WATER WARS: DETERMINING THE FUTURE OF DAM REMOVAL IN THE STATE OF OREGON

by

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During western expansion, dams helped settlers conquer nature and develop the frontier. Oregon depends on dams for flood control, efficient renewable energy, and irrigation. As 20th-century infrastructure ages, removing large dams across the West has become a practical and realistic goal for politicians and environmentalists alike. This trend peaked when the Federal Energy Regulatory Committee approved the removal of four massive dams on the Klamath River in Southern Oregon. This mass decommissioning is part of a shift from barricades to educated sustainability. Managing the health of aquatic ecosystems has become a priority of the state, and the first step in managing rivers is removing dams.

This research examines dam removal undertakings in Oregon and discusses the essential variables in these projects. This study generates a formula that helps determine the likelihood that a dam will be removed in Oregon. The investigation concludes with the idea that not all dams are created equal, and those that provide minimal utility for their surrounding ecosystems are unlikely to remain operational under Oregon law.

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Introduction

The Klamath Basin was once a thriving ecosystem filled with beautiful fish, diverse swamplands, and rare migratory birds. Intense wetlands covered most of this vast basin, making it difficult for settlers to develop or farm on the land. The region seemed impossible to develop until the National Reclamation Act, signed by President Theodore Roosevelt in 1902, made settlement and agriculture possible (Most, 2022). This Act created the Reclamation Service, which initiated the Klamath project. The Klamath project revolutionized the Klamath Basin, creating a network of dams, canals, and culverts to drain the basin's swamps and irrigate new farmland. The lower of the two lakes, Lower Klamath Lake, was almost completely drained, erasing 94,000 acres of marshland that was an essential habitat for migrating bird species (Most, 2022).

The Klamath Project allowed farmers to dominate the basin. Local wildlife started to suffer as water was depleted from the basin and pollutants were introduced. Massive die-off in Salmon occurred in 2002 and two endemic fish species, the Lost River and Short nose sucker, are now endangered. The Karuk, Yurok, Modoc, and Klamath tribes have relied on these fish for thousands of years (Most, 2022). The transformation of this basin from a diverse wetland to an agricultural hub has destroyed the ecological diversity these tribal communities relied on for survival and culture.

In the fall of 2022, the Federal Energy Regulatory Committee approved the removal of 4 Hydroelectric dams on the Klamath River. These dams are owned by PacifiCorp and were built to power the massive irrigation project in the Klamath Basin. The dam lacks the basic fish passage technology required under California and Oregon law (Gosnell, 2010). The removal of these dams is the largest removal event in U.S. history and inspired this research. Examining the

factors that go into a dam removal based on this event, and others in Oregon, should help indicate what dams are next to be removed.

By examining six key factors, it is hypothesized that dams on the Snake River are more likely to be removed than dams in the Willamette Valley or elsewhere. It is also hypothesized that dams that lack fish passage technology will be the most likely to be removed.

Literature Review

Dams have played an essential role in Oregon's development. They have helped the state advance its economy and create a thriving agricultural industry. Dams allowed Oregonians to settle in the Willamette Valley and Columbia Basin without fearing yearly flooding. Hydroelectric dams on the largest rivers in the state have gifted Oregon an energy source that doesn't release dangerous greenhouse gases. 39% of the state's energy comes from hydroelectric power, making Oregon one of the greenest states in the nation (Oregon Department of Energy, 2022). Dams also provide the state with a safety net of water that can be used to irrigate farmland and revive aquatic ecosystems (Schultz, 2002).

The historic benefits of dams cannot be overstated; however, there is a point where dams are overused and no longer benefit the communities they aim to serve. Oregon has well over 800 dams, most of which are privately owned irrigation dams (National Inventory of Dams, 2023). Recently, dam removal has become a common practice, and nationally, close to 1200 dams have been removed in the last twenty years alone (Wieferich, 2021). Most removals are small, privately owned dams of little significance, but some have been massive. The planned removal of four dams on the Klamath is a shockingly large exhibition that has left many people wondering what determines if a dam gets removed.

This section of the paper explores the history behind six variables that go into dam removal: collaborative action, fish, irrigation, flood control, energy production, and age.

Collaborative Action:

Collaboration has been instrumental in passing key environmental legislation across the globe. Having public, private, and governmental cooperation is essential to the success of an environmental project (Koontz, 2006, p. 17). The large scale of a dam removal, extends far beyond the immediate grasp of the removal site. These projects impact the entire river basins that run hundreds of miles in every direction. Having a partnership with various parties is crucial to finding a solution that represents the needs of all involved. Collaboration involves diverse stakeholders working together to resolve a conflict and develop a shared vision (Gray, 1989). With the intense set of stakeholders in dam issues, collaboration becomes a crucial component of dam removal or alteration arrangements.

Collaborative action is how well a group of stakeholders works together to address a common problem. In the case of dam removal, collaboration is a significant factor; often a precursor to a successful operation. In 1996, downtown Medford was the site for the demolition Bear Creek Dam, a removal necessary to restore salmon habitat (Smith et al., 2000). Smith discusses some of the important factors that went into this dam removal, collaboration being one of them. Starting a collaborative process for dam removal requires the identification of all potential stakeholders. The more parties represented, the increased chance of removal (Smith et al., 2000). Another essential component of collaboration is having a leader. In the Bear Creek removal project, Medford emerged as the movement's moderator. The city helped "coordinate project planning needs with each stakeholder, to resolve differences between them, and to secure permits and funding." (Smith et al., 2000, p. 213). These crucial steps by Medford were foundational in the composition of a successful dam removal resolution. Smith continues, "The goal is to agree with all stakeholders and be sure they are comfortable with the concept of dam

removal or breaching. This forms the basis for successful collaboration for the project" (Smith et al., 2000, p. 217). The successful removal of the Bear Creek dam was primarily due to the ability of multiple actors to work jointly to address a public issue. This collaboration format will be used in future dam removal projects and is critical for understanding what ones are next to be removed.

In the Klamath Basin, work by local governing bodies was significant in getting an agreement regarding the Klamath River's future. It all starts with four dams owned by the utility company PacifiCorp. PacifiCorp could not operate the dams without a license which expired in 2006. The Federal Energy Regulatory Committee (FERC) issued PacifiCorp a new license with the stipulation that they build fish passage devices on their dams (Ish, 2020, p. 265. The company decided it needed to be more financially burdensome and had to find a way to escape the economic responsibility of managing these dams. The Klamath Settlement Group (KSG) came into play to help find a solution to this issue.

The KSG was significant in accomplishing one of Smith's collective action goals, identifying a "leader to organize and guide the stakeholders" (Smith et al., 2000, p.17). The KSG became the leader of a movement to remove dams on the Klamath River and communicate with various stakeholders about their interests in this dilemma. The KSG created the Klamath Basin Restoration Agreement (KBRA) in 2008 to outline the ecological and economic goals of the basin, centered around the decommissioning of PacifiCorp's four dams: The J.C Boyle, Copco 1, Copco 2, and Iron Gate Dams (Ish, 2000, p. 273). Over 50 stakeholders signed the agreement in January 2008(Ish, 2020, p. 273). A separate contract between PacifiCorp and the KSG was signed called the Klamath Hydropower Settlement Agreement. This agreement established a pathway to remove the dams and outlined a plan to transfer ownership from PacifiCorp to the

Klamath River Renewal Corporation (KRRC), which would remove the dams (Ish, 2020, p. 274). This contract removed any liability PacifiCorp could have encountered during the removal process by transferring dam ownership to the KRRC. The ability of private, public, and non-profit actors to work together to sign this agreement was the most critical factor in the potential removal of the four Klamath dams.

The KBRA opening statement reads:

> "The Agreement is intended to result in effective and durable solutions which: (i) restore and sustain natural production and provide for Full Participation in Harvest Opportunities of Fish Species throughout the Klamath Basin; (ii) establish reliable water and power supplies which sustain agricultural uses and communities and National Wildlife Refuges; (iii) contribute to the public welfare and the sustainability of all Klamath Basin communities through these and other measures provided herein to resolve the disputes described in Section 1.2."

The strength of this agreement lies the clarity of its objectives, highlighted from irrigators to environmentalists. The success of this agreement started with collaboration. Without collaboration, there would be no Klamath River Restoration Agreement. Cooperation requires consideration of all stakeholders' interests to formulate a realistic solution, which is something the KRBA does incredibly well (Ish, 2020, p. 275). The success of the KRBA and Bear Creek demonstrate how Collaboration is an important priority in dam removal and should be inspirations for future dam removal projects.

Fish:

Salmon is the most important species in the Pacific Northwest. Their migratory patterns bring enormous quantities of nutrients from the ocean inland to fertilize otherwise barren lands. From people to insects, all creatures living in the northwest benefit from the yearly migration of

salmon. Over 95% of the body mass of a salmon is accumulated in the ocean (Schindler, 2003, p 32). This body mass includes precious nutrients like nitrogen, carbon, and phosphorus which are stored in their tissues. In some areas, nitrogen in riparian foliage along anadromous streams can be between 15.5% and 17.8% marine-derived (Merz, 2006, p. 999). These fish also provide a crucial source of nutrients for terrestrial animals. In Oregon and Washington, 130 species rely on salmon for nutrients (Schindler, 2003, p.3). On the human side, Salmon has been the most vital resource to indigenous groups in the Northwest for centuries. Many first nations in the Northwest have even been called 'Salmon Nations' because of their connection to the fish in every aspect of life. These fish were crucial food sources and essential for cultural and economic reasons (Reid, 2022, p. 12). Salmon ceremonies celebrated the return of the anadromous fish and the life cycle. These celebrations represent the connection between these nations and the environment, specifically their relationship with Pacific salmon. Even today, groups up and down the west coast continue to have strong links to salmon for everything for mental, social, cultural, and economic purposes (Reid, 2022, p. 12). The cherishing of this fish has been threatened by U.S. Western expansion, presenting salmon nations and ecosystems the difficult task of living without a keystone species.

Many predicted that Pacific salmon would spiral downward as settlers entered the West. U.S. Commissioner of Fish and Fisheries Spencer Baird warned in 1875 that Columbia River salmon could face a similar fate as Atlantic salmon because of habitat loss, overharvest, and damming (Taylor, 1998, p.37). A century and a half later, studies confirm that modern Oregon salmon runs are less than 5% of historical ones (Meengs & Lackey, 2005, p. 51). This decline coincides with large-spread environmental shifts due to humans and the suppression of the salmon nations.

As Baird's warning turned to reality, some sought to change the narratives around dams and their relation to salmon. Dams provide a natural barrier for migratory salmon returning to their spawning ground. A study from the University of Chicago in 1989 estimates that yearly salmon lost due to hydroelectric dams on the Columbia alone is between 3.5 million and 4.9 million (Booth, 1989, p. 208). Dams not only act as a barrier but also disrupt the natural flow of waterways, which impacts spawning gravel, raises the temperature, and increases the likelihood of pollutants due to industrial or agricultural reasons (Kaushik, 2007, p. 1). The decline in Coho Salmon in Oregon is from dams, water withdrawals, and unscreened diversions for irrigation (Buckhouse, 2002, Pg. 5).

Dams alter rivers by increasing temperature, lowering flow rates, and introducing additional sediment (NOAA, 2019). Stagnant water caused by dams can be warmed by solar radiation (NOAA, 2019). Migratory fish prefer cooler waters and have a difficult time surviving in dammed area and an even worse time migrating past these large concrete structures. Fish passage is crucial to maintaining a healthy migratory fish population on a dammed river. Oregon prioritizes fish passage in dams and other artificial river obstacles (Akpe, 2023). Fish passage is one of the more common legal paths the Oregon Government can take to remove a dam. When barriers are up for renovation, private owners have to consult with state officials, which opens the realm for discussion about fish passage. Often the state presents dam operators with options depending on the size and location of the dam. Generally, these options force the dam owner to install fish passage systems, like fish ladders, or risk losing their permit (Akpe, 2023). The legal background for this sentiment comes from Oregon Law 509.585, which states,

> "(1) It is the policy of the State of Oregon to provide for upstream and downstream passage for native migratory fish, and the Legislative Assembly finds that cooperation and collaboration between public and private entities is necessary to accomplish the policy goal of providing passage for native migratory fish and

> to achieve the enhancement and restoration of Oregon's native salmonid populations, as envisioned by the Oregon Plan. Therefore, except as provided in ORS chapter 509, fish passage is required in all waters of this state in which native migratory fish are currently or have historically been present.
>
> (2) Except as otherwise provided by this section or ORS 509.645, a person owning or operating an artificial obstruction may not construct or maintain any artificial obstruction across any waters of this state that are inhabited, or historically inhabited, by native migratory fish without providing passage for native migratory fish." (ORS 509.585 Fish passage required for artificial obstructions, 2021)

The statute entrusts the Oregon Department of Fish and Wildlife (ODFW) with the power to enforce this issue. The law encourages "cooperative partnerships to remedy fish passage problems" and enables the ODFW and dam owner to negotiate fish passage on the dam (ORS 509.585). Further on in state law 509 (section 625), the law reads,

> "If a person who owns or operates an artificial obstruction and who is required to provide fish passage under ORS 509.585 (Fish passage required for artificial obstructions) fails to provide a fish passage in the manner and time required by the State Department of Fish and Wildlife, the commission may remove, replace or repair the artificial obstruction or any parts of the obstruction at the expense of the owner or operator."(Power of department to inspect artificial obstructions and have fish passage constructed or remove obstruction, ORS 509.625, 1955)
>
> These laws give the ODFW a path to encourage private dam owners to alter their

structure to include fish passage. In an interview with Greg Akpe of the Oregon Department of Fish in Wildlife, he clarified that the state has funds to help with dam improvement that increases fish passage to native spawning grounds (Akpe, 2023). "The decision on how the passage is accomplished is on the owner and operator of the dam" (Akpe, 2023). State law 509 came into play when PacifiCorp was charged with updating their four lower Klamath River dams with Fish passage systems so they could qualify for a new long-term contract. (Lane, 2008, pg.3). Filling this prescription would cost PacifiCorp upwards of 300 million dollars (Lane, 2008, p. 3). With the ball in their court, PacifiCorp elected to pick an alternative right and hand the dams over to the KRRC.

The legal importance of fish passage was vital in gaining momentum to remove four barriers on the West's third-largest river. It will be an essential factor for future dam removal movements to consider.

Agricultural Irrigation:

Over half of the barriers in Oregon are primarily built for irrigation (National Inventory of Dams, 2023). In the United States, 42% of all freshwater withdrawals are used for agricultural irrigation (Dieter, 2018, p. 1). In Oregon, 5,780,000 acre-feet[1] of water are used for irrigation each year, and 77% of surface water that is used in the state is used for irrigational purposes (Dieter et al., 2018, p. 10). A dam slows the flow of a river, making it easier to store and move to agricultural fields near and far (Schultz, 2002, p. 6). Arid western states rely on irrigation from dams to grow crops.

The Klamath Project was a massive undertaking by the Bureau of Reclamation. The project aimed to make farming easier in the basin by giving farmers access to large amounts of water from various lakes and creeks. Tule Lake, Lower Klamath Lake, and wetlands around the basin have entirely dried up due to this project. Today water is pumped from Upper Klamath Lake, fed by a watershed starting east to the Cascades. After farmers use the water, it is returned to the Klamath River, which eventually flows to the ocean (Gosnell, 2010, pg. 368). Gene Souza, of the Klamath Irrigation District, stresses the importance of irrigation on the agricultural success of the region. This region heavily depends on the Klamath Projects water to grow crops and fund its economy (Souza, 2023). The decision to remove four dams on the Klamath River will not stop this irrigation project, but irrigators see it as a step toward losing their right to farm.

[1] Acre-feet, the area multiplied by the average depth of a waterway. One acre-foot is equivalent to 325,851 gallons.

The main concern for irrigators is that the government is shifting towards supporting environmental and tribal rights over agricultural ones (Goshnell, 2010, p. 376). Since 2000, there have been multiple instances where water to Klamath Project irrigators was curtailed because of dry conditions (Goshnell, 2010, p369). Dry conditions negatively impacted fish, and in 2002 low flow in the Klamath resulted in the death of 33,000 endangered Coho Salmon (Goshnell, 2010, p. 370). Irrigators are worried about a trend of public policy decisions that have limited their ability to farm in this region. The four dams set for removal on the Klamath do not contribute to the irrigation network. However, it is a step-in favor of fish protection over agriculture protection, harming the region's economy.

Savage Rapids Dam on the Rogue River represents one of Oregon's most significant dam removal projects (Taylor, 2021, p. 244). The removal of Savage Rapids Dam happened in 2009 because of the dam's shockingly poor fish passage score. This dam provided crucial water access to farmers in the Rogue River Valley from the late 1880s onward (Corl, 2021, p. 48). Like other rivers in Oregon, the Rogue's yearly flooding made it impossible to install traditional irrigation pumps that would wash away during yearly flooding (Corl, 2021, p.49). The Savage Rapids Dam birthed a reservoir of water that could easily be tapped into by irrigation pumps, allowing farmers to irrigate their crops in the Rogue Valley.

Today, the former site of the Savage Rapids Dam is home to a rather large irrigation system that uses a modern technique for pumping water out of the river (Corl, 2021, p.57). Alternative irrigation techniques will become necessary for a world marked by warming climate and less access to water. Currently, 40% of all water used for irrigation is wasted by evaporation or poor techniques that under-utilize the resource (EPA, 2017). Sustainable Irrigation hopes to address this waste by developing more efficient farming techniques and irrigating existing crops.

Mitigating evaporation caused by large dams is a component of sustainable irrigation (Velasco-Munoz, 2019, p. 19).

Dams still provide a crucial step in the Irrigation process. The Savage Rapids dams give an example of an alternative to this model, but these systems tend to be the exception, not the rule. In Oregon, agriculture is a significant driver of the state's economy. 13% of the state's sales and 326,617 jobs are tied to industry (Sorte, 2021). 45% of farms use irrigation, and 70% of all crops harvested are from irrigated lands (OEC, 2012, p. 5). removing dams in Oregon will always have an agricultural cost. Finding solutions that lower the impact of this cost is paramount to creating a successful irrigation project. Savage Rapids Dam is an excellent example of a compromise that worked for irrigators and environmentalists.

Flood Control:

Dams are often assumed to be flood control devices that protect towns and cities from unpredictable weather patterns and quickly rising river levels. They do provide this service, but only a few dams are primarily built with flood control in mind (National Inventory of Dams, 2023). The 1936 Flood Control Act authorized the mass construction of dams for flood control purposes across the United States (O'Neil, 1994, p. 168). This New Deal-era policy enabled the federal government and the Army Corps of Engineers to develop dams for flood control (O'Neil, 1994, p.168). This federal decision coincides with a framework shift in how people view and respond to floods. The settling of people near rivers meant more folks were vulnerable to rising water levels during yearly flooding events. The Flood Control Act gave the Army-Corp of Engineers leverage to build dams in areas at risk for flooding (O'Neil, 1994). The most notable dams developed with the primary goal of flood control were in the Willamette Valley and Rogue

Valley (USACE, 2017). government participation in curbing the frequency and severity of these floods led to industrial and agricultural development in traditional floodplains. In Oregon, 241 thousand people live in 100 or 500-year flood plans[2] (Peri, 2015). Dams protect these people from being displaced by yearly floods, but this also means the benefits of a flood are entirely lost.

Humans have used floods for generations to irrigate crops and bring new life to a river basin. In Oregon's Willamette Valley, winter weather can overwhelm agricultural land and jeopardize harvest (Rapp, 2015). As the Willamette Valley industrialized and people flocked to Oregon, there became an increased need to protect property from yearly weather fluctuations. The Willamette Valley Flood Control Project is a policy with the primary objective of preventing flooding in Oregon's most populated region. This project consists of 13 dams, operated by the Army-Corp of Engineers (USACE), that reduce flood risk. These dams (built between 1941 and 1969 under the flood control acts), have protected cities from floods, given local farmers a consistent water source for irrigation, and have a combined 408-megawatt hydroelectric capacity (USACE, 2017). Removal of the Willamette Project Dams seems far off due to their multiple beneficial functions.

Indigenous Sovereignty:

Water use in the West is plagued by an ugly history of colonialism and war, consistently pushing native nations to the margins in favor of supporting white farmers. The construction of

[2] The term "100-year flood" is misleading. It is not the flood that will occur once every 100 years. Rather, the flood elevation has a 1-percent chance of being equaled or exceeded each year. Thus, the 100-year flood could occur more than once in a relatively short period of time. Similar to a 100-year flood, a 500-year flood has a 0.2-percent chance of being equaled or exceeded each year (FEMA, 2009)

dams for irrigation and economic purposes was a tool for development and colonialism. It allowed Western settlers to increase their productivity on otherwise arid lands.

In Oregon, damming on the Columbia River continues to be one of the more meaningful events in the history of tribal communities. Damming of Celilo Falls on the Columbia in 1957 constricted tribal fishing rights to the point of no return. Celilo was the most abundant stretch of fishing stretches in the west and had been used by Native People for thousands of years (Barber, 1999, p.2). The Dalles Dam flooded the falls, pushing tribal communities further to the margins (Barber, 1999, p.3). The inexplicably cruel treatment of Native Nations by the U.S. government is best shown through the destruction of Celilo Falls and the breaking of treaties protecting the rights to fish.

Tribal treaties between Native Nations and the government held language retaining the exclusive right to take fish (Barber, 1999). A right allowing tribal members to fish on historic lands after they were moved to reservations. In Washington v. United States, a district court recognized that the right to take fish as promised in many treaties includes "the right to have those fish protected from man-made despoliation" (Goodman, 2000, p. 293). Dams are responsible for significantly depleting fishing habitats in Oregon, giving indigenous populations a case to use against dams if their treaties previously allowed access to fishing rights.

Legal water rights have been fundamental in many treaties in the battle to remove dams. Under U.S. law, tribal water rights are strongly connected to treaties and court cases determining the legal right of tribal nations to fish and operate in certain waterways (Church, 2015, pg. 3). The Supreme Court Case, *Winters V.S the United States* (1908), set a precedent for what would come for indigenous water rights. (Robinson et al., 2018, p. 866). On the Klamath, legal protection for two endemic fish in the Endangered Species Act, the Shortnose Sucker and the

Lost River Suckers, have been essential negotiating chips for those advocating change (Ish, 2020, p. 264). Tribes can access these fish through historic treaties that grant them rights to fish for these species. Klamath Basin tribes began advocating for the enforcement of these rights in the 1980s after they received federal recognition (Gosnell, 2010, p. 369). In 1999 the court case *Water Users v. Patterson* determined that the instream fishing rights in tribal treaties were a priority over irrigational rights farmers had in the Klamath Basin (Ish, 2020, p. 269). The Patterson ruling clashed with irrigators, who had been destroying the Klamath Basin's ecology to farm arid lands for years. This case confirmed that irrigators and dam operators on the Klamath River had junior water rights to the tribes, giving them significant legal leverage that would be used to institute the KBRA (Ish, 2020, p. 269).

Age:

The easiest way to tell when a piece of infrastructure is going to fail is by its age. That is no different with dams. Once a dam reaches 50 years it requires more maintenance and testing to remain operational. The average age of a dam in the Army Corp of Engineers catalog of 91,468 dams is 57 years (National Inventory of Dams, 2023). Like any infrastructure, dams require regular maintenance and eventually need removal or replacement. The operational lifespan of a dam is 60-120 years (Doyle, 2003). Anything approaching that mark has an easier time being removed, and recent removals have largely been due to the age of a dam. Even if the dam is not scored highly among the other factors, if it ages, removal becomes likely. In recent years removal has increased, and in the last 20 years, close to 1200 dams have been removed (Wieferich, 2021). These are mainly small aging dams, but it opens up a conversation about

removing more large dams (Doyle, 2003). As dams age, removal becomes more and more likely. This makes age a crucial component when examining dam removal.

Methods

This research examines the factors that go into dam removal and evaluates their importance to formulate an equation determining dam removal operations' success. The success of the KRBA, Savage Rapids Dam Removal, Bear Creek Dam Removal, guide the factors that determine the likelihood of removal. These Projects show that fish passage and habitat are essential variables for decommission. The above dams had legal support from government offices to remove them because they failed to provide endangered fish with adequate habitat protection. Beyond these factors, this research considers the strength of collaborative efforts by communities and non-profits to organize stakeholders in the removal process. It also explores the importance of selecting river sites for Indigenous communities and how intense their actions are in the fight for river restoration.

Conversely, we can also study variables that inhibit removal efforts. When examining dams on the Snake River, Columbia River, and Willamette River, a pattern of failure emerges that quickly reveals how dam removal can fall short. Suppose the dam provides a service such as reducing the risk of floods, providing large hydroelectricity, or creating an important reservoir for agricultural irrigation and industrial use. In that case, the dam seems unlikely to be removed. Additionally, removal is far less likely if a barrier is equipped with fish passage devices, such as a ladder. As mentioned, state law 509 requires dams to be fitted for fish passage or removed. Many barriers have preferred the former (Power of Department to inspect artificial obstructions and have fish passage constructed or remove the obstruction, 2001).

This next section aims to create a formula determining the essential elements necessary for dam removal. Considering each factor as either Pro dam removal or Against dam removal is

the first step in this process. Table one indicates each variable's category and an abbreviation for future use.

Pro Removal	Fish Passage and Endangered Fish (F)	Indigenous Sovereignty and Collaboration (C)	Age of Dam (A)
Against	Irrigation (I)	Energy Production (EP)	Flood Control (FC)

Table 1: Variables categorized as pro dam removal or against dam removal

For simplicity's sake, assigning each variable the same weight allows this research to conclude more flexible results and avoid the impossible task of determining what factor has the highest value. Each value should be weighed on a simple 1 through 12 scale. Where 1 is the lowest possible value, and 12 is the highest. Simply subtracting the values from each other reveals a formula balanced on the benefits of dams versus—the harms of barriers. If the outcome of the solution is a higher positive value, it means the dam is more likely to be removed. The lower value, including negatives, means the dam is unlikely to be removed.

$$(EP+FC+I) - (F+C+A)$$

The following sections will explain how to derive a score for each variable and provide an example of deriving that score on a dam in Oregon.

Calculations for Pro Removal Variables

This section explores how each variable in the equation will be calculated and gives an example of each calculation by testing it on Cougar Dam.

The calculation for F:

The value for *F* is based on two factors: how fish pass through a dam and how the dam harms endangered species. Fish Passage is scored on the presence and effectiveness of a dam's fish Passage devices. The first component of the score comes from the ODFW Fish Passage Barrier Priority List from 2019, which scores over 400 dams on how necessary it is that they are removed or altered for fish migration (ODFW, 2019). The scores on this list range between 24 and 710, but any dam below 200 tends to have anonymous or private owners, making it harder to research. Each score from this list will be multiplied by .01 so it can fit into the 1-12 scale. In this formula *fpbp(x)* is the Fish Passage Barrier Priority rating from the ODFW for each dam *(x)*. The variable *+/-ds is* for the presence of any fish passage device. A dam can score poorly on the ODFW rankings but still have a fish passage device, and recognizing that dam's attempt at providing fish passage is essential. *ds* range from 0-3 based on the presence and effectiveness of the fish passage device.

$$(.01(fpbp(x)) +/- ds)$$

The second part of this score is how a dam impacts fish species on Oregon's endangered species list. The ODFW highlights three endangered river fish in Oregon according to the Oregon Endangered Species Act (ORS 496.171-192). The Lost River Sucker, Lower Columbia Chinook Salmon, and Shortnose Sucker are the only three endangered in Oregon. On a federal level, the Upper Columbia River Spring Chinook Salmon and Snake River Sockeye Salmon are also listed as endangered (ODFW, 2021). The Shortnose Sucker and Lost River Sucker are endemic to the Klamath Basin and have significantly impacted water politics in that region (Ish, 2020). The Lower Columbia Chinook Salmon is the other fish on the Oregon endangered species list. This fish inhabits a region stretching from Bonneville Dam west to the Pacific Ocean.

Chinook Salmon runs through tributaries of the Columbia, including the Willamette. The Willamette basin has been dammed significantly since the 1930s, preventing chinook from returning to their native spawning grounds and altering their habitat (NOAA, 2014).

The Endangered Species portion (*es)* is calculated by determining the prevalence of an endangered species on a specific waterway. If a waterway has one of the three endangered fish species (according to ODFW), that dam is scored with an additional three points. If the dam contains a federally threatened fish, it receives one point per fish. Thus, the final formula for the *F* variable looks like this:

$$(.01(fpbp(x)) +/-ds)+(es)$$

Cougar Dam is one of the 13 Willamette Valley Project dams constructed in 1963 (USACE, 2019). It is on the south fork of the McKenzie River and is 519 ft. tall, making it the tallest dam in the state. When the dam was built, it had a fish passage system to transport adult and juvenile fish past the barrier to upstream sections of the McKenzie. The dam caused water temperatures downstream to increase, which reduced fish from migrating upstream. With no fish using the fish passage system, it was scrapped. The Army Corp of Engineers installed a temperature control tower completed in 2005(USACE, 2019). This tower allows operators to pump water from various depths behind the dam to be released, avoiding releasing warm top-level water heated by the sun (USACE, 2019). This has been successful, as downriver temperatures decreased and salmon have returned to the foot of the dam. With fish back, scientists devised a genius solution to get them from below the dam to their spawning grounds: trucks. ODFW and the Army Corp of Engineers load Chinook Salmon, Bull Trout, and other fish into trucks and drive them upstream past the dam (USACE, 2019). Fish migrating downstream

from above the dam need help passing it. A USGS survey shows that 56.8% of hatchery fish and 48.2% of wild fish during fall could pass the dam using the temperature control tower (Beeman, 2014, p.1). For these reasons, Cougar Dam has a score of 1 on the fish passage device score (*ds)*.

The ODFW Fish Passage score is 511, and the dam has harmed Juvenile Spring Chinook, meaning Cougar scores a 5.11 on *fbbp(x)*. Lower Columbia Chinook Salmon historically migrate past the dam, and the dam has locked them out of their historical range, giving *es* a value of 3. Therefore, the Cougar Dam's F score formula is:

$$(0.01(511)+1)+3=9.11$$

This is a high score, but deservingly so. The ODFW has Cougar Dam listed as the 18th worst dam for fish passage in the state, and it has been the subject of criticism regarding its failure to support a healthy ecosystem.

Calculating C:

C combines indigenous sovereignty (*IS)* and collaborative action (*CA)*. Each section is crucial to dam removal. Scoring this variable requires understanding previous treaties granted to tribal nations regarding water rights and fishing access. Legal protections for these rights often permeate dam removal debates and catalyze action by non-profits and government organizations (Gosnell, 2010, p. 371). If treaties have been broken because a dam altered a waterway or fishing site, that is grounds for a high score of *C.* The removal of barriers on the Klamath was primarily led by tribes in the Klamath Basin that advocated for their removal and received backing from government offices and non-profit organizations (Gosnell, 2010, p.363).

In most cases, Sovereignty is closely tied to food sovereignty and the protection of traditional dietary staples such as wild rice and salmon (Whyte, 2017, p.2). Dams can uniquely

harm sovereignty when they eliminate access to these foods or if they uniquely displace populations or cultural significance.

Suppose there are currently tribal efforts to remove a specific dam for sovereignty or cultural reasons; that gives this score a higher value. This demonstrates not only a desire for that dam to be removed but that there is a history that the dam is erasing. If a tribal organization actively advocates for removing a barrier, it scores a six and is denoted as *(ta)*. One way to achieve this score is through legal means. In 2019, The Nez Perce Tribe issued a legal complaint against Oregon over dams on the snake river, including Brownlee (Nez Perce, 2019). This petition would constitute a current effort by a tribe to remove a barrier. Another way to achieve this section is through protesting broken treaties. Fishing rights are protected in *U.S v Oregon* and *U.S. v. Washington*, two court cases that rule tribes are entitled to an equitable share of the salmon harvest and their historic instream rights (Goodman, 2000). Bringing violations of these rights to court demonstrates a legal need to act against a dam and shows a commitment by the tribal government to remove the obstruction.

Collaboration is intertwined with indigenous sovereignty, as tribal governments have been leaders on negotiating boards for removal projects. On the Klamath, success was primarily due to cooperation between stakeholders to create a legal and feasible solution to their ongoing crisis. The tribes were crucial in planning initial settlement agreements and persistently fought for an answer throughout the negotiating process (Gosnell, 2010, pp. 374-375). Dam owners are constricted to government contracts to run their dams, granting the government an inherent bargaining chip when negotiating a potential removal. When the government and local stakeholders are impacted by the dam (for better or worse), getting together and collaborating on a solution will yield a positive outcome.

Scoring collaboration requires information on the number of parties interested in a dam's potential removal and the presence or strength of public negotiations. The KBRA was signed by over fifty stakeholders, representing decades of work to solve the ecological crisis in the basin. This movement had many participants and a robust charter pushing stakeholders toward a resolution. The KBRA should be a model for future dam removals and an influence in scoring this variable. The score depends on the presence of an agreement that dictates the goals of each stakeholder and a common objective. This agreement will be denoted as *(sa)* for stakeholder agreement. If a contract exists, it has scored a 3. Additional scoring is given to the amount of pressure and action by entities to remove specific dams. Public pressure and government action have been crucial in the Klamath Basin. This section of the formula represents pressure's success in the Basin. Pressure, denoted by *(p),* can be identified in newspapers, non-profits, and government expenditures. The value of pressure is judged on the presence of significant removal articles, treaties, or movements outside of a general agreement. The equation below shows where (*x*) is a specific dam.

$$C=sa(x)+p(x)+(ta)$$

Sticking with the example of Cougar Dam on the McKenzie River, we can calculate a score for *IS.* Cougar Dam was built on land historically belonging to the Molalla tribe. The Upper Santiam band of the tribe inhabited the western part of the cascades in present-day Lane and Linn counties, including the site of the cougar dam (USACE, 2019). Little is known about this Molalla band (Zenk, 2022). The Molalla tribe was moved to the Siletz or Grand Ronde Reservations during the 1850s. Several archaeological sites have been uncovered in the reservoir

above Cougar Dam, but a review of the Government Land office identified no historic resources (Zenk, 2022).

Additionally, there are no formal calls to remove the dam by the Molalla tribe or others, meaning that the *tribal protest* section scores a zero. The test subject of Cougar Dam *sa(x)* would be zero because the dam has no stakeholder agreement regarding the removal nor has pressure to remove it broken through the reasonable bounds of the internet. Although Cougar is a dam with problems, a solid effort to remove it has yet to exist. For Cougar Dam, the overall score for *C* would be zero because neither of these sections produces a score.

Calculating A:

Most dams that get removed for age are older than 40 years. The USGS database on dam removal shows that the average age of a dam being removed is 93 years. The mode, or most common age of a dam being removed, is 49 years (USGS, 2023). For these reasons, it makes sense to start assigning value at age forty and progressively increase it as time passes. In this scoring, a dam gets a score of four at age forty, and each decade after, it increases exponentially. Using this exponential equation where *a* is the age of the dam and *e* is Euler's number you can assign a value for *A*:

$$2.3094e^{0.0137a}$$

Years	A Value
40	3.994777
50	4.5813227
60	5.2539898
70	6.0254234
80	6.9101252
90	7.924726
100	9.0882989
110	10.422717
120	11.953065

Table 2: Values for *A* based off dam age

This table shows the applicable score based off how old a dam is in years. It is based off the above exponential equation where *a* is years.

Also included is a table for how each year is represented by a value using the above formula (table 2). Using this formula on an example dam, Cougar, which is 59 years old, we simply plug in 59 for *a* and get 5.18 for *A*.

Calculations for Anti-Removal Variables

Calculating EP:

Hydroelectric dams provide Oregon with a green source of energy that powers the state without releasing greenhouse gasses that would contribute to climate change. The U.S. Energy Information Administration records indicate that 39% of Oregon's total electricity is generated by hydroelectric power (EIA, 2022). This power is generated at dam sites, where the gravitational potential energy in a flowing river is transformed into electrical energy and put onto the grid. Of Oregon's 31,920,643 MWh of hydropower generation, 10,972,309 MWh is exported to other states, representing a significant economic benefit for the state (Oregon Department of Energy, 2016). Most importantly is that this energy powers people's homes. Not all dams in the state produce hydroelectric energy; most of the energy comes from a few enormous dams on the Columbia River. Oregon has a total capacity of 8,923 MW3. Of that, 6,400 comes from dams on the Columbia River (EIA, 2020). The rest of the state's hydroelectric dams produce energy used on local energy grids or to power irrigation projects.

A score for this section depends on how much energy a dam produces. Outside of the dams on the Columbia, only one dam has a capacity of over 500 MW, Brownlee Dam on the

[3] MW and MWh are two different units of measurement. A Megawatt is a measure of power capacity of an electrical system and a Megawatt hour represents how much electricity is delivered through a system in an hour.

Snake (EIA, 2020). Rewarding dams that produce more significant amounts of energy is the objective, so a point will be awarded for every 50 Megawatts of capacity a dam has. Thus, the following equation:

$$EP= .01*MWc(x).$$

Where MWc(x) is the megawatt capacity of X dam. Any dam with power over 600 MW automatically receives a 12. A twelve is only reserved for four dams on the Columbia; The McNary, Bonneville, Dalles, and John Day Dams.

We can get a score for Cougar Dam using the Energy Information Administration data on hydroelectric energy production. The dam has a capacity of 26 MW; therefore, its EP value would be .52 (USACE, 2019).

Calculating FC:

Dams reduce the flood stress river adjacent populations have to deal with. Flood control is crucial to a government's commitment to protecting people and communities. In Oregon, only 40 barriers are built to prevent floods, according to the USACE. Dams that prevent downriver flooding and protect population centers are essential. If a barrier reduces the risk of downstream flooding, it should remain active as a simple security matter. While there are broad issues with preventing flooding, this research aims to provide a realistic idea of the likelihood of removing a dam, and under very few circumstances would governments remove a barrier that was protecting citizens from a natural disaster.

To stress the importance of flood protection as an interest of the state, any dam built to reduce downstream flooding should receive twelve points. Not all barriers are made to reduce flooding, and those that provide more minor flood control impacts should be rewarded fewer

points. Remote dams that minimize the risk of flooding for less than 500 people should receive half the points. Dams upstream of other “flood control” operations and in remote, unpopulated areas should not be considered flood control dams. For example, Brownlee Dam on the Snake River is only 13 miles upstream from Oxbow Dam, which provides similar services (Idaho Power, 2023). The 21 permanent inhabitants between the two dams is far below the 500 thresholds mentioned earlier (Sedax, 2023). The reservoir behind Brownlee controls the Snake River's flow and limits the potential flooding of the Columbia Basin. Still, with six other dams on the Snake, before it reaches the Columbia, this dam's unique utility is minimal. Dams like Brownlee should not receive flood control points because it lacks unique utility.

The example of Cougar Dam is less bleak than Brownlee. This dam was built with the primary purpose of reducing flooding and quickly scored a 12. This project controls the flow of the McKenzie and, along with the Blue River Dam, helps monitor the water flow of the McKenzie as it approaches Eugene and Springfield.

Calculating I:

Most dams in Oregon were built for irrigating agricultural lands. These dams have been significant for the economy and health of the state and its citizens. Unfortunately, these dams have affected the state's wildlife and ecosystems. Pinning the blame on irrigation is a logical step for environmentalists that see all barriers as harming the natural equilibrium of the state. Finding alternatives to irrigation systems reliant on dams is ongoing, and some other options exist, but the problem seems too monumental to solve. The removal of Savage Rapids dam, among others, demonstrates the possibility of moving away from traditional reservoir-based irrigation and towards a more sustainable approach.

Scoring *I* is based on the size of the irrigation district the dam is providing water. It also depends on how much water the barrier adds to that irrigation district. Dams control water levels and fill rivers with water during dry seasons, allowing irrigators to pump water year around. Cross-applying dam location with rates of regional water withdrawal, based on spatial data from Franczyk and Chang, helps reveal how vital a dam is for irrigation. *I* is primarily based on the acre-feet of water a dam provides an irrigational district. Determining how much water a dam directly adds to an irrigation system can be measured from Irrigation District websites that display their water sources. The acre feet number can be difficult to compare across districts, so basing it off the size of the agricultural basin will determine the score for *il* (irrigated land). The state's eastern half is significantly drier than the west, meaning irrigation is essential to year-round crop growth. A barrier in a predominantly arid region where damming is necessary for irrigation receives a higher score. Measuring the severity of drought comes from the U.S. drought monitor from the University of Nebraska, which shows the severity of drought in Oregon on five levels (No drought being one and exceptional drought five) (University of Nebraska, 2023). Each movement up the severity score receives a score of one. This drought score is only applicable if the dam/reservoir is used for irrigational purposes.

$$I=il(x)+ds$$

Data Used

This section examines the Data of each dam used in this research. This section will briefly explain each dam and then provide information about the dams used to run calculations to determine if the dam can or cannot be removed. Six dams are highlighted in this section, and the numbers, after being run through the equation, will appear in the results section.

JC Boyle Dam: JC Boyle is one of the four dams on the Klamath that is set to be removed starting in the summer of 2023. This dam acts as a control for the equation.

Hydro: 98.7 MW Capacity

Irrigation: This is not an irrigation dam. This dam only acts to produce power for the Klamath Basin (Aschbrenner, 2012).

Flood Control: Dam also provides no flood control benefits (Aschbrenner, 2012).

Fish: *fpbp* score: 660 (ODFW, 2019). The dam is part of a system of dams that harm migratory salmon and steelhead, including Coast Coho, which are threatened federally (ODFW, 2021). That being said, this is one of two dams with a fish ladder system, allowing migratory fish to travel past it.

Collaboration: Obviously, this dam is part of the KBRA that will see it destroyed in the coming years. This is a massive collaborative effort with 50 stakeholders signing on. Tribal movements have been very vocal about the need to remove JC as part of an effort to restore the Klamath Basin (Gosnell, 2010).

Age: 65

Lookout Point Dam: This is a giant dam on the middle fork of the Willamette River. It is one of the thirteen USACE dams in the Willamette Valley used primarily for flood control. It is 276 ft tall and near Lowell, 20 miles from Eugene (USACE, 2021).

Hydro: 120 MW Capacity (EIA, 2020).

Irrigation: Like the other USACE dams in the Willamette Basin, the lookout point dam supplies important water during dry summer months for Oregon's most productive agricultural area. The dam releases water from its reservoir to help maintain the flow of the Willamette River for Recreational, hydroelectric, and irrigational uses. It is unclear how much water is directly used for irrigational purposes, but it is known that the 13 dams dedicate a combined 327,650 acre-feet of water to irrigation (Jamin, 2022). It is in the area of least concern for droughts (Nebraska University, 2023).

Flood Control: USACE built this for flood control. Protects Southern Willamette Valley, including Eugene, from Willamette River Flooding (USACE, 2021).

Fish: *fpbp* score: 710 (ODFW, 2019). Lookout Point dam has no fish passage device, but some fish are out-planted above the dam using trucks (USACE, 2019). According to the Federal ESA, this dam impacts two threatened fish species: Upper Willamette River Chinook Salmon and Upper Willamette River Steelhead. (ODFW, 2021)

Collaboration: Minimal Collaboration to Remove the dam. No legal action by tribal governments or formal agreement between stakeholders to remove the dam

Age: 68 (EIA. 2020)

Brownlee Dam: One of the three dams in the Hells Canyon Project, Brownlee is on the Snake River as it flows between Oregon and Idaho. Brownlee is a 420-foot hydroelectric dam operated by Idaho Power Company. (NPCC, 2023).

Hydro: 585 MW Capacity (EIA, 2020)

Irrigation: Brownlee helps regulate powder river which is a tributary of the Snake in Eastern Oregon. This river is an irrigational hub for the Baker Project that helps irrigate 7,300 acres of

land along the river (USBR, 2023). This is a decent amount if irrigated land especially in eastern Oregon. It is in a drought zone with a score of two

Flood Control: Brownlee provides minimal flood control benefits. USACE reduced the level of Brownlee Reservoir in March to prepare for increased flows from snow melt (Graban, 1964, p.42). Six dams downriver could accomplish similar objectives, including Oxbow dam, which is 13 miles away (Idaho Power, 2023)). This dam still provides small utility for flood control, but nothing unique.

Fish: *fpbp* score: 645 (ODFW, 2019). No fish passage device exists (NWPCC, 2018). Snake River Sockeye is Endangered federally, and three other fish are threatened (ODFW, 2021).

Collaboration: The Nez Perce tribe issued a legal appeal for removal in 2019 (Nez Perce Tribe, 2022). The dam eliminates migratory fish from traveling to the upper snake river, posing significant harm to fish cultures in the region. This petition aims to recognize historic fishing rights on the Snake River (Nez Perce tribe, 2022). There is unity among tribal groups regarding the dams on the snake and their impact on migratory fish (Ibid). A formal agreement like the KRBA still needs to be implemented to remove these dams.

Age: 64 years (EIA, 2020)

Pomeroy Dam: This is a small dam on the Illinois River, a tributary of the Rogue, in Southern Oregon. It is a privately-owned irrigation dam that has been the subject of increased criticism by environmentalists in recent years. This dam is representative of most dam removal efforts in Oregon and is well-reported for its size (Chinook, 2023).

Hydro: 0 (Chinook, 2023)

Irrigation: Primarily used for Irrigation on the Illinois River and privately owned by Q Bar X Ranch (Chinook, 2023). The ranch irrigates Alfalfa and Hay. The amount of water used for irrigation is not available. The dam is in a drought area with a score of 1. There has been an agreement that a new irrigation infrastructure will be installed if the barrier is removed (Ibid).

Flood Control: The dam does not provide any utility for flood control.

Fish: *fpbp* score:494 (ODFW, 2019). dam Blocks 100 miles of Salmon and Steelhead Habitat in the rogue valley, specifically impacting Southern Oregon Coast Coho, which is federally listed as threatened (ODFW, 2021). The dam has no fish passage device (Chinook, 2023).

Collaboration: Water Watch Oregon (WWO), an organization aiming to restore and protect rivers and native fish, has helped advocate for removing this dam and others on the Illinois River. The dam owners and WWO agreed to work together to remove the barrier with little to no costs to the owners. Pressures from the WWO and the public have been intense, yet no movement from tribal organizations exists (WWO, 2021).

Age: 45

Keno Dam: Keno dam is the first dam upstream of the four dams to be removed on the Klamath River. This dam was built to regulate water flow in the Klamath before it entered the hydroelectric sites downstream (Durio, 2003).

Hydro:0

Irrigation: Keno was built for water regulation purposes and does not serve the Klamath project for Irrigation. Private irrigation occurs in the Keno Reservoir above the dam (Pacificorp, 2004).

Flood Control: Keno was not built for flood control purposes.

Fish: *fpbp* score:694 (ODFW, 2019). Keno dam is one of the few Klamath ams with a fish ladder system.

Collaboration: Keno is included in the Klamath Hydroelectric Settlement Agreement, where it is highlighted that the dam's rights will be transferred from Pacificorps (who currently owns it) to the Department of the Interior (KHSA, 2010, p.42). This section indicates no desire to remove it and includes plans for the dam's operation post-transfer. The Karuk tribe issued a statement advocating for the Keno dam because it re-regulates upstream unsteady flows generated from the Klamath Irrigation Project (Craig Tucker, 2016).

Age: 65 (ODFW, 2021)

Cougar Dam: At 519 feet tall, this is the tallest dam in the state. As part of the 13 USACE dams, Cougar regulates the flow of water on the south fork of the McKenzie River. (USACE Portland, 2023)

Hydro: 26 Mw Capacity (USACE, 2019)

Irrigation: Cougar Reservoir is not directly irrigated, but during summer months, water is released to maintain the flow of the McKenzie and Willamette. This process helps irrigators out when water would otherwise be scarce. No readily available statistics show what portion of the water released during the summer is used for irrigational purposes. Still, the 13 Willamette Basin has 327,650 acre-feet of water for irrigation (Jamin, 2022). It is in the second lowest drought zone area (scores a one).

Flood Control: This dam was built primarily with flood control in mind. The USACE built this dam, along with 12 others, to protect the Willamette Valley from floods and store water.

Fish: *fpbp* score: 511 (ODFW, 2019). Like Lookout, this dam is without a fish passage system and is home to Endangered Chinook (USACE, 2019).

Collaboration: As discussed earlier, this dam has no ongoing removal efforts. Some artifacts have been discovered in the Cougar Reservoir, but no tribal governments have issued a statement against the dam.

Age: 59

Results:

	FC	I	HE	Keep Score	F	CA	A	Remove Score	Total
Brownlee	2	8	11.7	**21.7**	11.45	8	5.549944	**24.99994352**	**3.2999**
Keno	0	3	0	**3**	7.94	3	5.626501	**16.56650096**	**13.567**
Pomeroy	0	6	0	**6**	7.94	5	4.278009	**17.21800915**	**11.218**
Lookout	12	7	2.4	**21.4**	11.1	0	5.862568	**16.9625681**	**-4.437**
Cougar	12	7	0.52	**19.52**	9.11	0	5.182501	**14.29250096**	**-5.227**
JC	0	0	1.974	**1.974**	7.6	12	5.626501	**25.22650096**	**23.253**

Table 3: Results table based off data points

This table represents the scoring breakdown for each dam based off the equation created in the above sections. This table holds the scores for each variable, the combined score for keeping a dam, the combined score for removing a dam, and a total score for each dam. The lower numbers in the total's column indicate a dam that is unlikely to be removed

After running the calculations for the dams above it is clear what ones are more likely to be removed. JC Boyle had the highest score by some margin, largely due to the existing agreements to remove it. This gave JC an edge in the collaboration category which was relatively insignificant for other dams. The two dams in the Willamette basin, Lookout and Cougar, received the two lowest scores. This was largely due to their importance as flood control dams and a lack of motivation to remove them. Pomeroy dam and Keno dam were very close in points, and based off this logic would be the next two dams to be removed. Pomeroy is already on the chopping block and Keno could be the next major removal project in the Klamath.

Brownlee dam had the highest score for keeping the dam and the second highest score for removing it. This dam provides great utility for local irrigation and hydroelectricity, but has a handful of issues making it controversial. Even though Brownlee had a high collaborative action score it's benefits to irrigation and hydroelectricity make it unlikely to be removed according to this equation. Below are three tables outlining the scores for each individual sub variable.

	tp	sa	p	CA		MWc	HE
Brownlee	6	0	2	**8**		585	**11.7**
Keno Dam	2	0	1	**3**		0	**0**
Pomeroy	0	3	2	**5**		0	**0**
Lookout	0	0	0	**0**		120	**2.4**
Cougar	0	0	0	**0**		26	**0.52**
JC	6	3	3	**12**		98.7	**1.974**

Table 4: Sub Variable Breakdown for Collaboration and Hydroelectric

this table shows the scoring breakdown based off the sub-variables. Here the scoring breakdown for Collaborative Action and Hydroelectric Energy are presented

	fbbp	ds	es	F		a	A
Brownlee	645	2	3	**11.45**		64	**5.549944**
Keno Dam	694	0	1	**7.94**		65	**5.626501**
Pomeroy	494	2	1	**7.94**		45	**4.278009**
Lookout	710	2	2	**11.1**		68	**5.862568**
Cougar	511	2	2	**9.11**		59	**5.182501**
JC	660	0	1	**7.6**		65	**5.626501**

Table 5: Sub Variable Breakdown for Fish and Age

This table breaks down the scoring for two of the variables based off their sub variables. In this it is breaking down age and Fish.

	Fc		il	ds	I
Brownlee	**0**		6	2	**8**
Keno Dam	**0**		2	1	**3**
Pomeroy	**0**		5	1	**6**
Lookout	**12**		6	1	**7**
Cougar	**12**		6	1	**7**
JC	**0**		0	0	**0**

Table 6: Sub Variable Breakdown for Flood Control and Irrigation

This table breaks down scoring for flood control and irrigation by examining the sub variables.

Discussion

The findings indicate that dam removal in the state can occur on a larger scale than in the status quo. Large dam removal projects, like the Klamath, can be one of many types of dam removal occurring. More emphasis should be placed on dismantling smaller dams that provide minimal utility. The benefit-to-cost ratio is most significant when a dam is built on a large river with fish passage devices. Dams like Brownlee demonstrate how larger projects can outweigh their issues by benefiting the public in multiple ways. Brownlee Dam, and others on the Snake, have been the subject of criticism over recent years, mainly relating to their poor fish passage infrastructure. Constructing fish passage apparatus on these rivers would quickly reduce the hate these dams experience. Keno is an excellent example of that. The fact that it has a fish ladder saved it from being removed like the four dams below it.

These findings also confirm the importance fish have on the dam removal process. Projects like Lookout Point and Cougar do not have large movements advocating for their removal. However, they receive significant attention and criticism for their lack of fish passage devices. Oregon law forces dams to install devices if needed, and today large dams still need essential passage technology like fish ladders. Most barriers that get removed in Oregon (for reasons outside of age) are removed because of a failure to protect fish rights. It would make sense for productive dams to install fish passage devices to avoid the state cracking down on them, but that does not seem to be happening.

Surprisingly, the results indicate the importance of flood control as a concept. The Willamette Basin dams examined have minimal benefits outside of reducing flood risk. That seems enough to keep them operational, as no one strongly advocates for their removal. The Hypothesis that dams with low fish passage scores and high collaborative action attempts would

be removed was not necessarily proven true. There needs to be more data to confirm one way or another, but Brownlee Dam demonstrates that bad fish passage scores and a solid movement for decommissioning the dam are not the only factors that matter.

A lack of a few essential resources limited this study. Most important was irrigation statistics. Statewide data on the acre-feet of water from specific reservoirs was not readily available for public use. This made creating a formula for irrigation difficult and caused the category to be more qualitative than quantitative. Having this data would deliver more accurate results and create a formula that could be re-applied to other states. The formula and logic can still be helpful if data is available; it just needs to be modified to reach the scale the data presents. Another issue was the variety of dams in the state. The state has over 800 dams shorter than 30 feet (USACE, 2023). Except for Pomeroy, every dam examined was taller than 30 feet. There needs to be more data for smaller private dams to determine when they should be removed. Most dams in the state are small private dams used for irrigation, and information on those dams tends to stay private. On that note, this research is only possible with the Army Corps of Engineers providing extensive non-bias information on their dams in the state. The most surprising conclusion drawn from this project was how much information the USACE provides on its dams.

Another recurring issue was quantifying social movements. Quantifying indigenous activism and joint movements is impossible to do. Finding a way to quantify these qualitative variables was a minor goal of this research that could be improved upon in the future. When studies quantify lived experiences, it inherently takes the value of those experiences. The reality of dam Removal is that it is not a quantitative event. It is more closely tied to social movements and court proceedings than anything else.

Weighing all statistics with the same value is also an inherent limitation of this research. This method ignores any bias the state may give to one factor or another. Doing it this way was a simple issue and allowed the research to be more flexible, given the missing data. When looking for future research, one should implement a scoring system that more adequately accounts for the inherent discrepancies between these factors. The state of Oregon prioritizes fish passage over other variables examined in this paper, meaning it should be weighed heavier than other factors. The state has yet to demonstrate a desire to remove dams with a poor fish passage score if they provide other types of utility (like Brownlee).

Another limitation is quantifying the collaborative action section. Collaborative action is a qualitative variable and is rarely present unless a dam is being removed, removed, or about to be removed. In this research, collaborative action tends to be a moot statistic unless the dam is criticized publicly. This formula does an exceptional job of rewarding protestors and collaborators who are presently advocating for the removal of a dam. However, it does not account for future protests that could erupt because of a dam's inherent flaws.

Considerable work still needs to be done in this field to determine a proper understanding of dam removal and its variables. This research gives an excellent outline for that process and highlights some fundamental processes that go into dam removal in Oregon.

Conclusion

This study examines the crucial variables to consider when removing a dam. By examining these variables, the research develops a simple mathematical equation determining the likelihood that a dam will be removed. This equation is then applied to a handful of dams in Oregon to see which ones should be removed in the future. Based on the results, Dams that provide multiple services are less likely to be removed when compared to dams that accomplish only one task. A large portion of this research is based on fish passage on rivers. The consensus is that dams with fish passage devices are less likely to be removed than those without them. Fish passage is the primary legal path for removal in Oregon. The removal of four dams on the Klamath is primarily due to pressures by state and federal governments towards the owners to install fish passage devices on the dams.

Future Dam removal projects can be accomplished by looking for legal routes for removal. Simply conversing about a dam's negative impact can tremendously affect its removal. The court of public opinion continues to impact removal significantly as it pressures private and public actors to remove or improve the structure. As Oregon moves towards a framework less concerned with dam development and more focused on sustainability, there will be more decommissioning of large dams. This research provides a stepping-off point for advocates interested in understanding the dam removal process and determining what dams could be next.

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