# Hydraulic Consequences of Invasive *Hydrilla* (submerged aquatic vegetation) in Tidal Channels: Implications for Wetland Maintenance

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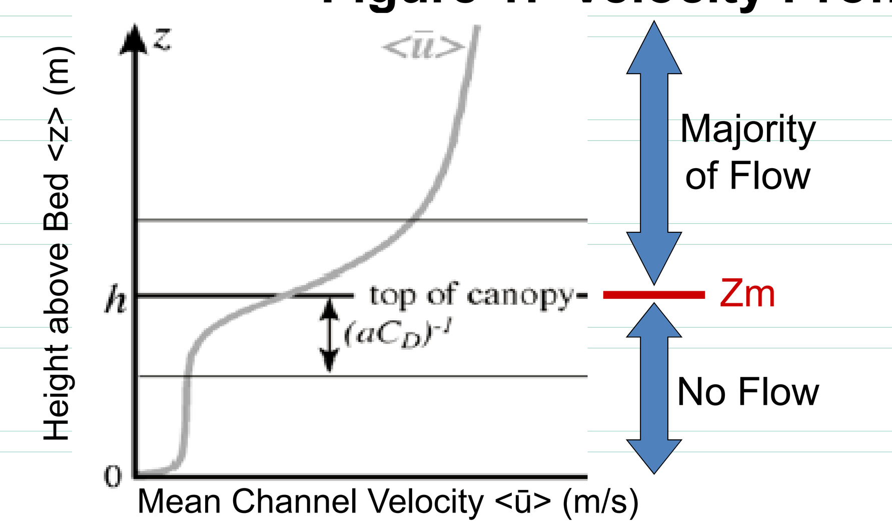
## I. Problem

Submerged aquatic vegetation (SAV) grows in tidal channels and shallow regions of the Chesapeake Bay. SAV showed widespread decline due to high suspended sediment loads, but it has been recovering in the Bay since the 1980's. SAV recovery includes invasive species such as *Hydrilla,* which can form dense mats in shallow channels. SAV can affect the flow structure in channels. The effect of *Hydrilla* on flow resistance, velocity and sediment fluxes within tidal marshes has not yet been researched.

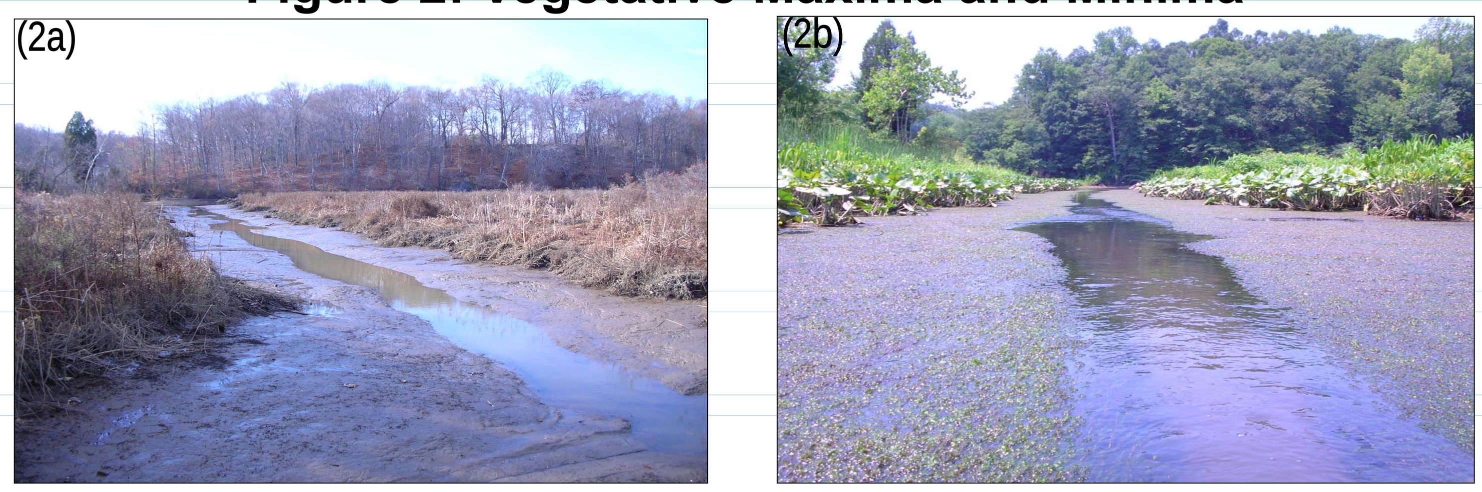
### Figure 1: Velocity Profile with SAV




Velocity distribution with a vegetative layer of height h, where h is equivalent to Zm. The thickness of the deflected vegetation canopy is $(aC_D)^{-1}$. For this study, a no flow region is assumed to exist below the top of the canopy. This simplifying assumption allows our study to move from the laboratory flume to the field.

From this diagram, flow resistance is calculated using modified shear velocity so that $u^{*\prime} = [gS(H - Zm)]^{1/2}$, where g is the acceleration due to gravity, S is the energy gradient, and H is the water depth. (Nepf and Ghisalberti, 2008)

### Figure 2: Vegetative Maxima and Minima




(2a) Channel pictured to the right shows no vegetation in the channel during late fall. This picture was taken during low tide.

(2b) The photo to the left was taken during maximum vegetation. This photo shows the *Hydrilla*-choked channel during ebbing tide.

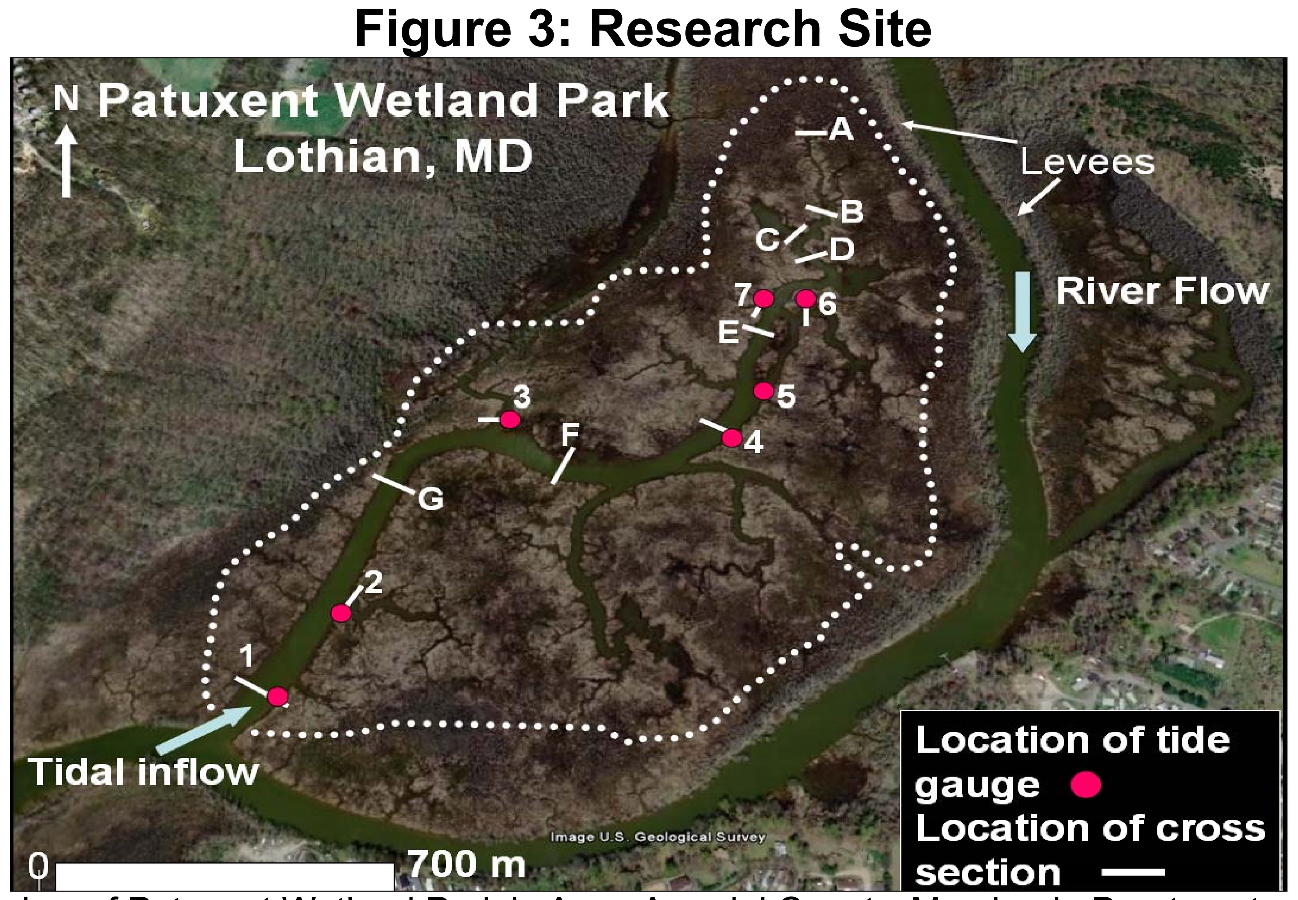
## II. Hypotheses

i) At maximum growth heights, *Hydrilla* growing on the channel bed will significantly increase flow resistance and thus reduce tidal channel velocities in Patuxent river marshes.

ii) The hydraulic consequences of flow resistance caused by *Hydrilla* can be observed in both the at-a-station and downstream hydraulic geometry equations. The equations for velocity, during maximum *Hydrilla* growth, will be significantly different from both theoretical values and measurements from other tidal systems.

iii) The hydraulic consequences of *Hydrilla* on channel velocities will decrease travel distances (length= velocity*tidal half-period). As a result, for most tidal cycle conditions, travel distances for water and sediment will be significantly less than the total length of the channel network.

### Figure 3: Research Site

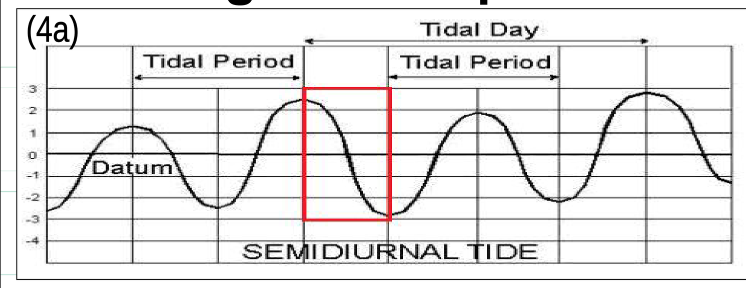



Aerial view of Patuxent Wetland Park in Anne Arundel County, Maryland. Due to natural river levees, river flow only enters the research site through the mouth inlet (Site #1), therefore, flow into the marsh system will be constrained by the inlet characteristics. (March 2007 image by USGS, accessed through Google Earth)

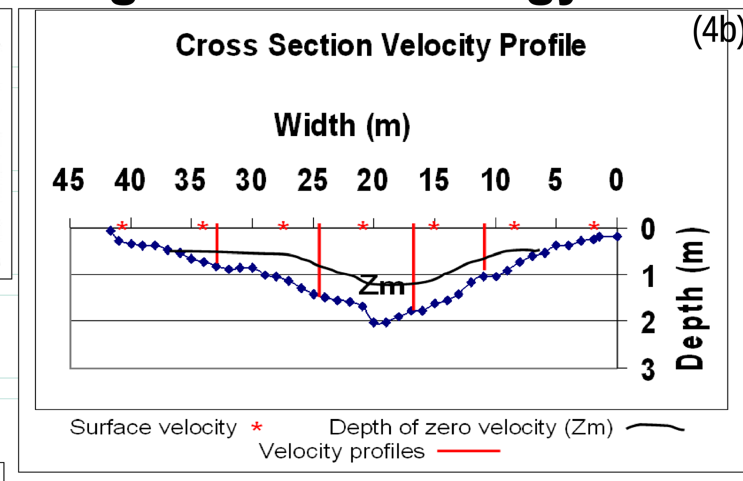
## III. Research Design

Field experiments are conducted during a half-tidal period (high to low tide). Equipment is set up prior to high tide so that gauge height can be established at slack tide, when the water surface is horizontal. The outgoing tide flows as a gravity wave with a measurable water surface gradient. Mean cross sectional velocity is determined from vertical velocity profiles. Maximum surface velocities are measured and used to calculate the proportional constant (ϕ) between maximum velocity and mean channel velocity (Chen and Chiu, 2002).

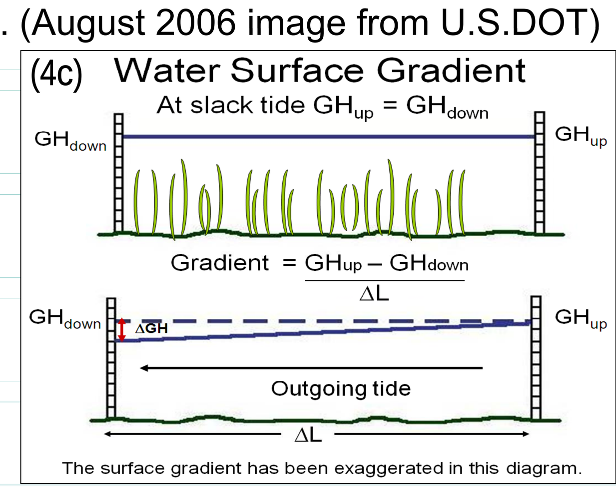
### Figure 4: Experiment Timing and Methodology




(4a) Semi-diurnal tide regime, experiments are measured on outgoing tide (red box). The y-axis is height above or below the datum. (August 2006 image from U.S.DOT)



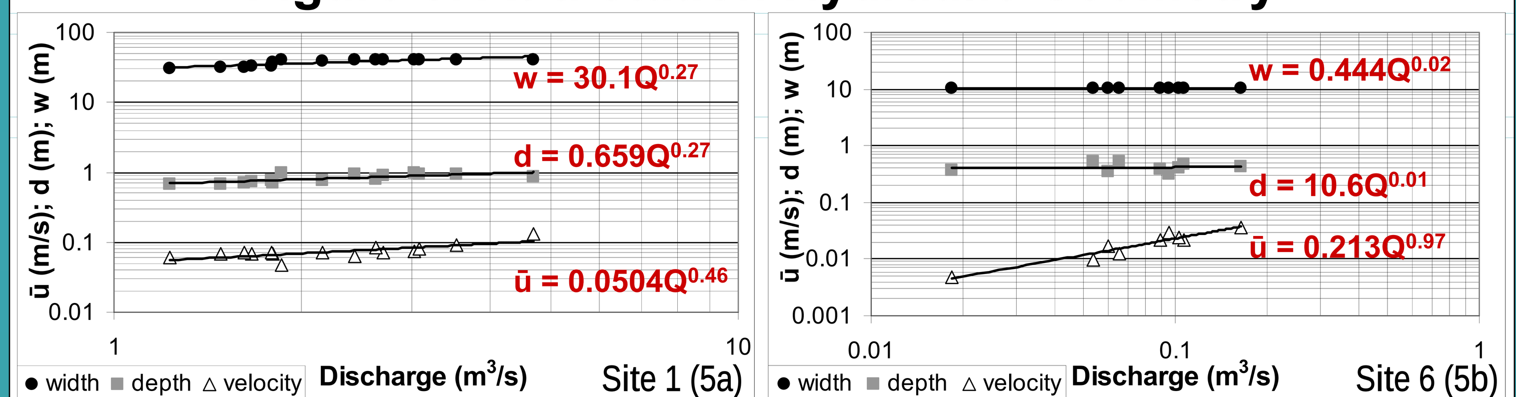

(4b) Cross section at channel mouth indicating where velocity measurements are taken.



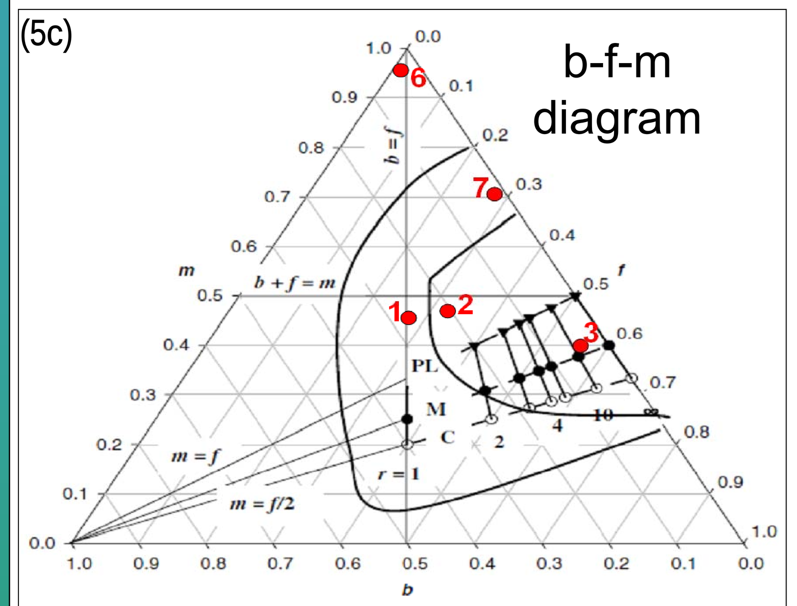

(4c) Schematic diagram illustrating how water surface (energy) gradient is measured and calculated.

## IV. Results

### Figure 5: At-a-station Hydraulic Geometry




(5a) Site 1 is closest to the marsh inlet. (5b) Site 6 is beyond the mid-point of the network length. Notice the two-fold increase in the velocity exponent upstream.

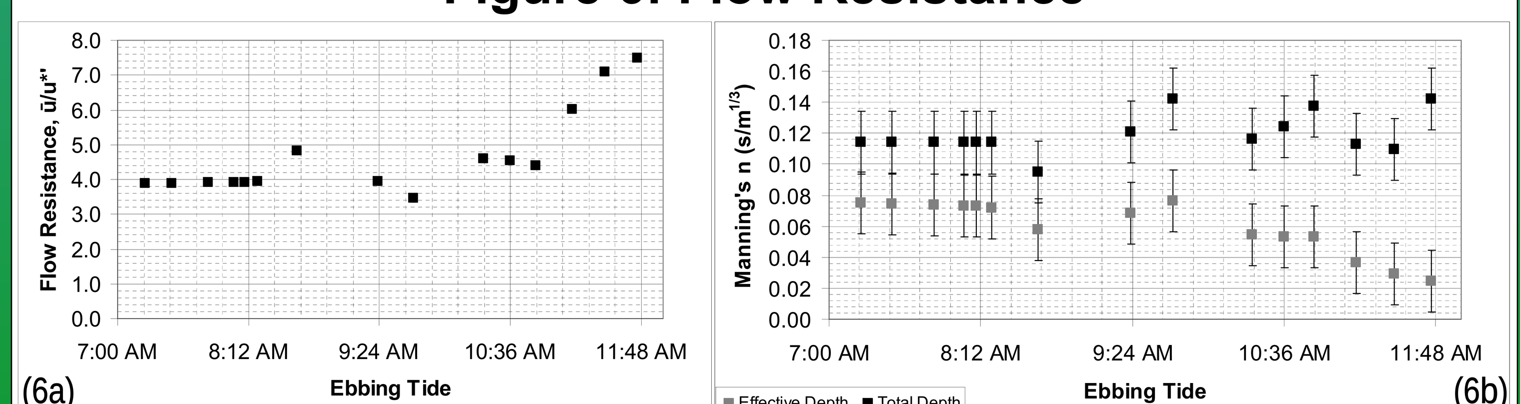



(5c) Inner semi-circle shows the highest concentration of terrestrial hydraulic exponent plots, whereas the outer semi-circle contains almost all exponents reported by Rhodes (1977).

**At-a-station Hydraulic Geometry**

| Site # | 1 | 2 | 3 | 6 | 7 |
|---|---|---|---|---|---|
| Distance upstream (m) | **59** | **236** | **557** | **1097** | **1097** |
| Exponent b (width) | 0.27 | 0.20 | 0.04 | 0.02 | 0.01 |
| Exponent f (depth) | 0.27 | 0.32 | 0.56 | 0.01 | 0.29 |
| Exponent m (velocity) | 0.46 | 0.48 | 0.40 | 0.97 | 0.70 |
| Coefficient a (width) | 30.1 | 17.4 | 15.0 | 0.44 | 6.64 |
| Coefficient c (depth) | 0.66 | 0.50 | 0.54 | 10.6 | 0.51 |
| Coefficient k (velocity) | 0.050 | 0.12 | 0.12 | 0.21 | 0.30 |
| Shape factor (f/b) | 1.0 | 1.6 | 14 | 0.5 | 29 |
| b + f + m | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| a*c*k | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |

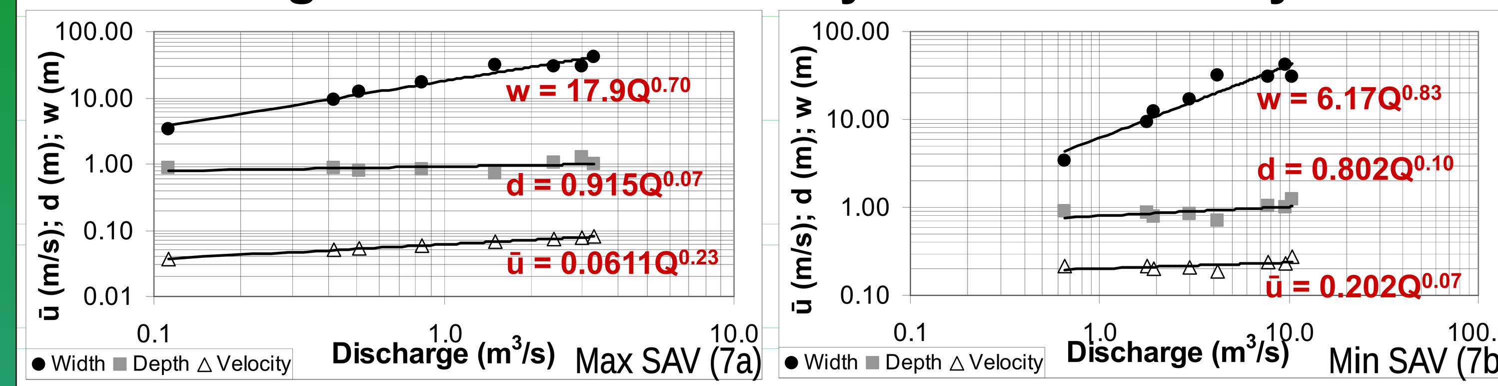
### Figure 6: Flow Resistance




(6a) Dimensionless flow resistance indicates a smoothing of the channel with ebbing tide. (6b) Manning's roughness coefficient, using effective depth (H - Zm), shows a smoother channel as the tide ebbs. Field observations indicate that vegetation flattens with outgoing tide, which leads to lower flow resistance over time (consistent with vegetative roughness calculations).

## IV. Results Continued

### Figure 7: Downstream Hydraulic Geometry




(7a) Downstream hydraulic geometry during maximum vegetation. (7b) The downstream hydraulic geometry under minimum vegetative conditions was estimated by constraining velocity with the lowest Manning n measured during vegetated conditions. At the measured SAV maxima, the velocity decreases upstream, indicating high flow resistance and a reduction of mean channel velocity as a result of the submerged aquatic vegetation.

**Downstream Hydraulic Geometry**

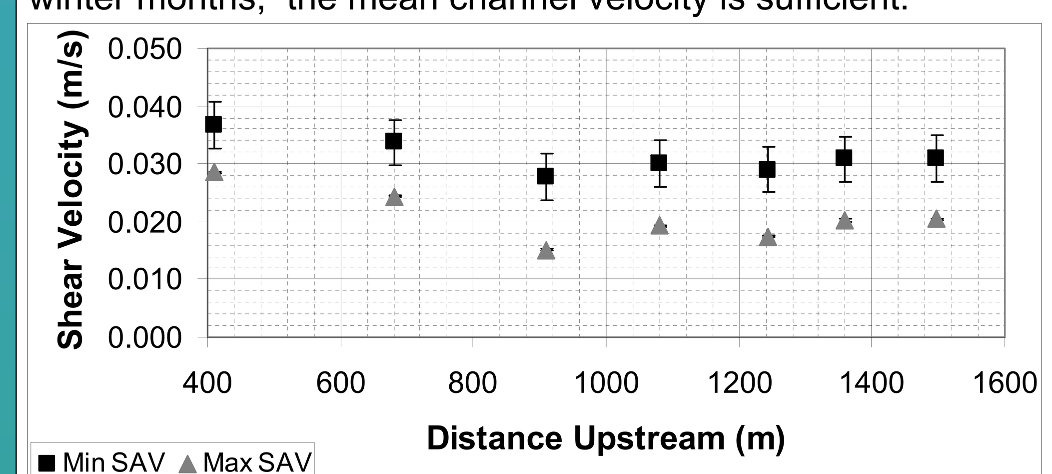
| Hydraulic Exponent | | Patuxent Marsh Max SAV (this study) | Patuxent Marsh Min SAV (this study) | Wrecked Recorder Creek[1] | Barnstable Marsh[1] | Langbein's Theoretical[2] | Langbein's Unnamed Estuary[2] |
|---|---|---|---|---|---|---|---|
| width | b | 0.70 | 0.83 | 0.77 | 0.74 | 0.72 | 0.72 |
| depth | f | 0.07 | 0.10 | 0.23 | 0.17 | 0.23 | 0.22 |
| velocity | m | 0.23 | 0.07 | 0.00 | 0.09 | 0.05 | 0.06 |
| slope | z | -0.035 | -0.05 | | | -0.12 | -0.10 to -0.17 |

([1]Myrick and Leopold, 1963; [2]Langbein, 1963)

The Wrecked Recorder Creek, Barnstable Marsh, and Unnamed Estuary studies were conducted in tidal systems that contained little to no submerged aquatic vegetation. All of the studies in the table show that width changes the most downstream. In addition, with the exception of this study (at maximum vegetation), all studies show that velocity changes the least downstream The dramatic increase in the velocity exponent under vegetated conditions indicates high flow resistance.

### Figure 8: Sediment Transport Implications

The total length of the network is ~1570 m. During vegetative maxima, the bankfull mean channel velocity at the network inlet is not sufficient to carry water from the mouth to the head of the marsh during an average tidal half-period. During long tidal half-periods and winter months, the mean channel velocity is sufficient.




(8) Shear velocity, u*, is calculated from hydraulic data. Suspension of particles can be estimated from the ratio of particle fall velocities to the shear velocity (Rouse Equation) During vegetative maxima, overbank deposits in the downstream region will consist of only clay and silt.

## V. Conclusions

i) The proportion of *Hydrilla* in a cross section increases upstream; this affects the at-a-station and downstream hydraulic geometries. At-a-station velocity exponents increase upstream indicating a rapid change in velocity as the tide drains and water levels drop to the height of the *Hydrilla*.

ii) Tidal systems are designed by nature to have exponentially decreasing width upstream, therefore forcing the velocity to remain constant upstream. During vegetative maxima this phenomena is not observed. In fact, velocity and therefore discharge decreases upstream suggesting an imbalance between flow resistance and morphology.

iii) Mean channel velocities limit transport distances of water and sediment into the marsh. Transport distances are less than the total channel length during vegetated conditions.

iv) With aquatic vegetation, shear velocities can only convey silt and clay into the mouth and only clay into the upper marsh. Under minimum vegetative conditions, shear velocities can transport some sand into the mouth.

v) The lack of upstream sediment deposition will make it difficult for the upper reaches of the network to keep pace with sea level rise. This deterioration has been observed in interior tidal network marshes.

## VI. References

Chen, Yen-Chang and Chiu, Chao-Lin, 2002, An efficient method of discharge measurement in tidal streams: Journal of Hydrology, v., p. 212-224.

Langbein W.B., 1963, The hydraulic geometry of a shallow estuary. Bulletin of the International Association of Scientific Hydrology, v. 8, p. 814-94.

Myrick, R.M. and Leopold, L.B., 1963, Hydraulic Geometry of a Small Tidal Estuary, U.S. Geological Survey Professional Paper 422-B, 18 p.

Nepf, H. and Ghisalberti, M., 2008, Flow transport in channels with submerged vegetation: Acta Geophysica, v. 56, p. 753-777.