A New Approach to the Siltation Problem in the Sand Storage Dam

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Abstract

Sand dams, a water harvesting system built in arid or semi-arid regions, collect and store water in saturated sands to increase water availability in dry seasons, while avoiding evaporation and reducing water-borne disease vectors. The capacity of the dam to store water depends on the texture of the sediment accumulated in the reservoir. An ideal sand dam is expected to wash fine-grained particles, especially silt and clay out of the reservoir, collecting only coarse particles to provide for maximum open pore space and minimum capillary retention (the water is typically extracted via an open well). Although conceptually simple, sand dam commonly failed due to the retention of fine particles. It has been recommended to build sand dams in stages to overcome this problem, with each stage low enough so that the shear forces of flow will keep silt and clay mobile, and pass them out of the reservoir. Although it is effective, this method is not preferred in terms of cost and time spent (repeatedly re-mobilizing a team to add to the dam). We present a new approach to the siltation problem by seeking an ideal shape (weir) cut in the face of a sand dam designed to provide shear forces such that coarse particles accumulation while washing the finer materials such as silt and clay. This will be done by finding a relation between the cut-outs of in the face of the dam and the sediment transport rates. Challenges in predicting sediment transport rate are investigated using both numerical and experimental modeling. We seek to reduce the failure rate of sand dams, and also provide for a method to re-establish sediment fills behind existing dams.

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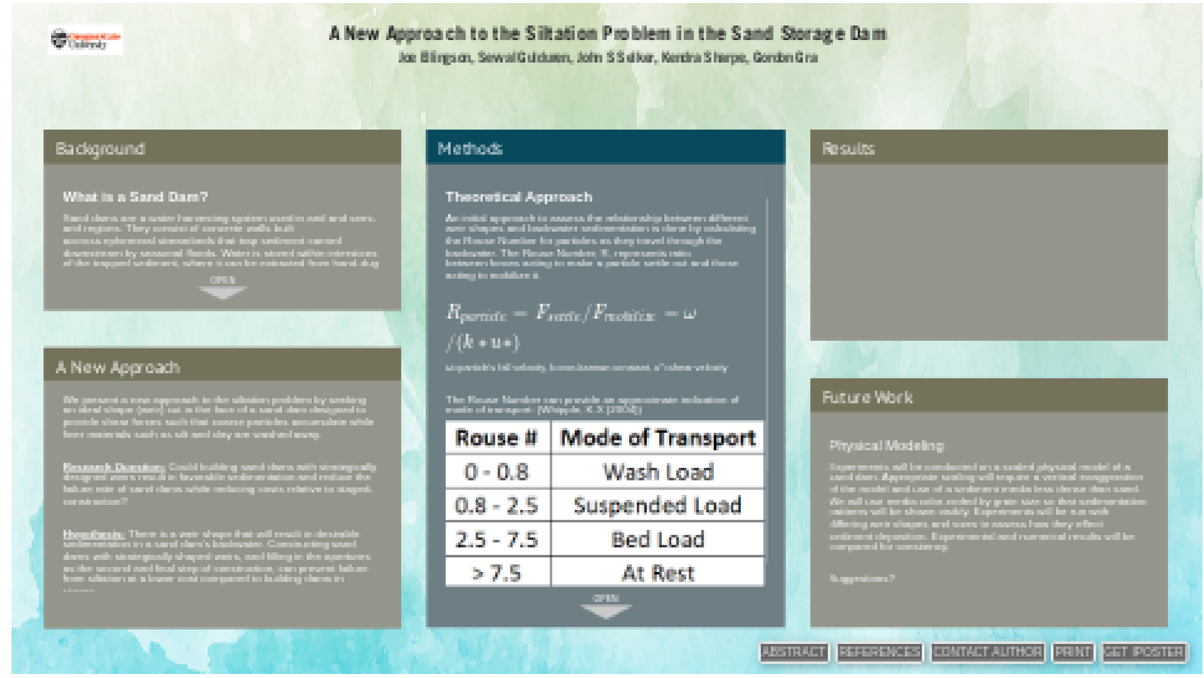

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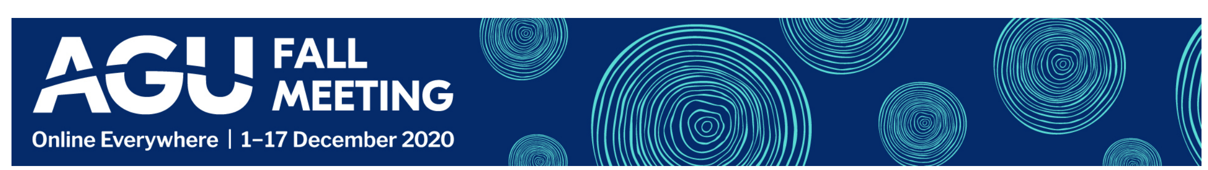

BACKGROUND

What is a Sand Dam?

Sand dams are a water harvesting system used in arid and semi-arid regions. They consist of concrete walls built accross ephemeral streambeds that trap sediment carried downstream by seasonal floods. Water is stored within interstices of the trapped sediment, where it can be extracted from hand-dug scoop holes, or groundwater wells. (Viducich, 2015).

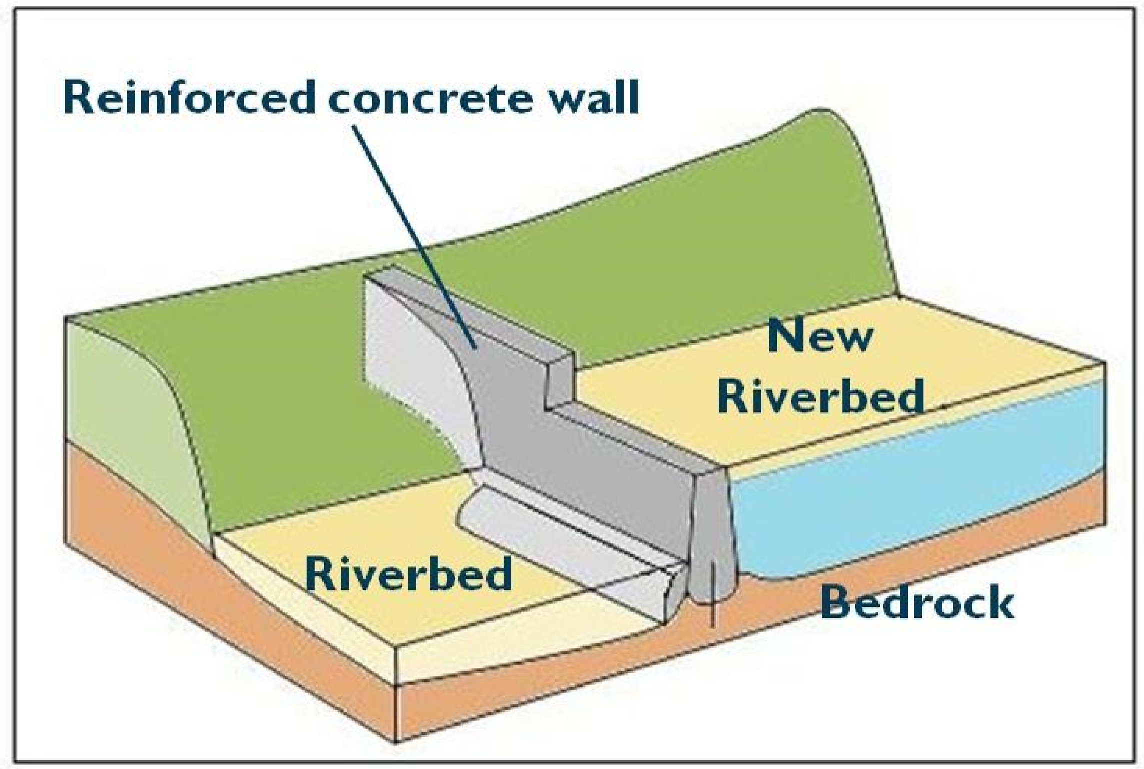

Figure 1. Sand Dam Diagram

Failure Due to Siltation

Coarse sands with uniform grain-size distributions are ideal for underground storage of water. The presence of fine sediments within interstices of a sand matrix (siltation) can reduce storage capacity make water extraction more difficult. The rate of sand dam failure due to siltation has been estimated as high as 90% (Nissen-Petersen, E. (2010)).

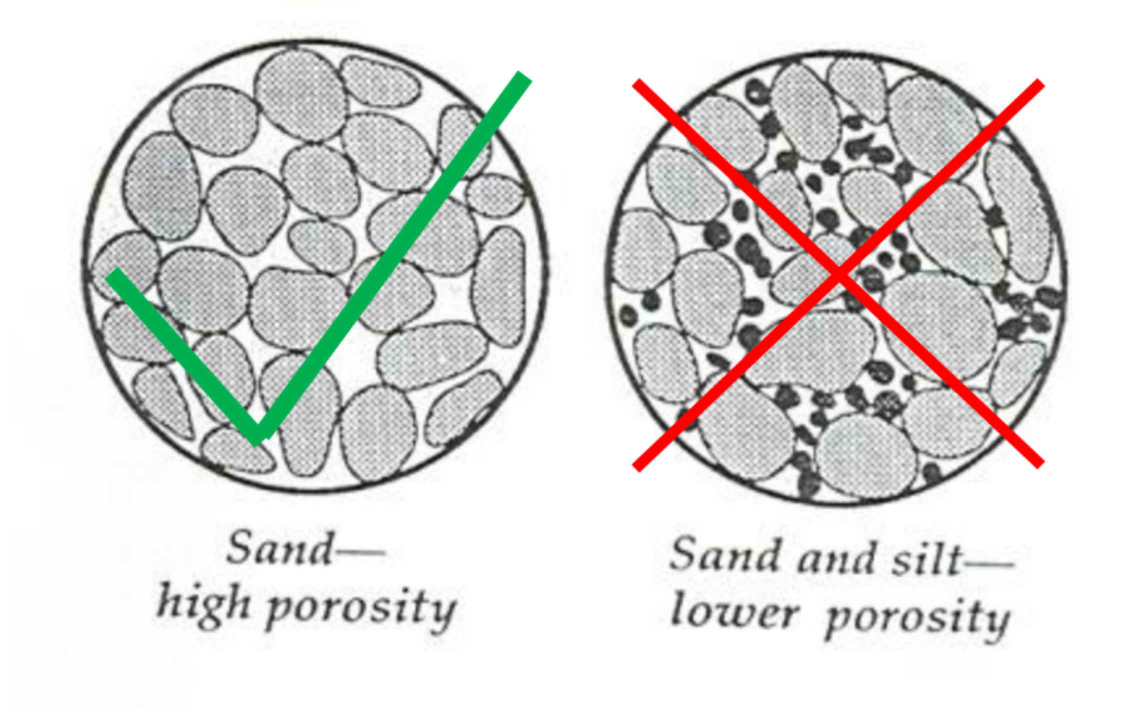

Figure 2. Affect of Siltation on Porosity

Staged Dam Construction

A common approach to prevent siltation is to build dams in several stages. This method is effective, but is costly and laborious as it requires several remobilizations to complete construction.

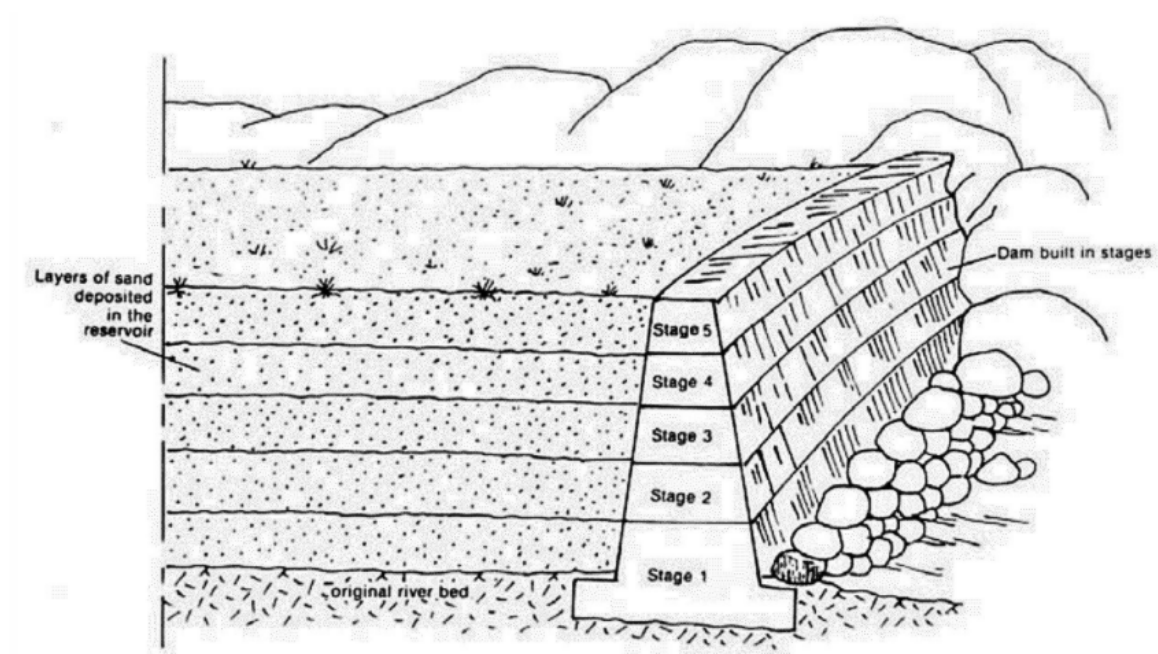

Figure 3. A Sand Dam Constructed in Stages

A NEW APPROACH

We present a new approach to the siltation problem by seeking an ideal shape (weir) cut in the face of a sand dam designed to provide shear forces such that coarse particles accumulate while finer materials such as silt and clay are washed away.

Research Question: Could building sand dams with strategically designed weirs result in favorable sedimentation and reduce the failure rate of sand dams while reducing costs relative to staged-construction?

Hypothesis: There is a weir shape that will result in desirable sedimentation in a sand dam's backwater. Constructing sand dams with strategically shaped weirs, and filling in the apertures as the second and final step of construction, can prevent failure from siltaiton at a lower cost compared to building dams in stages.

METHODS

Theoretical Approach

We assess the relationship between different weir shapes and backwater sedimentation by calculating the rouse number for particles as they travel through the backwater. The Rouse number, R, represents the ratio between forces acting to make a particle settle out and those acting to mobilize it.

$$R_{particle} = F_{settle}/F_{mobilize} = \omega/(k * u*)$$

ω=particle's fall velocity, k=von-karman constant, u*=shear velocity

The Rouse number is proportional to the inverse of the square root of bed shear stress.

$$R_{particle} \;\; \alpha \;\; 1/\sqrt{\tau}_{bed}$$

The Rouse Number can provide an approximate indication of mode of transport (Whipple, 2004):

Rouse #	Mode of Transport
0 - 0.8	Wash Load
0.8 - 2.5	Suspended Load
2.5 - 7.5	Bed Load
> 7.5	At Rest

Assumptions

- Particles within the bedload ($R \geq 2.5$) will be trapped by the dam, and those in the suspended and wash loads ($R \leq 2.5$) will not.
- An ideal weir shape will prevent particles smaller than 0.125mm in diameter from being trapped by the dam.

Thus, an ideal weir shape will maintain $R \leq 2.5$ for 0.125mm-diameter particles throughout their residence in the backwater.

Numerical Approach

HEC-RAS 5.0 River Analysis System software was used to evaluate the impacts of weir shapes on particle Rouse numbers in sand dam backwaters. Stream bed geometry was based on field data collected from a sand dam site in Kenya (Viducich, 2015).

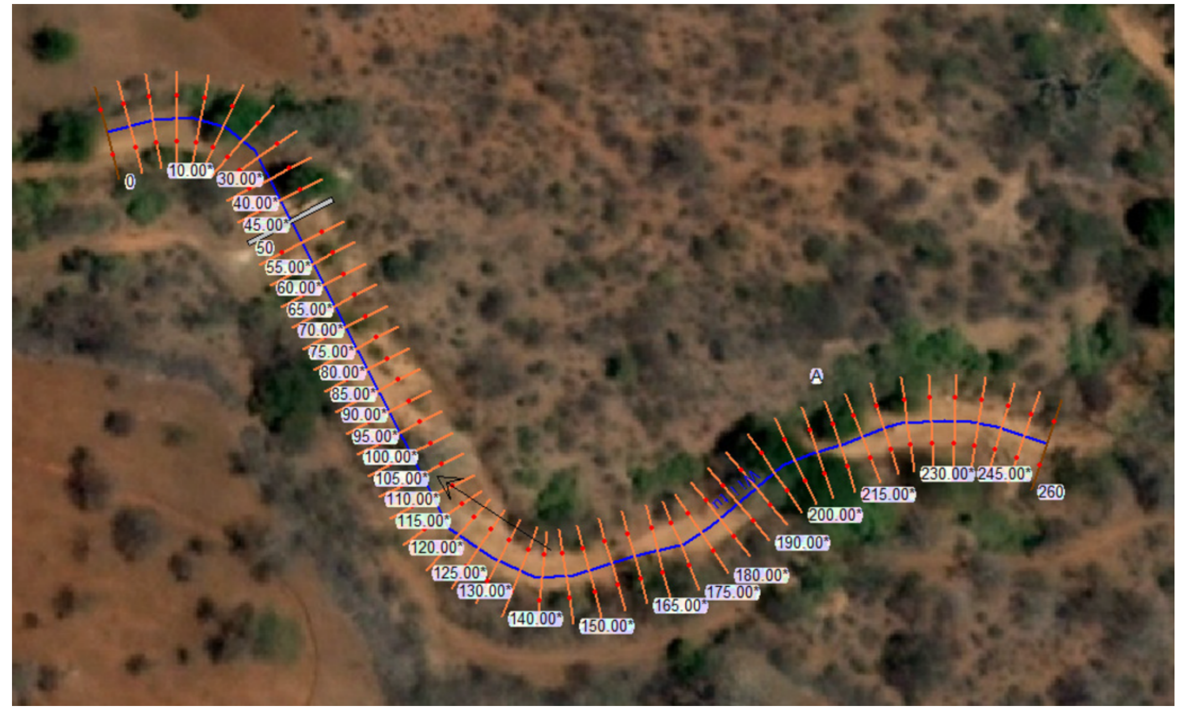

Figure 4. HEC-RAS Reach Geometry - Sand Dam Site in Kenya (Viducich, 2015)

Model Setup

A hydrograph was simulated with flow linearly increasing from 0 to 30 cubic meters per second over a period of ten days to assess sedimentation over a wide range of flows.

The model was run with four different weir shapes:

1. Rectangular
2. 60° V-notch
3. $x=y^2$
4. $x=0.3y^2$

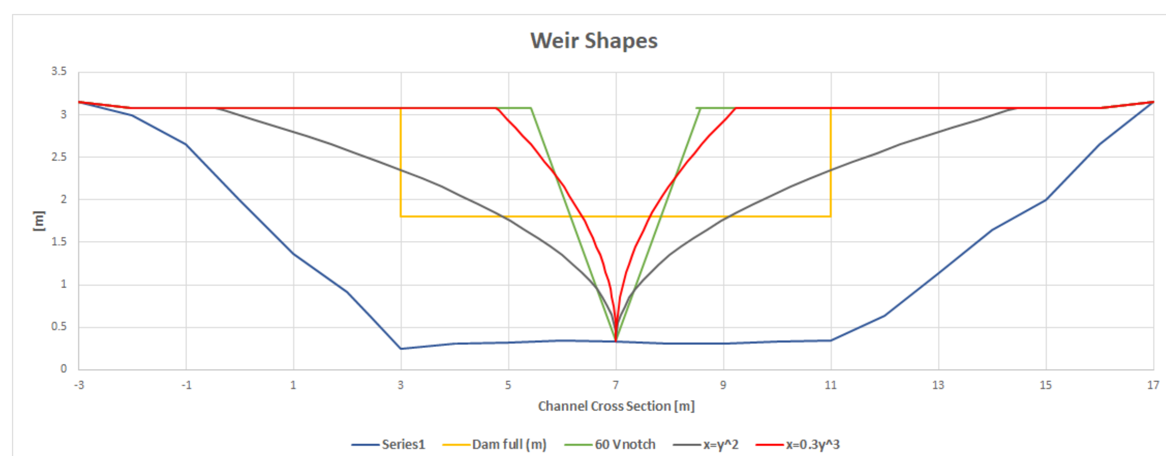

Figure 5. Cross Sections of Modelled Dams

Process

- Bed shear stress was calculated from unsteady flow data generated by HEC-RAS.
- Rouse numbers were then calculated for different particle sizes at each cross section.

Limitations

- As sediments accumulate in a sand dam's backwater, the elevation of the channel bottom increases. Our current HEC-RAS simulations do not take this changing geometry into account. Streambed geometry is set as it would be before any deposition occurs and is static throughout the simulation.

- Channel shear stress is calculated as the average accross the width of the channel.

PRELIMINARY RESULTS

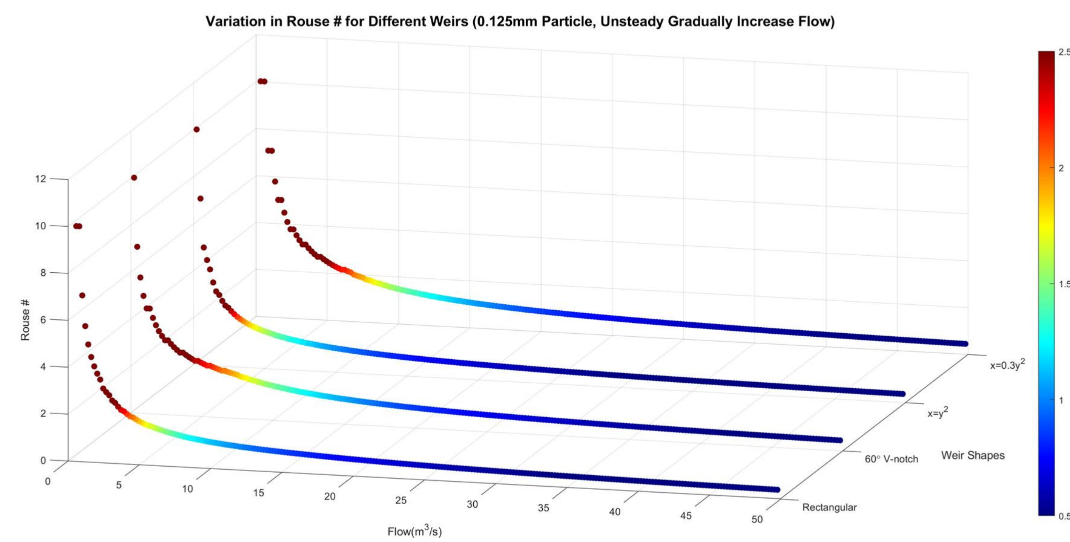

Figure 6. Rouse Numbers 10 meters Upstream of Weir for .125mm Particles

These preliminary results demonstrate an important relationship between weir shape and rouse number. At flow rates under 15 m^3/s, the $x=0.3y^2$ weir generates higher rouse numbers than the other weirs. This is because near the bottom of the channel, the $x=0.3y^2$ weir is quite narrow, limiting the area through which water can flow. This causes flow to become deeper and slower, decreasing the bed shear stress and increasing the rouse number.

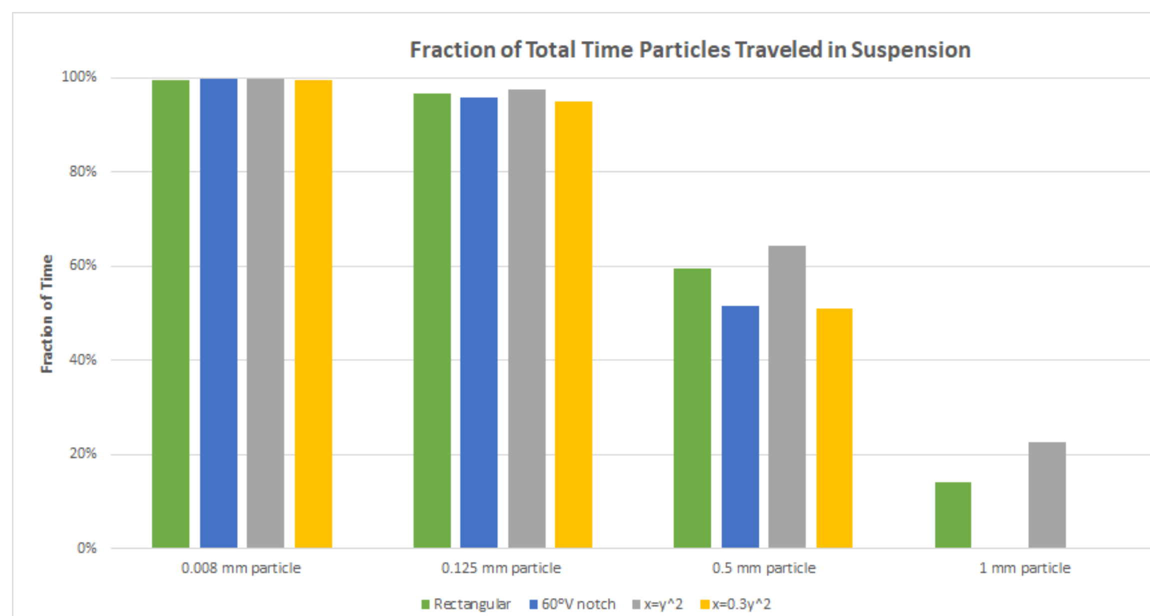

Figure 7. Time Fraction Results

This chart depicts the fraction of time that different sized particles are kept in suspension ($R \leq 2.5$) as they travel through the backwater (low percentages indicate that a particle is more likely to be deposited). The $x=y^2$ weir has the highest percentages because it has the largest area through which water can flow, resulting in shallower, faster flows with higher bed shear stress and lower rouse numbers.

FUTURE WORK

Physical Modeling

Experiments will be conducted on a scaled physical model of a sand dam. Appropriate scaling will require a vertical exaggeration of the model and use of a sediment media less dense than sand. We will use media color-coded by grain size so that sedimentation patterns will be shown visibly. Experiments will be run with different weir shapes and sizes to assess how they effect sediment deposition. Experimental and numerical results will be compared for consitency.

Suggestions?

We'd love to hear from you! Send us a message with the contact the author button below.

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ABSTRACT

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Figures:

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