ENERGY INNOVATIONS SMALL GRANT
(EISG) PROGRAM

EISG FINAL REPORT

The Sagebien Project

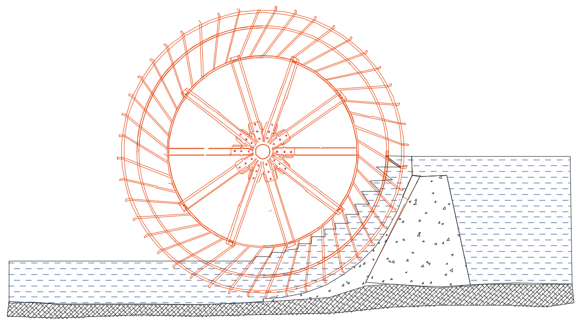

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Table of Contents

List of Figures

List of Tables

List of Appendices

Abstract

Original research was undertaken in the Amorocho hydraulics lab at UC Davis investigating possibilities of enabling fish passage through low head dams using a Sagebien waterwheel. A transparent 3' diameter wheel was constructed with the objective of testing its adaptability to pass fish up and down stream. The flume was 23" wide from .3 to almost 1.0 cfs of water for power and fish passage using a range of fish and internal blade configurations and speeds.

The Sagebien Wheel was tested for power at two speeds over a range of heads. The wheel developed a maximum of about 64 % mechanical efficiency. No fish would pass upstream through the wheel irrespective of speed, number of blades, or their shape. Downstream passage was effected in 3 cases. Two fish were cut by the wheel during passage.

The main impediment to fish passage was not the wheel, but difficulty of interesting fish to enter the wheel. Subsequent investigations of fish herding to and into the wheel were made. Two methods of herding fish were explored: a loop bubble curtain that was slowly dragged to and from the wheel, and an array of fixed loops activated in sequential patterns. Both succeeded.

In summary, the Sagebien wheel is efficient mechanically, but unlikely to be useful for transporting fish through dams due to its unattractiveness to fish. Bubble curtains were effective at moving fish to the wheel when the curtain surrounded the fish. Bubble curtains may prove very useful in large dam applications.

Keywords: Fish dam passage herding bubble curtain Sagebien waterwheel upstream guidance

The Sagebien Project

Executive Summary

Project Objectives

The Project' primary objective was to test upstream and downstream fish passage using a modified Sagebien water wheel. A secondary derived objective was to build a Sagebien wheel in a controlled flume that had a range of fish available for testing, and see if it could be modified to pass fish. In addition to passing fish up and down stream this project had as an objective to test the wheel for power efficiency using a Prony brake as this has not been done since the 1890's. Once wheel was constructed and tested for power output in the flume, it was exhaustively modified and test for fish passage. Finally, to get fish ***through*** the wheel, it is first necessary to get the fish ***to*** the wheel. Some fish would enter the wheel area, but this appeared to often be for the cover and protection of the wheel rather than much interest in passing. This varied from test to test. Thus, the derived final objective is to induce fish to approach the wheel.

Project Implementation

To meet these objectives, a 3 foot diameter Sagebien water wheel was built and tested for both power output and fish passage. The project was then divided into four sub objectives. First, to construct an accurate half size model wheel in a flume with controlled conditions with a testing and fish available to testing. Second, to study what was the power output of the wheel and how was that effected by modifications of the wheel to pass fish, third to run some long term experiments to see if fish were physically able and willing to pass through the wheel when next to it, and finally to explore whether fish go near or into the wheel to pass through.

Project Outcomes:

Objective 1: Build Test Facility

We build an accurate Sagebien wheel out of Plexiglas and Aluminum in a Flume in the Amorocho Hydraulics Lab at UCDavis. This facility allowed complete control of head and flow and had an abundance of freshly caught fish available for testing. Water flow and fish activity were easily monitored through the glass sides of the flume and the Plexiglas sides of the wheel.

Power measurements were made using a Prony brake built coaxially but outside with the wheel. The radius of the arm was 39.9" and the force was measured with a calibrated Toledo Postal scale. The RPMs were measured by timing the wheel using a small GE PLC as a time base.

We had fish available from other experiments at the facility and caught live near Sacramento. Of specific interest to California, we tested trout, salmon, and hitch. We focused on salmon (two cohorts) in different life stages and various indigenous trout at different life stages, and hitch on their upstream migration. We also briefly studied threadfin shad and pike minnows as very small fish models. The selection of fish was based primarily on fish age and motivation to travel up or down stream for a particular age at this time of year.

Objective 2: Measure Power

Since the wheel was constructed and operated in a hydraulics flume at UCDavis, measuring power generation vs flow was accomplished with instruments from Davis Hydro and calibrated instruments from the lab. The test wheel was a perfect hydraulic and power model of the 1870's technology, and was able to produce power at about 64 % hydraulic mechanical efficiency. This was about 10 – 15 % lower than expected. The low power was due almost entirely to the modifications of the wheel to pass fish. We had only 30 blades in for the power tests wheel would be normally set up for about 60. Further modifications to enhance fish habitat included very tight and rubbing seals that may have had excessive friction. Finally, small turbine models are always less efficient than larger wheels due to the high surface area to volume ratios.

Sub Objective 3: Pass Fish Passage tests

Fish were caught and available at the Amorocho Flume. There is an extensive fish handling facility available. Coho Salmon, Chinook Salmon, Brown and Rainbow trout, and hitch were used in most tests.

Upstream: The wheel was put in place and its configuration was explored to see is any fish would pass upstream through the wheel. Different configurations of blades, and speeds were tested. Because we were continually unable to get fish to pass upstream, most of our modifications were to make it easier and easier for them to pass. In the end, we removed most of the wheel blades so that only the outer ridge of the blades were used and 10 blades were left. This provided a weir of about 6"-7, an easy a passage as possible for the fish. Never-the-less, no fish would pass upstream. Typically about 30 % of the salmon would pass downstream. None of the trout or hitch would pass.

Motivation:

The Sagebien wheel as constructed for use in a flume has within it a broad crested weir of about 6" formed by the breast (bottom surface) under the wheel. This is the appropriate size of the size fish we were testing which varied between about 3" and 12". The 10" inch Coho winter run salmon were tested to see is they would pass upstream over this weir without the wheel in place over a wide range of flows. They showed no motivation to pass upstream. It is possible to argue that the fish were not motivated to go upstream in the lab situation, and therefore the negative results have to be tested in the field. The Coho Salmon would have the least motivation at this time of year, the trout would be able if motivated, and the hitch should have been motivated to swim upstream.

Down stream passage were not tested with only the breast (no wheel) in place. It is known that the salmon have a tendency to drift downstream passively. This was observed on many occasions with them schooling at the furthest downstream end of the flume from the wheel.

Passage Summary

No fish went through the wheel going upstream – primarily because over a wide range of flows the fish have no interest in going near the wheel. A few fish would swim up under the wheel, but would not pass through the wheel. It appeared that the fish were only interested in approaching the wheel as a hiding place or for protection from humans moving near the test flume.

Likewise typically, 1-2 out of 6 fish would pass down stream after many hours. The results were similar for all salmon. No trout or hitch passed downstream. This is compatible their motivation at this season of the year for their age. It appeared to the observers that the fish stayed from the large wheel thrashing in their channel, but this observation is a human subjective observation.

Objective 4: Attract Fish into wheel

For fish to pass through the wheel, the fish have to be induced to go into the wheel. This problem is identical to the problem faced at every fish passage in the world. Because the largest problem with getting the fish to pass through the wheel was getting the fish to approach the wheel, our research expanded in this area. This is a worthy stretch research objective in its own right because there are many technologies to move fish over dams. Many work. However, fish locks, fish ladders, fish trucks, all are inhibited by getting fish to come into the technology. Thus, under this derived sub-objective, we expanded the depth of the research significantly. We knew that fish might pass the Sagebien Wheel, if the fish would go to it. This we addressed in depth due to its wide applicability and this is discussed in the following sections.

Objective 4a Bubbles as a Fish Herding Mechanism.

We instituted an additional research topic; that is – how to herd fish to fish bypass facilities. We explored the literature, and built several fish herding test apparatuses in the flume above and below the wheel as part of our ongoing experiments. The mechanisms explored were based on moving air bubble curtains. The underlying principle is that fish interact with strange air bubble curtains, and that by moving the curtain, we could move fish that were associated with the curtain. In this work, then later in May conducted experiments:

1. We practiced first with various hand drawn air curtains, slowly dragging a single bubble curtain to and away from the wheel. This was very successful in moving fish for various sizes and types of fish.
2. A series of 21 loops of in ladder formation forming of moving loops of bubble curtain. This was quite successful at moving fish up and down the tank with the effect limited primarily by the barriers at the end of the flumes.

Conclusions

(What is the meaning or interpretation of the factual findings)

1. Efficiency: The Sagebien Wheel is a modestly efficient electric power generator from water. The model clearly shows the limitations of the technology. The Sagebien wheel, as in all water wheels, scales in size linearly with head. The total

costs therefore vary with a multiple power of the head. This contrasts with a pressure turbine where the equipments size drops with a fractional power of head. Thus, in water wheels, and this is no exception, are only useful at low heads where they can be very efficient. The Sagebien turbine turns very slowly. While this increases hydraulic efficiency through reduced turbulence, it requires a large gearbox. The maximum efficiency of 64 percent was lower than that recorded in the French literature because of the modifications to the blades for fish passage, the low head, and low number of blades.

2. In testing the Sagebien wheel, it became clear that in the entrance to the wheel, the blade drops like a guillotine cutting any fish that is only part way through the turbine on the upstream side of the upper bucket. This means that any fish that is going to pass has to be small relative to the bucket size and or pass through it quickly. There was no question from our observation that fish had the ability to move fast enough to pass through the wheel up or downstream if were they motivated. However, the mode of swimming downstream was drifting with the current, and this proved fatal to several fish moving downstream. Thus, we conclude that this fish passage technology has inherent limiting flaws.

3. This research addresses fish passage at dams, and a mechanism to help the fish across these barriers between habitats. We have concluded from this study that there are many efficient mechanisms of moving fish across dams, but the main problem is interesting fish to move into the various passage technologies. The Sagebien technology suffers from this problem excessively in that the fish have to enter in or under a large rotating mechanism for the technology to be effective. For this reason, concluded this project with research on getting the fish into the wheel. This work actively continues unfunded.

4. Air bubble curtains are effective at moving some fish some of the time. They may be effective at moving large amounts of fish to fish by-pass facilities.

Recommendations

We are continuing to test bubble curtains on various species of fish and under different conditions as resources permit. It must be emphasized that all fish are different in response to various physical stimuli, equally important that fish respond differently at different times in their life cycle, and depending on their conditioning at that moment. The following are recommended work items for further research.

The moving bubble curtains show considerable promise and should be researched further. This technology is interesting and needs research because if we can move fish – even certain types of fish, it will enable many fish transport and capture mechanisms. This technology may be useful in solving the problem of fish hesitancy at the entrance to fish passage devices. This is a universal problem, and if it can be solved, fish can be passed by many dams, and the savings in water that is currently in use to attract fish will be saved.

Public Benefits to California

The public benefits to California of this research is both direct and indirect. The objective we addressed is to be able to move fish past dams using less water. Using less water for fish attraction means that more water is available for irrigation and power.   In summary, the benefits that will flow from this include both power savings, water savings, and fisheries enhancement as described below:

Power Savings: Less water used for fish attraction flows. The result of this is that there will be more water for hydropower. More water behind dams available of gravity fed irrigation. If water is kept behind dams, it does not have to be pumped up by farmers from deep aquifers. This saves both water pumping cost to lift the water for the farmers on the water diversion canal, but also leaves more water in the water table reducing water pumping costs for non irrigation canal participants of all types.

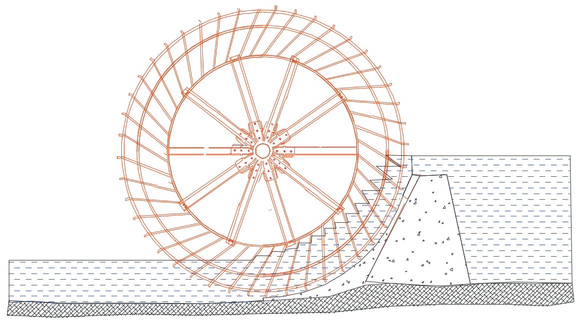
Water Savings: Less water used for fisheries bypass purposes implies means more water available for other uses. Further, if fish can pass using little water between habitats, then less water has to be used for this purpose.

Fisheries Enhancement: If fish have various habitats to choose from, there is a higher possibility that any fish will prosper.

For example, a typical target application is the Red Bluff dam here in California which is a major impediment to fish passing up and down stream. It forms the Red Bluff Lake on the Sacramento River. It also supplies irrigation water to most of the farmland down to Calusa. Because of its negative effect on fish passage, the dam is currently kept open from October to May to allow fish to pass. Keeping the dam open has eliminated gravity irrigation and a great amount of energy now to be used to pump the water up from the river bed to the irrigation canals.

In summary: In our original proposal it was thought that the Sagebien wheel could pass fish. While the wheel was found to poorly pass fish only in one direction, it was not found to be useful primarily because the behavior of the fish is such that they will not approach the wheel to pass. However, we discovered in this research that fish do respond in various ways to moving bubble curtains and that moving bubble curtains can be used to move fish. This is useful to move fish toward a bypass facility, and will help California fisheries management.

The Sagebien Projec



EISG

The California Energy Commission

By

Davis Hydro

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Introduction

This Pier subject area looks at the interaction of the environment and energy in California. The goal of fish passage through dams comes from concern for the fish that are impacted by dams which provide humans enormous benefits in hydropower, flood control, irrigation, recreation, and water supply. On the other hand, dams invariably change and destroy environment in which they are built. This work is an attempt to ameliorate that situation by looking a method to provide passage through the dams for fish.

This study took as its mandate a systems approach to the question how to get fish up and down stream in California using a modified form of a water wheel. This work is an attempt to look at undershot waterwheels in general and the Sagebien wheel in particular as possible technologies to pass fish up and down stream. The Sagebien wheel is a very efficient power generator, but suffers from the problem of all water wheels that the technology scales linearly with head, or the height of the water. It takes a 6 foot water wheel to pass water down a 3 foot drop. This means that the Sagebien wheel is applicable to the small diversion dams around Northern California diverting water into rice paddies, and is applicable to low head situations where fish would benefit from passing.

Report Organization –

This report is organized as follows: First, a description of the objectives of the study. These expanded during the research to accomplish the fish passage goal. Then we describe the approach along with the individual tasks. The research was stretched in a particular direction as the result of some surprising intermediate results, so there are more outcomes and conclusions than the original research agenda. Finally, we discuss the outcomes and conclusions from this work. The outcomes and conclusions are different from what was expected because we have extended the report in the direction of solving the underlying problem, within our technology as well as many others.

Project Objectives

The Sagebien Project's primary objective was to test upstream and downstream fish passage using the Sagebien waterwheel. To accomplish this objective there are several sub or secondary objectives that were identified:

- Build Model: A secondary derived objective was to build a test Sagebien wheel in a controlled flume and see if it could be modified to pass fish.

- Measure Power: A secondary derived objective is to test the wheel for power efficiency using a Prony brake, as this has not been done since the 1890's.

- Pass Fish: A secondary derived objective is to test whether fish would pass through the wheel through its modification.

- Attract Fish: A secondary derived objective is to induce fish to come into the wheel. This objective is identical to that of all fish passage technologies.

Project Approach

This section discusses the procedures we undertook and how the research was extended beyond the original wheel to a newly developed technology that may be instrumental in passing fish at all dams – not just at low head dams appropriate to the Sagebien wheel.

Objective 1

The objective of this research is to test the upstream and downstream passage of fish through a Sagebien water wheel in a laboratory flume. To do this test, it is necessary to accomplish several sub objectives outlined above and the approach taken to each is discussed in the following sections. This will then be followed with an outcome section that will discuss the accomplishment of these objectives and results of the tasks.

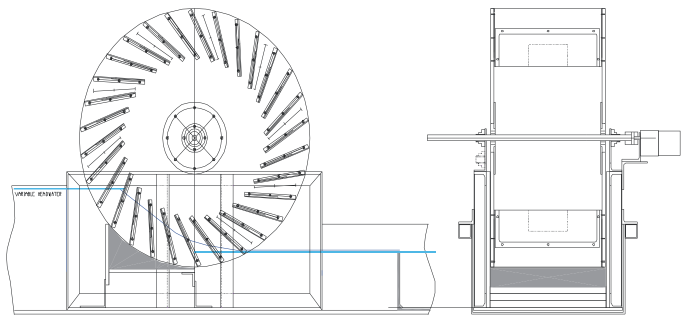

Figure 1 The Sagebien Wheel in Flume Cassette

Sub Objective 2: Build Model

To accomplish the project's main objective, a 3 foot Sagebien turbine (Figure I) was constructed from Plexiglass and Aluminum (Figure 1). It was sized to fit tightly into a flume that was 23.5" wide and over 50 feet long. The sides of the flume were raised 10" upstream of the wheel so that up to 9" of head could be developed with at least 6" of tailwater depth. The mill had provision for 2 fixed speeds, and other speeds by varying gear ratios. Only two were used. The sides were clear to facilitate watching the fish move through the sides of the mill.

All the blades in the mill were removable so that different number of blades could be tested. All blades were modifiable so that we could test fish passage through small or large slots in combinations of blades.
The mill was built and installed in the flume with some delay due to administrative problems at UCDavis.

Sub Objective 3: Measure Power

The wheel was constructed and operated in the Amorocho hydraulics flume at UC DAVIS. Measuring power generation vs. flow was accurately accomplished with calibrated instruments from Davis Hydro and from the lab. The test wheel was an accurate hydraulic and power model of the 1870's technology, and was able to produce power at about 64 % hydraulic mechanical efficiency.

Figure 2 Prony Brake drum on side.

Figure 2 shows the Prony brake in operation with the scale for power calculations. This Prony brake was constructed to measure power from the unit, and was used during all tests to help control the speed of the unit. The actual speed was regulated by the fixed gear ration of a drive motor/generator connected on the far side of the main shaft.

Sub Objective 4: Pass Fish

Experimental Conditions:

Experiments were conducted using the wheel described above. The flume was connected to a variable speed 5 Hp pump that was able to provide up to 2 cubic feet per second. The flume was modified on one end with flash boards so that the water on the up-stream side could be up to a foot higher than water on the lower side of wheel. Typical actual differential was only about 6”. Many different water flows, wheel speeds, and water levels were experimented with, but eventually two protocols developed: about 0.3 cubic feet per second (slow) and about 0.5 cubic feet per second (fast). The Sagebien wheel was set at 12 feet from the upstream end of the flume. For most the work reported here, the wheel turned at 2.4 RPM. A 7” weir[1] was placed at 11 ft downstream of the wheel to adjust the tail water height. This produced about 8” of depth below the wheel in the 23” wide flume. In the experiments, the “upstream” area between the wheel and where the water enters the flume was typically about 14” deep. The target water temperature in the flume was kept at 14 C (+/- <2C), and the fish that were used for the experiments were also held in the tanks with the same target water temperature. There are extensive fish holding tanks and. Fish were caught as needed and made available from other experiments in the lab. The fish used included:

- Coho salmon (average SL = 24.0 cm), in their smolt stage of their life cycle. During this life stage, they have tendency to want to swim down stream to oceans. This made them useful for downstream tests. This size and species are very strong swimmers, so they have the physical ability to go either way through the wheel or over the test weirs.

- Hitch (average SL = 13.7 cm), in their upstream spawning migration stage. They have tendency to want to swim up stream during this stage. This species likewise, are strong upstream swimmers, and have the physical ability to pass up or down stream over any of the test set-ups with the wheel in place or removed.

- Winter run Chinook salmon (average SL = 6.9 cm), in their parr stage of their life cycle. They stay in streams during this stage. These fish are smaller, and are not generally motivated to swim up-stream.

- Brown trout (average SL = 23.0 cm), which is a resident stream fish and moves around a stream for numerous reasons.

- Rainbow trout (average SL = 16.4 cm), which is resident stream fish. These trout species have tendency to want to stay in one place in streams but are able to swim up stream and down stream if motivated.

Biological Motivational Setting:

At this time of year and under the laboratory conditions presented to the subject fish, winter run Chinook salmon (“parr” stage), Brown trout, and Rainbow trout are all found in streams in the Sacramento basin. From behavioral studies these were selected for applicability and because some were likely to cross the wheel both upstream and down. Coho salmon (smolt stage), which migrate down streams to oceans, were likely to cross the wheel to the downstream from the upstream. Hitch (upstream spawning migration stage) were the most likely to cross the wheel to the upstream from the downstream. The trout - being station-keepers - were expected to move up and down at random.

[1] An 8” weir was also used in experiments to raise the tail water to encourage fish to enter the wheel.

Method

Informal Exploratory Tests:

After some exploratory trials with several fish types, experiments settled into a pattern of continually modifying the wheel and water conditions to get any fish to pass up or down stream. The results reported below followed from these exploratory tests using the most likely conditions, including flow, wheel speed, blade configuration, direction and fish type. For example, informal exploratory work was done at higher rpm and higher flow, but the fish had little interest in approaching the wheel even when left for extended periods (6-8 hours).

Structured Tests

Fish were released in the upstream or downstream of the wheel in separate batches to examine whether these fish were able to use the Sagebien wheel to go upstream or downstream. The numbers of fish that crossed the wheel were recorded over a period of time – typically 6 hours. The typical number of fish in an experiment was 6 for small fish (<15 cm). Because putting more than 4 large (>15 cm) fish in the glass flume was too crowded, only 4 fish were used for the "large fish" experiments.

The wheel has provision for changing speed, the number of vanes, as well as their height. As the result of the initial tests, the experiment fairly quickly focused on our slowest speed, the minimal number of blades, and the minimum vane height in the hopes that fish passage would be possible. This configuration lead to low power output and a fairly inefficient wheel as can be seen in the power tests due to internal spillage and poor bucket filling. Finally, the water level and flow were varied over the testing period to find a combination of flow levels, and vane numbers most conducive to fish passage.

Sub Objective 5: Attracting Fish into the Wheel

We expanded this particular research objective. That is, how to herd fish to fish bypass facilities. We explored the literature, and built several fish herding test apparatuses in the flume above and below the wheel as part of our ongoing experiments. The mechanisms explored were based on moving air bubble curtains. The underlying principle is that fish interact with strange air bubble curtains, and that by moving the curtain, we could move fish that were associated with the curtain. In this work, then later in May conducted experiments:

1. HAND DRAWN: We practiced herding first with various hand drawn air bubble curtains, slowly dragging a single curtain to and away from the wheel. Figure 3 shows the various configurations of loop dragging. A 15 foot test area of the glass flume of 23" wide) was used to conduct the air curtain experiments. A 25 ft long air tube was placed on bottom of the flume and air was sent from an air pump into the both ends of the tube to create a uniform amount of air bubbles throughout the tube. Before each experiment, the tube was set at the initial location shown in Figure 3, and fish were placed within the loop. During the experiments, 6 fish were used at a time. The loop was slowly pulled from the initial loop location. As the loop was pulled, the number of fish escaped from the loop and the location of the end loop was recorded.

For the experiments, winter run Chinook salmon (average SL = 6.9 cm) were used, and the results from these tests were recorded as the number of fish that crossed the loop as a function of loop position.

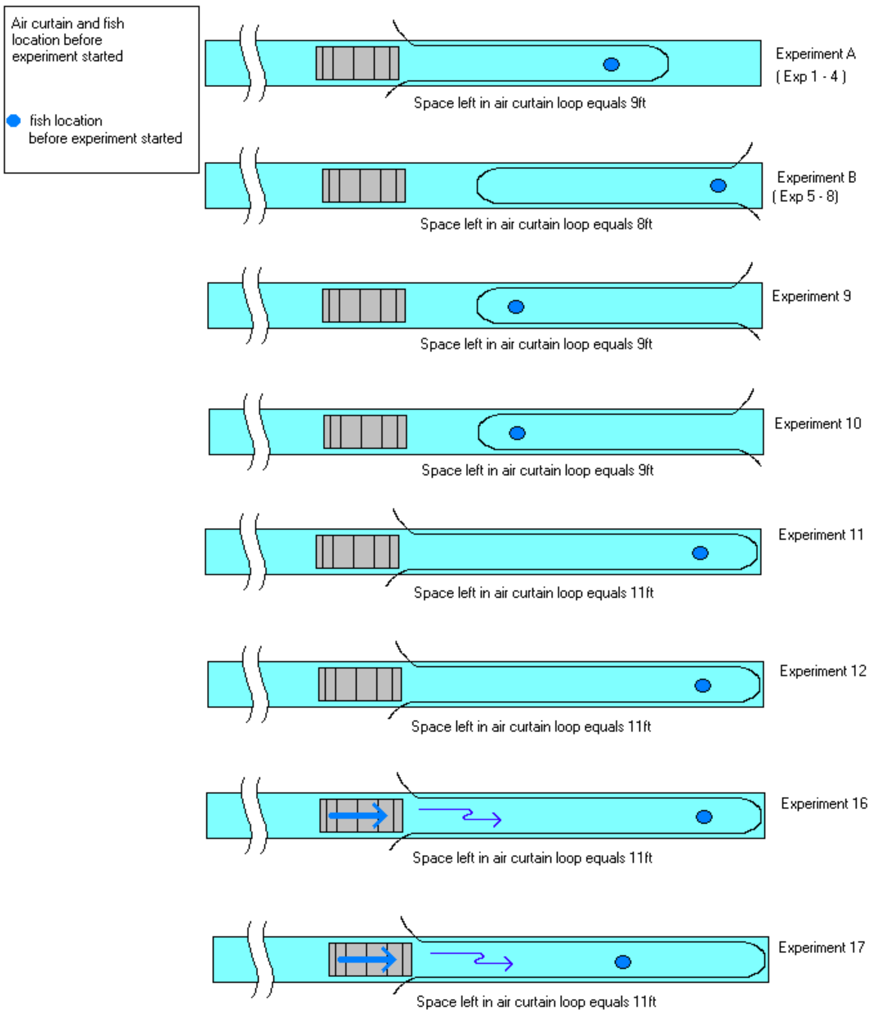

Figure 3 Hand drawn Loop Arrangements

2. FIXED ARRAY: A series of 21 loops of in ladder formation forming of moving loops of bubble curtain. This was quite successful at moving fish up and down the tank with the effect limited primarily by the barriers at the end of the flumes. These are described in the following section. Figure IV below shows the typical loop arrangements for the arrays.

Figure 4 Fish Herding Fixed Array Arrangement

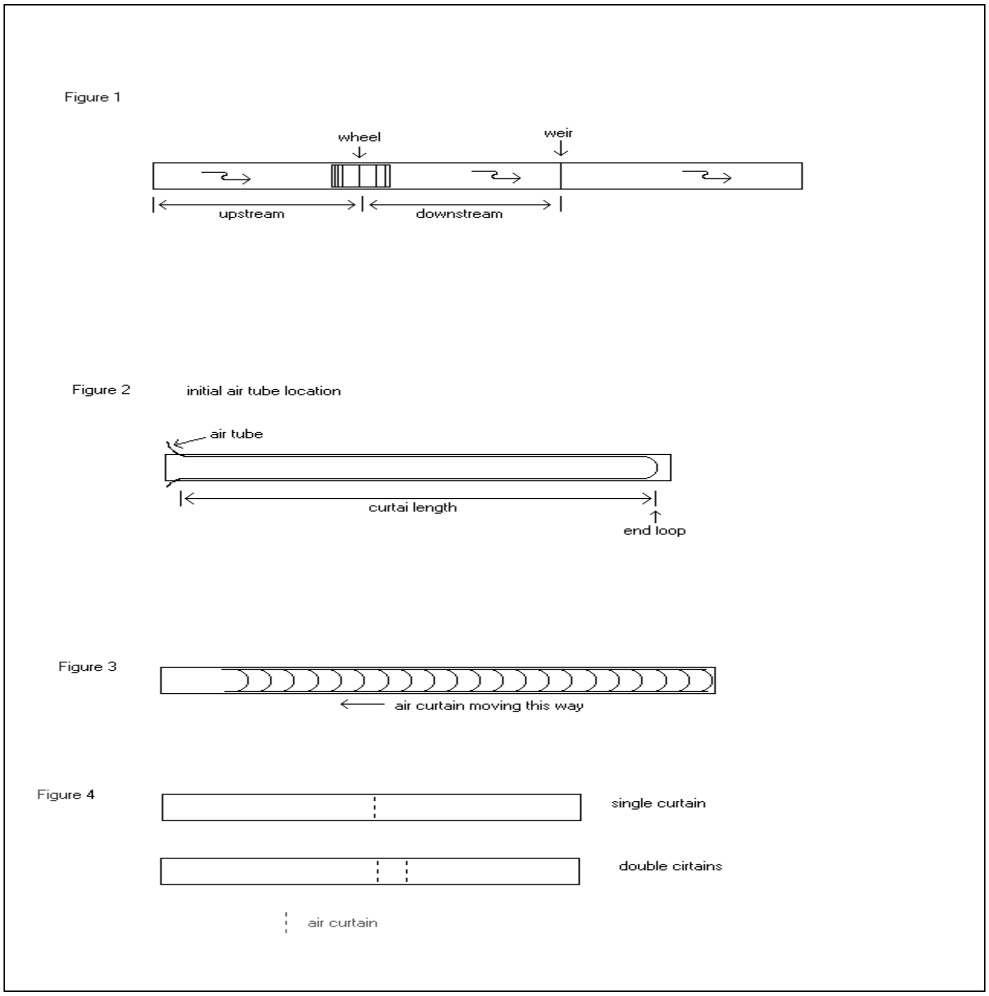

Figure 4 shows a 20 foot section of the 23" wide glass flume was used to conduct the air curtain experiments. The sidewalls and floor of the flume were covered with a black plastic sheet. 21 air tubes were fixed on bottom of the flume in 10 inches apart and each air tube was connected to a ganged solenoid valve. The bubbling curtain was activated in a sequence by the valves, which were connected to an air pump. The bubble curtains loops were programmed to be activated in sequence producing what appears as a single or multiple curtains that move up and down the flume acting like moving walls partially surrounding the fish. The curtains move under computer control from one end of the flume to the other and then repeated with no delay. The speed of the air curtain moving was varied in many informal experiments. In the results shown, it was set to move from tube to tube at 12 second increments. As the curtain was moved, the number of fish herded and the location of the curtain were recorded. For the experiments, 6 winter run Chinook salmon (average SL 6.9 cm) were used.

In addition to the air curtain experiments with the single herding curtain, experiments with double herding curtains (Figure 4) were also conducted. Because a computer was used control the valves, any combination of the loops could be used to make one or more curtains and moved at any rate. Typically patterns were set for a curtain every 21 or every 16 loops. When set for every 16, there would always be two curtains in the test area at the same time. This is closer to how we expect the technology to be used in the field.

Project Outcomes

The project outcomes are presented as follows, Power of the Sagebien Wheel, Passage of fish downstream, upstream, and finally we will then focus on the most promising outcome which was unexpected ways we can motivate fish movement to wheels and any other fish passage technology. The wheel was constructed and operated in the Amorocho hydraulics flume at UC DAVIS. The model wheel described above was an accurate model save it had fewer than the original number of blades that has not been used significantly outside of France for over 100 years. The flume in which it was tested was able to provide the head and flow that was reasonable for a wide range of fish.

Power Tests:

Measuring power generation vs. flow was accurately accomplished with instruments from Davis Hydro and the lab. Other than the adjustable number of blades, the test wheel was a perfect hydraulic and power model of the 1870's technology, and was able to produce power at about 64% mechanical efficiency. Figure 2 shows the Prony brake drum that was used with the lab scale for power calculations.

This Prony brake shown in Figure 2 was constructed to measure power from the unit, and was used during all tests to control the speed of the unit. Table 1 shows the results of the efficiency tests over a range of heads and loads.

Table 1 – Measured Efficiency

FLOW	Brake	RPM	Power out	Head	Watts	Efficiency
CFS	LBS		Watts	in inches	Input	Percent
0.230	4	2.4	3.3	5.13	8.3	40
0.243	6.75	2.4	6.4	6.58	11.3	56
0.298	7	2.4	6.7	6.99	14.7	45
0.338	7.32	2.4	7.0	7.16	17.1	41
0.384	7.55	2.4	7.3	7.11	19.2	38
0.240	5.71	2.4	5.2	5.59	9.5	55
0.298	5.79	2.4	5.3	6.09	12.8	42
0.288	5.7	2.4	5.2	5.92	12.0	43
0.305	5.07	2.4	4.5	5.06	10.9	41
0.208	6.13	1.2	2.8	6.76	9.9	29
0.277	6.56	1.2	3.1	7.31	14.3	22
0.346	7.64	1.2	3.7	7.43	18.1	20
0.145	5.2	1.2	2.3	5.16	5.3	44
0.211	6	1.2	2.8	5.60	8.3	33
0.253	6.5	1.2	3.0	6.14	11.0	28
0.295	6.95	1.2	3.3	6.40	13.3	25
0.183	4.3	2.4	3.7	4.41	5.7	64
0.240	5.4	2.4	4.9	5.09	8.6	57

0.288	6.5	2.4	6.1	5.62	11.4	53
0.313	6.5	2.4	6.1	5.74	12.6	48
0.353	7.55	2.4	7.3	7.01	17.4	42
0.302	7.3	2.4	7.0	6.88	14.6	48
0.270	5.8	2.4	5.3	6.18	11.8	45
0.217	5	2.4	4.4	5.88	9.0	49

In summary, maximum efficiency was 64 %. A complete Excel spreadsheet summary of the data measured is included as Appendix II to this Report. In summary, maximum efficiency was 64 %.

Passage of Fish Upstream:

The following is a summary of experiments with fish released in downstream of the wheel and allowed, but not artificially induced to swim upstream. In all cases the fish would orient themselves to the current, and in many cases individual batch members would have a tendency to swim upstream. However there was no other motivation for the fish to swim upstream. In the case of the Salmon, unlike the hitch or trout, it is part of their lifecycle to float downstream at this stage in their lifecycle. This suggests that the motivation to cross the wheel varied between groups of fish. No direct means was available to measure motivation.

Not one of the species crossed the wheel swimming upstream. Winter run Chinook salmon, Brown trout and Coho salmon and hitch showed some attempts to cross the wheel during the experiments, but they did not - even at the low speeds used and large bucket settings. Intermittent tests were done with winter run Chinook salmon at higher water speeds to see if the higher water flow would induce upstream migration. Table 1 Worksheet “data” in Appendix II shows the conditions of different tests. The codes for this table are in Worksheet “codes” in the same Appendix. Notes for the Runs are shown on sheet “notes”. The following is a discussion of these tests. The numbers in the table are averaged.

Run	# of total rep	Fish	Wheel Speed /# floats	Upstream Depth[2]	Down-stream Depth	Flow Rate	# of Fish in exp	# of fish passed wheel	Water flow thru wheel (cfs)	Comments
Wc-1	1	Winter run Chinook salmon	2.3 RPM /20	13.9 in	8.1 in	Slow	6	0		
	1	Winter run Chinook salmon	2.3 RPM /20	15.8 in	8.7 in	Fast	6	0		

[2] The upstream depth and downstream depth are taken at beginning and end of each experiment.

	1	Coho salmon	2.3 RPM /10	13.6 in	8.4	slow	4	0		
	1	Brown trout	2.3 RPM /10	13.7 in	8.3 in	slow	4	0		
	1	Rainbow trout	2.3 RPM /10	13.7 in	--- *	slow	4	0		*temporar y curtain in a way
	1	Hitch	2.3 RPM /10	13.9 in	8.2 in	slow	6	0		

Table 2 Fish Swimming Upstream

Detailed observations of the Experiments:

- **Winter run Chinook salmon** (average SL = 6.9 cm), in their "parr" stage - They have tendency to want to station-keep in streams, but able to swim up stream and down stream when motivated for food, shelter, fear, or other reasons. At this season of the year, they would normally be drifting downstream. These fish were fresh fish recently caught and had not been used in experiments[3]. They easily have the physical ability to swim through the wheel if so motivated. However, this was not observed. These experiments were run with a flow of about .3 cfs going through the wheel for the slow water velocity and .5 cfs for the fast water velocity.

  These fish were positively rheotaxic in the current and often swam in a school or mostly swam in a physical position during experiments. 2-3 fish would leave the school and swim up into the wheel during the experiment with both slow and fast water flow. There was high water turbulence under the wheel. The fish that were trying to swim into the wheel were swept down by the water before they passed the floats. There were few that reached to or touched the outer half of floats, but they did not proceed upstream.

- **Coho salmon** (average SL = 24.0cm) in their "smolt" stage: They have tendency to want to swim down stream to oceans. These "used" fish had been through other experiments. This experiment was run with a flow of about .3 cfs going through the wheel. The fish were observed to by positively rheotaxic and swam mostly in a loose group. Typically 2 fish out of 6 appeared to be wandered into position to cross the wheel for first one hour of the experiment. These fish were able to reach to or touched the outer half of the floats, but they appeared disinterested or pushed back by the water coming from the upstream or by the moving floats. After first one hour, fish were swimming in position mostly at 3-6 ft from the wheel, and did not approach it afterwards.

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[3] Fish that were fresh caught have been observed to behave differently from fish that have been used in some experiments. Tests reported here are annotated to be with "fresh" or "used". "Used" fish were also used for experimental runs testing wheel speed, water depth, sprint speed, and later for herding tests.

Motivation: Fresh fish of this type were also used is a separate set of experiments on motivation of the swim past the barrier of the Sagebien Wheel. In the first of these experiments, the wheel was removed and the 12" weir formed by the wheel's breast was left in place. The height of the water over this weir varied with the water flow from about .5 inches up to about 1.5 inches. 4 Coho Salmon fish were conditioned[4] for about 40 minutes in the flume then released to swim up or down stream below the weir to see if they would naturally pass up over the weir. Water flow was varied slowly over an hour from about .2 cfs all the way up to about .6 CFS to see if the fish would pass naturally up over the weir under conditions similar, to those that the wheel is expected to address. They did not pass over the weir. More interesting is that they never approached it, but rather drifted down stream and swam in place next to the down stream grate. They would not swim upstream, even when finally if provoked by visibly approaching them and disturbing them by manipulating the water over and just downstream of them.

A second set of motivation experiments with a different set of fish was looked to see if the height of the weir mattered. The breast was removed, and a 6 " board was used as a weir in about 5 inches depth of slack water. When "low" flow of about .5 cfs was used, there was about 1.5 " between the levels with about .5 inches of water coming over the weir. This should have been a trivial barrier for these fish. The fish showed no interest in approaching the weir. It appears the Coho Salmon are not good test animals in the flume to test for passage upstream, but may suffice to indicate downstream migration.

- **Brown trout** (average = 23.0 cm), resident stream fish – they have tendency to stay in streams but like the salmon have the ability to swim up stream and down stream through the wheel. These trout were also not fresh fish. The experiment was run with a flow of about .3 cfs going through the wheel. The fish were positively rheotaxic and swam mostly in a group. They swam in position at 9-10 ft away from the wheel for first 4.5 hours. Then they started to be active during the last 1.5 hours of the experiment. The reason for the change in activity is unknown. It may have been hunger or an increasing familiarity with the wheel. About 5 hours from the start of the experiment, 2 fish appeared to actively trying to cross the wheel. They swam up in between floats many times, and they sometimes swam over one float. There were, however, 2-3 floats to go over in order to reach to the upstream level clear of the wheel.

  Motivation: These trout were not motivated to swim over the next float. They stayed in the wheel until they were carried back into the downstream side of the wheel. There may not have been enough space in the chambers (in the wheel) to make another jump. However, the spacing the wheel had been increased at this point and further increases would have negated any effective power. Only 10 floats were used in this experiment, having been reduced from the original Sagebien design of about 60, and the spacing was there for the fish was about 30 cm. between the floats. Consider that the fish were 23.0

[4] All runs were made with "conditioned" fish. This means that they were brought slowly fromtheir holding pen temperatures to the temperature of the flume slowly. Typically there was little difference in the temperatures, for the "conditioning" was to let the fish adjust to the surroundings and the water. However, these motivation experiments were run during a warm spell so the fish had to be slowly warmed up the the flume temperature.

cm long, there was little room for acceleration.

- **Rainbow trout** (average SL = 16.4 cm), resident stream fish. These fish have tendency to stay in streams but able to swim up stream and down stream. It is unclear if these fish were "new" or "used". They were positively rheotaxic, and the experiments were run with a flow of about .3 cfs going through the wheel. During the first 3 hours of the experiment, one fish swam under the wheel but did not try to swim through the wheel. Other fish were swimming in position at about 3-6 ft from the wheel, and at no time showed any interest in entering the wheel. During the last 3 hours of the experiment, 4 fish were swimming in position at about 4-8 ft away from the wheel. They were evenly spaced out without grouping and showed no interest in entering the wheel.

- **Hitch** (average SL = 13.7 cm), in their upstream spawning migration stage. - They have tendency to want to swim up stream at this season of the year. We had just caught them fresh, and had not been in experiments. The experiment was run with a flow of about .3 cfs going through the wheel. 5 fish went below the weir as soon as the experiment started and stayed there until the end of the experiment. For first 3 hours of the experiment, the 5 fish constantly swam back and forth in a tight school in the below weir area. They were very active and explored extensively. They sometimes tried to swim over the downstream weir out of the experimental area. For the last 3 hours of the experiment, they mostly swam in a school.

  <u>Motivation: The h</u>itch swam very actively. These fish jump back and forth over the downstream weir few times during the experiment. During the first half of the experiment, this same fish often tried to swim into the wheel in the downstream area. The fish was able to swim up to the surface between floats, but the fish were pushed back. During the last half of the experiment, the fish sometimes swam in position facing into the current under the wheel, but not try to swim into the wheel. When placed downstream, the fish are motivated this time of year to swim upstream to spawn. Thus, these fish are the ideal fish for testing upstream fish passage.

Passage Downstream:

In general, fish swam near the wheel, although they had 12 feet of flume water. The fish were not drawn into the wheel because they were at bottom-middle depth. There were few fish that crossed the wheel drifting downstream. These species were winter run Chinook salmon and Coho salmon and hitch. They were swimming near surface and near the wheel where the opening to the downstream was located. They seem to be drawn into the wheel as the floats in the wheel draw the upstream water into the wheel. Table 3[5] shows the results of typical runs at 2.3 RPM.

[5] Appendix II shows complete results of different tests along with run specific notes.

Table 3 - Fish Swimming Downstream

Fish	# floats	Upstream Depth	Down-stream Depth	Flow Rate	# of Fish in exp	# of fish passed wheel
Winter run Chinook salmon	20	14.2 in	8.4 in	Slow	6	4
Coho salmon	10	13.8 in	8.4 in	slow	4	0
Coho salmon	10	14.5 in	9.4 in	fast	4	1
Brown trout	10	13.5 in	9.0 in	slow	4	0
Rainbow trout	10	13.6 in	7.3 in	slow	4	0
hitch	10	13.3 in	8.2 in	slow	6	1

- **Winter run Chinook salmon** (average SL = 6.9cm), in their parr stage – They have tendency to stay in streams possibly drifting down, but they are strong and are easily able to swim up stream or down stream. The experiment was run with "fresh" recently caught fish with a flow of about .3 cfs going through the wheel. All fish were released at the far upstream end from the wheel. They were positively rheotaxic, and swimming in a school at the beginning of the experiment. They gradually moved toward the wheel and started to swim up and down in the water column in a school as the experiment proceeded. 3 out of 6 fish were drawn into the wheel sometime between 3 and 3.5 hours from the beginning of the experiment. One of the fish was caught in the wheel and died while it was crossing the wheel. For the last 2.5 hours of the experiment, fish mostly stayed at the far end from the wheel. They seem to be nosing the upstream screen (at far end from the wheel). 1 additional fish crossed the wheel going downstream near the end of the experiment.

- **Brown trout** (average SL = 23.0 cm) and **Rainbow trout** (average SL = 16.4 cm), resident stream fish. These are reported together because they acted the same way. They both have tendency to stay in streams but able to swim up stream and down stream. The experiments were run with a flow of about .3 cfs going through the wheel. The behaviors of both species during the experiments were similar. No fish crossed downstream through the wheel during the experiments. Fish were positively rheotaxic, swimming in between bottom and middle depth. They spread out between the wheel and the upstream screen (at far end from the wheel) and sometimes they schooled. Few fish stayed near the wheel. However, when near it, they were not seem to be drawn into the wheel because they were at bottom – middle depth, which far from the surface where the opening to the downstream was located.

- **Coho salmon** (average SL = 24.0 cm), in their smolt stage. At this age, they have tendency to want to swim down stream to oceans. These fish were not fresh fish. This experiment was run with a flow of about .3 cfs going through the wheel. During the experiment, no fish crossed the wheel. Fish were positively rheotaxic, swimming near the bottom-middle depth throughout the experiment. During the first half of the experiment, 3 fish were in a school near the upstream screen 14 feet from the wheel and 1 fish was near the wheel. After about 30 minutes, fish started to stay at 6-12 ft away from the wheel as the experiment proceeded. Near the end of the experiment, all fish started to be near the upstream screen in a school Far from the wheel.

  Some runs were made at at.5cfs, the "used" fish were mostly in a school, positively rheotaxic, were swimming in position, at bottom – middle depth. They stayed within 6 ft from the wheel during most of the experiment time. Different numbers of fish occasionally swam back and forth during the experiment. 1 fish was caught in the wheel as it crossed the wheel at 5 hours after the start of the experiment.

- **Hitch** (average SL = 13.7 cm), in their upstream spawning migration stage - They have tendency to want to swim up stream. These fish were fresh fish. The experiment was run with a flow of about .3 cfs going through the wheel. For first 3 hour of the experiment, fish were in a school constantly swimming back and forth in all depth. 1 fish crossed the wheel during the first 30 minutes of the experiment. The caudal fin of the fish was partially missing, which probably happened while it was crossing the wheel. For last 3 hours of the experiment, fish were mostly swimming in position, positively rheotaxic and in a school. The hitch were the most illustrative because these fish were fresh, "unused" and most important they are naturally motivated this time of year to swim upstream.

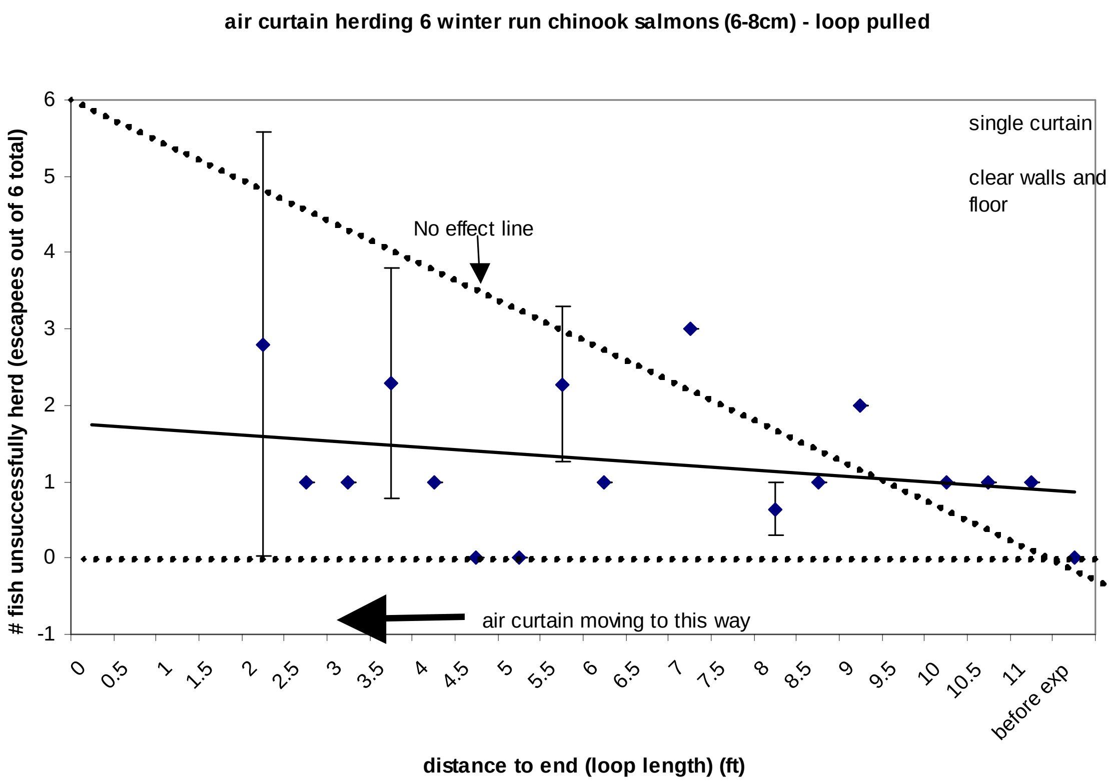
Herding

The main outcome of this research is some definition on an opportunity to herd fish. We have been able to show that we can statistically move some fish in a direction - in this case, into a fish bypass technology. By studying the response of many fish to moving air curtains, we have often observed a weak herding response. The results of our herding experiments were successful, and what follows is a description of those results.

Loop Dragging Results

We started fish herding experiments by very slowly dragging tubing that produced an air curtain up and down a flume with fish in it watching whether the fish would be influenced by it. The loop was effective at corralling the fish and moving them up or down stream. 4 total experiments were conducted and the results were plotted in the graph shown in Figure 5. The graph shows the relationship between the curtain position shown in Figure 2) and the number of fish that were on one side of the loop. The upper " No effect line" (dotted slope) in the graph shows number of fish outside of the loop if there were no effect of the air curtain to fish. For example, the loop was pulled up to the half way (point "A"). If there was no effect of the air curtain to fish and fish were at random location in the flume, there would be half of fish (3 fish) inside of the loop and other half (3 fish) outside of the loop (as 6 total fish in the flume) (point b in Graph 3). So this graph shows that the lower a line (of results) from "No effect line", the higher the success of herding fish.

Figure 5 Loop Pulled Air curtain



The solid linear black line is a linear regression line showing the result of the experiments. The number of fish that escaped out of the loop increased slightly as the length of the curtain shortened (approached to the end), but it was low over all and much lower than the "no effect line" which means most of the fish were successfully herded in these experiments.

During the experiment, fish were mostly in a group. They sometimes swam back and forth inside the loop. They often swam in position about ½ ft – 1ft inside of the end loop. As the curtain was pulled toward the end, they also moved toward the end with maintaining the distance from the end loop. 1-2 fish sometimes swam out of the curtain, but they quickly swam back into the curtain and joined to the rest of the fish in a group. Complete data tables are included in Appendix III.

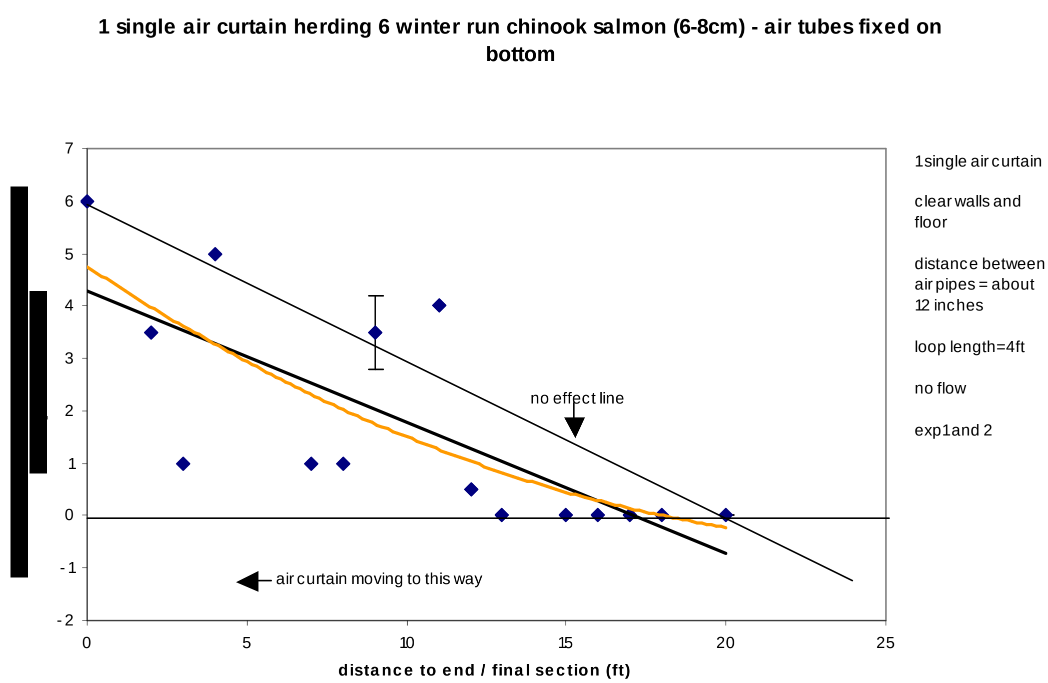
These results were promising, so we continued our experiments with the fixed arrays on the bottom moving the air curtains by sequencing the tubes. These results are reported next.

Fixed Array Results

When using a fixed ladder arrays for simulate moving loops we observed that we could move fish using air bubbles. The effect was observed to be small, but clear. Even in the chaotic environment of a hydraulics laboratory, the effect was observed to be significant and repeatable over many experiments. It makes little difference which direction the apparent bubble curtain was moved. 2 experiments with single bubble curtain and 2 experiments with double herding curtains were conducted and reported on here. The results were plotted in the same way as the previous air curtain experiments (loop pulled). The graph in Figure 6 shows the relationship between the distance of the curtain to the end and the number of fish that were not herd successfully. Both lines are located lower than the “no effect line”, but not as low as the result in the previous experiments with pulled loop. Because the line for the double curtain experiments is closer to “no effect line”, double curtains seemed to result in less successful herding , compare to the result of single curtain.

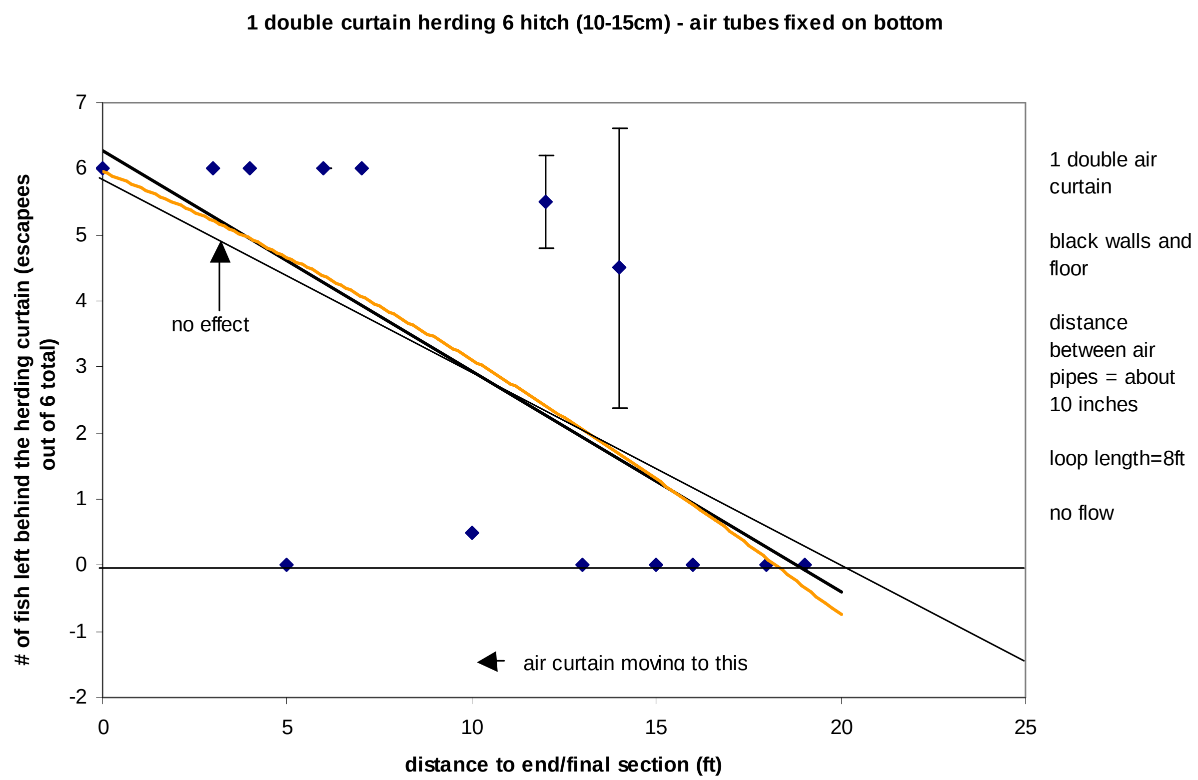
Fish were observed to be mostly in a group and herd successfully about up to the halfway of the flume. They mostly swam in a group, about 2 feet ahead of the herding curtain, up to the point. Then the distance between the curtain and the fish started to decrease when the herding curtain passed the ¾ point in the flume section. Fish would turn around and bolt across the curtain(s) before they got too close to the end. These results are typical behavior of winter run Chinook salmon with the fixed array. In the graph, the top light black line represents the loci of points that would be observed if there were no effect from the bubble curtain. Specifically starting at the end (20’) all the 6 fish would be to the left. As you move down the flume the number of fish at any one point should increase linearly until you reach the point at 0 from the end with all six fish to the right. That is the “no effect” line. This graph integrates two runs with the curtain moving toward and away from one end. It is clear that the fish move out ahead of the bubble curtain and stay there.

Figure 6 Fish Herding Results with fixed air curtain array



In addition to the experiments with winter run Chinook salmon, 2 experiments with double curtains were also conducted with hitch (average SL = 14 cm). The results were shown in Figure 7. The linear line is almost overlapped to the “no effect line”. However,

Figure 7 Hitch Herding Results with Fixed Air Curtain Array

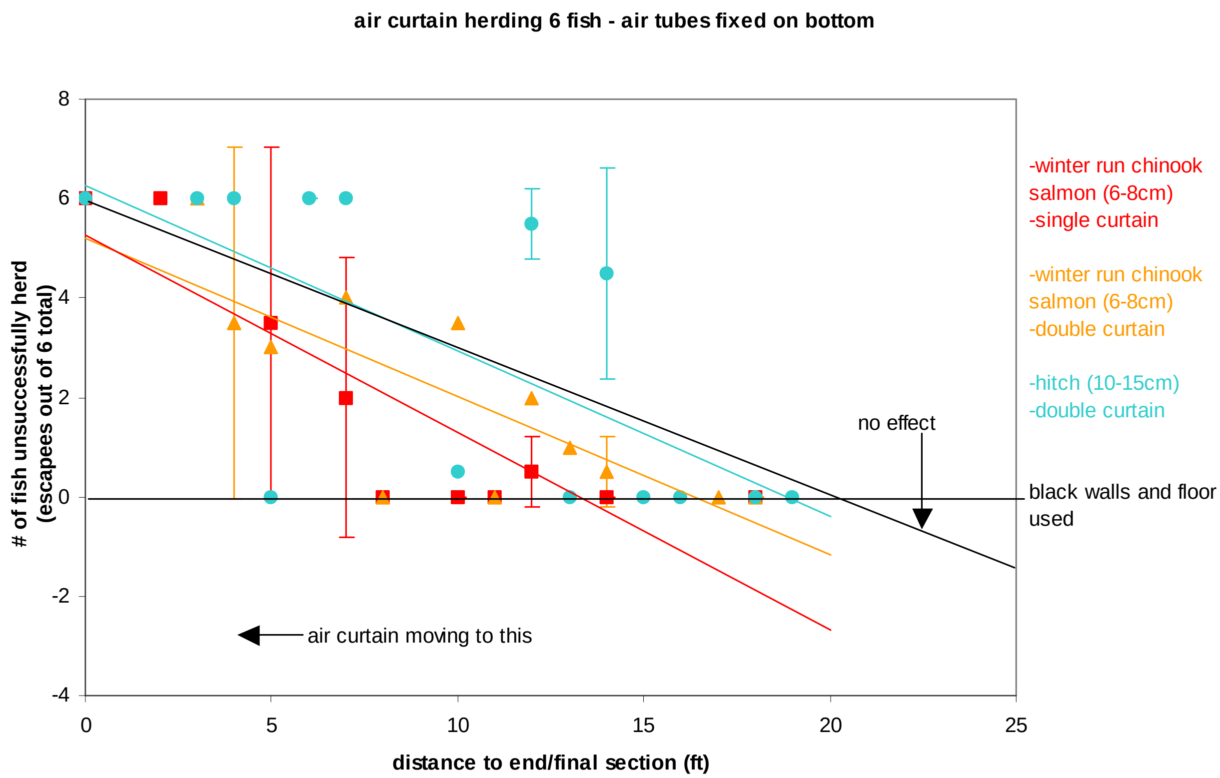


As the air curtain moves from 20 down to 10 feet almost no fish cross the curtain. During the experiments, hitch were swam in a tight group back and forth from one end from the other end of the flume to the other end. They often swam through the air curtains and continued swimming back and forth. They seem less care about the air curtains. Then the effect of the end wall becomes apparent and they bolt as a school shown by the grouping in the top left of the Figure. This was observed frequently. It was easy to observe the fish moving ahead of the advancing curtains of air until they swam in tight circles appearing trapped near the end of the flume, then they would bolt.

Summary

Two more sets of experiments were conducted with Chinook salmon and the results shown along with the hitch in Figure 8.

Figure 8: Summary of Herding with Fixed Arrays



Factors that inhibited the herding behavior were non-natural human movements of the observers and other occasional lab personnel and crowding near any "end" of the flume. Specifically, when the fish were herded in a direction, they would be observed to stay at a fixed position relative to a moving air curtain until the end of the flume loomed, then the fish would bolt back toward the middle of the test area in the flume.

Summary of Observations

Upstream Passage

Small fish were observed to have hard time to swim against the fast flow and turbulence underneath the wheel. We produced no evidence that lower flows would be sufficient to motivate fish to pass upstream. This was true whether or not the wheel was in place.

Larger fish, notably the hitch and the trout, were able to come up beneath the wheel to hide. Some fish swam up in between the floats, but they didn't seem to jump over the floats and reach to the upstream, although they were capable of it physically. Exceptions included only 2 brown trout which repeatedly swam over one float, but never went over the two floats necessary to get upstream. Thus, in some cases, fish spawning fish might be motivated enough to jump over few floats, but the motivation has to be there. Our primary target fish, the Coho salmon simply were not motivated to go upstream over any weir. The question of motivation can be broken down into:

A. a question of motivation to move at all, and
B. a question of overcoming repulsion from the artifice of the wheel.

In the case of the trout and the hitch, they are interested and willing to relocate (A), but not approach the wheel (B). In the case of these salmon at this phase of their lives, they are not willing to relocate at all - and only drift downstream.

Downstream Passage

Note that the entrance to the wheel was through a weir formed by the top of the breast 12" above the flume bottom. Fish were sometimes near the wheel, but almost all the time, they were not drawn into the wheel because they were at bottom-middle depth below the weir. Placing a slope in front of the wheel might help bringing the fish up toward the surface, at the level of the wheel and allow for easier passage. Several of the fish would pass through the wheel, and this might be improved in the field with a larger wheel in all dimensions. However, the utility of a wheel for transporting fish downstream is limited, as fish will naturally pass over a weir. Thus, to the extent that the B effect exists, the wheel will inhibit passage. The A problem exists at all fish passage facilities.

In general, fish mostly stayed away from the wheel during experiments. Some fish did not appear to be motivated to move in the test direction. Some of the fish were clearly afraid of the wheel to an extent that it inhibited any passage, and others were motivated to simply hide under or within the wheel making it appear that they are trying to go through the wheel when they are simply hiding.

Conclusions

This study comes to two conclusions, the first derived directly from the research objectives directly, and a second that was derived from experiments undertaken to overcome during the study of the wheel.

First, from within the original study protocol, we have concluded that moving fish through low head dams using a large water wheel is probably not useful. It does not appear to be kinetically or technologically difficult to pass them through provided they move quickly. The major problem is the behavior of the fish. They are simply not interested in moving into this water wheel, or any similar mechanical technology no matter how proficient it is in passing them upstream. Thus, we conclude that the problems of fish passage are directly related not to the particular technology, but in motivating the fish to enter it.

Lack of motivation for the fish to enter mechanical bypass facilities is identical to what is observed at every fish passage facility on real dams around the world. The fish elevators, fish locks, fish trucks, fish ladders all work – provided you can get fish to go to and into them. Because fish will not approach the particular technology, "Entrance" becomes the path-critical technology rather than the internal mechanical bypass mechanism. To meet this problem, an

increased effort was made to address it, and from that effort, we concluded that moving air curtains can be used to herd fish. The herding effect can be motivated by using numerous curtains following each other in regular patterns fish can be moved. This may prove very valuable when applied to fish at full sized dams. Important characteristics of the technology that needed to be addressed include:
.

- The amount of air creating a fear/attraction of location on response
- The length and shape of the air curtains
- The spacing of tubes that generate the curtains
- The speed of movement of the curtains
- The number of parallel tubes that make one curtain, and
- The pattern repetition rate of the curtains

These factors interact with the characteristics of the fish that are being moved such as: .

- Type of fish
- Age and season of the year
- Conditioning & Experience
- Familiarity with air curtains

One size does not fit all, and the flexibility of the bubble curtain technology has to be matched with the target fish at all times. Luckily, this is easy to do, as only characteristics 2 & 3 are not easily changed under computer control.

Recommendations

The ability to move fish ***to*** the wheel, and more generally to move fish in general to any fish passage technology is becoming a focus of research. The need for fish herding is a pervasive problem that permeates all fish passage technologies share, research on this problem is paramount. Our data suggest that fish herding is possible. Further, the discovered technology of moving air curtains may scale well to field situations. Much work remains. It is unclear that what motivates fish to move is dependent on fish type, age, location, time of day, season, etc. There is a large amount of field experimentation needed to find out how to herd specific fish in specific locations at specific days. Because what will work in one place on one species will not work on another, this work will be extensive. Never-the-less since man has chosen to block rivers and streams, he bears a responsibility to try to mitigate the effect on the environment, and one way to do that is to help the fish around the dams. This research will help show them the way.

Public Benefits to California

Background

Currently, California is faced with removing dams in this state because fish passage is being inhibited. For example, again at Red bluff dam, on the Sacramento River, the gates have to be open for fish passage now from October to May. The water from Red Bluff was used to supply irrigation water to a large number of farmers in the Sacramento Valley who now have to pump water. Currently, plans for complete dam removal are being considered along with alternative plans for having the dam remain open year around if no efficient passage is found for salmon. This will put a large burden on Central Valley farmers and will increase electricity usage in the state significantly.

If fish could pass this dam, which is only about 30 feet high, it would not have to be removed and considerable energy would be saved. This study was an effort looking at the possibility of using a series of smaller Sagebien wheels to pass fish around the dam. What was discovered is that there are good fish passage facilities at this dam, but as with many, the problem is interesting the fish in entering them.

Benefits Already Received From Study

A major benefit of this study is the realization, that fish can be herded to some extent with air curtains like cattle (or perhaps more accurately - cats). The effect of the curtain is incremental, only some of the fish are moved by any one curtain. The key to this technology is that the curtains can be made to appear to move past a point repeatedly thereby herding a large percentage of the fish over time as the result of repeated curtain movement.

Future Benefits

The preliminary results that fish can be herded will be very valuable to California and the world in the future because not only will the result be useful for helping fish around dams. Researchers in designing fish herding facilities at larger dams will save water, power, and fish. The technology might also be useful to help move fishing from open capture of wild stocks, to the partial herding of quasi-wild stocks for ours and the fish's benefit. Perhaps also fish herding will become part of fish capture or an quasi-open fish farming practice where the fish are not constrained by fences, but by migratory patterns that can be used with herding for efficient fish resource management.

Public Benefits / Costs

This is an experimental environmental technology study. To evaluate the economic impact amount of power saved, water supplied, and fisheries enhanced is far beyond the scope of this work. The indirect effects of fisheries improvements and better water use clearly swamp the direct economic effects of increased fish availability.

For this report, Table 4 lists some of the benefits of this technology if it is developed successfully. There are no significant costs other than the air pumping costs.

Table 4 Benefits and Costs of Fish Herding

Benefits at Dams Increase in fish for a given amount of attraction and spill flows at dams . Increase in gravity-irrigation water availability. Increase in hydropower due to reduction in attraction flow usage at hydropower dams.
Other Benefits Possible use in open-water capture. Possible use in helping guide fish past false outfalls. Assistance in Aquaculture and fish farming

Fish Herding Marketing and Development

Marketing & Development

This technology is very easy to market in that there is a pressing need for a technology to work. Presently, the FERC is requiring dams to be removed because they do not pass fish. The "marketing" of this technology will be after a bit more research. It needs to be tried at a full size dam. The problems we ran into in the flumes of people moving around, strange overhanging ends and the artificiality of a flume would be removed. As the technology of fish herding is developed, we will be using it at any interested dams and publishing results.

We have been just issued a US provisional patent on the use of air curtains as primary fish movement devices. The patent has been accepted for filing and is pending. A full utility patent is being applied for. We now intend, as stated above to study the range of applicability of the air curtain herding technology with real fish in real rivers. The research has been discussed with some professionals in the field, and a proposal is being prepared based on this preliminary work. We have discussed the idea with the Bureau of Reclamation and USWFS people at the Red Bluff dam and they have expressed an interest in some tests there if we can find funding. The good part of this technology is that it is economical, portable – does not require concrete, and can be reconfigured easily both for testing and later for different fish.

One of the work products developed here is a research protocol for further work in the Sacramento River. While there is some intellectual property being developed under this research, the main aspects of this work will be in the public interest. We intend to eventually apply it to the Red Bluff dam to assist the salmon of various age classes, the trout and, if possible other species, passing this dam as a test site.

Other Energy Commission Issues

Engineering, technical and most important behavioral issues remain significant. If the next test were to take place at a research site as a tributary to the Sacramento River, the following will have to be determined first:

- What materials will work and be reliable, benign in the open stream
- What fixed tubing spacing should be used and what shape patterns
- What types of fish does this work on, and how can it be modified to work on other types.
- What are reasonable sets of patterns and pattern timing to try in the control program.

Herding fish, like catching fish, is an art as well as a science. Since we are at the beginning of developing this art, it will not be obvious what are the best parameters. These will evolve from observation in the field.

Production Readiness: The simplicity of the technology allows it to be built from readily available materials with field assembly and modification. This is an assembly and control computer technology, not one that requires much special equipment. Thus, the only inhibition to production is understanding how to use the technology most effectively then set up the arrays and do the programming. These problems are not to be underestimated, but their solution is entirely a field research problem.

Endnotes

References

Akiyama S., Arimoto T., Inoue M., *Fish herding effect by air bubble curtain in a large circular tank.* Nippon Suisan Gakkaishi 58(1): 45-48 Jan 1992.

Page

Appendix I – Prony Brake Results.

Page

Appendix II – Fish Passage Data and Results

Page

Appendix III – Herding Results

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Appendix IV –Photographs