The Effects of Pond-Leveler Devices on Salmon Migration through Restored Riverine Beaver Pond Complexes

By

Bridger Machus & Helena Wilson

A Senior Thesis in Partial Fulfillment
of the Requirements for the Degree of
Bachelor of Science

Natural and Environmental Resource Management Option
School of Environmental and Forest Sciences
University of Washington
Box 352100
Seattle, Washington 98195-2100

Year
2018

Approved by _____
Faculty Thesis Supervisor

Date_____

_____ _____
Bridger Machus Helena Wilson

Abstract:

The North American beaver (*Castor canadensis*) is a keystone species and ecosystem engineer, capable of modifying the landscape and creating diverse habitats for other species. While beavers greatly alter landscapes, often in ways beneficial to native habitats and species, their dam-building can also create conflict with human land-use and infrastructure. One way to reduce human-beaver conflict is to adopt non-lethal approaches such as the use of pond-leveler devices. Pond-levelers, consisting of a pipe through the beaver dam with a cage around the inlet, control the water level of the pond by establishing a desired level, thereby reducing flooding and allowing beavers to persist. Little observational evidence exists, however, on whether pond-leveling devices create migratory fish barriers or otherwise impede fish passage. The objective of this research was to evaluate whether migrating salmon can pass through beaver dams fitted with standard pond-leveling devices, or around them under high flow conditions. We tested this by observational analysis at two pond-levelers on Big Spring Creek, King County, Washington during the 2017 autumn salmon migration. Target migrating species include chinook (*Oncorhynchus tshawytscha*) and coho salmon (*Oncorhynchus kisutch*). While we observed no migrating salmon due to historically low runs in our study system, we characterized stream hydrology throughout the migration window. During prolonged precipitation events stream stage overtopped dams, providing unhindered passage in our study areas. When dams were not submerged, passability was determined by evaluating whether a salmon's sustainable swim speed exceeded that of the observed stream velocity. During the 2017 migration period, over-dam stream velocity and through-dam velocity (i.e. within the pipe) were passable by adult salmonids during all periods of observation. The management implications, such as the increased use of pond leveler devices, of these results will help determine future strategies regarding beaver management at Big Spring creek as well as at other sites with similar ecological concerns.

Introduction

The Pacific Northwest is home to the iconic North American Beaver (*Castor canadensis*) and Pacific salmon. Certain salmon, such as the Puget Sound Fall Chinook, are threatened within Washington State. Because salmon are at risk, habitat restoration has become a conservation priority. Stream habitat restoration projects can attract beavers, due to the creation of favored beaver habitat. Once a beaver colonizes an area they will often build a dam to create a pond, which can cause flooding (Naiman et al. 1988). Flooding can increase the risk for habitat restoration project of failure or of not meeting design goals since the landscape can undergo such dramatic change, with potential unintended consequences to the restoration site. In some settings, pond-lever devices, which consist of plastic pipes that are inserted into beaver dams to control flooding and allow for water to flow through the dams (levelers, hereafter), can allow beavers and humans to coexist. Opinions vary, however, on how these devices affect fish movement and whether they impede upstream salmon migration. Although much of the existing evidence on this issue is anecdotal, concerns about fish passage continue to hamper widespread use of levelers across the Pacific Northwest, likely leading to a higher rate of lethal trapping, negating the benefits of beaver activity.

Salmon Habitat and Ecology

Anadromous salmon and freshwater ecosystems are inextricably linked; both migrating salmon and juveniles contribute to and consume within the food webs of a wetland (Gende et al. 2002). Salmon are predators within their trophic chain with a diet consisting of insects, invertebrates and other fish. Anadromous salmon begin their life cycle in stream gravels, migrate to the ocean where they feed and grow, and then return to the same stream where they were born, where they spawn and die shortly afterwards (Gende et al. 2002). Between their birth and final migration destination, many fish die. Those that are eaten provide sustenance to predators while those that are caught provide economic revenue for humans. Those that die along the way become part of the stream's food web, providing valuable nutrients brought from the ocean to the terrestrial river system (Gende et al. 2002). The salmon that make it to their natal stream and reproduce sustain future populations of salmon, population viability is a central focus of recovery efforts.

Salmon require habitat connectivity for upstream migration to spawning grounds. As salmon return from the ocean and swim upstream to their places of origin, barriers can impede migration, causing an increase in mortality and possibly preventing them from spawning.

Spawning gravel, habitat complexity, and juvenile rearing ground is essential habitat for salmon. Restoring stream heterogeneity, habitat complexity, and connectivity benefits salmon by increasing survival, especially in the early life stages (Anlauf-Dunn et al. 2014).

Recovery efforts have greatly increased since certain salmon species were listed as threatened or endangered under the Endangered Species Act of 1973. Within the past two decades, the United States has spent billions of dollars on aquatic habitat restoration (Battin et al. 2007). Restoration involves approaches such as planting trees along streams to provide shade and insulate cool water. Re-routing ditched streams to recreate natural meanders and increase habitat heterogeneity. Efforts are also being made to increase ponded surface waters for salmon refugia and foraging and adding large wood into river systems for improved complexity (Anlauf-Dunn et al. 2014). Regional groups such as the Puget Sound Shared Strategy for Salmon Recovery are focused on restoring habitat, removing species from the Endangered species List and protecting the health of thriving stocks to ensure continued success (Puget Sound Salmon Leaders' Forum 2000).

With increased development and human management of watersheds, the need for salmon recovery has become evident, and habitat restoration has become the primary focus of management. Retention of freshwater habitat is crucial for salmon survival, productivity and abundance (Roni et al. 2014). Habitat loss and fragmentation disrupts natural watershed processes that affect salmonid spawning and rearing habitat (Roni et al. 2014). Habitat restoration efforts are focused on restoring natural watershed processes that have been altered by humans to more historical conditions (Roni et al. 2014).

There are many natural and man-made barriers that may affect salmon's ability to migrate. These can be permanent or temporary barriers that depend greatly on flow conditions. Natural barriers include logs, wash outs, dry stream beds, fast water (i.e. areas with velocity higher than a fish's maximum swim speed), vertical drops and beaver dams. Anthropogenic barriers include dams, levees, floodways, causeways, weirs, culverts, flood control devices, roads, and stream re-routing. Barriers to salmon can vary greatly by species and life stage. Certain salmon species can swim faster for more prolonged periods than others, and juvenile salmon are typically slower than adults (Bell, M. C. 1990). All these factors influence salmon's ability to migrate past a barrier.

Beaver Ecology and interactions

Beavers are ecosystem engineers; they create, modify, and maintain habitat, often enhancing an ecosystem's resilience, species richness and biodiversity. Beavers modify the hydrology, biotic properties and geomorphology of the landscape (Rosell et al. 2005). Beavers alter the hydrology of riparian and wetland ecosystems by building dams in streams, which create beaver ponds. Beavers increase landscape heterogeneity, producing a diversity of habitats that can support an increased richness and abundance of species (Rosell et al. 2005). This greatly increases ecosystem resilience, allowing the ecosystem to resist perturbations and recover from disturbances faster (Rosell et al. 2005). Beavers change the species composition of the landscape as well as how the landscape functions (Rosell et al. 2005).

Beavers are considered to be a keystone species because they have a disproportionately large effect on their environment relative to their abundance (Paine 1966). Beavers create interactions between the environment and other species. They affect mammals, birds, amphibians, benthic organisms and fish. In the processes of a beaver modifying its landscape, it will remove a large amount of woody plant matter, creating space for faster-growing grasses and shrubs to the benefit of many mammals such as deer and elk. Birds, such as waterfowl that thrive in wetland environments, benefit greatly from beavers by having access to increased surface water and foraging. Amphibians benefit from beaver ponds because of the increased standing water readily available. Increases in habitat heterogeneity through wetland creation promote a greater abundance and diversity of benthic organisms (Malison et al. 2014). Beavers affect fish by creating ponds that have increased thermal variability, which benefits many fish species. This thermal variability allows fish to find areas of preferred temperature, as well as provide more abundant foraging opportunities (Pollock et al. 2003). Fish often rely on beaver ponds for rearing, refugia during high and low flow, and for overwintering. Ponds also create new habitat for fish species, such as lentic specialist species, that previously might not have been able to survive in the area.

Beavers were historically very abundant, with the North American population once estimated at over 500 million (Naiman et al. 1988b). European demand for fur prompted a decline in beaver in the Pacific Northwest and much of North America following colonialization. By the early 1900's beaver populations were estimated to number less than 10 million (Naiman et al. 1988b). As Europeans expanded westward they altered the land as they went. Landscapes once dominated by forests were converted to farmland and new cities were built. Humans occupied more land, filled in wetlands, cut down forests, and straightened or channelized rivers and

streams. Following near extirpation in many areas, beaver populations remained low due to wetland habitat destruction and continued exploitation (Naiman et al. 1988). Many considered beavers to be pests that flooded fields and ruined their land, and as a valuable commodity for their fur.

Due to changing trapping laws, a lack of predators, and an abundance of forage and habitat the beaver population is increasing rapidly in some areas (Naiman et al. 1988). The purposeful reintroduction of beavers into ecosystems has also contributed to the recent rapid population growth in some locales (Rosell et al. 2005).

Restoration projects intended to create habitat for species such as salmon often create habitat for beavers as well. Salmon habitat restoration often focuses on improving fish passage, instream structures, floodplain and off-channel habitat, riparian improvement, sediment reduction, and flow augmentation (Roni et al. 2014). Projects that restore riparian vegetation, such as planting cottonwoods and willows, will consequently provide beavers with food and dam-building materials that may have been absent for a century or more.

With the continued expansion of beavers across their historical range, there come challenges as well as opportunities. The long-term benefits of having beaver in the landscape include increased hydrologic stability and ecosystem resilience (Law et al. 2016). Ecosystem services provided by beavers include the slowing of stream flow, reduced erosion, flood control and cleaner water that is caused by the filtration of pollutants in the wetlands created by beavers (Pollock et al. 2003).

Pond-levelers

As beaver populations continue to increase, so will the number of beaver dams and ponds. Beavers' propensity to create dams at the narrowest points in streams often coincides with the location of culverts and other infrastructure. Damming in these areas frequently results in the backwatering or flooding of roads, farmland, and other property. Beaver damming can cause damage to private property, which poses a direct conflict between beavers and private land owners (Laramie et al. 2009). This creates a challenge for the management of beavers, and to habitat restoration projects. If these dams are removed, beavers often quickly build or repair new dams. If beavers are removed, more beavers will recolonize the area since the habitat is ideal for beaver presence, revealing the difficulty and importance of management.

Non-lethal beaver management techniques, such as pond-leveler devices are becoming more widely used, especially in areas where conservation or restoration is a focus. Pond-leveler devices are an important tool for beaver management, most commonly in small streams with an average daily discharge less than approximately 10 cfs (Taylor and Singleton 2014). Levelers are a beaver management method used to reduce flooding caused by dams (Figure 1). A pond-leveler consists of a large diameter (over 10”) flexible pipe installed through a beaver dam to lower pond-levels and decrease flooding upstream. The pipe allows for water to flow through the dam, decreasing the dam’s water holding capacity. The inlet of the pipe, which is located upstream of the dam in the beaver pond, has a cage placed around it to prevent the beavers from detecting flow and plugging the pipe. In stream systems with higher discharge volumes, levelers can use more than one pipe to increase conveyance. The pipes transport water through them to bring water downstream of the dam.

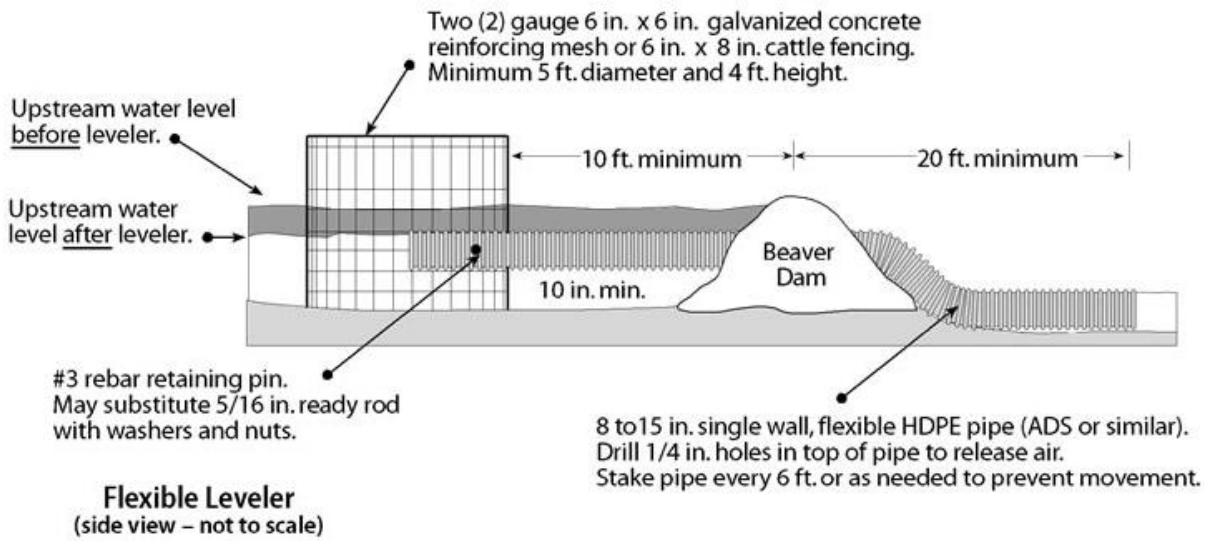

Figure 1 diagram of a pond-leveler device with pipe going through the beaver dam. This is the same style device used on our site (adapted from WDFW 2018.)

In systems with beaver dams and pond-leveling devices, salmon are likely to encounter levelers as they migrate upstream en route to their spawning ground. Beavers have been historically present in salmon-bearing streams; salmon have adapted strategies to migrate past these dams (Pollock et. al. 2003). Salmon are known to jump over beaver dams, maneuver themselves over dams, attempt to go around the dams, or pass directly through dams. When there is water overtopping the dam, which is often the case in high-flow winter conditions, beaver dams are

more passable for salmon migration. If, during the fall migration, water levels are low, and the beaver dam is significantly above water level, allowing no overtopping, the dam is potentially a more difficult barrier for salmon to migrate past.

The scientific literature has demonstrated natural beaver dams are usually passable for migrating salmon and other fish (WDFW. 2009) (Bouwes, N, 2016) (ODFW, 1997), but there has been little focus on the study of fish passage at dams where flow control devices have been installed. With the increasing presence of beavers in the Pacific Northwest the conversation surrounding this issue has become increasingly important. Pond-leveler devices are a non-lethal and humane beaver management strategy that allow beavers to remain in place, retaining many of the ecological benefits that they create. Some have voiced concerns that these devices may impede fish passage, however, resulting in controversy over their widespread use. Most of these concerns are based on anecdotal evidence; direct observations of whether these devices prevent salmon from migrating upstream past beaver dams are lacking. A greater understanding of how these devices influence fish migration is needed, as this approach is increasingly used as a beaver management strategy.

Objectives

In this study, we investigated whether beaver dams with flow control devices installed present fish passage barriers. Our objectives were to (1) characterize how pond-leveler devices affect salmon passage over beaver dams and by what means they pass through direct observation, use of remote wildlife cameras, and by fish snorkel surveys, (2) survey for adult salmon presence above and below dams to infer that passage has occurred, (3) characterize how the physical structure of dams with levelers installed affect localized hydrology during high flow events, and (4) compare flow conditions at levelers with known salmon swim speed limitations. Through these objectives we hope to provide evidence to inform beaver management in populated areas as well as address concerns regarding fish passage through levelers.

Methods

Research Area

We conducted our research on a stream within the Green River Watershed, near Enumclaw, Washington. This watershed is located on the west side of the Cascade Mountains, in King County, approximately 230 meters above sea level. The Green River is located on the Enumclaw Plateau, formed by a lahar from Mt. Rainer approximately 5,700 years ago. It is in the Foothills of the Cascades within the Pacific Coastal Ecoregion. The average annual precipitation in the basin is 192.7 cm of rainfall and 12.7 cm of snowfall. The basin has cold, wet winters and relatively warm, dry summers. Land cover in the basin is dominated by agriculture; mostly livestock. The general climate of the area supports vegetation such as Douglas-fir (*Pseudotsuga menziesii*), Western hemlock (*Tsuga heterophylla*), and willow species (Sitka, Pacific, Scouler's). Wildlife species present include, coho salmon (*Oncorhynchus kisutch*), chinook salmon (*Oncorhynchus tshawytscha*), Chum salmon (*Oncorhynchus keta*), pink salmon (*Oncorhynchus gorbuscha*), Coastal cutthroat trout (*Oncorhynchus clarkii clarkii*), Blue herons (*Ardea Herodias*), and North American beavers.

Our research site is located on Big Spring Creek, a tributary of the Newaukum Creek located in the Green River Basin watershed (Figure 2). This site was part of a restoration project by the King County Department of Natural Resources partnered with the US Army Corps of Engineers as part of the Green-Duwamish Ecosystem Restoration Project. This project aimed to relocate a stream that had been ditched and channelized back to its historic location, and in doing so, restored approximately 4,000 feet of stream habitat and 20 acres of wetland habitat. The project was intended to help protect endangered salmons refugia habitat and spawning grounds ("Newaukum Creek Basin Characterization Project Report July 2007"). The restoration of this site was completed in 2013 (Phase 1). The gradient of Big Stream Creek is 0.13% which contributed to the flooding caused by beavers. Low gradient streams are prone to beaver flooding because the site is easily able to be backed up by water over large areas. The project goal was to create a stream with meanders and 100-foot vegetated buffers around the stream. This section of the creek was colonized by several beavers in 2015 which built multiples dams along the stream, therefore there are now multiple beaver ponds on this site. The management of the beavers became necessary on this site when elevated pond-levels due to damming began to flood adjacent properties. Pond-leveler devices were installed at all beaver dams in 2016 to reduce flooding and stabilize pond-levels.

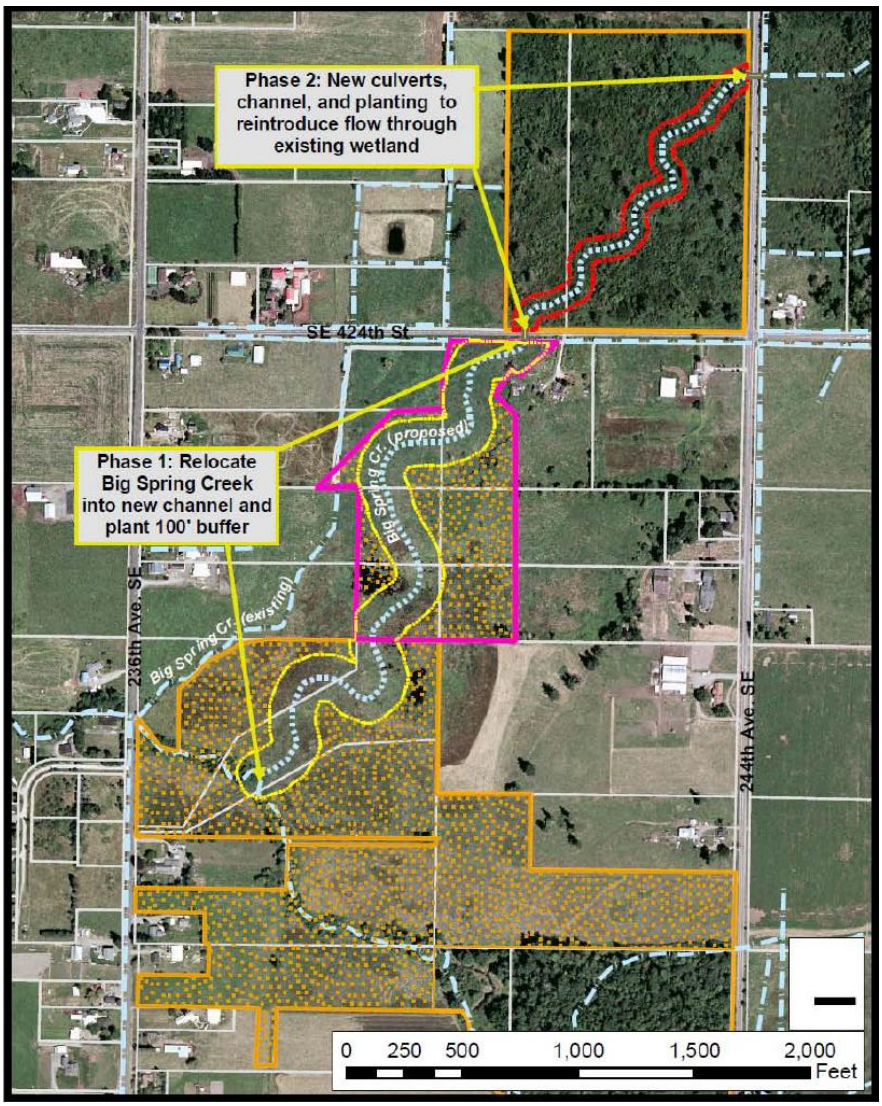

Figure 2 Research site location, Big Spring Creek, Washington State. Our research was conducted in Phase 1 of this figure. Note the sites proximity to the surrounding farmland and the restored meander to the creek.

Currently, within our study area at Big Spring Creek, there are five pond-leveler devices and four beaver dams (Figure 3). Most of our research was conducted at pond-leveler Device 1, Dam 1. We began our research here under the assumption that if salmon cannot make it past Dam 1 then they will not make it to any of the other dams upstream. We focused our observations to Dam 1 and Dam 2 during this study.

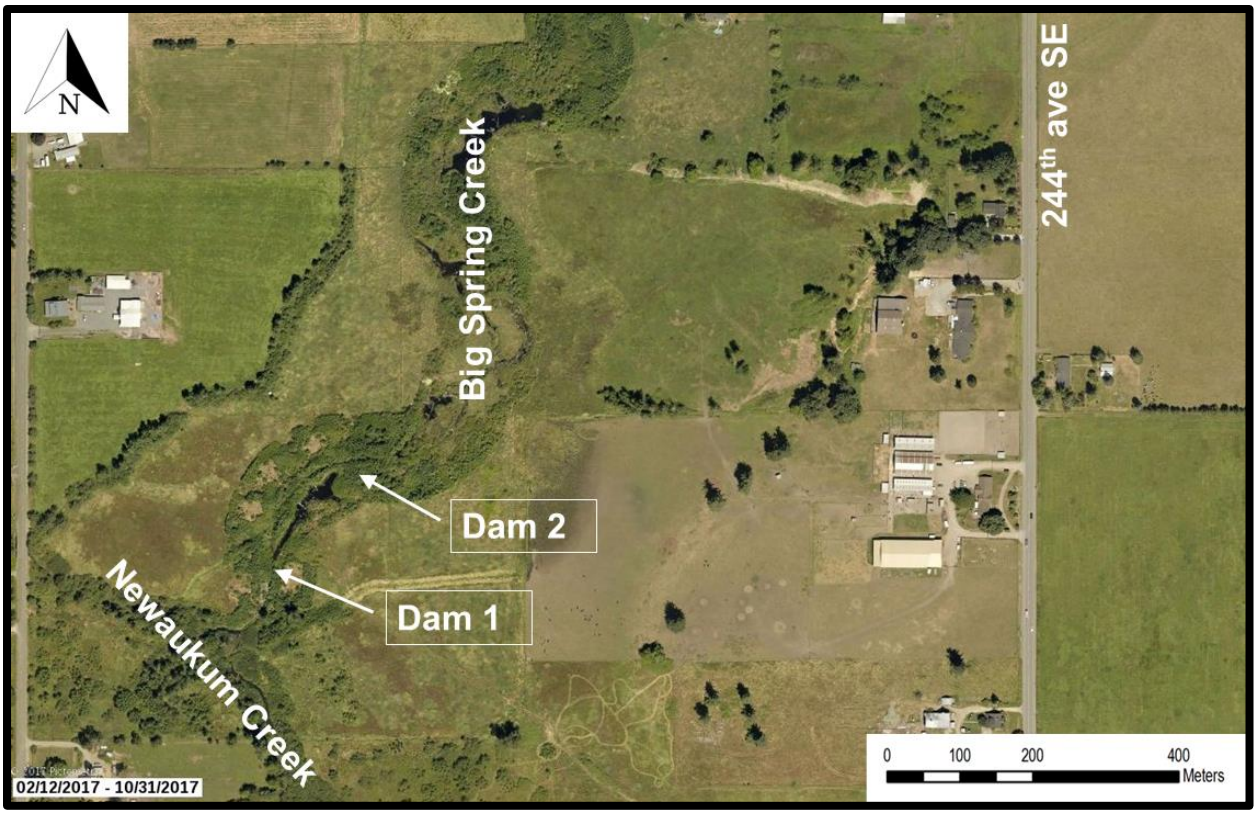

Figure 3 Big spring Creek research site showing visible beaver ponds above dam 1 and 2, along with Newaukum Creek and 244th ave SE for global reference.

Observation of fish presence and interaction with dams and pond-levelers

We conducted our research between October 10th, 2017 and November 28th, 2017. The site was monitored twice per week over this period, for a minimum of two hours per visit for direct observations of the fish presence and movement.

We conducted several types of observation in monitoring fish presence and migration (Table 1). We used direct observation, motion-detecting wildlife cameras, a daytime snorkel survey, and carcass counts. We conducted fish surveys which included identification of salmon species, abundance, location, time and energy required per passage attempt, and salmon behavior at the dam and leveler devices. Our study included the observation of salmon movement; this consisted of watching for salmon at the leveler devices and observing how they interact with it and attempt to move upstream.

We used remote motion-sensing cameras to observe salmon movement and activity when observers were not present. We installed three wildlife cameras that capture images via a motion detector. We placed two cameras at lever device 1 and one at leveler device 2. The cameras at device 1 were pointed at the location in which water overtopped the dam and at the face of the dam itself. These cameras were at two different angles and were set to take a video for three seconds every time motion was detected. The camera at dam 2 was facing downstream of the dam and programmed the same as the other cameras. All three cameras ran 24/7 and were equipped with a flash. These cameras can detect any wildlife presence that shows ample movement at the dams.

In addition, we took photos at designated photo points to show the dams throughout our research period, documenting changes in site conditions, including water level changes, dam structure changes, and dramatic site changes such as flooding.

We conducted a daytime fish snorkel survey to assess adult fish presence upstream of levelers. We conducted the survey with a King County fish biologist Dan Lantz on December 13th, 2017, which coincides with the late 2017 coho run in this system. The survey sampled two sections of the stream and one beaver pond. We sampled from the confluence of Big Spring Creek and Newakum Creek to leveler device 1, pond 1 and the stream section between leveler device 1 and 2 (Figure 3). We recorded species by size and class as they were observed. We recorded all fish and salmonid species we found, including adults, juveniles, minnows, and carcasses. This allowed us to document fish presence that we did not directly observe either at the dams or with the wildlife cameras, inferring that passage past any previous dams must have occurred by an undocumented means (Thurow 1994).

Table 1 Types of salmon migration observations implemented

Data Collection Methods		
Observation Method	**Dates**	**Data**
Direct observation	10/10-11/21	14 days x 3 hours per day= 42 hours
Wildlife cameras	10/24-11/21	3 cameras, focused on downstream dam face, continuous observation
Snorkel survey	12/13/2017	3 people x 3 hours/person = 9 hours

Hydrologic conditions at dams

We conducted hydrologic surveys, including flow and depth measurements of the stream to evaluate the hydraulic conditions experienced by migrating salmon during high and low flow events. We used a velocity meter (Swoffer Instrument Inc., model 2100 C140) to measure the velocity of the flowing water above and below the dam, at the dam, through leveler pipes, and where water was overtopping the dam. We measured water depth below the dam, above the dam, at the water overtopping the dam, and at the pond-leveler device outlet and inlet (Figure 4). These measurements allowed us to calculate and track discharge as it related to weekly precipitation and stream stage. Discharge from the pipes was calculated using the discharge formula (Q = A * V). The cross-sectional area (A) of the pipes is 0.073 m^2. Inputting the velocity (V) recorded resulted in the discharge from each pipe.

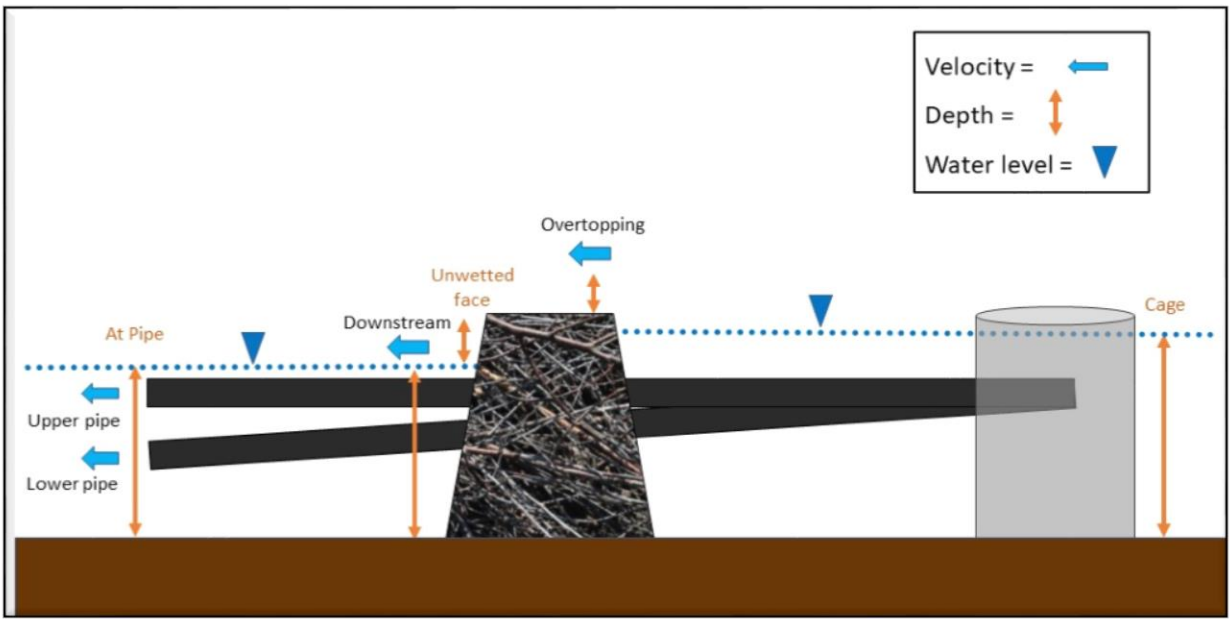

Figure 4 Velocity and depth measurements collected at pond-leveler devices. Note that Dam 2 excludes overtopping and downstream data points (i.e. velocity and depth).

Dam Structure

We monitored the structure and condition of the beaver dams throughout our research period. This included observing dam characteristics such as dam height, width, amount of water overtopping, and any new beaver modifications made to the dams. Other observations included flow conditions and hydrology of sites, and effects of pond-levelers on beaver dam's structure and stream flow. We compared know salmon swim speed limits to the velocity and discharge

recorded at the pond-leveler devices to determine whether flows were passable, based on hydrologic factors.

Results

Salmon migration surveys within the Green River Watershed

Migrating coho were documented by the Washington Department of Fish and Wildlife (WDFW) in Green River, 7.2 miles from Big Spring Creek. Live counts have been recorded by Washington Department of Fish and Wildlife since 1999 and are shown in **Error! Reference source not found.**. 2017 returns showed a decline from 2016 and was slightly lower than the 4-year moving average, resulting in a slightly below average coho run in the Green River Watershed during our research period. While this area was not part of our study area, it provides evidence that coho presence may historically low in the entire Green River Watershed.

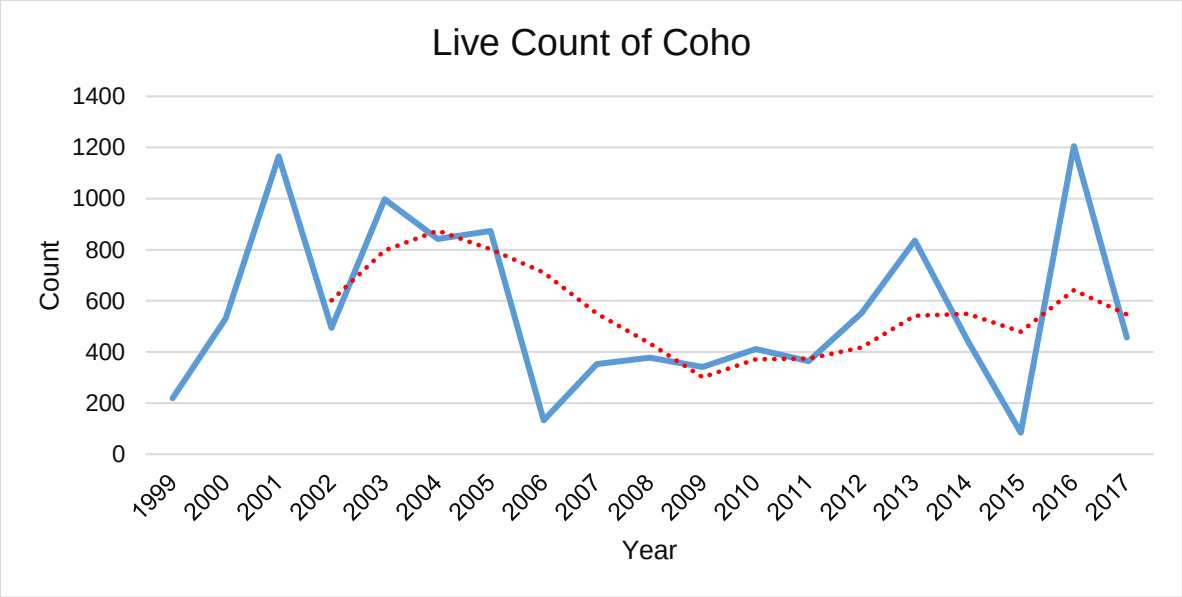

Figure 5 Washington Department of Fish and Wildlife historic live counts of coho in Green river, of which Big Spring Creek is a tributary. (WDFW, 2018)

Observation of fish presence and interaction with dams and pond-levelers

During our observation period we saw no migrating coho within our study reach at Big Spring Creek. We did document chinook presence in Big Spring Creek with one male chinook carcass observed at the start of our study above dam 2. The wildlife cameras we installed did not

observe any fish passage or attempts towards fish passage thereafter. The cameras did capture other wildlife present at the dams, which included footage of beavers walking on the dams, muskrats on the dams, and ducks swimming in the river. These observations provided insight into what other species frequented the dams as well as how these species interact indirectly or directly with the beaver dams. A detailed report of these wildlife observations was beyond the scope of this study and therefore the results are nor presented here.

When we conducted our daytime snorkel study both researchers were on site as well as fish biologist, Dan Lantz from King County. This study included a survey from the Newakum creek confluence to dam 1, from dam 1 to dam 2, and for a small portion on pond 2, just beyond dam 2. Between the three observers over three hours, we observed no fish in Big Spring Creek. This included no migrating adults and no juveniles. We were unable to evaluate Pond 1, as it was frozen, and the ice was too thick to traverse or break up.

Hydrologic conditions at dams

Precipitation and Streamflow

During the observation window, from 10/10 to 11/21, out study site experienced 38.71 cm of cumulative precipitation, as rain. The site received some amount of precipitation 11 out of the 13 days that we conducted research (Table 2). As our research progressed into November, storm and heavy rain events increased in intensity and frequency.

Table 2 Recorded precipitation during research period from King County gauge 44u.

Date site was visited	Weather by direct observation	Daily precipitation (mm)
10-Oct	cloudy	1.016
12-Oct	rainy	24.384
17-Oct	sunny partly cloudy	0.254
19-Oct	Heavy rain	49.276
24-Oct	sunny	0
26-Oct	overcast	0.254
31-Oct	sunny	0
2-Nov	rainy	6.096
7-Nov	cloudy, overcast, cold	0
9-Nov	rainy	5.842
16-Nov	rainy	9.144
21-Nov	rainy	16.256
25-Nov	cloudy	5.08
28-Nov	rainy/ cloudy	15.748

Big Spring Creeks near-flat topography made it very prone to bank overtopping and flooding given sufficient precipitation. Dam 1 had a wetted width of 3.6 m when the site was experiencing no precipitation. Minor levels of prolonged precipitation (i.e. <20 mm) resulted in some increase in discharge, a slightly wider stream wetted width, and water overtopping the dam. Flooding was not significant until the surrounding land reached its saturation point, which did not occur until November 16th. During and following heavy precipitation, the stream's wetted width expanded greatly due to flooding, at which point we could no accurately measure width. As precipitation increased, the amount of water overtopping the dam and the frequency of overtopping increased. Specialized events, such as bank overtopping occurred for multiple weeks, when precipitation was at its highest, which occurred from November 16th to November 28th and was still present during our snorkel survey on December 13th. The conditions observed during our research are considered normal for the site during previous years. Peak discharge in 2017 as noted in Figure 6, reached approximately 0.14 cms, a high similar to the past two years.

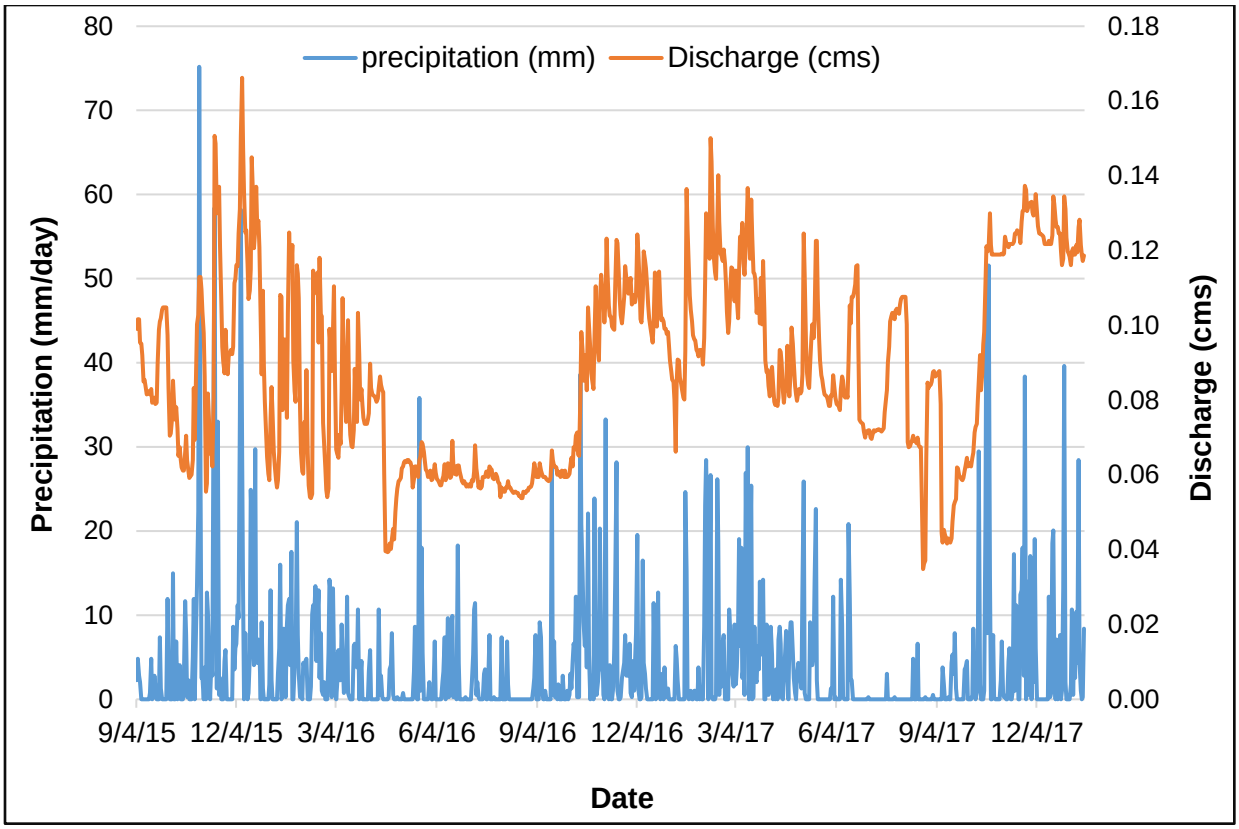

Figure 6 King County DNR gauge 44j (discharge) data at the top of phase 1 at Big Spring Creek and the 44u (precipitation) data from nearby, Enumclaw for the entire three-year period of recording for these devices.

Physical Findings

Velocity was recorded at locations identified in Figure 1 and showed several precipitation and stage-dependent trends. Daily stream discharge ranged from a low of .077 m^3/s to a peak of 0.12 m^3/s. Stream discharge maintained a relatively constant rate after hitting the low discharge recorded on October 24th (Figure 7).

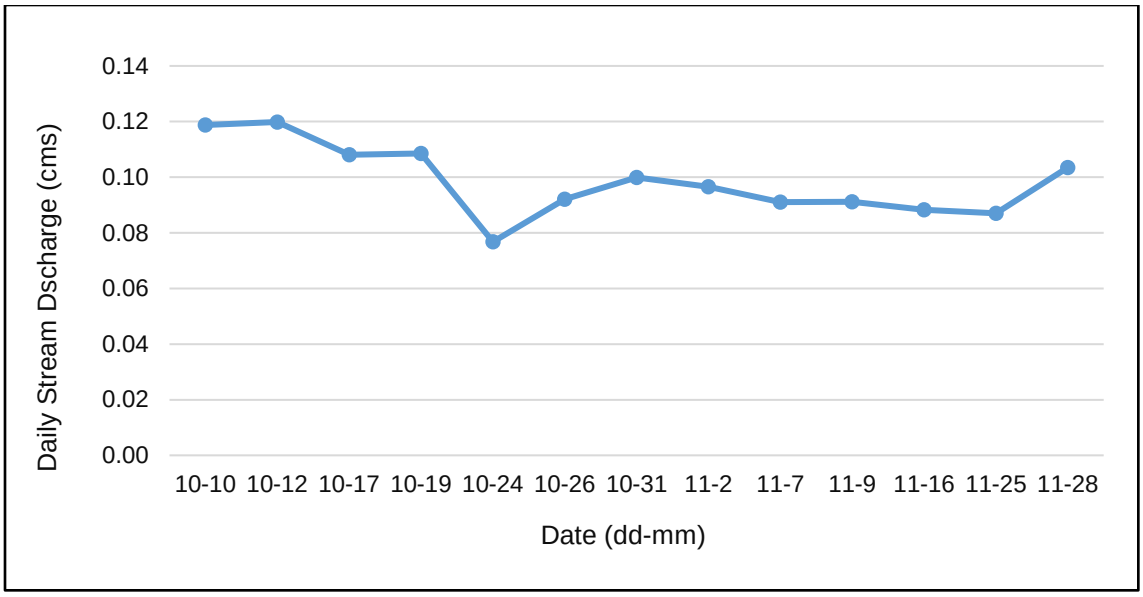

Figure 7 Daily Stream Discharge over duration of observation. This includes the total discharge from both upper and lower pipes as well as overtopping discharge when occurring (noted in red).

At both dam 1 and 2 the upper and lower pipes followed a similar trend throughout the study with the lower pipe at each device usually having a higher velocity than the upper pipe; this difference was most noticeable at Dam 2 (Figure 8). Velocity in both pipes at dam 1 ranged from 0.19 to 0.847 m/s. At Dam 2, velocity ranged from 0.25 to 1.14m/s.

As stream discharge increased in Big Spring Creek at Dam 1, we observed an inverse relationship between pipe velocity and stream discharge. With an increasing discharge charted on the x-axis in Figure 8 pipe velocity is seen decreasing. This is due to flow diverting over the dam instead of through the pipes. The dam began overtopping when discharge reached 0.118 cms, the point at which flow was too great to only flow through the pipes, thus diverting it over the dam, decreasing the flow through the pipes.

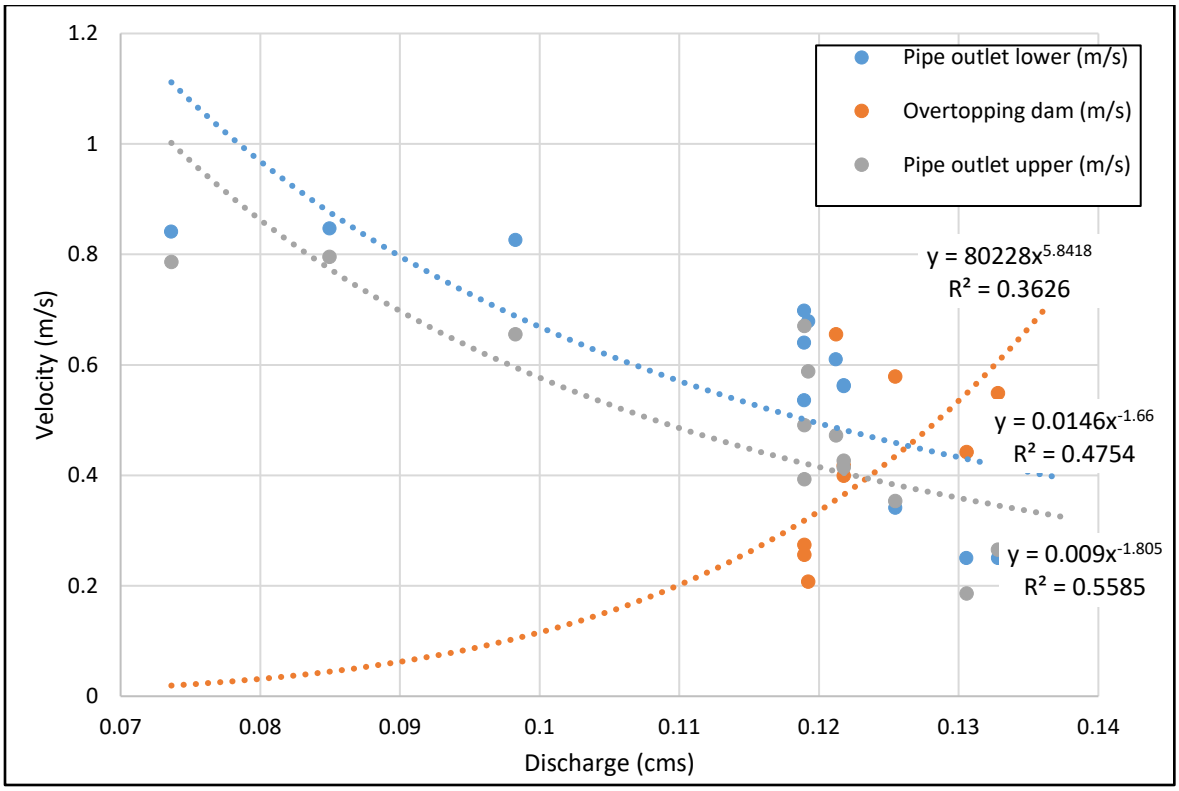

Figure 8 Big Spring Creek discharge vs recorded stream velocity at Pond-Leveler and Dam 1.

Velocity as a Barrier

We compared known fish swim speed limitations (Bell, M. C. 1990) with recorded flow conditions identified at Big Spring Creek. Maximum velocities recorded at each site were compared with the maximum swim velocities of each species of salmon on interest (Figure 9, Table 3). Maximum velocity recorded at Dam 1 was 0.85 m/s within pipes, and 0.64 m/s for overtopping flows. At Dam 2 the pipes reached 1.2 m/s with no overtopping flows.

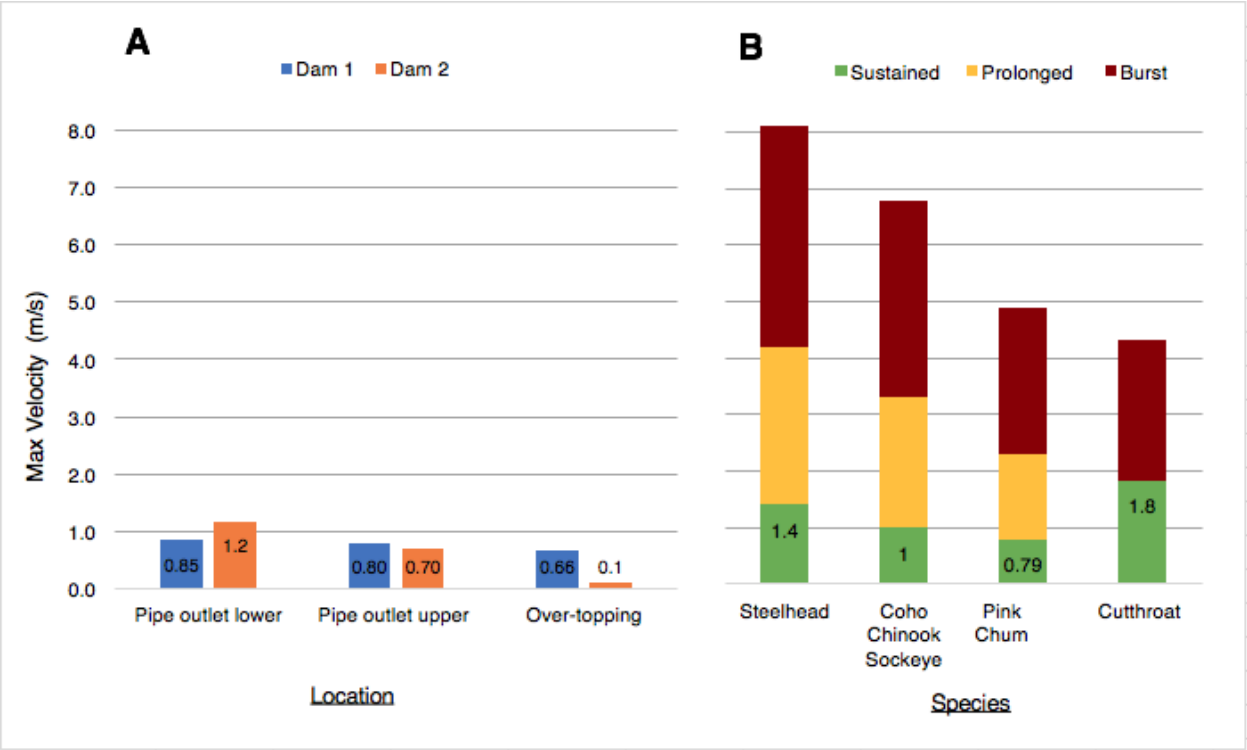

Figure 9 Maximum water velocities observed during the 2018 fish migration period (panel A) compared with the range of achievable salmon swim speeds (panel B). Sustained swim speeds can be sustained indefinitely while prolonged and burst ranges are limited by species swim endurance.

Table 3 Adult and juvenile coho fish swim speeds ranges, categorized as sustained, prolonged and burst.

		Fish swim speed capabilities (m/s)		
Fish type	**Species**	**Sustained**	**Prolonged**	**Burst**
steelhead	*Oncorhynchus mykiss*	0-1.4	1.4-4.2	4.2- 8.1
chinook	*Oncorhynchus tshawytscha*	0-1.0	1.0-3.3	3.3-6.8
coho	*Oncorhynchus kisutch*	0-1.0	1.0-3.2	3.2-6.5
sockeye	*Oncorhynchus nerka*	0-0.97	0.97-3.1	3.1-6.3
pink	*Oncorhynchus gorbuscha*	0-0.79	0.79-2.3	2.3-4.9
chum	*Oncorhynchus keta*	0-0.79	0.79-2.3	2.3-4.9
cutthroat	*Oncorhynchus clarkii clarkii*	0-1.83	N/A	1.83-4.27
coho (2")	*Oncorhynchus kisutch*	0.15-0.37	N/A	N/A
coho (3.5)	*Oncorhynchus kisutch*	0.305-0.52	N/A	N/A
coho (4.75")	*Oncorhynchus kisutch*	0.43-0.64	N/A	N/A

We defined stream velocity to be a barrier to fish passage when the velocity of the stream was greater than the maximum burst speed of each species of fish. The percent of time that the lower pipe velocity, upper pipe velocity, and overtopping velocity data points were within the range of salmon species swim speeds was calculated (Figure 10). 100% at the sustained category means that all a fish's time would be spent swimming at a sustained rate even at maximum stream velocity. Results show that there was no point where salmon would need to achieve burst speeds to overcome the stream velocity (Figure 9, Table 3, Figure 10). It is to be noted that steelhead and cutthroat never needed to exceed their sustained swim velocity to pass even the fastest of recorded stream velocities at any location. While the remaining species faired similarly, requiring only a small portion of their swimming to fall within the prolonged swim velocity range. Swim speeds of juvenile salmon are much slower, and they would not always be able to swim upstream through the pipes (Table 3).

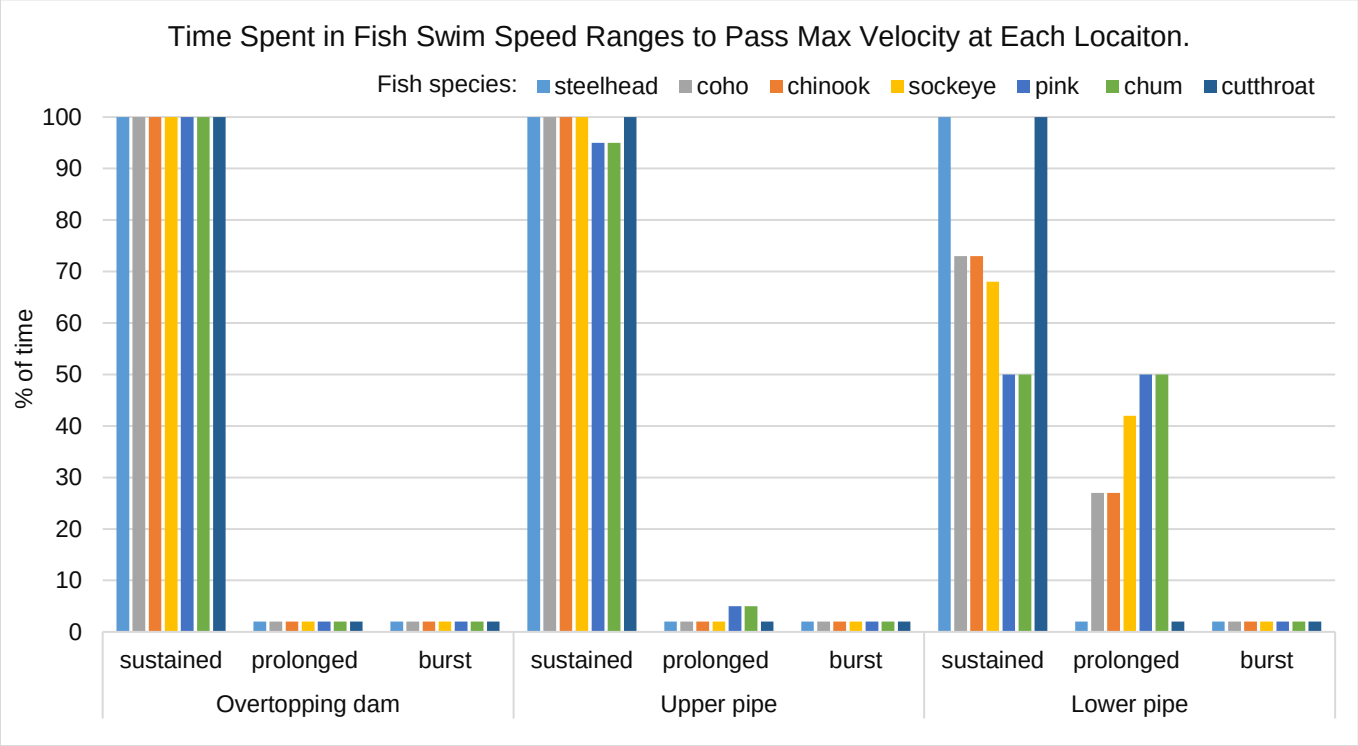

Figure 10 The percent of time that fish spent in each range of swim speed (Sustained, Prolonged, Burst) to pass the maximum recorded water velocity at each location on Dam 1. At no point did any species of fish need to swim at their burst speed to surpass any recorded water velocity.

Discussion

The presence of fish at Big Spring Creek was lacking, but this did not prevent us from making several insights during our research. Fish runs during the 2017 season were historically low and fish have been observed at Big Spring Creek in the past. We only found one chinook carcass and that individual was known to have migrated during a period of observed pond leveler maintenance prior to the start of our monitoring, we observed no living species. Chinook were present on site prior to monitoring, since our monitoring began at the end of their migration period and was focused primarily on the coho run. While we did not directly observe fish migration during this study, we were able to characterize streamflow conditions throughout the fish migration period, which provides evidence of the physical constraints present.

During high flow events, water levels overtopped the banks causing flooding around the dams, which created alternative swim routes for migrating fish. When present, fish could swim around the dam during these conditions if they didn't attempt to jump over the dam or swim through the leveler device. During these events the site was fish passable regardless of any known or unknown impairment by pond-leveler devices.

By comparing overtopping dam velocity to known fish swim speeds it is likely that stream velocity is never a barrier for the fish known to migrate through this system for the flow conditions observed during the 2017 season. Both maximum (i.e. burst) and prolonged fish swim speeds for all fish species were greater than the maximum overtopping dam velocity observed during our research. While velocities within the pipes was slightly greater, velocities in these pipes would likely not impede fish from swimming through the pipe if they attempt to do so. We considered that if fish were required to swim at burst speed during passage over dams, there may be some detriment to passage for some individuals. While pipe velocities were often too swift for juveniles during high flow, it is unlikely that juvenile salmon would be traveling downstream during high flow events. The pipes of the levelers would not be a barrier for juvenile fish given their behavior during this time.

Our stream discharge calculations demonstrated that as overtopping discharge increased, the discharge of water through the pipes decreased. This is likely caused by an increase in backwater pressure placed on the leveler outlets at the dam, as stage increased. This resulted in a lower velocity in the pipes as more water flowed over the dam instead of having to travel

through the pipes. This would increase the passability of the dam for fish. Bank overtopping and dam submergence also allowed fish to bypass the dams completely in many cases.

Based on the USGS discharge gage at the top of phase 1 of big spring creek (Figure 2), Big Stream Creek discharge never exceeded fish swim speeds; the stream was passable always during our observation period. By looking into USGS data for the Big Stream Creek site (September 2015 to December 2017), there has been no recorded discharge that would impede fish passage based on swim speed limitations.

This study is comparable to other 1st through 3rd order, low gradient streams with beaver presence. While the site-specific conditions results may result in some variability our findings yield important insights to salmon migration through beaver dams with pond-levelers.

Recommendations

We have provided the following recommendations for how follow-up studies could build on this research to further elucidate how fish behave while migrating through systems with beaver devices.

Replication/ Applicability

This research documents only one migration period, at one stream site. We recommend repeating this study for additional migratory periods at streams with dams and beaver devices that have different flow characteristics, physical constraints, and geomorphology. We recommend repeating this study at a site of similar climate and hydrologic conditions to have the most reliable results. This research was done on a lowland creek, with a low gradient, and multiple beaver dams on site. These aspects greatly affected our research site and our results.

Scope

The scope of our results can only be applied to sites of similar conditions and characteristics. Sites of different topographical and hydrologic conditions may result in variable outcomes compared to this study.

Caveats / Limitations

This study was limited by ability to observe fish, consistency of measurements, and the reliability of monitoring technology such as wildlife cameras and flow meters. Furthermore, we were challenged by lack of direct fish observations forcing us to infer our results based on available data collected during other scientific studies and hydrologic data collected during this study.

Conclusion

Our monitoring stream, Big Spring Creek, experienced conditions (e.g. precipitation, discharge, velocities, etc.) commonly experienced in ~2nd order streams of the Puget Sound lowlands, during times when fall-migrating salmon are present in the system. Velocities seen on Big Spring Creek would be categorized as low in comparison to other waterways in the watershed, such as in Newakum Creek or the Green River. Within our recorded velocities there was no point where fish would not have the swimming capabilities to migrate up Big Spring Creek through the levelers. Other migration barriers including the beaver dam itself and the structure of the pipes were negligible; for a majority of the research period the dam was completely submerged during high flow events, making these obstacles easily passable by fish. Based on these factors, conditions at the beaver dams and pond-leveling devices observed in this study suggest that fish passage was not hindered by beaver management devices. We conclude that the implementation of non-lethal pond leveler devices in stream systems such as Big Spring Creek provides flood control while also retaining safe migration conditions for salmon.

Acknowledgments

This research was supported by the King County Department of Natural Resources and the University of Washington. We thank our colleagues from King County, Joshua Latterell, Jennifer Vanderhoof, and Dan Lantz, who provided insight and expertise that greatly assisted our research. We also thank Benjamin Dittbrenner from the University of Washington for his advisement during this process. We thank Joshua Latterell for his comments that greatly improved our manuscript, along with generously providing a portion of the necessary equipment for this project. The access to our research site was in thanks to him and his team. We would also like to show our gratitude to the University of Washington School of Environmental and Forest Sciences which provided us the opportunity from which we were able to research and

write this manuscript, as well as the funding they granted us through the ESRM Senior Capstone Award to help make our research possible. Finally, we would like to thank Benjamin Dittbrenner for his continued dedication to this project. His consistent support proved to be the backbone from which we were able to conduct our research.

References

Anlauf-Dunn, K. J., E. J. Ward, M. Strickland, K. Jones, and M. Bradford. 2014. Habitat connectivity, complexity, and quality: predicting adult coho salmon occupancy and abundance. Canadian Journal of Fisheries and Aquatic Sciences 71:1864–1876.

Battin, J., M. W. Wiley, M. H. Ruckelshaus, R. N. Palmer, E. Korb, K. K. Bartz, and H. Imaki. 2007. Projected impacts of climate change on salmon habitat restoration. Proceedings of the National Academy of Sciences 104:6720–6725.

Bell, M. C. (1990). Fisheries handbook of engineering requirements and biological criteria. CORPS OF ENGINEERS PORTLAND OR NORTH PACIFIC DIV.

Bouwes, N., Weber, N., Jordan, C. E., Saunders, W. C., Tattam, I. A., Volk, C., … Pollock, M. M. (2016). Ecosystem experiment reveals benefits of natural and simulated beaver dams to a threatened population of steelhead (Oncorhynchus mykiss). *Scientific Reports*, *6*. https://doi.org/10.1038/srep28581

Gende et al. 2002. Pacific salmon in aquatic and terrestrial ecosystems. BioScience.

Laramie, H. A., S. The, W. Management, and N. Jul. 2009. A Device for Control of Problem Beavers. The Journal of Wildlife Management 27:471–476.

Law, A., F. McLean, and N. J. Willby. 2016. Habitat engineering by beaver benefits aquatic biodiversity and ecosystem processes in agricultural streams. Freshwater Biology.

Malison, R. L., M. S. Lorang, D. C. Whited, and J. A. Stanford. 2014. Beavers (Castor canadensis) influence habitat for juvenile salmon in a large Alaskan river floodplain. Freshwater Biology.

Naiman, R. J., C. A. Johnston, and J. C. Kelley. 1988a. Alteration of North American Streams by Beaver. BioScience 38:753–762.

Naiman, R. J., C. a Johnston, and J. C. Kelley. 1988b. Alteration of North American Streams by Beaver: The structure and dynamics of streams are changing as beaver recolonize their historic habitat. BioScience 38:753–762.

Newaukum Creek Basin Characterization Project Report July 2007.

ODFW (1997). Oregon Plan for Salmon and Watersheds (consisting of the Oregon Coastal Salmon Restoration Initiative, March 10, 1997 and as amended with the steelhead supplement, December 1997). Governor's Natural Resources Office, State of Oregon, Salem, Oregon.

Paine, R. T. 1966. Food Web Complexity and Species Diversity. The American Naturalist 100:65–75.

Pollock, M. M., M. Heim, and D. Werner. 2003. Hydrologic and Geomorphic Effects of Beaver Dams and Their Influence on Fishes. American Fisheries Society Symposium 37:20.

Puget Sound Salmon Leaders' Forum. 2000. Shared Strategy for Recovery of Salmon in Puget Sound.

Roni, P., G. R. Pess, T. J. Beechie, and K. M. Hanson. 2014. NOAA Technical Memorandum NMFS-NWFSC-127. Fish-Habitat Relationships and Effectiveness of Habitat Restoration.

Rosell, F., O. Bozsér, P. Collen, and H. Parker. 2005. Ecological impact of beavers Castor fiber and Castor canadensis and their ability to modify ecosystems 35:248–276.

Taylor, J. D., and R. D. Singleton. 2014. The evolution of flow devices used to reduce flooding by beavers: A review. Wildlife Society Bulletin 38:127–133.

Thurow, R. F. 1994. Underwater Methods for Study of Salmonids in the Intermountain West:1–32.

Washington Department of Fish and Wildlife. 2009. Fish Passage and Surface Water Diversion Screening Assessment and Prioritization Manual. Washington Department of Fish and Wildlife. Olympia, Washington.

Washington Department of Fish and Wildlife. (2018, March 12). [1999-2017 Green River Coho Live Counts]. Unpublished raw data.

Wildlife, W. D. (n.d.). *Living with Wildlife* . From Washington Department of Fish and Wildlife : https://wdfw.wa.gov/living/beavers.html