STREAMBANK STABILIZATION WITH WOODY DEBRIS STRUCTURES

RAW
ENGINEERING

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Abstract

Beginning in 2000 the USDA-ARS-National Sedimentation Laboratory tested 72 Large Woody Debris Structures (LWDS) in Little Topashaw Creek located near Oxford, Mississippi. These man made structures have proven to be an efficient method for channel erosion control and habitat rehabilitation. However, after three years 36% of the structures had failed. RAW engineering was given the task of analyzing these failures and improving the LWDS design. Multiple structure orientations and geometries were examined. Three LWDS designs were tested at the USDA-ARS Hydraulics Lab in Stillwater, Oklahoma. Experimental lift and drag coefficients and velocity profiles were found. This data was used to determine the optimal design. RAW Engineering's final design recommendation consists of rotating the original structure 180 degrees. This orientation has a lower drag coefficient and decreases the velocities better than the original structure.

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Problem Introduction

Scientists and engineers have gained a greater appreciation of the importance of large wood in fluvial systems in recent years. Wood can control channel form and migration rates as well as provide cover and a diversity of hydraulic conditions for all types of biota. The USDA-ARS-National Sedimentation Laboratory has tested Large Woody Debris Structures (LWDS) in the Little Topashaw Creek located near Oxford, Mississippi. These man made structures have proven to be an efficient method for channel erosion control and habitat rehabilitation. Figure 1 shows the typical plan of LWDS. Major advantages of these structures over existing stream rehabilitation methods include low cost and a natural, aesthetically pleasing design. In the summer of 2000 the USDA-ARS constructed 72 LWDS along a two kilometer stretch of Little Topashaw Creek. Three years after construction, thirty-six percent of structures had failed during high flows. The loss of these structures created the need for a more durable design.

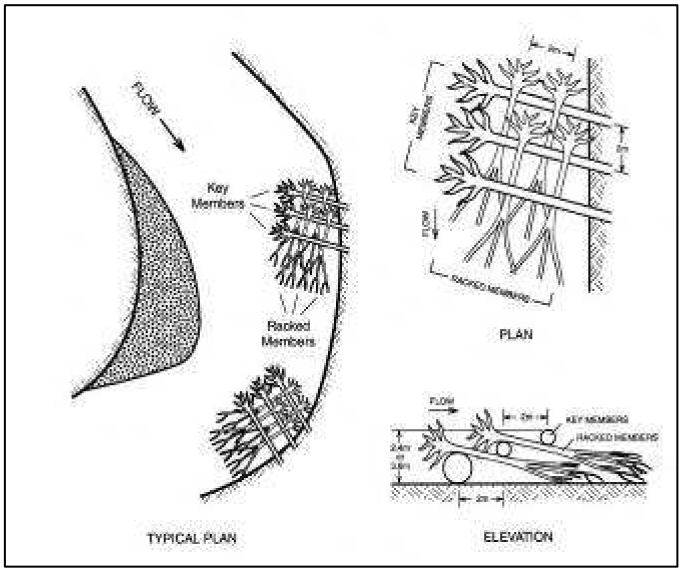

Figure 1: Original LWDS Structure

The USDA-ARS has asked RAW Engineering (RAW) to examine failure modes and potential design improvements for these structures. New designs must induce sediment deposition, improve stability and remain environmentally friendly and cost effective.

Statement of Work

The Little Topashaw structures slowed, stopped or in some cases reversed bank erosion. However, a large portion of these structures did not survive significant flow events. The LWDS were designed to withstand a 5-year return interval flow. Causes of failure were determined to be increased buoyant force due to drying of structure members, loss of branches and upper members of LWDS, and inadequate anchoring. The natural buoyancy and gradual decay of the large woody debris (LWD) are aspects of the design which can not realistically be altered. Therefore, our engineers focused on the forces exerted on the structure and the anchoring system. RAW analyzed the structure geometry and sought a more durable design. Another goal was to increase sediment deposition by altering the hydraulic conditions imposed by the geometry of the structure. Velocity profiles collected around and in the structure demonstrated the effectiveness of the structure to reduce stream velocity, whereby sediment can drop out of flow and collect around the structure. The deposition of sediment within and around the structure aids in the rehabilitation of the stream banks and increase structure stability.

Tests were performed at the USDA-ARS Hydraulics Laboratory in an outdoor flume shown in Figure 2. The concrete flume was six feet wide and capable of reproducing a wide range of flow conditions. RAW engineers created 0.115 scale models of the structures built at Little Topashaw Creek which were designed by Dr. Doug Shields. Froude number calculations were used to determine discharge velocity and depth. Equation 1 was used to calculate Froude number. For an explanation of this and other equations refer to Appendix B. An objective was to determine lift and drag forces imposed on the model for three different orientations. Test results were compared to theoretical lift and drag forces calculated for the structures. After analyzing the forces and velocity profiles, new design criteria developed, and areas in need of further research were identified.

Figure 2: Testing Flume

$$Fr = \frac{V}{\sqrt{gh}}$$

Equation 1: Froude Number

RAW engineers used the flume at the USDA-ARS Hydraulics Lab to evaluate forces on cabling systems during the fall semester. During the spring semester, Raw focused their efforts on measuring the lift and drag forces acting on alternate structure designs. Testing at the USDA-ARS Hydraulics Lab requires the use of siphons to draw water out of Lake Carl Blackwell. These siphons can not be used when the outdoor temperature is below freezing, because of the risk of damaging the system. As a result, testing was halted from November to March. During this interval our engineers visited the USDA-ARS Sedimentation Lab and Little Topashaw Creek in Mississippi. The team also made use of a one foot flume and a wind tunnel at the OSU Biosystems Engineering Lab, to perform qualitative analysis concerning structure orientation and geometry.

Literature Review

After years of removing wood from rivers and streams researchers now understand that large woody debris (LWD) is an integral part of stream ecosystems and has a major impact on stream hydraulics and erosion. Animals, natural events, and anthropogenic factors all contribute to the placement of wood in rivers and streams. Several reviews of the literature have shown that LWD provides physical habitat for aquatic fauna as described by Gippel (1995). Removal of LWD decreases the amount of habitat for macro invertebrates and fish and reduces diversity of hydraulic conditions in streams. This lack of LWD leads to increased channel velocity which leads to an increase in channel incision.

With scientists and engineers now trying to find ways to rehabilitate damaged stream systems, LWDS seem to be an obvious alternative for channel rehabilitation. According to Shields (2004), costs for LWDS construction near Oxford, MS were 19% – 49% of recorded costs for recent stone bank stabilization in the same region. Fischenich and Morrow (2000) say that objectives that may be accomplished with LWDS include: creating pool habitat, generating scour, increasing depths through shallow reaches, and reducing erosion. However, there are some major concerns with the design of LWDS. As stated by Shields (2004), the major design issues include: (1) use of buoyant materials,

(2) use of materials that decay, and (3) dual objectives of channel stabilization and habitat rehabilitation.

While many designs exist, ongoing research to design the ideal LWDS continues. Ideal LWDS should meet the following criteria: (1) provide habitat for aquatic biota, (2) reduce stream velocities to induce sediment deposition, (3) stabilize bank toe, (4) withstand up to five year return period flows, and (5) cost less than other forms of stream rehabilitation.

Traditionally, stream bank stabilization techniques have been both expensive and aesthetically unpleasing. Past attempts have also had very little success in providing wildlife habitat. Previous structures include vegetated rock walls, simple rip-rap structures and rock and gabion arrangements. Figure 3 contains pictures of rip-rap and rock and gabion structures.

Figure 3: Rip-Rap and Rock and Gabion

LWDS have many advantages over traditional rock structures which include: low cost, a natural look, and the use of locally available materials. LWDS, also provide a variety of habitats for wildlife, which is important in an ever increasing environmentally conscious society. One distinct advantage LWDS have over other types of structures is the formation of wildlife habitat while improving channel stabilization. The addition of LWD in the stream provides natural habitats for various species of aquatic biota. Another advantage is the ability to create natural stable banks rather than an artificial bank. Velocity decreases as the flow passes through the structure causing sediment to settle out at these lower velocities. Sediment deposition is a key factor that is not prevalent in other types of stabilization structures (Shields, 2004). The cost of the LWDS is generally lower than that of any rock structure. The cost of the LWD ranges from $12.90 to $164.50 per meter of channel length due to differences in design complexity. Traditional rock structures cost between $150.00 and $300.00 per meter (Fischenich, 2000).

Shields (2004) states the design of woody debris structures creates a few key problems. First, wood being a buoyant material, will have a tendency to float in high flow situations. Second, the fact that the structure is not fully submerged at all times directly affects the physical properties of the wood. The rate of decay of the structure members increases due to the continual soaking and drying of the structures. Design life of a LWDS is less than that of an artificial structure due to this decay.

Design Requirements

Shields (2004) states that the cost per unit length of bank treated must be less than the cost of traditional stone structures for the project to be feasible. The structure must be created with materials that are locally available. Certain types of wood are more durable over time and should be used where available. According to Johnson and Stypula (1993) western red cedar is the most desirable in terms of durability.

The structure must also contribute to and improve natural recovery and establishment of riparian zone habitats and plant communities. The structural design must be able to withstand at least a 5-year return interval flow without failure. The hydraulic abilities of the structure should be able to trap and retain sand-size sediments. The LWDS should not significantly increase the duration of overbank flooding during the growing season although flood stages may be increased. The structure should also be sized to promote berm formation. Geotechnical parameters allow for some additional mass wasting of vertical banks but the structures should trap and retain materials from the caving of the bank. The bank height should be reduced to stable levels when structures are filled with sediments. The construction criteria include minimal requirements for specialized training and equipment. Structures

Equation 2: Density

$$\rho = \frac{m}{v}$$

Equation 3: Drag

$$F_{drag} = \frac{\gamma_w \times V^2 \times C_D \times A}{2 \times g}$$

Equation 4: Buoyant force

$$F_{buoyant} = Volume(\gamma_w - \gamma_d)$$

should be built from within the channel using equipment that will cause minimal additional clearing and disturbance (Shields, 2004).

Fall Testing

Preliminary testing began in the fall. Tests were carried out at the USDA-ARS Hydraulics Lab near Lake Carl Blackwell in Stillwater, Oklahoma. A six-foot concrete, outdoor flume was used for these tests. RAW Engineering modeled the structures used at Little Topashaw Creek and used Froude similarity to create flows similar to the flows in Little Topashaw. The goal for these tests was to determine velocity profiles and forces acting on the anchoring system of the structure.

Figure 4: Fall Test Structure Orientation

Figure 5: Fall Testing Setup

Persimmon timbers were obtained to construct the LWDS model. A sample of the wood was weighed and then submerged in water using graduated cylinder. Equation 2 was then used to determine the density of the wood. Our engineers then calculated the forces acting on the structure using equations 3 and 4. Our engineers then constructed a 0.115 scale model of the LWDS built at Little Topashaw Creek. The width of the structure was set to be 1/3 that of the flume. The prototype to model ratio was determined using the model width as the governing parameter. The depth and velocity were calculated using Froude number similarity. A picture of the model is shown in Figure 4. Table 1 shows the prototype and model dimensions used for this experiment.

The model was anchored with cables running diagonally between the four corners of the structure. At the upstream end of the structure, the cables were extended through pulleys and connected to two Chatillon remote load cells that measured the cables respective tensions. Load cell measurements were obtained from a Chatillon DFGS 10. The equipment was capable of measuring forces from only one load cell at a time; therefore, our engineers had to duplicate testing procedures in order to collect pertinent data from both load cells which can be seen in Figure 5. Water flow was then established in the flume and normalized at a depth of 1.5 feet and a flow rate of 10 cfs. Velocity measurements were taken across the flume at increments of one foot and at four different depths. These measurements were taken at points ahead of, within, and behind the structure. To measure buoyancy, tailwater elevation was raised and flow was discontinued. This provided enough water to fully submerge the structure and provide zero velocity. Tension in a cable was then recorded. The flume was then drained, and the readout was switched to the other load cell, and then the test was repeated. Due the way

Table 1: Modeling

Scale Factor = 0.115	**Prototype**	**Model**
Structure		
Elevation (m)	3.45	0.40
Length (m)	17.6	2.02
Width (m)	5.3	0.61
# Key Members	5	5
Key diameter (m)	0.59	0.07
# Racked	16	16
Racked diameter (m)	0.36	0.04
Racked Length (m)	12.2	1.40
Flow		
Velocity (m/s)	1.2	0.41
Depth (m)	3.5	0.403
Q (m^3/s)	22.26	0.100
Froude #	0.205	0.205

the test was setup a statically indeterminate system was created and force data from this test proved inconclusive.

Fall Designs

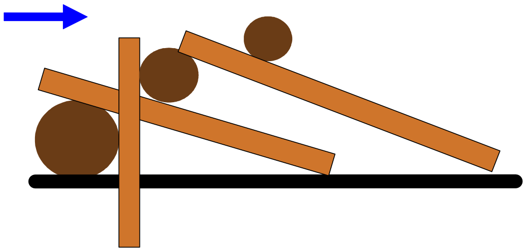

Figure 6: Fall Structure Recommendation

After fall testing RAW Engineering developed alternate designs for an LWDS. The first concept, that RAW came up with, included vertical piles driven into the streambed. Addition of a pile should provide additional structural support for the LWDS. Figure 6 shows a side view of this design. Concerns for this design were soil strength and additional cost. The next alternative included additional key members in the interior of the structure. Adding members to the interior of the structure will add resistance and decrease velocities within the structure. Additional key members would have a significant effect on sediment deposition, but could increase drag forces.

Summary of Site Visit to Mississippi

On January 27, 2006, the following participants: Doug Shields, Carlos Alonzo, Ryan Woolbright, David Mercer, Joe Paul Edwards, Roberto Espinoza, Paul Weckler, Rebecca Ward, and Sherry Hunt took part in a field trip to Oxford, Mississippi and Topashaw Creek, Mississippi for the purpose of having in-depth discussions of RAW Engineering's Senior Design project on large woody debris structures.

Report Discussion

Dr. Alonzo and Dr. Shields began the discussion by going over the team's report submitted in December. They suggested that for the final report, more data and better explanations to how the data was obtained be added (i.e. Froude calculations and force calculations). The calculations and the data presented in the report were not clearly explained to the readers; they suggested including appendices to show calculations. Dr.

Shields mentioned that the measured buoyant force should be within 10% of the calculated buoyant force. Dr. Alonso and Dr. Shields did like the velocity profiles in the report, and they did not believe more sophisticated testing techniques (i.e. ADV) for the velocity measurements were needed.

Figure 7: RAW Engineering in Little Topashaw Creek

Testing Discussion

After the report discussion, the group had a more in-depth discussion about current and future testing. In previous discussions between the team and Darrel Temple, it was suggested that PVC or Teflon be used to reduce the friction between the cables and wood contact points. However, Dr. Alonso and Dr. Shields suggested that friction was not an issue to be concerned with. According to Dr. Shields, friction in places where cables contact the wood would be insignificant. Additionally, Dr. Shields would like RAW to find a reliable drag coefficient for the structure. After testing the structure, Doug suggested comparing the results to the results reported by Dr. Alonso in 2005. In calculating the coefficient of drag, Dr. Shields suggested treating the area of the structure as a solid object.

The next part in the discussion was future testing. The idea was suggested that the woody debris structure should be tested in a more realistic setting such that the structure should be keyed into a bank. Keying into a bank could provide more realistic boundary conditions and flow characteristics as well as change the forces exerted on the structure. However, Dr. Alonso and Dr. Shields felt the current test set-up was fine. They also discouraged testing the idea of placing a pile through the structure. In their opinion, it would be cost prohibitive, and after visiting the Topashaw Creek site, RAW decided that a pile would not be a viable solution in this particular streambed. Instead, they suggested an idea that RAW Engineering had previously rejected. Dr. Alonso and Dr. Shields suggested changing the orientation of the structure by 180° and taking the same set of data. It is Dr. Alonso's belief that changing the orientation of the structure may reduce the drag force and possibly act in a manner similar to an airfoil. However, this design has the potential downfall of producing local scour downstream and eventually undermining the structure. Dr. Alonso and Dr. Shields then suggested comparing the forces calculated and measured for the two orientations.

Spring Testing Procedure

After visiting Oxford, RAW Engineering's goal was to devise a way to measure pure lift and drag forces. Once a method was developed, three series of test were carried out to find the desired data. First, a 1/50th scale model was tested in a one foot flume at the OSU-BAE Lab. Second, the same 1/50th scale structure was tested in the OSU-BAE wind tunnel. Once weather conditions had improved and temperatures had increased, the third and final test was carried out at the USDA-ARS Hydraulics lab.

Experimental Setup

RAW Engineering developed a three point measuring setup to determine lift and drag forces. The setup consisted of three load cells attached to the model through a series of cables and pulleys. One cable was attached to the top key member and ran straight downward perpendicular to the flow was used to measure lift and buoyant forces. Two more cables were attached to the second key member from the upstream side of the structure and ran forward parallel to the flow to measure pure drag force. The cables were extended through pulleys and each was connected to a load cell that measured the cables respective tensions. Figure 8 shows the test setup with the cables highlighted in green. The equipment used to measure forces consisted of three Artech 20210-100 Load Cells connected to Omega DP25-S Strain Gage Panel Meters. An Iotech Personal Daq (PDAQ) connected to a laptop computer and Personal DaqView software was used to convert and record the analog data from the strain gages. Using the PDAQ allowed for the utilization of multiple load cells and ability to log digital data. These capabilities were not available in the previous setup. The data acquisition setup is shown in Figure 9.

Figure 8: Test 1 Setup

Figure 9: Data Acquisition Setup

Preliminary Tests

For RAW's experimental setup to work correctly, the lines of action for the drag and resultant vertical forces needs to be known. These were found experimentally in a one foot wide flume at the OSU BAE Lab. A 1/50th scale model was made out of dowel rods. The lines of action of the forces were found by varying the location that strings were attached to and observing the behavior of the structure. Once equilibrium was detected the positions of the strings were recorded. These points were used for the large scale outdoor tests.

Once the design was finalized and the equipment was calibrated, tests were run in a four foot wind tunnel at the OSU BAE Lab. A 1/50th scale model was attached to a rod which imparts the drag force on a load cell. Forces on one structure were recorded at eight different yaw angles. The goal was to find out if the drag coefficient could be described as a function of the yaw angle. Drag forces on the structure were too small to be accurately measured by the load cells used; therefore, the data was inconclusive. This experiment did, however, provide the chance to try out the data acquisition system.

Main Experiment

RAW engineering ran three separate tests in the six foot concrete flume at the USDA-ARS Hydraulics Lab. In test 1, a model of the LWDS as described by Shields (2004) was used with a yaw angle of 15 degrees. Test 2 consisted of the same structure rotated 180 degrees. The original structure with a yaw angle of 0 degrees was used in the third and final test. RAW's objective for these tests was to compare the forces on the structures and each structure's ability of to decrease velocity.

Materials model LWD from the fall test was used. Model dimensions and flow rates were the same as previously calculated. The structure was oriented in the flume and attached to the load cells through cables and pulleys. Flow was then established in the flume and normalized at a depth of 1.3 feet and a flow rate of 10 cfs. Flow measurements were made with a modified Parshall flume and a point gauge. Using the upstream corner of the structure nearest the wall as a reference point, velocity measurements were taken at 9 and 1.75 feet upstream and 2.8, 6, and 14 feet downstream. Velocity measurements were taken across the flume at increments of one foot at four different depths. Measurements were taken with a Marsh-McBirney FlowMate2000. These measurements were taken at points upstream, within, and downstream of the structure. To measure buoyancy, tail water elevation was raised and flow was discontinued. This provided enough water to fully submerge the structure and provided zero velocity.

Test Results

Table 2: Force Results

	Calculated F_B (lb)	Measured F_B (lb)	% Error
Test 1 (15° Yaw)	7.2	7.9	9.72
Test 2 (15° Yaw)	7.2	7.4	2.78
Test 3 (0° Yaw)	7.2	7.6	5.56

Buoyant force measurements were used to evaluate the test setup. Table 2 compares the calculated and measured buoyant forces. All values are within 10% of the calculated force. Next an error analysis was done on the combined lift and buoyant forces to determine if the cable for measuring vertical forces was located along the line of action of the resultant force. Table 3 shows that error is less than 20% if the cable is within 6 inches of the line of action of the resultant force. This data show that the testing setup was accurate enough to provide justifiable data.

Table 3: Error Analysis

% Error in force readings				
Offset (in)	0	1	3	6
Test 1 (15° Yaw)	0	3.7	10.3	18.8
Test 2 (15° Yaw)	0	3.8	7.3	12.1
Test 3 (0° Yaw)	0	3.6	10	18.1

After the testing was concluded engineers at RAW analyzed the data in order to determine a drag and lift coefficients with the inclusion of an area term (C_DA and C_LA) for each structure that was tested. Normally when calculating a C_D value, it would be divided by the area perpendicular to the flow; however, with the structure's porous nature and irregular shape this area is difficult to calculate accurately. There was discussion of assuming a solid face or using image processing to find the area, but these options were deemed impractical. Using C_DA is not as straightforward as a pure C_D, but it is still relatively simple. Since area is just a length squared; the C_DA value is proportional to the scaling factor squared. This means the values determined from this experiment can easily be converted to values of a full scale LWDS. Table 4 shows the C_DA and C_LA values for the three tests.

Table 4: C_DA and C_LA Values

	C_D A (ft^2)	C_L A (ft^2)
Test 1 (15° Yaw)	7.66	0.00
Test 2 (15° Yaw)	3.95	0.08
Test 3 (0° Yaw)	4.63	0.03

Uncontrollable and inconsistent losses in the waterways upstream of the flume made reproducing a consistent flowrate from test to test difficult. Normalized velocities were calculated so that velocity profiles from different days could be compared. This consisted of dividing each velocity measurement by the bulk flow velocity. The bulk flow velocity was obtained from the point gage readings. Figure 10 shows an example of a velocity profile.

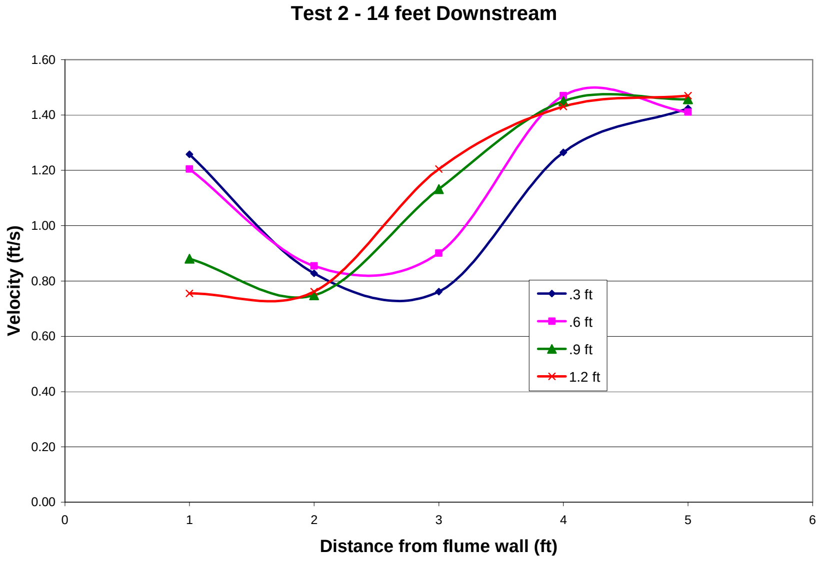

Figure 10: Sample Velocity Profile

Discussion

The testing and analysis shows that the second structure tested performed the best under our testing conditions. The second structure has the same dimensions and member orientation as the original structure only rotated 180 degrees. The structure has nearly the same capabilities as far as reducing local velocities, but the reduction is maintained throughout the structure as well as further downstream from the upstream end of the structure. With this reverse orientation, the drag force exerted on the structure was less than the drag force exerted on the original structure. Analysis of both the velocity profiles and the drag force measurements show that the reverse orientation of the structure performed better.

The results of the force analysis tests run on the three different structure placements provide drag forces and a combined lift and buoyant force. The testing and analysis shows that the second structure performed the best under our testing conditions. The second structure has the same dimensions and member orientation as the original structure only rotated 180 degrees. The calculated C_DA value for this orientation was less that the others structures. In turn the forces exerted on the structure in the stream will be less therefore decreasing the chance of failure due to anchor pull or break. The structure has nearly the same capabilities as far as reducing local velocities, but the reduction is maintained throughout the structure as well as further downstream from the upstream end of the structure. In comparing the calculated forces to the theoretical values, the percent error is within 6%. This shows that the cable placement was effective in calculating pure drag and lift/buoyant forces. Analysis of both the velocity profiles and the drag force measurements show that the reverse orientation of the structure performed better.

Recommendation

Maintaining the current yaw angle of 15 ^{o} is important to structure success. The yaw angle is what allows the structure to divert flow back to the center of the channel. It is crucial to displace this energy away from the stream bank to meet design criteria. The original design for LWDS geometry is satisfactory. It is recommended though that the current structure be rotated 180 ^{o}, maintaining the 15 ^{o} yaw angle. According to the forces calculated, using C_DA values from flume tests, earth anchors and cables should be able to withstand 11,000 lbs to account for lift and drag forces imposed on the LWDS. This structure orientation also slows velocities around the structure well compared to the other two orientations. Using these design criteria the cost should be equal to the cost of the structures in the original study.

RAW Engineering recommends that more in depth research be done before these types of LWDS are widely used in the Southeastern United States. The model structures built by RAW Engineering consisted of roughly cylindrical members; structures in the field will contain branches, rootwads and other irregularities that could influence drag forces and ability to decrease velocities. Extra mass and asymmetrical shape from these irregularities should help to decrease velocities in the channel. RAW feels that the overall shape would not change much, and the coefficient of drag would not be greatly increased, but tests would need to be done to know for certain. Another area of concern is the boundary conditions. The model used in RAW’s tests was not keyed into the flume, and was not close to the flume on the downstream edge. Yaw angle and diversion of flow were determined to be more important for this test. From visual observations and measured data, the structure appeared to increase the velocity on the bank side of the structure. Further study would need to be done to determine if this structure could possibly increase erosion.

Budget

RAW Budget			
	Purchase Date	**Desription**	**Price ($)**
Testing Supplies	11/15/2005	Pulleys, I-bolts, Cable, Zip Ties, Turnbuckle, Wire Clips, Quicklinks	$40
	11/15/2006	Wood Members of Structures	N/A
	2/16/2006	Artech 20210-100 Load Cells, Omega DP25-S Strain gage Panel Meters	$1,000.00
	3/31/2006	PDaq Data Acquisition Device, Lapttop Computer, Marsh-McBirney FlowMate 2000	Property of BAE Department
	3/31/2006	Miscallaneous Testing Supplies	$19.08
Travel	1/26/2006	Lodging: Oxford and Memphis	$490.09
	1/26/2006	Motor Pool: Van Rental, Pike Pass Charges	590.22
		Total	$2,139.39

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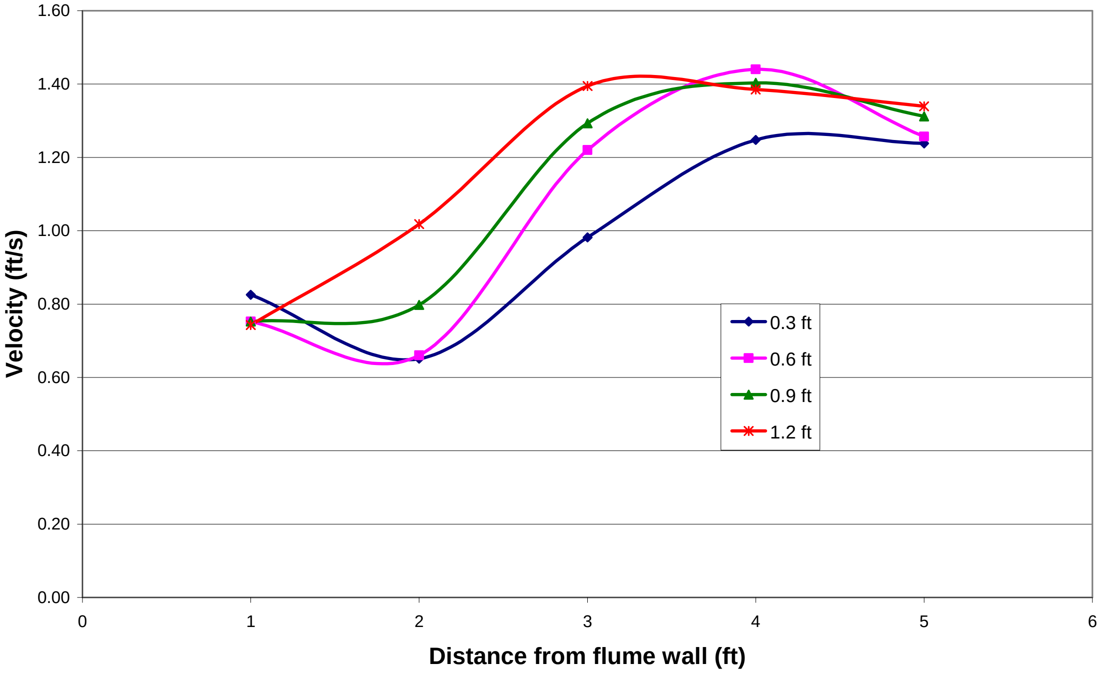
Appendix A

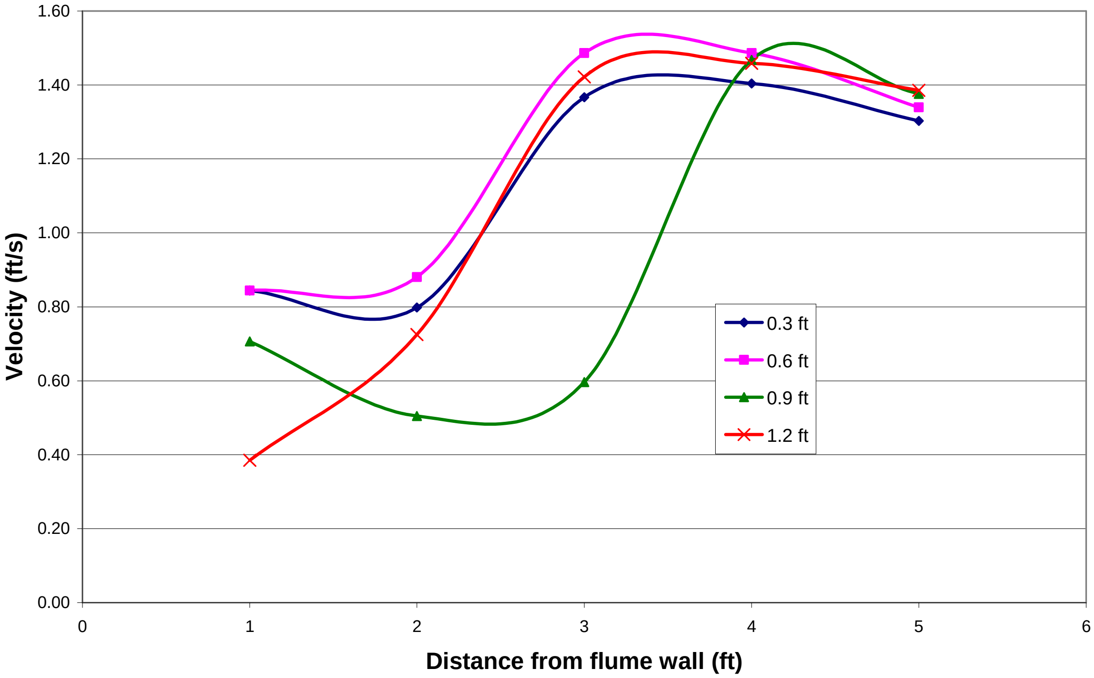
Velocity Profiles: Test 1

V_0 = 1.09	*14 ft Downstream*				
Distance from wall (ft)	**1**	**2**	**3**	**4**	**5**
Depth (ft)	**(V/V_0)**				
0.3	0.83	0.65	0.98	1.25	1.24
0.6	0.75	0.66	1.22	1.44	1.26
0.9	0.75	0.80	1.29	1.40	1.31
1.2	0.74	1.02	1.39	1.39	1.34
	74 in. Downstream				
Depth (ft)	**(V/V_0)**				
0.3	0.84	0.80	1.37	1.40	1.30
0.6	0.84	0.88	1.49	1.49	1.34
0.9	0.71	0.50	0.60	1.47	1.38
1.2	0.39	0.72	1.42	1.46	1.39
	38 in. Downstream				
Depth (ft)	**(V/V_0)**				
0.3	1.01	0.91	1.40	1.40	1.28
0.6	1.00	1.40	1.59	1.31	1.35
0.9	1.07	0.40	1.52	1.43	1.38
1.2	0.17	0.62	1.58	1.44	1.38
	21 in. Upstream				
Depth (ft)	**(V/V_0)**				
0.3	1.00	0.98	1.15	1.07	1.07
0.6	1.13	1.00	1.21	1.14	1.06
0.9	1.12	1.16	1.19	1.12	1.17
1.2	1.14	1.16	1.17	1.11	1.17
	9 ft Upstream				
Depth (ft)	**(V/V_0)**				
0.3	1.04	0.91	1.01	0.95	1.00
0.6	1.06	1.09	1.12	0.99	1.03
0.9	1.19	1.15	1.06	0.95	1.03
1.2	1.17	1.15	1.06	0.94	1.11

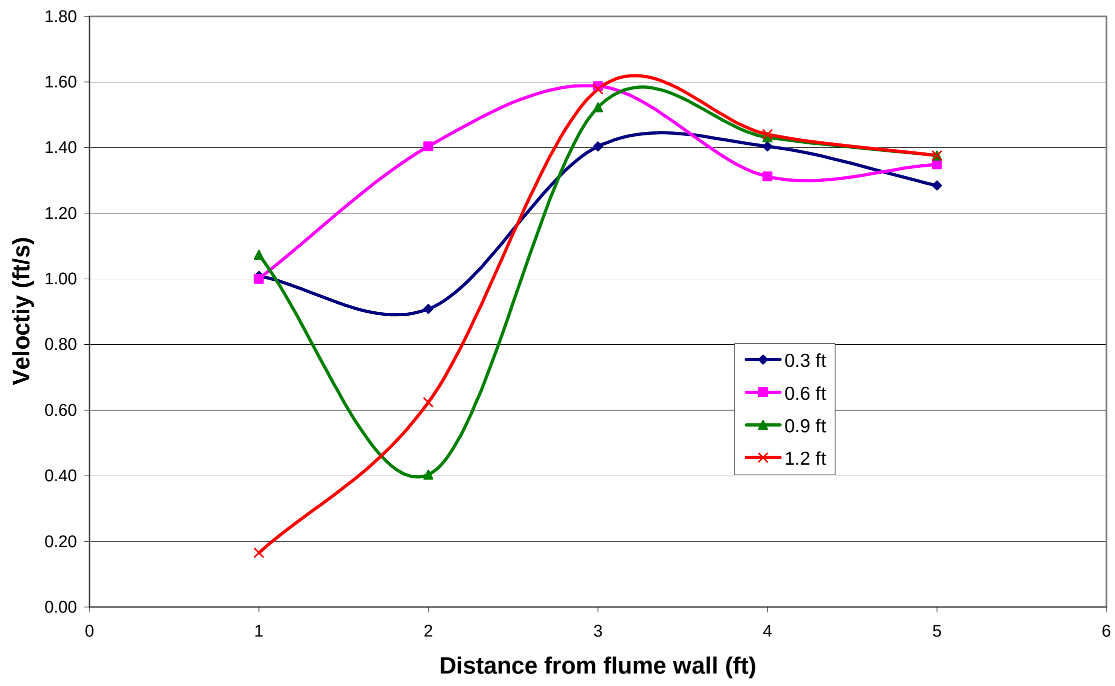
Test 1 - 14 feet Downstream



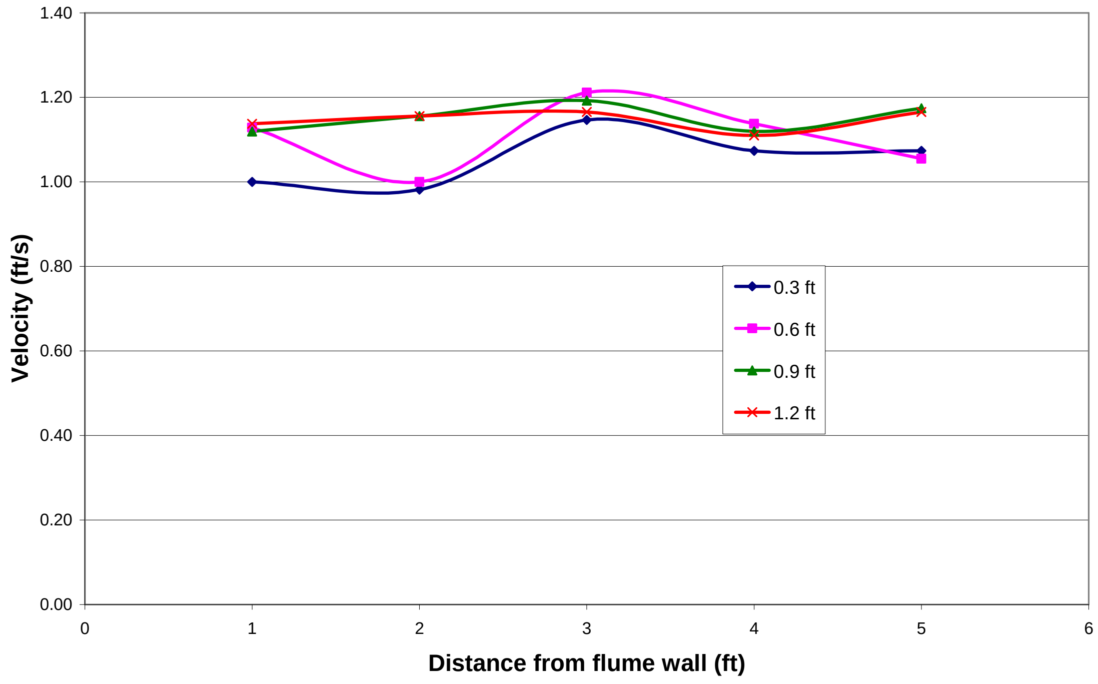
Test 1 - 74 inches Downstream

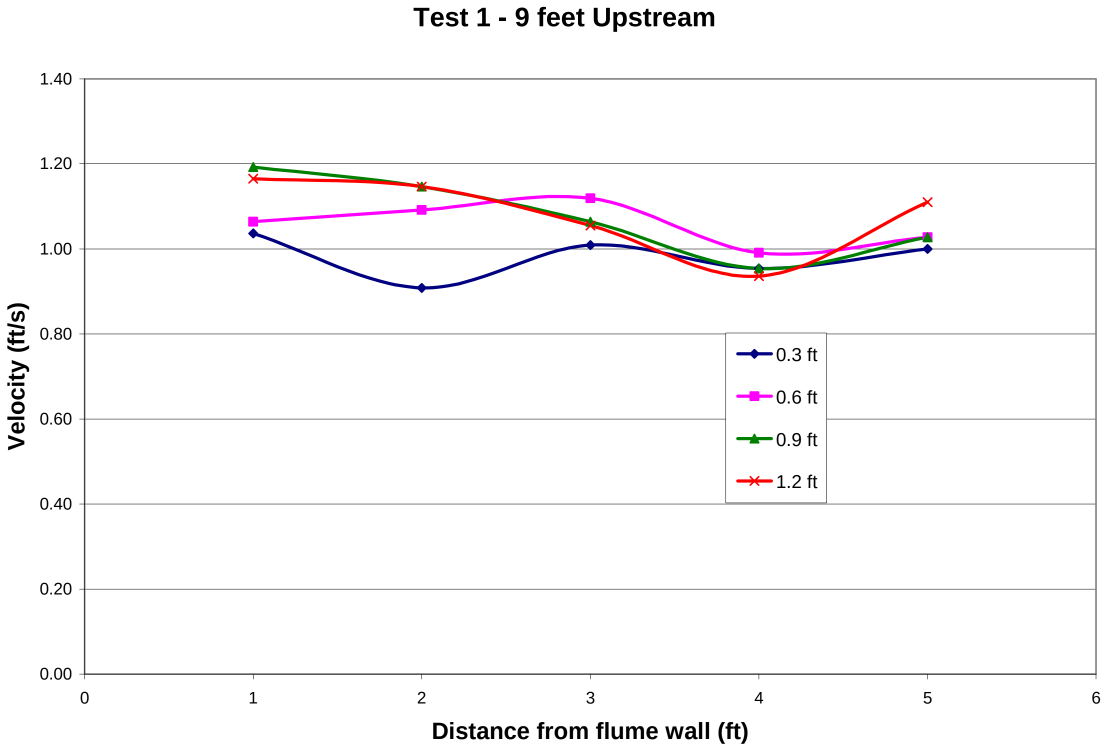


Test 1 - 38 inches Downstream



Test 1 - 21 inches Upstream

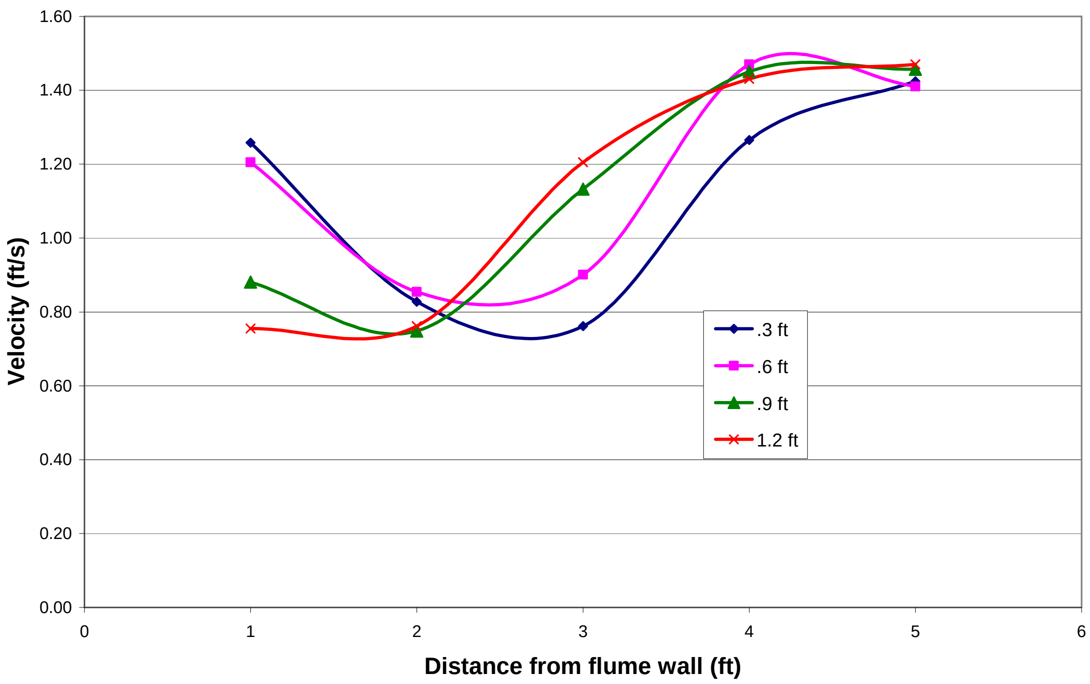



Test 1 - 9 feet Upstream
Velocity (ft/s)
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0
1
2
3
4
5
6
Distance from flume wall (ft)
0.3 ft
0.6 ft
0.9 ft
1.2 ft

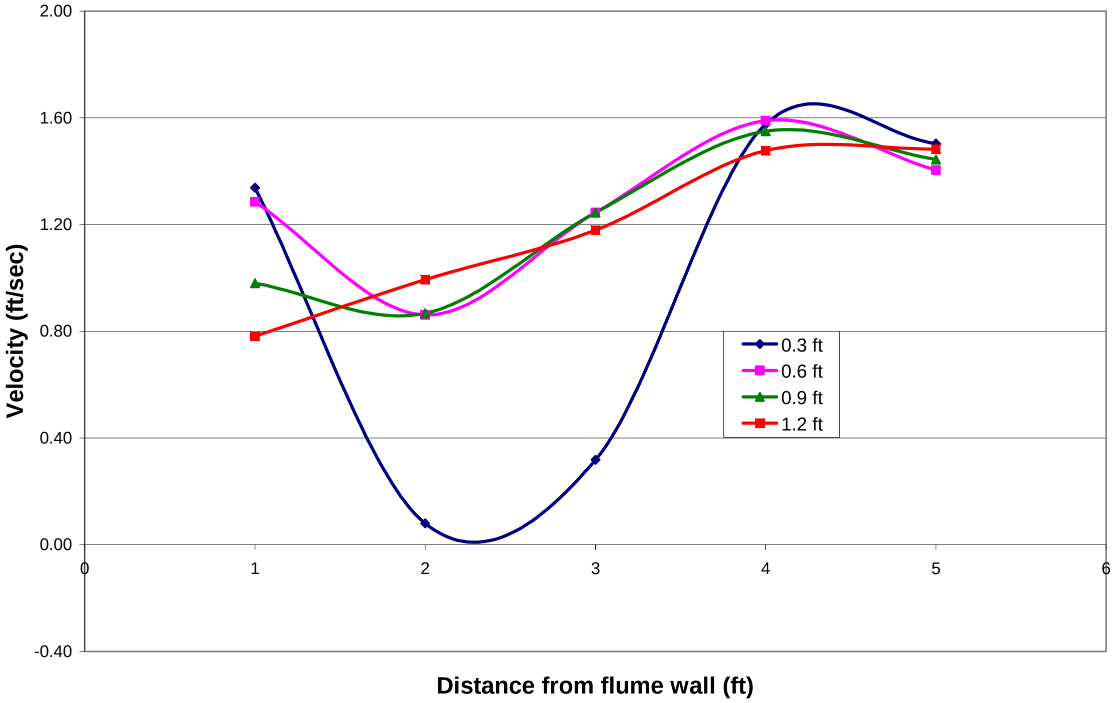
Velocity Profiles: Test 2

V_0 = 1.51	*14 ft Downstream*				
Distance from wall (ft)	**1**	**2**	**3**	**4**	**5**
Depth (ft)	**(V/V_0)**				
0.3	1.26	0.83	0.76	1.26	1.42
0.6	1.21	0.85	0.90	1.47	1.41
0.9	0.88	0.75	1.13	1.45	1.46
1.2	0.75	0.76	1.21	1.43	1.47
	74 in. Downstream				
Depth (ft)	**(V/V_0)**				
0.3	1.34	0.08	0.32	1.58	1.50
0.6	1.28	0.86	1.25	1.59	1.40
0.9	0.98	0.87	1.25	1.55	1.44
1.2	0.78	0.99	1.18	1.48	1.48
	38 in. Downstream				
Depth (ft)	**(V/V_0)**				
0.3	1.10	1.24	1.19	1.26	1.31
0.6	1.21	1.34	1.03	1.33	1.36
0.9	1.08	-0.08	1.41	1.35	1.36
1.2	0.81	1.16	1.17	1.36	1.37
	21 in. Upstream				
Depth (ft)	**(V/V_0)**				
0.3	1.15	1.04	1.09	1.01	1.13
0.6	1.29	1.16	1.15	0.99	1.19
0.9	1.22	1.25	1.19	1.13	1.16
1.2	1.08	1.23	1.15	1.17	1.21
	9 ft Upstream				
Depth (ft)	**(V/V_0)**				
0.3	1.18	1.11	1.13	0.93	1.09
0.6	1.23	1.21	1.18	0.99	1.09
0.9	1.23	1.22	1.15	1.08	1.13
1.2	1.18	1.17	1.12	1.06	1.07

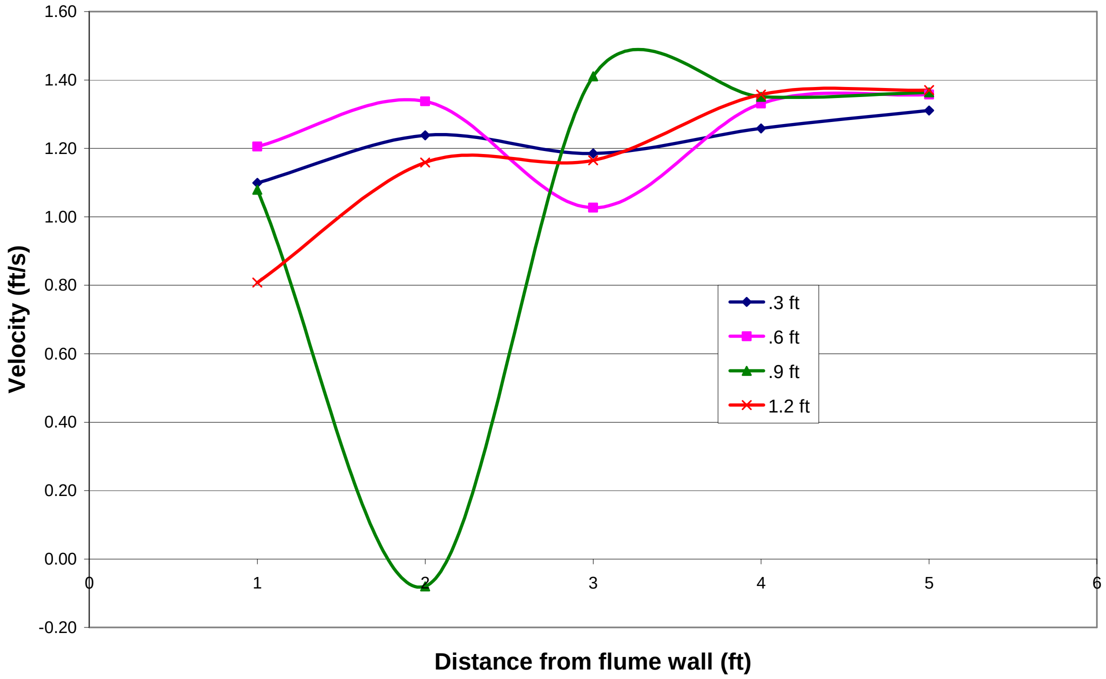
Test 2 - 14 feet Downstream



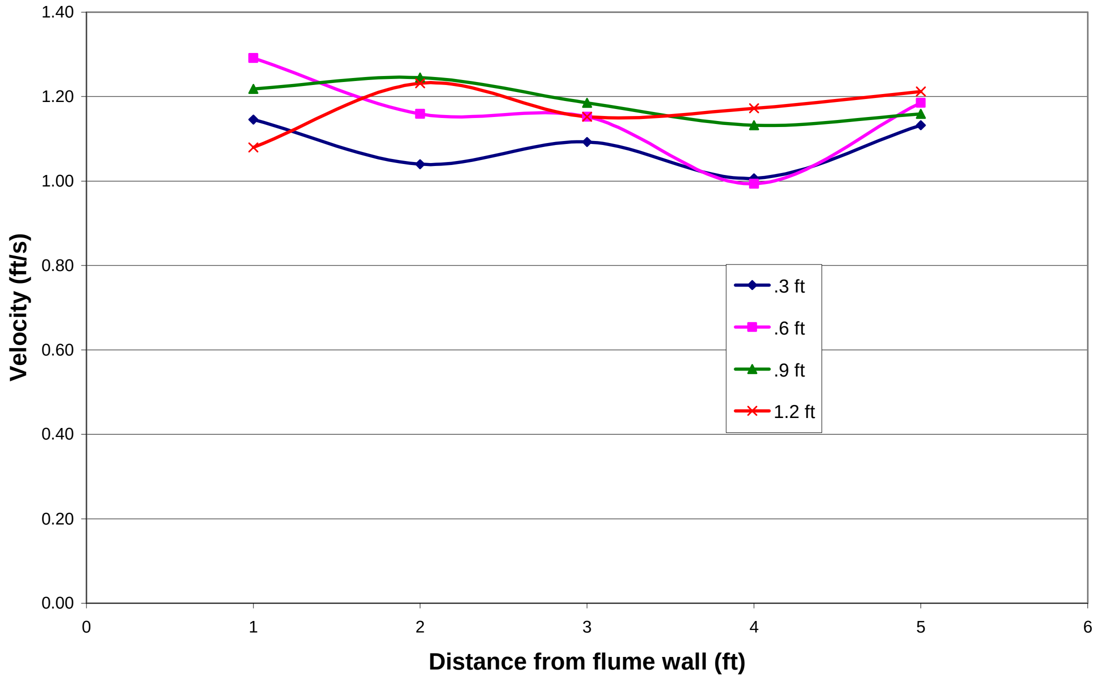
Test 2 - 74 in Downstream

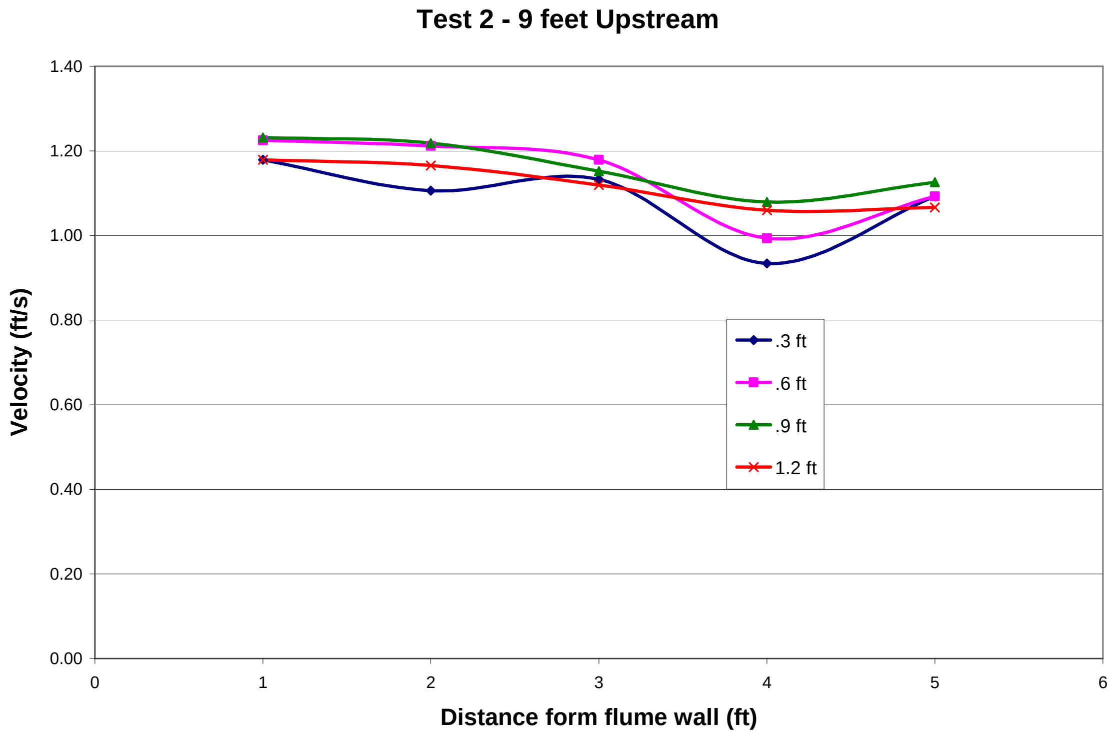


Test 2 - 38 inches Downstream



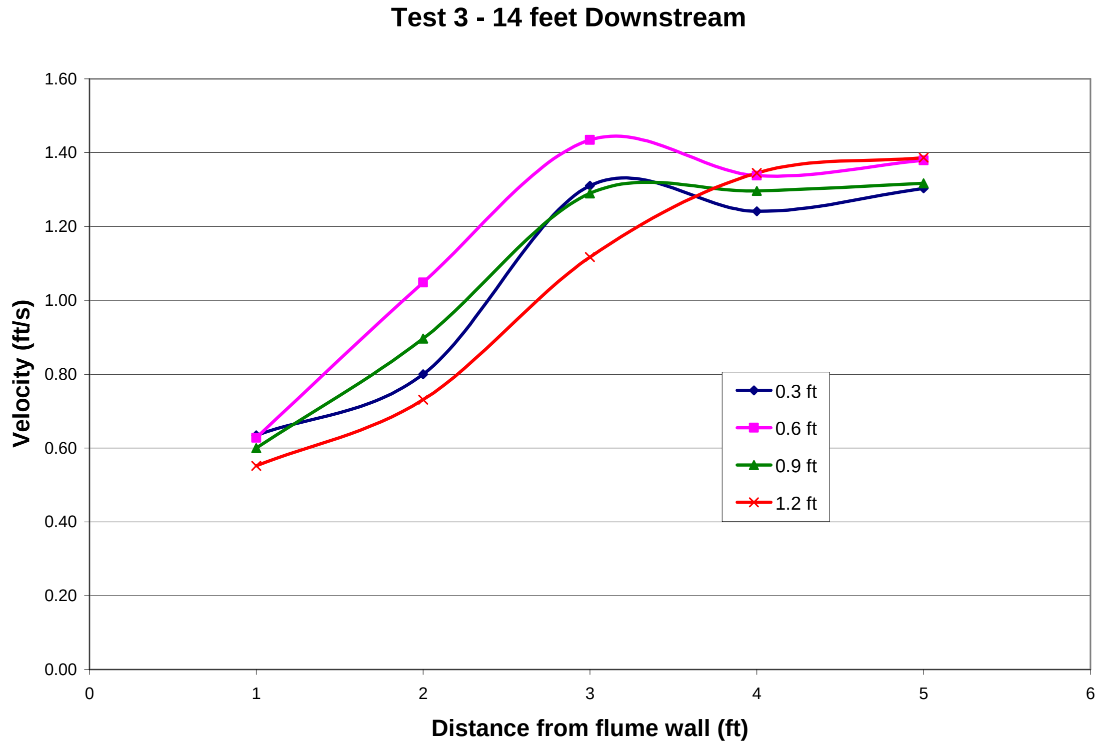
Test 2 - 21 inches Upstream

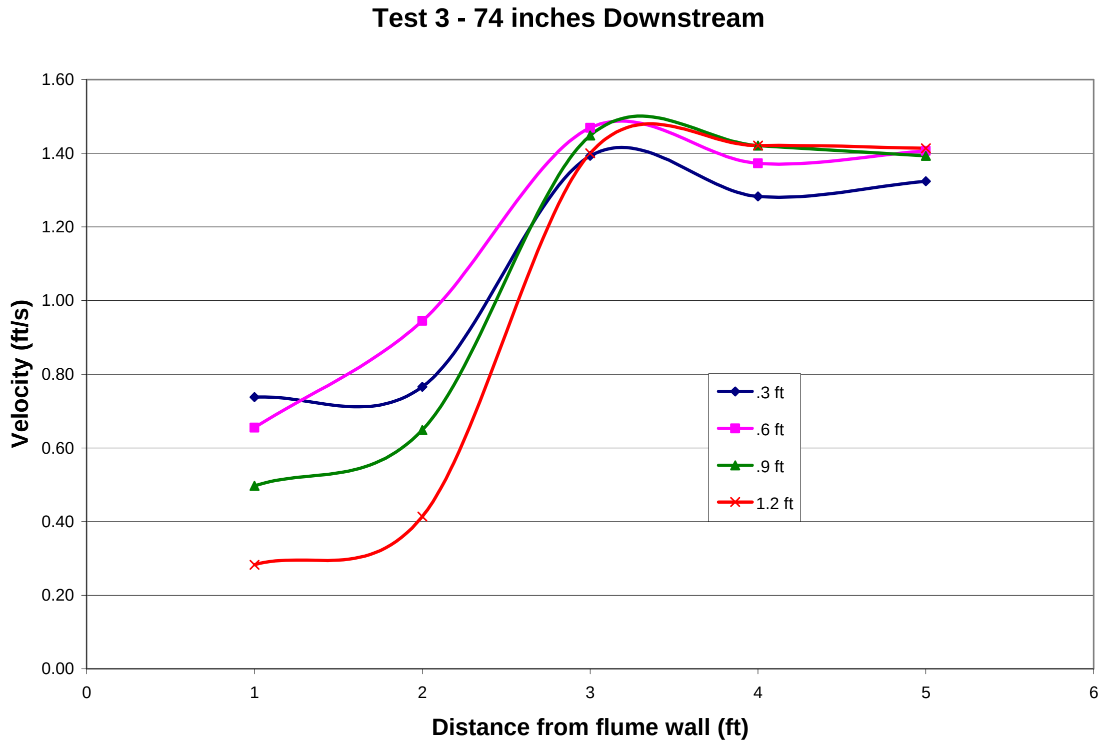



Test 2 - 9 feet Upstream
Velocity (ft/s)
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0
1
2
3
4
5
6
Distance form flume wall (ft)
.3 ft
.6 ft
.9 ft
1.2 ft

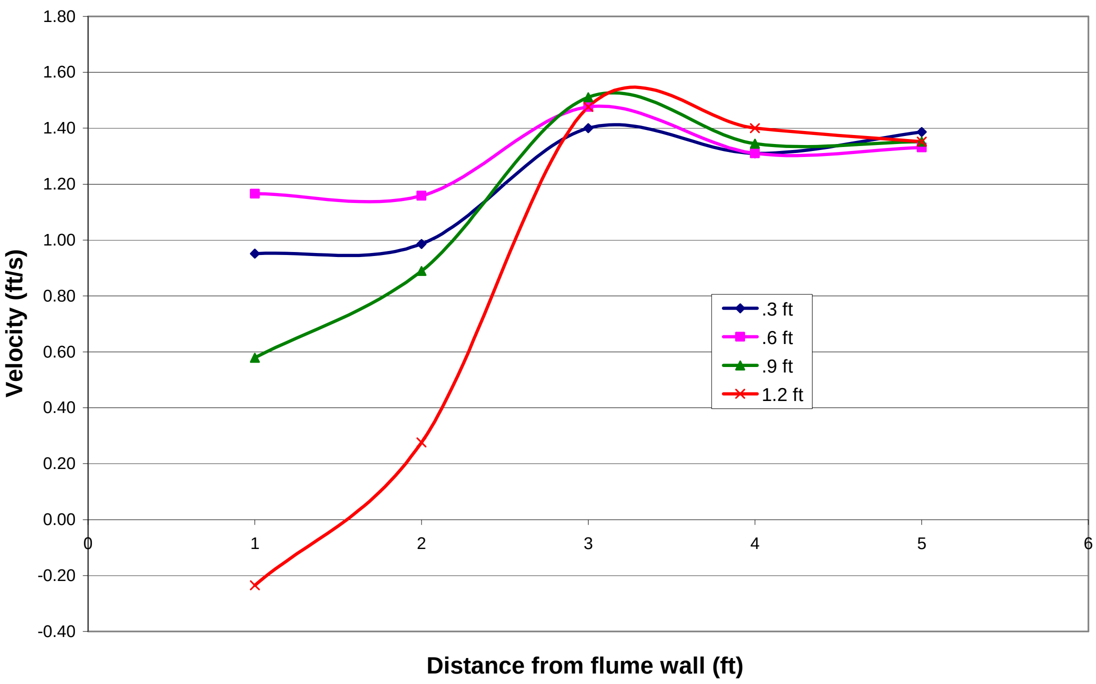
Velocity Profile: Test 3

V_0 = 1.45	***14 ft Downstream***				
Distance from wall (ft)	**1**	**2**	**3**	**4**	**5**
Depth (ft)	**1**	**2**	**3**	**4**	**5**
0.3	0.63	0.80	1.31	1.24	1.30
0.6	0.63	1.05	1.43	1.34	1.38
0.9	0.60	0.90	1.29	1.30	1.32
1.2	0.55	0.73	1.12	1.34	1.39
	74 in. Downstream				
Depth (ft)	**(V/V_0)**				
0.3	0.74	0.77	1.39	1.28	1.32
0.6	0.66	0.94	1.47	1.37	1.41
0.9	0.50	0.65	1.45	1.42	1.39
1.2	0.28	0.41	1.40	1.42	1.41
	38 in. Downstream				
Depth (ft)	**(V/V_0)**				
0.3	0.95	0.99	1.40	1.31	1.39
0.6	1.17	1.16	1.48	1.31	1.33
0.9	0.58	0.89	1.51	1.34	1.35
1.2	-0.23	0.28	1.48	1.40	1.35
	21 in. Upstream				
Depth (ft)	**(V/V_0)**				
0.3	0.80	0.94	1.08	0.99	1.14
0.6	0.85	1.01	1.09	1.02	1.14
0.9	0.94	1.12	1.08	1.03	1.14
1.2	1.08	1.17	1.11	1.08	1.17
	9 ft Upstream				
Depth (ft)	**(V/V_0)**				
0.3	1.13	0.98	0.97	0.83	0.99
0.6	1.13	1.15	0.98	0.87	0.99
0.9	1.20	1.16	1.02	0.95	1.01
1.2	1.18	1.10	1.04	1.02	1.03

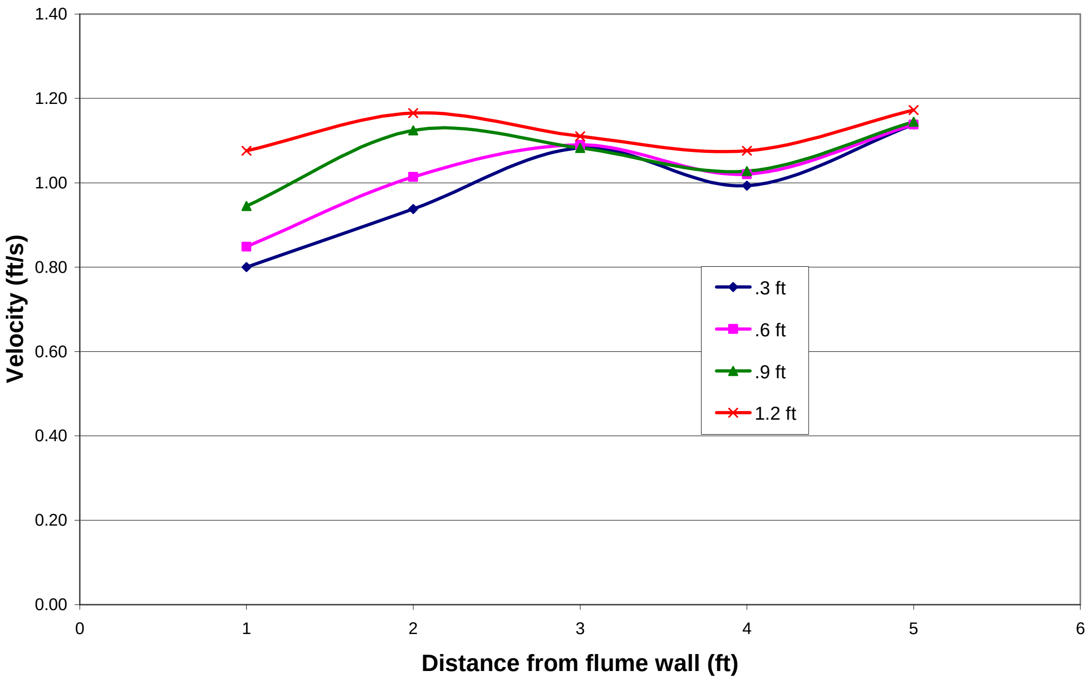

Test 3 - 14 feet Downstream
Velocity (ft/s)
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0
1
2
3
4
5
6
Distance from flume wall (ft)
0.3 ft
0.6 ft
0.9 ft
1.2 ft


Test 3 - 74 inches Downstream
Velocity (ft/s)
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0
1
2
3
4
5
6
Distance from flume wall (ft)
.3 ft
.6 ft
.9 ft
1.2 ft

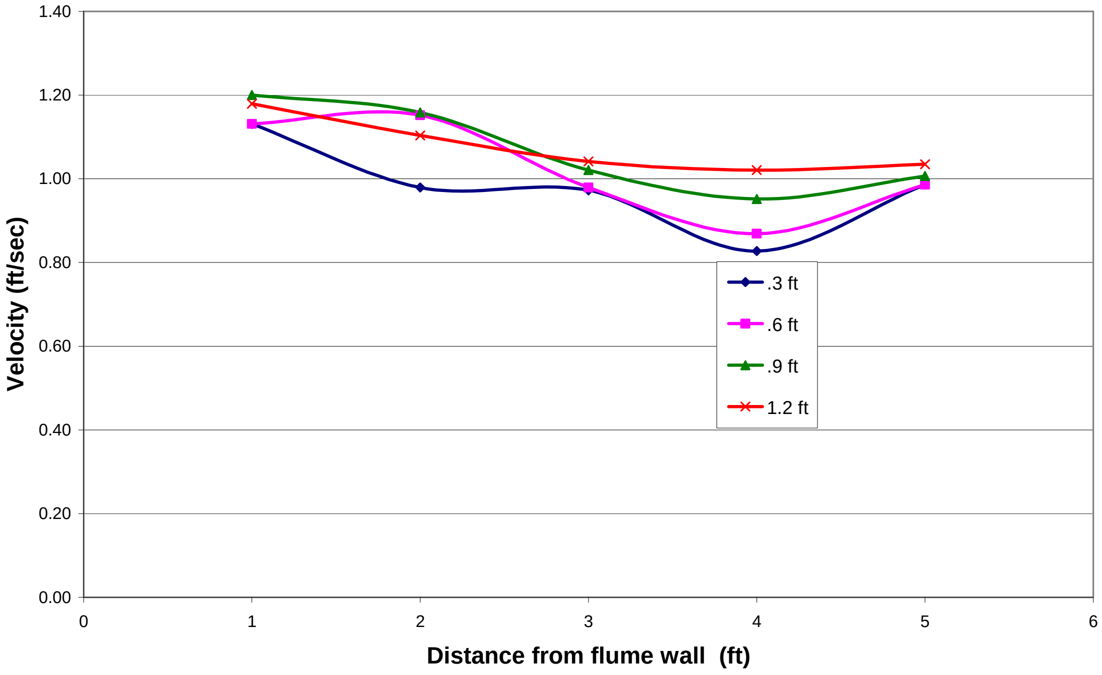
Test 3 - 38 inches Downstream



Test 3 - 21 inches Upstream



Test 3 - 9 feet Upstream



Appendix B

Major equations and calculations used in this project

Equation 1: Froude Number $Fr = \frac{V}{\sqrt{gh}}$

Equation 2: Density $\rho = \frac{m}{v}$

Equation 3: Drag $F_D = \frac{\gamma_w \times V^2 \times C_D \times A}{2 \times g}$

Equation 4: Buoyancy $F_B = v \times (\gamma_w - \gamma_D)$

Equation 5: Scaling Ratio $SR = \frac{l_m}{l_P}$

Equation 6: Force Scaling $F_P = F_m \times \left(\frac{l_P}{l_m}\right)^3$

Where: V is bulk flow Velocity, g is the gravitational constant, h is the flow depth, m is the mass, v is the volume, γ_w is the unit weight of water, A is area perpendicular to flow, γ_D is the unit weight of dry wood, l_m is the characteristic length of the model, l_p is the characteristic length of the prototype, F_p is the force on the prototype, and F_m is the force on the model.

	F_m (lb)	F_p (lb)	Fr #
Test 1 (15° Yaw)	16.05	10552	0.17
Test 2 (15° Yaw)	16.04	10542	0.23
Test 3 (0° Yaw)	13.57	8919	0.22

This table shows the forces and Froude numbers from each test. Froude numbers are within 15% of the theoretical. This means there is some variation, but the numbers are sill comparable. The table on the next page is a representative sample of the data output from RAW's force measurement and data acquisition system.

Time	Date	Cell_1	Cell_2	Cell_3
hh:mm:ss	MM-DD-YYYY	V	V	V
14:31:32	4/10/2006	6.68	2.11	13.76
14:31:34	4/10/2006	6.71	2.16	13.76
14:31:36	4/10/2006	6.69	2.18	13.76
14:31:37	4/10/2006	6.66	2.17	13.76
14:31:39	4/10/2006	6.65	2.15	13.78
14:31:41	4/10/2006	6.65	2.19	13.77
14:31:43	4/10/2006	6.73	2.21	13.75
14:31:45	4/10/2006	6.72	2.20	13.73
14:31:46	4/10/2006	6.70	2.16	13.75
14:31:48	4/10/2006	6.72	2.19	13.74
14:31:50	4/10/2006	6.73	2.21	13.73
14:31:52	4/10/2006	6.76	2.19	13.74
14:31:54	4/10/2006	6.71	2.22	13.74
14:31:56	4/10/2006	6.71	2.17	13.75
14:31:57	4/10/2006	6.68	2.18	13.74
14:31:59	4/10/2006	6.75	2.14	13.72
14:32:01	4/10/2006	6.75	2.15	13.70
14:32:03	4/10/2006	6.77	2.15	13.68
14:32:05	4/10/2006	6.81	2.14	13.68
14:32:06	4/10/2006	6.75	2.17	13.69
14:32:08	4/10/2006	6.79	2.17	13.69
14:32:10	4/10/2006	6.69	2.16	13.68
14:32:12	4/10/2006	6.75	2.19	13.70
14:32:14	4/10/2006	6.73	2.19	13.70
14:32:16	4/10/2006	6.76	2.22	13.70
14:32:17	4/10/2006	6.76	2.14	13.71
14:32:19	4/10/2006	6.71	2.12	13.70

Woody Debris Streambank Stabilization

Joe Paul Edwards
Roberto Espinoza
Dave Mercer
Ryan Woolbright

BAE 4022 – Spring 2006

Agricultural Research Service

RAW ENGINEERING

BIOSYSTEMS & AGRICULTURAL ENGINEERING
Oklahoma State University

Project Sponsor

Agricultural Research Service

- Federal Agency that conducts research to develop solutions to agricultural problems of high national priority

National Sedimentation Lab – Oxford, Mississippi

Damage due to Erosion

Large Woody Debris Structure

LWDS
From
Pacific
Northwest

Traditional Bank Stabilization Methods

Rip-Rap

Rock and Gabion

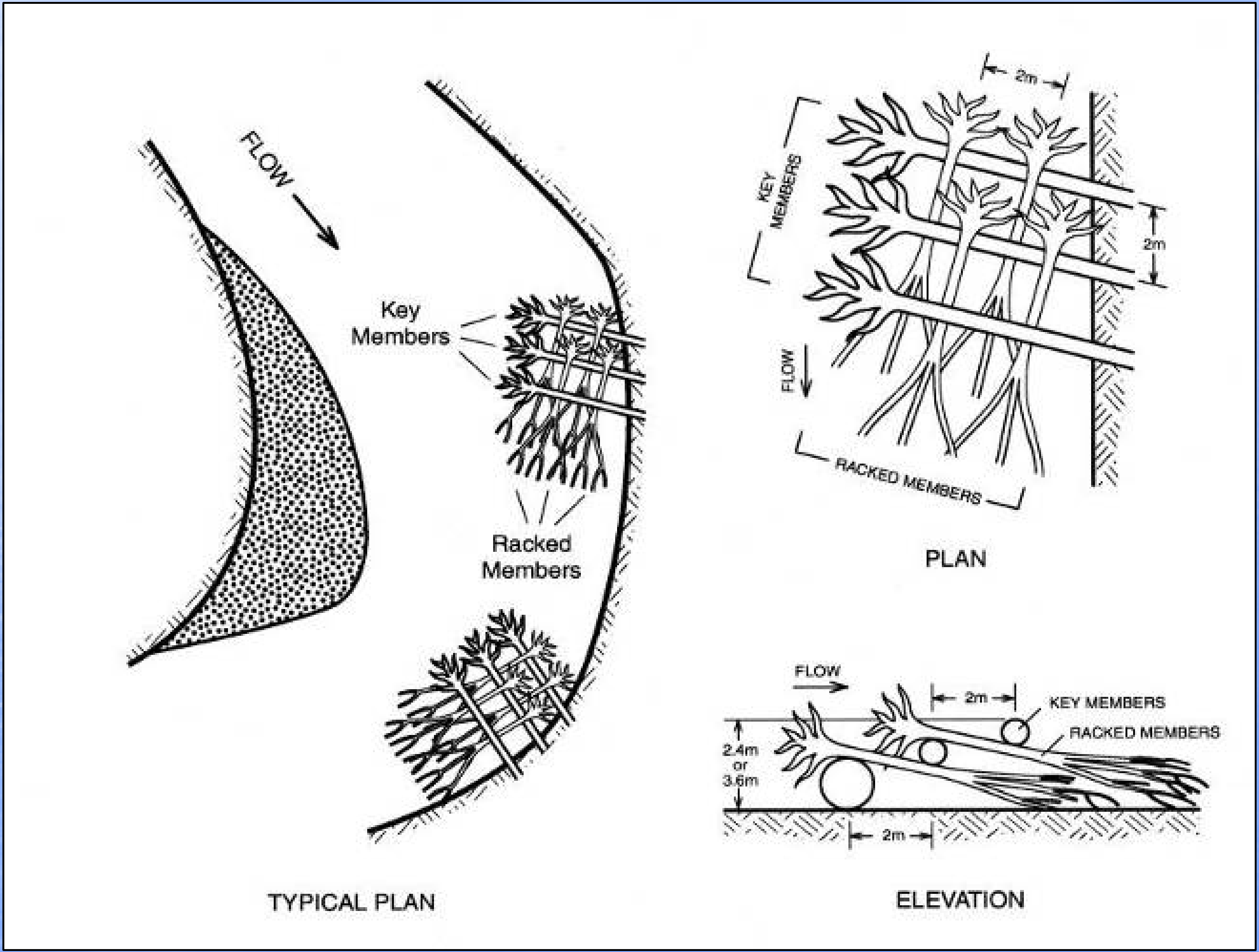
Project Introduction

- Benefits of LWDS
  - Reduction of channel erosion
  - Habitat rehabilitation
- Original design implemented in Little Topashaw Creek.
- 36% of structures failed after 3 years.

Criteria for Ideal LWDS

- Provide habitat for aquatic biota
- Reduce stream velocity and induce sediment deposition
- Stabilize bank toe
- Withstand 5-yr return period flows
- Cost less than traditional methods

LWDS Original Design



LWDS on Little Topashaw Creek

Site Visit - National Sedimentation Laboratory Oxford, Mississippi

- Examination of structure remains
- Assessment of failure modes
- Analysis of bed material

Successful LWDS 7 Years After Installation

Design Challenges

- Use of buoyant material
- Use of materials that decay
- Dual objectives of channel stabilization and habitat rehabilitation

Objectives

- Examine hydraulic characteristics
- Determine drag coefficient
- Develop new design criteria

Modeling

- Prototype to model ratio was determined using the channel width as the governing parameter.
- Velocities and depths were calculated using Froude number similarity.

$$Fr = \frac{V}{\sqrt{gh}}$$

Modeling

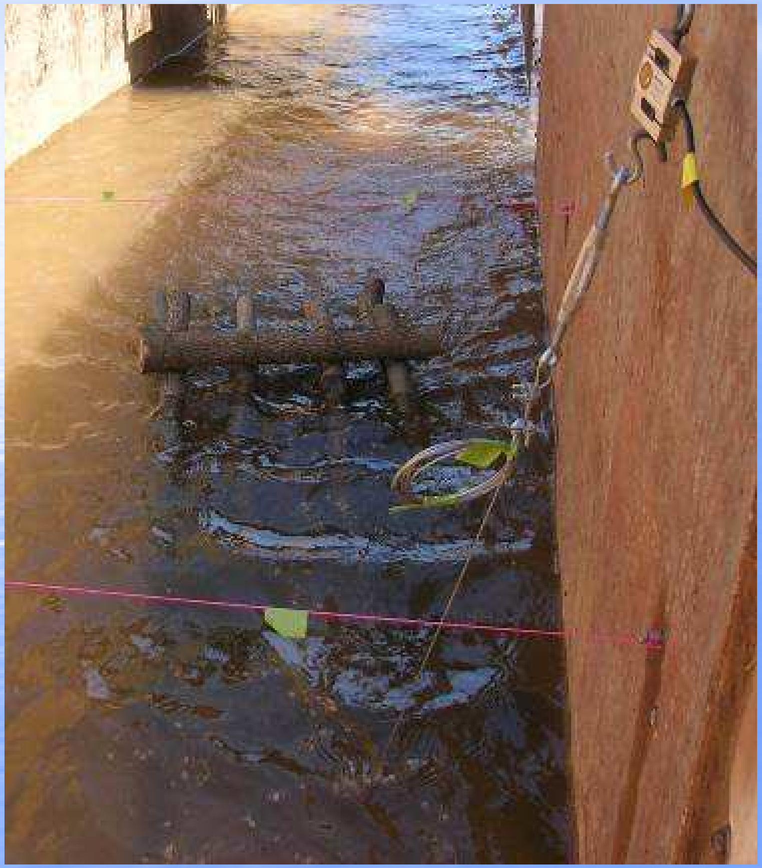
Scale Factor = 0.115

	Prototype	Model
Structure		
Elevation (m)	3.45	0.40
Length (m)	17.6	2.02
Width (m)	5.3	0.61
# Key Members	5	5
Key diameter (m)	0.59	0.07
# Racked	16	16
Racked diameter (m)	0.36	0.04
Racked Length (m)	12.2	1.40
Flow		
Velocity (m/s)	1.2	0.41
Depth (m)	3.5	0.403
Q (m^3/s)	22.26	0.100
Froude #	0.205	0.205

Testing Facilities

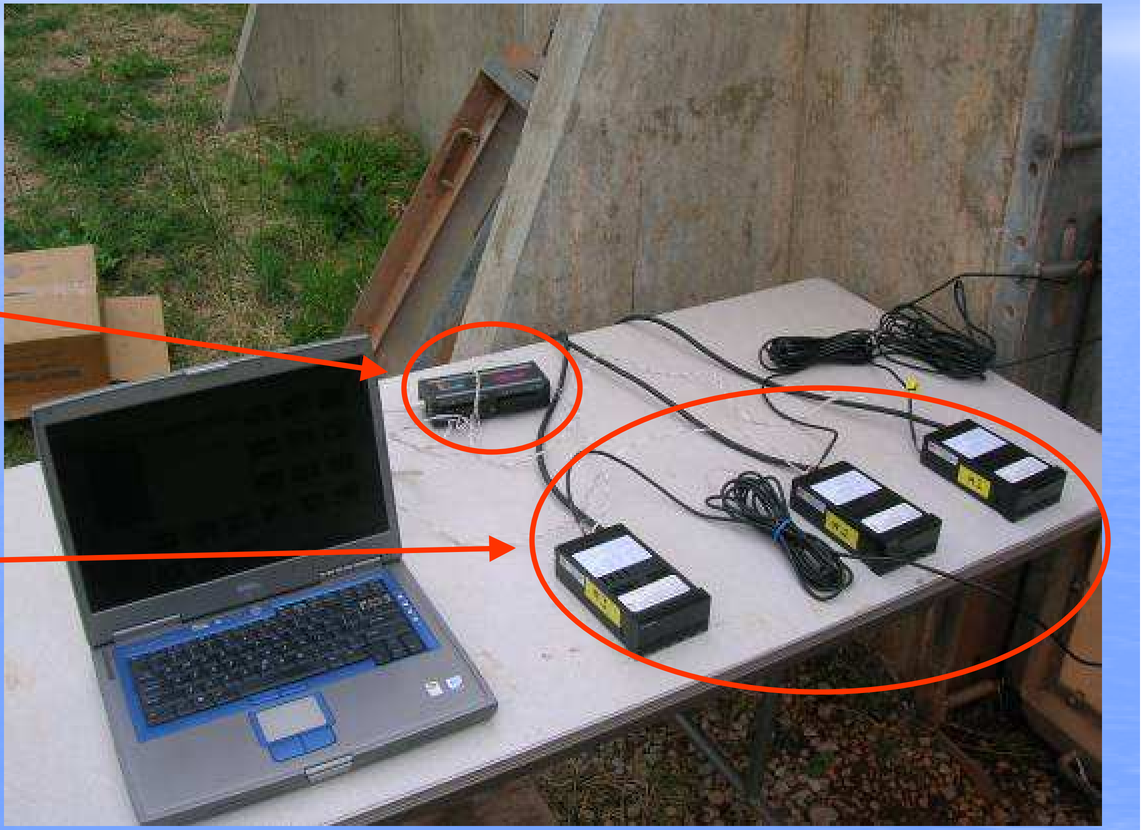
USDA-ARS Hydraulics Lab, 6 ft wide concrete flume.

Testing Setup

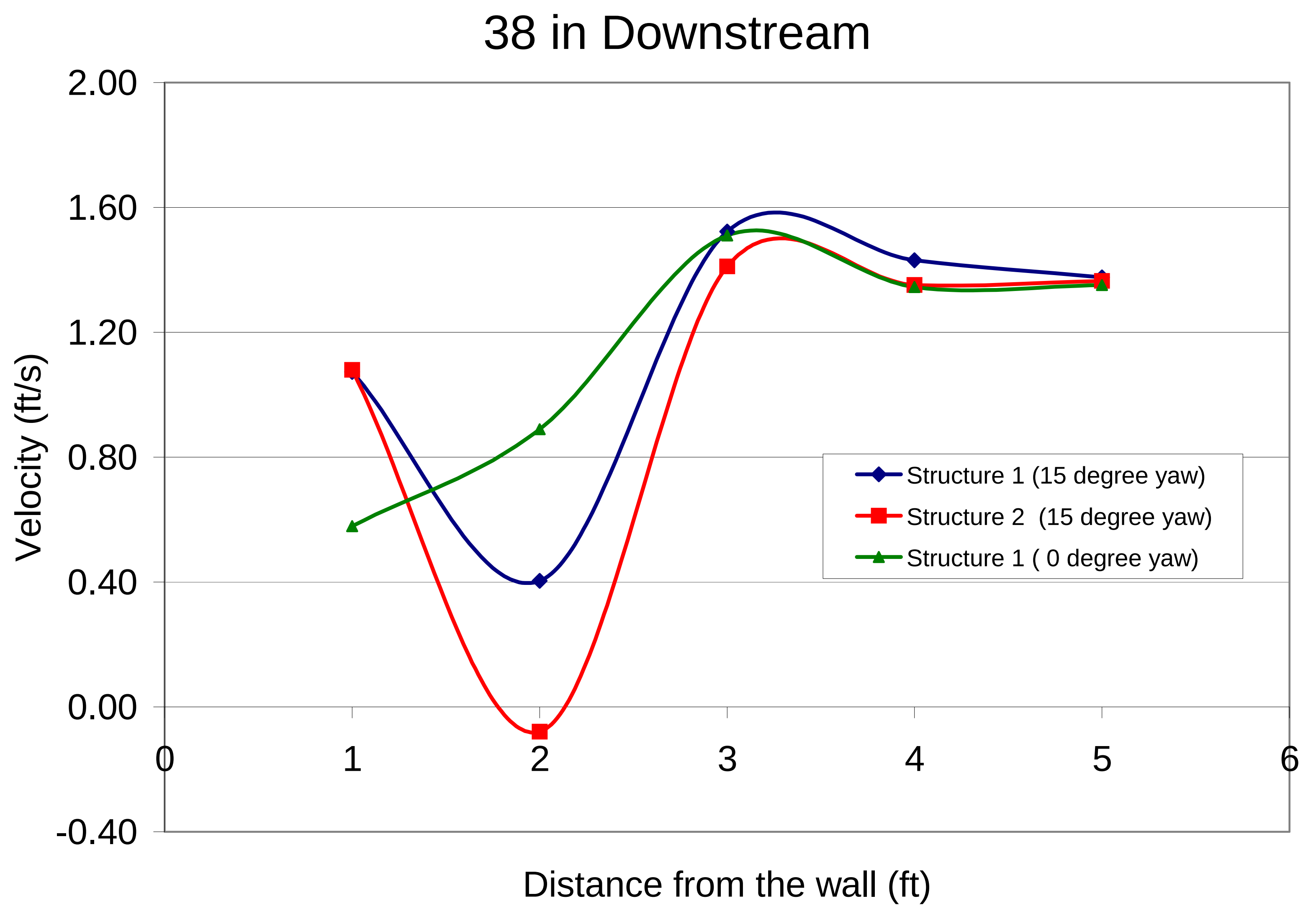


Testing Setup

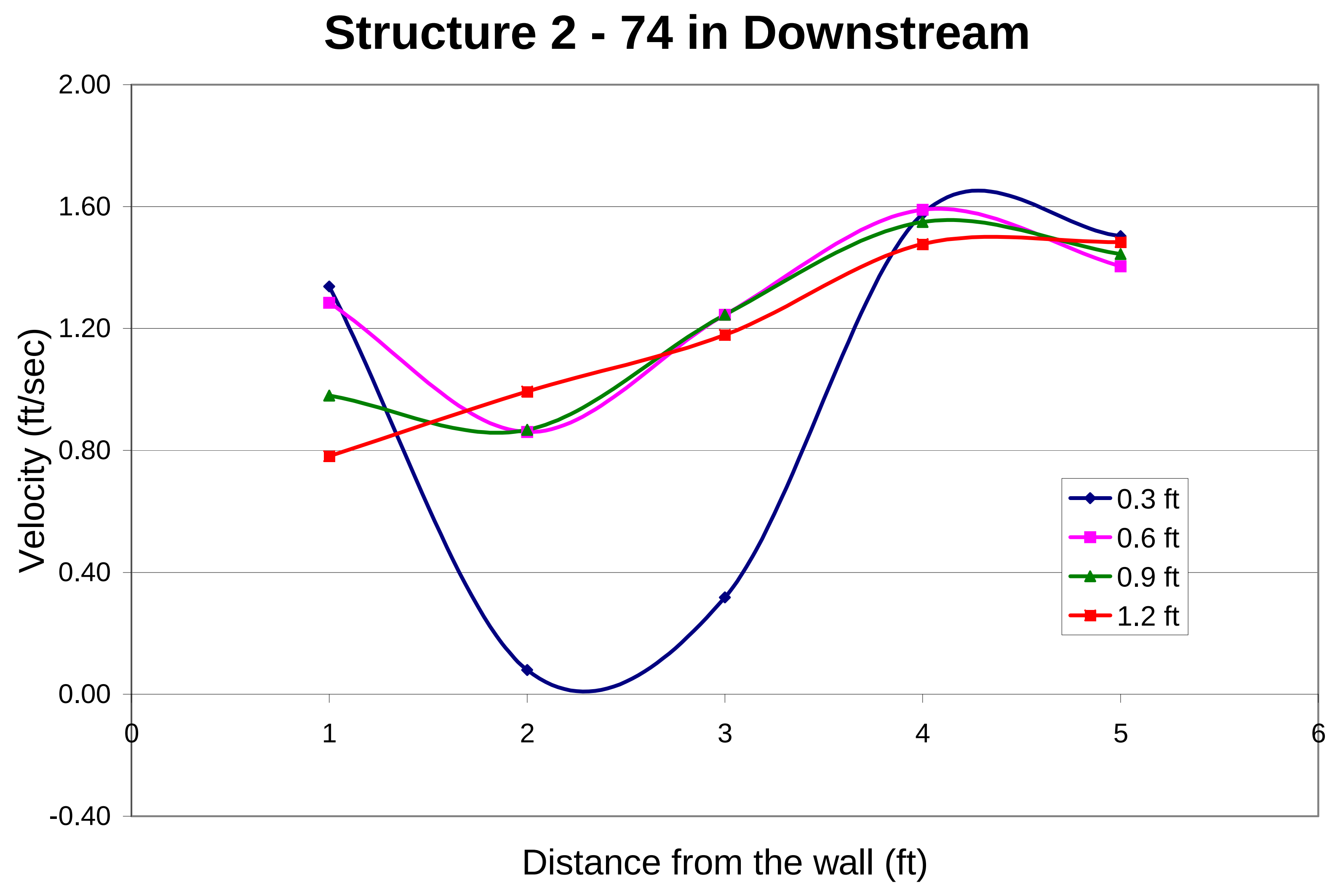
- 3 Artech 20210-100 Load Cells
- Iotech PDAQ Data Acquisition System
- 3 Omega DP25-S Strain Gage Panel Meters
- Dell Laptop



Downstream Velocity Profile



Downstream Velocity Profile



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Test Results

	C_D A (ft^2)	F_m (lb)	F_p (lb)	Fr #
Structure 1 (15° Yaw)	7.66	16.05	10552	0.17
Structure 2 (15° Yaw)	3.95	16.04	10542	0.23
Structure 1 (0° Yaw)	4.63	13.57	8919	0.22

$$C_D A = \frac{2F_D}{\rho V^2}$$

$$F_p = F_m \left(\frac{L_p}{L_m} \right)^3$$

Conclusion

- Structure 2 performed better
  - Lower downstream velocity
  - Lower drag force
- Further research is needed
  - Boundary conditions
  - Rootwads and branches

Recommended Design Criteria

- Similar geometry and construction, but rotated 180°
- Anchor and cabling system should withstand 11kips (50 kN).
- Yaw angle 15°

Acknowledgements

ARS Sedimentation Lab, Oxford, MS.

- Dr. Carlos Alonso
- Dr. Doug Shields

ARS Hydraulics Lab, Stillwater, OK.

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Oklahoma State University

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- Wayne Kiner
- Jana Moore
- Dr. Marvin Stone
- Dr. Dan Storm
- Dr. Paul Weckler

Questions?

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Problem Introduction

Scientists and engineers have gained a greater appreciation of the importance of large wood in fluvial systems in recent years. Wood can control channel form and migration rates as well as provide cover and a diversity of hydraulic conditions for all types of biota. The USDA-ARS-National Sedimentation Laboratory has tested Large Woody Debris Structures (LWDS) in the Little Topashaw Creek located in Oxford, Mississippi. These man made structures have proven to be an efficient method for channel erosion control and habitat rehabilitation. Figure 1 shows the typical plan of LWDS. Major advantages of these structures over existing stream rehabilitation methods include low cost and a natural, aesthetically pleasing design. Three years after construction, thirty-six percent of structures failed during high flows. The loss of these structures has created the need for the establishment of a more durable design.

The USDA-ARS has asked RAW Engineering (RAW) to examine failure modes and potential design improvements for these structures. New designs must induce sediment deposition, improve stability, and remain environmentally friendly and cost effective.

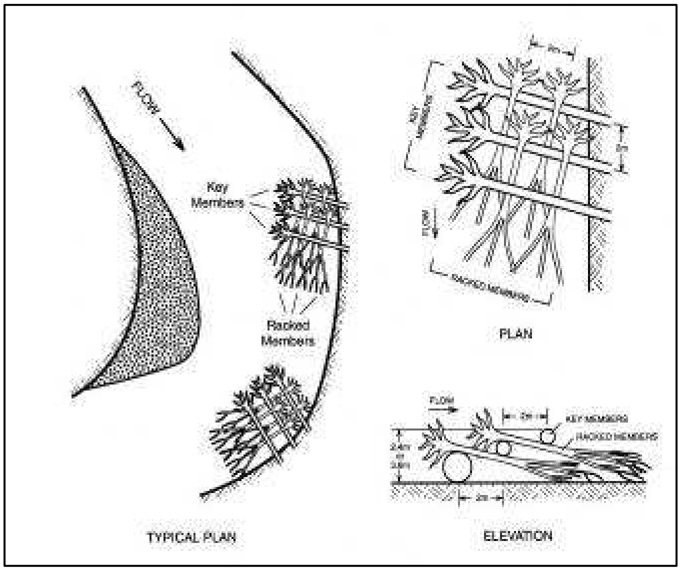

Figure 1 Typical plan of LWDS (Shields 2001)

Statement of Work

The Little Topashaw structures slowed, stopped or in some cases reversed bank erosion. However, a large portion of these structures did not survive significant flow events. The LWDS were designed to withstand a 10 yr flow event with a minimum life of five years. Causes of failure were determined to be increased buoyant force due to drying of structure members, loss of branches and upper members of LWDS, and inadequate anchoring. The natural buoyancy and gradual decay of the large woody debris (LWD) are aspects of the design which can not realistically be altered. Therefore, our engineers will focus on the performance of the anchoring systems. Using scale models, our engineers will determine forces acting on the anchors and compare them with theoretical forces the structure was subjected to. RAW then plans to analyze the structure geometry and develop a more durable design. Another goal is to increase sediment deposition by altering the hydraulic conditions imposed by the geometry of the structure.

Testing will take place at the USDA-ARS Hydraulics Laboratory in an outdoor flume shown in figure 2. The concrete flume is six feet wide and capable of reproducing a wide range of flow conditions. First, RAW engineers will recreate the structures built at Little Topashaw Creek using dimensional analysis and similarity to determine the scale of the model and hydraulic conditions. RAW will build an approximately 1/6 scale model of the LWDS designed by Dr. Doug Shields. Froude number calculations will be used to determine discharge velocity and depth. Equation 1 was used to calculate Froude number. Models will be made of Eastern Red Cedar or another suitable, locally available wood. RAW engineers will perform tests with scale models of the LWDS and determine the forces acting on the anchoring system. The results of these tests will be analyzed and compared to theoretical lift and drag forces calculated for the structures. Statics and Strength of Materials concepts will then be applied to determine a more resilient design. The new design will likely include alternate structure geometry, changes in anchoring positions and cable orientation to minimize the forces acting on the anchors.

Figure 2 Large Concrete Flume at USDA-ARS Hydraulics lab

$$Fr = \frac{V}{\sqrt{gh}}$$

Equation 1 Froude Number

Testing at the USDA-ARS Hydraulics Lab requires the use of siphons to draw water out of Lake Carl Blackwell. These siphons can not be used in subzero temperatures. Due to this fact, there will be little or no availability for testing from

November through March. The lab does have some smaller indoor demonstration flumes. Kinematic similarity is difficult to achieve in these flumes, but they can provide an excellent visual representation of flow variations through and around a structure. RAW engineers will use these flumes to evaluate alternate designs during the winter months. Large scale testing on revised designs will resume in the spring. During this interval our engineers believe RAW and its sponsors would benefit from a trip to the USDA-ARS Lab in Oxford, Mississippi.

Task List

See Appendix A

Literature Review

After years of removing wood from rivers and streams researchers now understand that large woody debris (LWD) is an integral part of stream ecosystems and has a major impact on stream hydraulics and erosion. Animals, natural events, and anthropogenic factors all contribute to the placement of wood in rivers and streams. Several reviews of the literature have shown that LWD provides physical habitat for aquatic fauna as described by Gippel (1995). Removal of LWD decreases the amount of habitat for macro invertebrates and fish and reduces diversity of hydraulic conditions in streams. This lack of LWD leads to increased channel velocity which leads to an increase in channel incision.

With scientists and engineers now trying to find ways to rehabilitate damaged stream systems, LWDS seem to be an obvious choice for channel rehabilitation. According to Shields (2004) costs for LWDS construction near Oxford, MS was 19% – 49% of recorded costs for recent stone bank stabilization in the same region. Fischenich and Morrow (2000) say that the objectives that can be accomplished with LWDS include creating pool habitat, generating scour, increasing depths through shallow reaches, and reducing erosion. However, there are some major concerns with the design of LWDS. As stated by Shields (2004), the major design issues include: (1) use of buoyant materials,

(2) use of materials that decay, and (3) dual objectives of channel stabilization and habitat rehabilitation. While many designs exist, ongoing research to design the ideal LWDS continues. Ideal LWDS should meet the following criteria: (1) provide habitat for aquatic biota, (2) reduce stream velocities to induce sediment deposition, (3) stabilize bank toe, (4) withstand up to five year return period flows, and (5) cost less than other forms of stream rehabilitation.

Traditionally, stream bank stabilization techniques have been both expensive and aesthetically unpleasing. Past attempts have also had very little success in providing wildlife habitat. Previous structures include vegetated rock walls, simple rip-rap structures and rock and gabion arrangements. Figure 3 contains pictures of rip-rap and rock and gabion structures.

Figure 3 Rip-Rap   Rock and Gabion

LWDS have many advantages over traditional rock structures, including low cost, a natural look and the use of locally available materials. LWDS, also provide a variety of habitats for wildlife, which is important in an increasingly environmentally conscious society. One distinct advantage LWDS have over other types of structures is the formation of wildlife habitat while improving channel stabilization. Placing wood, a natural material in the flow mimics natural habitats. Velocity decreases as the flow passes through the structure. Sediments settle out at these lower velocities. Sediment deposition is a key factor that is not prevalent in other types of stabilization structures (Shields, 2004). The cost of the LWDS is generally lower than that of any rock structure. The cost of the LWD ranges from $12.90 to $164.50 per meter of channel length due to differences in design complexity. Traditional rock structures cost between $150.00 and $300.00 per meter (Fischenich, 2000).

Shields (2004) states the design of woody debris structures creates a few key problems. First, wood being a buoyant material, will have a tendency to float in high flow situations. Second, the fact that the structure is not fully submerged at all times, directly affects the physical properties of the wood. The rate of decay of the structure members increases due to the continual soaking and drying of the structures. Design life of a LWDS is less than that of an artificial structure due to this decay.

Design Requirements

Shields (2004) states that the cost per unit length of bank treated must be less than the cost of traditional stone structures for the project to be feasible. The structure must be created with materials that are locally available. Certain types of wood are more durable over time and should be used where available. According to Johnson and Stypula (1993) western red cedar is the most desirable in terms of durability. The structure must also contribute to and improve natural recovery and establishment of riparian zone habitats and plant communities. The structural design must be able to withstand at least a 5-year return interval flow without failure. The hydraulic abilities of the structure should be able to trap and retain sand-size sediments. The LWDS should not significantly increase the duration of overbank flooding during the growing season although flood stages may be increased. The structure should also be sized to promote berm formation that creates a two-stage channel similar to a stable Stage V or VI channel within the region. Geotechnical parameters allow for some additional mass wasting of vertical banks but the structures should trap and retain materials from the caving of the bank. The bank height should be reduced to stable levels when structures are filled with sediments. The construction criteria include minimal requirements for specialized training and equipment. Structures should be built from within the channel using equipment that will cause minimal additional clearing and disturbance (Shields, 2004).

Testing Procedure

Testing took place at the USDA-ARS Hydraulics lab, located in Stillwater, Oklahoma. The tests were set up in an outdoor concrete flume having a width of six feet.

RAW Engineering attempted to accurately model the structures used at the Little Topashaw Creek and the flows to which these structures were subjected. The goal of these tests was to determine velocity profiles and forces which were applied to the anchoring systems. Experimental results will be compared to theoretical values to determine if original structures are performing as designed. Our engineers will then analyze the acquired data and design new structure geometries and anchoring systems to minimize the forces on anchors and provide a more durable structure.

Equation 2 Density

$$\rho = \frac{m}{v}$$

Equation 3 Drag

$$F_{drag} = \frac{\gamma_w \times V^2 \times C_D \times A}{2 \times g}$$

Equation 4 Buoyant force

$$F_{buoyant} = Volume(\gamma_w - \gamma_d)$$

Figure 4 Equations

Figure 5 LWDS Model in Flume

The first step was to obtain the persimmon timbers used in constructing the LWDS model. A sample piece of the wood was weighed and then submerged in water using graduated cylinder. Equation 2 was then used to determine the density of the wood. Our engineers then calculated the forces acting on the structure using equations 3 and 4. Our engineers then constructed a model of the LWDS tested at the Little Topashaw Creek. The model dimensions were calculated using Froude number similarity. The width of the structure was set to be 1/3 that of the flume. The prototype to model ratio was determined using the model width as the governing parameter. Model is shown in figure 5. The model was anchored with cables running diagonally between the four corners of the structure. At the front end of the structure, the cables were extended through pulleys and connected to two Chatillon remote load cells that measured the cables respective tensions. Load cell measurements were obtained from a Chatillon DFGS 10. The available equipment was capable of measuring forces from only one load cell at a time. Therefore, our engineers had to duplicate testing procedures in order to collect pertinent data from both load cells which can be seen in figure 6. Water flow was then established in the flume and normalized at a depth of 1.5 feet and a flow rate of 10 cfs. Velocity measurements were taken across the flume at increments of one foot and at four different depths. These measurements were taken at points ahead of, within, and behind the structure. To measure buoyancy, tailwater elevation was raised and flow was discontinued. This provided enough water to fully submerge the structure and provide zero velocity. Tension in a cable was then recorded. We then drained the flume and switched the readout to the other load cell and repeated the test.

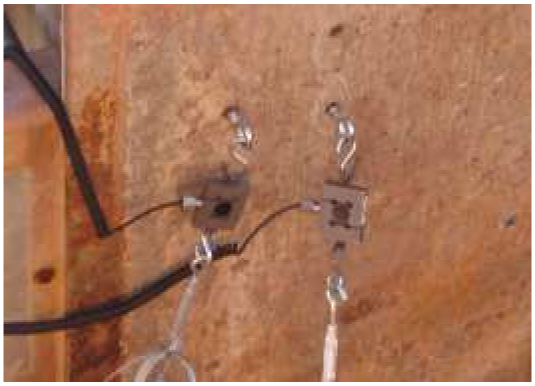

Figure 6 Load Cells

Test Results

Engineers at RAW performed these tests 11/22/2005 at the USDA-ARS Hydraulics Lab. Table 1 shows the hydraulic conditions at testing and ideal conditions calculated. The data shows that our tests were well within a practical range to obtain realistic data. Calculated forces and measured tensions can be seen in Table 2. These tensions were

	Run 1	Run 2	Ideal
Point Gauge	0.455	0.453	NA
Flowrate (cfs)	11.35	11.28	10.89
Depth (ft)	1.75	1.79	1.75
Area (ft^2)	10.5	10.75	10.5
Velocity (ft/s)	1.08	1.05	1.04
Froude #	0.144	0.138	0.138

Table 1 Hydraulic conditions

Forces (lb)	Theoretical	Measured
Buoyant	11.26	7.79
Drag	3.47	2.95
Sum	14.74	10.74

Table 2 Force comparison

obtained under steady hydraulic conditions. Measured tensions recorded were below calculated forces. There are multiple possibilities for this. Calculated forces were higher than actual forces. Not all of the forces induced by the water were transferred to the cables. Frictional forces between the structure and flume resisted part of the induced force. Table 3 shows the vertical components of the measured tensions. This is the force that will be acting on the anchors. The forces acting on the anchors are less than the calculated forces under steady flow. However, the peak forces occurred before the flow stabilized. While the flow was rising the measured tension was twice that of the steady state tension. This trend will most likely hold true on full scale models in natural stream systems. If this is the case, then a factor of safety for the design of anchoring systems should be added for this dynamic load.

F_v (lb)	Cell 2	Cell1	ΣF_v (lb)
Buoyant	5.15	2.02	7.17
Drag	2.75	0.08	2.83
Sum	7.90	2.10	10.00
Peak	10.84	8.55	19.39

Table 3 Vertical forces

Velocity data was measured with a Marsh-McBurney flow-mate 2000 velocity meter. We entered the data into MS Excel and graphed the profiles. Figure 7 shows the velocity profile behind the LWDS model; other velocity profiles can be found in Appendix C. Approach velocity was consistent. The velocity began to drop at the bottom of the channel in front of the structure. Velocities within the structure were significantly lower than outside the structure. The velocity behind the structure was lower than the velocity on the open

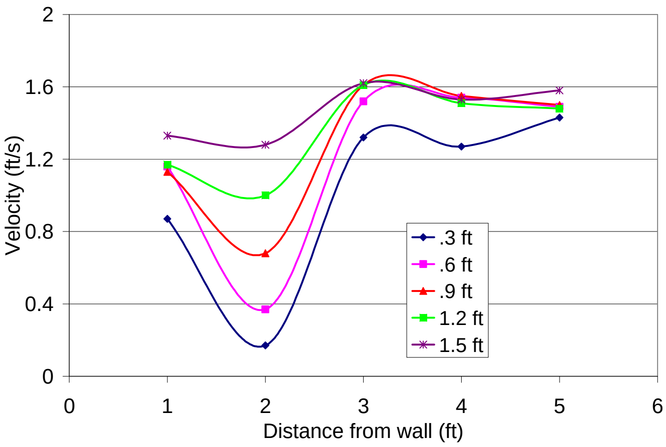

Figure 7 Velocity profile behind structure

side of the channel. These results show how the structure will work in the field to induce sediment deposition in and behind the structure. At lower velocities, the water will not have enough energy to transport sediments, and the particles will then settle.

Discussion:

While the measured forces were less than the calculated buoyancy and drag at steady state, our force calculations were inadequate for the dynamic loading due to the initial surge of water. Structures in natural stream systems will undergo low flows that increase to a peak and then decrease. Therefore, it is important to look into this type of flow as well as a steady uniform flow. More testing is needed to quantify how the structure reacts to varying flows with time. We would also like to test forces at each anchor and record the forces over time.

The LWDS model that RAW Engineering tested affected velocities in a way consistent with previous designs. Velocities will be slowed even more when entire trees are used as opposed to cylindrical members. This area of the design is adequate, but could possibly be improved.

Our contacts at the USDA-ARS encouraged RAW to neglect the geotechnical aspects of this problem in order to simplify calculations and models. We now feel that this could have a major impact on the structure’s stability and sediment deposition. We hope to include geotechnical aspects in future tests and designs.

Designs:

Our engineers have come up with two easily implemented solutions. The first solution is to add a factor of safety of at least 2 when designing the anchoring systems for LWDS. This factor of safety will account for the peak force during the initial surge. Next we suggest that all the members of the structure be bound together. Bounding of members will minimize shifting and loss of members. Both of these solutions will increase the stability of the structure with a minimum additional cost.

RAW Engineering has developed alternate geometries for LWDS design. Our engineers will analyze these new designs for stability and sediment deposition throughout the spring semester. The first concept we would like to test includes vertical members driven into the streambed. We believe this will provide additional structural support for the LWDS. Figure 8 shows a side view of this design. Concerns for this design are soil strength and additional cost. The next alternative includes additional key members in the interior of the structure. Adding members to the interior of the structure will add resistance to decrease velocity. Additional key members will have a greater effect on sediment deposition than strength. This design can be seen in figure 9.

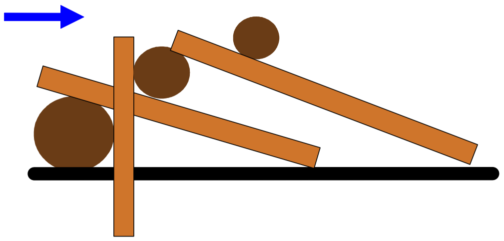

Figure 8 LWDS with vertical member

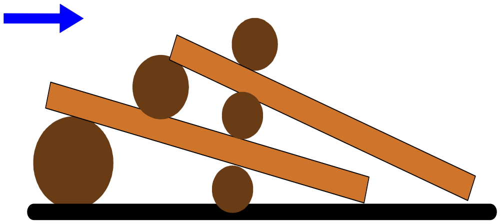

Figure 9 LWDS with additional key members

Conclusion:

RAW engineering has researched the problem, performed tests, and generated new design concepts. We will develop a better explanation of the hydraulic conditions induced by the structures and forces exerted on the structures. Our next step is to carry out more in depth experiments and generate a final design. Our engineers will construct models of the new designs and test them throughout the next semester. Our final design will be presented at the end of the spring semester.

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Appendix A

Task Summary

- 01 Research Project
    - 01-01 Project description
    - 01-02 Structure Geometry
    - 01-03 Anchoring System
    - 01-04 Modes of Failure

- 02 Determining Project Goal
    - 02-01 Meeting with Carlos Alonso and Doug Shields
    - 02-02 Project Definition
    - 02-03 Schedule

- 03 Develop Testing Methods
    - 03-01 Froude Number modeling
    - 03-02 Determine model scale
    - 03-03 Schematics for testing procedure
    - 03-04 Determine Possible dates for testing

- 04 Equipment and Materials
    - 04-01 Collect Woody Debris Samples
    - 04-02 Obtain appropriate range of load cells
    - 04-03 Obtain Marsh-McBirney Flowmeter
    - 04-04 Purchase hardware
    - 04-05 Estimate Cost of Testing

- 05 Testing Procedure
    - 05-01 Build LWDS model
    - 05-02 Run Test in Concrete Flume
    - 05-03 Data Collection

- 06 Evaluate Data
  - 06-01 Compare to Theoretical
  - 06-02 Determine Weaknesses

- 07 Engineer New Design
  - 07-01 Evaluate Stability
  - 07-02 Evaluate Hydraulic Conditions
  - 07-03 Analyze Potential Sediment Deposition
  - 07-04 Determine Cost and Feasibility

- 08 Meet with Project Sponsor
  - 08-01 Plan to Visit Sedimentation Lab in Oxford
  - 08-02 Travel to Mississippi
  - 08-03 Introduce New Design

- 09 Test Design
  - 09-01 Determine Stability
  - 09-02 Determine Sediment Deposition

- 10 Revise design
  - 10-01 Evaluate Design and Make Final Changes

- 11 Present Final Design to sponsor
  - 11-01 Compose Final Report
  - 11-02 Create Power Point Presentation
  - 11-03 Present Design

Appendix B

Budget

	Budgeted Items	Description	Purchase Date	Date	Comments	Cost
1	Flume Test Anchoring Items	Pulleys, I-bolts, Cable, Zip Ties, Turnbuckle, Wire Clips, Quicklinks	Nov. 15, 2005	Nov. 15, 2005 - End of Testing	Purchased at Lowe's	$40
2	LWDS materials	Wood Members of Stucture	N/A	Nov. 15, 2005 - End of Testing	Taken from Dr. Weckler's Property	N/A
3	Chainsaw	Used to acquire wood for LWDS	N/A	Nov. 12, 2005	Two saws borrowed from Wayne Kiner and Paul Weckler	N/A
4	Transportation	Visits to the Hydraulics Lab	N/A	Both Semesters	Vehicles Checked Out from BAE Lab	Unknown
5	Trip to Sedimentation Lab in Oxford, Mississippi	Vehicle Travel, Lodging	Second Semester	Second Semester Date Unsure	560 miles to Oxford so 1200 miles Total Travel at $0.45 a mile, 2 Night Stay at $50.	$840.00
6	Additional Testing Material	Anything Needed for Testing	TBD	TBD	Materials will be Needed for Further Testing Next Semester	TBD

Appendix C

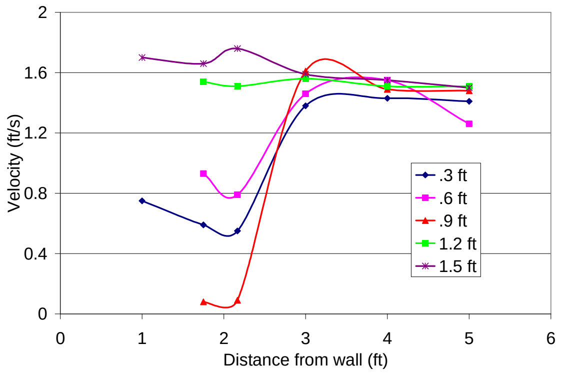


Figure A.1 Velocity profile within structure

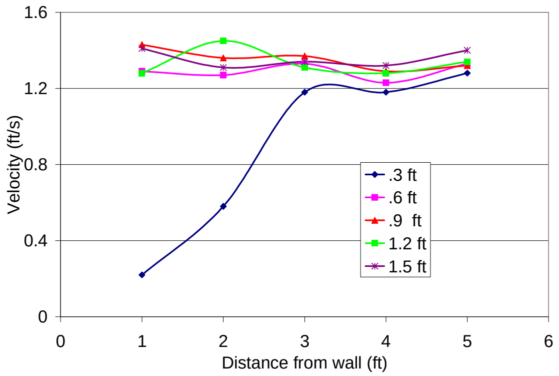


Figure A.2 Velocity profile at beginning of structure

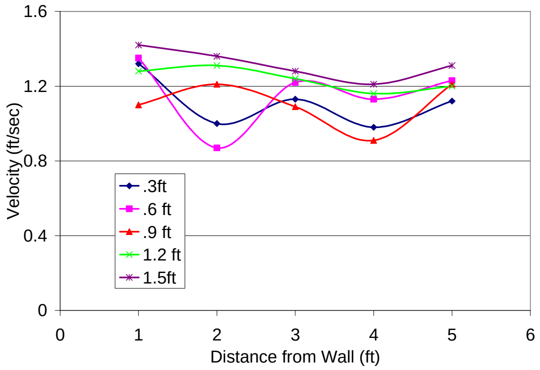


Figure A.3 Velocity profile ahead of structure

Woody Debris Streambank Stabilization

Joe Paul Edwards
Roberto Espinoza
Dave Mercer
Ryan Woolbright

BAE 4012 – Fall 2005

Agricultural Research Service

RAW
Engineering

BIOSYSTEMS & AGRICULTURAL ENGINEERING
Oklahoma State University

River and Waterways Engineering

Mission Statement:

At RAW Engineering we strive to provide efficient, economical and innovative solutions to environmental problems without compromising the conservation of our natural resources.

Project Sponsor

Agricultural Research Service

Federal Agency that conducts research to develop solutions to agricultural problems of high national priority

National Sedimentation Lab – Oxford, Mississippi

Large Woody Debris Structure

LWDS
From
Pacific
Northwest

Agricultural Research Service

RAW
ENGINEERING

BIOSYSTEMS & AGRICULTURAL ENGINEERING
Oklahoma State University

Project Introduction

- Benefits of LWDS
  - Reduction of channel erosion
  - Habitat rehabilitation
- Original design implemented in Little Topashaw Creek.
- 36% of structures failed.

Criteria for Ideal LWDS

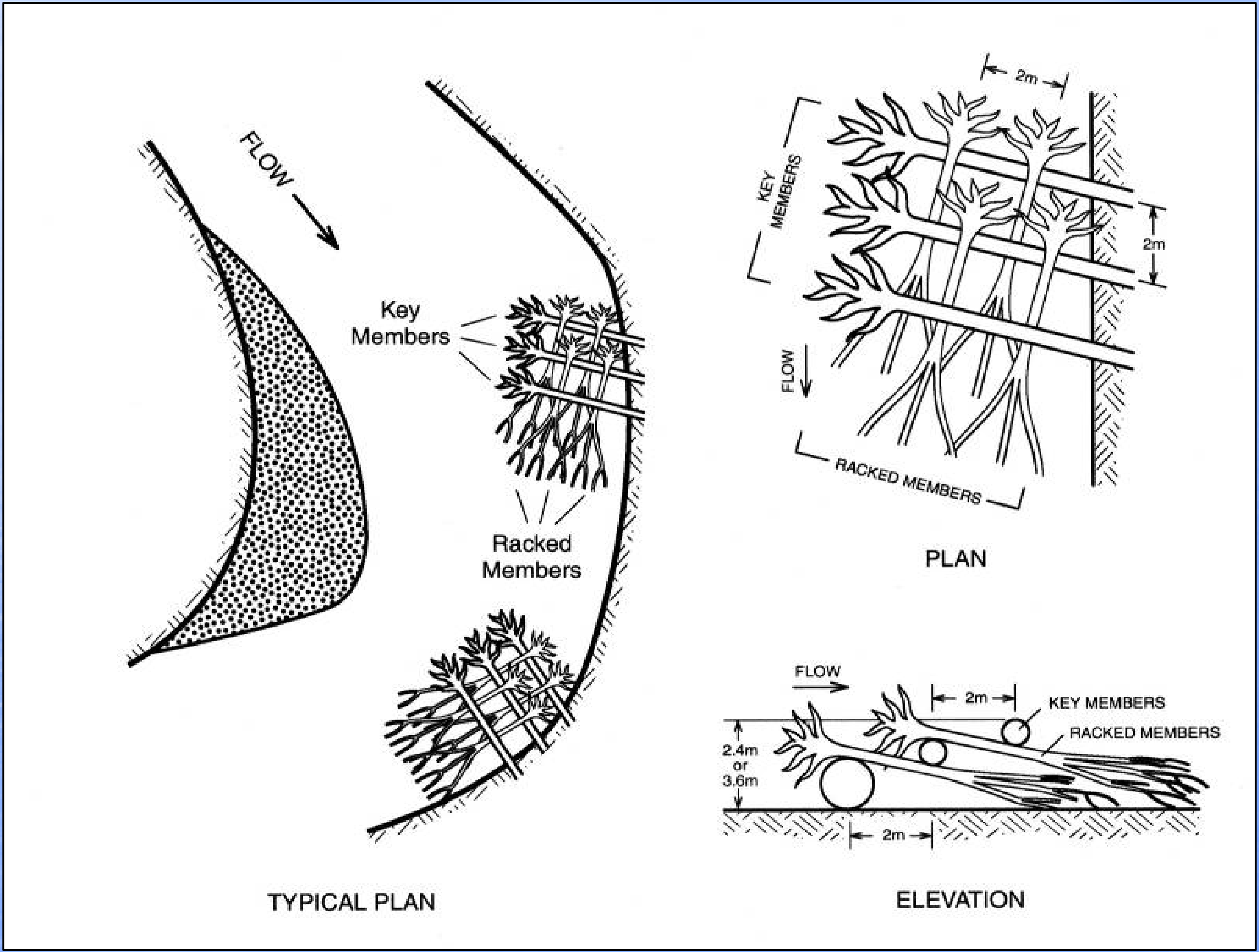
- Provide habitat for aquatic biota
- Reduce stream velocity and induce sediment deposition
- Stabilize bank toe
- Withstand 5-yr return period flows
- Cost less than traditional methods

Traditional Bank Stabilization Methods

Rip-Rap

Rock and Gabion

LWDS Original Design



LWDS on Little Topashaw Creek

Design Challenges

- Use of buoyant material
- Use of materials that decay
- Dual objectives of channel stabilization and habitat rehabilitation
- Soil Strength

Objectives

- Examine failure modes
  - Anchoring system
- Examine hydraulic characteristics
- Design a more durable structure
  - Alter structure geometry
  - Alter anchoring system

Modeling

- Kinematic and dimensional similarity were used to determine model parameters.
- Prototype to model ratio was determined using the channel width as the governing parameter.
- Velocities and depths were calculated using the Froude number.

$$Fr = \frac{V}{\sqrt{gh}}$$

Modeling

Scale Factor = 0.152

	Prototype	Model
Elevation (m)	2.6	0.40
Length (m)	17.8	2.12
Width (m)	5.3	0.61
# Key Members	5	5
Key diameter (m)	0.59	0.07
# Racked	16	16
Racked diameter (m)	0.36	0.04
Racked Length (m)	12.8	1.40

Collecting Structure Material

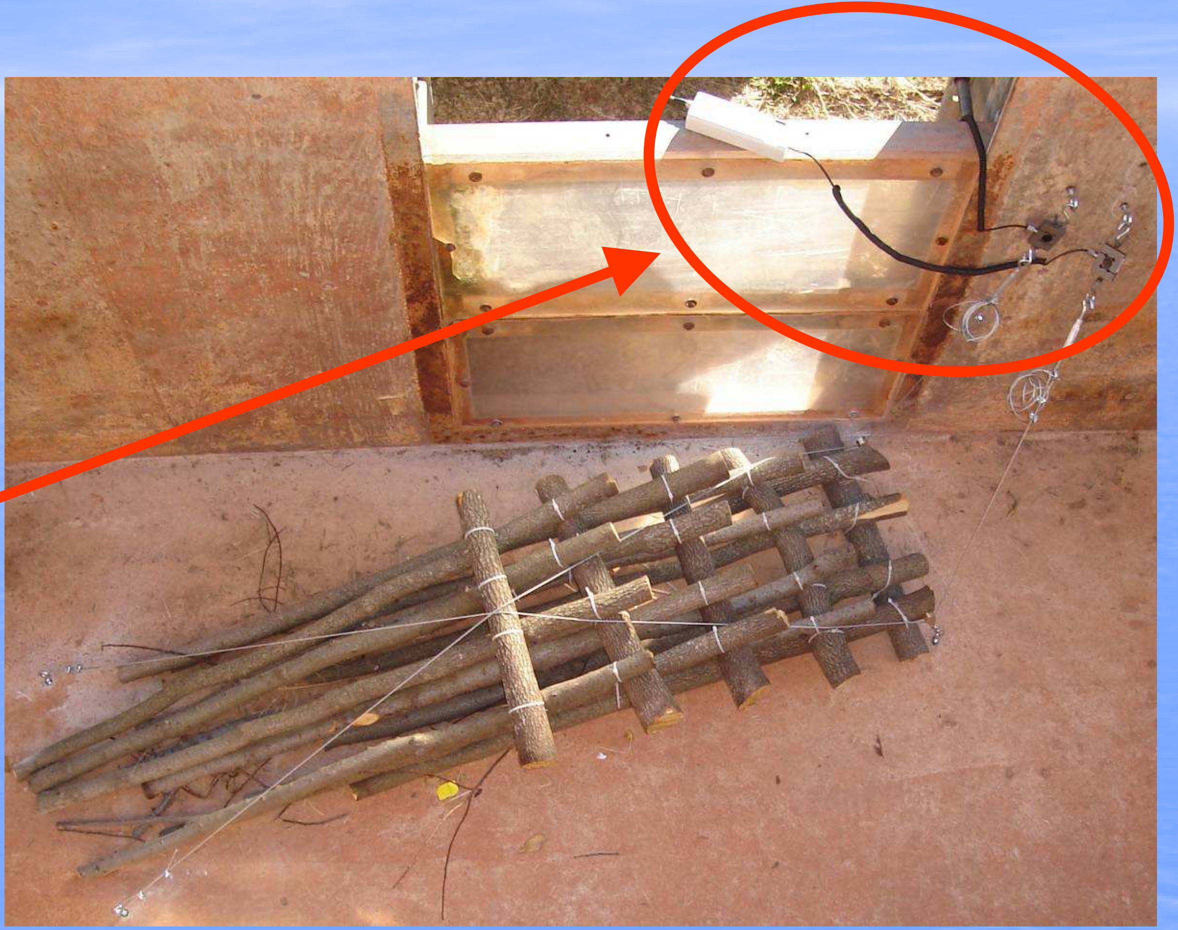
- Harvesting trees NE of Stillwater

Testing Facilities

USDA-ARS Hydraulics Lab, 6 ft wide concrete flume.

Testing Setup

- Structure secured with two diagonal cables
- Load cells attached to walls of flume

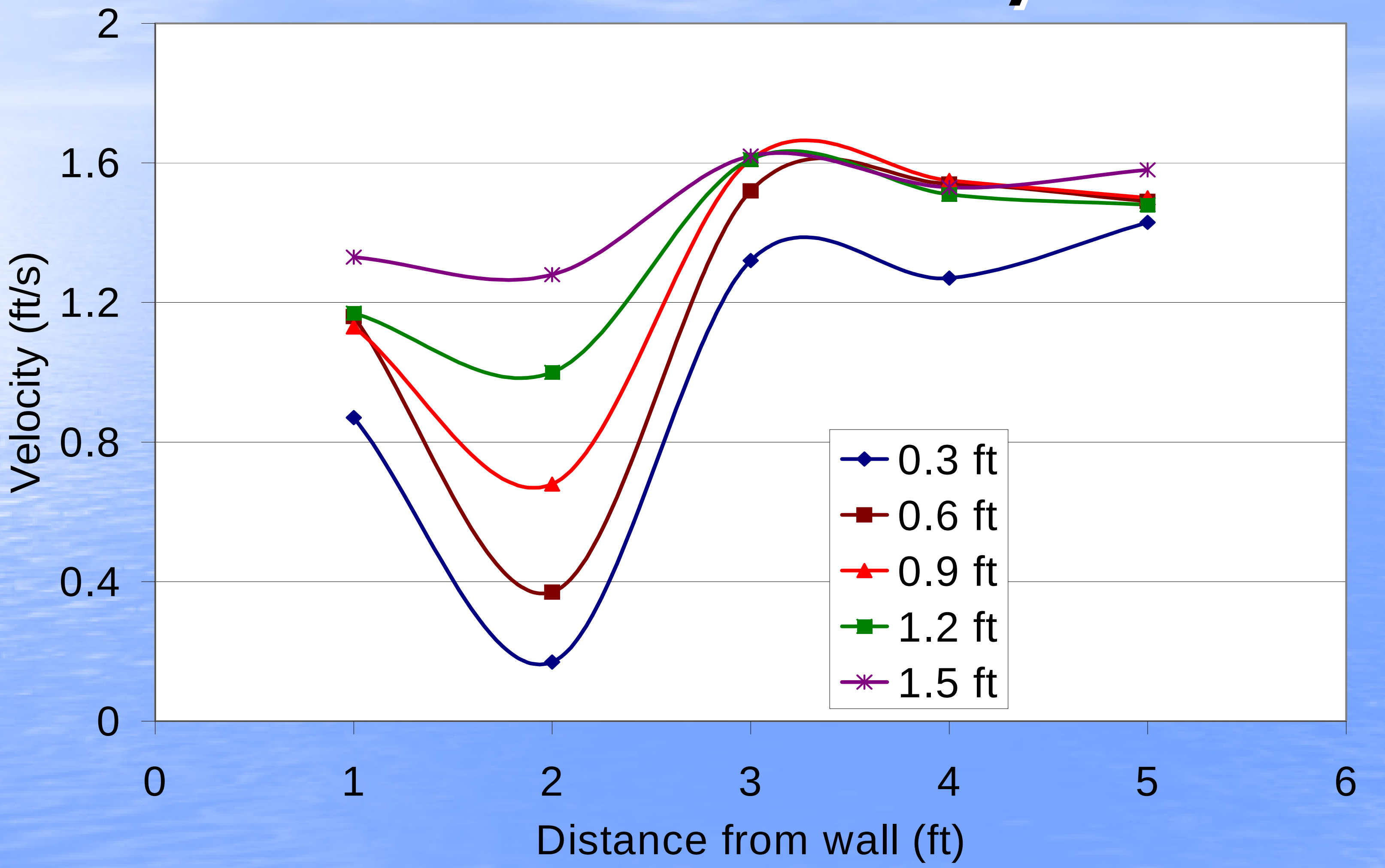


Test Results

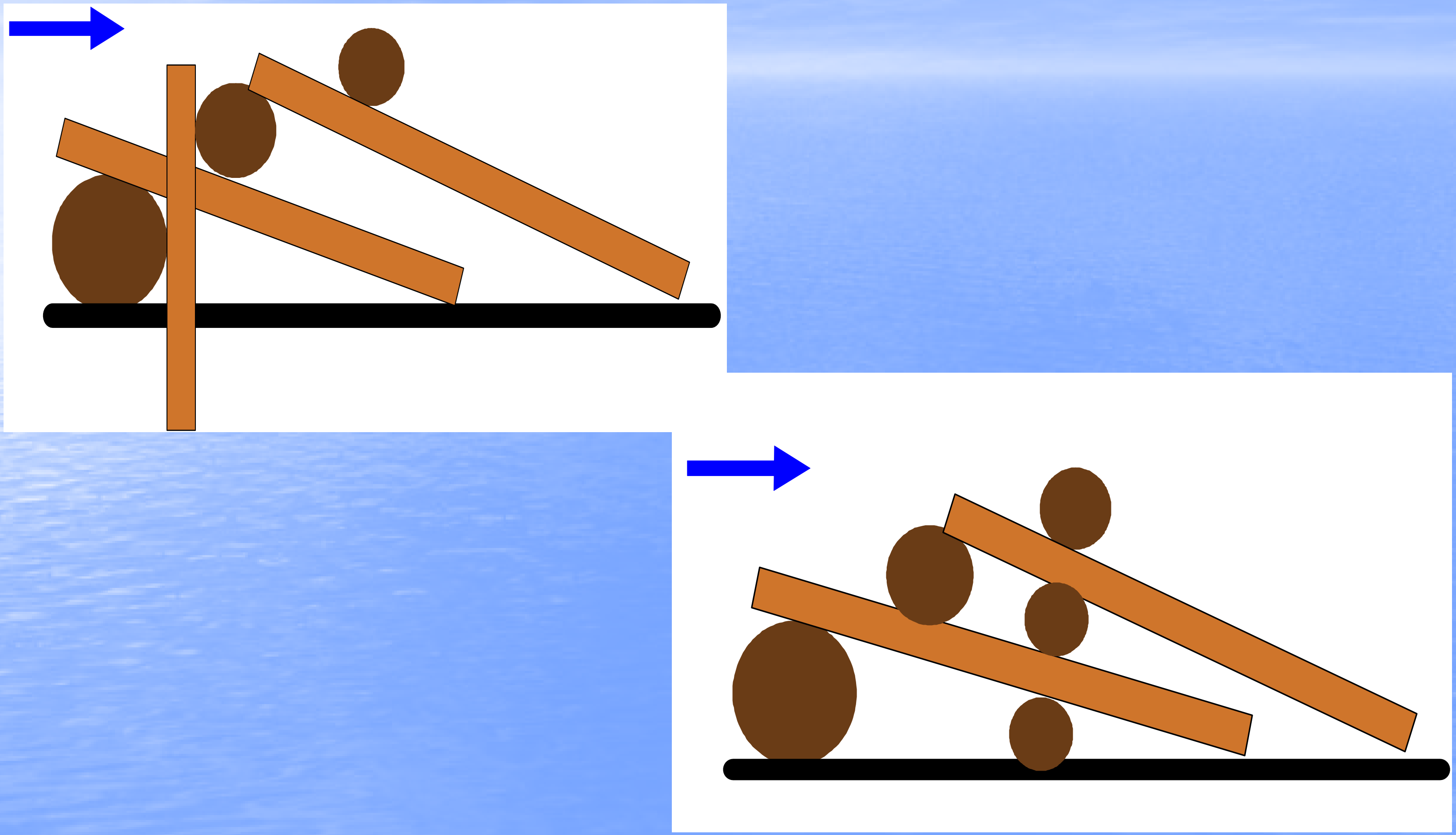
Forces (lb)	Calculated	Measured
Buoyant	11.26	7.79
Drag	3.47	2.95

F_v (lb)	Cell 2	Cell1	ΣF_v (lb)
Buoyant	5.15	2.02	7.17
Drag	2.75	0.08	2.83
Sum	7.90	2.10	10.00
Peak	10.84	8.55	19.39

Downstream Velocity Profile



Future Design Concepts



Conclusion

- Structures as built are promising
- More testing is needed
- Design alterations could provide support needed to make LWDS a viable long term alternative for stream rehabilitation

Acknowledgements

ARS Sedimentation Lab, Oxford, MS.
- Dr. Carlos Alonso
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Biosystems Engineering Faculty
- Dr. Dan Storm
- Dr. Paul Weckler

Any Questions?

¿Preguntas?