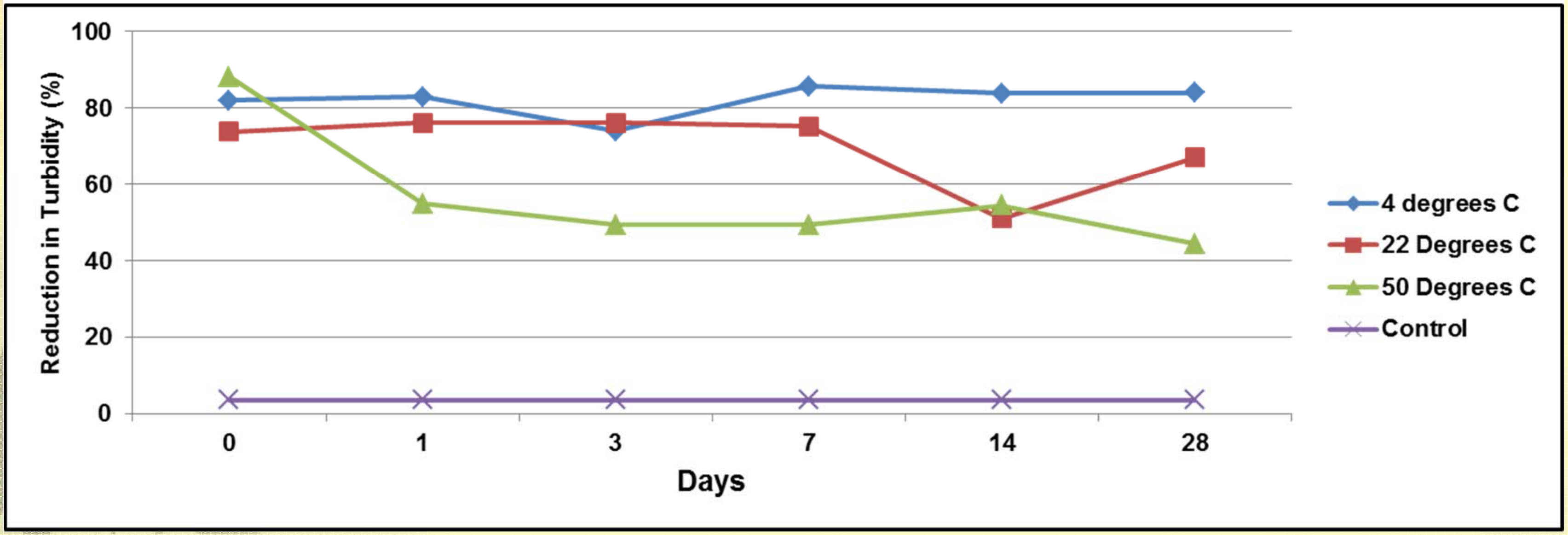
f_{ij}: Fraction of the flocs

Physical Mechanism	Collision Frequency Function
Brownian Motion	$K_{i,j}^{Kh,B} = \frac{2}{3}\frac{B_Z T}{\rho\nu}\frac{\left(r_i + r_j\right)^2}{r_i r_j}$
Turbulent or Laminar shear	$K_{i,j}^{Kh,SH} = \frac{4}{3}\left(\frac{\varepsilon}{\nu}\right)^{0.5}\left(r_i + r_j\right)^3$
Inertia in Turbulent Flow	$K_{i,j}^{Kh,IN} = 1.21\frac{\rho_{sj}}{\rho_j}\left(\frac{\varepsilon^3}{\nu^5}\right)^{0.25}\left(r_i + r_j\right)^2 abs\left(r_i^2 - r_j^2\right)$
Differential Settling	$K_{i,j}^{Kh,DS} = \frac{2\pi g}{9\nu}\frac{\rho_{sj} - \rho_w}{\rho_w}\left(r_i + r_j\right)^2 abs\left(r_i^2 - r_j^2\right)$
Effective Collision frequency	$K_{i,j}^{eff} = K_{i,j}^{Kh,BR} + \sqrt{\left(K_{i,j}^{Kh,Sh}\right)^2 + \left(K_{i,j}^{Kh,IN}\right)^2 + \left(K_{i,j}^{Kh,DS}\right)^2}$

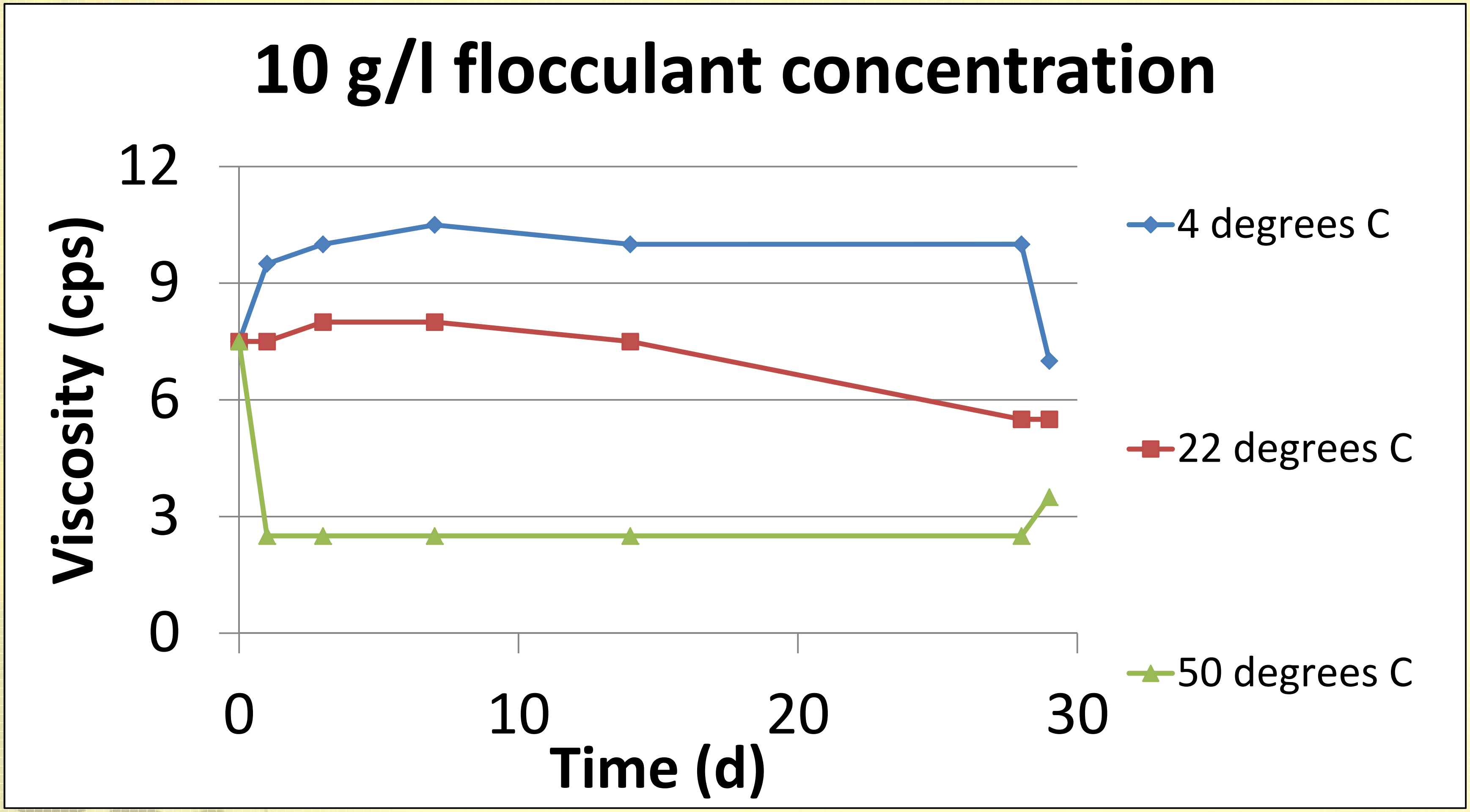
FLOCCULANT PROPERTY IMPACT STUDIES

Temperature (using HydroFloc)

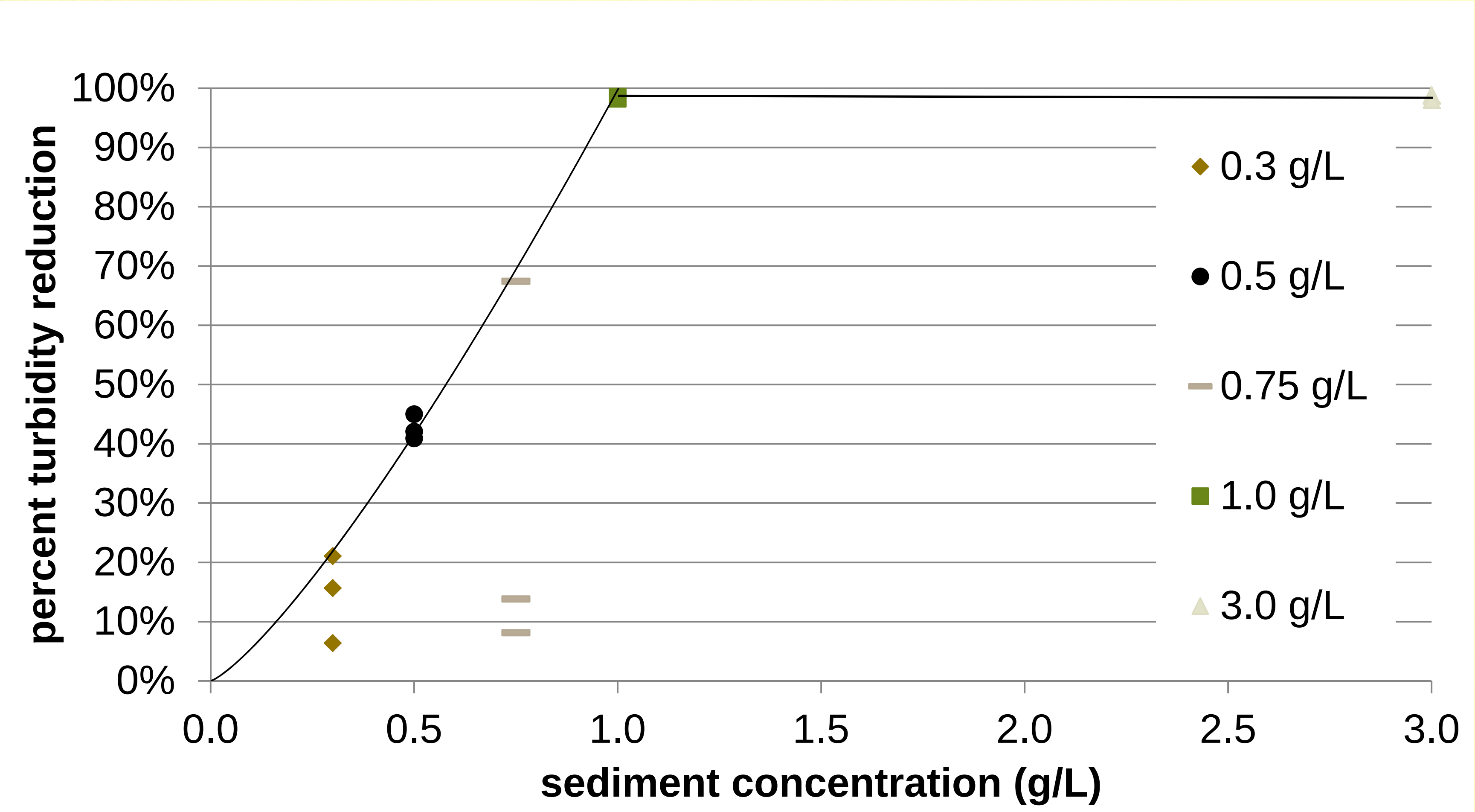




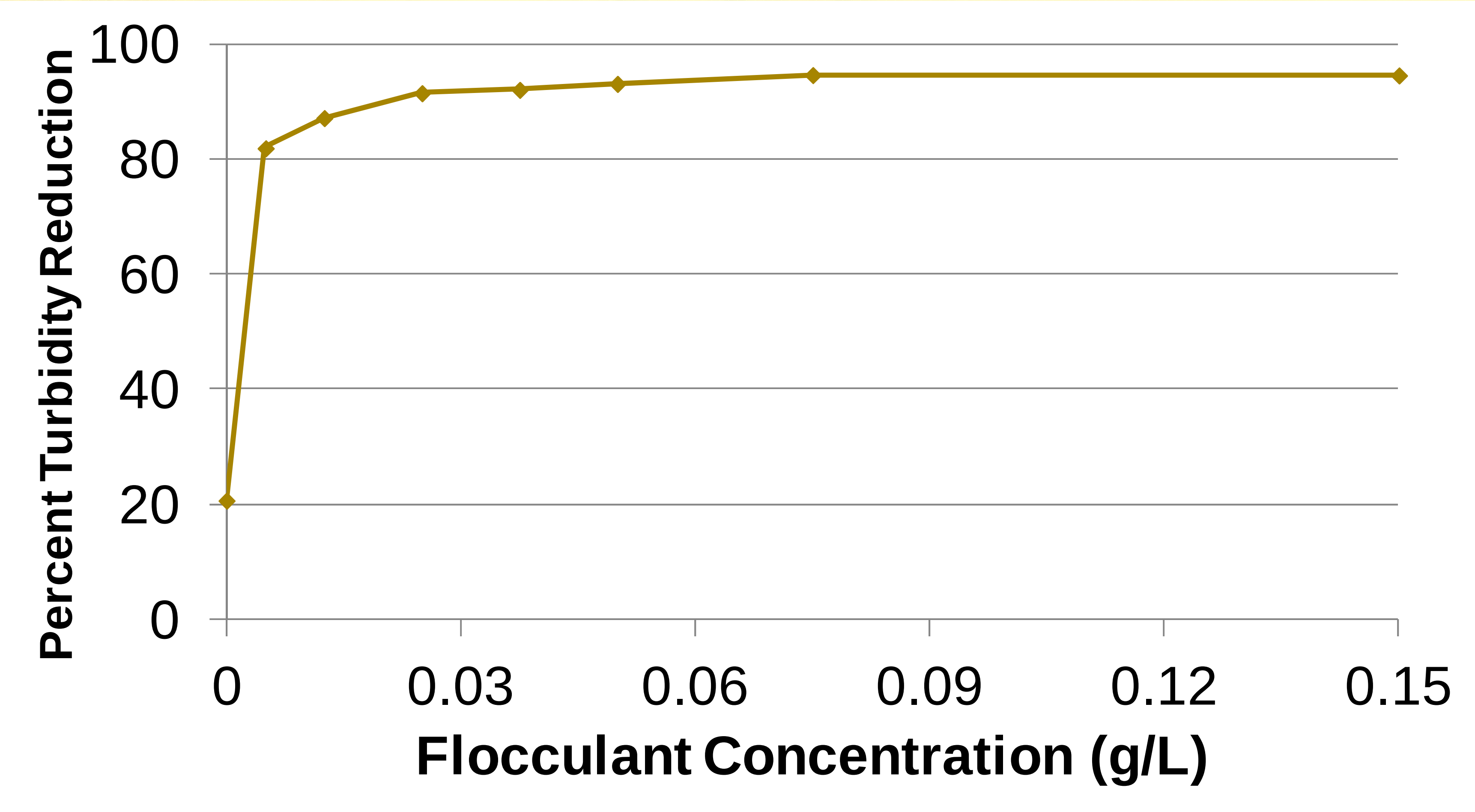
Viscosity and Temperature (HydroFloc)



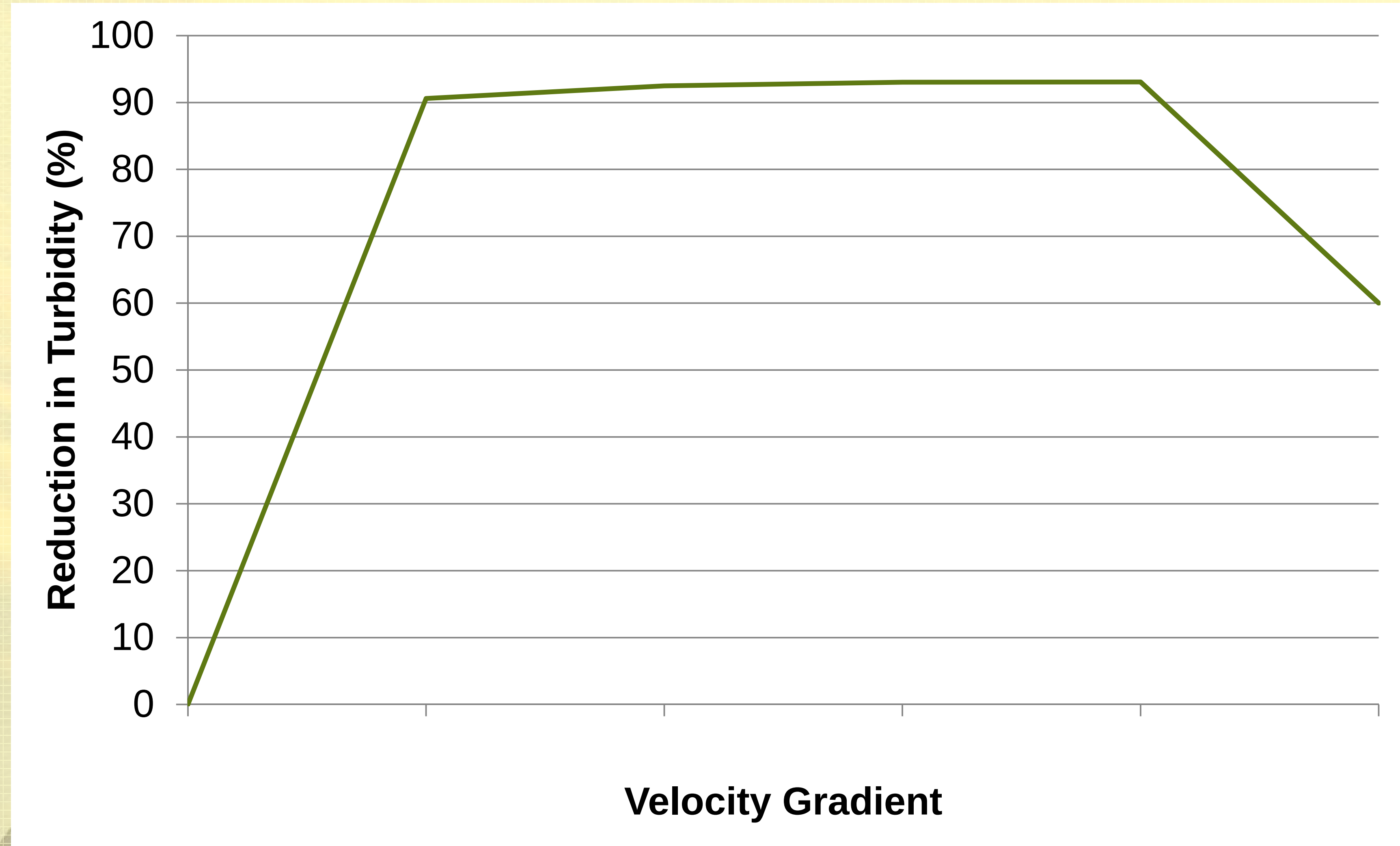
Sediment Concentration



Flocculant Concentration (Hydrofloc)

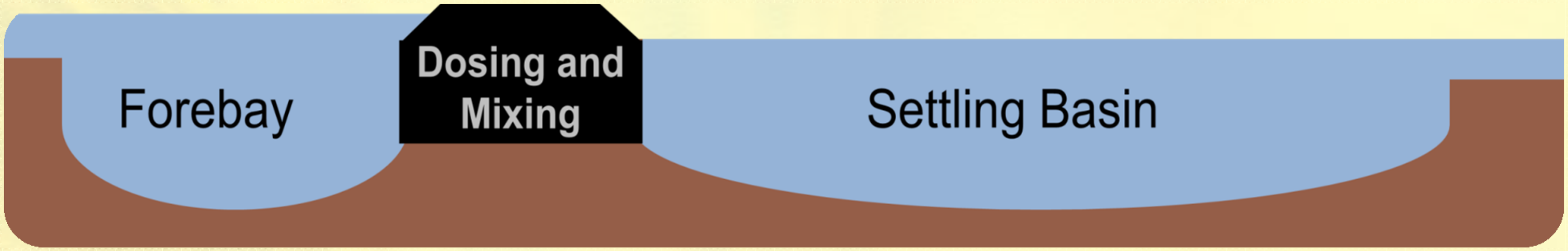


Velocity Gradient (Theoretical)

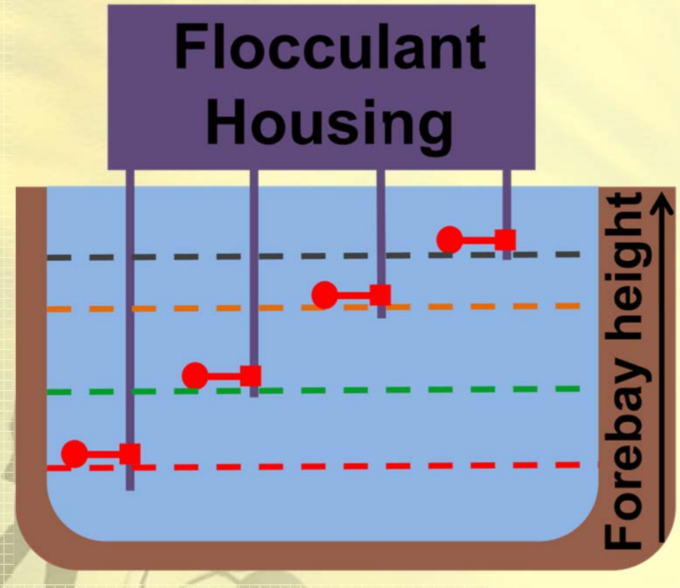


SIMPLE PASSIVE DEVICE FOR LIQUID FLOCCULANT INJECTION AND MIXING

OSU System

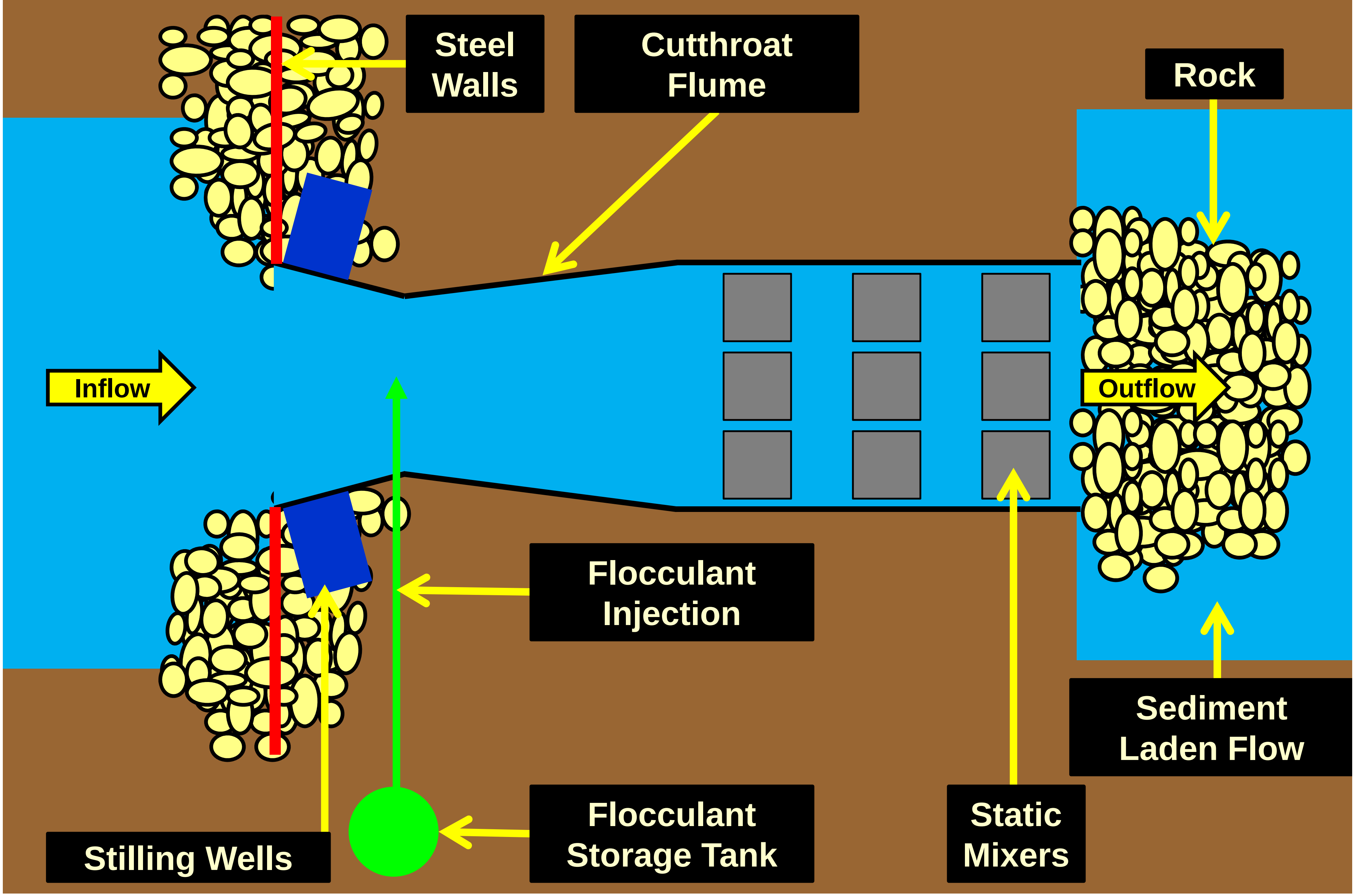


Dosing Apparatus

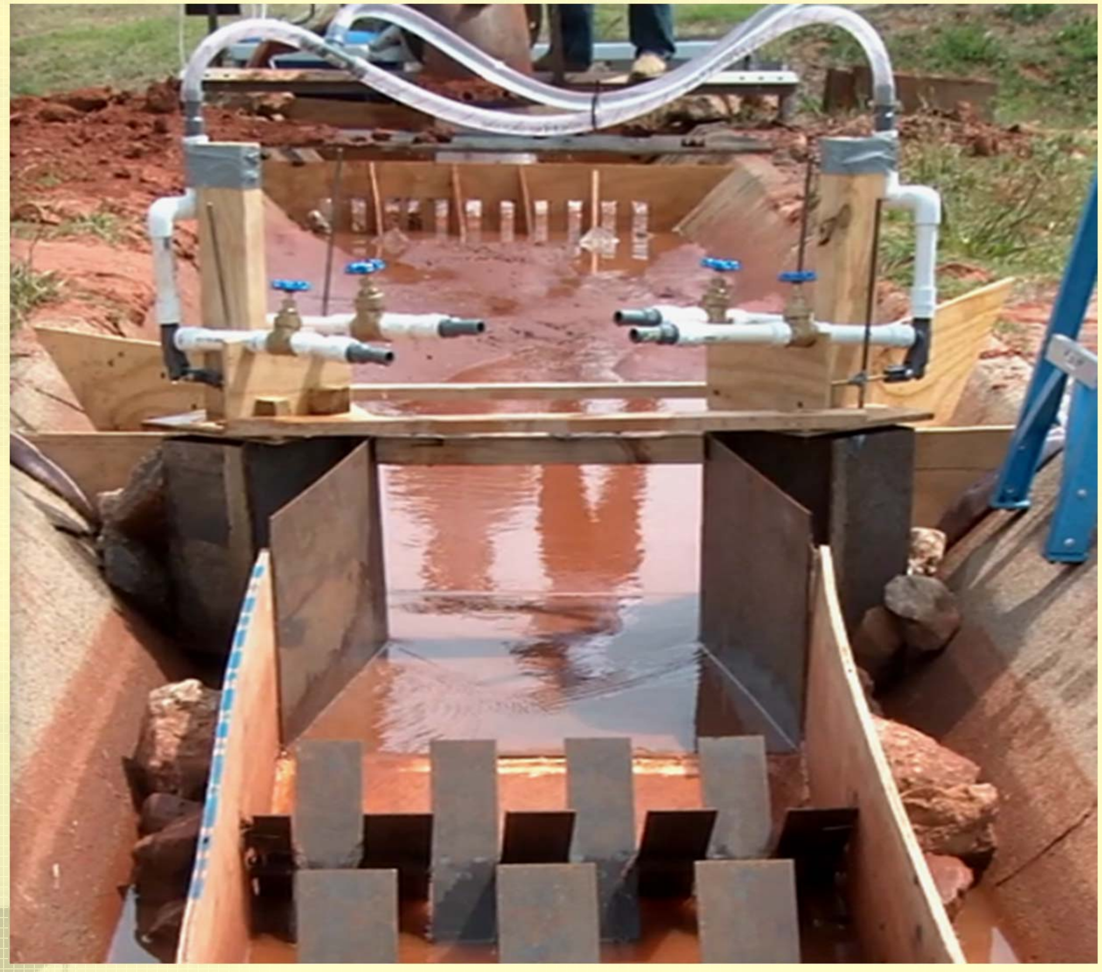


As forebay stage increases additional floats are actuated which correspond to increasing flow through flow control structure

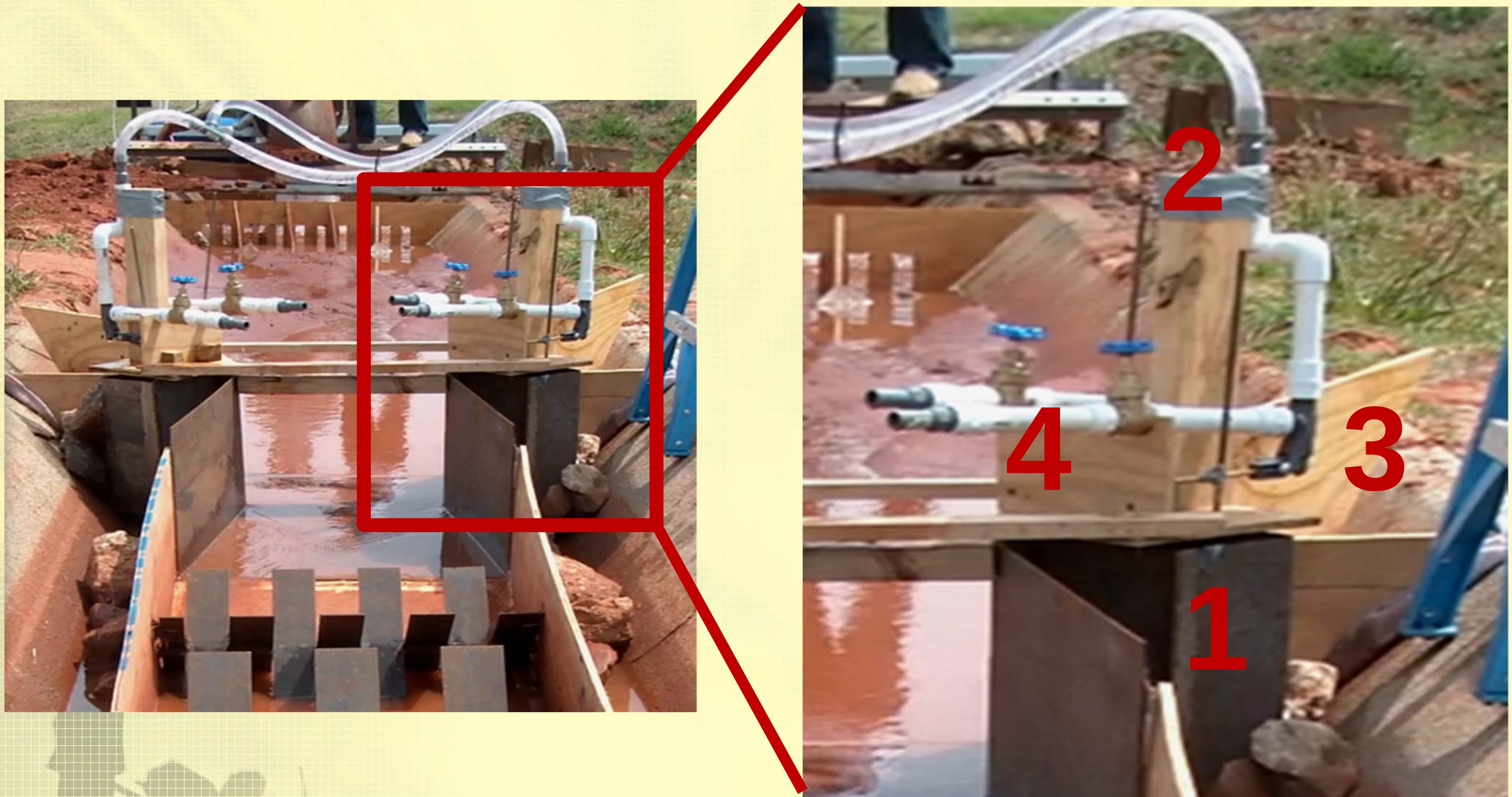
Top View – Injection and Mixing Apparatus



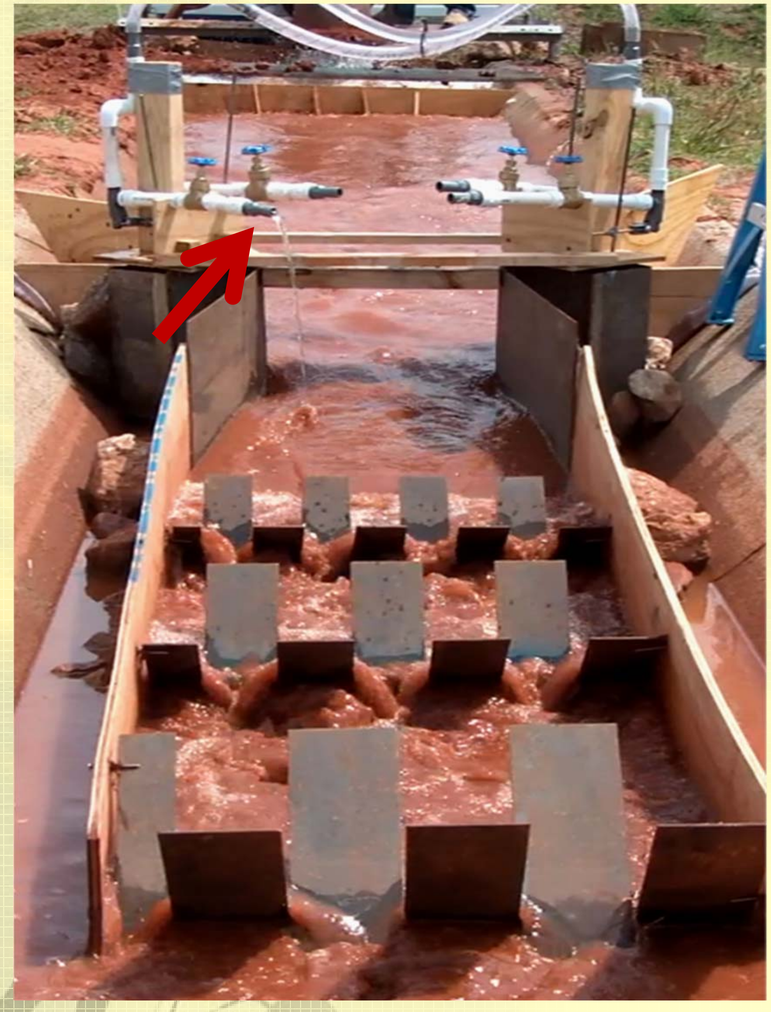
OSU System

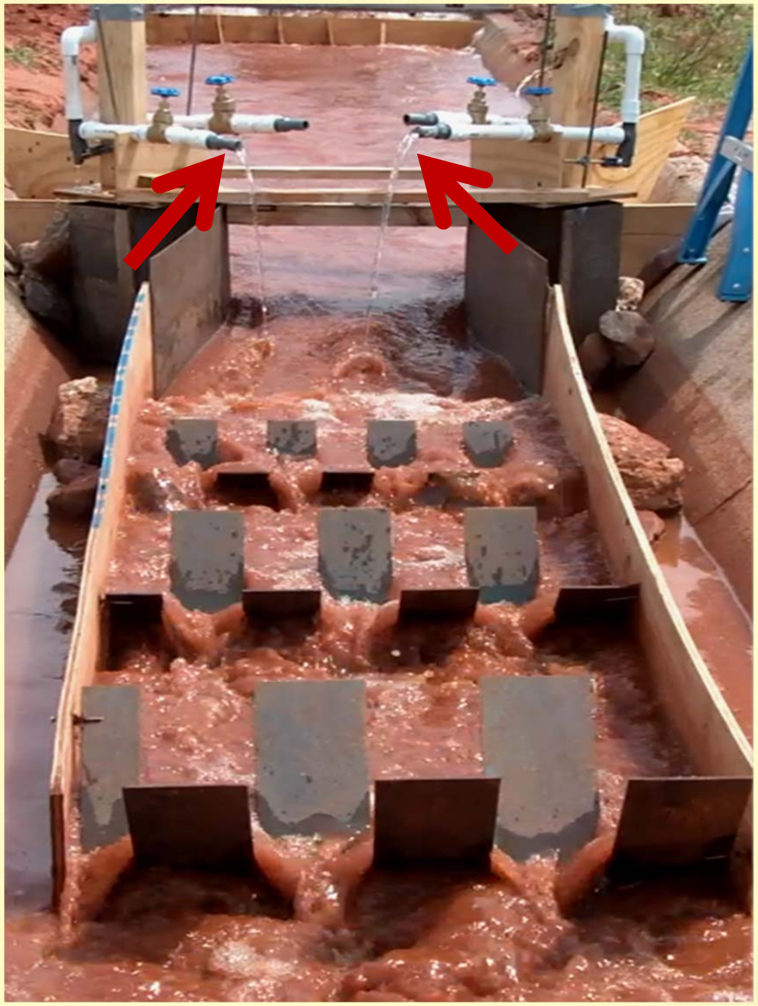


OSU System

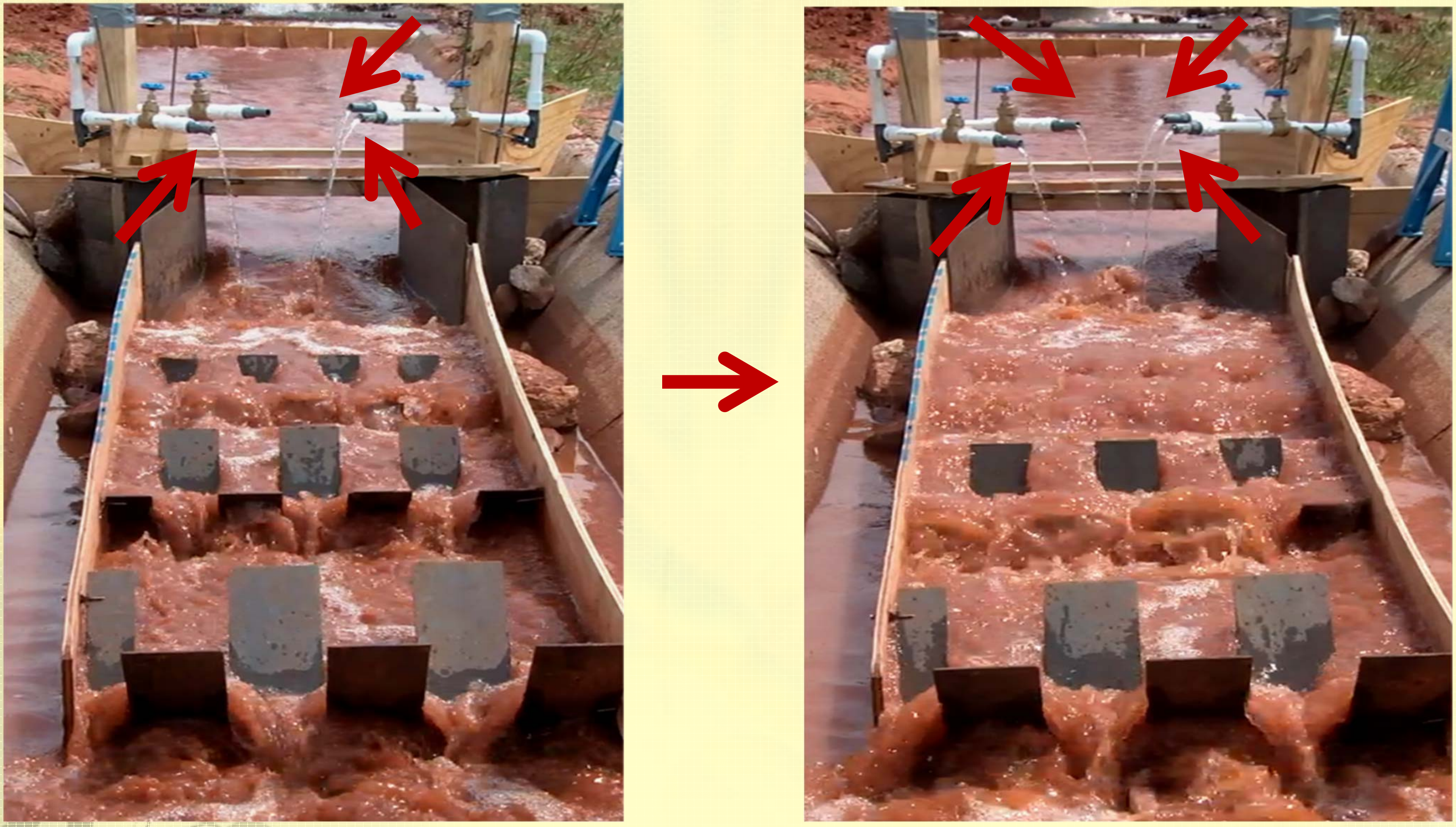


OSU System





OSU System



Results

Inflow Turbidity

2400

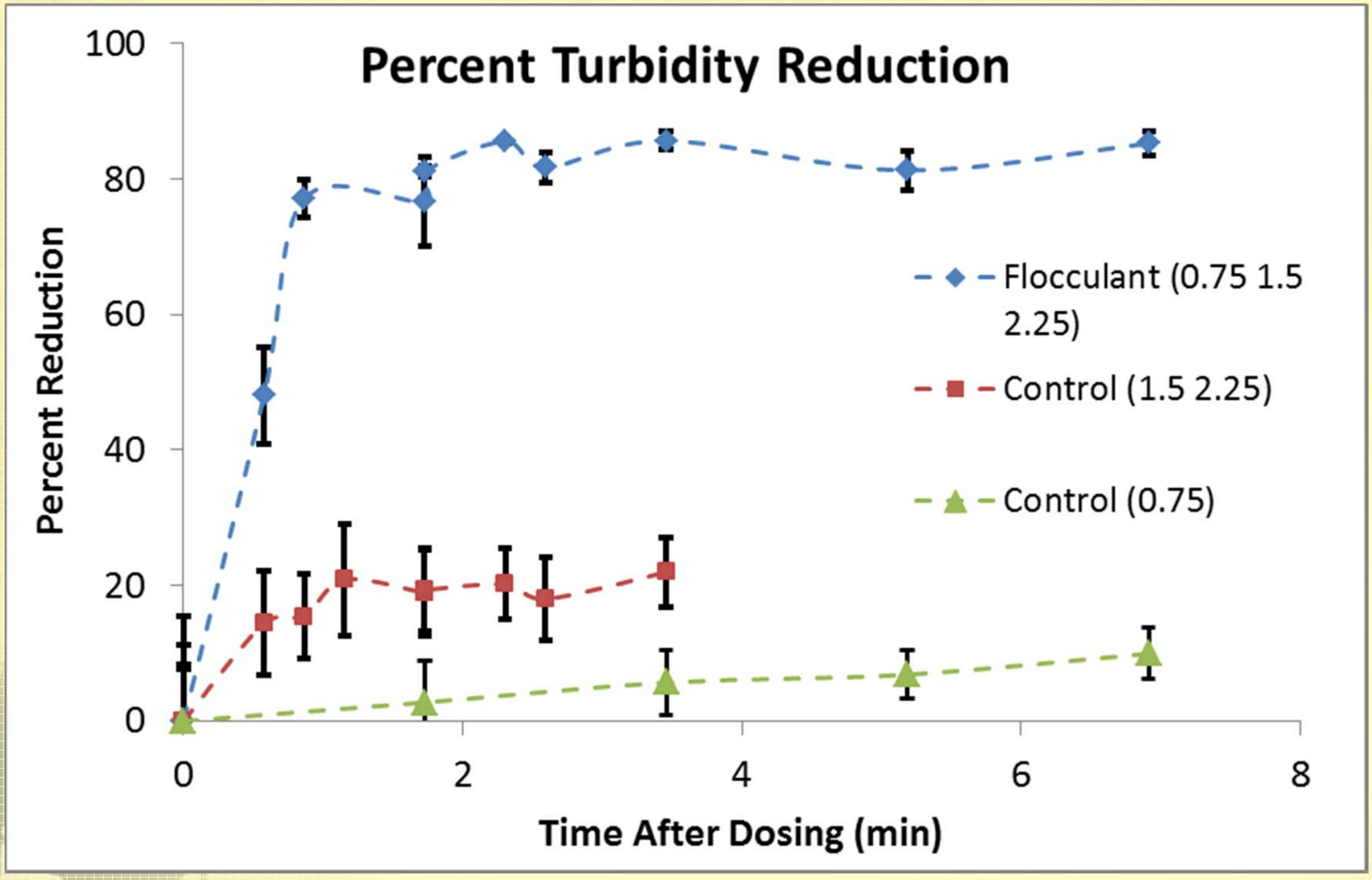
No Flocculant

1990

Flocculant

340

OSU System Results



Turbidity – Eroded Particle Size Distribution

SEDIMENT PROPERTIES AFFECTING FLOCCULATION

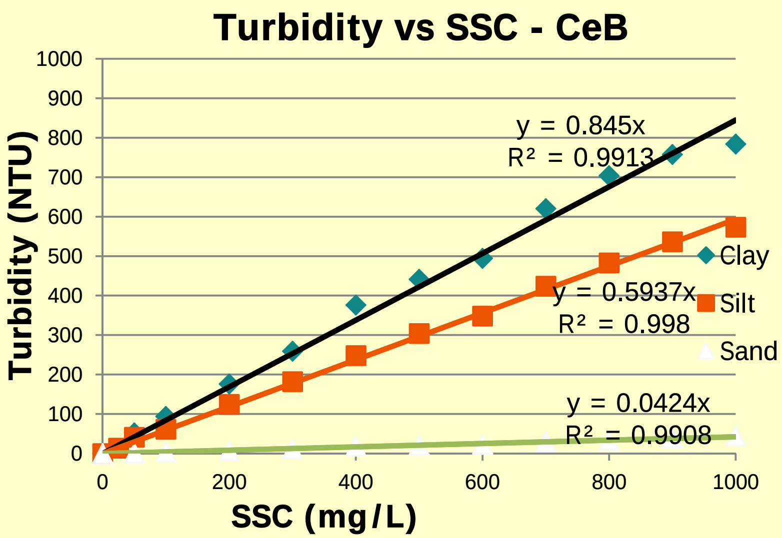
Rain on Samples to Generate Runoff…

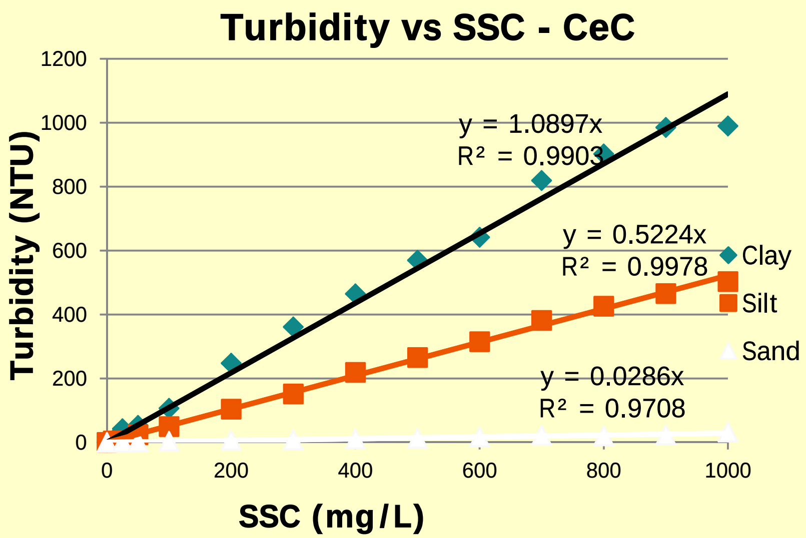
…and Erode Particles

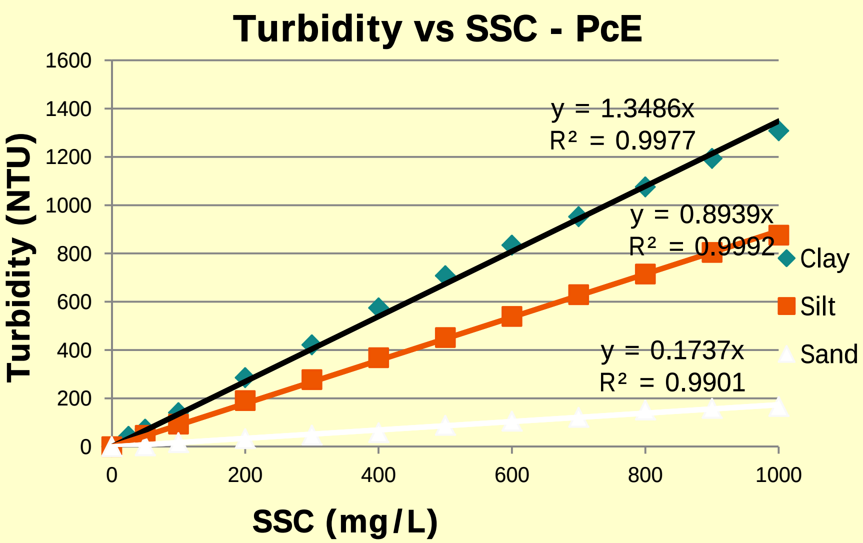
Turbidity – SSC Relationship

SEDIMENT PROPERTIES AFFECTING FLOCCULATION

Relationship between Turbidity and Particle Size Classifications



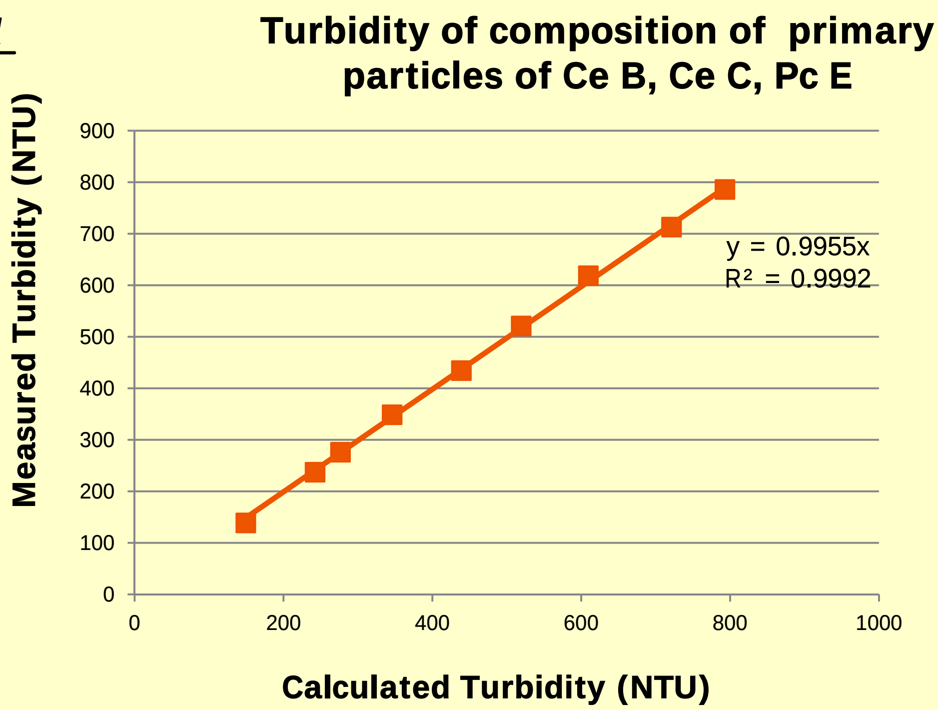




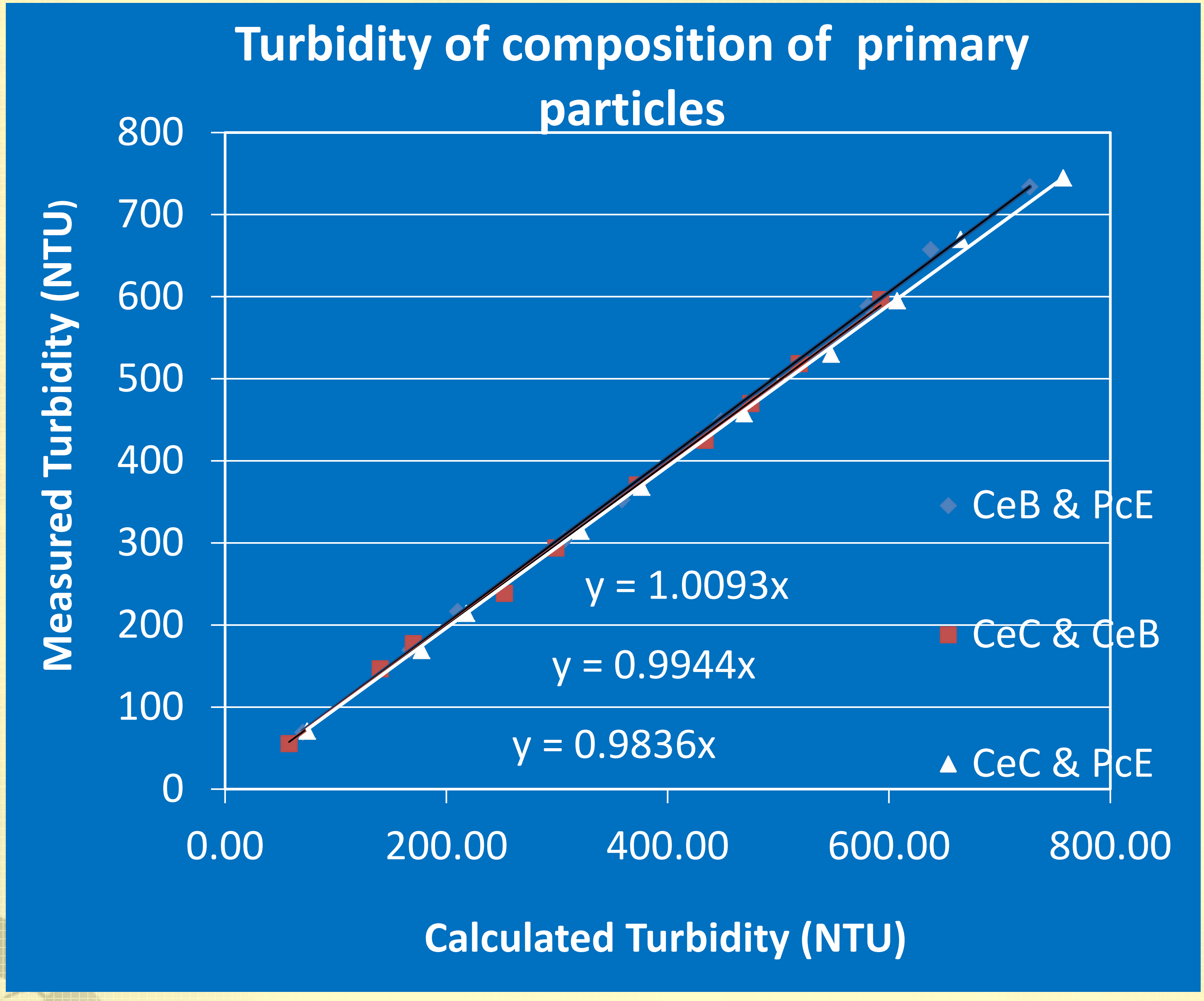
Relationship between Turbidity and Particle Size Classifications

$$T_b = \frac{k_{sa}Tss_{sa} + k_{si}Tss_{si} + k_{cl}Tss_{cl}}{Tss_{sa} + Tss_{si} + Tss_{cl}}$$

The linear model works very well when combining varying fractions of sa, si, & cl for a given soil

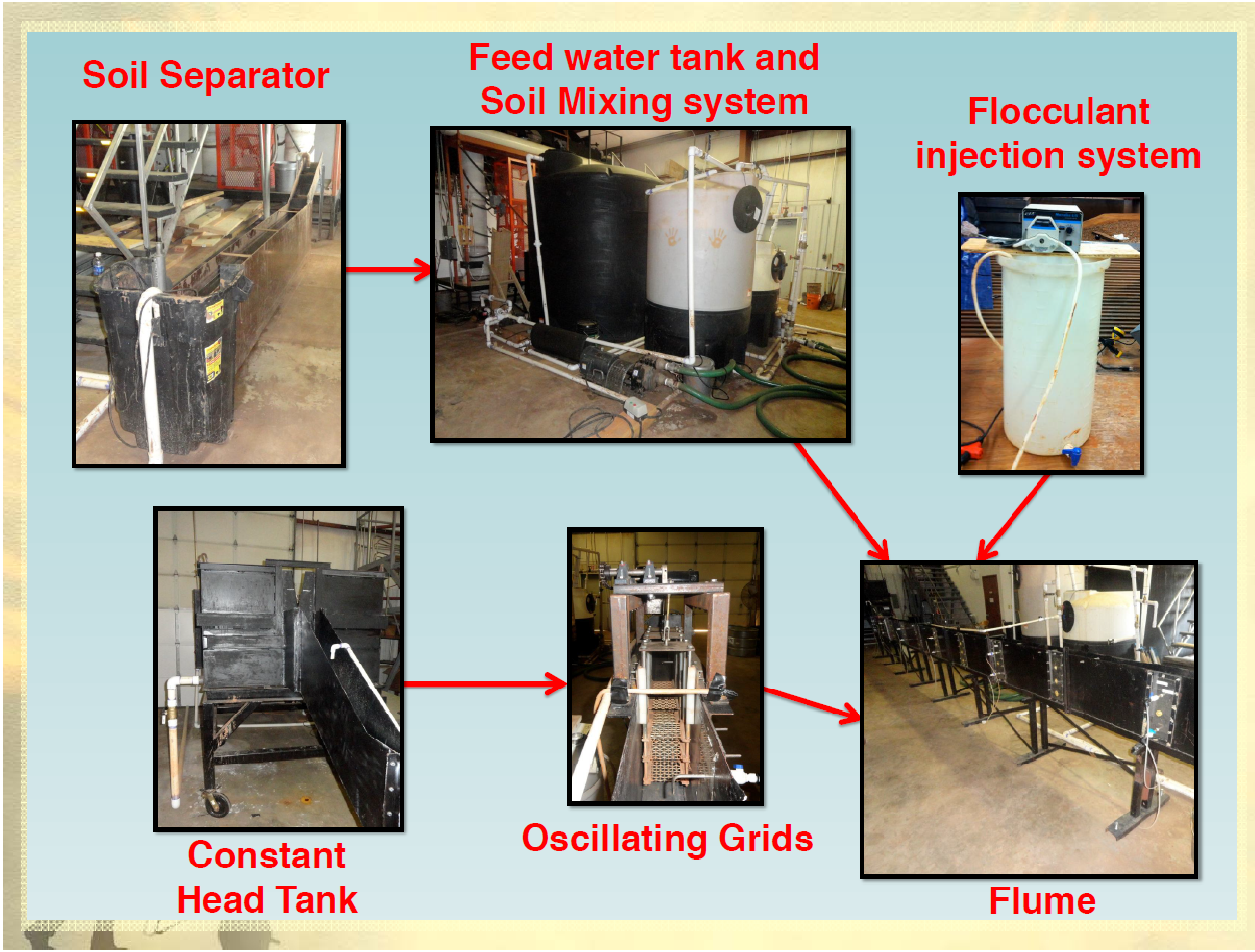


Combined Primary Particles from Two Soils



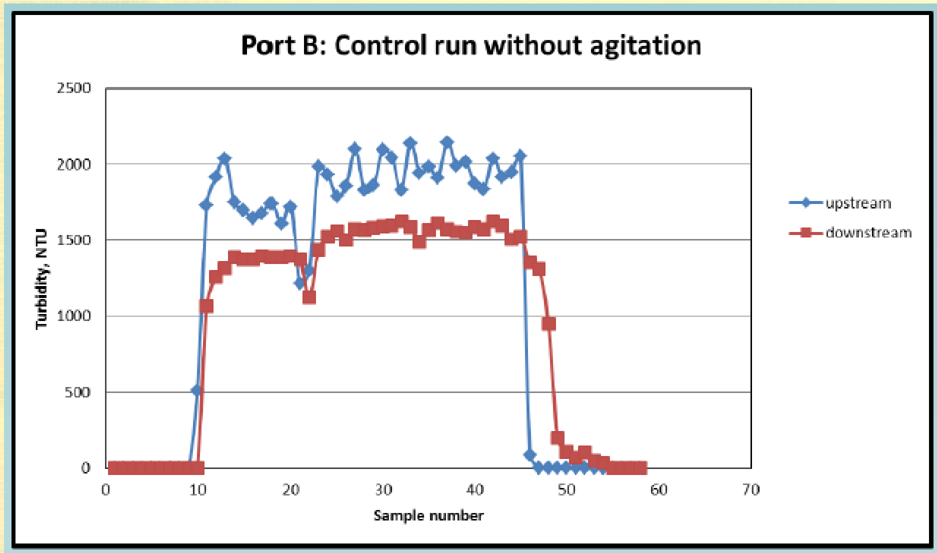
Estimation of Flocculation constants for various soils

SEDIMENT PROPERTIES AFFECTING FLOCCULATION

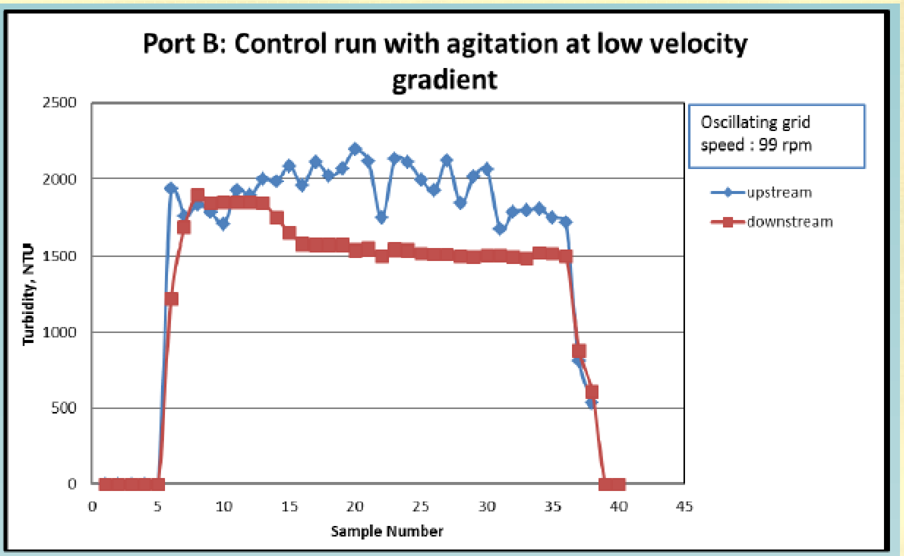

Soil Separator
Feed water tank and Soil Mixing system
Flocculant injection system
Constant Head Tank
Oscillating Grids
Flume

Flume Apparatus

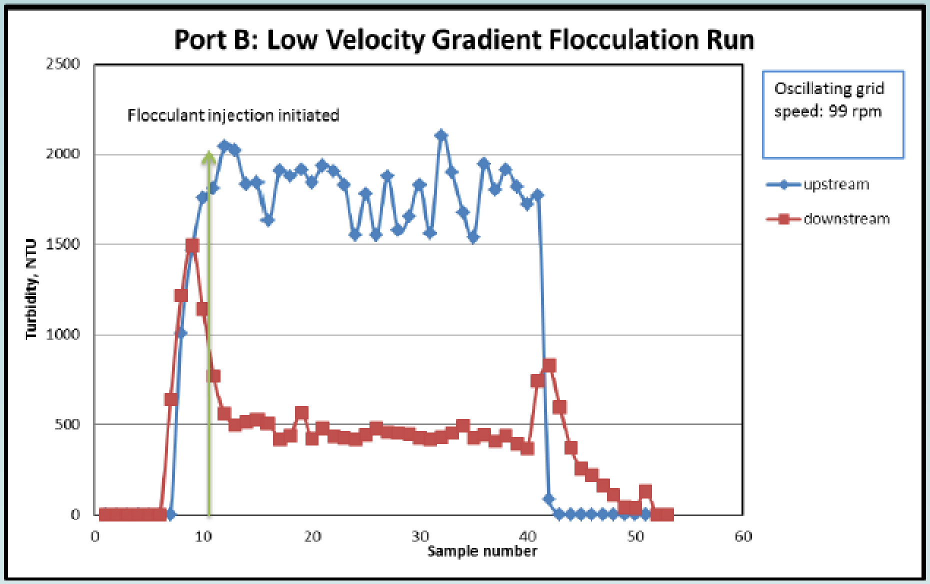
Results



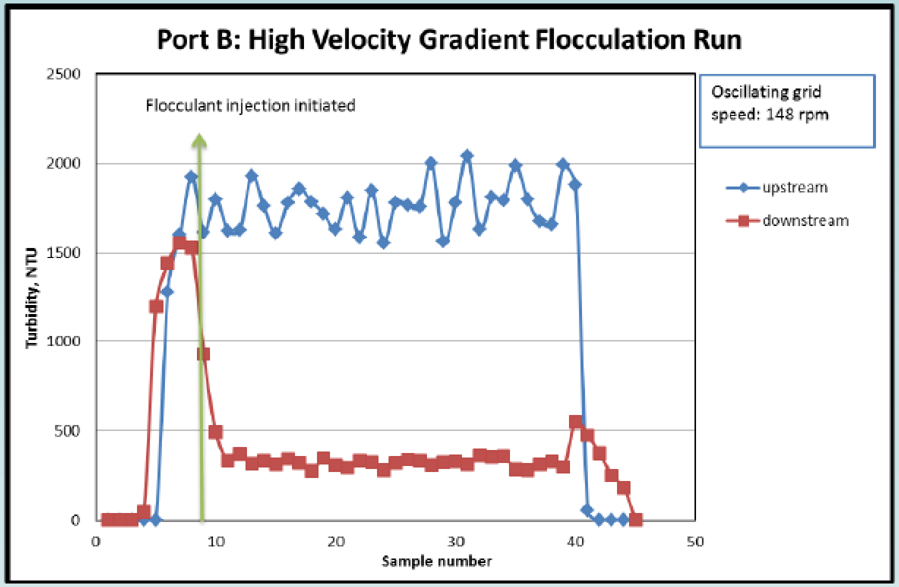
Port B: Control run without agitation
Turbidity, NTU
Sample number
upstream
downstream



Port B: Control run with agitation at low velocity gradient
Oscillating grid speed : 99 rpm
Turbidity, NTU
Sample Number
upstream
downstream



Port B: Low Velocity Gradient Flocculation Run
Flocculant injection initiated
Oscillating grid speed: 99 rpm
Turbidity, NTU
Sample number
upstream
downstream



Port B: High Velocity Gradient Flocculation Run
Flocculant injection initiated
Oscillating grid speed: 148 rpm
Turbidity, NTU
Sample number
upstream
downstream

Conclusions and Take Aways

- After we finish with the final soil flume runs, we will be developing a custom jar test so that flocculation factors can be more efficiently estimated.

Conclusions and Take Aways

- Based upon these results, the field apparatus can be designed to optimize flocculation based on sediment concentration, flocculant concentration, velocity gradient, and temperature.

Conclusions and Take Aways

- The results of the four parts of this study will be combined with an existing sediment transport model to predictably reduce the turbidity of construction site runoff for selected soil-flocculant concentrations.

Conclusions and Take Aways

- Even though the US EPA has rescinded the turbidity limit, some states still have limits enacted.
- This system can save valuable space for detention ponds in areas with limited area, such as linear construction sites.

Questions???

Jar Test Results

Floc	Pros	Cons
Hydrofloc	Greatest removal efficiency Long stability in concentrated form	Very high viscosity
Superfloc 705	High removal efficiency Moderate viscosity	Difficult to mix Very short stability
FloPam SH (solution)	Easy to mix Low viscosity High removal efficiency	Short stability Difficult to mix
FloPam VLM (solution)	High removal efficiency Moderate Viscosity	Very short stability