Velocity Profiles through Emergent Reed Canary Grass (*Phalaris arundinacea*)

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Abstract

*Reed canary grass (*Phalaris arunduinacea*) is a widespread invasive species that lives in both wet and dry environments, including streams and river beds. Previous research has focused on removal methods (Apfelbaum, 1987) and computer modeling the effect of reed canary grass on geomorphology in comparison to native species (Martinez, 2013). This study presents an experimental analysis of how a patch of reed canary grass affects velocity distributions at two separate water depths. A natural surrogate in an artificial channel is used to model reed canary grass and acoustic Doppler velocimeters were used to measure velocities around the patch. This study finds that: (1) a wake zone in which velocities are significantly decreased forms for at least 90 cm behind the patch; (2) velocities increase significantly around the edges of a patch; and (3) in the absence of roots or dead underbrush near-bed velocities are increased. The study also demonstrates that reed canary grass affects water velocities independently of water depth. These results suggest that further research should be directed in two areas: (1) flume studies of sedimentation; and (2) understanding how the near-bed structure of reed canary grass affects velocities.*

I. Introduction

Reed canary grass (*Phalaris arundinacea*) is one of fifteen species in the *Phalaris* genus, which is present on every continent, excluding Antartica and the island Greenland (Apfelbaum, 1987). Originally native to North America, through cultivation for forage and silage reed canary grass has spread far beyond its initial range (Apfelbaum, 1987). Known to inhabit wet and dry environments it is now found in a variety of wetland and stream conditions, in which it forms thick rhizomatic patches displacing native species and changing the geomorphological structures of the environment (Apfelbaum, 1987) (Martinez, 2013). Many attempts have been made to control or remove reed canary grass (Apfelbaum, 1987); however, their failure has led others to attempt to better understand the geomorphological effects of reed canary grass (Martinez, 2013). This study hopes to contribute to an understanding of the hydraulics around reed canary grass by modeling patch of vegetation at two different water depths.

Reed canary grass is both a uniquely hardy and a uniquely variable plant (Apfelbaum, 1987) (Martinez, 2013). Spreading radially outwards it is often observed to form monocultural patches (Apfelbaum, 1987). Its hardiness has led to many traditional chemical and physical removal efforts to fail (Martinez, 2013). The ease by which it spreads (by seeds, roots, and clippings) also causes difficulty with removal projects (Wisconsin Reed Canary Grass Management Working Group, 2009). This is coupled with a high phenotypic variability, which is observed independently of environmental conditions—height, stem size, blade size, and patch size all vary greatly under the same environmental conditions (Apfelbaum, 1987). Important to this study is the added fact that reed canary grass possesses anoxia tolerant rhizomes, allowing it to survive periods of submersion longer than most other grasses (Apfelbaum, 1987).

In stream environments, reed canary grass affects three main geomorphological processes: (1) bank stability; (2) water velocities and sediment deposition; and (3) channel morphology (Martinez, 2013). Previous studies have mainly examined how reed canary grass on banks and channel sides have affected the above three processes (Martinez, 2013). This study focusses on the second of these processes by modeling a patch which has broken off the stream bank and settled into place downstream in the middle of the stream. By collecting velocity profiles at two different water depths we hope to gain a better understanding of the water velocities at play around reed canary grass.

II. Methods

As an invasive species, reed canary grass could not be used in any artificial channel that is drained into a sewage system. In order to replicate the hydraulic effects of reed canary grass, a similar surrogate was needed. In choosing a surrogate, it was decided the two most important aspects to maintain were the frontal area of the plant and the flexibility. It was also desired to be as close to reed canary grass morphology as possible and for the surrogate to be usable in a variety of conditions and flume sizes. Frostick, et al., 2014 served as a basis for much of the surrogate selection process, including the scaling procedure.

In modeling reed canary grass it was desired to be as close to the morphological and physical characteristics of the plant. Within these, it was determined most important to replicate the frontal areas and flexibility of the plant. Reed canary grass is much less flexible than other native grasses (Martinez, 2013) and flexibility is known to have an an important effect on hydraulics even if it is infrequently modeled (Frostick, et al., 2014).

Reed Canary Grass Measurements

Morphological and physical measurements were collected at a site on Lookout Creek in the HJ Andrews Experimental Forest. Two types of data were collected, morphological data and flexibility data.

Figure 1: *The left bank of Lookout Creek at the location where measurements were collected (Brian Draeger).*

The Lookout Creek location sampled is located directly upstream of the point at which Lookout Creek flows into the Blue River Reservoir off of Nation Forest Road 15. There were two large patches of reed canary grass located on either side of the bank on a ledge about five feet above the water level. At higher water levels, the grass would have been directly alongside the bank; however, measurements were taken during a drought year so the stream and reservoir were much lower than normal. This may have also affected both the quantity of plants and physical properties measured.

Figure 2: *The right bank of Lookout Creek at the location where measurements were collected (Brian Draeger).*

A total of eight 70 cm by 70 cm plots, with four on either side of the stream, were selected in an effort to represent the total variability

Morphological Parameter	Mean
Number of Plants per 4 ft ^{2}	93.3
Height (cm)	106.8
Diameter at 20% of height (cm)	0.29
Diameter at 80% of height (cm)	0.23
Width of blades (cm)	1.26
Length of blades (cm)	23.42
Number of blades per plant	6

Table 1: *Morphological Characteristics of Reed Canary Grass. The table records means of all the observed features.*

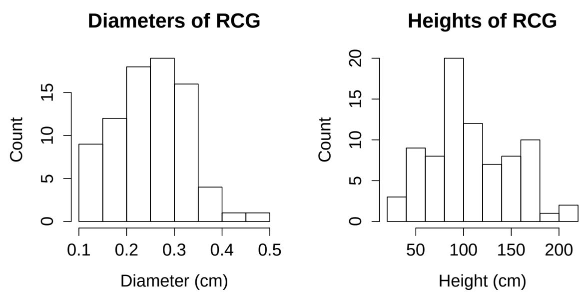

Figure 3: *Morphological Characteristics of Reed Canary Grass. The table records means of all the observed features. The first histogram contains data on the distribution of diameters and the second histogram contains data on the distribution of heights.*

within patches. The total number of plants in each plot were counted, and then 20 plants of varying heights were selected. On these plants, the height was measured, followed by the diameter at both 20% of the total height and 80% of the total height. The blades were then removed from the plants and counted. The blade with median size (determined by sight) was selected and its length and width were measured. (Elliot, personal communication, 2015)

Returning to the same locations where the morphological data was collected, an additional six 70 cm by 70 cm plots were selected. Within these plots, ten plants were chosen of average heights, as determined by sight. The plants were then brought out of the field for the flexibility measurements. Each individual plant was placed flat on a table with the bottom fixed to the table by hand. A load cell was then attached approximately half way up the height of the plant and pulled horizontally a distance that caused the plant to flex, but not break. Both the force and displacement were recorded. For each plant these measurements were collected four times; the plant being rotated between each measurement. These measurements were then used to calculate the bending stiffness of the plant, as well as the flexural rigidity and elastic modulus (Wilson, 2003). These are given by the following equations, where F=Force, w=deflection, I=Mass Moment of Inertia, d=diameter, L=the distance from end of the plant to the load cell.

$$\text{Bending Stiffness} = \frac{F}{w}$$

$$\text{Flexural Rigidity} = J = \frac{F}{w}\frac{L^3}{3}$$

$$\text{Elastic Modulus} = \frac{J}{I} = \frac{F}{w}\frac{L^3}{3}\frac{1}{I} = \frac{F}{w}\frac{L^3}{3}\frac{64}{\pi d^4}$$

In addition to the above measurements, frontal area measurements were also collected on 70 cm by 70 cm plots. Five plots at Lookout Creek were selected and a (off)-white sheet was placed behind the plots. Pictures were then taken from the front of the plot. A MAT-

Elasticity Parameter	Mean
Bending Stiffness (N/m)	0.535
Flexural Rigidity (N/m^2)	0.0302
Modulus of Elasticity (GPa)	5.812

Table 2: *Elasticity Characteristics of Reed Canary Grass. The table contains means for the three flexibility parameters, as calculated from Wilson.*

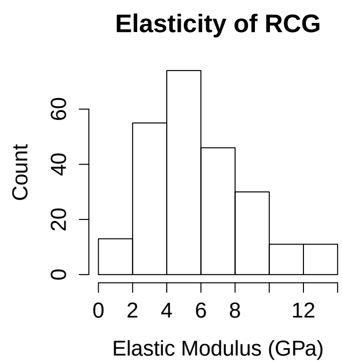

Figure 4: *Elasticity Characteristics of Reed Canary Grass. The histogram contains data on the distribution of Elastic Modulus—the distributions for the other parameters were similar.*

LAB code was written to isolate the pixels with the highest red and blue values in the RGB color space. It was assumed that pixels with the highest red and blue values would be the white sheet and those with lower red and blue values would be the green grass. Green was not used for this isolation, as the grass and white sheet had near equal green values in the RGB color space. Thresholding for the red and blue values was determined on a case by case basis for red and blue separately by sight. This gave a frontal area of approximately 65%-80%, with an average of 72%.

Modeling the Vegetation

Both artificial materials and plants were selected for testing. The diameters of these materials were measured and recorded. Flexibility measurements, as above, were also measured. For manufactured materials, either only one sample was measured or properties were sourced from the Internet, but for plants 2-5 specimens were measured. The diameters of the materials were then used to determine a scaling factor for use in Froude scaling as described in Frostick, et al., 2014. Using the scaling factor, the elastic modulus, flexural rigidity, and bending stiffness of the materials were compared to the 5-95% intervals found for the reed canary grass. It was also determined if the height would be appropriate for use in flumes of both small and large size.

The top seven candidate surrogates were selected and judged by how well they satisfied a criteria (Table 3). The best candidates are acrylic rods and either the Shenandoah switch grass (*Panicum virgatum* 'Shenandoah') or Overdam Grass (*Calamagrostis x acutiflora* 'Overdam'). In order to maintain greater morphological similarity, the Shenandoah switch grass was chosen over the acrylic rod as the surrogate. Because of the wide variation found in both reed canary grass and Shenandoah switch grass, the scaling factor for the Shenandoah switch grass was assumed to be 1 for the purposes of this experiment.

Material	d_m (cm)	Scaling factor x	Flexural Rigidity (Y or N)	Elastic Modulus (Y or N)	Bending Stiffness (Y or N)	Approximate Cost	Height (on a scale of 1 to 4)	Available from:
Acrylic Rod (extruded)	0.159	1.64	Y	Y	N/A	~$0.47/6ft rod	4	Online: eplastics
Steel Cable	0.155	1.68	Y	Y	Y	$0.26/ft	2	Home Depot
Broom Bristle Grey	0.09	3.07	Y	N	N	~$12/broom	1	Home Depot
Broom Bristle Red	0.12	2.14	Y	Y	N	~$12/broom	1	Home Depot
Nylon 6	0.238	1.1	N	Y	N/A	$0.27/ft	3	Online: Port Plastics
She. / Over Poaceae	0.19-0.25	1.1-1.4	Y	Y	Y	~$12-$18/gal. pot	3	Nurseries near Corvallis, OR
N. Sea Oats	0.17-0.22	1.2-1.6	Y	N	N	~$12-$18/gal. pot	3	Nurseries near Corvallis, OR

Table 3: *Summary of Material Criteria Satisfaction. It was observed whether the material fell within the appropriate range for each flexibility parameter ('Y' for falling in the range, 'N' for falling outside of it). For height, the material was ranked on a scale of 1 to 4 on how well it could be implemented in a wide range of flume sizes, based predominantly on the height of the flume/height of the material. For example, the broom bristles, being very short, would only work in a small flume, and thus receive a 1. Since the acrylic rods can be ordered at any length (up to 6ft long), they could work in any flume, and thus receive a 4. Costs from the suppliers listed are approximate and do not include shipping and handling.*

Flume Set Up

All measurements were collected within a B-12 Hydraulic Demonstration Channel (manufactured by Engineering Laboratory Design, Inc.) located in the Merryfield Hall of Oregon State University, henceforth referred to as the "Merryfield Flume". The channel was a total of 335.8 cm (11 ft.) long, 30.48 cm (1ft.) across, and 43.54 cm tall. About the last 30 cm of the flume was located behind the tail weir and the first foot was ahead of the head gate. The water, therefore, flowed in about a 274 cm long channel.

Water depths were controlled using the tail weir, and two depths were selected. One depth with the tail weir fully upright, but not all the way extended, which led to a water depth of approximately 21 cm; this was the water depth used in "Lower Depth Trial". The second water height had the tail weir again fully upright, but this time the weir was fully extended leading to a a water height of approximately 38 cm; this was the water depth used in "Higher Depth Trial".

Plant Installation

The bottom of the flume was lined with a sheet of pink rigid foam insulation, which was 2.54 cm tall (held down by screws and shims). Plant stems were then inserted into this foam. The foam held the stems in place and did not allow them to move or bend until exiting the foam. Plants were removed and reinserted into previously formed holes, without any noticeable difference. The foam began about four inches after the front of the head gate and ended about a foot before the tail weir. The foam could not be installed in the last foot of the flume because of a metal protrusion on the bottom of the flume.

The plant was placed in a 15.24 cm by 15.24 cm patch beginning 152 cm down the flume and ending 167.24 cm down the flume. Plants were originally placed every inch. In order to ensure that this spacing retained the frontal area found for a 70 cm by 70 cm patch of reed canary grass, photos were taken of the patch and the frontal area was calculated using the same methods as above. Stems were then added or removed to attain a frontal area in the desired range (65%-80%), at most this resulted in 1-5 stems being added or subtracted.

Because of the constraints of the height of the flume, the plants were cut into approximately 35 cm lengths (of which about 2.54 cm was inserted into the foam). In cutting the plants into these lengths, variation was allowed to occur to better represent real world conditions.

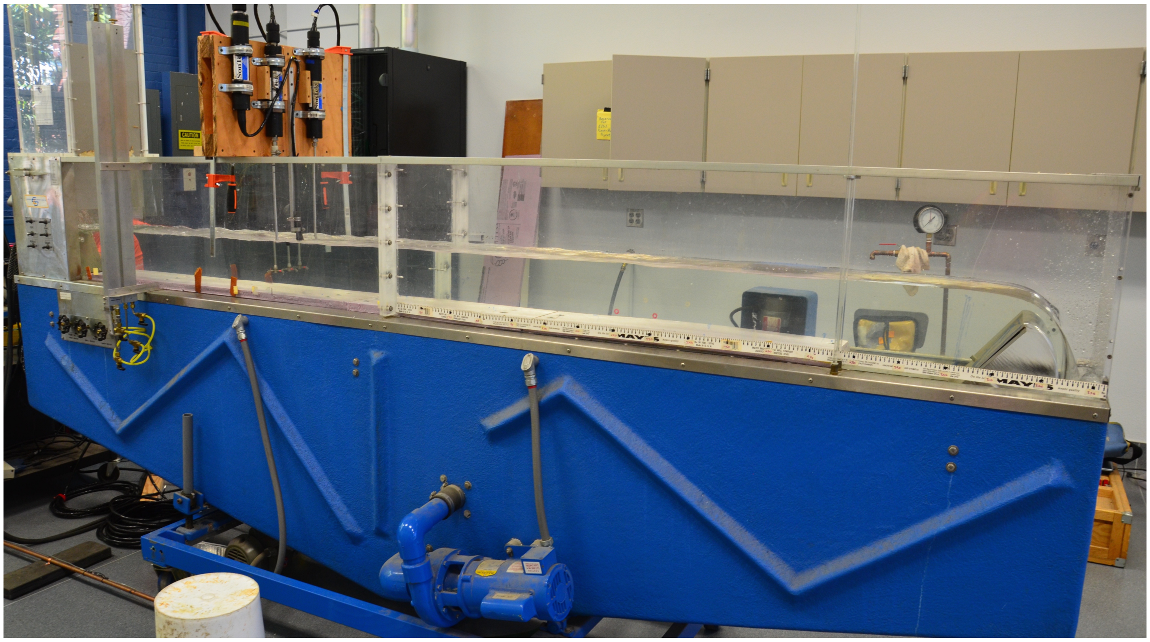

Figure 5: *The Flume (Brian Draeger).*

Fully Developed Flow

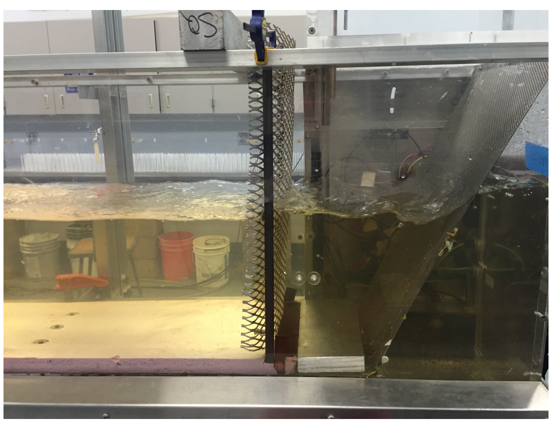

Figure 6: *The diffuser attached to the front of the flume. The window screen was later affixed downstream to the diffuser.*

To determine that fully developed flow occurred within the flume, velocity measurements with both Sontek Acoustic Doppler Velocimeters and Marsh-McBirney Velocimeters were collected along the length of the flume. These measurements showed both that the velocity was higher on the left-hand side of the flume and that the velocities did not reach a logarithmic profile before the patch. This led to the installation of an additional diffuser at the front of the flume, a window screen attached to this diffuser, and a metal block extending the rigid foam installation all the way forward (figure 6). While this solved the discrepancy of speed on each side of the flume, it did not ensure that a logarithmic profile was achieved. However, no further modifications to the flume were made.

Coordinate System

The coordinate system used was defined as follows. Looking down the flume, the origin was set directly on top of the foam, on the left hand side, at the end of the diffuser. The positive x-axis pointed in the direction of flow, the positive z-axis pointed perpendicular to the flume, and the positive y-axis was defined by the right-hand rule (pointing right across the flume).

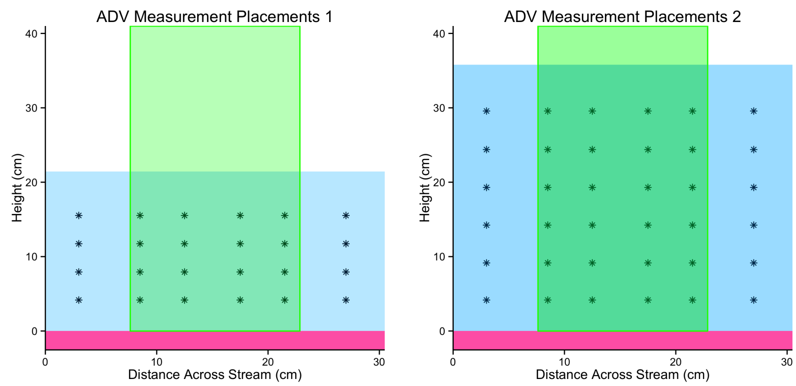

Figure 7: *These figures display the points at which velocity measurements were collected within the flume at each given cross section. The stars are the measurement locations, green denotes the location of the plant within the flume, blue denotes the water height, and pink denotes the rigid foam. Measurement locations are not exact due to the way the flume was mounted, but they should be within approximately ±1mm in all directions. The water depth marked is an average at a variety of positions throughout the flume; in general depth did not change greatly throughout the length of the flume.*

Velocity Measurements

Velocity Sampling Procedure

Velocities were measured at two different depths. One depth of 21.43 cm and another depth of 35.79 cm. The first depth was about half way up the height of the plant and the second depth was near the top of the plant, thought not completely submerged—"Lower Depth Trial" and "Higher Depth Trial" respectively.

For each depth, velocities were measured at five cross sections through the flume. The first cross section was located at 122 cm down the flume, which was determined to be adequately in front of the patch to avoid back watering effects. The second cross section was located at 152.4 cm down the flume, which was directly in front of the patch. The third cross section was located directly behind the patch at either 177.8 cm or 182.88 cm, depending on the the depth. The fourth cross section as located at 228.6 cm down the flume, and the last cross section was collected at 259.08 cm down the flume, which was located ahead of the end of the rigid foam insulation. These cross sections were chosen in order to have: (1) a reference point for velocities; (2) an idea of the back-watering caused by the plant; (3) an idea of the velocities directly behind the plant; and (4) and (5) an idea of the extent of the wake zone.

Velocities were taken at semi-regular spacings through each given cross section (figure 7). This spacing was chosen in order to both capture the velocities along the wall, near the edge of the patch, and in the middle of the patch. When plants were too close to the ADVs, they were manual moved out of the way.

Velocities were measured at 50 Hz for 120s with a downward-looking Sontek Acoustic Doppler Velocimeter that was aligned with the z-axis of the flume. The sampling volume was approximately 0.3cm^3 consisting of a cylinder about 6mm in diameter and 9mm in height and was located about 5 cm from the tip of the probe. The velocity range was set to ±30 cm/s.

Analysis of Velocity Measurements

ADV data was processed using WinADV (Wahl, 2000). WinADV processed the data to remove data with correlation coefficients < 40% and signal-to-noise ratios of < 15. The remaining data was then despiked using the phase-space threshold algorithm (Goring and Nikora, 2002). The data was then time-averaged in WinADV and summary statistics were also produced.

Contour plots and velocity profiles were created to visualize the data. The contour plots were created using the filled.contour command in R (Smith, personal communication, 2015). The velocity profiles were created using the ggplot2 library for R. Contour plots were created for the velocities at each depth. An additional contour plot was created for velocities averaged across all depths. Velocity profiles were created at each cross section with velocities at a given depth averaged across the flume (in the y-direction).

III. Results

Lower Depth Trial

The contour plots show how velocities change in the xy-plane at given depths, as well as an average effect across depths (figure 8). In the average plot (the last graph in figure 8) a wake zone forms behind the patch and the velocity increases along the sides. At the reference cross section 30.48 cm ahead of the patch, the velocity is on average 18.5 cm/s. Behind the patch, in the wake zone, velocities are 4.5 cm/s slower and on the edges, 7 cm/s faster. Moving in the direction of flow, velocities even out, though they remain slower in the center and faster on the sides.

Examining velocity contours by depth gives a modified picture (figure 8). At the lowest depth (4 cm), velocities are much more even throughout the flume. Velocities increase by 5 cm/s along the sides and decrease 2 cm/s in the wake zone. The size of the wake zone is also much smaller at this lowest depth. At the next depth (8 cm), the wake zone is larger and velocity differences are increased. The velocities on the sides are 5 cm/s faster again and in the wake zone are 3 cm/s slower. At the third depth (12 cm), the wake zone enlarges again, and the velocities decrease by 8 cm/s and increase by 7 cm/s. At the last depth (15 cm), the wake zone is of a similar size as the previous depth and the velocity differences are also the same.

The velocity profiles show how the grass effects velocities differently at different depths, similar to the contour plots at the different depths (figure 9). Ahead of the patch, the velocities are essentially vertical. Behind the patch, the velocities are increased at low depths and decreased at high depths. This continues all the way to the end of the flume.

Higher Depth Trial

Again, the contour plots show how velocities change in the xy-plane at given depths, as well as an average picture across depths (figure 10). In the average plot (the last graph in figure 10), a narrow wake zone is present behind the patch, narrowing downstream, and everywhere else velocities are fairly uniform. In the reference cross section, 30.48 cm ahead of the patch, the velocity is an average of 10.67 cm/s. Behind the patch, in the wake zone, velocities are 1.5 cm/s slower and on the edges, 4 cm/s faster. Moving in the direction of flow, the wake zone and velocity differences both shrink, though the wake zone still does not end before the end of measurements.

The velocity contours at individual depths are similar to, though different from the average contour (figure 10). At the lowest depth (4 cm), velocities appear to be entirely even throughout the flume. A wake zone behind the patch does not appear and instead velocities in the cross sections behind the patch are consistently 4 cm/s faster. At the next depth (9 cm), a wake zone does appear with velocities 1 cm/s slower in the wake zone and velocities 6 cm/s faster on the sides. At the next depth (14 cm) the wake zone is significantly larger and the differences much more substantial. In the wake zone, velocities are 2 cm/s slower and on the sides 4 cm/s faster. At the next depth (19 cm), velocities increase by 1 cm/s on the sides and decrease by 1 cm/s in the wake zone. At this depth (19 cm),the wake zone also narrows on one side (the furthest side in the y direction), but widens on the other side. Mov-

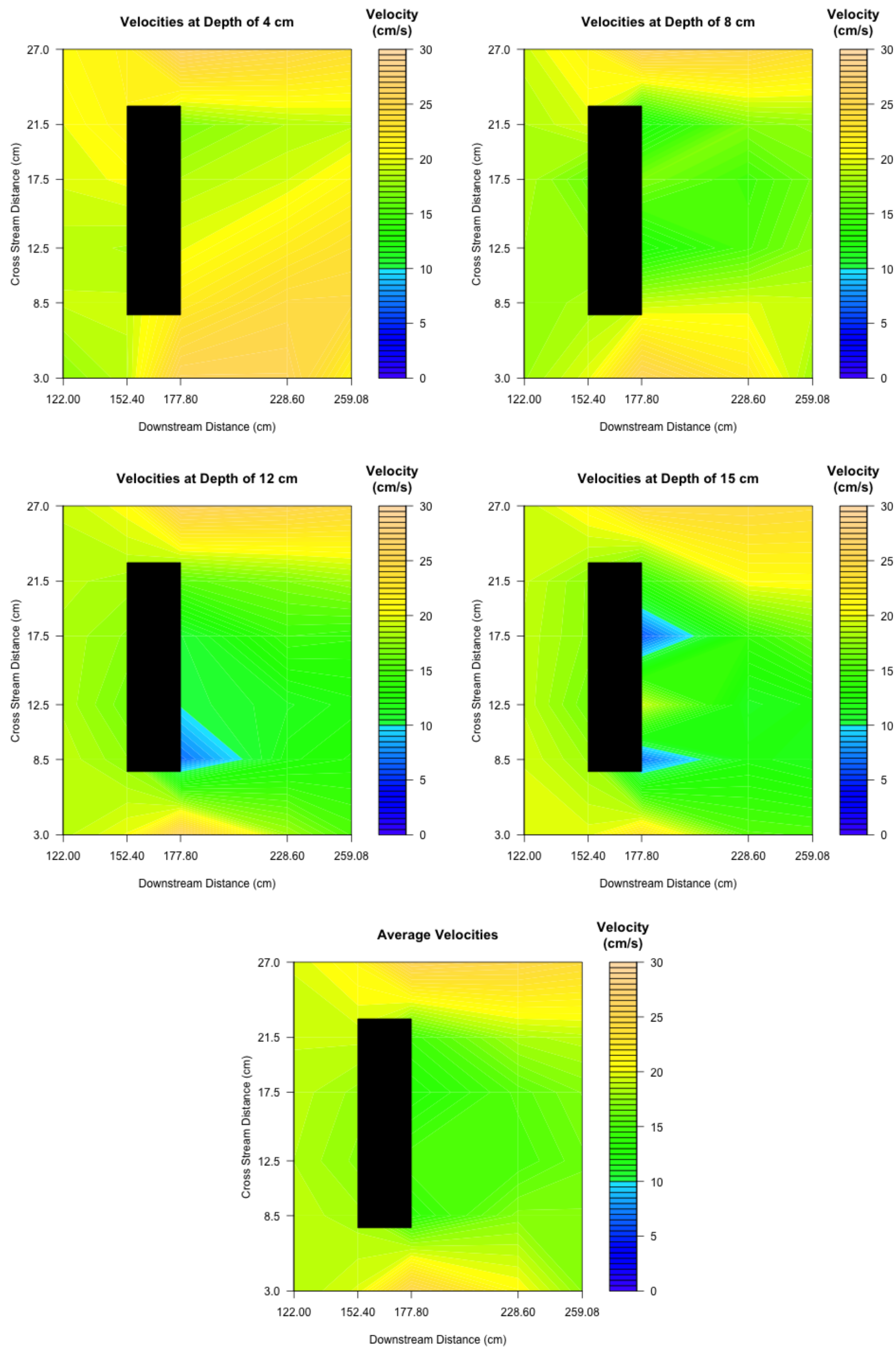

Figure 8: *Contour Plots for Velocities at a Given Depth (for Lower Depth Trial). The black box represents the location of the plant patch (distortion of the axes makes it rectangular). The final plot displays a contour plot for velocities averaged across all depths.*

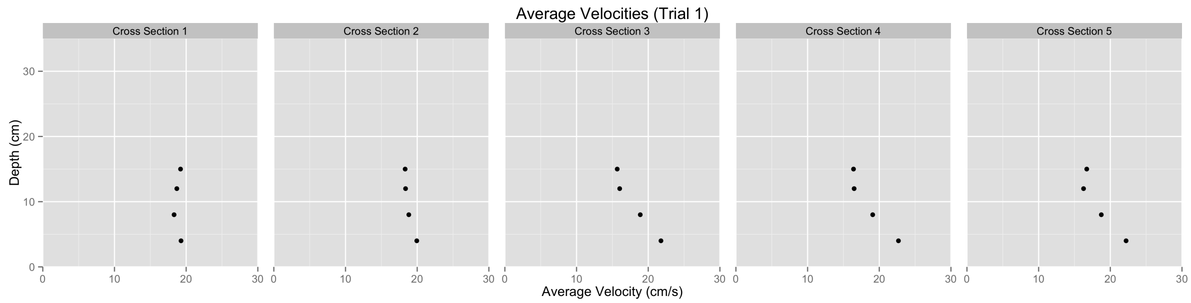

Figure 9: *Velocity Profiles at a Given Cross Section (for Lower Depth Trial). The plant patch is located between Cross Sections 2 and 3.*

ing up to the next depth, the wake zone retains a similar shape (non-symmetric) and velocities increase by 2 cm/s on the side and decrease by 2 cm/s in the wake zone. At the final depth (30 cm), the wake zone shrinks marginally, and velocities are increased on the sides by 2 cm/s and decreased in the wake zone by 2 cm/s.

The velocity profiles for the Higher Depth Trial show a similar behavior to the profiles for the Lower Depth Trial at the lowest depths (figure 11); however, at higher depths do not decrease rather stay constant.

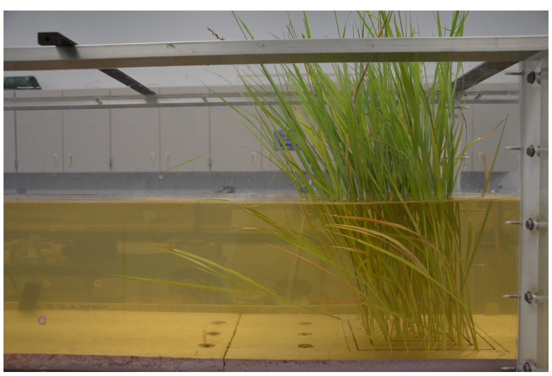

Figure 12: *The plant patch at the lower water depth. Deflection is minimal.*

Also of interest was the degree to which the grass was deflected by water at both depths. In both cases the grass was deflected, though only to a small degree. At no height would the grass become deflected to the point of submersion. Pictures of the grass and its deflection at both heights are in figures 12 and 13.

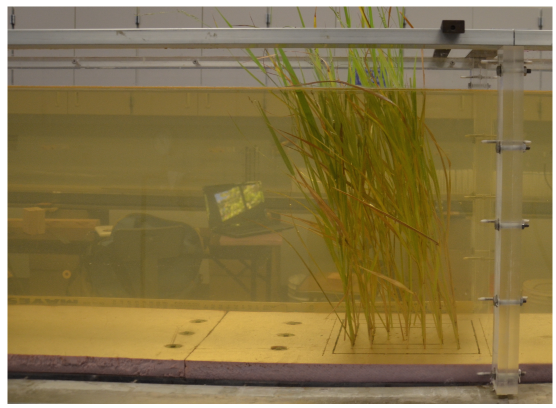

Figure 13: *The plant patch at the higher water depth. Deflection is again minimal.*

IV. Discussion

Comparison of Trials

At both water depths, the water velocities are similarly affected by the plant patch. A wake zone forms behind the patch and velocities increase along the edges. This can be explained by two effects. First, the plant displaces the water to the sides, increasing the velocity in those areas. Next, the plant exerts a drag force on the water, causing the water to decelerate ($F = ma$), and the velocity to decrease in those areas. The quake zone forms in the same manner at each depth and similar percent changes in velocity are observed.

At both water depths we also see similar velocity profiles. Near the bottom, the water is barely affected by the the grass and at higher

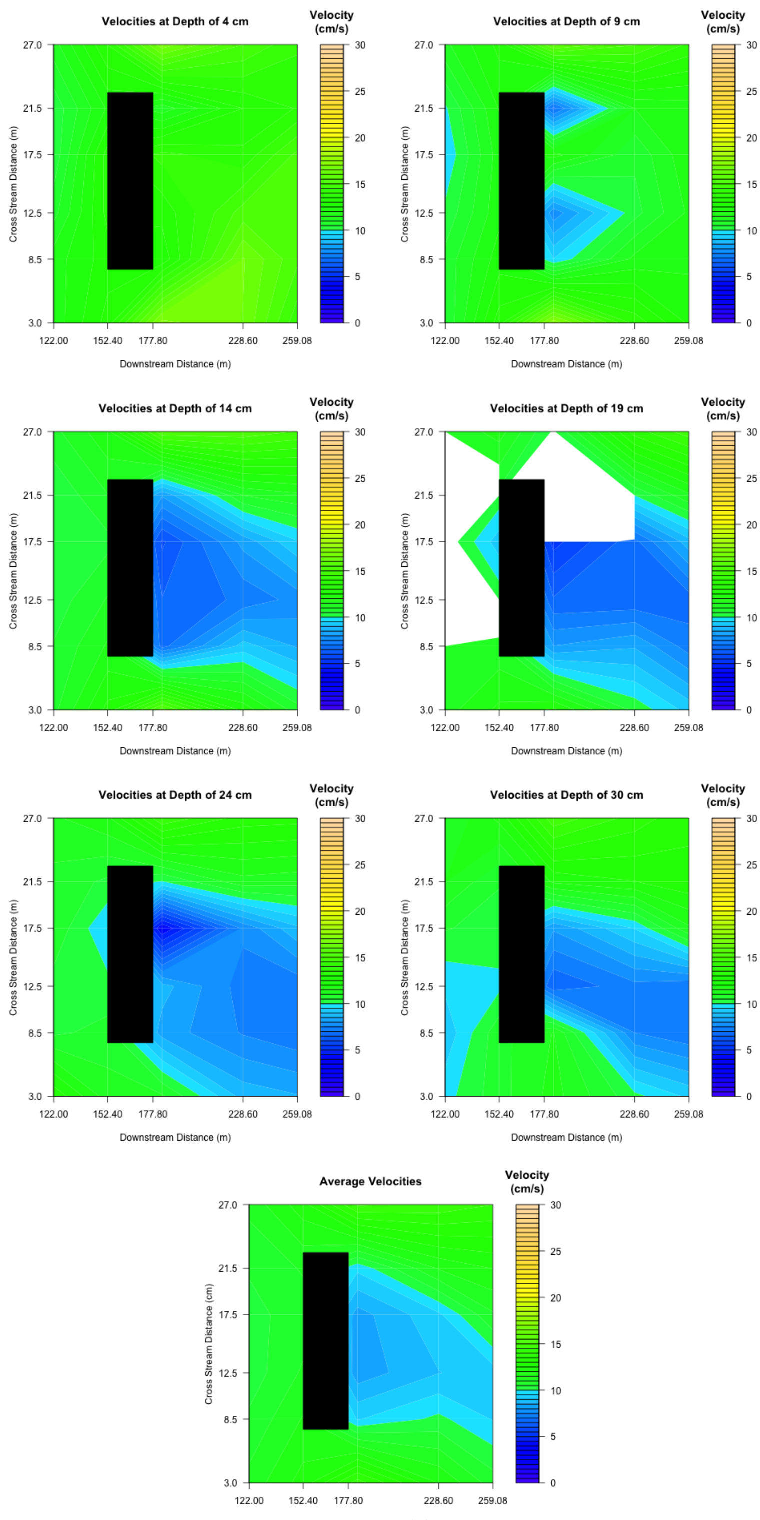

Figure 10: *Contour Plots for Velocities at a Given Depth (for Higher Depth Trial). The black box represents the location of the plant patch (distortion of the axes makes it rectangular). The final plot displays a contour plot for velocities averaged across all depths.*

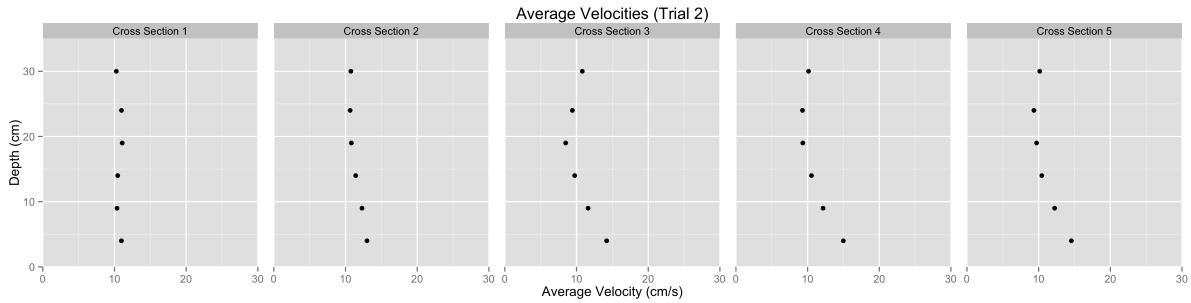

Figure 11: *Velocity Profiles at a Given Cross Section (for Higher Depth Trial). The plant patch is located between Cross Sections 2 and 3.*

heights, the plant cases a greater effect (slowing velocities further). This is explained by the fact that as you go up in plant height, the number of blades increases; and thus, the frontal area also increases. The greater frontal area increases both the effect of the drag force and the displacement. While there are slight differences between the velocity profiles, the profile for the higher depth is effectively a continuation of the profile for the lower depth.

From the above information, we can conclude that at different water depths are affected in a similar pattern. Thus, at higher water depths, the reed canary grass will decrease velocities more, simply because it is occupying a greater area in the stream. Additionally, at lower water depths than this measured, it can be conjectured that the reed canary grass would have a negligible affect on velocities. These increased velocities at lower depths, would suggest that rather than increasing sedimentation behind that patch, reed canary grass may cause scour to occur behind it.

Study Limitations

Fully Developed Flow

A concern in interpreting these results is that fully developed flow was not achieved within the flume. Velocities varied as desired in the y-direction and were predominantly pointing in the x-direction; however, a logarithmic profile was not observed with depth. This leads to comparing velocities at different depths to be inadvisable. With greater time and resources, achieving fully developed flow would be trivial through either a larger flume or a greater number and variety of diffusers. Nonetheless, even under fully developed flow conditions, one would expect similar responses to the velocities from the patch in general. The specific magnitudes of velocities would likely be different, but some inferences can be made about how the velocities would have changed even under fully developed flow conditions.

Use of a Surrogate

Under ideal conditions, reed canary grass would have been used in these experiments. The use of Shenandoah switch grass as a surrogate for reed canary grass raises a few points of concern. While great effort was exerted to replicate the morphological and physical properties, there are properties that vary between the plants. For example, no measurements in aquatic conditions were taken on either the reed canary grass of Shenandoah switch grass. In the physical process of modeling two further sacrifices were made.

First in only using approximately 35 cm of the plant, certain process were likely changed. Since there were less leaves on the sections chosen than on the reed canary grass, there may have been a different effect on velocities. However, because frontal area was maintained between the reed canary grass and Shenandoah switch grass, this issue may have been mitigated.

It is also known that reed canary grass's rhizomatic structure affects the geomorphology of streams (Martinez, 2013) and through the use of stems this was not modeled. Similarly, in our measurements, it was observed that there were large patches of dead matted reed canary grass on the ground, which was also not modeled. Both of these would have a great effect on the roughness introduced by the patch near the bed and would have likely drastically reduced the high near-bed velocities observed.

V. Conclusion

As a small grassy plant, the effects of reed canary grass on hydraulics and geomorphology is greatly understudied (Martinez, 2013). However, as seen in this and other studies, reed canary grass can have a non-negligible effect (Martinez, 2013). Directly studying this effect is difficult, as introducing an invasive plant to an environment is not possible. Computer modeling (Martinez, 2013) or further flume studies using a surrogate, such as this study, are required to better understand the hydraulics around and through reed canary grass, specifically its effects on sedimentation and geomorphology.

This study demonstrated three hydraulic effects of reed canary grass: (1) a wake zone in which velocities are significantly decreased forms for at least 90 cm behind the patch; (2) velocities increase significantly around the edges of a patch; and (3) in the absence of roots or dead underbrush near-bed velocities are increased. The study also demonstrates that reed canary grass affects water velocities independently of water depth.

Further research is required before a full understanding of the ways reed canary grass affects sedimentation is reached. While Shenandoah switch grass models many of the morphological and physical properties of reed canary grass, the use of it in this study failed to capture the near-bed structure of reed canary grass. Since the near-bed velocities would have a great effect on sedimentation interpreting them outside of the assumptions made in modeling is impossible. The effect of the developing conditions within the flume must also be considered in interpreting near-bed velocities.

These results suggest that further research should be directed in two areas: (1) flume studies of sedimentation; and (2) understanding how the near-bed structure of reed canary grass affects velocities. Understanding these two (entwined) issues will contribute to an understanding of how reed canary grass affects stream channel geomorphology and that can be controlled or adapted to; leading to better management practices for this invasive species.

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