

DYNAMIC COMMERCIAL FISHERY CLEANING SYSTEM

EXPO DESIGN WINNER

The Dynamic Commercial Fishery Cleaning System team, Fins for Filtration, participated in the Engineering Expo May 2, 2014 at the University of Idaho. The team was awarded two prizes, Excellent Booth and Excellent Technical Presentation.

Project Start Date: Sept 1, 2013
Project End Date: May 2, 2014

May 9, 2014

University of Idaho

*Department of Mechanical
Engineering*

ENGINEERS ON THE PROJECT

TEAM FINS FOR FILTRATION

- Kaitlin Wicher – Biological and Agricultural Engineering
- Matt Francis – Biological and Agricultural Engineering
- Jeremiah Schroeder – Mechanical Engineering
- Levi Dawes – Biological and Agricultural Engineering

TABLE OF CONTENTS

Contents

Executive Summary	3
Background	3
Problem Definition	4
Goals and Deliverables	4
Specifications and Design Constraints	4
Project PLAN	5
Tasks and Schedule.....	5
Tasks	5
Schedule	5
Concepts Considered	6
Siphoning Vacuum Pump.....	6
Modified Moving Baffle	7
Concept Selection	8
System Engineering.....	9
Future Work.....	11
Appendices.....	12
Senior Design Technical Report – Dynamic Commercial Fish Raceway Cleaning System	12
Computation Fluid Dynamics Simulations Summary.....	12
Abstract	12
General Simulation Details	12
Study 2 – Velocity Scaling Analysis	20
Study 3 – Parametric Analysis of Horizontal Plate Length.....	23
CFD Future Work	24
Flow Characteristics	25
Prototype Solidworks Drawing Package.....	26
Engineering EXPO Poster	30

EXECUTIVE SUMMARY

Fins for Filtration Design Team worked on designing a dynamic cleaning system that will effectively clean commercial fishery raceways by removing fish excrement and residual food particles that reside in the raceway, known as biosolids. Current methods at Clear Springs Foods Inc., a large commercial fishery, are manually pushing waste by hand with large, wood frame screens to the separated quiescent zone of the raceway. This process is delicate and time consuming, due to how easily the fine particles re-suspend during cleaning. Once the waste reaches the quiescent zone, it is removed using a vacuum system that is attached to a piping network that discharges to a settling lagoon, where the fish manure is sold as fertilizer or disposed of properly. The goal of this project was to design a dynamic system that would reduce the man hours for Clear Springs Inc., which currently take from 100 to 150 hours of continuous cleaning each week.

The development of a dynamic cleaning system that can clean the raceway in a hands-free process can ultimately benefit commercial fisheries by reducing the time spent cleaning raceways. The design team has currently devised a baffle cleaning concept that in theory will solve Clear Springs Inc. cleaning problems. This design utilizes the continuity equation in fluid dynamics by reducing the cross sectional area of the channel, thus increasing the velocity on the bottom of the channel to suspend the particles for enough time for the natural flow of the channel to carry particles to the quiescent zones at the end of each raceway. The benefit of this design is its hands-free operation, leaving employees free to work on other tasks while the biosolids are moved into the quiescent zone.

BACKGROUND

Commercial fisheries such as Clear Springs Inc. operate at full raceway capacity year round. This is due to the fact that commercial fishery's differ from research fishery's by growing fish for food production. With continuous feeding and hatchery operations occurring on such a large scale, large amounts of biosolid accumulate continuously in each raceway. The current raceway operations require regular, continuous cleaning by pushing biosolids via wooden frame screens and manually removing them once they are deposited in the raceway quiescent zone. Clear Springs Inc. spends up to 150 employee hours a week manually cleaning their raceways in such a manner. The development of a mechanical system that cleans the raceway can be beneficial to companies like Clear Springs Inc. in the commercial fishery business.

The proposed design could effectively reduce the hours required by employees to continuously clean the raceways, leaving them more time to perform other daily operations. This reduction in cleaning time will ultimately improve daily tasks and hopefully increase profit margin while leaving employees to focus more on fish health and other operation and maintenance tasks. Automated procedures not only benefit the company and their employees, but also has the potential to increase fish health. Since the proposed system will decrease the amount of time that employees spend in the raceways, the potential of spreading diseases from raceway to raceway decreases. The constant procedure of employees moving from raceway to raceway quickly has the potential for the employees to bring diseases from raceway to raceway via their waders and shoes. Since the proposed system will only require employees to install the system before the cleaning procedure begins, the potential for cross contamination from employees can be reduced. Furthermore, since the device operates on its own, employees will have the ability to clean the device

when moving it from raceway to raceway, since they will have more time to perform task such as this between cleaning periods.

PROBLEM DEFINITION

Goals and Deliverables

The goals and deliverables for this project are as follows:

1. Provide an automated system that reduces employee hours for cleaning purposes.
2. Reduce the need for employees to spend extended lengths of time in each individual raceway.
3. Increase all around cleaning and hatchery operations and maintenance efficiency.
4. Increase fish health by reducing the potential for cross contamination of diseases in hatchery raceways.

Specifications and Design Constraints

The project specifications and design constraints are as follows:

1. Cannot reduce raceway flow by more than 1 cfs so that dissolved oxygen levels in the water do not drop below 6 mg/L. A decrease in dissolved oxygen as specified will kill fish populations within minutes.
2. Employee hours must be reduced sufficiently to justify the cost of putting this system in to production.
3. The proposed design must be lightweight and portable so that employees can easily maneuver the device from raceway to raceway with ease.
4. The proposed design must be waterproof, and must function in outdoor conditions continuously.
5. The proposed design must be easy to perform maintenance when necessary.
6. The proposed design must be able to withstand forces generated by the flow within the hatchery raceways.

PROJECT PLAN

Tasks and Schedule

Tasks

The design team assigned tasks to each group members as follows. Matt Francis was responsible for all data collection and managing team notes and documents. Levi Dawes was responsible for the designing and management of the team Wiki page, in which all design phases as well as final design concepts could be accessed. Jeremiah Schroeder was responsible for all Computational Fluid Dynamic (CFD) modeling, SolidWorks modeling, and lead construction on final model scales. Kate Wicher was responsible for managing team meetings as well as SolidWorks modeling and assisting Jeremy in conducting and analyzing CFD modeling. All team members were responsible for conducting model testing, analyzing model testing data, and presenting data to Dr. Tao Xing, project instructor.

Schedule

The project was divided up into two design phases, since the design class was separated into two semester the team utilized the first semester by researching and discussing different design concepts and the second semester by testing and developing the chosen design concepts. Phase one included the various research necessary to develop multiple design concepts. The team discussed improvement of current and past design concepts with experts in the hatchery business. During this time the team also discussed the feasibility of various designs with the client, Clear Springs Inc. The team also utilized this phase to visit the Clear Springs Inc. hatchery to gain a better understanding of the layout and design constraints. Several ideas were finalized in December 2013 for the second design phase in order to develop a working, conceptual model prototype. These designs included a modified, moving baffle and a siphoning vacuum pump.

The second phase of the project involved designing and testing two conceptual designs. This included model scale flume testing and analyzing Computational Fluid Dynamic (CFD) models of design concepts. Model scale testing was conducted on a small scale flume and by February 2014 a final design was chosen to develop a working conceptual model. This design was the modified, moving baffle. The team spent the remainder of the second design phase developing conceptual models using SolidWorks and CFD and constructing working model scale prototypes to present to the client as well as for the Engineering Expo.

CONCEPTS CONSIDERED

Siphoning Vacuum Pump

The design team developed the concept of utilizing a siphoning vacuum pump for removing biosolids from the hatchery raceways. This design focused on gravity and siphoning power to provide adequate suction so that the cost and maintenance of an electrical pumping network would not be necessary. In order to achieve this design, the construction of a cylindrical vacuum head would be manufactured that span the width of the hatchery raceway, 18 ft. The device would be fixed to a set of wheels powered by a cable winch system or small electric motor to move the vacuum head down each raceway. To achieve removal, the vacuum head would be attached to a piping network that brought biosolids to the hatchery settling lagoon.

Clear Springs Inc. already utilized a piping network to manually remove biosolids from the raceway quiescent zones. This works by attaching a hand held vacuum head and manually removing biosolids which are then fed into the hatchery piping network that carry the biosolids to the settling lagoon. The siphoning vacuum pump essentially works with Clear Springs Inc. current biosolid removal network. By attaching the siphon vacuum head to a series of flexible pipes that connect to the existing network, biosolids are removed without the need for employees to clean any of the biosolid from the raceways. However, depending on how many siphon vacuum head are constructed, employees will need to move the system from raceway to raceway.

The design team developed two model scale siphon vacuum for a small scale flume with the following dimensions: 6 in wide, 10 in deep, and 12 ft long. Both model scale siphon heads were constructed out of 1 in diameter PVC pipe, 6 in in length. The first model scale prototype utilized a 1/8 in gap cut along the width of the PVC pipe with the ends sealed. Two clear plastic tubes were also attached to the model to carry biosolids from the bottom of the flume. The second model prototype utilized 1/8 in holes drilled along the width of the PVC pipe, the ends were also sealed and the same clear plastic tubing was utilized to carry biosolids from the bottom of the flume. Both designs were tested to ensure that the concept of removing the biosolids was achieved. Both models worked equally well in removing biosolids.

The team brought this design to Clear Springs Inc. to discuss the feasibility of the design. Two design constraints were identified as problematic for this application. First, no more than 1 cfs of flow through the raceway can be removed for more than a period of 5 to 15 minutes. This constraint proved to be problematic for this design since significant amounts of water were required to provide adequate siphon suction to remove the biosolid layer from the raceway. Second, this design requires that the siphon vacuum head is always connected to the piping system while cleaning occurs. This was problematic due to the limited amount of space available between each raceway and within the raceway. Each raceway is separated by a 3 ft high and 8 in wide barrier. Daily operations require that the employees be able to walk across raceway barriers. Due to this, piping for the siphon vacuum head cannot be installed on the raceway barriers. Furthermore, since the raceways are at capacity year round making installing the piping within the raceway impossible. Also, piping for the siphon vacuum head would need to be flexible to allow the siphon vacuum to move along the raceway to provide cleaning. Piping exposed to the elements such as very hot summers and cold winters could lead to cracks in the piping system, which in turn can cause more maintenance issues than desired.

Designing a system that mechanically moved the siphon vacuum down the raceway would need to be heavy enough to keep the vacuum on the bottom of the raceway and light enough to move from raceway to raceway. Also, the system that provides movement would need to be waterproof. These issues can increase the cost of the system as well as increase maintenance on the system. For these reasons the siphon vacuum design was not chosen for this application.

Modified Moving Baffle

The design team developed a conceptual model of a modified, moving baffle. A baffle is defined as a “barricade” within the raceway channel in order to increase the velocity of the water along the bottom of the raceway. This is accomplished by decreasing the cross sectional area of the raceway in order to increase raceway velocity at the bottom of the channel, as described by the continuity equation in fluid mechanics. Since the density of the biosolid particles is only slightly heavier than water, the biosolids will be forced down the raceway as the baffle moves down the raceway. Baffles are currently in operation at Clear Springs Inc. in their small, indoor hatch facility housing the newly hatched juvenile fish.

The design team began the design for a modified, moving baffle by analyzing CFD data. The CFD reports analyzed can be found in the Appendix of this document. CFD allowed the design team to analyze various baffle configuration and geometries that would carry the biosolid particles down the raceway to the quiescent zone. Several baffle configurations and geometries were considered for this design. First, a basic horizontal baffle was analyzed as a baseline. Second, a baffle with a horizontal plate attachment was analyzed to determine if the attachment of such a plate would limit biosolid particulate suspension. Finally, a baffle with a diffusor was analyzed to determine if a diffusor device would limit biosolid particulate suspension.

Once the CFD results were analyzed, model scale testing of stationary baffles was conducted to determine the optimal reduction in cross sectional area of the raceway channel that increased channel velocity at the bottom while limiting suspension of biosolid particulate. These model scale tests were conducted using a flume, and were completed to prove the effectiveness of the baffle design. The test results proved that the baffle is a sufficient device to remove biosolid particulate. Model testing also indicated that a moving baffle should be used since once the biosolid particles re-settle in the raceway prior to the quiescent zone.

With conclusions determined from model scale testing of stationary baffles, as well as input from fish hatchery expert from the University of Idaho Aquaculture Research Institute Scott Williams, the design team began designing and testing the concept of a moving baffle to transport the biosolids to the quiescent zone. The concept behind a moving baffle is to place the baffle in a system which moves the baffle along the raceway to keep the biosolid particulate suspended long enough to ensure that it reaches the raceway quiescent zone so that the biosolid can be removed.

The design team constructed a moving baffle model made out of aluminum and plastic that moved under the force of the water flow in the flume to prove the moving baffle concept. The design team conducted three tests using a vertical, moving baffle. All three tests were conducted at the same flow, 9 in of water in the flume channel, and at three different cross sectional areas. This was done to determine at what speeds and cross-sectional areas biosolid removal and that biosolid particulate suspension was limited. Conceptual SolidWorks drawings of the model moving baffle can be found in the Appendix of this document. Next, a horizontal plate was attached to the vertical baffle as analyzed in CFD to see if the

horizontal baffle would limit biosolid particulate suspension compared to the lone vertical baffle. Results showed that no difference in biosolid particulate suspension was observed.

The moving baffle met the design criteria for Clear Springs Inc. since no loss of dissolved oxygen occurs with this device, the device is waterproof and will withstand outdoor operating conditions, can easily be moved from raceway to raceway from employees, and reduces hours spend cleaning by employees. Full scale conceptual drawings of the moving baffle were drawn in SolidWorks, and can be found in the Appendix of this document. The design team concluded that since the full scale prototype is 18 ft in length, dividing the moving baffle into three separate parts that connected together in the raceway was desired. This was to make moving the baffle from raceway to raceway easy for Clear Springs Inc. staff. After discussing the moving baffle concept with Clear Springs Inc., the design team choose the moving baffle to remove biosolid particulate from the hatchery raceways.

CONCEPT SELECTION

The use of the baffle system was chosen for many reasons as opposed to the siphoning vacuum system. The current siphoning vacuum system is useful when used in tandem with the baffle system to remove the collected biosolids at the end of the raceway but would not be suitable for the whole raceway length. The siphoning vacuum system would require a length of hose at least 120 ft long to span the whole length of the raceway. Hose this long would create issues such as entanglement with vacuum head, knotting of the system, obstruction from cleanup, and would require employees to spend time retracting the hose in. The issue of the cost of this piping and need for storage was another detracting factor. The baffle system offered many advantages of a very minimal design as well as upkeep cost and time spent maintaining.

Additionally while experimenting with a siphon vacuum method in our flume we realized that the quantity of water removed from the flume was too great to maintain an adequate amount of water in the raceway. The water would not siphon out at lower rates and this is unsuitable for a full-scale design. Not only would there create a large drop in flow in the raceways which would decrease oxygen levels and potentially kill fish but this would also create an additional waste stream of mostly water. This waste stream might need to be treated separately from the current method of pumping into a settling basin because of the quantity of water produced. The fact that these complications would add extra costs and maintenance for Clear Springs Inc, employees drew us towards the use of the baffle system.

During our first Design Review meeting and visit to the Clear Springs facility we were able to view a small scale baffle used in their raceways for the juvenile fish. These small scale baffles worked effectively in the small-scale of a few feet by a few feet with a short length of around six feet. These were also stationary. Clear Springs seemed particularly interested in the use of a moving full-scale baffle that would be able to clean the lengths of their full scale raceway averaging 120 ft long. Because of their interest in the baffle system and the reasons explained above our team decided on engineering a full-scale moving baffle.

After testing different baffle conformations including variations with a horizontal plate using the computational fluid dynamics program ANSYS Fluent, the simple vertical baffle was chosen. A detailed report of the ANSYS Fluent trials are available in the appendix. Experimental testing reconfirmed that there was not a significant benefit to any of the horizontal plate configurations. The height of the baffle wall played an important role in the re-suspension of particles, and in the flume experiments it also determined the speed at which the baffle moved downstream. The horizontal plate tested in the flume did

extent the region of horizontal flow under the baffle but once the period of extended flow ended the recirculation and mixing of suspended particles did not appear to be drastically improved. Therefore the vertical plate was chosen, it creates the desired amount of particle suspension and movement downstream without unnecessary weight added to the baffle and cart system. The addition of a horizontal baffle does not result in a great improvement in particle movement and would add additional weight to the system that would make daily movement and use by one or two employees more troublesome.

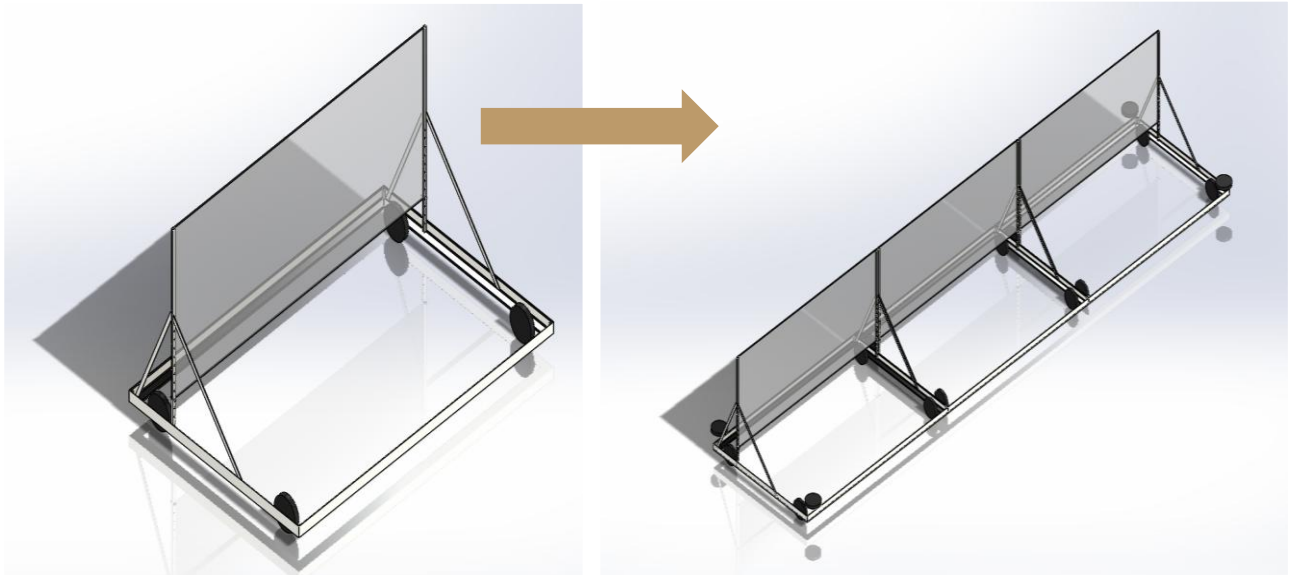
The benefits of the proposed baffle design include reduction in the amount of hours employees spend cleaning, automation of cleaning without the need to enter the raceway and portability from one raceway to another. This low investment capital design will provide continuous service to any number of raceways while requiring low maintenance. The simple vertical baffle has proven to be sufficient in its cleaning capabilities. The vertical baffle is adjustable for immediate changes to the speed of the baffle movement down the raceway. The vertical baffle design will be an adequate solution to reducing employee hours. The vertical baffle design provides Clear Springs Inc. with a durable and practical design alternative to their current method of cleaning. The most important characteristics considered in concept selection was the capital cost, versatility and degree of maintenance.

SYSTEM ENGINEERING

The baffle is designed to fit the full cross sectional area of the raceway dimensions specified by our client Clear Springs Inc.. Our small-scale model fit the dimensions of the flume used in experimental testing. Because of the large width to depth ratio of a full scale raceway the baffle was designed to be a composition of three baffle systems of equal dimensions that can be detached from each other using a pin-and-hole connection by the employees. The three baffle pieces can be more easily handled by the employees. As mentioned before the materials recommended were chosen to be light weight and durable. The cost of maintenance and part replacement was considered in the overall design selection.

Additional features of the baffle system include gussets for support and side wheels for extra support for smooth movement down the raceway. In the case that the full scale baffle moves too quickly down the raceway a damper system may be implemented. The vertical baffle is recommended to be placed off center of the midline of the baffle cart frame for added stability when the force of the water is pushing the cart downstream. The side closer to the frame will take the force of the water. The baffle height will be adjustable with pin-and-hole connections. Clear Springs Inc. have a process to sort the adult fish from the younger fish and move the larger down to the lower raceway by using a grated bar screen. Our team thought that the coupling of the two processes, raceway cleaning and fish sorting, would prove desirable. The baffle was therefore designed to have a removable baffle wall that could be replaced by the grated bar screen to automate the process of sorting fish as well. This versatility is designed to provide extra incentive and reason to invest in our design.

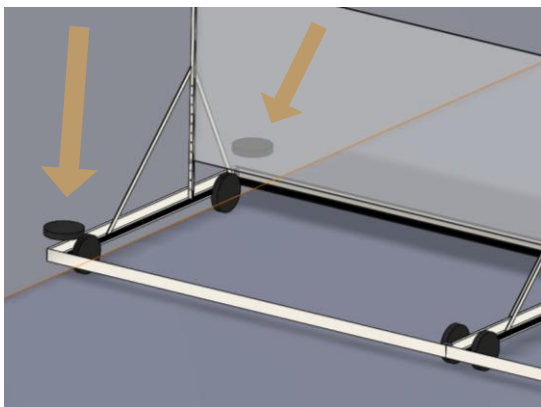
The small-scale cart and baffle were designed using material and configurations that were meant to mimic the design proposed for a full scale baffle. Aluminum metal for durability, light weight and longevity when used in water was chosen for the basic frame and baffle channels. Gussets were added for additional strength. Plastic was chosen as the most water resistant and light weight material. The parts were attached to each other using GB weld for the small scale design, actual welding on the full scale system is recommended. The small scale design was machined in the University of Idaho machine shop and tested in a flume provided by Dr. Jim Liou. SolidWorks sketches of the small scale baffle and full scale baffle are in the appendix for reference.



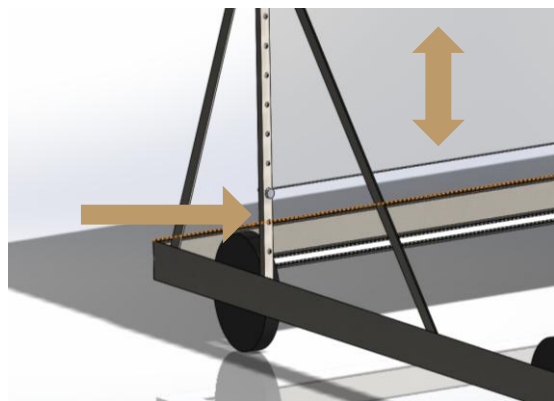
Single Baffle Cart Design

Full-scale Three Piece Design

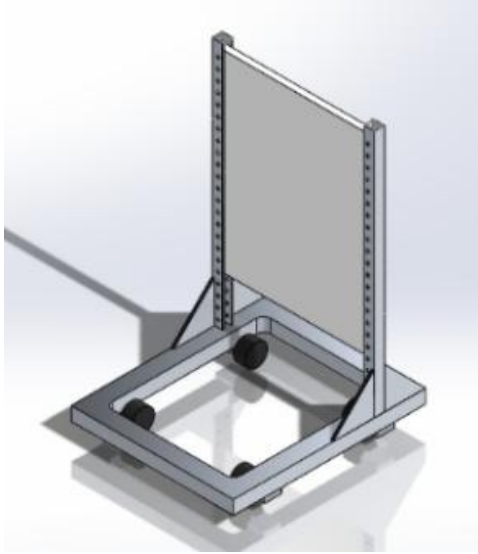
Above the individual baffle cart system is represented with its four wheels for stability. This cart would be the center cart; the other two carts will have side support wheels for smooth baffle system displacement. The side carts will have six wheels total, four vertical and two horizontal wheels.



Horizontal Wheels



Pin-and-Hole Connections



The small-scale baffle was designed using the materials and geometry that our team believed was ideal. Not shown is the additional horizontal plate that was attached to the very bottom of the vertical baffle wall for testing. The horizontal plate was nine inches long, the same length as the vertical wall.

Small Scale Baffle Design

FUTURE WORK

The scope of our project did not allow for any full scale testing of our baffle device in a raceway. The next step in verifying the merits of our design would necessitate that a full scale baffle and stand are designed, machined, and tested. In order to reduce maintenance of the baffle, we recommend the use of aluminum and plastic whenever possible to decrease the amount of rusting, water damage or algal growth that could occur when used continuously. These materials would also decrease the weight that employees would need to lift when moving the baffle system from one raceway to another. Wheels with no ball-bearings are recommended because they are less likely to be damaged by algal growth and water. Further additions that could be designed for the baffle system include a damper system if the baffle system moves too quickly through the raceway and horizontal wheels suspended on a spring system to maintain even downstream movement.

Aspects to consider further are the desired speed of the baffle down the raceway and where the baffle system should be stopped before the end of the raceway to ensure that the suspended biosolids are allowed to settle out of the raceway before they are able to flow over the weir of the raceway and into the lower raceways. Optimization of the baffle stopping distance should ensure maximum particles collection in the quiescent zones and result in as much or more particle collection as with the method currently used by Clear Springs Inc. Desired baffle speed will depend on the degree of water turbulence and particle re-suspension downstream of the raceway. Roughness of the actual raceway bed made of cement is expected to differ greatly from the smooth plastic surface that was used during experimental testing. The height of the baffle wall can be lowered to overcome any resistance incurred by the friction on the wheels. If optimal particle suspension occurs with the baffle wall very low with a higher speed a damper system could be used to moderate the speed of the baffle system if needed.

APPENDICES

Computational Fluid Dynamics Report

SENIOR DESIGN TECHNICAL REPORT – DYNAMIC COMMERCIAL FISH RACEWAY CLEANING SYSTEM

COMPUTATION FLUID DYNAMICS SIMULATIONS SUMMARY

Abstract

Computation Fluid Dynamics (CFD) was used extensively throughout this project. The purpose of conducting these simulations was to gain a better understanding of the fluid mechanics of water flowing past a baffle in a raceway. More specifically, flow patterns that would likely promote clouding of biosolids were observed, and attempts to remedy this clouding were assessed. The CFD simulations were conducted in three different studies. The first study analyzed attempted to find the maximum allowable height of the baffle which still re-suspends biosolids based on the critical shear stress for trout biosolids. Baffles with modified geometry were then compared to the plain baffle to see if they would reduce clouding. The baffle with a horizontal plate attached to the bottom edge appeared to be an improvement. The second study was used to determine the appropriate method for scaling the velocity to achieve similarity in a scale flume. Various model scale simulations were compared to a full scale simulation, and the conclusion was reached that model scale tests should be conducted at the same Reynolds number as the actual raceway. Finally, a parametric study was conducted to observe the effect of changing the length of the horizontal plate. The results suggested longer plates were better, but the benefit of adding the horizontal plates was no longer clear with the velocity scaled appropriately. Further analysis of potential modifications, multiphase simulations, and analyses of the effects of moving the baffle would be appropriate future work.

General Simulation Details

1. Software – ANSYS Fluent
2. Geometry – Dimensions of the CFD domain matched the length and depth of the model scale flume
 - a. Length = 110.75 in
 - b. Depth = 9.306 in
 - c. Baffle placed in center of domain
3. Grid – Approximately uniform
 - a. Along inlet and outlet faces – 100 divisions
 - b. Along top and bottom faces – 1100 division

- c. Grid resolution confirmed by comparing wall shear stress to exact solution for laminar flow over a flat plate see Figure 1.

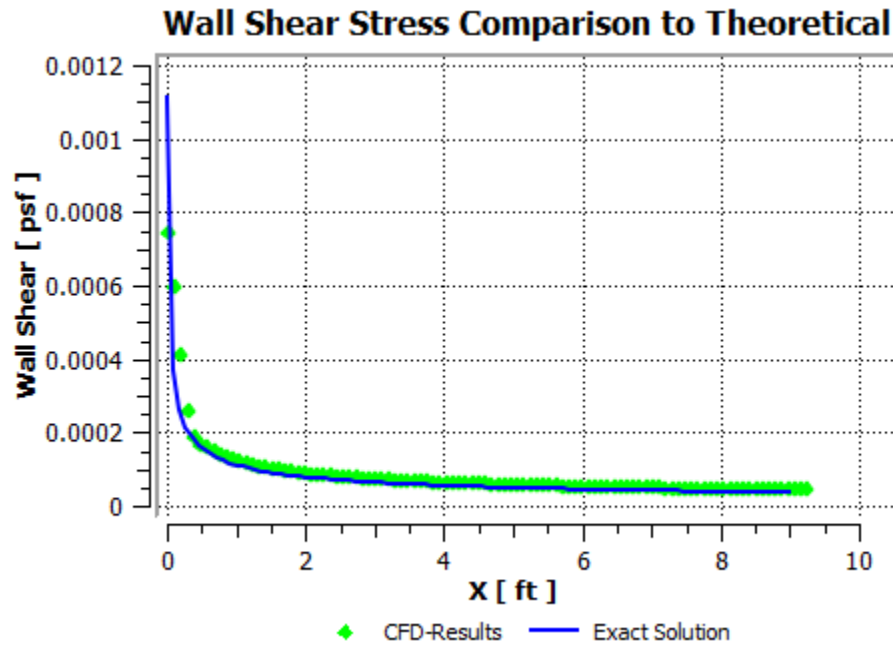


Figure 1 Grid resolution study results

- 4. Physics
 - a. Spatial – 2D Planar
 - b. Time – transient (except for flat plate simulation)
 - c. Viscous model – laminar
 - d. Fluid – water
 - i. Density – 62.3151 lb_m/ft³
 - ii. Viscosity – 0.0006739848 lb_m/ft-s
- 5. Boundary Conditions
 - e. Inlet – uniform velocity inlet
 - f. Outlet – pressure outlet
 - g. Bottom surface/baffle surface – no-slip wall
 - h. Top surface – slip wall (specified shear = 0). This means that the free surface was not resolved. Rather it was modeled as a frictionless wall where the free surface should be.
- 6. Solution Method
 - i. Scheme – PISO – skewness-neighbor coupling disabled
 - j. Pressure discretization – second order
 - k. Momentum discretization – third order MUSCL

- l. Transient formulation – second order
- 7. Calculation
 - m. Residuals convergence tolerance – 0.0001
 - n. Max iterations per time step – 100
 - o. Reporting interval – 10
 - p. Time step – 0.5 seconds
 - q. Number of time steps 100 – 250 (as necessary)
 - r. Animations – 2
 - i. Velocity Contour – updated every time step
 - ii. XY plot of shear stress on bottom wall – updated every time step

Study 1 – Baffle Modifications

When this study was conducted, the researcher felt that the inlet velocity should be same as in the actual raceway because this would create similar shear stresses on the floor of the raceway. Thus, for all simulations in the first study, the inlet velocity was 0.1407 ft/s. The simulation began by running simulations to find the maximum allowable baffle height which provides the critical shear stress. Smith and Liou [1] report this to be 0.083 N/m² or 0.00173 lb_f/ft². The animation of the shear stress plot revealed a large peak in the wall shear stress directly underneath the baffle. This first peak in shear stress was relatively steady throughout the simulation, unlike the peaks downstream, which were dramatically unsteady. Figure 2 shows an example the shear stress plot for a standard baffle.

Because the other peaks in the shear stress were so unsteady, the shear stress at the the first peak was used to assess the critical shear stress requirement of the baffle. Three simulations were required to determine the maximum baffle height. This was found to be 4.75 in. The results from these simulations are simulations are shown below in

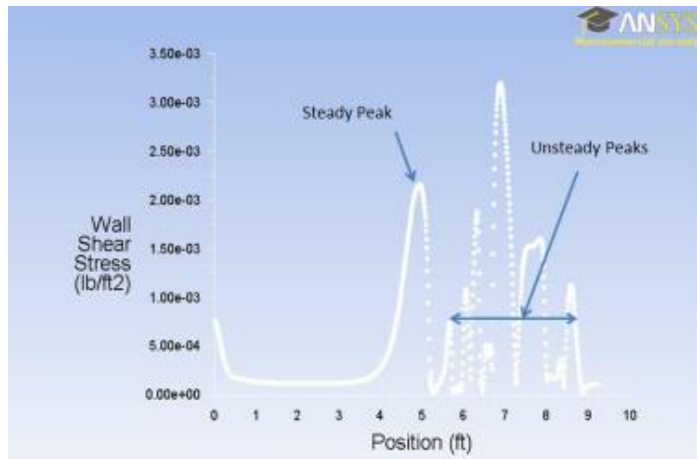


Figure 2: Snapshot of wall shear stress

Table 1: Maximum baffle height results

Simulation Number	Baffle Height (in)	Approximate Peak Wall Shear Stress (psf)
1	4	0.00230
2	4.5	0.00185
3	4.75	.00175

After determining the appropriate height for the baffle, simulations of five proposed baffle modifications were run. All of these simulations were conducted with the baffle placed at 4.75 in height. The modifications are shown below in Figure 3 , where the horizontal plate length L was 12 in for all simulations.

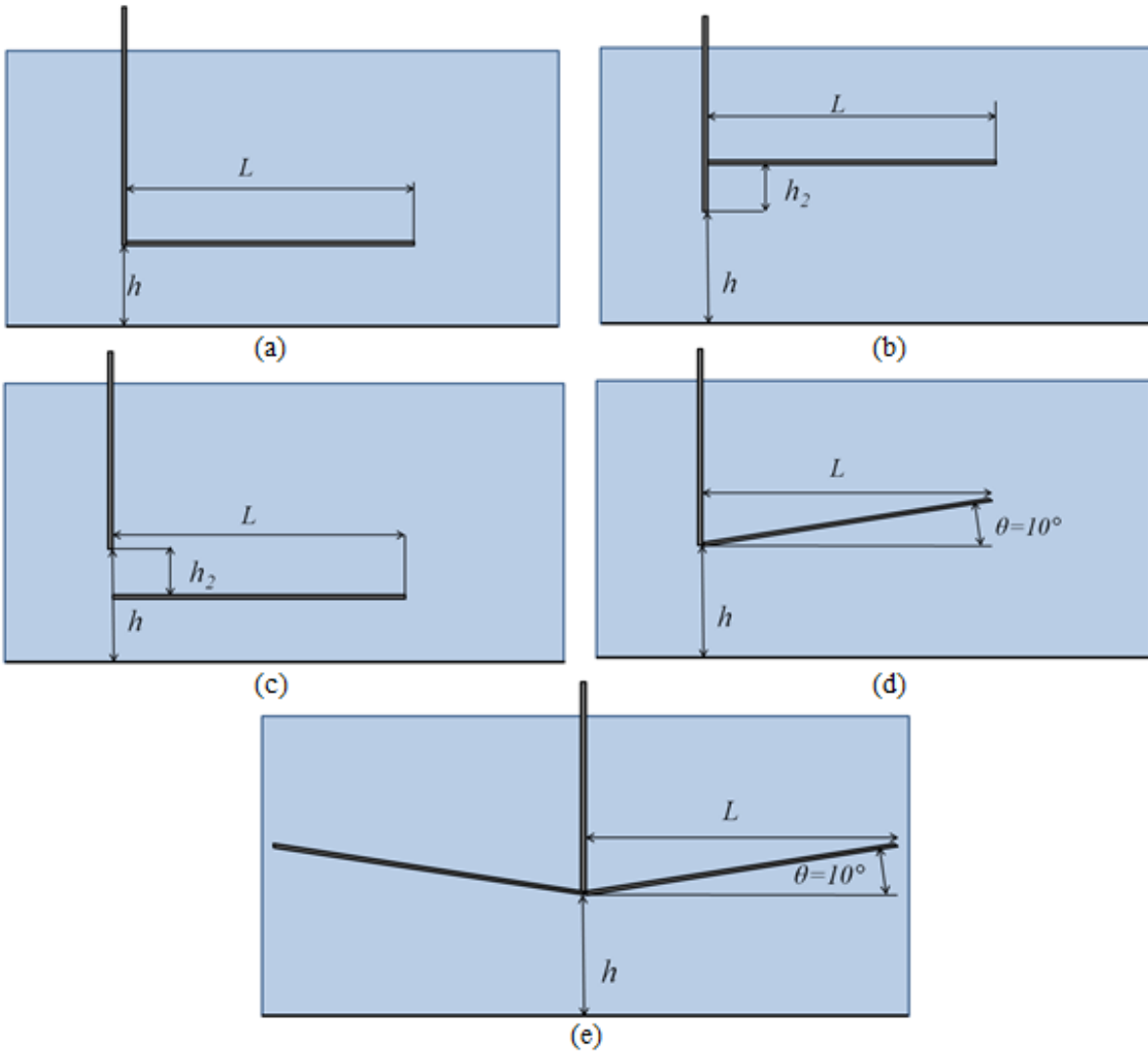


Figure 3: Baffle modifications: (a) Horizontal plate, (b) Horizontal plate shifted up, (c) Horizontal plate shifted down, (d) Diffuser plate, (e) Nozzle and Diffuser Plates

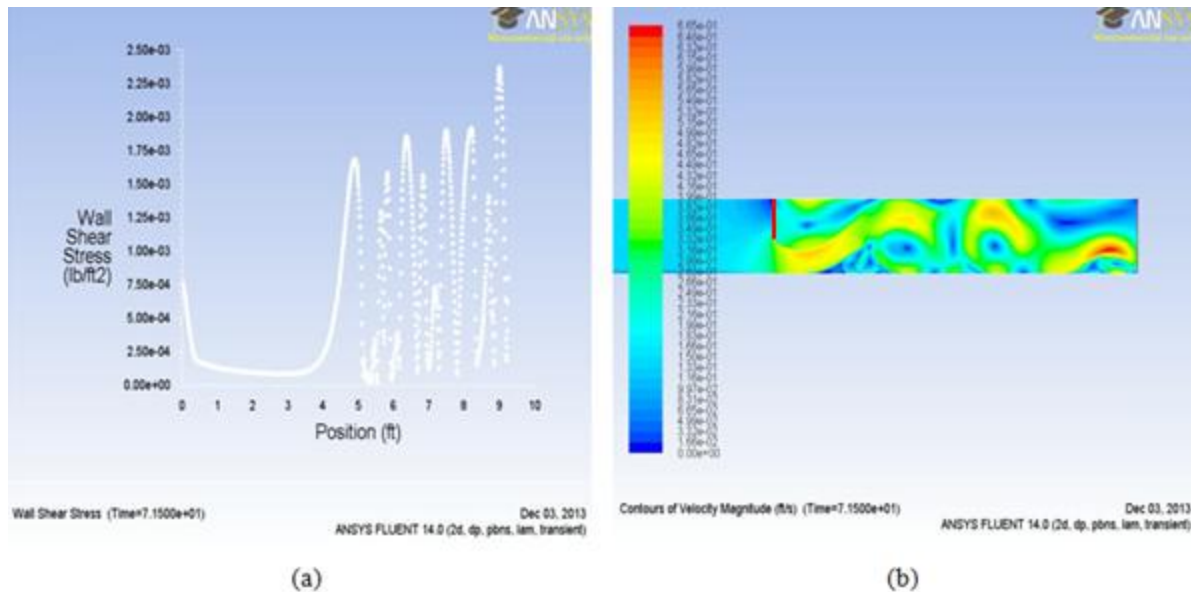


Figure 4: Simulation results for baffle height 4.75 in (a) wall shear stress on raceway floor and (b) velocity contour

As shown in Figure 4, vortices form behind the standard baffle. These vortices shed and then roll down the raceway, and they are likely one reason that clouding is such an issue with these baffles. The water also seems to immediately sweep upwards after the baffle. This could possibly sweep particles up into the water rather than keeping them close to the floor.

Figure 5 shows a velocity contour of flow past a baffle with a horizontal plate. The plate appears to reduce the degree to which the flow sweeps upward after the baffle. Also the large vortices do not form until much further downstream. Keeping these vortices further downstream from where the particles are being re-suspended will likely reduce clouding. This appeared to be a very promising modification compared to the standard baffle.

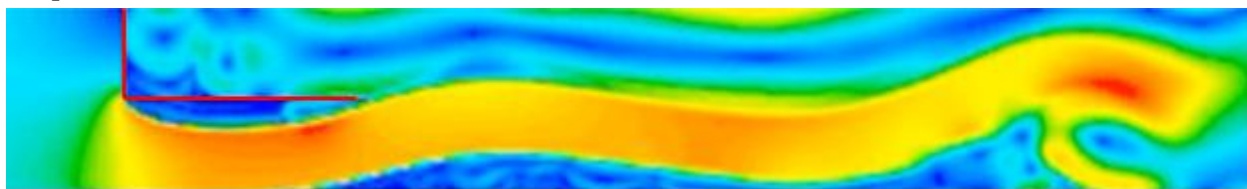


Figure 5: Velocity contour for flow past a baffle with a horizontal plate

Figure 6 shows the velocity contour for the baffle with the plate shifted upwards. This baffle is clearly worse than the standard baffle. It quickly forms and sheds vortices immediately behind the baffle and would, most likely, dramatically increase clouding.

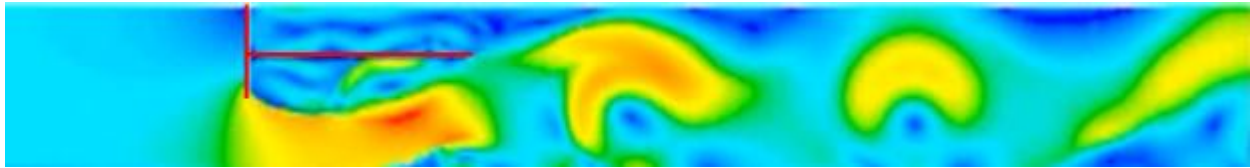


Figure 6: Velocity contour of flow past a baffle with a horizontal plate placed 1.75 in above the bottom edge of the baffle

Error! Reference source not found. shows the velocity contour for the baffle with the plate shifted downwards. This produces dramatically irregular flow patterns and vortices and would also be very unsuitable for raceway cleaning.

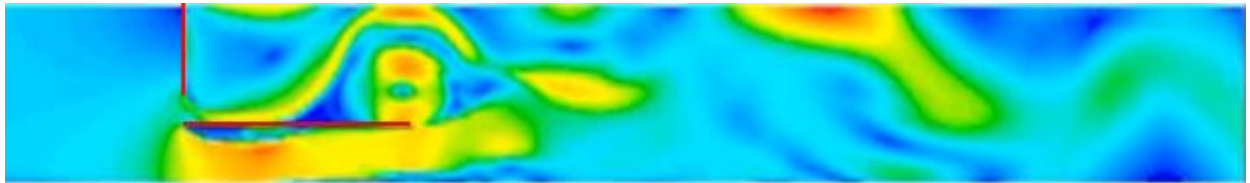


Figure 7: Velocity contour of flow past a baffle with a horizontal plate placed 1.75 in below the bottom edge of the baffle

Figure 8 shows the velocity contour of the flow past the baffle with a diffuser. This flow appears to be very similar to the standard baffle, with the upward sweeping motion of the fluid and the large shedding vortices. The effect seems slightly reduced, but this is probably not a helpful modification to the baffle design.

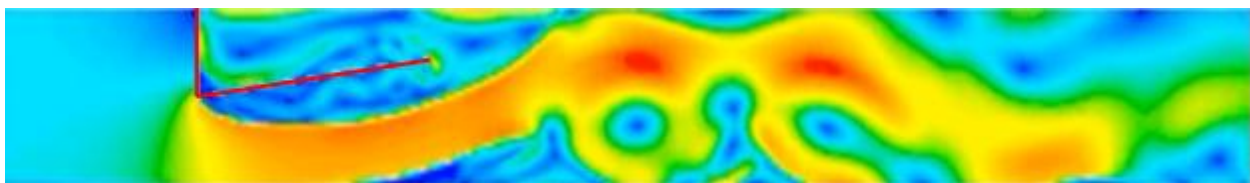


Figure 8: Velocity contour of flow past a baffle with a diffuser downstream

Figure 9 shows the velocity contour of flow past a baffle with a nozzle and a diffuser. This velocity contour appears to be an improvement on the baffle design. The vortices shed further downstream from the baffle. Also the flow appears to be much more stable, which can be seen in the animation.

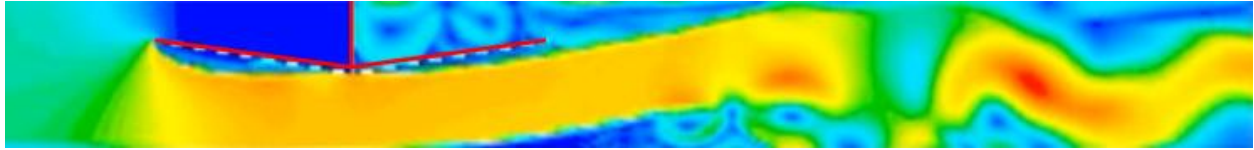


Figure 9: Velocity contour of flow past a baffle with a nozzle upstream and a diffuser downstream

These baffle geometries also changed the shear stress on the raceway floor. In most cases, the modifications decreased the shear stress. This means that these baffles would need to be placed lower into the water in order to reach the critical shear stress. These results are presented in Table 2. This shows a major drawback of the nozzle/diffuser style baffle. Since the shear stress was reduced so much, this baffle would have to be placed much lower. Most likely, the flow would then become more unstable than it appears in the velocity contour in Figure 1.

Table 2: Wall shear stress of the modified baffles

Baffle Geometry	Shear Stress (psf)
Horizontal Plate	0.0014
Plate Shifted Up	0.0014
Plate Shifted Down	0.0016-0.0022 (very unsteady and irregular)
Diffuser	0.0015
Nozzle and diffuser	0.0008

One interesting effect of adding the horizontal plate is that the downstream peaks in the wall shear stress appear to be reduced as shown in Figure 10. This seems to indicate that the re-suspended particles would settle closer to the baffle since it is less likely that the shear stress will reach the critical shear stress in this area.

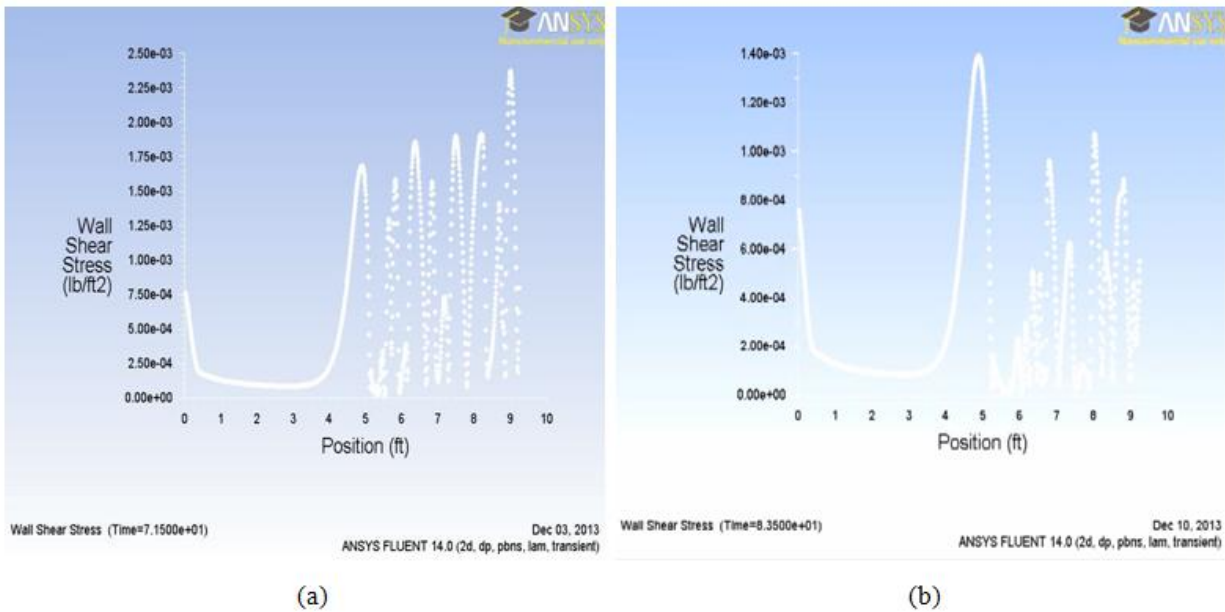


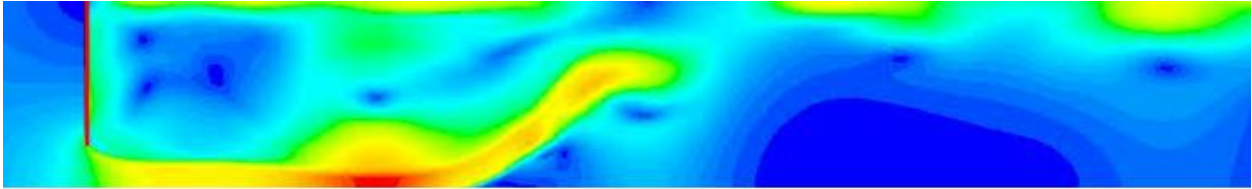
Figure 10: Comparison of downstream shear stress between (a) the standard baffle and (b) the baffle with a horizontal plate. The downstream shear stress tends to be lower in the baffle with the horizontal plate (b).

Study 2 – Velocity Scaling Analysis

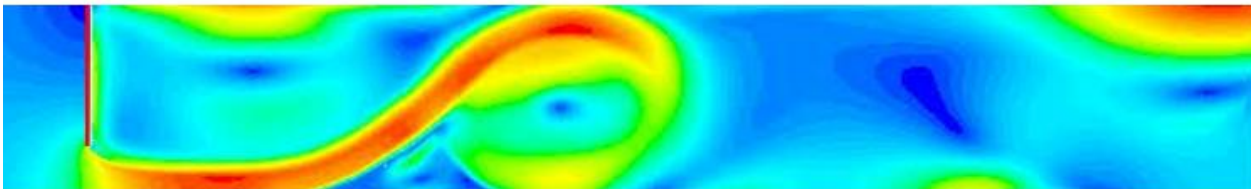
After conducting the initial CFD study, the validity of setting the inlet velocity as the velocity in the full scale raceway was questioned. Another set of simulations was run in order to determine what the appropriate method for setting the average velocity for a scale analysis of the baffle. Three possibilities were considered: The same velocity as the full scale (as discussed previously), Froude number similarity (which is commonly used with free surface flows), and Reynolds number similarity (which is used for flows dominated by viscous force). Thus four simulations were run as described below.

1. Full scale simulation – Inlet velocity = 0.1407 ft/s
2. Model scale simulation – Inlet velocity = 0.1407 ft/s
3. Model scale simulation (Froude number similarity) – Inlet velocity = 0.0715 ft/s
4. Model scale simulation (Reynolds number similarity) – Inlet velocity = 0.544 ft/s

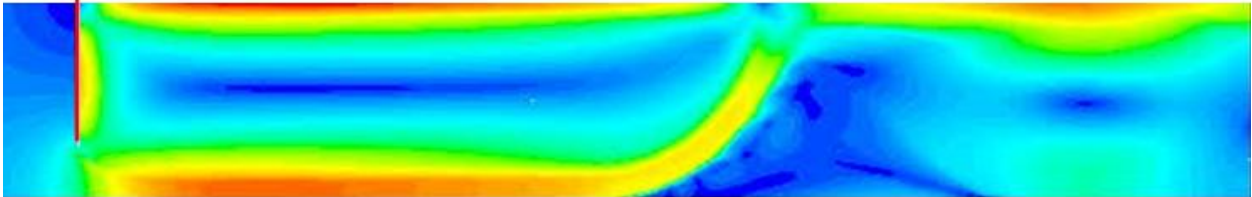
The full scale simulation was run using with a depth of 36 in and a length of 426 in. Before conducting the model scale simulations, the full scale simulation was run iteratively until the baffle was placed low enough to achieve the critical shear stress. This height was found to be 10 in, thus for the remainder of the simulations, the model scale baffle height was 2.585 in. Snapshots of the velocity profile of the four simulations are shown in Figure 11.



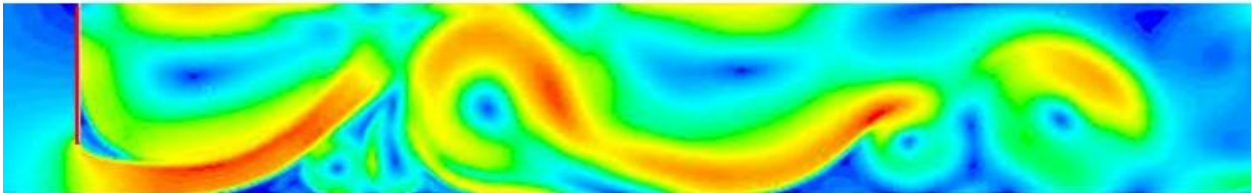
(a)



(b)



(c)



(d)

Figure 11: Velocity contour snapshots from scaling analysis: (a) Full scale, (b) Same velocity, (c) Same Reynolds number, and (d) Same Froude number.

None of the initial simulations matched perfectly with the full scale simulation, however the Reynolds number simulation appeared to match most closely. The velocity contour animation for this simulation appeared to have too small of a time step to adequately capture the flow physics. Using the Strouhal number, which relates the frequency of events within two scaled flows:

$$St = \frac{fL}{v}$$

the frequency of the time steps was increased for the Reynolds number simulation. The time step was thus reduced from .5 s to .0334 s. After running this simulation, it was found that the model scale flow with the same Reynolds number as the full scale flow behaves exactly the same as can be seen in Figure 12.

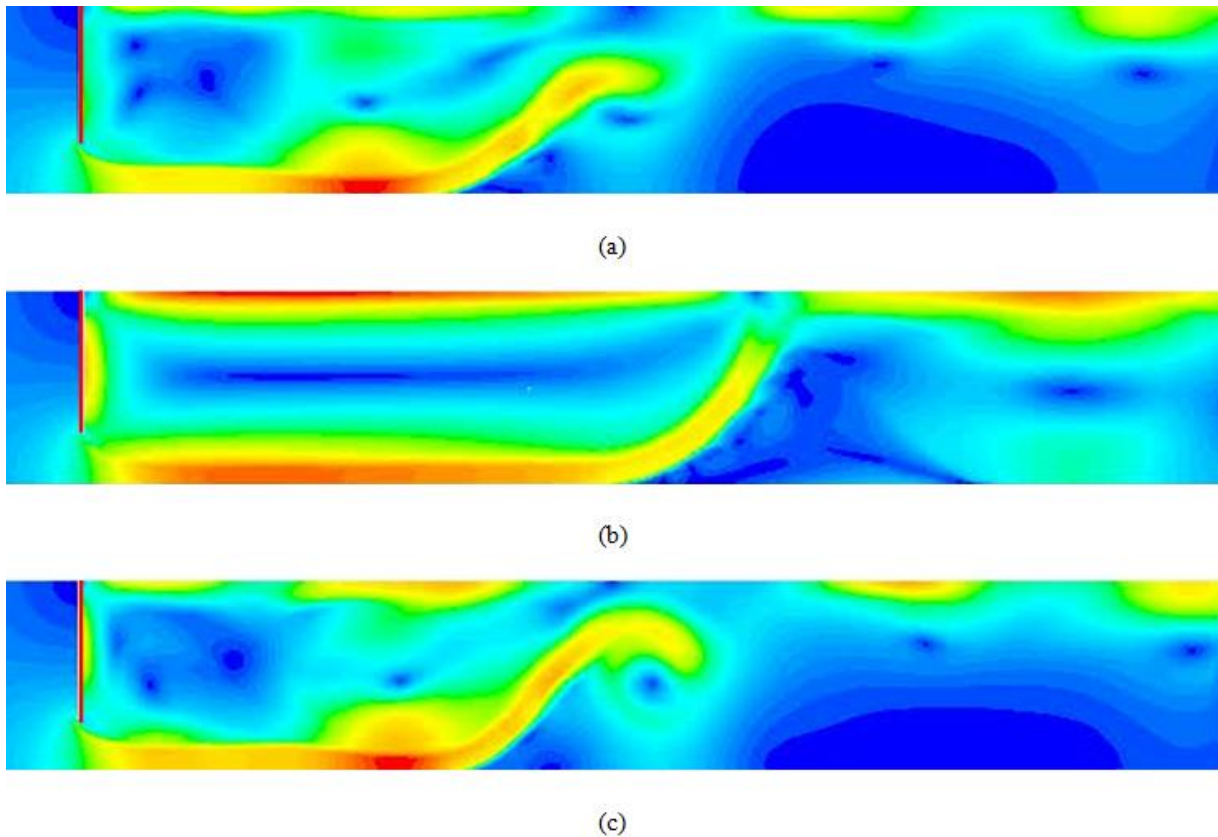


Figure 12: Snapshot of velocity contours: (a) Full scale, (b) Reynolds number, and (c) Reynolds number with adjusted time step.

This has a number of implications. Most obviously, when conducting experimental studies at the model scale, the fluid velocities will need to be about four times those in the full scale raceway. The Strouhal also indicates that events in the model scale flow will occur with a frequency approximately fifteen times that of the full scale flow. Finally, it should be noted that with the scaled flow, the wall shear stress at a given location will not be the same between the model and full scale raceways. Rather, the shear stress *coefficients* will be the same. The consequence is that wall shear stress will be approximately fifteen times higher in model scale tests. This is a serious issue because the suspension of biosolids

depends on the wall shear stress. It would be advisable for future experimental work to be conducted with a particulate that has a higher critical shear stress than the actual trout biosolids.

Study 3 – Parametric Analysis of Horizontal Plate Length

The last study conducted was to observe the effect of changing the length of the horizontal plate. The same baffle height was used as in the previous study (2.585 in), and Reynolds number similarity with the adjusted time step was used. Four simulations were run with plate lengths of 4 in, 8 in, 12 in, and 16 in. The results seemed to show that the flow was less turbulent with longer horizontal plates. However, now that the simulation was conducted with Reynolds number similarity and a lower baffle height, the benefit of adding the horizontal plate was no longer obvious. It appeared that the horizontal plate had little benefit and may actually increase turbulence. Snapshots of the four simulations are shown in Figure 13. It is recommended that one views the velocity contour animations of these studies in order to gain a more thorough understanding of the flow physics than snapshots can provide.

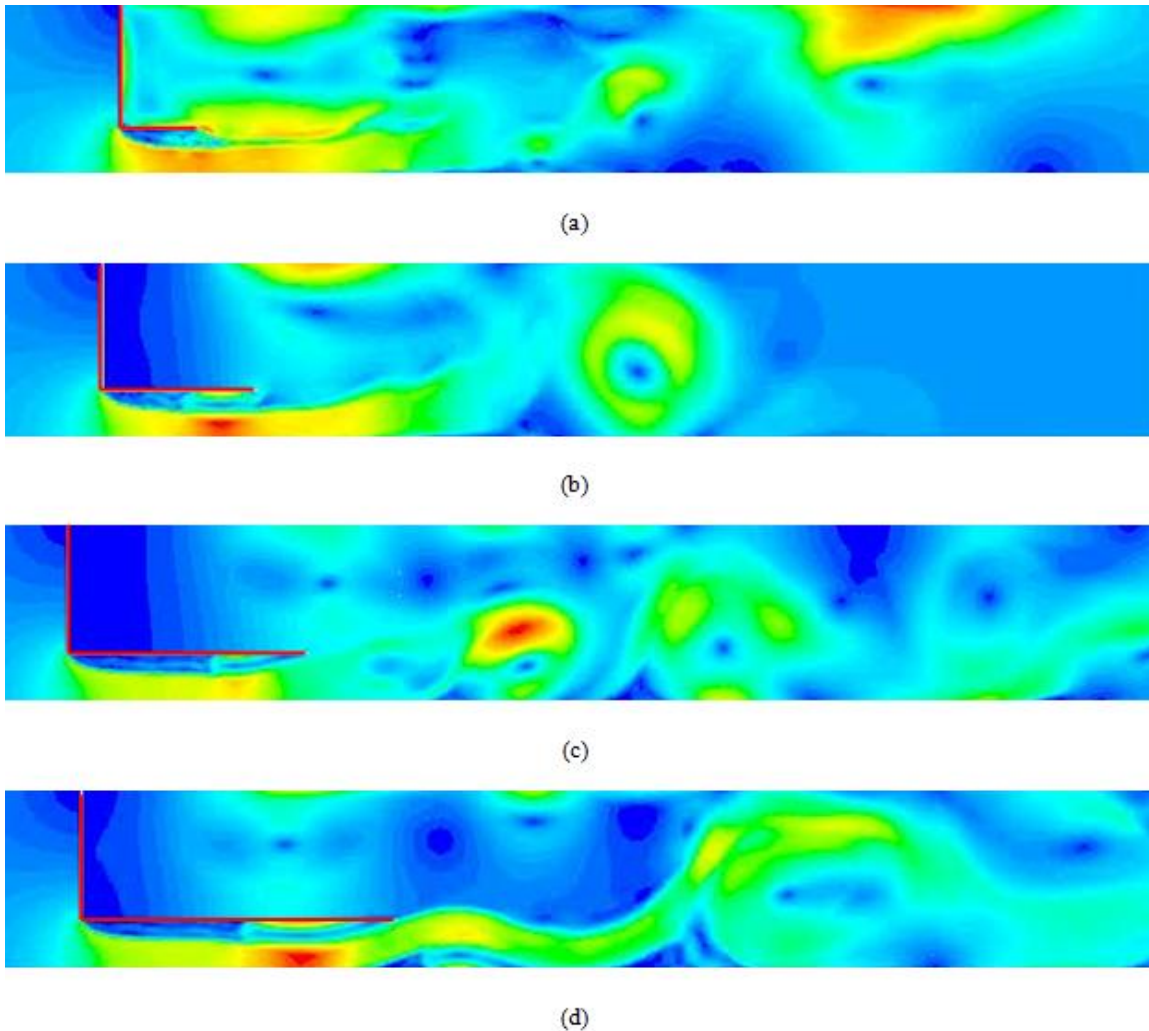


Figure 13: Snapshots of velocity contours of baffles with various length horizontal plates: (a) 4 in, (b) 8 in, (c) 12 in, (d) 16 in

CFD Future Work

Potential for much more research and simulations exists. It may be possible that better modifications than the horizontal plate exist. For example, studying the effect of the angle of the plate would be helpful, especially since no simulation of the diffuser was conducted with the velocity scaled correctly. It would also be beneficial to conduct 3D simulations that would include the effect of the baffle structure and width of the raceway. Probably, the most important would be link the observations made in the CFD simulations to those made experimentally. As of yet, our understanding of what causes clouding is still elementary. This would be greatly benefitted by a multiphase simulation that would include the particulates.

FLOW CHARACTERISTICS

Model Scale Flume

The model scale flume we are using is controlled by a $\frac{3}{4}$ horsepower pump with a 30 gallon tank that serves as both the intake and outlet for the flume, so it is a continuous system once it is full of water. The flume is 12' long, has a width of 6" and the flow depth can be varied, but we kept it at approximately 9" deep throughout each experiment.

At the end of the flume there is a rectangular shaped sharp crested weir. At each of the experiments we kept the water at 0.75" above the weir. The weir is the same width as the channel so there is no choke or increase in velocity. I used the Francis Weir Equation to calculate the flow rate through the channel. The equation is listed below:

$$q = 3.33(b - 0.2h)h^{\frac{3}{2}}$$

Where "q" is the flow rate in cfs, "b" is the width of the flume in ft, and "h" is the height of the water above the weir in ft. Setting "b" equal to 0.5 ft and "h" equal to 0.0625 ft, we get that the flow rate in our flume is approximately 0.025 cfs. Using the continuity equation we can establish a mean velocity of 0.0676 ft/s. The velocity in the flume is going to vary somewhat at the entrance and exit due to turbulence and flume shape, but it is safe to assume this as a mean value.

Full Size Raceway

On average the raceway has a mean flow rate of 7 cfs, with a water depth of 3 ft and a width of 18 ft. Using the continuity equation we can calculate that the flow velocity is 0.130 ft/s (about twice as fast as our model scale flume).

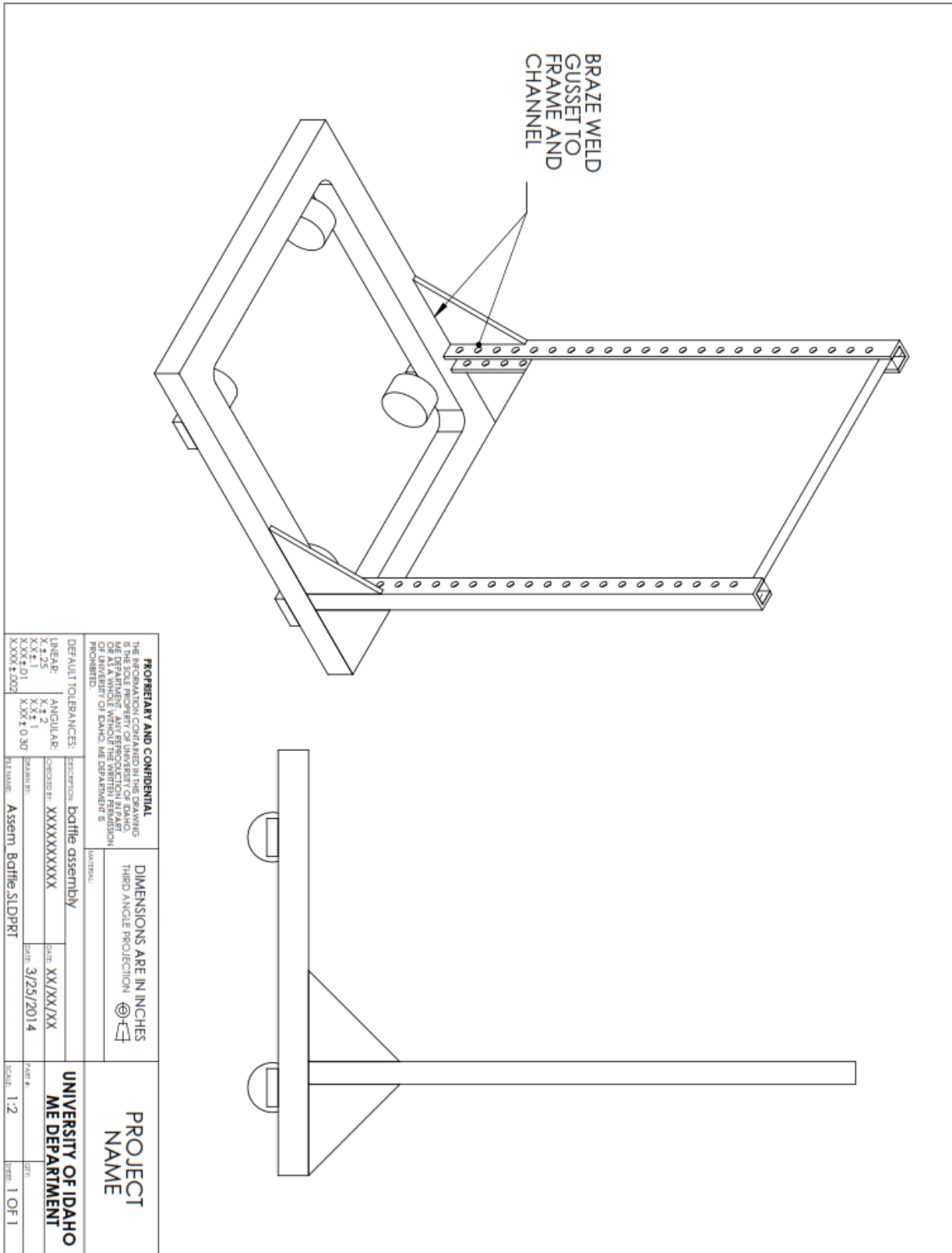
Calculating Flow Characteristics

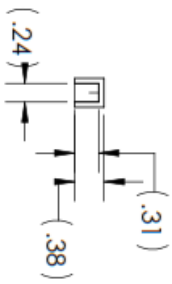
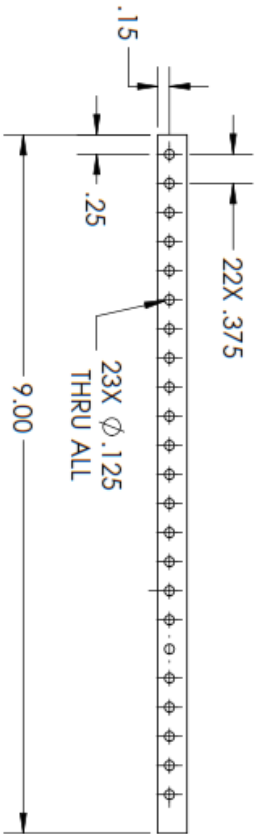
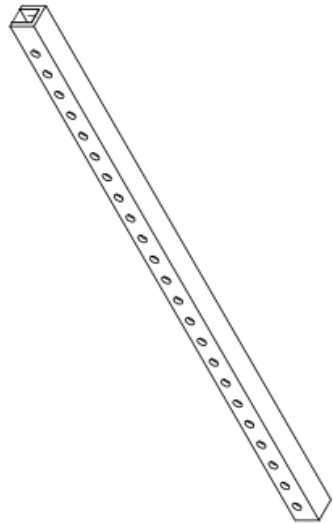
Calculating the Reynolds number and Froude number for both channels we can see that we have subcritical turbulent flow, as is to be expected, and which means dimensional analysis can be applied to find similarities between the two water bodies since they have similar flow patterns. To find the experimental height of the baffle off the raceway floor in a full size flume, we used dimensional analysis based on the optimal baffle height in our scale flume. We found that the optimal height based on speed, effectiveness, and reduced clouding of our small scale baffle in the flume was 1 inch baffle gap between the raceway floor and the baffle edge. From here we computed the specific force for a rectangular channel using the equation below:

$$SF = \rho g y^2 \left(\frac{b}{2} \right) + \rho Q V$$

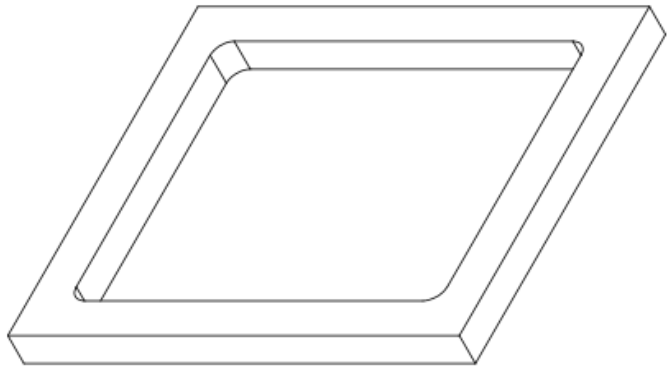
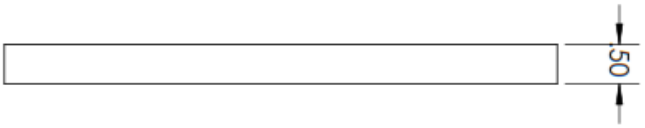
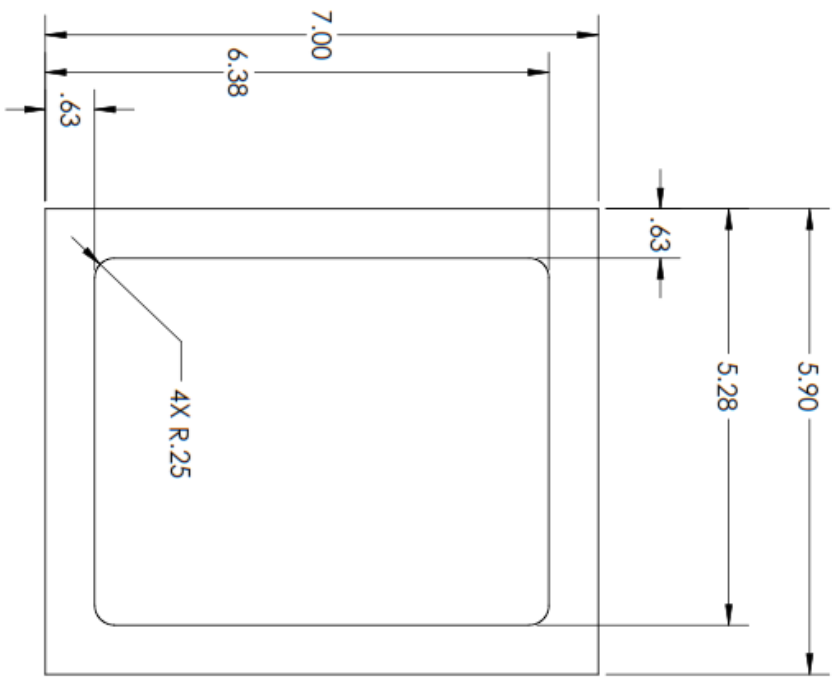
Using this equation and the values from our optimal baffle height ($y=1$ ") a specific force in units force per unit mass was calculated. To apply this to the full size raceway the value calculated was scaled in per unit area. Both sides of the equation were then multiplied by the theoretical area of the full size raceway, and back solved to find the baffle height y. With this we got that for optimal cleaning, the full size baffle gap should be 5.5 inches from the baffle edge to the raceway floor.

PROTOTYPE SOLIDWORKS DRAWING PACKAGE

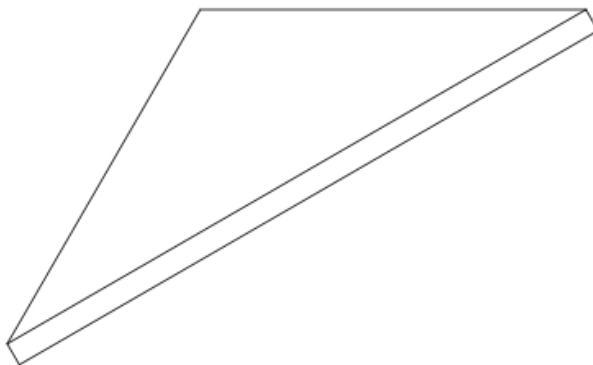
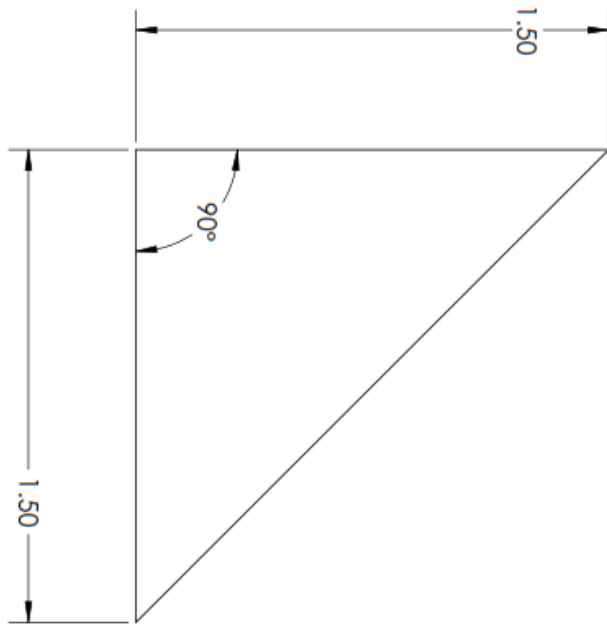




PROPRIETARY AND CONFIDENTIAL THE INFORMATION CONTAINED HEREIN IS UNCLASSIFIED EXCEPT WHERE SHOWN OTHERWISE AND IS THE SOLE PROPERTY OF UNIVERSITY OF IDAHO ME DEPARTMENT. ANY REPRODUCTION IN PART OR IN WHOLE WITHOUT THE WRITTEN PERMISSION OF UNIVERSITY OF IDAHO, ME DEPARTMENT IS PROHIBITED.		DIMENSIONS ARE IN INCHES THIRD ANGLE PROJECTION		PROJECT NAME UNIVERSITY OF IDAHO ME DEPARTMENT	
MATERIAL: Aluminum		DESCRIPTION: Channel		PART #: SCALE: 1-2	
DEFAULT TOLERANCES: LINEAR: .0025 ANGULAR: .031 HOLE DIA: .0025 HOLE POS: .0025		CHECKED BY: XXXXXXXXXXXX DATE: 3/25/2014		SHEET #: SHEET: 1 OF 1	
REFERENCE: Urod_bottle.SLDprt					



<p>PROPRIETARY AND CONFIDENTIAL</p> <p>THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF UNIVERSITY OF IDAHO. NO PART OF THIS DRAWING IS TO BE REPRODUCED OR TRANSMITTED IN ANY FORM OR BY ANY MEANS, ELECTRONIC OR MECHANICAL, INCLUDING PHOTOCOPYING, RECORDING, OR BY ANY INFORMATION STORAGE AND RETRIEVAL SYSTEM, WITHOUT PERMISSION IN WRITING FROM THE DEPARTMENT OF MECHANICAL ENGINEERING OF UNIVERSITY OF IDAHO, ME DEPARTMENT 5 PROHIBITED.</p>		<p>DIMENSIONS ARE IN INCHES</p> <p>THIRD ANGLE PROJECTION</p>		<p>PROJECT NAME</p> <p>UNIVERSITY OF IDAHO ME DEPARTMENT</p>	
<p>DEFAULT TOLERANCES:</p> <p>LINEAR: ±.25 ANGULAR: ±.2 HOLE: ±.01 X.XXX ±.002</p>		<p>DESIGNATOR: Frame</p> <p>CHECKED BY: XXXXXXXXXXXXX</p> <p>DATE: XX/XX/XX</p>		<p>PART #:</p> <p>SCALE: 1:2</p>	
<p>UNIVERSITY: Aluminum</p>		<p>DATE: 3/25/2014</p>		<p>SHEET: 1 OF 1</p>	
<p>REVISION: Frame Bottle.SLDprt</p>					



PROPERTY AND CONFIDENTIAL		THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF UNIVERSITY OF IDAHO. IT IS TO BE KEPT IN CONFIDENTIALITY AND IS NOT TO BE REPRODUCED OR TRANSMITTED IN ANY FORM OR BY ANY MEANS, WITHOUT THE WRITTEN PERMISSION OF UNIVERSITY OF IDAHO. ME DEPARTMENT IS PROHIBITED.		DIMENSIONS ARE IN INCHES		THIRD ANGLE PROJECTION		PROJECT NAME	
DEFAULT TOLERANCES:		DESCRIPTION: Gusset		MATERIAL: Aluminum				UNIVERSITY OF IDAHO ME DEPARTMENT	
LINEAR: .0025	ANGULAR: .1	CHECKED BY: XXXXXXXXXXXXX	DATE: XX/XX/XX			PART #:		SHEET: 4	
XXX ± .01	XXX ± 0.30	DRAWN BY:	DATE: 3/25/2014			SCALE: 2:1		SHEET: 1 OF 1	
XXXX ± .002		REVISION:	Wedge.SLDPRT						

Problem Definition

Our objective is to design an automated cleaning system which requires little maintenance to reduce fine particulate from accumulating in raceways. Flow rates through the raceway should not be sacrificed in order to ensure fish health.

Current Method → Proposed Solution



Figure 1: Push-screen Cleaning

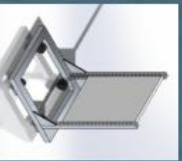


Figure 2: Baffle model

Methodology

With the aid of experimental data and computational fluid dynamics modeling, our goal is to provide our client Clear Springs Inc. with a functional baffle design to improve on their current human-powered push-screen method.

Design Constraints

- ❏ Decreasing flow by 1 cfs for more than 5 minutes can kill fish due to decreased dissolved oxygen levels
- ❏ Reduce/eliminate time spent by employees in the raceways
- ❏ Reduce re-suspension of particulate
- ❏ Reduce hours employees spend cleaning



Team: Levi Dawes, Kate Wicher, Matt Francis, Jeremiah Schroeder
Lead Professor: Dr. Tao Xing

Project Learning

- ❏ Advanced fluid dynamics
- ❏ Precise machining of model-scale baffle
- ❏ Data analysis and interpretation
- ❏ Computational Fluids Dynamics
- ❏ SolidWorks structure modeling

Full-Scale Design Proposal

The proposed baffle system would be comprised of three units, each six feet long, which could be easily moved from one raceway to another by one or two people. After attaching the three units and inserting the plastic baffle, the system could be left to slowly travel down the raceway by the force of the water. Horizontal wheels would be in place to prevent the baffle from jamming against the raceway wall.



Figure 3: Three Piece Full-scale Baffle Design

Model-Scale Testing

- ❏ Adjustable baffle wall height
- ❏ Only allows passage of water below the baffle wall
- ❏ Moved by the force of water (no external power needed)
- ❏ Detachable horizontal plate
- ❏ Lightweight/waterproof material



Figure 4: Experimental Testing of Model-Scale Baffle

Computational Fluids Dynamics Modeling

The simulations have provided detailed visualizations of the flow pattern past a baffle. The results have shown that adjustments to baffle geometry such as a horizontal plate have the potential to reduce clouding. Simulations were also used to verify that Reynolds Number similarity should be used when conducting scale experiments of baffles.

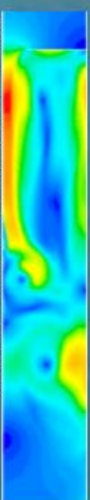


Figure 5: Snapshot of Flow Patterns Past a Vertical Baffle

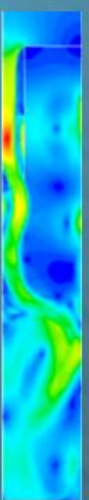


Figure 6: Snapshot of Flow Patterns with a Horizontal Plate