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Salmon Passage Notes

Snake and Columbia River Fish Programs Jan 1998

Regional scientists are investigating numerous options to determine how to bring back dwindling anadromous fish stocks to the Columbia and Snake rivers. Under the National Marine Fisheries Service March 1995 Biological Opinion on hydro operations and salmon, the Corps, in concert with others, is evaluating several long-term changes that could be made at the dams to improve salmon passage.

These measures range from natural river level drawdowns of dam reservoirs, to keeping the existing system with some improvements. The region will be making decisions on the options for operating and reconfiguring the dams for fish in the next several years. Two potential changes, improvements to the turbine environment and development of surface bypass systems for juvenile fish, are examined in this issue of *Salmon Passage Notes*.

Evaluating Technologies for Improved Fish Passage

by Sarah Thomas, freelance writer, Portland, OR

Making Turbine Passage Safer for Fish

Juvenile fish migrating from upstream rearing areas to the ocean face many dangers, including getting past as many as nine dams. The dams have several different passage routes for juvenile fish, but even at dams with very effective juvenile bypass systems, some fish will take the turbine passage route.

Under present conditions survival of fish that pass a dam via powerhouse turbines is estimated to be from 89 to 94 percent. But when multiplied nine times, even small improvements in turbine passage survival can be significant.

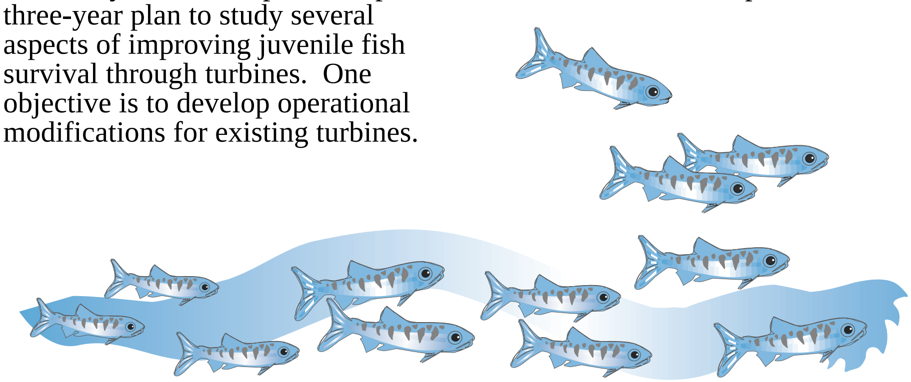
In recent years, Corps biologists and engineers have come together with scientists from the National Marine Fisheries Service, the Department of Energy, Bonneville Power Administration, several public utility districts, the Idaho National Engineering Laboratory, and the Electric Power Research Institute to examine fish survival through turbines.

In 1995, a 16 member Turbine Technical Working Group was formed specifically to share information and develop a coordinated approach to studying and solving turbine passage problems. At a Turbine Passage Survival Workshop in spring of that year, 20 experts in various fields from government, industry and universities, along with a participating audience of over 50, discovered together that nobody knew very much about what actually harms or kills fish when they pass through the turbines.

"Our knowledge base of the turbine environment from a fish passage standpoint," says Corps biologist John Ferguson, "is that it's a black box. From an engineering discipline we have a great deal of information on the machinery in the powerhouse. And we have lots of engineering expertise to redesign turbines. But we don't know what actually injures the fish. What we're trying to do now is figure out how to understand the turbine environment from the fish passage standpoint so we can make some design corrections."

Last year, the Corps developed a three-year plan to study several aspects of improving juvenile fish survival through turbines. One objective is to develop operational modifications for existing turbines. Another is to study fish as they travel through turbines to see what actually happens to fish in the turbine environment and figure out ways to improve conditions. Study results will be factored into the major decisions that the region will make within the next several years on how run the Columbia and Snake hydropower system to return fish stocks to sustainable levels.

The majority of the turbines in the Columbia system are what are called Kaplan turbines. They consist of a vertical shaft with propeller-type blades which turn when water flows over them. This, then, turns the shaft, which turns the rotor, which spins inside the stator to generate electricity. Kaplan turbines have adjustable blades. Computers automatically adjust the angle of the blades so the machine will operate at its best efficiency, depending on the amount of water flowing into it through the wicket gates. "At each flow rate there's one peak efficiency



point,” explains Corps engineer Brian Moentenich. “To increase power we open the gates and to maximize efficiency we change the blade angle to just the right spot.”

But when the blades are slanted at certain angles, gaps form between the blades and the hub, and between the blades and the discharge ring—the outer casing around the turbine. Scientists believe fish can get caught in these gaps and be killed or injured. Studies done by the Chelan County Public Utility District at Rocky Reach Dam suggest that the gaps seemed to be a significant hazard, causing a two to three percent injury rate.

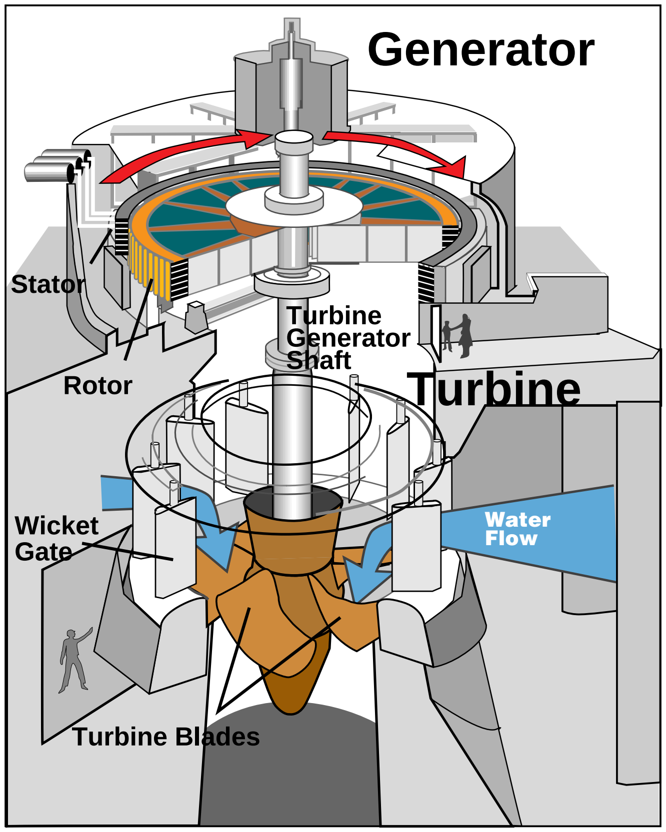
While not known absolutely, it appears that closing these gaps would be better for fish. Subsequent model tests on the Rocky Reach turbines determined that minimizing the gap near the hub would not significantly affect turbine performance. As a result of this work, the Corps decided to build and test a special runner design for Bonneville Dam first powerhouse. This would be combined with a more spherical discharge ring to further reduce gaps at the periphery of the blades.

The new design is called a “minimum gap runner” (MGR). It eliminates gaps by making the corners of the blades longer and milling out notches in the hub for the longer corners to fit into when the blades are tilted at a steep angle.

The Bonneville first powerhouse, which was built in 1938, is currently being rehabilitated. It appears that the new MGR design may provide efficiency improvements as well as be better for fish, so the Corps decided as part of the turbine rehabilitation, to install and test an MGR turbine at the first powerhouse. An old-style turbine will be tested at the same time to compare effects on fish. This could be especially beneficial at Bonneville because there fish are distributed lower in the turbine intake system, says Ferguson, particularly at night, and particularly in the summer, so more fish go under bypass screens and through the turbines.

“During testing, we’re going to release fish at different locations so they will pass through the turbine in different spots,” says Ferguson, “the hub gap, the tip gap and at mid-blade in both machines.” The researchers then will compare the results for the old and new turbine designs. Fish injury will be examined at different power outputs and efficiency levels as well.

Installation of the first MGR at Bonneville Dam first powerhouse will be completed this summer.



A turbine is **not** like a blender, Moentenich says. Turbines spin much slower—about 70 to 90 revolutions per minute as opposed to 5,000. The turbine itself is very big (up to about 27 feet across) so the areas between the blades are large, and because the water is moving the blades, rather than the blades pushing against the water as happens in a blender, the fish and the water and the blades swirl in the same direction and all move together.

What scientists call “strike” is caused by fish hitting solid parts of the machine, both moving parts and those that are stationary. These include stay vanes, wicket gates, turbine blades and hub, and a pier in the water discharge area. Strike appears to be the main cause of fish injury and mortality in most turbine fish passage studies.

Water shear, which happens when two parallel jets of differing velocities of water pass next to or near each other, can cause injuries such as torn gills, and can even be fatal. Cavitation might also harm fish passing through turbines. Cavitation results when water flow reaches a zone of low pressure where bubbles form, followed by a zone of high pressure which causes the bubbles to collapse.

The sudden change in pressure experienced from highest pressure immediately above the turbine blades to lowest pressure immediately below might also be harmful to fish. “We haven’t put a high priority on pressure changes because we think it’s probably not much of a problem based on the way fish are structured,” says Ferguson.

Another possible hazard to fish was recently identified at Bonneville Dam. People who work in the heart of the turbine areas had installed hand grips and platforms so they could safely work on the machines. Recent model tests indicate, however, that these protrusions may be injuring fish that strike them as they pass through the turbines. “This could explain some of the injuries we’ve seen to fish," says Rod Wittinger, another Corps engineer. "These were surprises. Workers need these safety aids because it's cold, it's wet, it's dark and it's slippery," Wittinger explains. The workers have now been instructed to remove them each time they finish working in the area.

Since no one has been able to see inside a turbine, it has been impossible to say exactly what causes which injuries. That's what scientists have set out to determine.

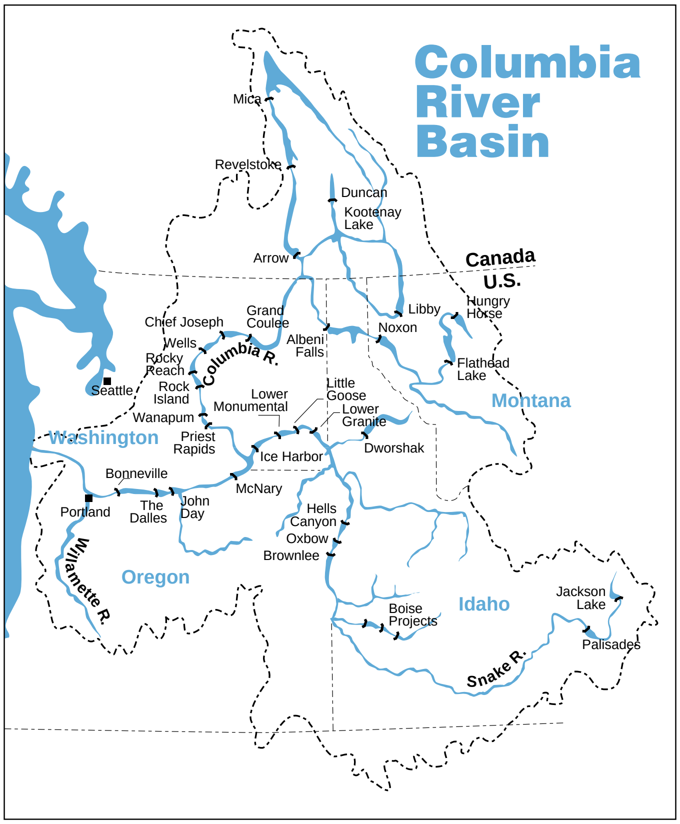
One of the major discoveries that came out of the Turbine Workshop was that at least 50 percent of the known injuries and deaths to fish appeared to be done by mechanical injury. The need for information regarding fish distribution within the turbine environment was identified as well. The Corps has agreed to study these areas. Laboratory pressure tests will be performed by the Electric Power Research Institute. The Department of Energy is studying the effects of shear and turbulence on fish.

To begin to open up the black box of the turbine, the Corps is performing tests on a model as well as at an actual dam.

The Turbine Working Group looked at eight different hydroprojects to determine which would be best for study of the whole turbine environment—from the turbine intake through the wicket gates, over the blades out through the draft tube and into the discharge area. McNary Dam on the lower Columbia River was chosen, based on the ability to perform both biological and engineering testing at that dam. Because McNary has 14 units, using one for testing purposes would cause minimal interference with hydrosystem operations. Since McNary has a screened fish bypass system, effects can be tested with and without screens in place.

The Corps Waterways Experiment Station in Vicksburg, Mississippi has a scale model of a McNary turbine with Plexiglas sides, which allow engineers and biologists to see the turbine workings. The model was constructed using actual measurements of the McNary machine, so what scientists are seeing through the Plexiglas is an exact model of the fish environment. The model runs at scale speed and represents the entire turbine passageway from the forebay and intakes through the draft tube to the tailrace.

Scientists release neutrally buoyant beads into the model environment. The beads are the same specific gravity as fish and are about the same size in relation to the model that fish are in relation to an actual turbine. Researchers can watch the progress of the beads through the model.



"Given what these tests are showing us," Wittinger says, "we know a lot of our assumptions before were wrong. So there's already been a lot of rethinking."

"The big picture from our initial work," says Ferguson, "is that if you think rotating turbine blades are a problem—they aren't. When you look at the beads going through the model they almost never come in contact with the blades. What we have seen is that the beads will strike the stationary members—the stay vanes and the wicket gates. We have been so focused on the blades being the problem. But it looks to us now that the fixed members are more of a problem than the blades. We never would have thought that."

Based on the model, scientists will try to isolate the areas of the machine that are the biggest problems, and determine the point to release actual test fish. "We release beads in the model until we get a very definite pathway trace that says if you put fish in this location in the intake, they will pass over this area that you're interested in having them pass over," Ferguson explains.

"We begin to take this mystical black box and tease apart the elements of it and say, we think *this* is not a problem, but we think *this* is," says Ferguson. "To find out how much mortality we can attribute to stay vanes and wicket gates. How much to the blades? To the pier nose in the discharge area? That's what the turbine program is essentially all about."

"From my observations," says Wittinger, "it looks like there might be many 'sweet spots' in the machine—routes where fish are not harmed. And some areas that appear to be dangerous. The majority of fish make it through the turbines without being hurt. So there's got to be a good path through there."

One thing scientists found from watching the beads that they did not expect was turbulence in the draft tube when the machine is running at best efficiency. "We knew we had turbulence," Wittinger says, "but we didn't know we had this much. Maybe some of the abrasion damage we're seeing is that the fish are hitting the walls in the draft tube because of the turbulence."

"The critical assumption is that we can use the model to predict fish behavior," Ferguson explains, "that beads in the model equal fish in the turbine. If fish behave differently than beads, then we can't use the beads to forecast where the fish are going to go."

To find out where real fish go, tests are planned at McNary Dam for fall 1998. Sonic tags will be put on the fish before they are released. These will send a signal to receivers placed at four different locations in the intake area at McNary Unit 5. As the fish pass through, they can be located three-dimensionally in the water column and through time. Scientists will then find out if beads equal fish. "If that's verified," says Ferguson, "we can use the McNary model to make a whole lot of predictions. If not, then we'll have to go back and rethink the program."

◆ Phase I of the Turbine Survival Program involves discovering what harms fish in turbines—through the MGR tests at Bonneville, through the model testing at the Waterways Experiment Station and through biological testing at McNary.

◆ Phase II of the program will proceed with engineering work to solve the problem areas.

Although the funding for the studies has been reduced from what was originally planned, scientists are trying to get enough information, says Wittinger, "to be able to say, in time to assist in regional decisions, that for the turbines, this is what we can do. We can improve survival from "x" percent to "y" percent if we redesign these things. So then that's an option. It's part of the mix in answering the questions, do we take the dams out? Put in surface bypasses? Extended screens? Do we fix the spillways? Put in better turbines?"

"What we're trying to do here is to solve the problem of turbine fish passage," says Wittinger. "And to provide options."

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Exploring Surface Bypass

Surface bypass is new and it's old," says Corps biologist John Ferguson. "It's been around for a long time. We just didn't know it." The early dams that were built on the rivers—Bonneville, The Dalles, McNary, Ice Harbor—were built with sluiceways used to spill trash and ice over the dams, Ferguson explains. The sluiceways open on the upstream face of the powerhouses, and skim water, trash and ice from the surface of the forebay and channel it to the tailrace. It turns out that fish also use this route to get past the dam.

Surface bypass is a strategy for passing juvenile salmon around a dam powerhouse by taking advantage of specific migrational behaviors of the juvenile fish. Because juvenile salmon prefer to swim in the upper part of the water column, surface bypass will theoretically guide more fish, with less delay and stress than the existing screened bypass systems.

Research has shown that, at The Dalles Dam, approximately 43 percent of the fish use the sluiceway to bypass the dam, with only 3 percent of the water flow. In other words, of the several hundred thousand cubic feet per second (cfs) of water passing the dam, only about 3,500 cfs goes through the sluiceway, yet this small percentage carries 43 percent of the juvenile fish. "This is a highly efficient rate of fish passage for the volume of water used," says Ferguson.

The juvenile fish bypass systems currently in use require juvenile salmon to dive, or "sound," 70 feet or more down toward the turbine intake, before being guided by submerged screens back up into the bypass channel. Because juvenile salmon prefer not to sound, they tend to linger in the forebay (upstream) of the dam, where they are more vulnerable to predation.

Fish that are guided by the submerged screens may encounter high water velocities and significant pressure changes as they are diverted back up into the bypass channel. Once the fish dive, some may even continue to sound below the guidance screen and into the turbine unit itself, also encountering pressure changes and other forces that can be harmful to juvenile salmon.

Surface bypass has the potential to counteract many of these factors by recreating the skimming and "directing" effect observed with the ice and trash sluiceways.

In the 1990s, a successful surface bypass system was completed at Wells Dam (Douglas County Public Utility District) on the mid-Columbia River.

Wells has a unique dam configuration with the spillways located above the powerhouse, rather than next to it as is the usual configuration. The turbines pull water from deep in the forebay while the spill above draws water—and fish—from the upper levels. In the early 1980s no juvenile fish bypass system existed there, and engineers encountered discouraging problems with trying to use guidance screens at the dam.

They turned instead to the idea of a surface bypass system. Engineers placed vertical slots in every other spillway entrance to create attraction currents. Approximately 2,000 cfs passes through each slot at a velocity of about two feet per second—a small amount of water relative to the amount passing through the powerhouse. Over 90 percent of the fish now pass through this modified spillway.

Because of the potential benefits, the National Marine Fisheries Service in its biological opinion on salmon and the hydro system called for the Corps to investigate and develop the concept of surface bypass.

In July 1994, the Corps held a brainstorming meeting with representatives of regional fishery agencies, architectural and engineering firms, and federal and state agencies to discuss concepts and ideas of how to meet biological opinion requirements, provide accurate performance results and cost estimates, and be ready to deploy surface bypass if the region decides to use it.

"Based on the success at Wells," says Brayton Willis, project manager for the surface bypass research effort at Lower Granite Dam, "we thought we may be able to make significant improvements over our existing bypass system. And if we could do that, then surface bypass may be a viable option for improved fish passage and survival."

After the brainstorming meeting the Corps designed a prototype surface bypass to be tested at Lower Granite Dam. Scientists chose that dam because it is at the upper end of the system, where large numbers of juvenile salmon and steelhead pass, and because of concern for endangered stocks there. A prototype surface bypass was installed at Lower Granite in 1996. It consists of 39

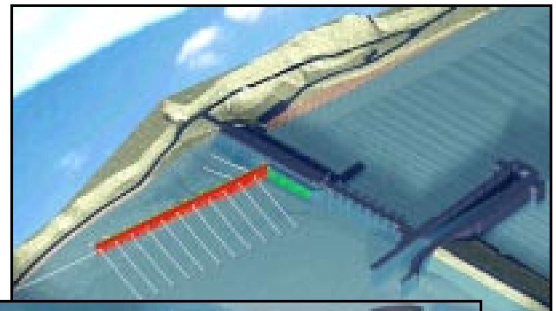
modules, most of which are 60 feet deep and 20 feet across. The entire structure, which extends across the front of turbine units 4, 5 and 6, is 375 feet long and weighs four million pounds.

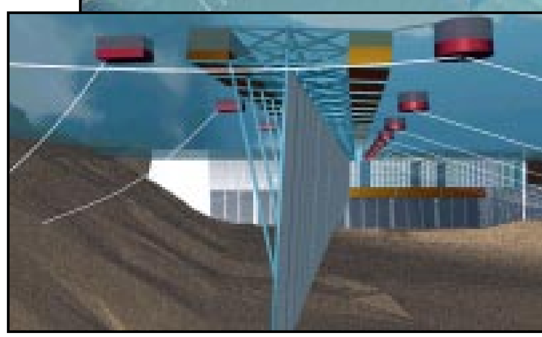
The first surface bypass tests at Lower Granite were conducted in 1996. Scientists had hoped to attract 80 percent of the juvenile fish, but the tests showed limited success. Modifications were made for the 1997 test and fish passage improved somewhat—40 percent of fish approaching the structure actually entered it. In combination with the existing juvenile bypass screens at the dam, 92 percent of the fish were kept out of the turbines, which is a five to seven percent improvement over the guidance efficiency with extended screens alone. And, the fish took less than two hours to pass through the bypass and over the spillway, avoiding delay and exposure to predation.

At Lower Granite the turbine intakes are very big and gradual. They were designed to pull water from the entire depth of the reservoir to maximize power production. But at Wells Dam, because the spillway is located directly above the powerhouse, the turbine intakes were designed to pull water from the lower levels of the reservoir only, leaving the upper part to flow through the spillway.

To mimic the Wells configuration, engineers designed a Simulated Wells Insert for Lower Granite to change the shape of the turbine intakes at the three units where the surface bypass prototype is installed. The bottom of the structures will be extended another 20 feet down, to create a lower current of water to the turbine intakes. This new design will be tested at the dam in 1998.

Another promising possibility to guide fish more effectively is what is called a behavioral guidance structure. This structure is a floating steel curtain which would extend from a point 1100 feet upstream of the dam, downstream to the surface bypass, and suspend 60 to 80 feet down from the surface of the water. It would act as a guidance wall, creating a new, simulated "shoreline" for fish to follow, directing them into the surface bypass, over the spillway, or wherever scientists wanted them to go.





A behavioral guidance structure will be tested at Lower Granite Dam in 1998 in combination with the Simulated Wells Intake. The guidance structure can be installed and removed fairly simply to test its effectiveness. Scientists see potential for increased fish guidance efficiency as well as cost savings if the guidance structure is successful.

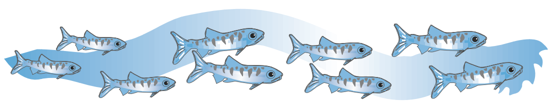
If tests show surface bypass is an effective way for fish to pass dams, design features will have to be specific to each dam and to the life stage behaviors of fish at that dam. At Bonneville Dam first powerhouse the Corps will test a two slot, four-unit prototype surface bypass in 1998. The fish entrance will have adjustable slots: one five feet wide, the other 20 feet wide, to compare fish behavior with the two configurations.

At John Day Dam the Corps is designing a surface bypass to replace the four skeleton turbine bays at the dam. Skeleton bays are concrete turbine pits without turbines, constructed in case of future need for increased hydropower. The skeleton bays would be modified into a bypass system that would appear similar to a very shallow spillway. Water and fish would be skimmed off the surface and bypassed directly to the tailrace below the dam.

At The Dalles Dam scientists are looking at ways to enhance the sluiceway passage by keeping more fish surface-oriented.

Numerous combinations of options for fish bypass are possible, all with varying costs. Surface bypass systems could be used alone or in combination with extended screens or with behavioral guidance structures.

“Because each dam is different, it’s important we understand how the migrating juvenile salmon respond to the varying hydraulic conditions that we create around these structures,” says Corps engineer Mark Lindgren. “Understanding what fish do under the different test conditions gives us a clearer picture of how well these bypass structures really perform. We’re looking for solutions that are effective as well as affordable.”



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