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Passing Judgment on Fish Passage Technologies

Introduction

In the early 1900s, the installation of the Elwha and Glines Canyon dams across the Elwha River completely blocked the course of the salmon which once navigated the river each year to their annual breeding site.[1] The salmon population was decimated, and the Lower Elwha Klallam Tribe, which lived along the river, lost the supply of fish they once relied on.[2] In 1995, government officials judged that the environmental damage the dam was causing merited a $26.9 million[3] dollar removal project. When considering other rivers across the world, policymakers are asking themselves the same question: how much are fish worth?

On the surface, hydropower appears to be a very attractive energy source which is both renewable and often cost competitive with fossil fuels. Figure 1 compares the levelized cost of electricity for various energy sources, ranking hydropower as more cost effective than conventional coal, nuclear, or any renewable energy source. Although most ideal hydropower locations in the United States have already been dammed,[7] many developing nations, primarily located in Asia and South America, are considering hydropower as a potential solution to their country's rising energy needs.[4] Unfortunately, hydropower's attractive exterior conceals substantial environmental costs, including the harm inflicted on fish populations which can no longer freely navigate the river. In order to decide whether hydropower is a viable contributor to a nation's clean energy future, it is important to determine the scope of these environmental dangers how easily they can be mitigated. This paper discusses the challenges involved with implementing fish passage technologies and measuring their effectiveness and analyzes whether the hydropower industry has sufficient standards for fish passage and effectiveness monitoring of fish passage techniques.

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[1] http://www.ferc.gov/EventCalendar/Files/20041018094218-fish-pass-final-report.pdf
[2] http://ehp.niehs.nih.gov/120-a430/
[3] http://www.nps.gov/olym/learn/nature/elwha-faq.htm
[4] http://www.forbes.com/sites/jamesconca/2014/11/04/the-hidden-cost-of-hydroelectric-power/#2823f33e114e

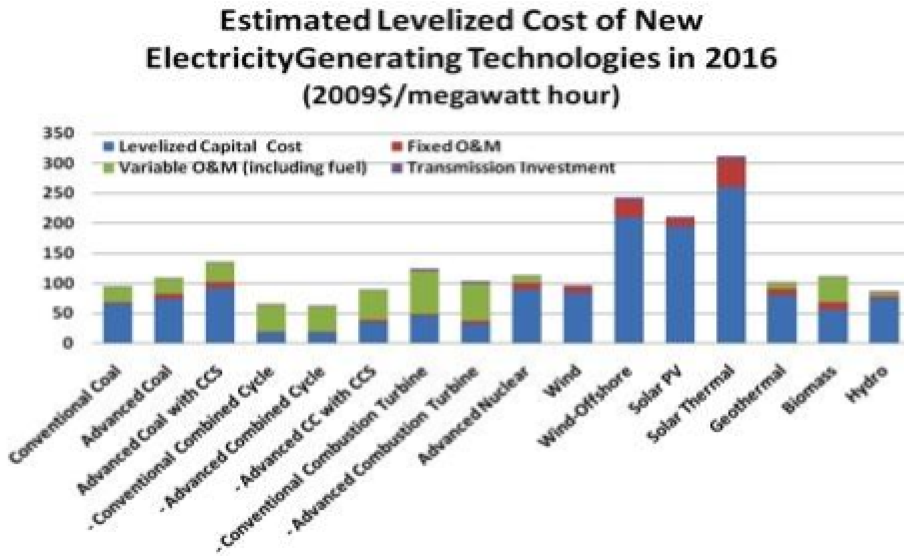

Figure 1: Cost of various conventional and renewable energy sources, estimated from the Energy Information Administration's 2011 Annual Energy Outlook.[11]

Why Fish Passage Measures Are Necessary

Most hydropower plants can be broadly divided into two categories: conventional hydro, which involves damming or significantly diverting a river, and microhydro, which uses in-stream technologies to generate power from smaller turbines, often located within the flowing river.[5] This paper focuses solely on conventional hydroelectric dams, which leave a far greater environmental footprint and require more elaborate measures to minimize fish fatalities.

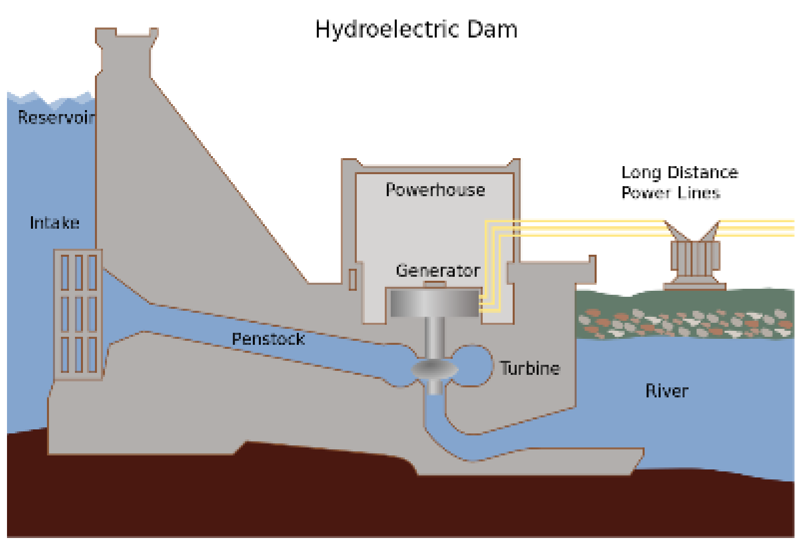

Figure 2: Diagram of a conventional hydropower dam.[9]

A traditional hydropower plant is constructed by obstructing the course of a river with a dam. With the flow restricted, a large reservoir forms upstream of the dam. Water flows through an intake, where the potential energy of the water is

[5] http://energy.gov/energysaver/microhydropower-systems

converted into kinetic energy of a spinning turbine.[6] This energy is then converted to electrical energy, as shown in Figure 2.

Without effective fish passage techniques, dams severely disrupt the passage of fish up and down the river. The harmful effects of dams are often most pronounced in populations of anadromous fish such as salmon and alewife, which spend their lives in the ocean but migrate upstream to breed. Without upstream fish passage technologies, many fish are unable to find their way to breeding grounds and are unable to reproduce. Trapped just below the dam, they are vulnerable to predators (including humans) which can further destroy the fish population. If fish do find themselves above the dam, navigating the dam heading downstream can be just as difficult. Fish can be de-scaled or killed by being sucked into turbine blades. Even fish which are not directly hit by the turbine frequently are wounded or killed by barotrauma - physical harm from the rapid change in barometric pressure between the bottom of the reservoir and the surface-level water on the other side of the dam. To adjust to the new pressure, the fish's swim bladder swells rapidly and may rupture. The fish's eyes bulge, and its stomach may burst through its mouth.[7] Along with anadromous fish, studies have also shown that dams are detrimental to freshwater fish, which can also be killed in turbines or sluiceways, and catadromous species (such as the American eel), which live in freshwater but travel to the ocean to lay eggs.[8]

Without a thriving fish population, the health of entire ecosystems could be at risk. Pacific salmon, for instance, are an important food source for 137 other species. As they migrate upriver to spawn annually, they transport marine minerals which are essential to river ecosystems. In fact, trees on the banks of spawning rivers gain 22-24% of the nitrogen in their foliage from salmon and grow almost three times as fast as trees on rivers where salmon do not spawn. Healthy tree growth in turn prevents erosion of soil along river banks. If fish are not able to effectively navigate dammed rivers, the entire ecosystem will suffer. Many fish are also central to the local economy. Pacific salmon, for instance, support a $3 billion fishing industry which involves over 10,000 jobs per year.[6] These environmental costs are so pronounced that fish passage technologies have become a regular part of hydropower projects.

How Fish Passage Technologies Work

Much of the difficulty in establishing guidelines for the effectiveness of fish passage systems stems from the wide variety of environmental conditions surrounding dams and the array of fish passage technologies created to address them. Most upstream fish passage technologies come in one of three general categories. Fish ladders (and their relatives, such as vertical-slot fishways), shown in Figure 3, allow fish to swim up a series of elevated pools. Fish elevators, lifts, and locks involve crowding fish into a small container and then transporting them over the dam. In some areas, the "trap and truck" method of capturing fish and transporting them to the other side of a dam (or a series of dams) is employed, either as a permanent measure or a temporary

[6] https://en.wikiversity.org/wiki/Power_Generation-hydro_Power
[7] https://www.sciencedaily.com/releases/2014/04/140414140802.htm
[8] http://www.westcoast.fisheries.noaa.gov/fish_passage/about_dams_and_fish/fish_ladders.html

solution until more cost-effective technologies can be implemented.[9] The greatest challenges in upstream fish passage technology involve ensuring that the fish find these passages and are fit enough to use them. The latter consideration is especially problematic for fish ladders, which generally are designed for one species of fish with a certain swimming or jumping ability and may not be able to accommodate weaker or differently sized fish.

Technologies to let fish pass downhill are generally newer and less extensively tested. A simple (but pricey) way to prevent fish from being sucked into a turbine is to install a physical barrier such as a screen or net across the turbine intake. These are often used in conjunction with bypass pipes or sluices which carry the fish safely to the other side of the turbine and sounds, lights, and racks which direct fish toward these safe passages. Alternatively, dams can periodically spill water over the top of the dam, carrying fish with them. Like with upstream travel, "trap and truck" is a viable temporary (and in rare cases permanent) possibility. Prominent challenges these technologies include ensuring that fish find the passages and that the flow rate and pressure change in pipes and sluices do not harm fish.

These fish passage techniques are costly but do not severely undermine the viability of hydropower as a cheap energy source. Averaging the mitigation costs per MWh of the dams surveyed in the 1994 survey of "Environmental Mitigation at Hydroelectric Projects" for the Department of Energy, we can roughly estimate that upstream and downstream mitigation costs together cost [illegible]MWh in 1993 dollars.[10] Referring again to Figure 1, we can see that fish passage costs will probably be around 5-6% of total dam costs.* Although this expenditure is substantial, it is not enough to eliminate hydropower as a cost-effective option. Given the vital importance of fish populations to the ecosystem, it is important that dams implement these measures and ensure they are working effectively.

Effectiveness Monitoring and Relicensing

Determining whether fish passage measures are working is challenging, as fish passage technologies have highly variable effectiveness. In the most extreme cases, they may do more harm than good. West Enfield Dam, for example, found that more fish fatalities occurred in the bypass created to let fish pass uphill than had been killed by the turbines themselves.[11] Vertical slot fishways, another uphill passage strategy, are hydraulically efficient, but prove harmful in rivers containing larger fish such as shad and alewife, which may be de-scaled during their journey through the narrow slots.[12] Certain technologies such as fish ladders, which are designed predominantly to enable the passage of a certain species of fish with strong swimming and jumping skills, may be less effective at preserving other species. The Buchanan Dam, for example, used a vertical slot fish ladder which passed an estimated 92% percent of

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[9] http://www.ferc.gov/EventCalendar/Files/20041018094218-fish-pass-final-report.pdf
[10] http://www1.eere.energy.gov/water/pdfs/doewater-10360-vol.2.pdf
*I know I'm comparing data from 2 different years!!! It will all be one year in the next draft.
[11] http://www.ferc.gov/EventCalendar/Files/20041018094218-fish-pass-final-report.pdf
[12] http://www.asmfc.org/uploads/file/FishPassTechnologyForASMFCspecies_Oct2010.pdf

chinook salmon but only 69% of steelhead trout.[13] Even when performance is comparable, the cost of fish passage can vary widely. The Jim Boyd Dam for example, spent $21.1/MWh to achieve "acceptable" fish passage, while Twin Falls Dam was able to reach the same standard for only 4% of the price.[14]

Achieving effective fish passage is not merely a matter of determining the greenest and cheapest technology and applying it to all hydropower dams. As stated in a technology assessment prepared for Congress, "There are no 'sure things' in the world of fish passage technology." Each dam faces a unique array of environmental concerns and technological challenges. As a result, it is extremely difficult to create standardized, quantitative guidelines for monitoring the effectiveness of fish passage systems. This same variability, however, makes standardizing measures of fish passage effectiveness more essential than ever. Without doing this, it is difficult to compare different technologies and evaluate whether they are working.

Although many licensing articles for dams require that they perform some sort of effectiveness monitoring, the results of these effectiveness studies are characterized by a lack of standardized, quantitative ways to describe the effectiveness of fish passage. A report on "Fish Passage Technologies: Protection at Hydropower Facilities",[14] for instance, lists the fish passage goals over several hydropower dams along with the results they achieved. Some of the dams had concrete objectives: 80% efficiency in the spring and 70% in the summer at Wells Plant, for example, or the "no induced mortality" standard adopted by the Twin Falls Dam. Many other dams, however, reported more nebulous goals such as "decrease turbine entrainment" at the T.W. Sullivan Plant or "Pass American shad and Atlantic salmon." The reported achievements of the dams vary in specificity too, from Little Falls, which reported less than 1% turbine entrainment out of over 100,000 fish passed each season), to Lowell, which reported bluntly that it had "no established monitoring program" but that the "existing sluice is considered ineffective." Without standardized guidelines for how to choose a desired result and quantify how well the dam is performing at that metric, it is difficult for government regulators, the public, or even dam owners themselves to evaluate how well the dam is doing.

Dams may report their achievements using different metrics because they obtained data using different data collection methods. The most recent report by the FERC on fish passage surveyed 52 hydropower dams with fish passage technologies. Of those, approximately 30% did not have effectiveness monitoring requirements. Of the data from the 46% which had in fact submitted effectiveness monitoring documents, many used data which was "qualitative, anecdotal, or in other ways, too limited for meaningful analysis."[15] Of the 34 dams which included upstream passage, the report authors were only able to find meaningful data on how many fish were using fish passage technologies in eight of the dams. Only three of the dams provided data estimating fish passage as a proportion of the total fish approaching the dam.[15] This extra step is not taken frequently because estimating the total number of fish in the water is significantly harder than counting the number which manage to cross fish the dam's fish passage technologies. Although determining the total available salmon population may involve creative measures

[13] http://www.osti.gov/scitech/servlets/purl/392793/
[14] http://ota.fas.org/reports/9519.pdf
[15] http://www.ferc.gov/EventCalendar/Files/20041018094218-fish-pass-final-report.pdf

such as radiotagging fish or estimating based on the numbers of fish crossing dams farther down the river, performing this type of analysis is essential to differentiating between highly efficient dams operating in rivers with low fish populations and dams with poor efficiency but large raw numbers of fish present.

The timing of effectiveness studies also makes it difficult to gain a true picture of the effectiveness of any particular fish passage setup. Currently, the FERC requires dams seeking a renewal of their 30-50 year license to submit a statement about the environmental impact, including the cost to migrating fish. About five years before its licence expires, a dam will start monitoring the effectiveness of the environmental measures it is implementing. The dam will then submit an application to the FERC, which writes an environmental assessment supporting the decision to relicense the dam. If the dam is found severely lacking, however, the FERC submits an environmental impact statement voicing its concerns, which the dam must address in order to renew its license.[16] This system makes it difficult to discover and implement the most effective fish passage technologies. Since effectiveness monitoring is often only mandated each time the dam wants its license renewed, dams could conceivably fail to recognize that their fish passage methods were ineffective for a full 50 years.[16] Increasing the frequency with which fish passage effectiveness is monitored also allows dam owners to record changes in fish numbers over time. If a dam without effective fish passage techniques only monitors the size and movements of a fish population shortly before it is relicensed, then it is difficult to establish the ideal amount of fish which should be able to pass the dam. Even if fish population levels remain fairly consistent today, they may be only a fraction of the number present prior to the construction of the dam. Additionally, infrequent monitoring makes it difficult to distinguish between environmental changes caused by the dam's technology and unrelated environmental changes.[16] Sufficiently addressing the challenges of fish passage requires increasing the number of dams with required effectiveness monitoring and requiring effectiveness studies at more regular intervals, and establishing quantitative goals and metrics for evaluating a dam's progress toward these goals.

Fortunately, it seems as if the hydroelectric industry is moving in the right direction. As dams seek to renew their licenses, more of them are required to implement fish passage technologies (91% of newly licensed dams in 1996, up from 33% in 1990), and more are required to monitor their effectiveness (61% in 2004, up from 21% in 1991).[17] The industry still has a ways to go, however. Much federal data on the effectiveness of fish passage appears to be dated (the most recent FERC report on fish passage effectiveness was from 2004), and there still appears to be no publicized quantitative industry standards for fish passage effectiveness or monitoring.

Unlike many other power plants, which operate in carefully controlled internal environments, hydropower plants must interact with a complex and ever-changing ecosystem which ensures that no two fish passage installations will perform the same way. It may be tempting to try to draw one verdict on whether hydropower is (or can be) a "green" technology. The reality, however, is that the environmental impact of hydropower can only be accurately measured on a case-by-case basis, and that the hydropower industry is still developing the standards to achieve this.

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[16] https://www.princeton.edu/~ota/disk1/1995/9519/951907.PDF

[17] http://www.ferc.gov/EventCalendar/Files/20041018094218-fish-pass-final-report.pdf

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