Re: Project ID: 35034

Fish Behavioral Guidance Through Water Velocity Modification

Natural Solutions response to the request for a response from the ISRP relative to Mainstem funding project # 35034. What follows after the Natural Solutions initial remarks, are the Comments and Questions from the ISRP Rrgarding Natural Solutions Innovative and Mainstem project proposals:

Goal of the eductor test: "This project is intended to provide a field examinatin of the zone of influence, and magnitude of influence of induced turbulent flow in quiescent water bodies. Flow fields will be provided with the use of venturi eductors of various sizes, orientation and combination. These flow fields will be measured and mapped using a combinationof current meters, doppler acoustic current profilers, GPS equipment, thermometers and other pertinent devices."

Natural Solutions: We would like to thank the ISRP for its constructive review of our Mainstem proposal and for the opportunity to respond. We took the reviewer's advise and contacted Chuck Peven of Chelan County PUD. We provided him with some of our data (video and report of 8" test at Goose Bay) and have discussed this concept over the phone. His response is included later in this document.

We would like to begin by stating that the use of "induced turbulence" for migrational guidance is a recent concept. They hypothesis that a "trail of turbulence" in the quiescent forebay environment of dams could guide fish was made by Dr. Charles Coutant in 1998.

In 1997, Lakeside Engineering conducted experiments at the Penacook Upper Falls Hydroelectric Plant in New Hampshire (Penacook), using water currents to guide Atlantic salmon smolts to a trap in the passage route. (Truebe & Truebe 1999)

More recently, research has been conducted at the Cowlitz Falls Dam. Starting in 1999 and continuing through 2002, induced turbulence for fish guidance has been the focus of research at the Washington Dept. of Fish and Wildlife Fish Program and the USGS Columbia River Research Laboratory.

In their annual report for 2000, they state "To date few field studies have used induced current to guide juvenile salmonids." (Darland, et al. 2000)

Dr. Rollin Hotchkiss of WSU is currently engaged in research in fish preferential swim paths. He states "First of all, I must say that I am no expert on what makes juveniles respond favorably. We are still in the testing stages of our work, and our results are preliminary. I cannot reveal results we have achieved at this point because they have not been checked and cleared with my co-principal investigators." (R. Hotchkiss, personal communication)

The point we are trying to make is that this area of research is so new that there is only preliminary data available. Field tests at Penacook and Cowlitz Falls Dam show that fish can be guided by induced turbulence. How they are guided or what they "cue on" is still in question. The following except from the annual report for 2000 "Evaluation of Directed Flow to Improve Fish Guidance for the Surface Collection Program, Cowlitz Falls Dam," illustrates this need. "Our study provides evidence that appropriately scaled turbulent plumes can guide fish; however, much remains unknown about the response of juvenile salmonids to turbulence. (pg. 32 Darland, et al. 2000)

It is the primary focus of the Natural Solutions proposal to bridge this information gap. By providing ADCP "current profiles" of turbulent plumes or "flow fields" and the velocity vectors within those plumes or "flow fields" we can begin constructing an engineering platform for future system design. This is the purpose of Year One testing.

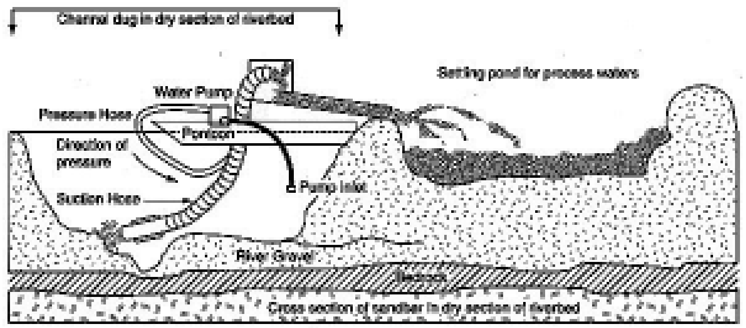
In Year Two, the biological "field testing" will provide information on where smolt travel in these turbulent plumes or "flow fields" and this information can be overlaid on the "flow field" profiles to determine if there is an area and/or velocity that smolt prefer. This data can be produced for each species to aid in design and deployment in the future. Year Three would be confirmation of the "field test" in Year Two. Without the baseline understanding of the flow fields or turbulent plumes, field tests would conclude, once again, that they can be used to guide fish, but provide no understanding of HOW.

We would close this part of our response by stating that this appears to be an opportunity to collaborate with researchers and develop a means of applying the results of research as data is generated. This would result in reduced development time and reduced deployment time for a savings in fish and revenue.

In January 2001, we did an extensive Internet search for dredge manufacturers. Using the four largest search engines, we found the following manufacturers:
Crisafulli Manufacturing — Glendive, MT
Dredge Masters International, Inc. — Hendersonville, TN
Ellicot International — Baltimore, MD
Freivokh Technologies — Holland
Damen Dredging Equipment, Inc. — Mt. Juliet, TN
VMI, Inc. — Cushing, OK
Keene Engineering — Chatsworth, CA
Gold Divers — Mound House, NV
Gold VAC (Dalyn Enterprises) — Bradshaw, NE
Pro Line — Auburn, CA
Only the last four — Keene Engineering, Gold Divers, Gold VAC, and Pro Line — manufacture venture eductor dredges and of these only Keene Engineering provides one over 5" diameter. Their largest production dredge is 8" diameter, and in the past has custom designed several 12" diameter dredges.

Natural Solutions: Venturi pumps have a history in dredge mining and are often referred to as suction dredges. In that industrial application the suction end of the eductor is used to "vacuum" materials off the bottom of streams or sea floors. The discharge end of the eductor is connected to a discharge pipe and the slurry of sediment and water is transported via pipe to another location for processing. Because the zone of influence is small the suction end is fitted with tubing and extended to near the materials of interest.

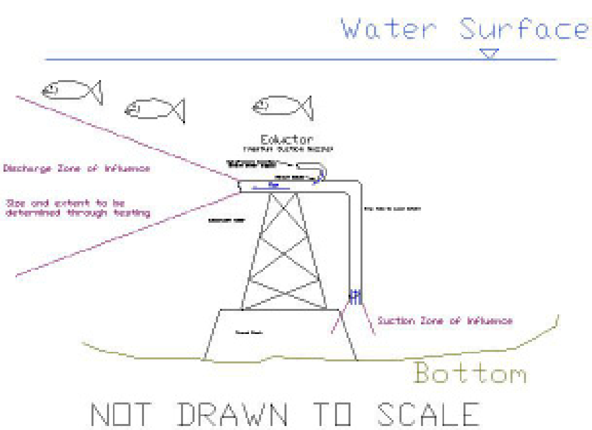
Operating the Dredge on a Dry Sandbar



Because of the nature of their traditional use the available engineering data addresses parameters in terms of traditional uses. Engineering parameters include suction developed, materials per hour moved, materials lift height, and discharge distance in an enclosed pipe. For example the following was taken from manufactures web page.

"Three Inch Jet Reclamation
Dredging System
Model RDS3

Designed for small projects. Dredge sand and silt to a maximum distance of 150 feet with a lightweight portable system. Move up to 3 cubic yards per hour. Powered by two 8 HP Honda or Briggs Engines directly coupled to our powerful P285 high pressure pumps. Equipped with a 3 inch twin jet-power jet for maximum output, 150 feet of 3 inch suction hose, 2 each 10 foot sections of pressure hose which attach to a powerful jetting system, 2 foot valves with hose assemblies and a swivel suction tip. Equipped with all necessary

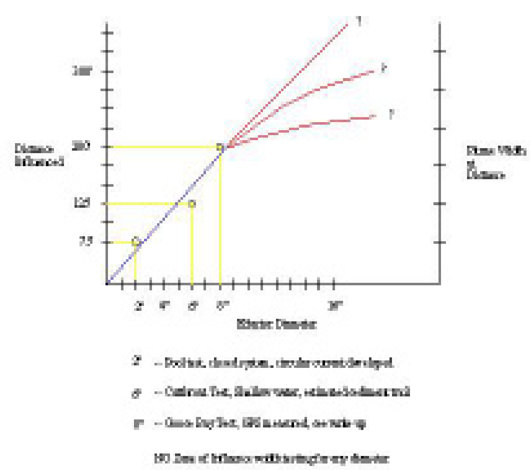


The Natural Solutions proposal would retain the suction hose to move the intake water to locations which would have less migrating fish and therefore minimized fish entrainment and possibly cooler waters. Unlike traditional applications of eductors, fish guidance applications only move water not a slurry of water and materials.   While traditional uses focus on the suction side of the system as the "business end" of the unit, the Natural Solutions proposal views the discharge side as the "business end". Moving water with eductors to create conditions for moving or guiding fish is a new application with new challenges and parameters of interest.

Defining and measuring all of the important parameters is the first goal of this funding proposal. Collaboration with researchers in the relatively new field of induced turbulence to design, deploy, and field test for biological response of migrating salmonids is the ultimate goal.

Suction side parameters are still important. What is the flow field generated by eductors ranging from 4" to 16" in size? With our field experience to date with an 8" eductor that flow field is only a few feet. To fully understand and delineate that zone of influence we propose using a variety of water measurement tools (current meters and ADCP) to map that flow field.

Discharge side parameters are very important. They are the focal point of our proposed initial investigations. Mapping the discharge plumes created by a range of eductor sizes is a fundamental goal of this proposal. Given traditional applications, there has been no need for this data and it does not appear in the manufacturer's data we have reviewed. Natural Solutions has created the following graph based on field experience to date.



To date Natural Solutions has done some preliminary testing on 2”, 4”, 6” and 8” eductors. (See report by Johnson, Burns and staff - May 31, 2002, and accompanying video). However, the scope of these tests is preliminary and was limited by available resources. Still, based on those observations and measurements these relatively small units are capable of altering water particle velocity at ranges of up to 200 feet or more (8” unit-Goose Bay Test).

We believe that larger eductors will have ranges up to 600’ or more. However, range alone is not the only parameter of importance for designing fish guidance systems. The entire discharge zone of influence needs to be mapped. Intuitively and based on our in field observations, we believe that zone will be generally conical in shape. Water surface effects such as wind and wave action will influence the actual shape as will bottom surface conditions such as contours and substrates.

We have observed flow fields develop from operating eductors in quiescent water bodies. Surface boils and whirl pools develop. The discharge fluid leaves the eductor at velocities in the 10’/sec to 12’/sec range. However, within a short distance (20’ or less) the velocities decay rapidly as energy of the eductor discharge water is imparted to the previously static waters of the Lake or Reservoir. This energy exchanged is dynamic, and visible pulses occur in the surface turbulence and in velocity meter readings. Shear zones develop, decay, and shift from location to location. Directional vectors fluctuate. The flow field in very complex. The Natural Solutions proposal will examine such flow fields with state of the art water measurement tools. It is unlikely that a full mathematical description of such a flow field will be delineated; that is not the goal of this project. The goal is to look for general patterns that can be recreated for the purposes of fish guidance. Much like engineers develop a head and discharge curve for a standard pump through testing, our goal is to develop a zone of influence map for a range of eductors. This will provide the engineering platform that is sorely lacking.

This research is not intended to develop fish velocity prefernce data. We agree with the ISRP asseement that significant amounts of such data already exist. Migrating fish likely have a volocity preference that varies by size, species, and level of smoltification. The intent of our research is to not recreate such biological research. Our goal is to create a venturi eductor based system that will provide the conditions conducive to guide fish to safe passage or other locatins. eductor pumping to create velocities conditions that guide fish to safe passage routes or other desired locations. The ISRP raised legitimate concerns about determining if fish response would be negative (adverse- repulse) or positive (attraction). We believe that some elements of both will occur. Only field testing will provide this answer.

Personal communications with Dr. Rollin Hotchkiss (WSU) and observations cited by Truebe and Truebe suggest that fish tend towards the shear zone or that mixing zone between quescient water and current. We believe that our systems will create such interfaces that are desireable and thus form a positive attraction for fish. We also believe that higher velocity areas, especially those regions near the eductor discharge and for a limited distance down the centerline of the flow field will repulse fish. However, such high velocity areas will be generally buffered or surrounded by areas of slower moving water. Thus, over a wide range in the zone of influence, fish will have the option of moving into the zone to a point at which they feel comfortable, but will unlikely proceed farther. In our view this is a two pronged approach to guidance. Furthermore, because a velocity continuum will exist, systems are more likely to work for a wider range of species.

Additionally, under stratified water conditions and with the use of drop tubes on the suctions side, thermal effects will also be present in the zone of influence. Mapping thermal mixing and thus thermal zones of influence will also be possible under the Natural Solutions proposal. Seasonal thermal changes may provide yet another guidance motivation for migrating fish.

The ISRP raised legitimate questions regarding eductor sizing, numbers of eductors, and spacing. They have literally hit the nail on the head with the intent of this research. The goal of this proposal is to define the zone of influence of a range of eductors and to create the engineering base needed to answer just those questions. It may be possible today to learn with radio tracking data that a group of fish enter a hypothetical forebay primarily on the right bank, generally distributed across a 50 to 150 meter swath, at a depth of 3 to 15 meters. If the safest passage route is on the left bank with an entrance of 15 meters wide by 5 meters deep, how do you get the fish to find it?

Traditional approaches have been "suction" oriented. For example, the spill bay openings

ISRP: Fundamental questions from the ISRP review of the Innovative project: Would the implementation ultimately prove safe for juvenile salmon and other fish?

NATURAL SOLUTIONS: It is true that there is potential risk to juvenile salmon and other fish. Our goal is to identify and then minimize the risks associated directly with our system. The eductor tecnnology that is the heart of our system has a suction side and a discharge side. Internal velocities in the eductor can be very high (varies with size). Velocities at the suction side may exceed the burst speeds of migrating fish and entrainment is possible. Velocities on the discharge side have been measured in the10'/sec to 12'/sec range on smaller eductors (2" to 8" diameter). However, the discharge velocities dissipate over relatively short distances (relative to the entire zone of influence) and are buffered by the entrainment of additional water from the static zones around the eductor. Energy is imparted from the discharge water to the static water creating a flow cone with higher velocities in the center and progressively lower velocities towards the exterior. The full magnitude of the these velocities and the full zone of influence is not currently documented. The goal of this project is to measure and map the velocities throughout the zone of influence at both the suction and discharge ends of the eductor. Until such mapping is complete the full risk cannot be defined.

Mitigating actions can also reduce the risk to fish such as adding a drop tube to the suction end of the eductor and withdrawing water from deep in the water column where densities of migrating fish are much lower.

Preliminary tests on 3" to 6" westslope cutthroat trout were performed in a Montana pond. [See Brian Marotz response to preliminary review of Mainstem project.] These fish were chosen because of their size and availability. Fish were delivered to the pond directly from the hatchery. From a total of 1000 fish, 800 were bucket dumped around the perimeter of the pond. The remaining 200 were dumped in a shallow pen. From that 200 fish, 100 were recaptured with a dip net and carried to the eductor site in a five-gallon bucket. They were then poured into a smaller bucket and then poured through a 4" pipe directly into the suction side of a 6" eductor. Mortality for pond released fish was 3. Determination of the mortality for the 100 control group was compromised by cattle damaging the pen and releasing the control group into the pond. Prior to this release, 1 dead fish was retrieved from the control group within the first 24 hours. Mortality for the eductor transported fish was 8. Fish that passed through the eductor were observed orienting in the induced current and feeding within minutes of passage.

Similar, more robust tests need to be performed before final risk determinations are made, but initial observations are very promising and suggest that direct eductor passage risks are not excessive.

Finally, any risk associated with velocity guidance needs to be compared to risks associated with conventional passage, including spill, which is a physical risk to individual
fish, and gas saturation risks to the host of species in the river environment. The goal of this project is to find a net reduction in risk to fish passing hydro projects.

ISRP: How many of these eductors would be needed at the entrance to the typical forebay?

Natural Solutions : This is a site specific but worthy question. The intent of this project is to develop the baseline information of zones of influence for a range of eductors sizes. Current mapping and subsequent deliniation of the full zone of influence will provide system designers the tool required to place single and arrayed systems of eductors. Site bathymetry, existing velocity profiles, and radio tracking data for existing migration patterns will also influence the placement and number of eductors.

ISRP: How far downstream would the velocity enhancing effect of the eductor jet last?

Natural Solutions: Downstream velocity effects as well as the width of the zone of influence and the distribution of velocity throughout the zone of influence are the parameters of interest that this project intends to measure and map. Preliminary data using simple current meters found that an 8" eductor is capable of enhancing velocity over 200' downstream of the discharge side of the eductor. This is very encouraging and should be contrasted to recent flow field mapping on the surface weir at Lower Granite, which had a zone of influence upstream of only 60'. We believe that our system will have a significantly greater zone of influence per unit cost than spilled water and will have more design flexibility.

ISRP: The lack of information on the safety of this method of increasing water velocities for juvenile salmon is indicative of the general lack of biological criteria for development and operation of the appliance. The proposal needs to demonstrate further interaction with fish biologists familiar with the issue.

Natural Solution: We recognize our limited biological experience and incorporated the

ISRP advice by expanding biological review of our proposals. We have included Brian Marotz (Montana Dept. of Fish, Wildlife and Parks) and Dr. Alexander Zale (MSU) as consultants.

ISRP: The lack of information on how eductor-based passage devices would fit into the forebay of a Columbia River low head dam may be indicative of a shortage of hydraulic physics and engineering content in the proposal. Figures are sorely needed to show the layout and positioning of project components (eductors, etc) for both a theoretical (or actual) fullscale forebay and for the prototype testing.

Natural Solutions: Mapping of the hydraulic flow fields is the intent of this proposal. Traditional uses of the eductor technology are significantly different than the proposed application and thus no data has been found in the literture reviewed that answers the question "What is the zone of influence on the suction and discharge end of an eductor?" While modeling may be an alternative to physical measurement, the results of modeling are only as reliable as the assumptions made in the modeling process. Actual field testing helps solve three issues: (1) provides baseline expected conditions or calibration data for future modeling efforts; (2) allows for deployment issues to be identified and resolved; and (3) provides actual flow field maps for review by biologists and others who design fish passage systems.

*QUOTE FROM DR. HOTCHKISS

ISRP: The issue of scale needs to be addressed: what might be the size and cost of pumps and eductors needed to produce enough hydraulic change to be meaningful to fish. The proposal gives a tantalizing view of what might be accomplished, but it does not go far enough to allow evaluation of the chances for success. The proposal is too preliminary to be competitive.

Natural Solutions: Testing to date has been on relatively small, but possibly still applicable. Sizes of eductors include 2", 4", 6", and 8" units. Changes of velocity and zones of influence were significant and extended as far as over 200'. Given that surface weirs at Lower Granite had flow fields less than half that size and still appear to have influenced fish, we believe we are in, or approaching applicable scales. Natural Solutions is currently constructing a 16" eductor for testing. It is possible to envision an arrayed system of various size eductors that create a combined series of flow fields that extends several hundred yards upstream from a potential passage route. Costs of operations would be in terms of 10's to 100's of horse power for the entire system. As a comparison, if a project is currently spilling 100 MW of energy, which could replaced with a 10 MW eductor array, a very large flow field could be created at a significant annual savings and possibly a major reduction in gas levels in the river. We expect final designs in this range of magnitude for projects the size of the Snake River dams.

*Refer to responses to Mainstem review.

ISRP: General, non-task specific comments. An important technical point is the ratio of motive water to effluent water, said to be 1:5 ? 1:6 for a four inch eductor tube used in dredge mining. The actual ratio of motive:effluent in the example of the proposal for application to juvenile salmon is 1:7, i.e. 6400 gpm motive flow to produce 44,800 gpm effluent flow. 44.8/6.4 = 7.0

Natural Soulutions: We stand corrected with regard to our initial information on motive to discharge water ratios. The initial rules of thumb used were incorrect and overstated the ability to move water. Tests conducted by Natural Solutions suggest that a 1:3 ratio is a better approximation. Specifically, for each unit of motive water, three units of total discharge leave the eductor. This is the combined flow of one unit of motive water plus two units of venturi induced flow. This illustrates in part also why the zone of influence of the suction side is significicately less than the discharge side. However, it should also be noted that the discharge water imparts energy to previously static water in the forebay. We observed the zone of influence in Goose Bay from an 8" eductor. Static water on the lateral margins begins to accelerate down stream in response to the eductor discharge. The interface of these two zones of water creates interesting turbulence including whirl pools and surface boils.

ISRP: The proposal's use of the term "thalweg" is confusing, substituting "thalweg" in place of term, "thalweg flows." For example, the statement in the proposal incorrectly equates bulk flows with thalweg, "the hypothesis that bulk flow or thalweg can be generated in the far & intermediate fields of forebays ." (Section e. Proposal objectives, tasks and methods, Objectives, first para.) A thalweg is the line defining the lowest points along the length of a river bed. Water particle velocities and turbulence are typically maximized in this part of a river, hence the interest in, "thalweg flows," and "thalweg velocity" in relation to juvenile salmon migrations. Thalweg is not a synonym for "bulk flows."

Natrual Solutions: We recognize this semantic distinction and have corrected our use of the terminology.

Comments: Task (A) 2002 - 3D Profile the Zone of Influence of Venturi Eductors.

ISRP: What sizes of eductors are being tested? The proposal states, "These tests will be performed with each eductor size, " but this paragraph contains no information on what size eductors are being tested.

Natural Solutions: We will test a range of sizes, including 2", 4", 6", 8", 16", and 24".

ISRP: Why are the eductor tubes initially being tested from locations on the bottom [of the test reservoir] up? The region of interest for juvenile chinook is from the top down, with the likelihood function of finding fish with depth being something like a Poisson shaped curve with its mean (depth) depending on the race (stream or ocean) and state of maturity.

Natural Solutions: The intent of testing is to evaluate a variety of mounting depths and orientation. The sequence of testing can be scheduled to meet criteria as defined by the biological team.

ISRP: What will be the size of the hydroacoustic "dead zone" adjacent to the air-water interface and the water-bottom interface? The "dead zone" is where the noise generated by reflection of the hydroacoustic signals from the ADCP renders interpretation of observations from this instrument problematic at these depths.

Natural Solutions: Current meter and ADCP limitations will be addressed with the aid of specific equipment manufactures.

ISRP: What is the range of the vertical scale of the data describing the zone of influence (i.e. does it start at zero depth, or at some point below the surface dictated by the limitations of the ADCP?).

Natural Solutions: Vertical measurements will match the zone of influence. A continuum of measurements will be made to profile from as near surface as possible given equipment limitation to as near substrate as possible given equipment limitations. Specific equipment manufactures will be consulted to determine strengths and weakness of each measurement devices.

ISRP: Will the values used to describe current vectors in the "zone of influence" at the surface (air-water interface) be actual measurements, or extrapolations?

Natural Solutions: Exact boundary layer conditions will not be quantified in this test. Video recordings, die tests, and near surface current velocities will be measured as allowed by equipment limitations. It is envisioned that the zone of influence can be broken into a family of cubes or cells and the average conditions for these cells measured. The exact size of the cells has not been determined and Natural Solutions welcomes further ISRP and equipment manufacture input on this issue.

ISRP: Why are current meters not being employed to augment the ADCP for surface current measurements?

Natural Solutions: We have modified our original innovative projects proposal to incorporate current meters as suggested by the ISRP.

Task (B) 2002 - Determine the parameters of eductor sizing, efficiency, spacing and ability to replicate bulk flow.

ISRP: What is known about the physics and engineering of large venturi eductors?

Natural Solutions: Product specifications for commercially available venturi eductors focus on suction created, materials load per hour, suction head, and discharge distance of slurry in an enclosed pipe. Manufactures we consulted had not done open water tests of the type proposed by Natural Solutions because the proposed use is non-traditional. Data likely exists on orifice flow and throat conditions and may be useful in assessing risks to passing fish.

ISRP: What are the likely problems of scale?

Natural Solutions: There may be problems of scale for building larger and larger eductors. Mining application eductors tend to be in the 2" to 8" size range. The largest mining eductor we discovered through an exhaustive search was 12" in daimeter. Motive water to total discharge ratios may change and thus efficiency losses may occur. Other issues may exist. One focus of Year One testing is to identify and quantify these parameters.

ISRP: Is there a theoretical concept (equation) or rule of thumb describing how power/ pumping capacity requirements increase as a function of eductor diameter to guide the engineering work?

Natural Solutions: There are engineering equations to describe the theoretical concepts associated with nozzle velocities, orifice diameters, eductor length, suction developed, and total discharge. Available engineering data will be gathered and competent, experienced engineers consulted as needed if larger eductors are constructed.

ISRP: Could juvenile salmon be attracted by the flow net created by pumping motive water from the river?

Natural Solutions: Motive water intakes could cause small zones of influence and attract migrating fish and debris. These areas will also be mapped to determine their size. Self cleaning screens will be pursued as needed.

ISRP: Would the motive water intakes need to be screened?

Natural Solutions: Most likely yes. See above.

ISRP: Would current velocities created by pumping near the motive water intake ever exceed the maximum burst swimming speed of a juvenile salmon?

Natural Solutions: See above.

Task (C) 2002 - Design and Build a Prototype Environmental Eductor for Deployment and Testing.

ISRP: What are the engineering and biological criteria that would be used to judge whether it is reasonable and prudent to proceed with the large bore prototype? For example, if x describes the distance along a horizontal line perpendicular to the direction of thrust in a cross section of the "zone of influence", and v is current velocity, what values of dv/dx are biologically unacceptable? Practically speaking, at what rates of change in velocity with distance are shear forces sufficient to cut the smolt into pieces?

Natural Solutions: Cutting force or water knife effects are most likely to occur inside the eductor unit. Maximum velocities will occur at the nozzles of the motive water. As noted in responses elsewhere, intakes will be sited to avoid vacuuming in migrating fish. Testing on a 6" eductor showed a very high survival rate for entrained fish. Further testing is warranted across a range of eductor sizes and fish species.

ISRP: Could this project create a "water knife' that would kill smolts that came within range? If it could have been shown that the domain of dv/dx does not include values considered lethal, this would have been a big selling point for this proposal.

Natural Solutions: It is our intent to map produced velocities to determine maximum velocities and maximum velocity gradients. Our observational experience is that near the discharge velocities are in the range of 10'/sec to 12'/sec and decay rapidly as energy is imparted to the surrounding waters. After a zone of influence "develops" after initial start-up, there appears to be a buffer of slower moving water around the high velocity area. Again, the intent of the proposal is to map and define these parameters.

ISRP: Questions regarding potential deleterious effects of the technology on survival of juvenile salmon are raised in the proposal but not answered. Some examples follow. Quote from the paper, "Since there are no moving parts in the eductor tube, gravels (or fish) can pass through the eductor without damaging it ? or in the case of fish, damage to themselves." (About Venturi Eductors, second para.) Comment: Moving mechanical parts are not the only things capable of creating physical forces that can injure or kill juvenile salmon. Hydraulic forces such as cavitation and shear can also kill or injure.

Natural Solutions: The above reponses recognize the ISRP comment. Our intent is to map or measure the effects. Direct entrainment tests on cutthroat trout are promising for the smaller 6" eductor, but need to be refined and performed on larger units with other species. Also, the risks of direct entrainment can be mitigated with drop tubes to areas of lower fish densities. The risks of eductors need to be reviewed in a tradeoff context to the risk of turbine passage or gas supersaturation.

ISRP: Quote from the paper, "(2) The extreme velocities produced at the center of the "zone of influence" will cause smolt to shear way, not be entrained, and thus serve as a velocity "curtain"." (Venturi Eductors, third para.)

ISRP: Quote from the paper, "Since the mining industry has largely been concerned with the amount of suction produced, no one has prepared graphs or flow charts for the discharge side of the eductor: hence, the purpose of this project. About Venturi Eductors, third para.) Comment: The data from the discharge side of the eductor should be used in conjunction with biological information already available to develop criteria for deciding if development and application of a big bore eductor would have the desired positive effects on the survival of the juvenile salmon.

ISRP: How much effluent flow would be needed at a typical far field forebay location?

Natural Solutions: We believe that once the zone of influence for a range of eductors is mapped, that a "tool kit" will be available to design conditions preferred by fish. Deliniating the actual fish preferences within the scope of this project are being addressed in other venues by other researchers. What is important is that as fish preferences are defined that a complementary suite of tools are available to create conditions that meet those preferences. The goal of this project is the development of flow field mapping for a variety of eductor sizes and then collaboration with biologists to "tune" a system to guide fish to safe passage routes.

ISRP: What fraction of the average flow of the river in question is 100 cfs?
Natural Solutions: We believe that fish experience the conditions in the immediate area around them. Traditional fish attraction approaches that express the bypass flow as a function of percentage of river appear to us to rely on velocity flow fields developed by divergent streams of water. Our approach is to input energy into the system to accelerate water to create velocities to which fish respond. This should allow for passage guidance with smaller than traditional volumes of water.

ISRP: This raises the question of how many of these Venturi eductors would need to be placed in the far field forebay to have the biological effects intended. Conversions to cfs are as follows: 44,800 gpm is 99.83 cfs is about 100cfs. 1000gpm = 2.233 cfs, so 44,800 gpm = about 100 cfs. Approx = 1:7 ratio of motive to effluent flow.

Natural Solutions: The intent of the proposal is to directly tied to this question. While current experience suggests that an 8" eductor can influence velocities out to 200' or more, the actual number of eductors needed is a function of existing current (bulk flows), river bathymetric conditions (thalweg), historic radio tracking data, and passage orifice location. Mapping zone of influence of larger units and arrays of influence should help complete the puzzle to allow a final system design.

ISRP: Would flows of 100 cfs be sufficient?

Natural Solutions: While reluctant to comment on flows until flow fields are mapped and velocities are chargted, we can comment on water influenced by an 8" eductor. In the field test at Goose Bay, using an 8" eductor, 510,000 gallons of water were affected. See complete response under Mainstem comments.

ISRP: Would more than one eductor of this size be required?

Natural Solutions: This would be a site specific determination.

ISRP: What is the practical limit on the size of venturi eductors, i.e. how much bigger than 48 inches in diameter can Venturi eductors be constructed?

Natural Solutions: We do not have a definitive answer to this question at this time. However, consulting with Keene Engineering indicates that the amount of, and pressure of, motive water is the limiting factor.

ISRP: Are there Venturi eductors as large as 48 inches in diameter in operation today, or have there ever been historically?

Natural Solutions: Our Internet search and conversations with manufacturers has not yielded evidence of such large eductors. The value of large eductors needs to be weighed against the performance of arrayed smaller eductors.

Task (D) 2002 - Physical Testing Prototype Environmental Eductor - With and Without Engineered Induced Turbulence.

ISRP: What biological criteria are to be evaluated during testing of the prototype?

Natural Solutions: Step one is to determine the conditions in the zone of influence and compare that with fish preferences. Step two is to design a "tuned" system with the aid of biologists. Step three is to deploy a tuned system and measure fish response to the system during on and off conditions. If fish guide to the desired location when the system is operational it will indicate the potential of the system as a fish guidance tool.

Task (G) (2003) - Evaluation of Natural Like Bypass Inlet and Demonstration of the Behavioral Guidance System's Ability to Entrain Smolt. Comment: This needs to happen long before step G.

Natural Solutions: We believe that a natural like bypass inlet has great promise and we are progressing in designing such systems. The ultimate success of any bypass is the ability to guide fish to the entrance of the bypass and hence our decision to focus initial efforts on the eductor induced guidance system. The system also has application at sites where a bypass may not be feasible. Deployment of the guidance system at a project that now relies on large levels of spill has the potential to reduce the required levels of spill and save significant amounts of money on an annual basis. Such savings could finance construction of bypass facilities.

ISRP: The project has some other drawbacks as well. The work will take place in Montana where there will not be access to migrating salmon or the dams where problems in passage are proposed to be addressed. It is proposed for two years, whereas the request for proposals specifies a limit of 18 months unless sufficient justification is given for a longer study period.

Natural Solutions: Our logic for physically mapping systems initially in Montana was to reduce the size of travel budgets. Furthermore, testing in non ESA fish bearing waters reduces permit requirements. Provided budgets are flexible we are willing to consider testing at any and all sites recommended by the ISRP.

8/2/2002 (preliminary) recommendation: Fundable only if response is adequate
8/2/2002 comments A response is needed. There are still issues that need to be addressed from the innovative review.

Natural Solutions: We have attempted to extract all specific and explicit questions from the Innovative review and address them above. The following are responses to questions and comments in the Mainstem review.

ISRP: The potential value of this concept might be in the creation or enhancement of attraction flows at surface collectors or other bypass systems currently under development at dams in the Columbia Basin.

ISRP: Biological information already available ought to make it possible to develop criteria for deciding whether development and application of a large bore eductor would have the desired effects on guiding juvenile salmon. For example, tests of surface collectors at Rocky Reach Dam as well as Lower Granite and Bonneville dams probably have

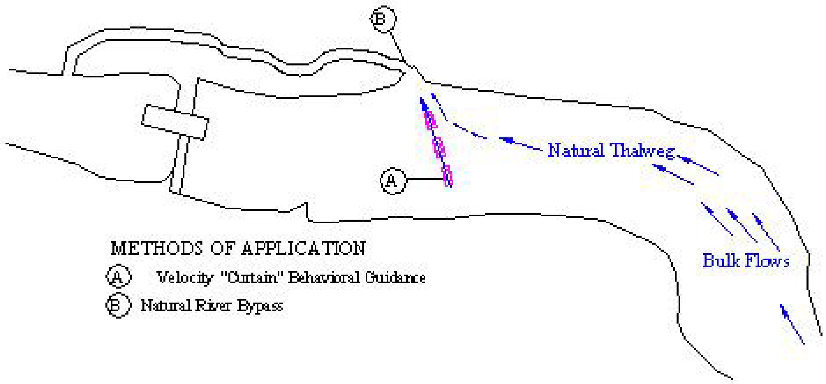
developed information on volume and velocity of water required (or that are inadequate) to attract juvenile salmon away from the turbine intakes and direct their movements elsewhere.
Natural Solutions: We agree that biological data currently exists that sheds some insight on fish preferences. We understand that further work is being done to delineate how fish use turbulent bursts, shear zones, and velocity gradients. Our work should be viewed as a parallel process to define what flow fields can be created in forebays and elsewhere. The goal of our work is to create the hydaulic tool box of eductor and eductor arrays that biologists can use to create the conditions preferred by fish. Mapping flow fields in an important step in this direction.

ISRP: How would the eductor-based passage devices would fit into the forebay of a Columbia River low head dam?

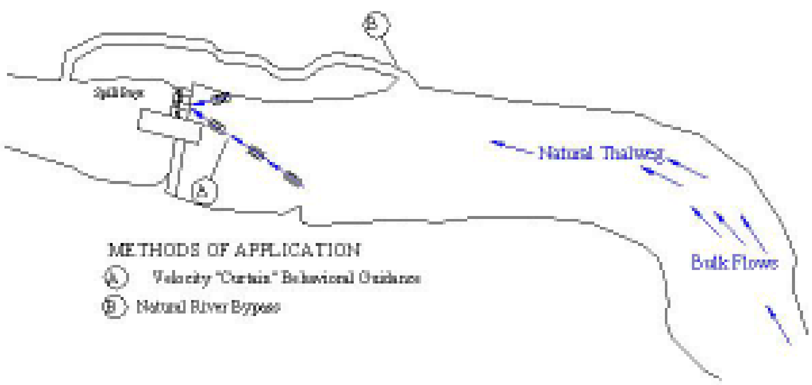
Natural Solutions: Eductor-based passage devices would be used to create currents in the forebay that direct fish to safe passage routes. These would be currents with turbulence, surface boils and other complex patterns that compare favorably to natural river conditions. Actual placement locations could be designed based on the many interacting variables associated with fish migration.

Some of these variables would be telemetry tracking of the normal migratory path into the far forebay, bathymetry maping of the forebay, and existing hydraulic conditions in the forebay. Using this information and the flow field engineering data generated in Year One of this proposal, combined with the information provided by biological testing of preferred fish paths, an eductor or eductor array can be designed to induce currents of sufficient magnitude and direction to guide fish to safe passage routes.

ISRP: Show the layout and positioning of project components (eductors, etc) for both a theoretical (or actual) fullscale forebay and for the prototype testing.

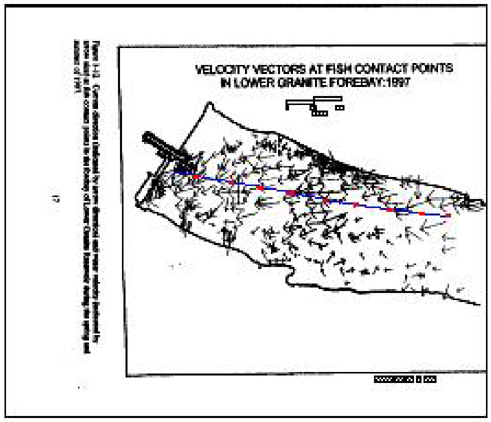


Velocity Enhancement System --Guidance to Alternative Bypass



ISRP Sample one and ISRP

Velocity Enhancement System --Guidance to Single Spill Bay



Sample Array of 16" Eductors
Spacing Extrapolated from 8" Size
Hypothetical Placement in Response to ISRP
Assumes directed to spillbay
Illustrative to show relation to existing fish paths

ISRP: Address the issue of scale: what might be the size and cost of pumps and eductors needed to produce enough hydraulic change to be meaningful to fish.

Natural Solutions: Prototype testing to date suggests that flows can be generated for a distance of 210' with an 8" eductor (see field test report - Goose Bay) The amount of water influenced by this eductor is considerable as the following calculations demonstrate. Please not that although the flow field is generally conical in shape, the depth of Goose Bay did note allow the full development of this cone. Because of this, these calculations are based on a triangular shape.
Flow Field length was 210'
Flow Field width was 50'
Average depth was 13'
210' long x 50' wide = 10,500 sq. ft
10,500 sq. ft divided by 2 = 5,250 sq. ft
5,250 sq. ft x 13' deep = 68,250 cu ft
68,250 cu ft x 7.48 gal = 510,510 gal

However, volume and velocity of water alone may not be the only criteria for developing a system. Dr. Rollin Hotchkiss of WSU states "It may be that a series of 2" eductors are much more effective than a 24" or larger eductor. Our results, coming out now, but too late for your response, may be useful to you." (R. Hotchkiss, personal communication)

This is why we have a Year One budget item in our proposal for a review of the flow field data generated by researchers and biologists working with induced turbulence. We believe it is necessary to combine our engineer data with their research to produce a cost effective as well as effective means of guiding fish.

The issue of cost and sizing of systems is a little more difficult to answer. Because pump pricing can have a wide range, depending upon design specs, and given that deployment systems will vary according to site condition, firm costs are difficult to arrive at. Another factor that influences pricing is the material used for the eductor. Stainless steel would be far more expensive than steel tubing. However, we will try to "guesstimate" a cost.

Eductor size	Pump req'd	Cost	*Daily cost to operate
8"	Godwin GSP 300 HV 30 HP	$34,000	$13.50
16"	Godwin GSP 800 HV 80 HP	$113,000	$36.00
32"	Simflo VST 200 HP	$233,000	$90.00

*Daily cost to operate is calculated on the present cost of power @ $25/MWH

This pricing does not include the cost of deployment or the cost of providing power to the submersible pumps. Pricing can also be affected by the use of a single pump to provide motive water to an array of smaller eductors. There are a large number of variables that can affect the cost of an eductor based guidance system.

ISRP: Is fish behavior going to be positive or negative to this attraction?

Natural Solutions: We believe that fish response will be both. The cone of influence will have highest velocities in the center and progressively lower velocities radially outward. The closer to the eductor, the more extreme the gradient. Fish that enter the zone of influence have the opportunity to enter as far into the cone as desired until a preferred velocity and/or turbulent level is found, this would be a positive attraction. If velocities or turbulences that exceed fish preferences are encountered deeper in the cone, no further entrance would occur and negative responses would take over.

Other factors such as temperature gradients may exist as well, especially if suction tubes are placed at depth to take advantage of thermal layering. This may also produce positive attraction under seasonal conditions.

Noise at the eductor and at the motive water pump may give negative cues to fish and repulse them from the highest velocity and suctions zones.

ISRP: The proposed use of cutthroat trout for tests of efficacy of the device or concept is not appropriate for a test of potential application to problems with juvenile fish passage in the mainstem Columbia and Snake rivers, which is where we perceive that its utility might lie.

Natural Solutions: The following response was received from Brian Marotz, Montana Dept. of Fish, Wildlife and Parks: "I agree that ultimately, the device should be tested on smolt-stage juvenile salmon. I believe that was the intent of the proposal from the onset. However, there are several unknowns that need to be tested before launching tests on ESA-listed salmon. Earlier ISRP comments expressed concerns about the potential for harm to fish if individuals were inadvertently entrained through the device, rather than simply influenced by the zone of turbulence/velocity. There was also concern about the potential for "water knife" if a fish contacted the zone of velocity perpendicular to the direction of flow. Testing eductor entrainment seemed to be a logical first step.

Your proposal and responses indicated that the intake to the motive water and/or eductor tubes could be situated in such a way to avoid direct fish entrainment. Still, it remained uncertain what effect, if any, entrainment through the eductor might have on fish. In this test, I argue that the size of the fish, not species or degree of anadromy, is most important. It was convenient to run a first test using westslope cutthroat trout (WCT) in a pond setting, because I had access to surplus fish and was planning to stock them in the pond anyway. I had little control over the size of the fish, and knew at the onset that the WCT would average 4-5 inches total length and would be small compared to salmon smolts. Nonetheless, I thought it prudent to use surplus WCT rather than an ESA-listed species for the initial trial.

Results of the "quick and dirty" test showed a moderate degree of mortality (i.e. 8 fish out of 100 fish entrained through the eductor died within 48 hours, compared to 1 of 100 of the control gourp #1 and 3 out of 800 of the control group #2. I said "quick and dirty", because the test could have been controlled better. For instance, the enclosure for control group #1 was breached by livestock after 24 hours and the control group escaped into control group #2 (one fish was found dead in the enclosure Group #1 and 3 in Group #2. Combined, a total of 4 out of 900 control fish died due to handling alone). The eductor enclosure remained intact until it was dismantled after more than 48 hours. Most of the fish that died were about 3 inches long (only one large fish [>7 inches] died after being entrained through the eductor. We could have standardized handling better and we could have acclimated the fish longer before conducting the test. We could have assured greater water clarity (sediments were mobilized by the eductor during operation). We could have observed the fish longer after the test. All this is water under the bridge at this point, because we did the best we could in one 6 hour test on Friday and a weekend's observation. The bottom line is, by design, the fish aren't supposed to become entrained and if they do, the mortality is manageably low. Entrainment can be mitigated by design.

I recommend testing "water knife" on surplus fish prior to running tests on smolts. I anticipate that eductors can be oriented to avoid having fish contact the current at right angles. I also anticipate that fish will detect the zone of turbulence and avoid injury. To my knowledge, cases of mortality and injury due to water knife have been associated with turbine discharge and outlet situations where the discharge seam is sharp edged (not diffuse turbulence) and the fish get sheered before they even detect, or can avoid, the velocity seam. Unless I've missed something, that simply wouldn't occur with your eductor design, but it still warrants a test to be sure. The ISRP reviewers apparently have the same concern. For that reason, I think your proposal of sequential tests is the proper course to follow.

Will the fish response to the device be positive or negative? Good question. I suspect, as you stated in your proposal, that the fish would guide positively on the velocity curtain set up by an array of eductors. That is, as opposed to the documented random movement fish exhibit when they venture into reservoirs with little discernable current. The intent is to guide fish by creating a detectable current and the basis of your proposal is to see if that will positively guide fish. I question how you can answer that question apriori. Did the ISRP reviewer miss that? I do agree that a guidance test should be done on smolt-stage salmon and you should jump at the chance if you can find a suitable site. If that occurs, I recommend using a hormonal measure (e.g. ATPase or suitable measure) to assess the level of smoltification. Stratify the results on fish health and size and examine different eductor arrays and tube sizes. It would be best if water clarity can be assured to allow direct observation. If not, you might consider hydroacoustics or tag detection (radio, sonic or PIT tags). All that requires funding and that's the basis of your proposal. I hope you receive funding.

I also envision applications for the technique in the Columbia headwaters, not just the lower Columbia and Snake. Let's discuss this some time."

ISRP: What is needed is a test with juvenile salmon that are ready to migrate downstream. Perhaps a test site could be found at a so-called acclimation pond somewhere in the Columbia Basin.

Natural Solutions: We agree a test with migrating fish is needed. However, physical parameters of the system need to be defined first. Risk areas will then be delineated, and the system "tuned" by biologists. At that point a bio response test is warranted and needed.

ISRP: Discuss the plan for the intake end of the water line for the Venturi supply. There would be a need to locate it outside of the area where fish might be affected by it.

Natural Solutions: A drop tube has been proposed on the suction side or intake side. This would drop down into the lower depths of the pool out of the high density zone of mirating fish and into the cooler thermal zones (if present). Entrance conditions to the drop tube could be further modified with a "collar" system or a series of progressively larger sleeves. For example a fixed telescoping like configuratation. This would enlarge the intake diameter and reduce orifice speeds. Other siting considerations may further reduce the potential for entrainment, such as placing the unit in a cluster of large boulders, or screening. Mapping the zone of influnce of the suction side will help resolve these uncertainties.

Subject: venturi eductors
Date: Thu, 22 Aug 2002 14:24:21 -0700
From: "Peven, Chuck" <chuckp@chelanpud.org>
To: "Gordon Burns (E-mail)" <online@initco.net>
CC: "Yount, Tracy" <tracy@chelanpud.org>, "Seaman, Shaun" <shaun@chelanpud.org>, "Purdom, Roger" <purdom@chelanpud.org>, "Dick Whitney (E-mail)" <rwhitney@televar.com>

Gordon, nice talking to you the other day. I appreciate that the ISRP suggested you contact me concerning your use of venturi eductors to help guide fish in large river systems. Our company has been working on finding creative solutions to fish passage challenges at our Rocky Reach project on the Columbia River for many years. I believe that the principles that you suggest that may make the eductors work are occurring naturally in the forebay at Rocky Reach. We have a large eddy system that appears to concentrate fish in one area of the forebay that makes them more susceptible to guidance.

In reviewing your film on the eductors, it appears to me that your device may make sense to test in some applications and situations. We in fact may be interested in a test at Rocky Reach forebay one day after our new fish bypass system has been tested to try to guide species, such as sockeye salmon, both vertically and horizontally.

In short, I think your eductors hold promise for use in certain applications and situations in guiding juvenile salmonids in large river systems.

Please let me know if I can be of any further assistance.

Best regards,

Chuck Peven
F&W Supervisor
Chelan PUD