Trust Fund 2009 Work Program

Date of Report: September 30, 2010: Progress Summary
Date of Next Progress Report:
Date of Work Program Approval: June 16, 2009
Project Completion Date: ~~Dec 30, 2011~~ June 30.2012

I. PROJECT TITLE: Controlling the Movement of Invasive Fish Species

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Location: Laboratory studies will be conducted at the Saint Anthony Falls Laboratory, Minneapolis and the St. Paul Campus of the University of Minnesota.

Total Trust Fund Project Budget:	**Trust Fund Appropriation:**	**$**	**300,000**
	Minus Amount Spent:	**$**	**138,643**
	Equal Balance:	**$**	**161,357**

Legal Citation: M.L. 2009, Chp.143, Sec. 2, Subd. 6d.

Appropriation Language:
$300,000 is from the trust fund to the Board of Regents of the University of Minnesota to develop and test sonic barriers that could be effective in preventing and controlling the movement of invasive carp in Minnesota's waterways. This appropriation is available until June 30, 2012, at which time the project must be completed and final products delivered, unless an earlier date is specified in the work program.

II. PROJECT SUMMARY AND RESULTS:

Great ecological benefit for many Minnesota lakes will be gained if effective barriers can be constructed to control the movement of invasive carp. A class of barrier technology, that shows promise for this application, is based around the use of air bubble curtains that generate sonic and other fields. Not only do the physical fields, e.g., sound and displacement, generated by bubble curtains have the potential to be targeted to exploit the biology of carp, barriers based on bubble curtains can also be inexpensive, portable, and safe.

The goal of the current project is to design and assess the effectiveness of bubble curtain barrier technologies as a means of controlling carp movements in the connection channels of lake systems.

Two main outcomes are expected:

(1) Laboratory flume studies to demonstrate the effectiveness of bubble curtains as a potential barrier for carp movement. This will involve (i) measuring and analyzing carp responses to the physical fields generated by various bubble-curtains and (ii) the optimization of bubble curtain designs under various flow conditions.

(2) Preliminary determination of the effectiveness of bubble curtain barriers to control carp movement at the field scale. This testing will utilize the Outdoor Stream Laboratory (OSL) and main channel at the Saint Anthony Falls Laboratory; facilities that provide a field scale stream settings which can be tightly controlled and monitored. This approach will, through systematic testing and enhancement, assess the feasibility of carp barrier designs based on bubble curtains.

III. PROGRESS SUMMARY AS OF *(date)*:

Amendment Approved: 12/17/2009

Quoting from the letter of Prof Cuthbert send to LCCMR on 11/04/2009. “Unexpectedly the deep well that supplies this center with water suffered a complete failure this past August. After a lengthy process we have discovered that premature pump failure was the cause and that we need to replace the pump along with many of its associated wires and pipes to get the center running so that the studies can take place. The total cost of the repair is estimated at $20,000. We have secured $5,000 from the College and I am contributing $5,000 from the department for this replacement cost. The only capitalized cost will be the $7,000 pump, which will come from university funding. Both of the LCCMR projects which are slated to use this facility have budgeted for supplies for this center and the PIs are willing to support this repair effort ($5,000 Pelican; $4,000 Voller)”

The functioning of the deep well in the aqua center referred to in Prof Cuthbert’s letter is critical element in the completion of the work in Result 2. In addition a more detailed testing is now planned for Result 2, requiring a reassignment of effort.

To cover the contribution to the deep well fix identified in Prof Cuthbert’s letter and the increased effort in Result 2, I am requesting a shift of $6,109 into the Result 2 Budget. This will cover the $4,000 of the well fix cost plus a $2,109 increase in personnel costs. This additional funding is covered by a reduction of $1,308 in the personnel costs of Result 1, a reduction of $4,210 in the personnel costs of Result 3, and a reduction of $268 in the non-capital equipment cost of Result 3.

Summary 3/31/2010

A preliminary design of bubble curtain fish barriers has been completed (see detailed report in **result status 3/31/2010 for Result 1**). Two distinct barrier designs have been identified, developed and build. One is based on a fine-bubble diffuser and the other on a coarse-bubble diffuser. The primary physical properties that can be controlled through diffuser design are the bubble size, frequency of formation, and density of bubble curtain. Preliminary results indicate that these two designs will be able to produce a wide range of barrier induced physical, flow and sound conditions. The next stage of the project is to measure and quantify the physical fields generated by the designed barriers,

As the project moves forward the plan is to incorporate the barrier deigns into experiments that will determine the response of fish in the vicinity of a bubble diffuser barrier operating under a variety of conditions. In addition to well designed and understood bubble diffuser technologies this requires experimental set ups for testing fish behavior. Of key importance is a controlled environmental that can track fish movements automatically through the use of PIT tags. At this point such an experimental facility has been realized and the effective ways of tracking fish with PIT tags has undergone preliminary testing.

Amendment Approved 6/25/10

We are requesting that a small amount of funds ($3,576) initially allocated for civil service staff at SAFL be re budgeted for an undergraduate student worker. Note this will require adjustment in personnel costs and a reduction of the SAFL lab fee, see Budget Justification.

Summary 9/30/2010

A key result this last half year has been the development of a bubble barrier that shows a reasonable level of effectiveness. Over a 7 hour testing period it has been demonstrated that the barrier can reduce fish passages by 75%. This level of effectiveness could be sufficient for the use of these barriers in the management of common carp movements. Ongoing work is directed at (i) further improving the barrier design and (ii) developing an understanding of fish behaviors in the vicinity of the barriers. Below a more complete summary is provided. Full details are given further below in reporting the finding of the Project Results.

A study to identify and quantify the hydrodynamic fields generated by a bubble curtain barrier has been completed (see detailed report in **result status 9/30/2010 for Result 1**). The focus of the measurements has been on the flow and acoustic fields generated by the two diffuser types. Understanding the physical fields will help direct the design of barriers to be tested with carp at the Aquaculture Center. Measurements have revealed that the fine-bubble diffuser generates a relatively strong flow field, but weak acoustic field; while the coarse-bubble diffuser generates a weaker flow field, but considerably stronger acoustic field. Both diffusers were found to generate a sound that is within the hearing range of carp that is significantly higher than background noise in the flumes.

A PIT tag system to detect carp movement within the test tank at the Aquaculture Center was developed and tested (see detailed report in **result status 9/30/2010 for Result 2**). The PIT tag system includes three to four antennas spanning the channel width at evenly spaced locations around the test channel. The antennas passively detect when a carp implanted with a PIT tag (microchip) passes through a specific point in the tank. The system has been tested to be approximately 99% accurate to detect carp passage. Along with the tracking system, a strict testing protocol has been developed to restrict the amount of variables influence carp behavior between tests.

The initial Mark I barrier test included a single fine-bubble diffuser with an air-flowrate of 1 and 2.5 $Ls^{-1}m^{-1}$. The lower flowrate test had a dual objective of proofing the PIT tag tracking technology and initial assessment of viability of bubble barriers. The Mark I barrier was found to delay carp movement by approximately 15 seconds, **but did not prevent passage of carp over the bubble barrier.**

Initial barrier tests and physical measurements indicating that larger hole diameters generates a stronger acoustic field led to the development of the more vigorous Mark II barrier. The Mark II barrier consists of 6 diffusers ranging from a fine-bubble diffuser on the up-stream end to an ultra-coarse-bubble diffuser on the down-stream end, while four coarse-bubble diffusers occupy the space between. The purpose of the bubble size increase was to generate a sharp sound pressure level gradient across the entire thickness of the barrier**. The Mark II barrier was found to reduce carp passage by 75%; a number that falls within a range where the management of carp movement with bubble technologies may be possible.** Full details and statistical analysis of the Mark I and II barrier tests are provided in **results status 9/30/2010 for Result 2**.

As the project continues, the plan is to perform more robust testing of the Mark II barrier to confirm the positive results, and develop a Mark III barrier to improve carp deterrence. Further development will work to include an underwater transducer to create a precisely controlled acoustic barrier. The barrier designs will continue to be incorporated into experiments that will determine the response of carp within close proximity of the barrier. An optimal barrier design will eventually be implemented in a real field setting either at the SAFL Outdoor Stream Lab or a select field site.

Amendment Request 3/31/11

Due to personnel changes we will no longer be using our post-doc position. We intent that the components of the work plan assigned to this position to be taken over by graduate students. To allow for this we would like to shift the remaining budget assigned for the post-doc into the budget line for graduate students (see amended Attachment A).

In relation to the above we note that our current specified end date is 12/30/2011. We understand, however, that per the appropriation language, the money is technically available until June 30, 2012. As such, to allow for completion of the work we would like to also amend the project end date to June 30, 2012.

In addition, as the project has unfolded we have realized that the experimental and testing protocols developed in Results 1 and 2 will continue to be revised and used as we move into field scale testing. As such, we would also like to adjust the end dates of Results 1, 2, and 3 to coincide with the project end date.

Summary 3/31/2011

A study to identify how environmental effects modify the physical fields generated by a bubble barrier is nearing completion (see detailed report in **result status 3/31/2011 for Result 1**). The focus of the measurements has been to determine how depth and flow variations change the flow and sound fields reported in **results status 9/30/2010 for Result 1**. Understanding how the environmental effects modify the fields will provide some insight into acceptable flow and depth ranges that the barrier can be expected to perform without a drop in efficiency. Measurements have revealed that increased depth decreases the flow strength, but decreased depth increases the sound gradient. Flow normal to the bubble curtain was found to deform the curtain in the direction of flow; this deformation was evident in the sound and flow fields for both diffuser types. The barrier is not expected to have any significant decrease in the sound field for flows less than 30cm/s.
Further development and testing of the barrier design has been undertaken. Similar to the development of the Mark II barrier, the Mark III barrier was developed to maximize the sound production of the barrier by bubble formation. The Mark III barrier consisted grid configuration of all ultra-coarse-bubble diffusers, supplied with a three-fold increase in air over the Mark II barrier. Full details and statistical analysis of the Mark III barrier tests are provided in **results status 3/31/2011 for Result 2**. **The Mark III barrier was found to reduce carp passage by 75%; similar to the results of the Mark II barrier.** The lack of increased effectiveness may indicate that we have reached the maximum stopping potential of bubble sound-driven barriers. Further investigation in the biological flume at the Aquaculture Center and the physical flume at SAFL will look at using sound generation from underwater transducers. Although the bubble barrier alone could be a useful component in an integrated management strategy for controlling movement and recruitment of carp it would not be 100% effective at stopping juvenile carp movement in a given reach.

A macro-behavior study of the carp was also completed, with a purpose of understanding the behavior of carp in the vicinity of the bubble barrier. By studying the dispersal of carp during the behavioral tests, the carp clearly correlated their movements to the presence of the small current present in the biological flume in the absence of the barrier. With the barrier operating, this behavior became clearly compromised and no distinct directional motion was observed. Full description of this study is provided in **results status 3/31/2011 for Result 2**.

IV. OUTLINE OF PROJECT RESULTS*:*

Result 1: Laboratory Investigation: Engineering

Description: The objective of this phase of the study is to develop the necessary engineering infrastructure to allow for the building, design and optimization of bubble curtain barriers. The main goals are to (i) design and develop devices for creating bubble curtains in flume systems, (ii) to identify, measure the physical fields created by said bubble curtains, and (iii) to understand how these physical fields are modified by different operating (pressure, orifice placement, etc) and environmental (flow velocity, flow depth, temperature, etc) conditions.

Summary Budget Information for Result 1:	**Trust Fund Budget:**	**$ 99,956**
	Amount Spent:	**$ 70,594**
	Balance:	**$ 29,362**

Deliverable	**Completion Date**	**Budget**
1. Designs of diffusers for bubble curtains	3/31/2010	$33,000
2. Quantitative description of the physical fields generated by sub-aqueous bubble curtains	9/30/2010	$33,000
3. Quantitative description of the effects of design and environmental parameters on the physical fields generated by a bubble curtains	~~3/31/2011~~ 6/30/2012	$33,956

Completion Date: 3/31/2011

Results status of *(11/10/2009):*
Laboratory flume is set up (sand substrate and insulation added)
Preliminary designs of bubble diffusers has been started.
Theoretical and technical understanding of sub-aqueous measurement of sound fields has been established.

Amendment Approved: 12/17/2009
See Section III for details related to the approved amendment.

Result Status as of *(3/31/2010):*

Preliminary Design and Development of Bubble Curtains in Flume Systems

(Report by Dan Zielinski, Graduate Student)

1.0 Introduction

Common carp (*Cyprinus carpio*) comprises over half the biomass in a third of Minnesota lakes. The feeding habits of this species significantly disrupt lake sediments leading to an over-enrichment of nutrients which dramatically reduces water quality. Great ecological benefit will be gained if effective barriers can be constructed to control the movement of invasive carp. A class of barrier technology, that shows promise for this application, is based around the use of air bubble curtains that generate acoustic and other hydrodynamic fields. The goal of the current project is to design and assess the effectiveness of bubble curtain barrier technologies as a means of controlling carp movements in the connection channels of lake systems.

The use of acoustic and hydrodynamic barriers for the control of invasive species remains largely untested (Webb et al. 2008). Only a few publications regarding the use of bubble curtains as a barrier are in peer-reviewed literature; these studies focused on a range of species including Bighead Carp (Taylor et al. 2005), Atlantic Salmon (Welton et al. 2002), and Eurasian Ruffe (Dawson et al. 2006). The Taylor and Welton studies used a bubble curtain in conjunction with an independent sound projector. The Dawson study paired the bubble curtain with an electrical barrier. The bubble diffusers were created by holes drilled into PVC pipe with air-flowrates through ranging from approximately 0.1 to 1.0 $Ls^{-1}m^{-1}$. The bubble diffuser utilized by Taylor and Welton was a proprietary device developed by Fish Guidance Systems. The diffuser utilized by Dawson consisted of 0.4 to 1.0 mm holes drilled at evenly spaced distances of either 6.25 or 12.5 mm. These studies did not focus on using the bubble curtain as a primary means to deter the fish, nor was there an in-depth analysis of the physical fields generated.

Outside of the aquaculture field, bubble curtains or diffusers have been studied by engineers and scientists as a means to aerate and induce mixing in stratified lakes. These studies investigated the generated velocity fields (Brevik et al 2001) and turbulence (Chen et al 2001); however, the depths considered for these studies were considerably greater than 1m for most cases. The implementation of a bubble curtain for this project will be in a connecting stream between ‘nursery’ lakes, with depths typically less than 0.5 m. In addition, any research studying acoustic properties of bubble curtains have been limited to use as an acoustic screen for underwater noise. The bubble curtains used in the Brevik study were coarse bubble diffusers made by drilling 0.8 to 0.5 mm holes into a steel pipe and plexiglass tube with an air-flowrate of ranging from approximately 1 to 4.5 $Ls^{-1}m^{-1}$.

The objective of this phase of the study is to develop the necessary engineering infrastructure to allow for the building, design and optimization of bubble curtain barriers. Based on the previously mentioned literature, the bubble diffusers will consists of plastic tubes with holes evenly spaced throughout. The primary physical properties that can be controlled through diffuser design is the bubble size, frequency of formation, and density of bubble curtain. Prior to testing, two distinct diffuser types were identified: fine-bubble and coarse-bubble diffusers. This report will outline the design and development of each diffuser in a flume system and possible configurations to be tested in the second phase of the study.

2.0 Flume System

Testing of the bubble diffusers will be performed at the University of Minnesota’s Saint Anthony Falls Laboratory (SAFL) and the Aquaculture Center. Initial testing without fish, to determine the generated acoustic and hydrodynamic fields will be performed at SAFL; while testing for efficacy with live specimen will be performed at the Aquaculture Center. The SAFL flume is a straight flume, fed by the water diverted from the

Mississippi River, with the following dimensions: 20 in. wide x 36 in. high x 30 ft long. The bubble diffusers will be placed at the mid-point of the flume anchored with a wood base buried in sand. Air will be supplied to the bubble diffusers through a laboratory compressed air line capable of high pressure and high volume. Physical fields will be measured by various instruments attached to a fully articulated cart located along the length of the flume.

The Aquaculture Center flume is a circular flume constructed from setting a 1 m diameter tank inside a 3 m diameter tank. Air will be supplied through the use of a portable air-compressor. Select measurements of the physical fields can be obtained through the use of a semi-mobile instrument bracket. Air-supply at both sites will be monitored and controlled through the use of a pressure gauge and rotameter.

3.0 Bubble Curtain Background

Understanding the formation of a single bubble through an orifice is vital to developing diffusers that can create well defined and predictable physical fields. Bubble formation is driven by two main components, buoyancy and surface tension. The buoyancy force acts to drive the bubble towards the surface, while the surface tension acts to keep the bubble attached around the orifice. As the bubble size increases, the buoyancy force overcomes the surface tension and the bubble detaches from the surface. Bubble formation creates pressure waves (sound) throughout the liquid and accounts for most of the sound generated by a bubble curtain. As the bubbles rise, they coalesce (two or more bubbles form one larger bubble). The thickness of the bubble curtain also increases as the bubbles rise. These characteristics were utilized in the design of the two diffuser types: fine-bubble and coarse-bubble.

3.1 Coarse-Bubble Diffuser

The first of two diffuser types is indentified by the relative large size of bubbles produced when air is forced through the diffuser. The coarse-bubble diffusers consist of PVC pipe with holes manually drilled at constant spacing. The hole sizes range between 1 mm to 10 mm, and the spacing varies between 0.5 cm to 10 cm. The minimum hole size is determined by the smallest available drill bit and large diameter holes (>10 mm) will not be considered as maintaining a constant air-flow through every hole would be suspect. Figure 1 displays the typical bubble curtain generated by the coarse-bubble diffuser. Note the mixture of large and small bubbles.

Figure 1. Typical bubble curtain provided by coarse-bubble diffuser (1mm holes at 2.5 cm spacing)

Work by Lin et al. (1994) indicated that the diameter of a detached bubble from an orifice will always be larger than the orifice; they also stated that for small orifices, the bubble size in highly dependant on the liquid and diffuser surface tension. The result of this research indicates that 2.5 mm and 1 mm diameter orifices, drilled in the same material, would create similar sized bubbles. As is shown in Figure 2, the typical bubble size generated by the 1 mm hole diffusers near the PVC and surface are approximately 10 mm and 15 mm, respectively. Note the distinct change in shape between the two locations, the bubbles near the PVC are far more elongated (can also be seen in Figure 1).

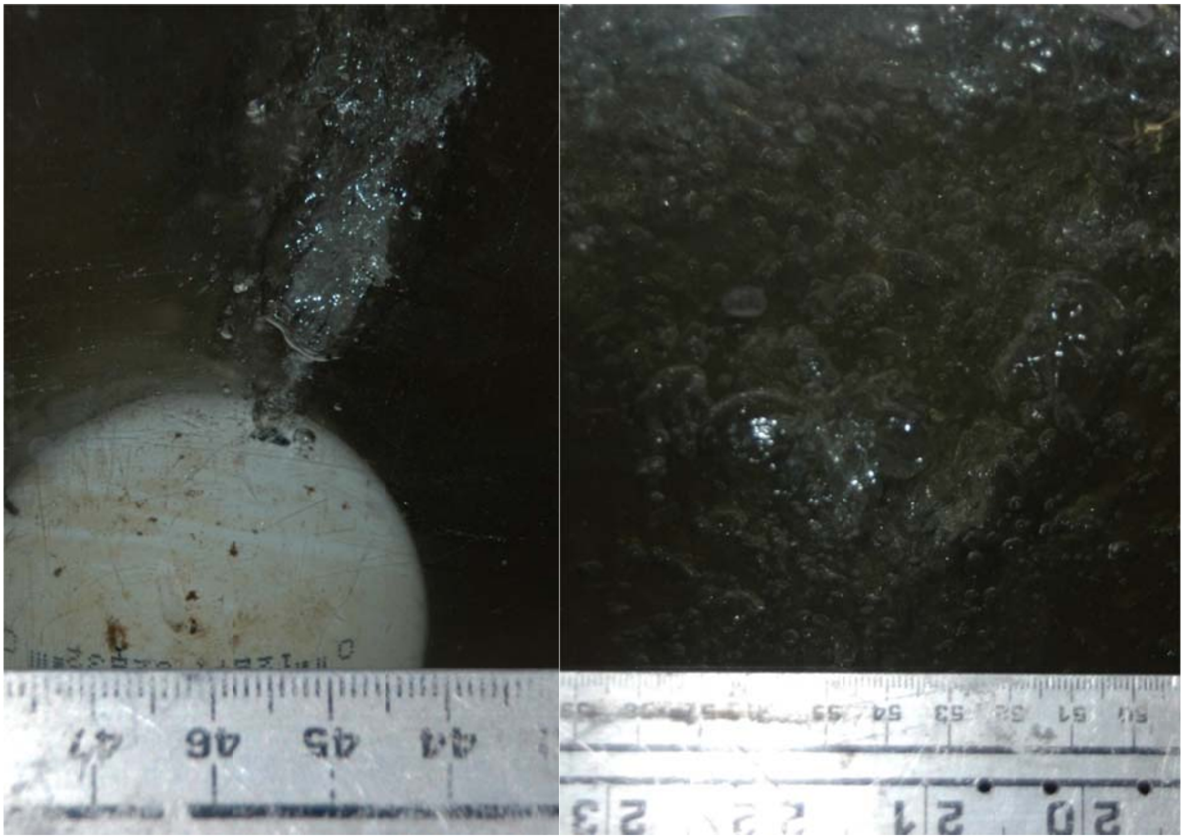


Figure 2. Typical bubble size near PVC and at surface for 1 mm holes

The lateral spacing of the holes in the PVC provides control over the density of the bubble curtain. Spacing too large would create gaps near the diffuser, possibly large enough for fish passage. Spacing too small creates immediate overlapping of individual bubble plumes; however, spacing of less than 0.5 cm is time consuming and difficult to maintain a perfectly straight line of holes. Only one line of holes restricts the thickness of the bubble curtain; however, multiple diffusers can be used in series to create a thicker curtain.

The final physical feature that can be controlled to manipulate the bubble curtain is the air-flowrate. The PVC pipe used for this application is not rated for high pressures, which limits the maximum air-flowrate that can be used. Lin et al. (1994) found that increasing the air-flowrate does not increase bubble size, but increases the frequency at which bubbles are created. As an initial condition for testing, the diffusers will be supplied with a low and high air-flowrate of 2.5 and 2.8 $Ls^{-1}m^{-1}$, respectively (flow rates are associated with air pressures of 50kPa and 100kPa, respectively). By inspection, an air-flowrate less than 2.5 $Ls^{-1}m^{-1}$ creates a thin, insubstantial bubble curtain.

3.2 Fine-Bubble Diffuser

The second type of diffuser to be considered for this research is a fine-bubble diffuser, which creates bubbles significantly smaller than the coarse-bubble diffuser. The fine-bubble diffuser consists of porous polyethylene, which is manufactured to have a complex, homogenous pore structure throughout the entire wall. A sample portion of I inch diameter porous pipe with a typical pore size of 35 microns was provided by GenPore Inc. The pore size can be reduced to 10 microns, but with reduced pore size, the chance of clogging increases. The porous pipe is also available in hydrophilic and hydrophobic formulations. The hydrophobic formulation will be utilized in this research based on the work by Lin et al. (1994). Figure 3 displays the typical bubble curtain generated by the fine-bubble diffuser. Note the almost homogenous, dense bubble curtain.

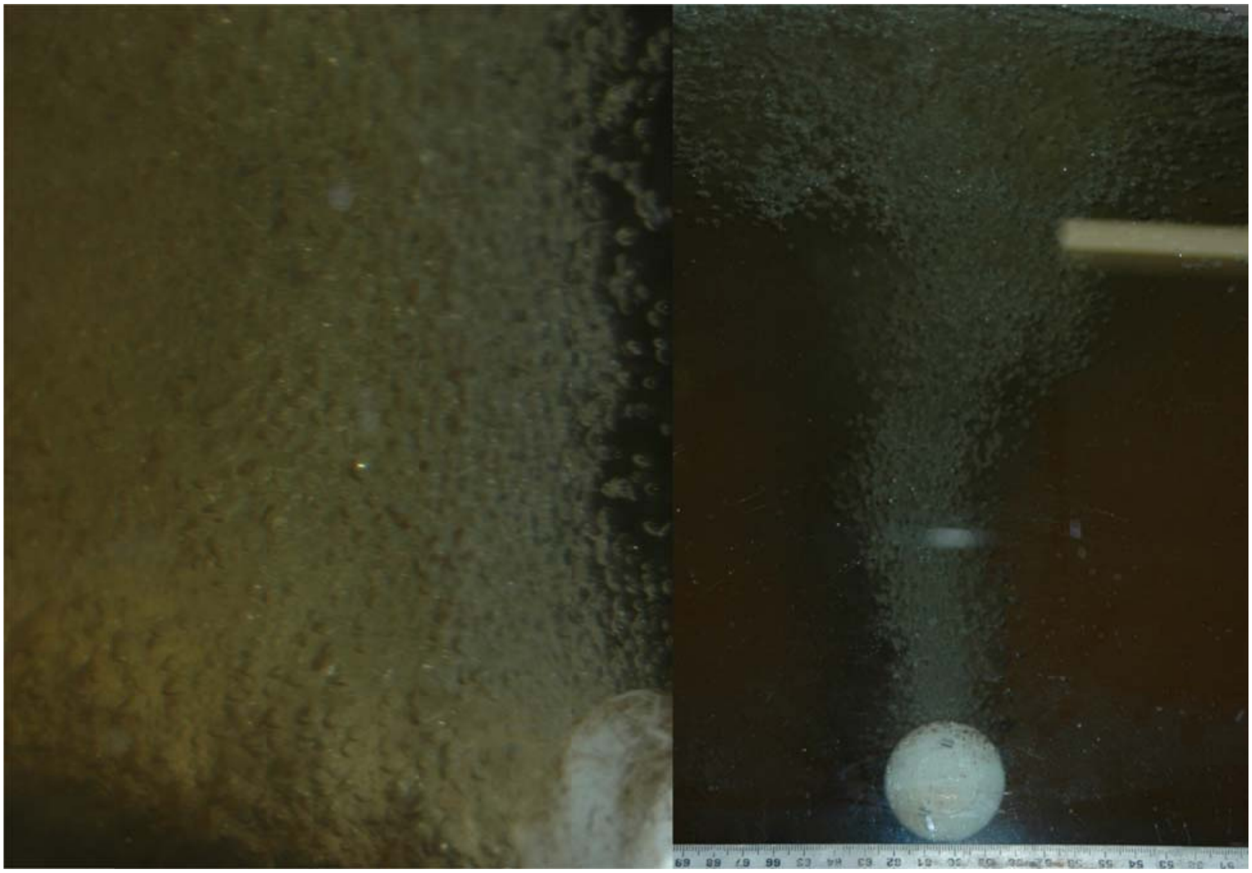


Figure 3. Typical bubble curtain provided by fine-bubble diffuser (30 micron holes)

Figure 4 displays the typical bubble size near the diffuser and at the surface. Note the homogeneity of the bubble curtain near the pipe and surface in comparison to Figure 1 and Figure 2.

The typical bubble size is 1-2 mm near the pipe, which is an order of magnitude smaller than the coarse-bubble diffuser formed bubbles. The bubbles near the surface are approximately 2-5 mm in size.

The thickness of the bubble curtain expressed by the porous pipe is slightly thinner than the pipe diameter, as bubbles are formed along the entire surface of the pipe; therefore, the curtain thickness is significantly larger than the coarse-bubble diffuser. The thickness of the curtain at formation causes the width near the water to be thicker than that generated by the coarse-bubble diffuser as well. The homogenous distribution of pores removes the chance for gaps to form laterally along the diffuser. In general, the bubble curtain created by the fine-bubble diffuser is far denser than that formed by the coarse-bubble curtain for a constant air-flowrate. As the air is expressed evenly along the surface of the fine-bubble diffuser, the curtain can lacks directional control. The fine-bubble diffusers will be subjected to the same air-flowrates as the coarse-bubble diffusers.

3.3 Diffuser Configurations

Each type of diffuser will be tested individually at SAFL to determine which physical diffuser properties can optimize the physical fields generated by a bubble curtain. The optimal design or designs will be additionally tested at the Aquaculture Center for efficacy with carp. Based on the preliminary results of the Aquaculture Center testing, multiple diffuser configurations will be developed and similarly tested. The additional configurations to be tested are not determined yet, but a few configurations that may be tested are included in Table 1.

Table 1. Multiple Diffuser Configurations

Configuration	***Description***
1	A fine- and coarse-bubble diffuser in series with coarse curtain pointed vertically
2	Configuration #1 with the coarse curtain pointed upstream
3	Multiple coarse-bubble diffusers in series
4	A fine-bubble diffuser with additional coarse-bubble holes drilled
5	Multiple fine-bubble diffusers

4.0 Additional Studies

This report classifies the design and development of diffusers based on the size of bubbles generated: coarse and fine. This report also identified a few multiple diffuser configurations to be tested in the second phase of this study. The second phase of this study will investigate the physical fields generated by the curtains as well as how these fields can be manipulated by diffuser properties. The results of this study will be outlined by a report on 9/30/2010. Physical field testing at SAFL and preliminary testing on carp at the Aquaculture Center are currently ongoing.

Result Status as of *(9/30/2010):*

Characterization of physical fields generated by bubble curtains

(Report by Dan Zielinski, Graduate Student)

1.0 Phase II: Hydrodynamic Fields Created by Bubble Curtain

The objective of this phase of the study is to identify and quantify the hydrodynamic fields generated by a bubble curtain barrier. Understanding what fields are generated by the diffuser will help create a clear link to what physiologic responses may cause carp to be deterred by said barrier. The measurements taken on flume experiments at SAFL have focused on two main physical fields: flow and sound pressure level (SPL). Temperature and dissolved oxygen levels were also measured to gain additional understanding of fluid interaction with the bubble plume; however, at this time no distinct features were evident in these fields to possibly deter carp. Each diffuser type (coarse-bubble and fine-bubble) was tested individually at two increasing air flow-rates to determine the distinct differences between types, and how the physical fields are manipulated. Measurements were taken along the centerline of the flume in a grid pattern extending up to 4m up- and down-stream of the barrier over the full depth of flow. Note that all experiments were performed without any channel flow. Figure 1 displays the diffuser set-up and measurement locations.

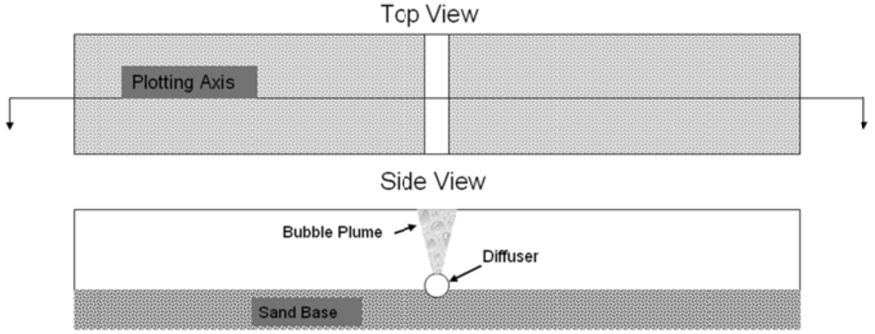


Figure 1. Diffuser set-up and measurement location

The flow field is of primary interest as water movement intuitively effects fish behavior. Carp, as all fish, utilize their lateral line system to detect fluid motion in their environment through the use of microscopic sensory units called neuromasts [Urick, 1975]; therefore, the flow field generated by rising bubbles should be quantified as it is surely detected by nearby carp. The flow field can be decomposed into two categories: domain scale velocity field characterized by recirculation cells [Brevik et. A.l, 2002;Fannelop et. Al., 1991], and small scale turbulence [Chen et. al., 2001;Kundu, 1990]. Fish neuromasts range in size from 10 to 400μm in length and can detect minute fluid motions, presumably small eddies, along with the mean fluid flow [Urick, 1975]. Eddies are identifiable structures that occur in turbulent flow which are typically defined by a spinning motion [Kundu, 1990], and start at a length approximately equal to the domain size (or flume width/depth/length) and through viscous forces are dissipated to less than 1mm in size. Characterizing the fluid motion and how diffuser type effects the magnitude of large and small scale fluid motion will help determine which scale of fluid motion influences carp movement more or at all.

Carp are identified as hearing specialists [Webb et. al., 2008], and their specific sensitivity to sound has been at the center of a wide variety of barrier designs [Popper et. al., 1998;Taylor et. al., 2009;Webb et. al., 2008;Welton et al., 2002]. The main goal of an acoustic barrier is to generate a sound that is powerful enough to incite an avoidance response while not allowing the fish to acclimate to a monotone sound (i.e. single frequency and amplitude). A bubble barrier is expected to generate sound through the creation of bubbles [Lin et. al., 1994] and fluid motion driven by rising bubbles [Tonolla et. al., 2009]. The key components to a sound field detected by carp are the frequency and amplitude of a sound pressure wave; the sound must be within the carp hearing frequency range and powerful enough to be heard over background noise [Popper, 1972). Sound pressure levels generated by a single bubble have been documented [Leighton, 1994]; however, a robust description of the SPL generated by a bubble barrier is not available in literature. We will characterize the sound generated by the bubble barrier and determine whether it is substantial enough to be detected by carp.

This section will outline the instrumentation used, and fully describe the hydrodynamic fields generated by a bubble curtain barrier and how it relates to barrier development.

2.0 Instrumentation

A variety of instruments were used to characterize the physical fields generated by the bubble curtains. The following is a list of apparatus used and specific fields measured:

1. SonTek 16-MHz MicroADV (Acoustic Doppler Velocimeter) – three-dimensional velocity measurements at a sample rate of 50-Hz

2. MSCTI SN 5 (20 K Temperature Probe) – instantaneous temperature at a sampling rate of 100-Hz

3. Dissolved Oxygen Probe – dissolved oxygen level sampled at a rate of 100-Hz

4. BK 8103 Hydrophone – piezoelectric transducer to measure sound pressure level at 50-kHz

Each of these instruments were attached to a mobile cart and mounted on a telescoping arm to repeatedly take simultaneous measurements upstream and downstream of the barriers. Velocity measurements from the ADV were collected and analyzed using the SonTek software package HorizonADV and WinADV. The temperature and dissolved oxygen probe data were collected using a data acquisition board and software program TracerDAQ. A one minute continuous sample was taken at each measurement location of the velocity, temperature, and dissolved oxygen level. Hydrophone data collection required the use of a 5V power pre-amplifier and National Instruments SC-2345 signal conditioning and connector box to digitize the signal. The data was finally collected by the National Instruments software package LabView and further analyzed using Matlab. At each measurement location, four 10-sec sound wave samples were obtained.

3.0 Flow Field

Research by Brevik [2002] and Fannelop [1991] have shown that the domain scale velocity field generated by a bubble curtain can be broken down into two subcategories: near- and far-field. The far-field flow is dominated by a horizontal recirculation cell extending approximately two times the depth away from the curtain. The near-field flow is dominated by the vertical velocity of the bubble plume and occurs within close proximity of the bubbles. The distinct difference between these two categories is the maximum velocity in the far-field acts parallel to the channel flow while the near-field acts perpendicular to the channel flow, creating a sharp velocity gradient. As a carp presumably swims from far- to near-fields, the velocity gradient should be detected and may disrupt an up- or down-stream migration.

Using the MicroADV, we calculated the time-averaged velocity vector at various locations along the centerline of the SAFL flume up- and down-stream of the diffuser. From the velocity vectors we calculated the streamlines (the line tangent to the local velocity vector) for each given diffuser set-up. Figure 2 provides the velocity vector plot for the fine-bubble diffuser at an air flow rate of 2.5 $Ls^{-1}m^{-1}$ and set at a depth of 0.25 m. Figure 3 provides the corresponding streamline plot to the velocity vectors plotted in Figure 2. The streamline plot is included to highlight the location of the stagnation point, or center of rotation of the recirculation cell. Note, the x- and y-axis have been normalized by the depth of flow.

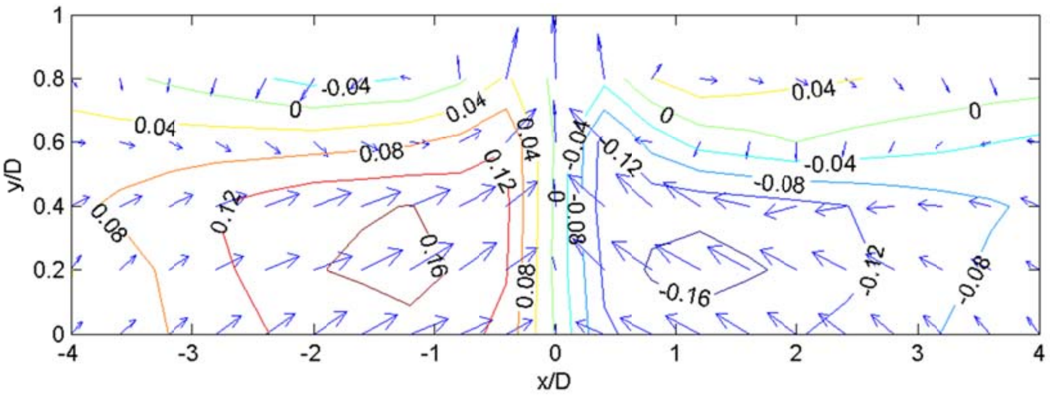


Figure 2. Velocity field for fine-bubble diffuser at 2.5 Ls^{-1}m^{-1} and a depth D=25cm (velocity contours are in m/s)

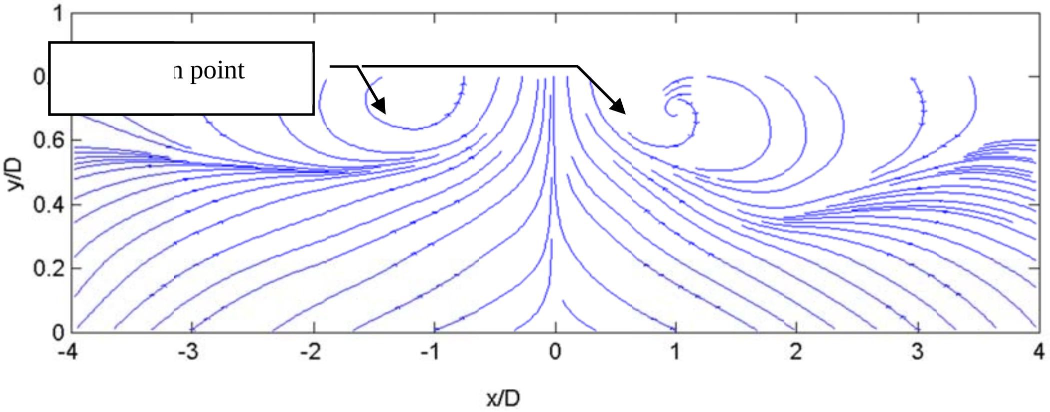


Figure 3. Streamline plot of velocity field generated by fine-bubble diffuser at 2.5 Ls^{-1}m^{-1} and a depth D=25cm

Figure 4 provides the velocity vector plot for the coarse-bubble diffuser at 2.5 Ls^{-1}m^{-1} and set at a depth of 0.25 m. Figure 5 provides the corresponding streamline plot to the velocity vectors plotted in Figure 4.

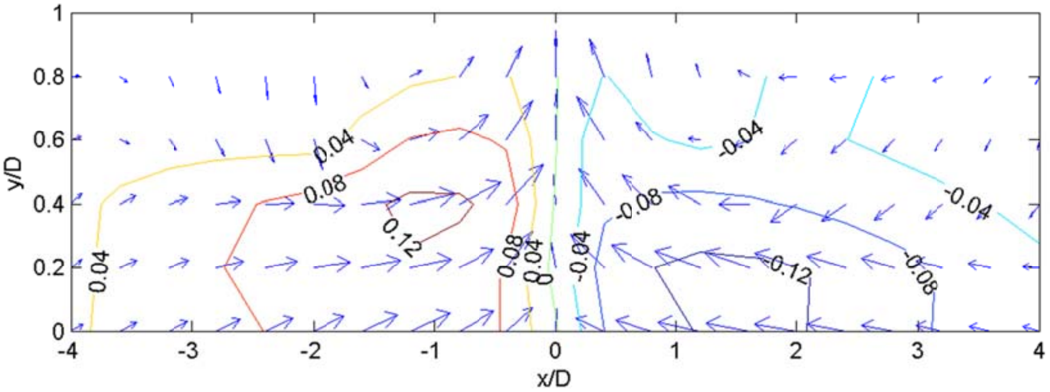


Figure 4. Velocity field for coarse-bubble diffuser at 2.5 Ls^{-1}m^{-1} and a depth D=25cm

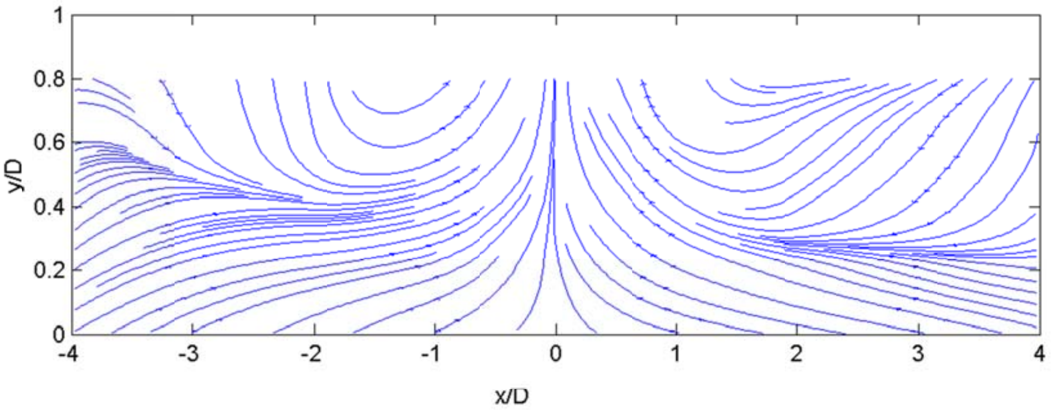


Figure 5. Streamline plot of coarse-bubble diffuser at 2.5 $Ls^{-1}m^{-1}$ and a depth D=25cm

Comparison of the two different types of diffusers in Figures 2-5 indicate that the flow generated by the fine-bubble diffuser is stronger than the coarse-bubble diffuser (16 cm/s vs. 12 cm/s). The stagnation point for both configurations is located approximately at a similar horizontal position (x/D = +/-1). The vertical location of the coarse-bubble diffuser is unknown as it is located shallower than the ADV could measure, while the vertical position is approximately y/D=0.75 for the fine-bubble diffuser. The horizontal component of the velocity in the far-field, in the absence of mean channel flow, can be predicted by equations derived from the Entrainment Method [Fannelop et. al., 1991] and Kinetic Energy Method [Brevik et. al., 2002] using the air flow rate and depth of diffuser as dependant variables. The vertical velocity component is more difficult to predict using these models, but is of less significance in the far-field; therefore it was omitted. Both methods were used to compare with the velocity measurements; while each method predicted a similar maximum velocity, the Entrainment Method better predicted the stagnation line (points at which the horizontal velocity is zero). These predictive models will be used to specify what flow-rate may be required to create a recirculation cell with velocities that can overcome the mean channel flow (i.e. so the mean channel flow does not sweep the recirculation cell downstream).

Fluid motion detected by the lateral line system is not limited to large scale motion of water, as demonstrated by the recirculation cells in Figure 2-5, but includes the small scale water motions that are closer to the scale of the sensory unit itself. First, we must determine if the fluid motion, or eddy, itself is large enough to be detected by a neuromast, yet small enough as to not be interpreted as the mean flow. The smallest scale that an eddy can exist before viscous forces convert the mechanical energy into thermal energy is called the Kolmogorov length scale [Kundu, 1990]; The Kolmogorov length scale was calculated at various points along the centerline of the flume by performing a fourier transform and cross correlation of the instantaneous velocity data obtained by the MircoADV consistent with [Brigham, 1974;Kundu, 1990;Ramirez, 1985]. Figure 6 and 7 provide a plot of the Kolmogorov length scale for the fine- and coarse-bubble diffusers in a 25 cm deep flow at an air flow rate of 2.5 $Ls^{-1}m^{-1}$.

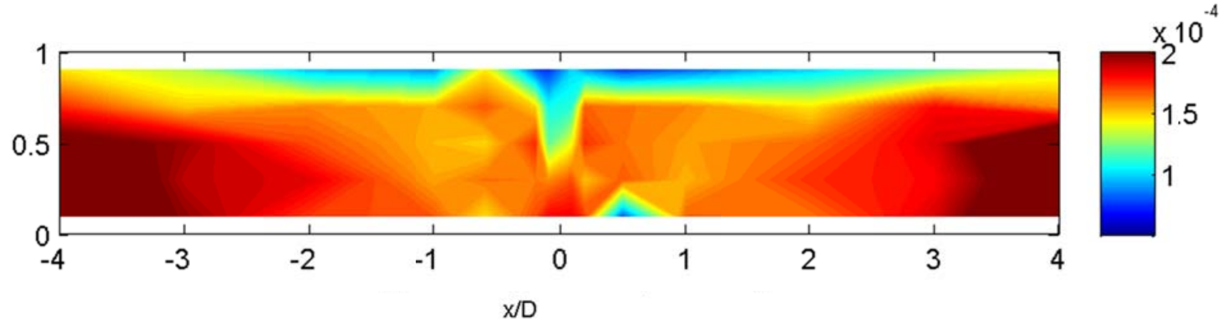


Figure 6. Kolmogorov scale for fine-bubble diffuser in depth D=25 cm (scale is in m)

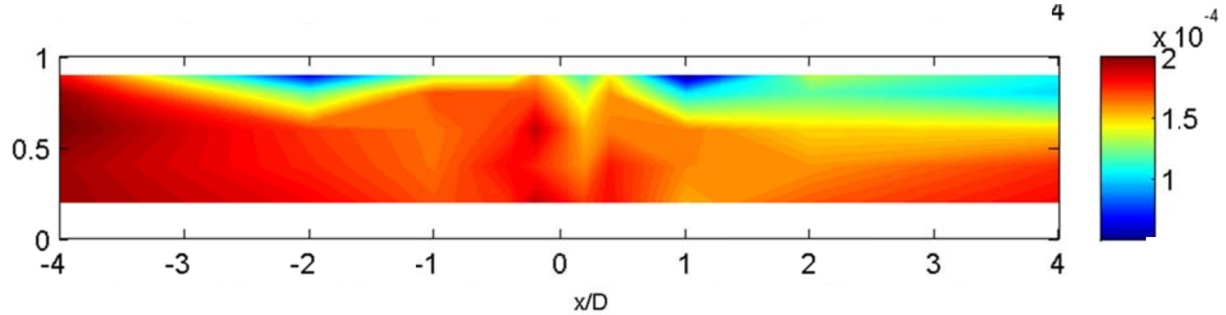


Figure 7. Kolmogorov scale for coarse-bubble diffuser in depth D=25 cm (scale is in m)

Note the eddies are sustained at much smaller scales close to the bubbles and surface, and that there is no significant difference between the fine- and coarse-bubble diffusers. The Kolmogorov length scale of each diffuser is approximately 0.05 mm, which is on the order of the smallest neuromast, and presumably detected by the carp.

The key aspects of each flow measurement including maximum velocity, stagnation point location, and Kolmogorov length scale for each test is included in Table 1. The fine-bubble diffuser was tested at a restricted flow rate of 1 $Ls^{-1}m^{-1}$ to match with initial diffuser test with carp at the Aquaculture Center. The fine-bubble diffuser was also tested at 50 cm to see the effect of water depth on the physical fields. Note that the Kolmogorov length scale does not vary significantly between diffusers; however, the large scale velocity fields are slightly stronger using the fine-bubble diffuser.

Table 1
Flow field characteristics of diffusers

Diffuser Type	Flow-rate ($Ls^{-1}m^{-1}$)	Depth (cm)	Maximum Velocity (cm/s)	Stagnation Point Location (X,Y)	Kolmogorov Scale (mm)
Fine-Bubble	1	25	8	(+/-1,0.6)	0.08
	2.5	25	16	(+/-1,0.75)	0.05
	2.8	25	17	(+/-0.8,0.6)	0.06
	2.5	50	13	(+/-1.5,0.75)	0.07
	2.8	50	16	(+/-2,0.75)	0.05
Coarse-Bubble	2.5	25	12	(+/-1,>0.8)	0.05
	2.8	25	13	(+/-1.5,>0.8)	0.04

3.0 Sound Pressure Level

Carp are considered hearing specialists because they have specialized rib bones called Weberian Ossicles that allow the swim bladder to act as an additional sound pressure transducer to accompany their inner ear, increasing their sensitivity to sound levels in their environment [Webb et. al., 2008]. Exploitation of this has lead to the development of acoustic barriers to limit movement of carp [Popper et. al., 1998;Taylor et. al., 2005;Welton et. al., 2002]. The limited barrier designs highlighted in literature rely on an additional underwater transducer to produce a specific sound field, and some have been used in conjunction with bubble diffusers with ambiguous results. Our measurements quantify the acoustic properties, including sound pressure level and frequency, generated by a fine- and coarse-bubble diffuser; which will be used to compare with the audiogram for carp (response curve for sound detection).

A basic understanding of sound properties and measurements techniques is important to review prior to presenting the results. A sound wave is a longitudinal wave, in which particles are displaced parallel to the direction of the motion of the wave (i.e. the particles oscillate locally). The frequency of the wave oscillations is one of the more prominent properties of sound, and is measured in cycles per second (Hz). The other prominent property of a sound wave is the acoustic pressure (P) or magnitude of the sound pressure wave. Acoustic pressure, generally reported in kPa, is merely the product of the particle velocity, speed of sound in a given medium, and the medium density; which is easily measured by electronic equipment such as hydrophones. The hydrophone captures a sound waveform which is viewed in the time-domain. A fourier transformation of the waveform allows the sound wave to be viewed in the familiar frequency domain, in which the amplitude of the sound wave is plotted dependently of individual frequencies [Brigham, 1974;Ramirez, 1985]. Once each sample is transformed, the average of four 10-sec samples is used to describe the sound at each measurement point. These plots also introduce the decibel (dB), a common unit of measure for sound pressure level. A decibel is a logarithmic ratio of the measured sound pressure amplitude to a reference pressure (for underwater measurements in this paper, ref. 1μPa). To give an idea of scale, a 20 dB increase is equal to a 10 times increase in pressure. Figure 8 displays a typical SPL plot for background and with the diffuser on, while indicating key features of the sound signal. The background sample was taken with no flow through the flume and most laboratory noise was isolated to less than 100 Hz. The maximum SPL of 105 dB occurs at 300 Hz; while the SPL less than 100 Hz is mostly due to water motion noise on the hydrophone, and is classified as pseudo-noise. The resonant frequency is a characteristic of the flume size, and indicates that any sound at a lower frequency can not propagate within the flume [Akamatsu et. al, 2002].

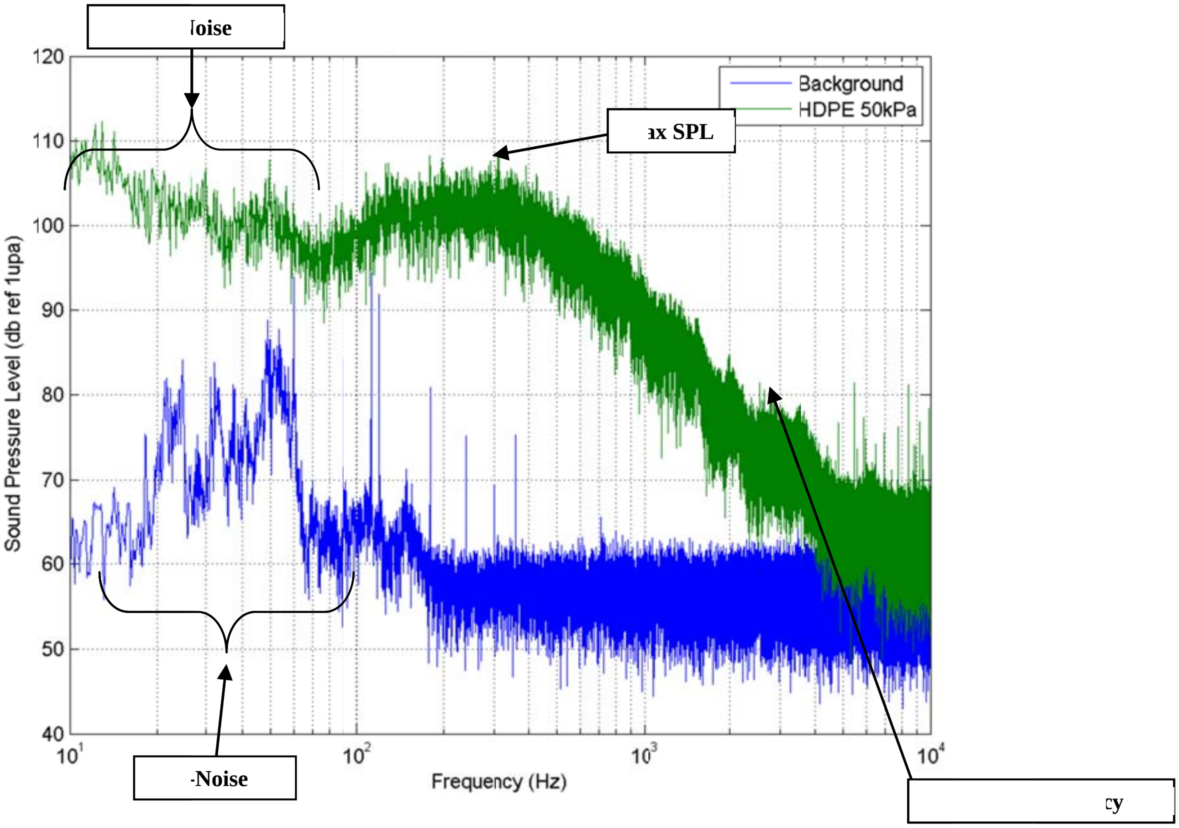


Figure 8. Typical SPL plot, highlighting key features

The audiogram for carp as presented by [Popper, 1972] indicates that the most sensitive region of hearing is between 100-500 Hz down to a SPL of 60 dB. Another important factor to contend with is the “cocktail party” effect in which fish are unable to decipher a specific sound within their hearing range unless it is 10 dB above background levels [Popper et. al., 1998]. Note in Figure 8, the fine-bubble diffuser generates a sound approximately 40 dB greater than background noise at a particular location within the specified hearing range of carp. Figure 9 provides a contour plot of the SPL above background for the fine-bubble diffuser at an air flow rate of 2.5 $Ls^{-1}m^{-1}$. Note the sharp gradient of SPL in the x-direction away from the barrier and location of the 10 dB contour indicating a zone of influence.

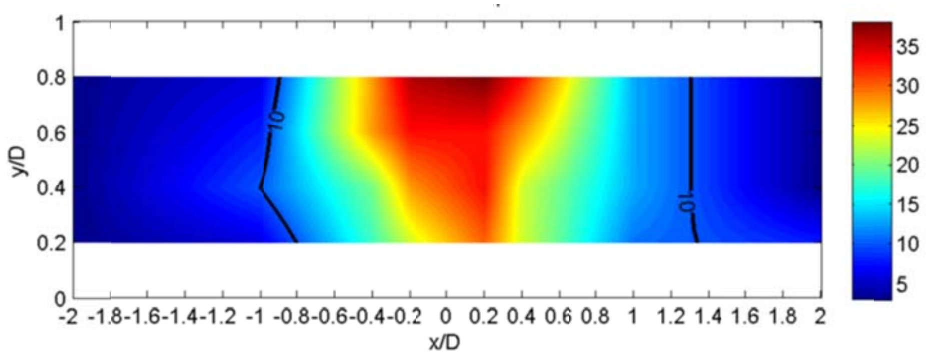


Figure 9. SPL above background for fine-bubble diffuser at a depth D=25 cm (scale is in dB)

Figure 10 displays the SPL above background for the coarse-bubble diffuser at an air flow rate of 2.5 $Ls^{-1}m^{-1}$.

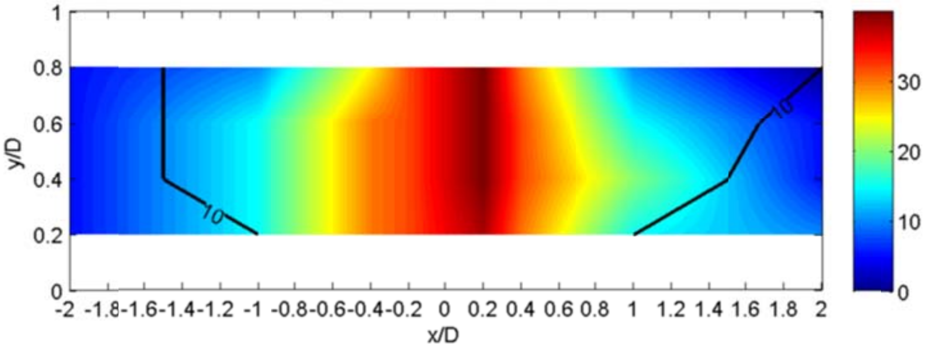


Figure 10. SPL above background for coarse-bubble diffuser at a depth D=25 cm (scale is in dB)

It is important to note that sound measurements in a confined tank will vary from tests in an unconfined domain. Low frequency sound is subject to a "cutoff phenomena" which states that sound at a frequency less than the cutoff frequency will attenuate rapidly; while a sound at a frequency higher than the cutoff frequency attenuates slowly, but may be subjected to scattering and absorption [Urick, 1975]. Attenuation is defined as a signal strength loss of 20 dB after a certain length, the attenuation length. The cutoff frequency in a confined flume is equal to the resonant frequency of the flume, and Akamatsu [2002] demonstrated that sound at a frequency equal to the resonant frequency can theoretically propagate indefinitely. Akamatsu also constructed theoretical formulas to predict the resonant frequency of a specific tank size and attenuation length for any frequency. Figure 11 demonstrates the attenuation of a 500 Hz sound signal generated by the fine-bubble diffuser, at an air flow rate of 2.5 $Ls^{-1}m^{-1}$, plotted along with the theoretical attenuation. Note approximately at a distance equal to one depth away from the diffuser, the signal has nearly vanished at all depths.

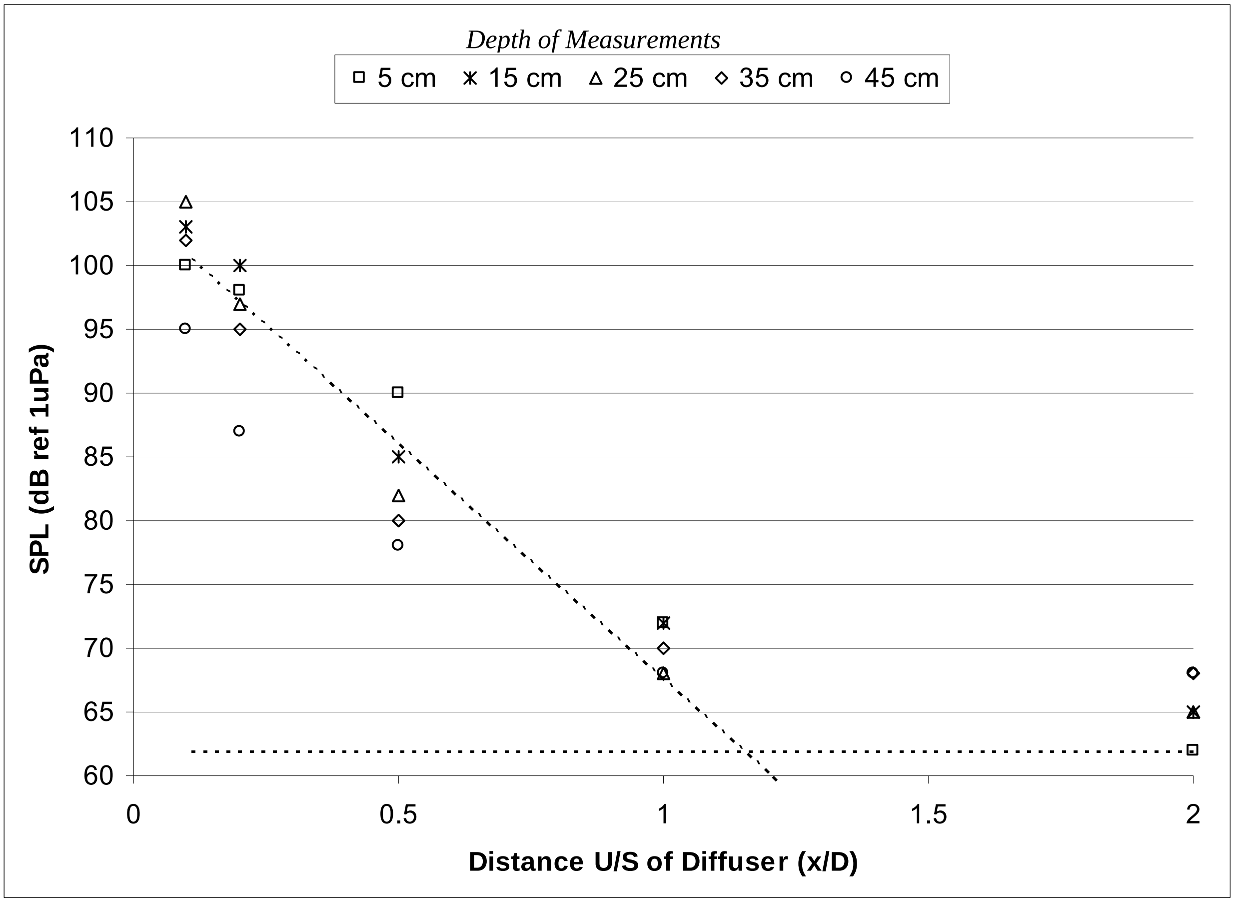


Figure 11. Attenuation plot for fine-bubble diffuser at depth D = 50 cm

The rapid attenuation of the primary sound signal is important to highlight, as this creates a natural gradient. Attenuation at the lower frequencies also prevents the sound generated from the barrier to be broadcast a significant distance upstream or downstream of the barrier, potentially allowing carp to acclimate to the sound.

Overall we quantified the acoustic field generated by each diffuser at varying flow rates and Table 2 provides the maximum SPL within 100-500 Hz and distance at which a 10 dB increase is experienced.

Table 2
Maximum SPL of each diffuser

Diffuser Type	Flow-rate ($Ls^{-1}m^{-1}$)	Depth (cm)	Maximum SPL (dB)	Influence Distance (x/D)
Fine-Bubble	1	25	90	+/- 0.6
	2.5	25	100	+/- 1.0
	2.8	25	112	+/- 1.6
	2.5	50	98	+/- 0.6
	2.8	50	110	+/- 1.2
Coarse-Bubble	2.5	25	120	+/- 1.6
	2.8	25	125	> +/- 2.0

4.0 Developed Barriers

4.1 Mark I Barrier

The initial Mark I barrier tested at the Aquaculture Center was a single wand fine-bubble diffuser. The porous material utilized by the fine bubble diffuser is novel to bubble barrier designs based on the limited number of designs described in literature [Dawson et. al., 2006; Taylor et. al., 2005;Welton et. al., 2002]. Testing an individual wand served a dual purpose of being a starting point for barrier design and prototype experiment for the PIT tag detection system. Description of the pit tag detection system will be addressed in a later section. A electric air-compressor was used to supply air to the wand at a maximum rate of approximately 1.0 $Ls^{-1}m^{-1}$. A single wand at such a low pressure did not create a very robust barrier, resembling the typical aquarium air stone rather than impressive barrier. Upgrading the air supply to a gas powered air-compressor allowed a maximum sustained air-flowrate of 2.5 $Ls^{-1}m^{-1}$, similar to that tested at SAFL. Figure 12 provides the top view of single fine-bubble diffuser at an air-flowrate of 2.5 $Ls^{-1}m^{-1}$. The acoustic field generated by the Mark I barrier was confirmed with hydrophone measurements to be similar to that studied at SAFL.

Figure 12. Top view of Mark I barrier at 2.5 $Ls^{-1}m^{-1}$

The Mark I barrier appears to have retarded carp movement but not limit the number of passages through the barrier. A full summary of the Mark I barrier test is provided in **result status 9/30/2010 for Result 2**.

4.2 Mark II Barrier

Due to the relatively minimal effect of the Mark I barrier on carp movement, a sizable increase in dimension, gradient, and air-flowrate was integrated into the design of the Mark II barrier. The design of the Mark II barrier also focuses on the hypothesis that the acoustic field is the primary agent for limiting carp passage; therefore, a gradient of SPL was created in the downstream direction by using a combination of different diffusers. The Mark II diffuser consists of the following (looking up- to down-stream): one fine-bubble diffuser supplied by gas-powered compressor, four coarse-bubble diffusers supplied by regenerative blowers, and one ultra-coarse diffuser (3 mm diameter holes spaced at 5 cm) also supplied by regenerative blowers. Figure 13 provides a diagram of the Mark II barrier configuration.

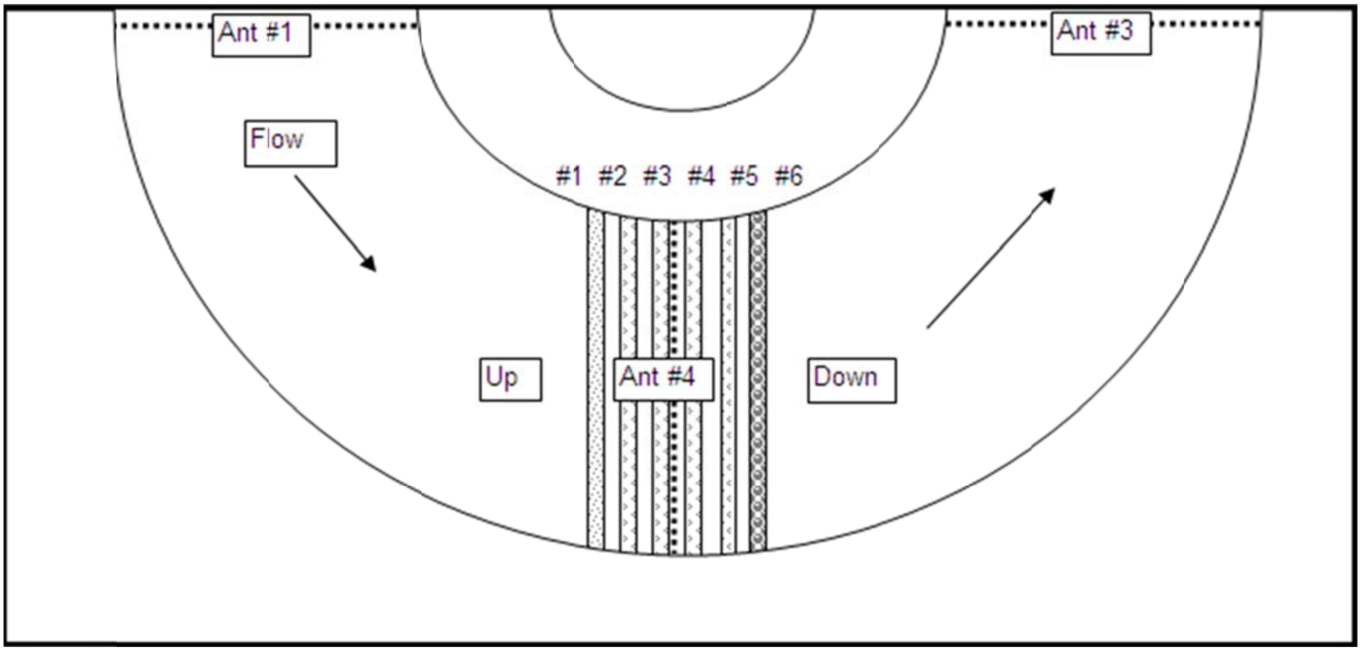


Figure 13. Diagram of the Mark II barrier in the Aquaculture Center

The air-flow to diffuser #2 to #5 is controlled by a PVC manifold capable of directing the quantity of air to each diffuser. The regenerative blowers are capable of supplying greater amounts of air at low pressures. The total air-flowrate supplied to the entire Mark II barrier is 31.5 $Ls^{-1}m^{-1}$, approximately a 10 times increase of the Mark I barrier. The Mark II barrier thickness also increased from approximately 10-15 cm to almost 1 m.

The SPL generated by the barrier without the fine-bubble diffuser was measured by placing the hydrophone 10 cm upstream of #2 (indicated as US) and 10 cm downstream of #6 (indicated as DS). While maintaining the location of the hydrophone constant, multiple combinations of diffusers were tested to find the optimal sound field. Figure 14 presents the SPL at 150 Hz 10 cm up- and down-stream of the diffusers incrementally adding or removing selected diffusers.

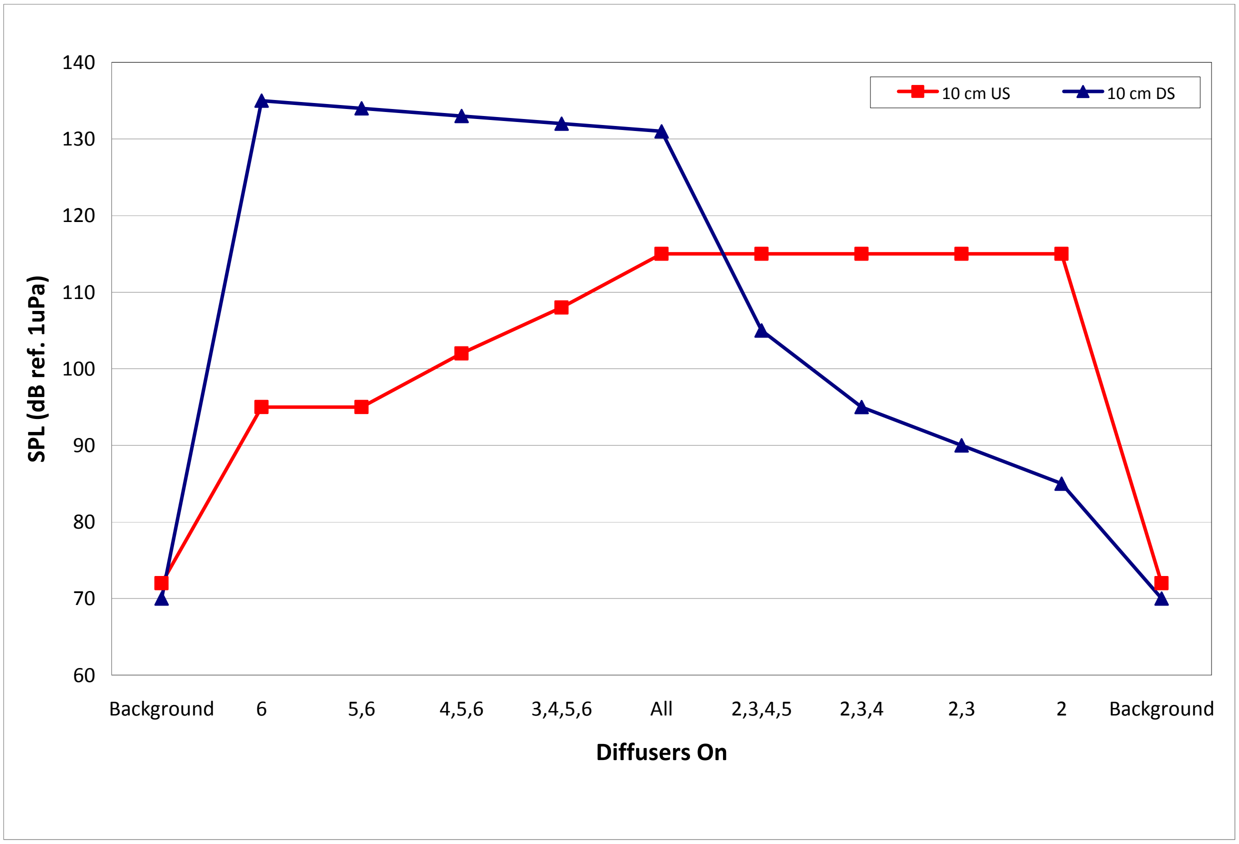


Figure 14. SPL of Mark II barrier without fine-bubble diffuser

Note the maximum SPL of 135 dB occurs only when the ultra-coarse diffuser is supplied all the air; however, only a 4 dB decrease is observed when the air is distributed between all 5 diffusers. The constant SPL generated near the edge of the barrier indicates that the SPL on the up- and down-stream sides of the barrier is controlled by each respective exterior diffuser. We selected the optimal setting to be full air supplied to all diffusers, as this creates the strongest SPL throughout the entire barrier. Adding the fine-bubble diffuser is expected to increase the complexity of flow fields, and extend the SPL on the up-stream side of the barrier at 100 dB. Figure 15 provides a top view of the Mark II diffuser with and without air supplied. A summary of the Mark II testing with carp is provided in **result status 9/30/2010 for Result 2**.

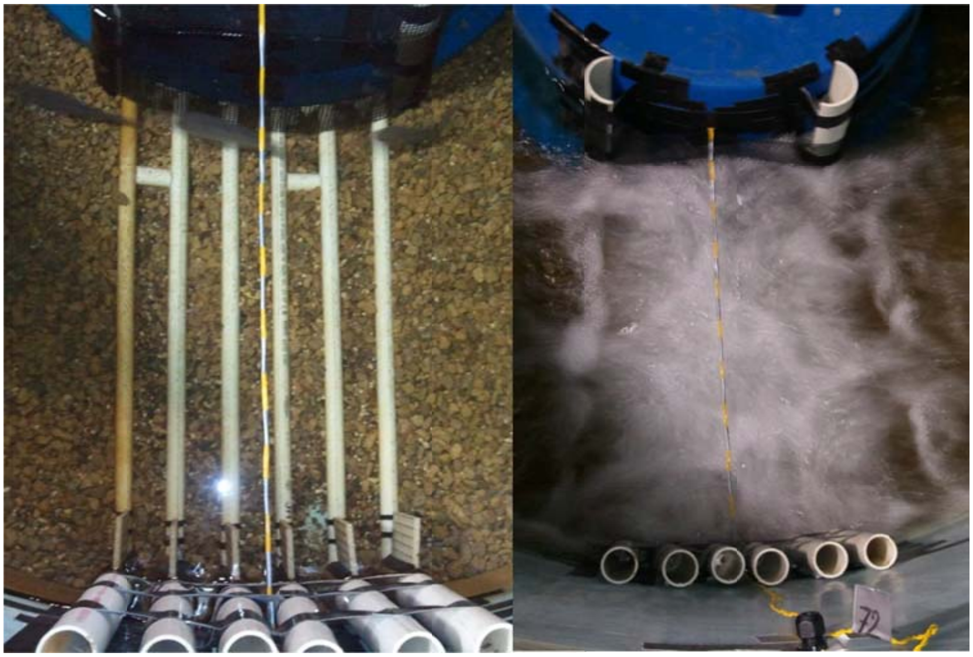


Figure 15. Top view of Mark II barrier without (left) and with air (right)

4.3 Future Barriers to Test

As a revision to the conclusions section in **results status 3/31/2010 for Results 1**, we have considered alternative future prototype barriers to be tested. The Mark III barrier will consist of multiple ultra-coarse diffusers or some combination of coarse and ultra-coarse diffusers, positioned in a grid to create a more dense bubble curtain. Diffusers will be set in pairs, with each pair having its air supplied by an individual regenerative blower. The estimated air-flowrate through the entire barrier is 90 $Ls^{-1}m^{-1}$, or three times the Mark II barrier. The larger diameter holes in the ultra-coarse diffusers clearly generate the strongest SPL, as shown in Figure 14. Decreasing the spacing or changing the orientation of the diffusers should help reduce any spaces between individual bubble plumes that the carp may pass through. Another alternative that will be studied is an acoustically enhanced barrier. Underwater transducers can supply a SPL of approximately 160 dB at any frequency between 100 Hz – 10,000 Hz. The precise control granted by this design should enhance our understanding of what physical field repulses the carp. An acoustic barrier will be studied with and without an accompanying bubble curtain, as bubble plumes have been shown to decrease sound propagation.

Tests to determine the effect of environmental factors on the bubble barriers, as well as measuring the physical fields generated by the underwater transducers are ongoing at SAFL. The results of this study will be outlined in a report on 3/31/2011. We also plan to install the optimal barrier design, as concluded by testing, at the SAFL Outdoor Stream Lab or select field site to determine how to implement the barrier in an actual stream and field test with PIT tagged carp.

Result Status as of *(3/31/2011):*

Modification of Bubble Barrier due to Environmental Effects

(Reported by Dan Zielinski, Graduate Student)

1.0 Phase III. Environmental Effects of Bubble Barriers

The objective of this phase was to study how environmental effects (i.e. flow and depth) modify the physical fields generated by the bubble barrier. The bubble barrier was designed to reduce recruitment of juvenile carp from nursery lakes to stable bodies of water, by being placed within the small interconnecting channels between water bodies. These channels have typical dimensions of <0.5m deep and 1-3m wide and usually experience seasonal flooding, The diminutive size of the channel and shallow water makes most current barrier technologies unattractive. A bubble barrier should be ideal for this application as the bubble curtain does not require human control to adjust to rapidly varying conditions. Understanding how the physical fields generated by the bubble barrier are affected by changes in flow and depth should provide insight into a safe operating range that these barriers can be effective.

The final portion of this section outlines the design of the third bubble barrier tested under the same behavioral tests as in **results status 9/30/2010 for Results 1 and 2**. The design and complimentary measurements associated with the Mark III barrier are included. Results of the carp behavioral tests are provided in **results status 3/31/2011 for Results 2**.

2.0 Variations in Flow Depth

Relatively narrow channels are prone to large fluctuations in flow depth during high flows as a means to increase flow capacity, so the first variable we studied for effects of barrier performance was depth. In **results status 9/30/2010 for Results 1** we quantified the physical fields generated by a fine- and coarse-bubble diffuser in 25cm, and 50cm of water. In the previous section, Table 1 and Table 2 provide the characteristic magnitude of the velocity field and sound pressure level (SPL). A close inspection of these results reveals that an increase in depth from 25cm to 50cm does not greatly affect the strength of flow or acoustic fields. The fine -bubble diffuser at $2.5 Ls^{-1}m^{-1}$ and $2.8 Ls^{-1}m^{-1}$ air flow rate saw a reduction in the maximum velocity of ≈15% when the depth was increased to 50cm. The SPL for the same settings only experienced ≈2% reduction in magnitude. A reduction in velocity magnitude was expected as the increased depth provides more dissipation to the flow fields. The maximum SPL does not change as the acoustic input does not change between experiments and the maximum SPL occurs right next to the diffuser openings.

A significant change in the sound field does occur as a result of the increased depth. Sound attenuates so rapidly in water less than 1m deep that any change in depth will greatly affect the SPL gradient. This phenomenon is demonstrated by the relatively large change in attenuation length for a similar sound signal in 25cm and 50cm deep water. Performing similar calculations as those required to generate Figure 11 in **results status 9/30/2010 for Results 1**, reveals that the length at which it takes a sound at 150 Hz to decrease 20 dB is 17cm for 25cm and 26cm for 50cm of water. Essentially this illustrates that in 25cm of water a sound signal loses strength at a rate 35% faster than in 50cm of water, increasing the SPL gradient. The increase in the sound gradient due to shallow water is important to note as sharp physical gradients are key to the barrier design, as they may elicit a more immediate avoidance response from the carp.

3.0 Variations in Flow Velocity

The behavioral tests in **results status 9/30/2010 for Results 2** were performed under current velocities ≈5cm/s. The flow was selected to minimize the effect of current on the bubble curtain, while still providing an overall flow direction to motivate carp movement. This flow is less than expected in real field sites, and higher flows were investigated to determine how they modify the bubble barrier. Flow data is often not available for the outlets of nursery lakes due to their remote location; however, limited flow data was collected by the Sorensen Lab Group, from the University of Minnesota, on nursery lakes in central Minnesota. Their data indicated that velocities in the typical interconnecting channel range from 10cm/s to 1m/s, with the mean velocity ≈20cm/s. Using the same experimental set-up described in **results status 9/30/2010 for Results 1** section 1.0, we quantified the physical fields generated by a single fine- and coarse-bubble diffuser under 10cm/s and 20cm/s.

Bubble curtains are driven by a buoyancy force pushing a group of bubbles towards the surface of the water. Researchers have identified that bubbles greater than 1mm in diameter have a constant rise velocity between 25cm/s and 30cm/s [Leifer et. al., 2000]. Under the influence of flow normal to the bubble curtain, the bubble curtain is expected to undergo some angular deformation θ, as shown in Figure 1.

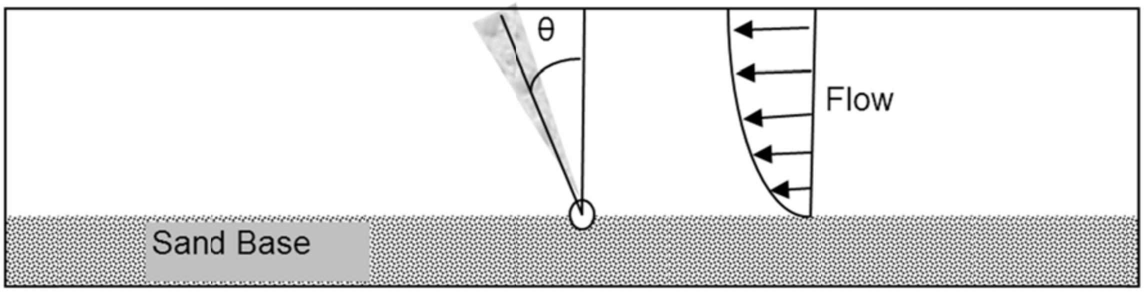


Figure 1. Angular deformation of bubble curtain under normal cross flow

Using basic trigometry, it is clear that θ≈45° when the depth average velocity is equal to the rise velocity. A channel velocity greater than 30cm/s will deform the bubble curtain so the longitudinal reach of the bubble curtain becomes much greater than the depth of flow, effectively stretching the bubble curtain.

3.1 Flow Measurements

Similar to **results status 9/30/2010 for Results 1**, using the MicroADV, we calculated the time-averaged velocity vector at various locations along the centerline of the SAFL flume with the fine- and coarse-bubble diffusers under approximately 10cm/s and 20 cm/s cross flow. From the velocity vectors we calculated the streamlines (the line tangent to the local velocity vector) for each given diffuser set-up. In the interest of brevity, we will present the physical field measurement results for the 20cm/s flow as they display a more pronounced change in flow and SPL patterns. Figure 3 provides the velocity vector plot for the fine-bubble diffuser at an air flow rate of 2.5 $Ls^{-1}m^{-1}$ and set at a depth of 0.25 m. Figure 4 provides the corresponding streamline plot to the velocity vectors plotted in Figure 3. The streamline plot is included to highlight the location of the stagnation point, or center of rotation of the recirculation cell. Note, the x- and y-axis have been normalized by the depth of flow.

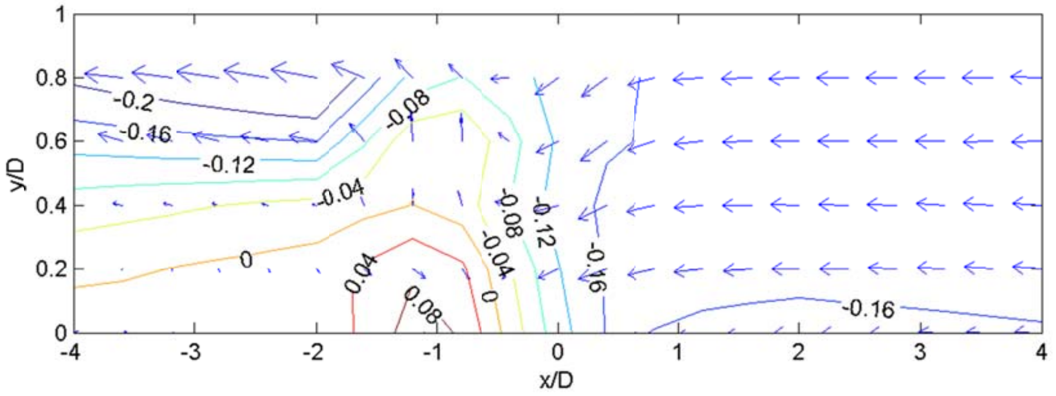


Figure 3. Velocity field for fine-bubble diffuser at 2.5 $Ls^{-1}m^{-1}$ and a depth D=25cm under 20cm/s cross flow (velocity contours are in m/s)

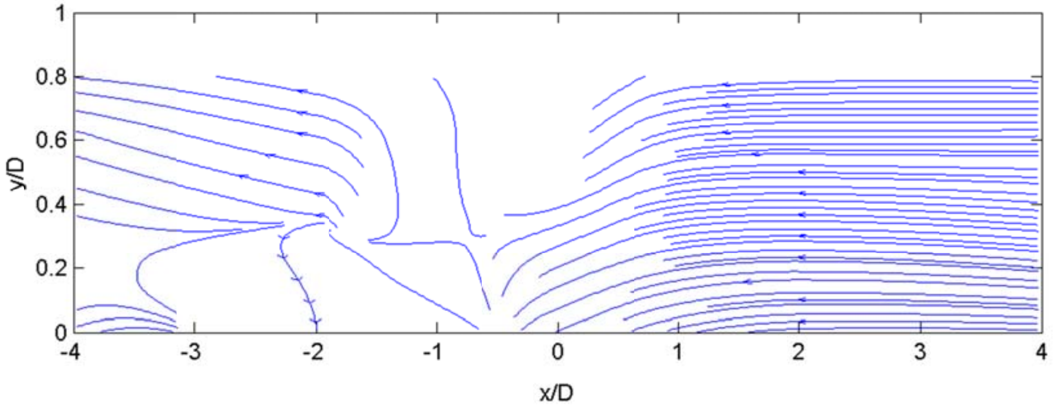


Figure 4. Streamline plot of velocity field generated by fine-bubble diffuser at 2.5 $Ls^{-1}m^{-1}$ and a depth D=25cm under 20cm/s cross flow

Note that the stagnation point (point of zero velocity) can only be identified on the downstream side of the barrier between x/D=-2.5. This is significantly different than the location found under no flow conditions (x/D = +/-1). Figure 5 provides the velocity vector plot for the coarse-bubble diffuser at under the same conditions. Figure 6 provides the corresponding streamline plot to the velocity vectors plotted in Figure 5.

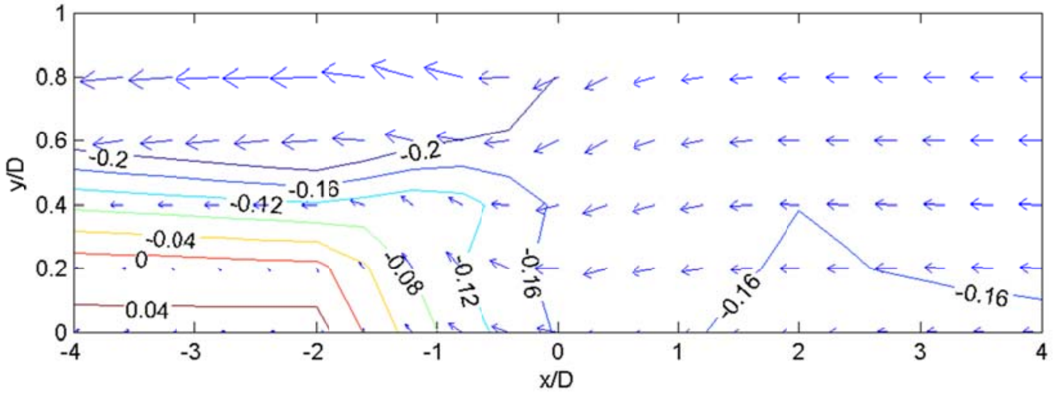


Figure 5. Velocity field for coarse-bubble diffuser at 2.5 $Ls^{-1}m^{-1}$ and a depth D=25cm under 20cm/s cross flow (velocity contours are in m/s)

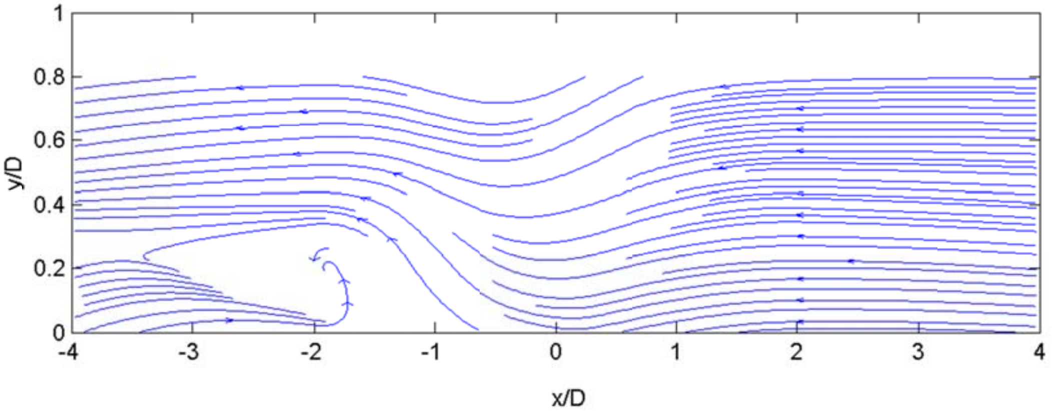


Figure 6. Streamline plot of velocity field generated by coarse-bubble diffuser at 2.5 $Ls^{-1}m^{-1}$ and a depth D=25cm under 20cm/s cross flow

Note the stagnation point is located in approximately the same location as the fine-bubble diffuser. The fine-bubble diffuser clearly creates a strong upward plume in the proximity of the bubble curtain, while the coarse-bubble diffuser appears to have dissipated flow strength near the surface (velocities down-stream of the curtain are equal to background flow). During each flow test, the angular deformation was calculated for each diffuser and compared to expected values presented in Figure 7. The expected angular deformation is calculated as follows:

$$\theta = 90° - \tan^{-1}\left(\frac{L_{rise}}{L_{long}}\right) \qquad (1)$$

Where

L_{rise} = vertical distance traveled by bubbles (depth of water)

L_{long}=longitudinal distance traveled in time required for bubbles to reach the surface

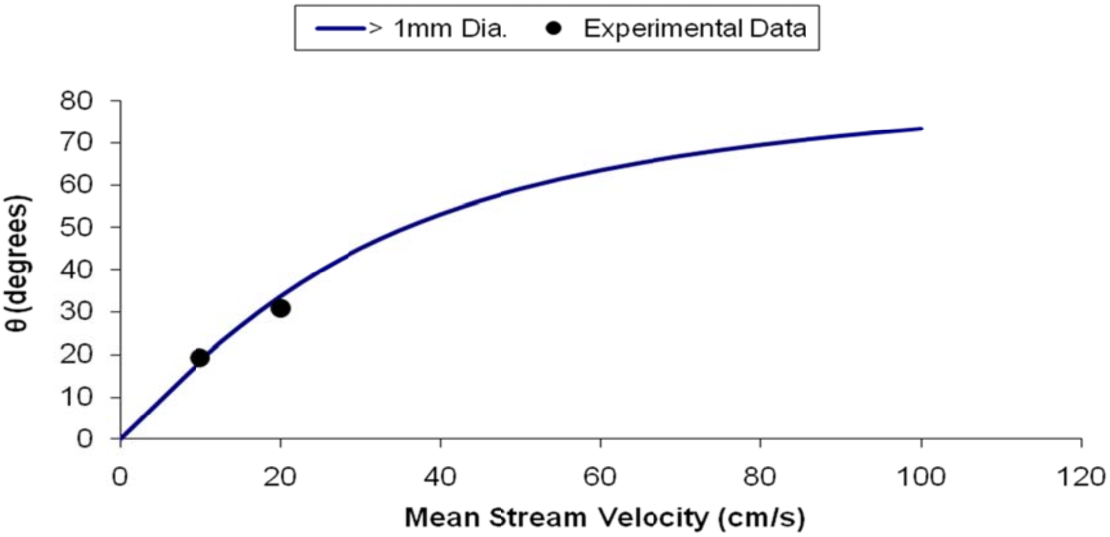


Figure 7. Expected deformation angle of bubble curtain with experimental data provided

Note the close agreement of experimental data and the expected deformation. The deformation did not change with respect to the bubble size, confirming that bubbles >1mm in diameter will rise at approximately the same velocity.

3.2 Acoutic Measurments

Based on work by Tonolla et. al. [2009], sound generated by flow is expected to increase as velocity increases due to increased turbulence. Increased background sound levels increase will decrease the SPL above background, decreasing the range of influence due to sound of the barrier. Tonolla et. al. [2009] showed that turbulence created by flow around in-stream objects generates significant underwater noise; however the sound attenuates quickly due to shallow water losses discussed earlier. Based on the assumption that the barrier would be placed in a location acceptably away from flow obstructions, background noise should be reduced. Applying a uniform flow across each barrier sans flow obstructions, we obtained the increased background SPL due to flow through a channel. The experimental background levels are expected to be similar to field conditions as the barrier would ideally be placed within a control section free from flow obstructions. The background SPL due to 10 cm/s and 20 cm/s flow was 70dB and 75dB (between 100-500Hz), respectively. This represents only an increase in background noise as the background SPL under no flow was 62dB (between 100-500Hz).

Similar to **results status 9/30/2010 for Results 1**, we measured the SPL field generated by a fine- and coarse-bubble diffuser under 2.5Ls^{-1}m^{-1} air flow rate under 10cm/s and 20cm/s flow. Sound pressure waves propagate at a velocity much greater than the flow velocity (i.e. 1500m/s vs. 20cm/s), so the magnitude of the sound field is not expected to be affected by flow. Figure 8 and 9 provide a contour plot of the SPL above background for the fine- and coarse-bubble diffuser, respectively, at an air flow rate of 2.5 Ls^{-1}m^{-1} with 20cm/s flow.

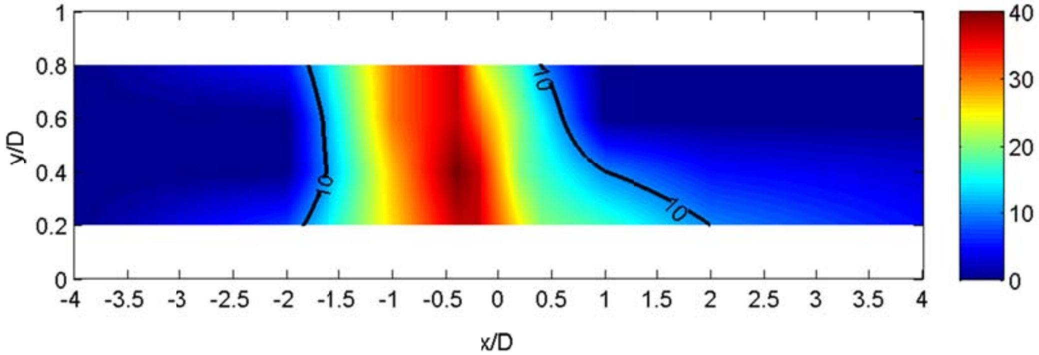


Figure 8. SPL above background generated by the fine-bubble diffuser at 2.5 Ls^{-1}m^{-1} and a depth D=25cm under 20cm/s cross flow

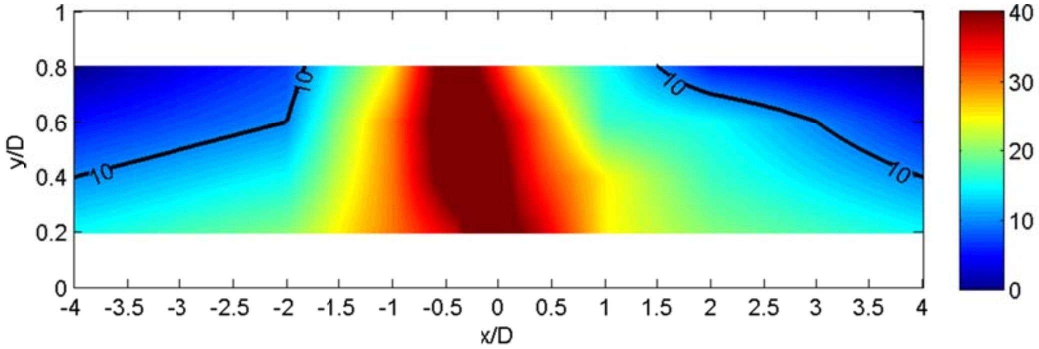


Figure 9. SPL above background generated by the coarse-bubble diffuser at 2.5 $Ls^{-1}m^{-1}$ and a depth D=25cm under 20cm/s cross flow

Note the maximum SPL has a down-stream facing deformation, as noted in Figure 7. The resulting angle of deformation in the sound field is a result of anisotropy of sound attenuation along the bubble curtain. Manasseh et. al. [2004] demonstrated that sound propagates along a bubble chain more efficiently than normal to it; indicating that for a sound source (diffuser) at the bottom of the channel, the peak sound intensity will match the location of the bubble curtain. Longitudinal stretching of the maximum SPL may not decrease the effectiveness of the barrier to stop carp, as Figure 8 and 9 clearly show a vertically continuous sound gradient well within the carp hearing range. However, it should be noted that the sound gradient may not be vertically continuous if the cross flow is sufficiently strong to break-up the bubble curtain enough to disrupt the propagation of sound along the curtain. Based on the SPL field created under 10cm/s and 20cm/s, the bubble curtain is not expected to see an decreased performance for flows less than the bubble rise velocity of 30cm/s. Further tests would need to be performed for flows much greater then 30cm/s.

4.0 Developed Barriers (Part II)

4.1 Mark III Barrier

The Mark III barrier was designed to maximize the air-supply equipment available at the Aquaculture Center; this also corresponds to a maximum air-supply that can be effectively scaled-up to an existing channel. The design of the Mark III barrier focuses on the hypothesis that the acoustic field is the primary agent for limiting carp passage as the velocities generated by the bubble barrier are not significantly greater than naturally occurring velocities in a flashy stream. In contrast to the Mark II barrier, the Mark III barrier is characterized by a constant air flow over a uniform barrier; therefore, the SPL is constant from the up-stream to down-stream sides. Figure 10 displays the typical layout of the Mark III barrier. The Mark III barrier consists of PVC pipe containing ultra-coarse holes (3 mm diameter holes spaced at 2.5 cm) with a pipe grid spacing of 12.5cm X 16.5cm. The ultra-coarse holes were selected to provide the highest SPL while not reducing the air-pressure to a point of non-uniform bubble curtains. The PVC grid is separated into four individual quadrants, each supplied by a single regenerative blower. The total air-flowrate supplied to the entire Mark III barrier is 108 $Ls^{-1}m^{-1}$, approximately a 3 times increase of the Mark II barrier. The Mark III barrier thickness remained consistent with the Mark II barrier at 1m. An interesting feature of the Mark III barrier is the individual cells of bubble curtains created by the grid layout. The bubble cells provide a labyrinth configuration of curtains that removes any gaps that carp could possible navigate through, i.e. the carp must pass through a bubble curtain.

Figure 10. Mark III configuration (no air supplied)

The SPL generated by the barrier was measured by placing the hydrophone 10 cm upstream and 10 cm downstream of the barrier. The maximum SPL generated up- and down-stream is approximately 124 dB, which is approximately 40 dB higher than background. The SPL was also measured in the rear section of the tank to be 85 dB, which at less than 10 dB above background falls within the “cocktail party” effect and should be undetected by carp. The Mark III barrier does not have an equivalent SPL field as the Mark II, approximately 10 dB drop on the down-stream side and 10 dB gain on the up-stream side. Maximum SPL reduction is the result of reduced blower efficiency and greater demand of air in each diffuser quadrant. Figure 11 provides a top view of the Mark III barrier with air supplied.

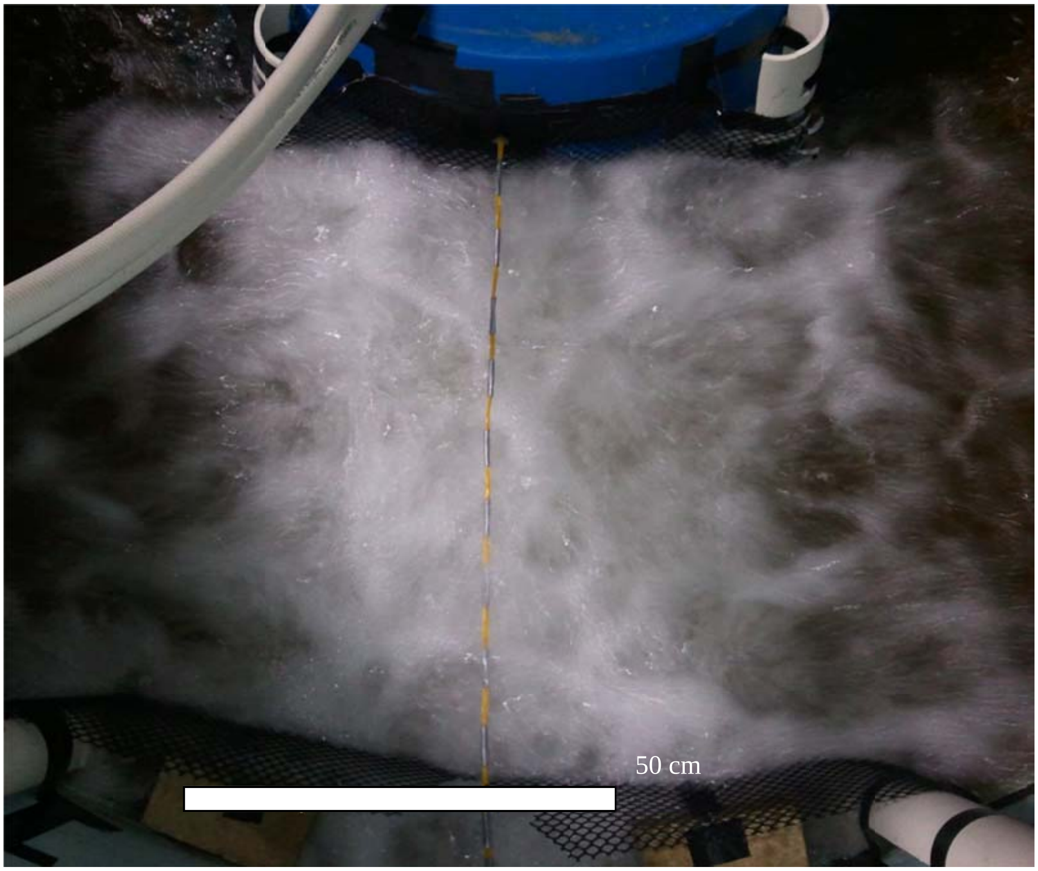


Figure 11. Top view of Mark III barrier and with air

Result 2: Laboratory Investigation: Biology

Description: The objective is to determine whether bubble curtains produce sensory stimuli that can impede the directed movement of juvenile invasive common carp. Biological work will proceed in three steps: i) Determining if a bubble curtain can impede carp from moving either down- or up-stream in a laboratory flume running at a typical field depth; ii) Determining what sensory field is responsible for this impediment ; iii) Determining how to optimize this field(s) to impede carp movement in a laboratory flume.

Summary Budget Information for Result 2:	**Trust Fund Budget:**	**$ 116,000**
	Amount Spent:	**$ 66,059**
	Balance:	**$ 49,941**

Deliverable	**Completion Date**	**Budget**
1. Testing and documentation of the effectiveness of bubble curtains to impede the movement of juvenile carp in a laboratory flume. Questions:	~~3/31/2011~~ 6/30/2012	$116, 000

What is level of deterrence? Why does the curtain it deter movement? How can it the repulsive effects be optimized		

Completion Date: *3/31/2011*

Results status of *(11/10/2009):*
Plumbing and pump refurbishment for lab tanks have been initiated.
Investigation is underway toward developing and implementing PIT systems to track the movement of the fish relative to bubble barrier and other stimuli in the lab tanks

Amendment Approved: 12/17/2010
See Section III for details related to the approved amendment.

Results status of *(3/31/2010):*
The lab is now operational. The supply of well water and re-circulated water is working. The lab is now equipped with large circular tanks supplied with water. PIT systems to track the movement of the fish relative to a bubble barrier have been installed and evaluated in one tank. In addition, the lab has been prepared for fish holding in several separate tanks. Experimental common carps have been transferred to the lab and equipped with PIT tags. Tests show that the installed PIT systems are capable of detecting fish movements.

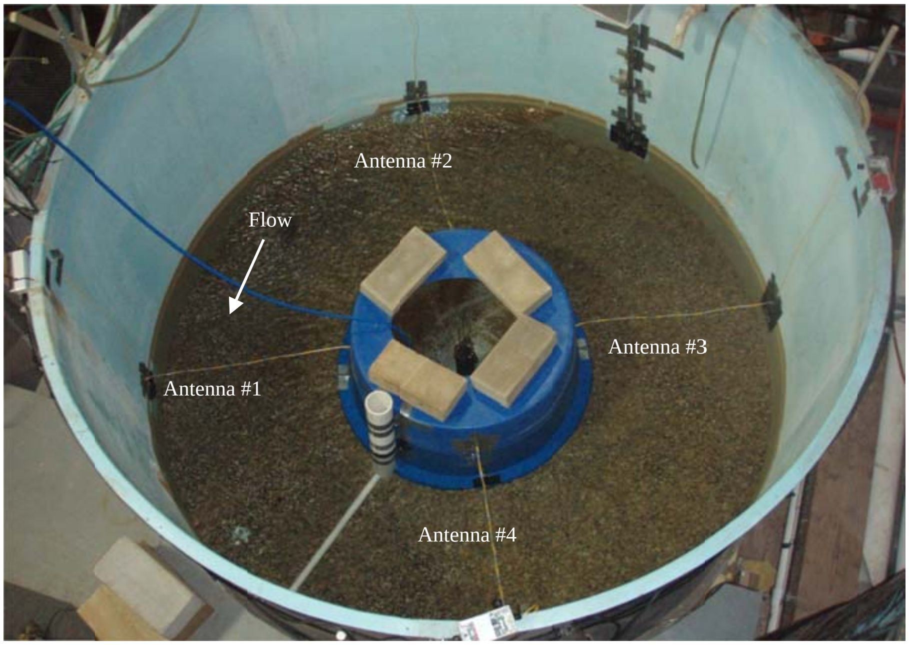
Results status of *(9/30/2010)*:

Bubble Barrier Testing

(Report by Dan Zielinski, Graduate Student)

1.0 Development of Fish Tracking System

The key component of the Aquaculture Center testing is the controlled experimental environment which tracks fish movements automatically through the use of radio frequency identification (RFID) PIT tags. A PIT tag consists of a microchip that contains a unique identification number that can be detected/recorded passively when passing through a specifically tuned antenna. Each antenna is made of wire wound in loops and connected to tuner boxes, which are in-turn connected to a reader. The reader sends out a signal that allows each individual antenna to detect if a PIT tag is within its sensing range. The sensing range can be manually adjusted via wire thickness, number of loops, and fine tuning of the tuner box. The antenna used in the experimental tank have a reading range at approximately 1.0 meter, meaning a PIT tag with in 0.5 m up- or down-stream of the antenna will be detected. Four antennas are evenly spaced around the test tank as seen in Figure 1. The antennas are numbered sequentially 1 through 4.



The reader logs all detections onto a memory card which is downloaded via computer program Procomm Plus. Each detection log includes the date, time, PIT identification number, length of consecutive detections, and location of detection, from which we can calculate how many times a carp passes in an up- or down-stream direction (i.e. 1-4-3 or 3-4-1). The Mark I barrier configuration used three antennas, with the barrier located between two as seen in Figure 1. The Mark II barrier configuration uses four antenna with the #4 antenna located directly over the barrier.

The PIT tag is inserted into the body cavity of randomly selected carp. Only one PIT tagged carp is allowed in the test tank at a time, as multiple PIT tags cancel each other if in the same detection range simultaneously. The only way a PIT tag will not be detected, once the system is tuned correctly, is if the tag is oriented within 10 degrees of parallel to the antenna. Through the Mark I and II barrier tests, the PIT tag system has captured 99% of all possible detections.

2.0 Fish Testing Protocol

A strict testing protocol is paramount to reduce the number of variables that could influence carp behavior during a given testing period. Following the experiments by Zydlewski et al [2005], our tests will be carried out at the Aquaculture Center in a circular tank with PIT tag antenna evenly spaced in the channel. A moderate flow of 5 cm/s is generated in a counter-clockwise direction by a freshwater input. Water is continuously cycled through a re-circulation system via a drain separated from the fish by the central tank as seen in Figure 1. All experimental carp were caught in the wild by electro-fishing. All fish are maintained onsite in four separate tanks onsite; a separate tank for tagged/untested, tagged/tested, untagged/untested, and untagged/tested carp. All tanks are kept in relative darkness by placing tarps overtop and water is continuously re-circulated. The carp are fed pellets once a day at approximately 10:00 am. Water temperature is maintained at approximately 21 degrees C in all tanks, to reduce any undue stress on the fish during testing.

All tests are carried out in complete darkness to remove any visual influence of the bubble curtain; tests occur between the hours of 10:00 PM and 6:00 AM, with a tarp covering the test tank and all lights off in the laboratory. An attempt is made to randomly select fish from the untested populations, so as to generate independent results. Each test consists of selecting one PIT tagged fish and two untagged fish and placing them in the test tank. The first 10 minutes of each test is considered acclimation time, and not included in the data analysis. The test period encompasses the following 7 hours of detections. During the tests, all extraneous electrical systems are turned off, to reduce noise detected by the antenna. For every test completed with air supplied to the barrier, one control test is completed. A control test consists of using a new group of fish in the test tank with the barrier in place, but not supplied air. Once the testing is complete, all fish are weighed and measured for total body length. The fish are then separated into the holding tanks with tested fish, for future tests. No fish is used in the test tank twice throughout the barrier on, or corresponding control, test for a given barrier type.

The detections are analyzed using the computer program Matlab and MS Excel to calculate the number of passages over the barrier, average passage time, number of detections at the barrier, and average time spent near the barrier. Due to the limited size and large variability in the data sets, the probability reported in the following sections is a result of the Mann-Whitney U test.

3.0 Barrier Test Results

3.1 Mark I Barrier

The Mark I barrier tests have a dual objective of prototyping the PIT tag detection system and as a starting point for the barrier designs. The Mark I barrier was supplied an air-flowrate of 1.0 and 2.5 $Ls^{-1}m^{-1}$. A total of four control tests, four barrier tests with 1.0 $Ls^{-1}m^{-1}$, and two barrier tests at 2.5 $Ls^{-1}m^{-1}$. A limited number of tests were completed due to issues with high fish mortality. The PIT tag system preformed well over all tests, limiting the number of missed detections to less than 1% of all detections. Detections are considered missed when the carp is detected at two non-consecutive antennas. All control tests indicate a strong tendency for the carp net movement to be downstream, which is expected when as the carp cannot orient to the substrate in the darkness. Figure 2 provides the total up-stream passages over the barrier for the control and two flowrates. Figure 3 provides the total down-stream passages over the barrier for the control and two flowrates. Note that there is a slight decrease in movements when the barrier is on in both directions, but is not statistically significant. Also note that all bar graphs are provided with standard error bars.

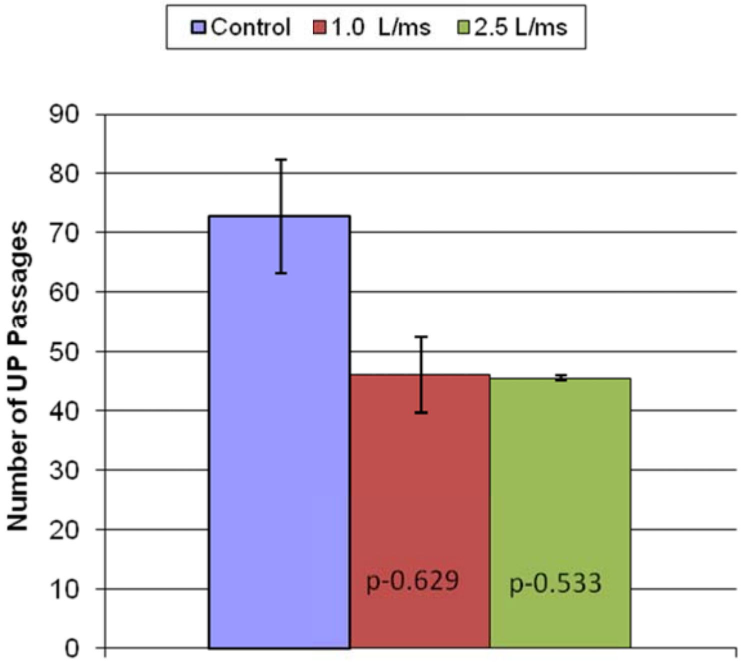


Figure 2. Number of up-stream passages over the Mark I barrier

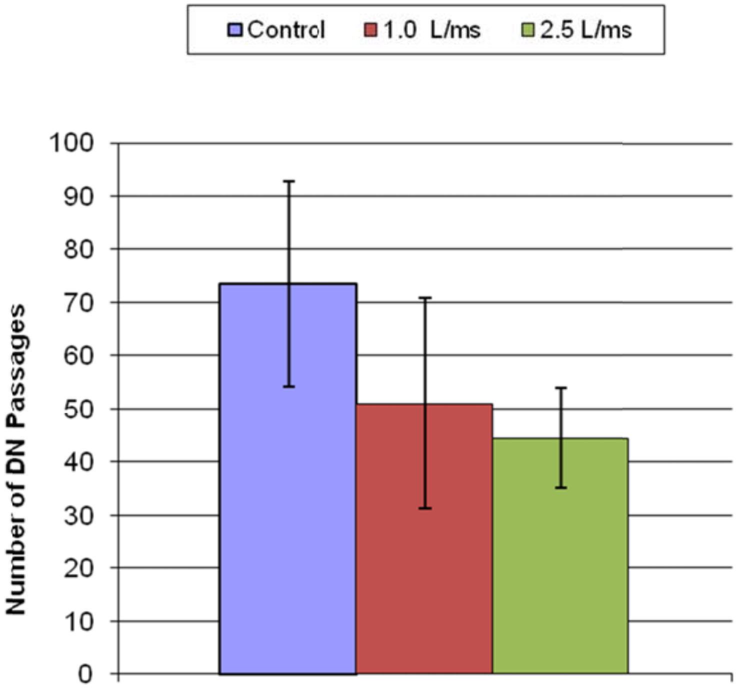


Figure 3. Number of down-stream passages over the Mark I barrier

Figure 4 and 5 provide the mean time required to pass over the barrier during the control and two flowrates. Note that the passage time increases for the barrier on configurations, and is statistically significant with $p < 0.05$.

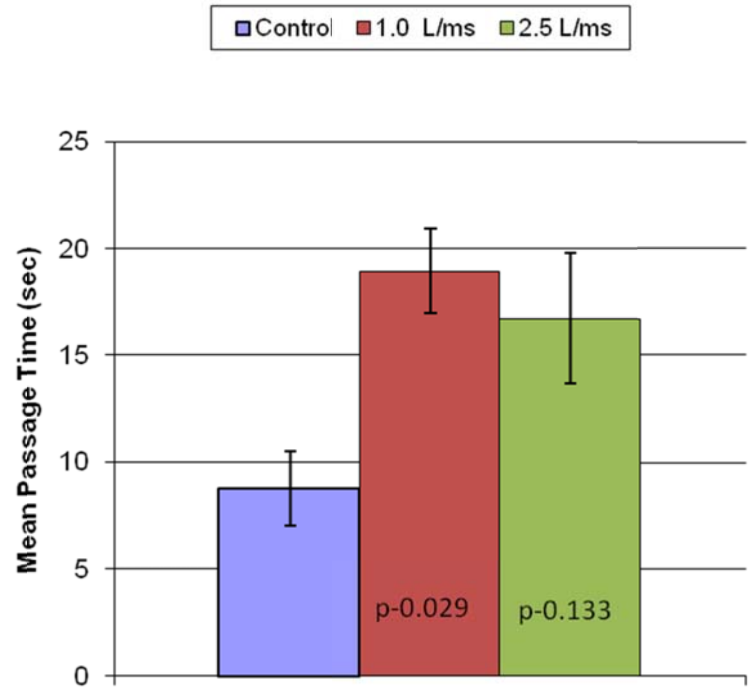


Figure 4. Mean passage time to cross Mark I barrier in the up-stream direction

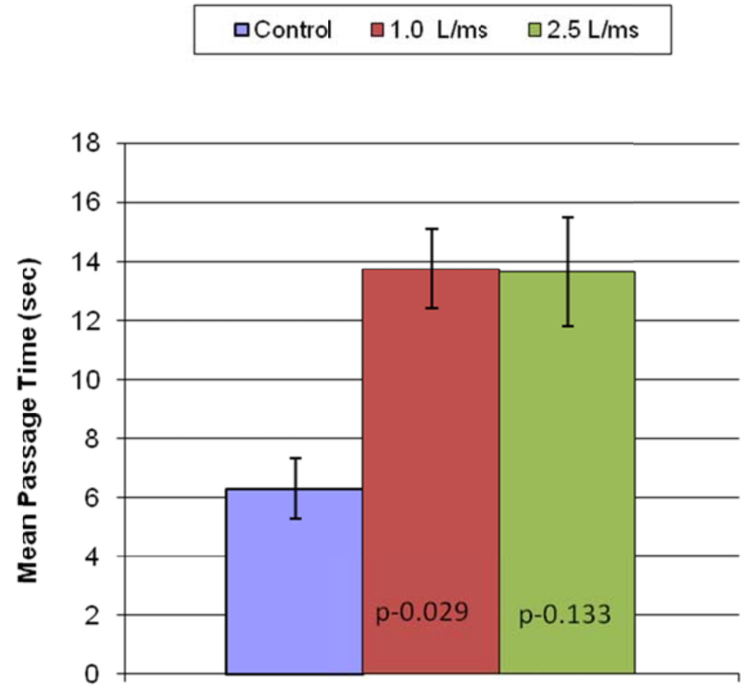


Figure 5. Mean passage time to cross Mark I barrier in the down-stream direction

The limited number of tests restricts the statistical significance of these results; however, the barrier tests indicate that the Mark I barrier may retard carp movement by approximately 10 seconds.

3.2 Mark II Barrier

The Mark II barrier discharges 10 times the air-supply as the Mark I barrier and represents a significantly more vigorous bubble curtain. A four antenna experimental configuration provides more information on the carp movements, as the antenna located directly over the barrier can detect the total time the carp spend near the barrier. A total of 8 tests were performed with 31.5 $Ls^{-1}m^{-1}$ air-flowrate and without air-supplied to the barrier. Figure 6 and 7 provide the total up- and down-stream passages over the Mark II barrier during the control and barrier tests. Note the decrease in passages is statistically significant, indicating that the barrier does limit carp movement.

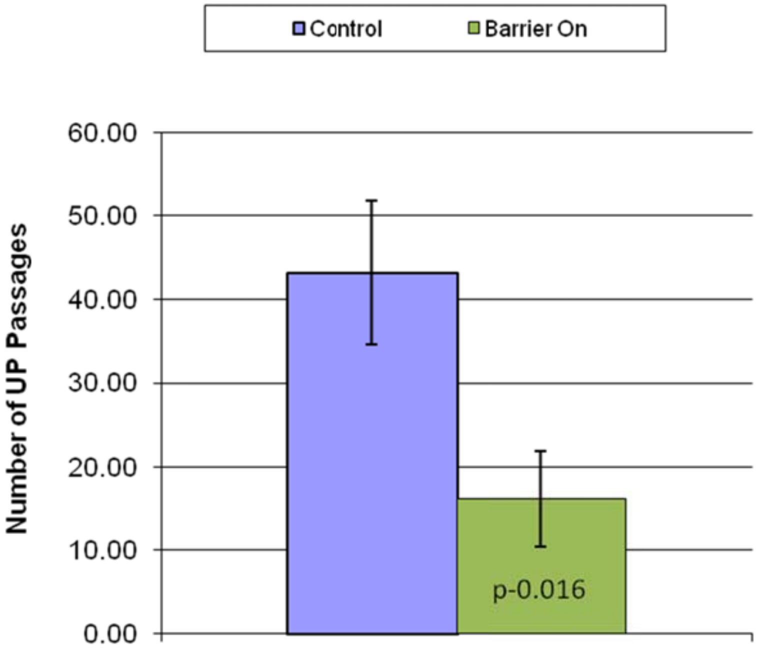


Figure 6. Total number of up-stream passages over Mark II barrier

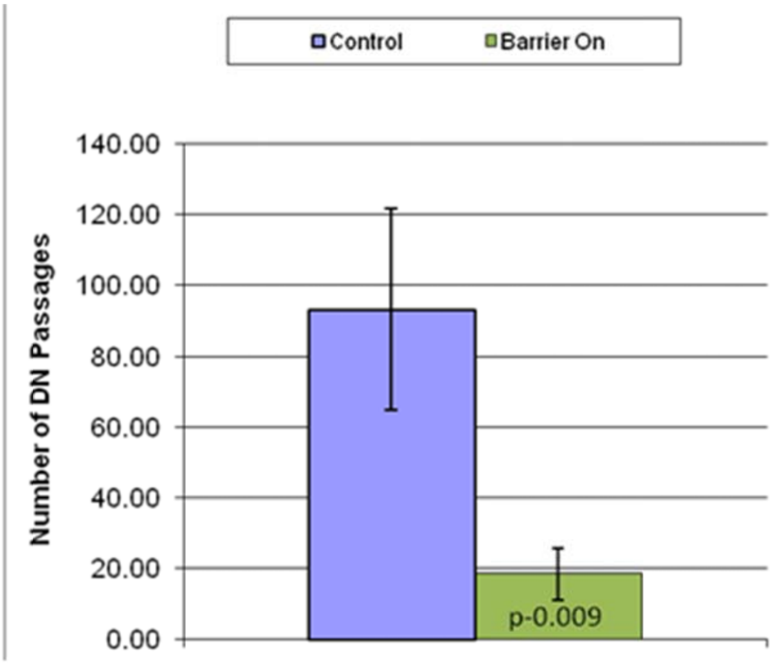


Figure 7. Total number of down-stream passages over Mark II barrier

Figure 8 displays the total number of passages between any two antennas as an indication of the relative activity of the carp being tested. Note the 30% decrease in total passages when the barrier is on is mildly statistically significant with *p*~0.05. The number of passages can be interpreted of a rate of movement by the carp over the testing period. During the control tests, the carp averaged 2 passages per minute, while that number decreased to 1.5 passages per minute. The reduced number of passages between any two antennas could be a result of the reduction of passages over the barrier, which accounts for approximately 200 passages. Despite the reduced activity between control and barrier test, it is important to note the carp are consistently active in all tests.

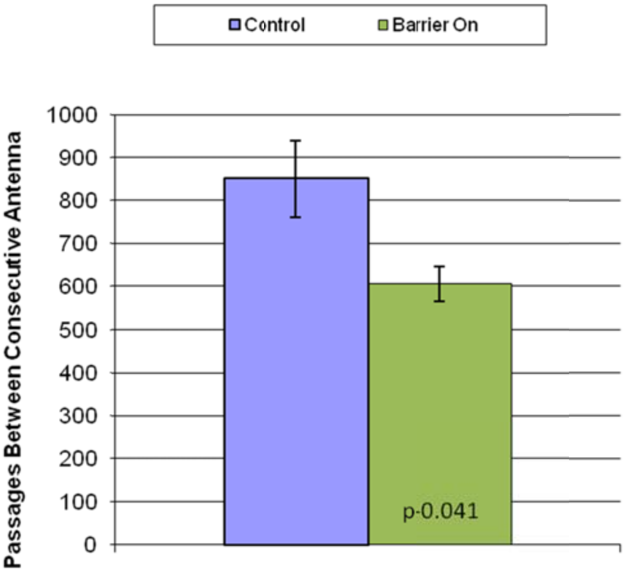


Figure 8. Total number of passages between any two consecutive antennas

Figures 6 and 7 clearly demonstrate the desired effect of the barrier on carp movment. Although the Mark II barrier does not completely stop all carp passage, it does decrease the number of passages in the up- and down-stream directions by approximately 60% and 80%, respectively. There was no statiscial difference between control and barrier tests in the passage time; however, this cannot be compared to the Mark I test results as the antenna configuration changed from 3 to 4 antennas.

4.0 Conclusions

Overall, the results of the Mark I and II barriers clearly demonstrates the accuracy and effectiveness of the RFID PIT tag detection system. The experimental configuration and testing protocal proved to be an effective method for the initial testing of the bubble barrier designs. The Mark I barrier results indicate that a 10 second delay on the carp passage over the barrier is achieved; however, no significant stoppage was observed. The Mark II barrier results demonstrated approximately a 60% and 80% decrease in carp passages in the up- and down-stream directions, respectively. With a slight decrease in carp activity between the control and barrier tests, we can show that the carp remained consistantly active during all 16 tests. The results of these tests will be used to develop a Mark III barrier, which is outlined in **restults status 9/30/2010 for Result 1**.

Results status of *(3/31/2011):*

Bubble Barrier Testing Continued

(Prepared by Dan Zielinski, Graduate Student)

1.0 Mark III Barrier Results

In the previous work we showed that our Mark II barrier is effective at deterring the movement of carp, in particular we showed that the barrier reduced the number of passages over the barrier by 75% in the up- and down-stream directions. The main focus of the last period of work has been to see if a bubble barrier with a 3 fold increase in air flow rate in comparison to the Mark II barrier would be more effective.

The Mark III barrier consists of a grid configuration of ultra-coarse diffusers supplied with an air flow rate of 108 Ls-1m-1. A more detailed description of the Mark III barrier design is presented in **results status 3/31/2011 for Results 1**.

This barrier was tested under the same test protocol as the Mark II barrier (see **results status 9/30/2010 for Results 2**). A total of 7 tests were performed with 108 $Ls^{-1}m^{-1}$ air flow rate and without air-supplied to the barrier. Figure 1 and 2 provide the total up- and down-stream passages over the Mark III barrier during the control and barrier tests. Note that during the Mark III barrier testing, one test resulted in zero passages during the 7 hour test period. Figure 3 displays the total number of passages between any two antennas as an indication of the relative activity of the carp being tested. Using this metric, the carp clearly maintained a similar level of activity during the control and barrier-on tests.

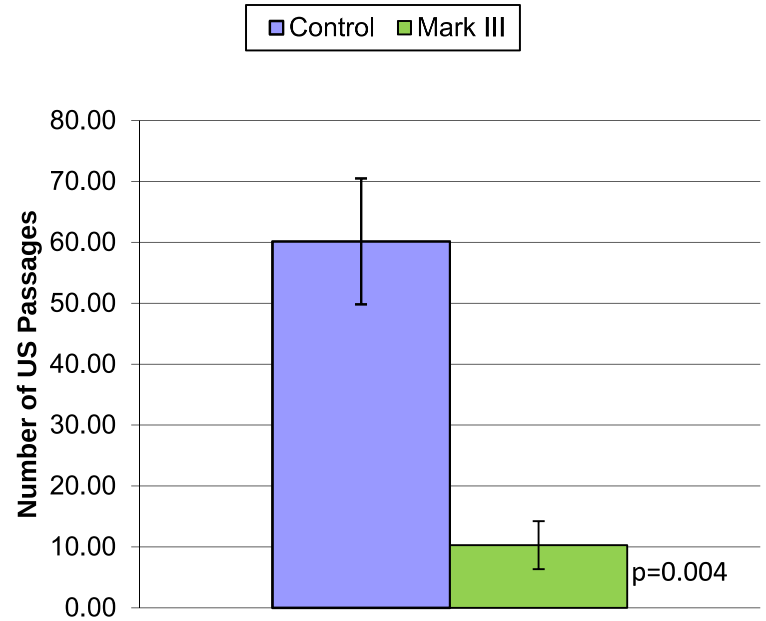


Figure 1. Total number of up-stream passages over Mark III barrier

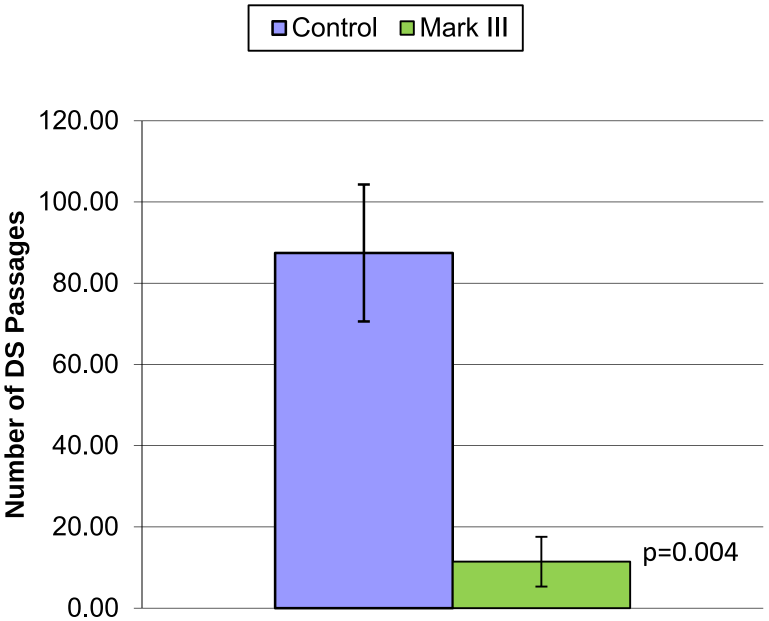


Figure 2. Total number of down-stream passages over Mark III barrier

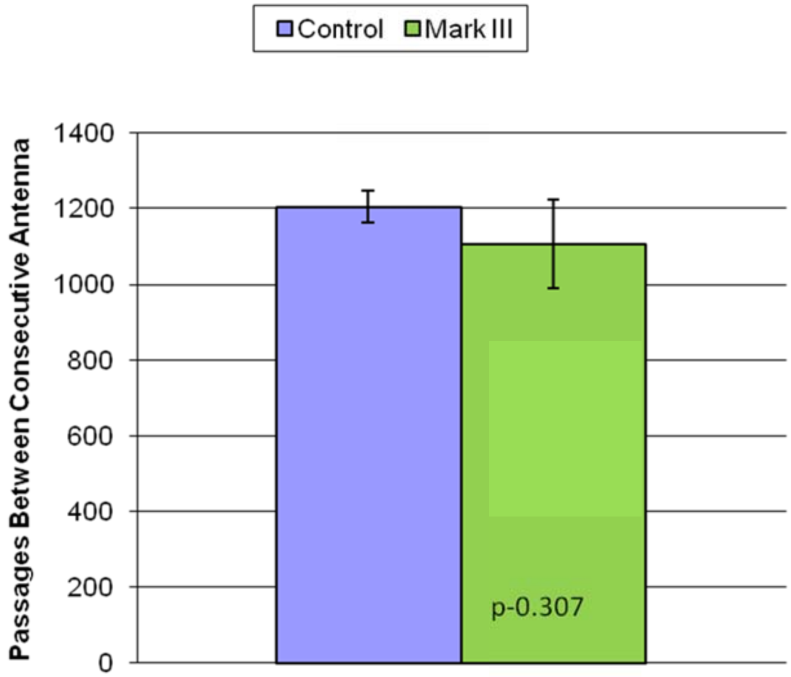


Figure 3. Total number of passages between any two consecutive antennas

Although the raw numbers are improved a rigorous analysis shows that there is no statistical difference from the Mark II barrier, resulting in a total of 75% reduction of passages in each direction.

This suggests that with bubbles alone we may have reached our maximum stopping potential. In this case, stopping potential is defined as the ability of a barrier to reduce the number of passages over the barrier within the testing period. In our test facility the juvenile carp are forced to stay within a close proximity of the barrier, potentially forcing more interaction with the barrier than in a natural setting. Therefore, in a natural setting when carp are not required to stay close to the barrier, the reduced number of passages could correlate to a complete stoppage of passage, hence stopping potential. With reference to the increase in air to the Mark III barrier and subsequent results indicate a further increase in the intensity of the bubbles may not lead to an increase in the effectiveness of the barrier. Although a bubble alone barrier could be a useful component in an integrated management strategy for controlling the movement and recruitment of juvenile carp, it would not be 100% effective at stopping carp movement in a given reach.

Due to the apparent plateau of stoppage potential via bubble intensity, further investigation in the biological flume at the aqua center and the physical flume at SAFL will look at using sound generation devices. An underwater transducer in conjunction with a bubble curtain should provide a more intense acoustic field paired with the turbulence generated by a bubble barrier.

2.0 Macro-behavior study

An objective of this study is to develop an understanding of carp behavior in the vicinity of a bubble barrier. In this last reporting period an analysis of the bubble barrier tests has indicated a significant change in the macro-behavior of the fish related to their swimming patterns.

The behavior pattern we are interested in observing in this analysis is the spatial variance over time, which describes how carp disperse with and without the barrier. The first step to obtaining the spatial variance, square deviation from the mean, of the carp movement data requires that a position time series be generated for each trial. The PIT tag system only records the position of the fish as it enters the reading range of one antenna, not the exact location at a set time interval. The data log must be transformed from a circular reference to linear reference to visualize the net movement during each trial. Whereas the barrier effectiveness tests only reported the crossings over the barrier in a certain direction, the position time-series will provide the net direction of movement. This is accomplished by assigning each passage between antennas with the centerline distance between antennas. Figure 4 and 5 provide the control and diffuser on test position time series data for the Mark II barrier. Note that a positive distance is in the downstream direction.

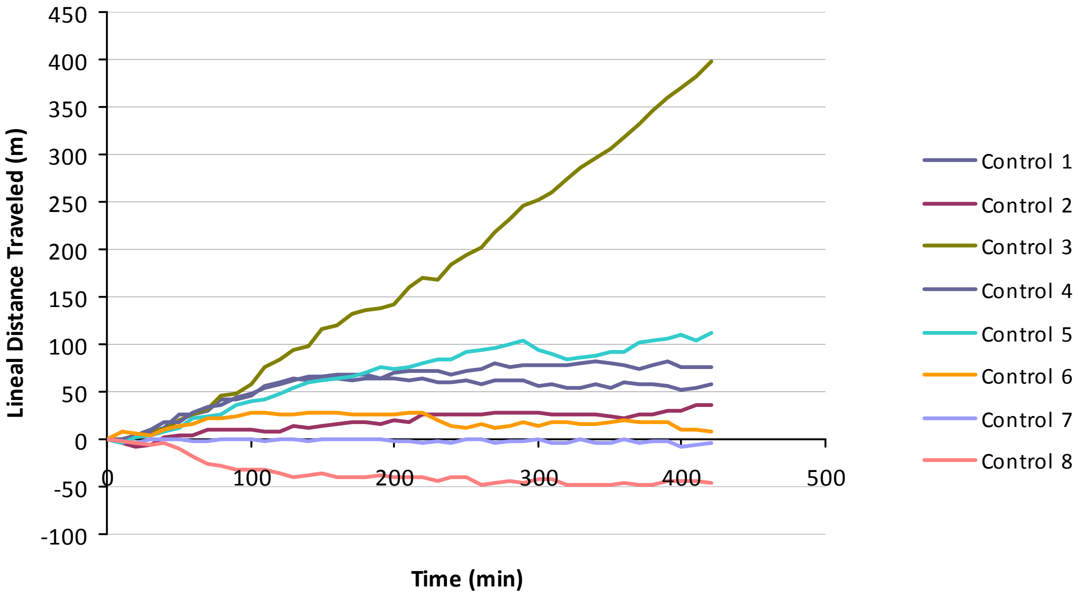


Figure 4. Position time series for Mark II control tests

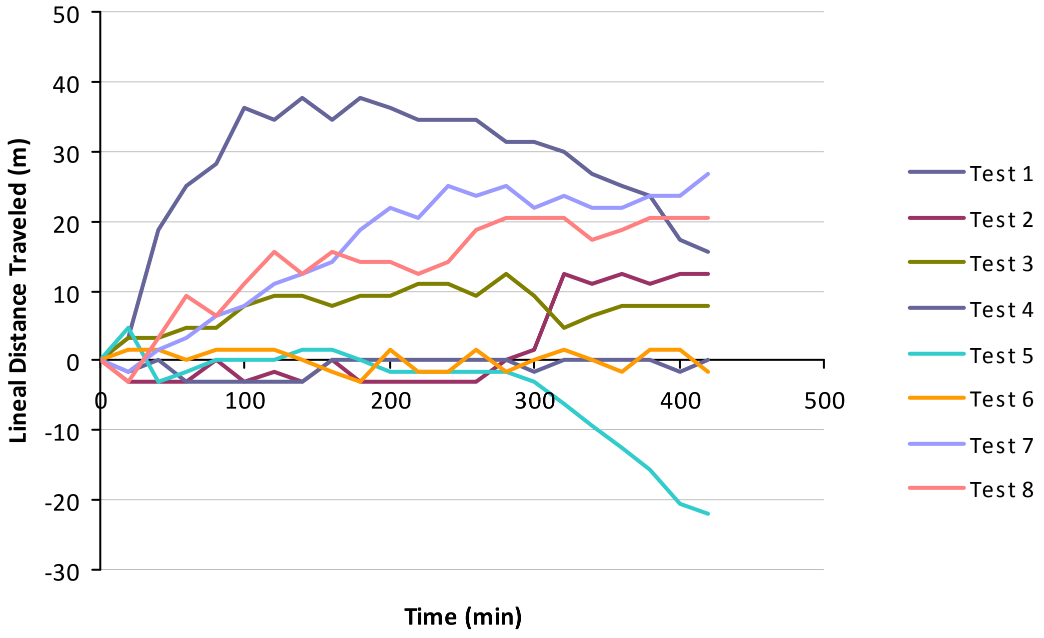


Figure 5. Position time-series for Mark II diffuser on tests

The position time-series for all trails are compiled, for the Mark II and III barrier tests, to generate the spatial variance of the carp at a specified time step of 20 mins. Each test represents the movements of one individual carp, apart from some population. Therefore, the spatial variance is a result of dispersion as opposed to pure diffusion. The low carp population during the testing may cause advective transport to dominate. Figure 6 displays the spatial variance of the control tests for the Mark II and Mark III barrier tests combined.

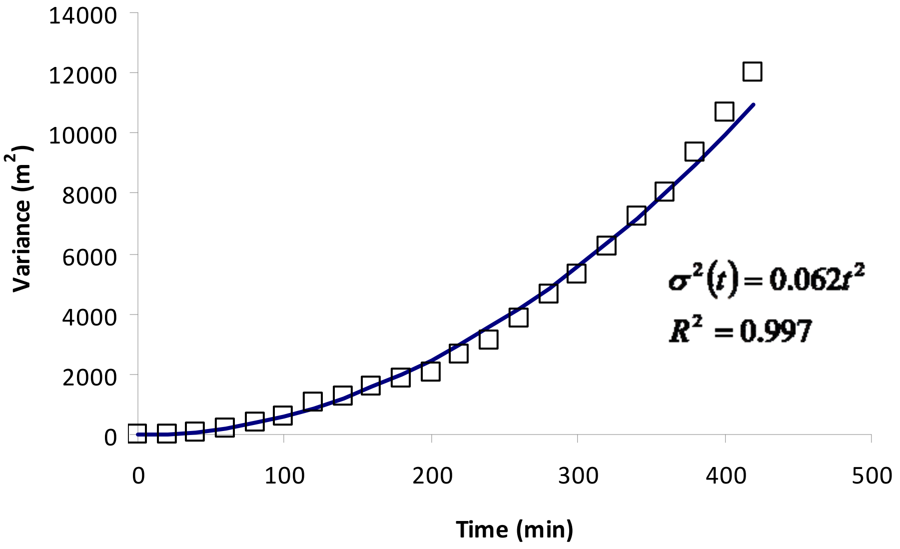


Figure 6. Dispersion of carp during control tests from Mark II and III trials combined

Note the high correlation with the power-law trend provided by the blue line in Figure 6. This relationship as well as the downstream trend in the time-series plots indicates that the carp were influenced by the slight background flow (drift) in the testing tank. Figure 7 displays the dispersion of carp during the Mark II and Mark III diffuser on trials, separately. Note that the variance of the diffuser on trials results in no discernable trend.

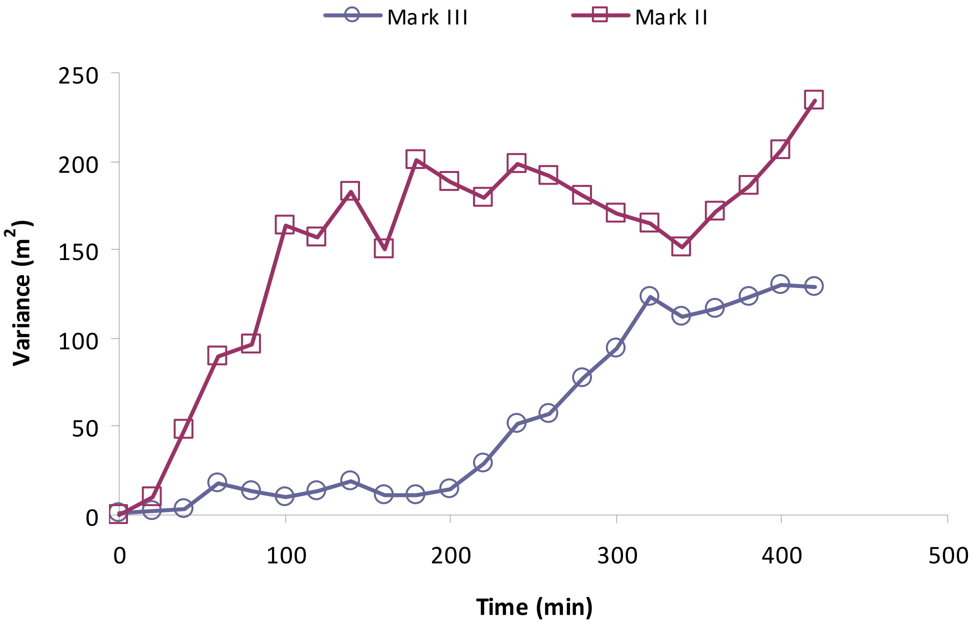


Figure 7. Dispersion of carp during Mark II and Mark III diffuser on trials

So the main conclusion to draw from this is that in the absence of the bubble barrier the average movement (drift) of the fish is clearly correlated to the presence of the small current. With the barrier operating, however, this behavior is clearly compromised and no distinctive direction of motion is observed. A breakdown of the spatial variance trend between the control and diffuser on tests indicates that a distinct behavioral change occurs. Change in carp behavior, whether it is from an avoidance response or stress, indicates that the Mark II and Mark III barriers each provide significant stimuli that carp detect and respond to.

Result 3: Field channel investigation
Description: The objective of this phase is to integrate the engineering and biological studies in results 1 and 2 to construct an outdoor carp barrier which employs a bubble curtain(s). This study will be conducted in the Outdoor Stream Laboratory Stream Lab (OSL) and main channels at SAFL which are highly controlled and monitored facilities mimicking field conditions. The main goal is to test the effectiveness of bubble curtain barriers in stream conditions.

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Summary Budget Information for Result 3:	**Trust Fund Budget:**	**$ <u>84, 044</u>**
	Amount Spent:	**$ 1,990**
	Balance:	**$ <u>82,054</u>**

Deliverable	**Completion Date**	**Budget**
1. Testing and documentation of the effectiveness of bubble curtain barriers to deter the movement of carp in small streams (SAFL OSL and main channel)	6/30/2011	<u>$ 42,044</u>
2. Identification of the bubble diffuser designs that have the best potential to create bubble curtain based carp barriers for small streams. (SAFL OSL and main channel)	~~6/30/2011~~ 6/30/2012	<u>$42,000</u>

Completion Date: 12/30/11

Results status of *(11/10/2009):*
Advance cannot be made on this result until deliverables on Results 1 and 2 are met.

Amendment Approved: 12/17/2009
See Section III for details related to the approved amendment.

Results status of *(3/31/2010):*
Progress has been made on Results 1 and 2 and it is expected that a preliminary field channel study will by carried out and reported on 9/30/2010.

Result Status as of *(9/30/2010):*
As noted in detail in the complete reports above. The first two components of Result 1—Design and understand of the bubble barrier are essentially complete. The next phase will look at improving the design through the biological findings in the ongoing Result 2.

Result Status as of *(3/31/2011):*
Based on the results of the behavioral study in Result 2, a barrier similar to the Mark II and Mark III barriers will be installed in the Outdoor Stream Lab (OSL) at the Saint Anthony Falls Laboratory during May and June. The study will include buidling a barrier with integrated control section to place at select locations within the stream, and installing a similar PIT tag system to track carp movements. A select number of carp will be placed within the stream and have their movements tracked over some time period. The purpose of these tests is to confirm whether carp interact differently with the bubble barrier in a more natural setting. The preliminary channel study will be carried out and reported on 06/30/2011.

Result Status as of *(6/30/2011):*

V. TOTAL TRUST FUND PROJECT BUDGET:

Personnel: $ 257,268
(Note: includes 30% lab fee on $15, 489 salaries of SAFL employees = $4,647)

Equipment/Tools/Supplies: $ 39,732

Details of estimated expenditures

--Modifications of Flumes (2-3 small laboratory flumes) (includes, refurbishing, plumbing and pumps, sound installation, instrumentation); $10,732
--Modification of SAFL Outdoor Stream Lab and Main channel (includes, hardware for channel design, Instrumentation for monitoring environmental conditions -water quality, temperature, flow-, compressors for bubble generation); $7,000
--Manufacture of 4-5 diffusers to create bubble curtains; $3,000
4 Hydrophones (to measure and create sound, B&K 8103 or similar, $1000 per) $4,000
--Video Camcorder with DVD recording and infrared capabilities $800
--Lap-top computer with lab-view software dedicated to data collection and signal processing from hydrophones $1,500
--Cost of fish (~1500 juvenile carp with fed-ex shipping and handling, $3 per fish) $4500
--Fish Storage Tank, $1,500
--Fish Care and feeding, $4,000
--General experimental supplies (tubing, data storage devices, clamps, etc). $2,700

Travel: $ 3,000
($ 2,000 will go toward allowing Duluth based PI to attend 6-8 meetings in MSP –made up of mileage arte and one-night in a hotel per visit- $1,000 for post doc travel)

TOTAL TRUST FUND PROJECT BUDGET: $300,000

Explanation of Capital Expenditures Greater Than $3,500:

VI. PROJECT STRATEGY:

A. Project Partners:

Vaughan Voller, Civil Engineering and SAFL (PI) $16,500
Miki Hondzo, Civil Engineering and SAFL (Co-PI) $15,000
Allen Mensinger, Biology, UMD (Co PI), $16,000
Peter Sorensen, Fisheries, Wildlife and Conservation Biology (Co-PI) $15,000
TBA(Post-Doc) $101,000
Mike Plante SAFL (Machinist) $4,639
Chris Ellis SAFL (Engineer) $15,497
Adam Recknor SAFL (Accountant), $4,056
TBA Graduate Student, $66,000
TBA Undergraduate RA, $3,576

B. Project Impact and Long-term Strategy:

Common carp (*Cyprinus carpio*) comprises over half the biomass in a third of Minnesota lakes. The feeding habits of this species significantly disrupt lake sediments leading to an over-enrichment of nutrients. This process, referred to as eutrophication dramatically reduces water quality. Research on the common carp is actively supported by the LCCMR and two watershed districts and is demonstrating that the root of the problem are common carp 'nursery' lakes which feed into larger lakes through small creeks. However, while presently funded/ ongoing research is suggesting solutions to suppress carp reproduction and abundance in these nurseries, the utility of this work could be held back by an inability to stop young carp from re-infesting cleared systems through the inter-connected creeks. Fish barrier technologies that show promise for this application are those based around air bubble curtains. Not only do the physical fields, e.g., sound and displacement, generated by bubble curtains have the potential to be targeted to exploit the biology of carp, barriers based on bubble curtains can also be inexpensive, portable, and safe. To date, however, there has been no public domain research on appropriate design guidelines for optimizing air bubble curtain barrier technologies. The main objective of this proposal is to address this shortfall and provide design guidelines for the use of bubble curtain barriers in small inter-connecting creeks. In addition to providing a potential ecological management tool for the control of common carp already in Minnesota lakes this project may also provide key information toward building effective tools for the Asian carp; a species which poses a very similar suite of challenges.

C. Other Funds Proposed to be spent during the Project Period:

Salary support for the participation of the manager of the Outdoor Stream Lab at SAFL in this project will be covered by funds from SAFL. In addition basic operating costs for this major research facility will be also be covered by SAFL

D. Spending HIstory:

VII. DISSEMINATION:

1. Publications in peer-reviewed literature
2. Presentations at scientific meetings
3. Web site, http://personal.ce.umn.edu/~voller/

VIII. REPORTING REQUIREMENTS:

Periodic work program progress reports will be submitted not later than 3/31/2010(Note due to hiring logistics project will not start until Aug 30, 2009), 9/30/2010, 3/31/2011, 6/30/2011. A final work program report and associated products will be submitted between June 30 and August 1, 2012 as requested by the LCCMR

Project Title:Novel barrier technologies for invasive species of fish													
Project Manager Name: *Vaughan Voller*													
Trust Fund Appropriation: $ *300,000*													
2009 Trust Fund Budget			**Result 1 Budget:**	**Amount Spent** *(3/31/11)*	**Balance** *(3/31/11)*	**Result 2 Budget:**	**Amount Spent 3***/31/11)*	**Balance** *(3/31/11)*	**Result 3 Budget:**	**Amount Spent** *(3/31/11)*	**Balance** *(3/31/11)*	**TOTAL BUDGET:**	**TOTAL BALANCE**
			Laboratory Investigation: Engineering			*Laboratory Investigation: Biology*			*Field channel investigation.*				
BUDGET ITEM	**BUDGET ITEM**	**BUDGET ITEM**											
PERSONNEL: wages and benefits	**Append: PERSONNEL: wages and benefits As of 06/24/10**	**Append: PERSONNEL: wages and benefits As of 03/31/11**	85,881	65,377	20,504	98,000	54,845	43,155	68,740	1,990	66,750	252,621	130,409
Vaughan Voller(PI) 4%FTE ($16,500)													
Miki Hondzo(Co-PI) 4%FTE ($15,000)													
Allen Mensinger(Co PI) 6%FTE ($16,000)													
Peter Sorensen(Co-PI) 4%FTE(15,000)													
TBA(Post-Doc) 100%FTE (~~$101,000)~~		Post-Doc 100% FTE Nov 10-Aug 11 ($ 30,375)											
Mike Plante (Machinist) 4%FTE (incluses a 30% charge for lab fees) ($3,568)													
Chris Ellis(Engineer) 8%FTE(includes a 30% charge for lab fees)($~~14,672~~)	Chris Ellis(Engineer) 6.5%FTE(includes a 30% charge for lab fees)($11,921)												
Adam Recknor(Accountant) 3%FTE($4,056)													
TBA Graduate Student 45% FTE (2 years of project)(~~$66,000~~)		Dan Zielinski + others, Graduate Students 62% FTE (3 years of project)($136,625)											
	Undergraduate Students Research Assistants (357.6 hours at $ 10 per hour) $3576												
Lab Fees (the use of employees of SAFL is subjected to a 30% charge to cover lab fees)			1,575	260	1,315				3,072		3,072	4,647	4,387
Chris Ellis Engineer 30% of ~~$14,672=$4,401~~	Chris Ellis Engineer 30% of $11,921=$3576												
Mike Plant Machinist 30% of $3,568=$1,071													
Non-capital Equipment / Tools (Detailed breakdown of cost provided under section V on project work plan)			7,000	3,202	3,798	7,000	4,732	2,268	6,732		6,732	20,732	12,798
Aqua Center well fix. 25 Hp Grundfos Submersible pump with fixtures and fittings Total cost $ 20,000. This ENTF project is providing 1/5 of this cost						4,000	4,000	0					
Supplies (Fish and other experimental supplies, detailed breakdown provides under section V on project work plan)			5,000	1,755	3,245	5,000	2,214	2,786	5,000		5,000	15,000	11,031
Travel expenses in Minnesota (details provided in section V of project work plan)			500		500	2,000	268	1,732	500		500	3,000	2,732
COLUMN TOTAL			**$99,956**	**$70,594**	**$29,362**	**$116,000**	**$66,059**	**$49,941**	**$84,044**	**$1,990**	**$82,054**	**$300,000**	**$161,357**