Technical Report No. 14-10

Waterfall Creek Hydroelectric Project, Hydrology and Fish Surveys, 2013

by

Brad Dunker

April 2015

Alaska Department of Fish and Game **Division of Habitat**

Symbols and Abbreviations

The following symbols and abbreviations, and others approved for the Système International d'Unités (SI), are used without definition in the following reports by the Divisions of Sport Fish and of Commercial Fisheries: Fishery Manuscripts, Fishery Data Series Reports, Fishery Management Reports, and Special Publications. All others, including deviations from definitions listed below, are noted in the text at first mention, as well as in the titles or footnotes of tables, and in figure or figure captions.

Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat or long
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	log_2, etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

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by

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TABLE OF CONTENTS

Page

LIST OF TABLES

Table **Page**

LIST OF FIGURES

LIST OF APPENDICES

ACKNOWLEDGMENTS

I would like to thank Dillon Shults, Alaska Department of Fish and Game Intern, for his assistance with field work, drafting trip reports, and preparing us for the field. His assistance was invaluable to the project. I would also like to thank the City of King Cove for providing logistical support and access to the site. I specifically acknowledge the City's hydropower staff for their commitment to this project. I would also like to thank some of my Alaska Department of Fish and Game colleagues: Michael Daigneault and Megan Marie for their assistance in developing the study plans and providing invaluable guidance throughout the project, and Josh Brekken for his assistance with field work.

EXECUTIVE SUMMARY

The Alaska Department of Fish and Game (ADF&G), Division of Habitat, issued a Fish Habitat Permit in January 2013 to allow the City of King Cove to construct a hydroelectric power generation project on Waterfall Creek. ADF&G conducted a hydrology and fish presence/absence study in Waterfall Creek during the summer of 2013 for the purpose of collecting additional pre-project data on stream flow and fish presence. Monitoring sites were established in the lower and upper portions of the proposed bypass reach to investigate habitat characteristics, such as discharge, depth, and wetted perimeter. A pressure transducer was installed at the lower monitoring site to record continuous water stage data. Fish sampling was conducted throughout the bypass reach to determine presence/absence and general distribution of fish.

Flow measurements were limited during the 2013 study because of challenges accessing Waterfall Creek. Measured flows in 2013 generally were lower than those recorded in 2005–2006. Data reported in 2005–2006 showed base flow conditions in late April, spring snowmelt peak discharge in late May and June, summer low flow in early August, and fall precipitation peak discharge in late August and September. During this study, discharge was measured during July and August and for a brief period in late September; peak discharge events driven by fall precipitation were not evident in 2013.

Dolly Varden (*Salvelinus malma*) and pink salmon (*Oncorhynchus gorbuscha)* were captured or observed during the study. Dolly Varden were present throughout the portion of the bypass reach sampled. Dolly Varden catch per unit effort was greatest at the middle bypass reach sites; mean fork length also was highest at these sites. Pink salmon use of Waterfall Creek was first documented during project permitting. During this study, adult pink salmon were observed displaying spawning behavior and redds were present in the middle and lower section of the bypass reach.

Data collected during 2005–2006 and 2013 indicate that Waterfall Creek flows are often lower than the allocated 12 cfs water right. In the future, these data would be useful in advance of permitting decisions. For much of the year, bypass reach flows will be limited to the 1 cubic feet per second (cfs) instream flow requirement, water diverted from Springs Creek, and accretion flow; the potential effects on fish passage or maintenance of stream function are unknown. Post-construction monitoring is needed to understand the biological changes associated with a 12 cfs water withdrawal on the anadromous pink salmon and resident Dolly Varden.

INTRODUCTION

High energy costs and an abundance of suitable streams and rivers for hydropower development in rural Alaskan communities have led to a number of hydropower and hydrokinetic projects being considered. Most communities are proposing traditional hydropower developments on smaller river systems (<500 cubic feet per second [cfs]) that include small dams used to pond and divert water to a powerhouse. The projects typically have little to no water storage capacity. The dams are often placed at a relatively high elevation in the stream system to create enough head pressure to run the turbine. Often, these projects include large bypass reaches relative to the overall length of the stream.

Data collection before flow alteration and post-flow alteration monitoring have been identified as critical needs in accurately assessing the biological changes of flow alteration on a river system (Lloyd et al. 2003; Poff and Zimmerman 2010). Small Alaska communities have limited financial resources. When considering long-term, cost-saving hydropower, limited hydrology and fish resource data are collected to characterize the local fish and water resources. Also, few Alaska streams are gauged and resource managers must make decisions regarding hydropower development with minimal project-specific hydrology and fish data. Under these constraints, regulatory decisions are based on extrapolation of the existing data, assumptions regarding potential biological impacts, and professional judgment. The validity of these assumptions can be tested over time with appropriate data collection and monitoring.

Hydropower development may have multiple biological resource concerns including adequate fish passage, sufficient instream flow within the bypass reach to maintain the indigenous aquatic life, or altered sediment transport and flow variability that maintain aquatic habitats. Because of the variability among fish species regarding movement, habitat use, and survival strategies, it is difficult to predict the impacts of hydropower development without site specific data on local fish, hydrology, habitats, and the expected alterations to each (Grant and Noakes 1987; Nielsen 1992; Nislow et al. 1998; Bujold et al. 2004; Bradford et al. 2011). Maintaining connectivity to smaller tributary stream systems that provide seasonal habitat for spawning salmonids or growth of rearing juveniles contributes to the overall success of the fish populations in the watershed. Ebersole et al. (2006) found that a tributary stream in Oregon that was nearly dry in midsummer supported a large spawning run of coho salmon (*O. kisutch*) in the fall and rearing juveniles that utilized this habitat when available experienced high growth rates and emigrated as larger smolts as compared to other parts of the watershed.

Poff and Zimmerman (2010) conducted a literature review on ecological responses to alteration of natural flow with an emphasis on projects completed in the last decade. Dams were used to alter natural flow regimes in 88% of the 165 papers reviewed. Among those papers reviewed, 92% reported negative ecological change (e.g., loss of habitat, loss of stream function) in response to flow alterations. Fish populations consistently responded negatively to changes in flow magnitude. Under reduced flows, 80% of the studies reported more than 50% reduction in aquatic organism diversity where flow magnitudes exceeded 50% decrease. Other meta-analyses reported that 87% of studies reviewed showed changes in either geomorphic or ecological variables, or both, as a result of reduced flow volumes (Lloyd et al. 2003). Disrupting the natural flow regime can segment stream habitat, reduce water levels, or increase water temperature over an extended period of time by eliminating freshets and other pulse events that help maintain lower water temperatures. Alteration of stream flow and incomplete information on the river systems being impacted can result in unintended impacts to the aquatic biota and ecosystem functions of a river system that cannot be reversed once a hydropower project is developed.

A recently approved, but not yet constructed, small hydropower project is proposed on Waterfall Creek (Anadromous Waters Catalog [AWC] No. 283-34-11000-2009), near King Cove. The Waterfall Creek hydroelectric project is authorized to withdraw up to 12 cfs at any given time; there is a 1 cfs minimum spill requirement at the diversion dam. An adjacent stream (locally known as Springs Creek) will provide flow to the middle bypass reach through a piped diversion. Springs Creek diversion flows combined with accretion flows from below the water intake are estimated to be 2 cfs at the upper limit of anadromy delineated in the Anadromous Waters Catalog (HDR 2011; Johnson and Coleman 2014). Water used for power generation will not be returned to Waterfall Creek; rather it will be discharged to Delta Creek (AWC No. 283-34-11000) about 200 meters upstream of the confluence of Waterfall and Delta creeks (Figure 1). During the project review process, fish presence and distribution in Waterfall and Springs creeks was investigated using 3 capture methods: electrofishing, minnow traps, and foot surveys (HDR 2008, 2010, 2011). In Waterfall Creek, pink salmon were documented in the lower and middle reaches and Dolly Varden were present from the mouth to the waterfall; no fish were observed or captured above the waterfall. Dolly Varden were more abundant throughout the lower and middle reaches; distribution was sporadic in the steeper stream reach approaching the waterfall. In Springs Creek, Dolly Varden were captured in the lowermost reach only.

OBJECTIVES

The purpose of this study was to collect hydrology, fish presence/absence, and anadromous fish distribution data in the bypass reach of the proposed Waterfall Creek hydropower project. At Waterfall Creek, we intended to establish a stage/discharge relationship to document the range of flow and establish a stage/depth relationship. In regards to fish, we investigated the presence and absence of fish in the bypass reach to better understand their habitat use and distribution. These data will supplement the baseline data collected for the proposed project to better understand local hydrology and fish resources prior to hydropower development. More complete data will provide a better baseline condition in which to compare post-construction flow alteration conditions and assess changes after dam construction and water diversion. Information gathered during this study can be used for more informed decision-making for future hydropower projects.

STUDY AREA

The Waterfall Creek watershed is about 3.9 km^2 in size. Waterfall Creek originates in multiple high gradient headwater tributaries that flow over interbedded sedimentary and volcanic rocks. Waterfall Creek contains 1 waterfall that is about 21.3 m in height. The lower reaches of Waterfall Creek are moderate to high gradient and discharge into Delta Creek. Natural discharge in the lower reach of Waterfall Creek is estimated to range from 1 to 21.3 cfs based on over a year of data collected during 2005 and 2006. Low flow occurred in April and high flow in late-September.

The lower boundary of the study area is located at the confluence of Waterfall Creek and Delta Creek (Figure 1). This stream reach is moderate to high gradient (4-10% slope). The creek channel is composed primarily of boulder substrate with cobble and pebbles present in the small pools (Figure 2). Small steps are present throughout the lower reaches of the creek.

Figure 1.–Waterfall Creek basin and study area. Note the existing Delta Creek Hydroelectric Facility and tailrace, where diverted Waterfall Creek water would be discharged.

The upper extent of the study area is within the proposed middle bypass reach of Waterfall Creek, near pre-project sampling sites and the proposed water diversion from Springs Creek. Upstream of this point, the creek flows through a gorge that creates a high gradient step-pool stream channel with exposed bedrock outcrops and large boulders. Numerous large steps are present in the upper bypass reach (Figure 2).

Figure 2.–Lower reaches of Waterfall Creek (left) and upper bypass reach (right).

Waterfall Creek is a specified anadromous waterbody that is known to support pink salmon (*Oncorhynchus gorbuscha*) (Johnson and Coleman 2014). Pink salmon spawn in Waterfall Creek. Resident Dolly Varden (*Salvelinus malma*) are present throughout the creek downstream of the 21.3 m waterfall.

METHODS

HYDROLOGY DATA STUDY DESIGN

A stream gauge (Carter and Davidian 1968) was used to obtain a continuous record of stage and discharge at the site. An In-Situ LevelTROLL 500[1] vented pressure transducer was installed in the middle of the study area in a small pool at 55.124° N, -162.276° W. This pool was expected to contain water during low flow conditions. The transducer was installed in the creek bottom by clearing some deposited gravel away from a bedrock outcrop and placing the transducer in the creek on the bedrock outcrop. The transducer was partially buried in the removed depositional cobble and with cobble from the surrounding area. Large boulders were used to secure the transducer in place. The vented cable was secured to a rebar stake and to large woody vegetation on top of the bedrock outcrop. The transducer was powered by AA batteries internal to the device. The transducer location was marked by GPS and was surveyed to semi-permanent benchmarks (e.g., large boulder) to establish the elevation of the instrument. Pressure and temperature readings were recorded every 30 minutes continuously throughout the study period. This gauge was operated from July 16 to September 1, 2013, and again on September 17–18, 2013.

A modified version of the wetted perimeter method (Annear and Conder 1984; Annear et al. 2004) was used to establish a stage/depth relationship at different locations within the bypass reach. Wetted perimeter is the distance along the stream bottom from the right wetted edge of the stream to the left wetted edge of the stream at a measured discharge. Wetted perimeter was

[1] Product names used in this report are included for scientific completeness but do not constitute a product endorsement.

chosen as a metric because of its ease of use on ungauged streams and its assumption that flows needed to maintain riffle habitat would also sustain fish passage, aquatic organisms, and stream function in other habitats within the stream (Nehring 1979; Annear et al. 2004).

The Instream Flow Council (Annear et al. 2004) recommends the use of the wetted perimeter method in bedrock-controlled high gradient streams with well-defined rectangular-shaped riffles and no significant floodplains. They caution, however, that this method assumes a relationship between habitat and biology and uses only hydraulic data to make recommendations. Additional habitat assessment and fish surveys should be conducted in conjunction with the wetted perimeter method. Selecting an appropriate cross section site influences the validity of the collected data. The cross section site should be located within a riffle at the shallowest portion (i.e., grade control). Riffles are selected because they are controlled by channel geometry rather than a downstream flow control, sensitive to changes in flow, and are the first segments of a stream to dry during low flow conditions. Deviation from this location could result in artificially high or low instream flow recommendations.

Two stream cross-sections were established at the grade control of representative riffle habitats in the bypass reach. The lower bypass reach cross section was collocated with the pressure transducer site (Figure 3) and was located near the discharge weir and cross sections conducted by HDR, Inc. during project permitting (HDR 2008; HDR 2010). The upper bypass reach cross section site was located near the discharge location of the proposed Springs Creek diversion (HDR 2011). Flow velocity was measured at each cross-section and discharge was calculated during each field visit. Rebar stakes were placed on top of the streambank to mark the cross section locations. A laser level and sag tape were used to establish a temporary benchmark (level line) and determine distance from the point of beginning (rebar stake on the right bank facing upstream) to the corresponding rebar stake on the left bank. Discharge was measured by partitioning the creek into 16 to 20 subsections, calculating the area of each subsection using measured width and depth data, measuring mean water velocity in each subsection (from the water surface, 60% total depth), then calculating the cross-section discharge by summing the subsection discharges (Rose and Johnson 1976). The pressure transducer data were compared with the measured discharge at each cross section to establish the stage/discharge relationship.

Site visits were made twice during the summer of 2013 to install the pressure transducer, measure cross-sections, and obtain instantaneous discharge measurements. Data were downloaded from the pressure transducer to a laptop using the WinSitu software. Discharge measurement data and other site visit notes were recorded in a waterproof field notebook. Photographs of the gauge site, discharge measurement transect, and the stream were taken during each visit.

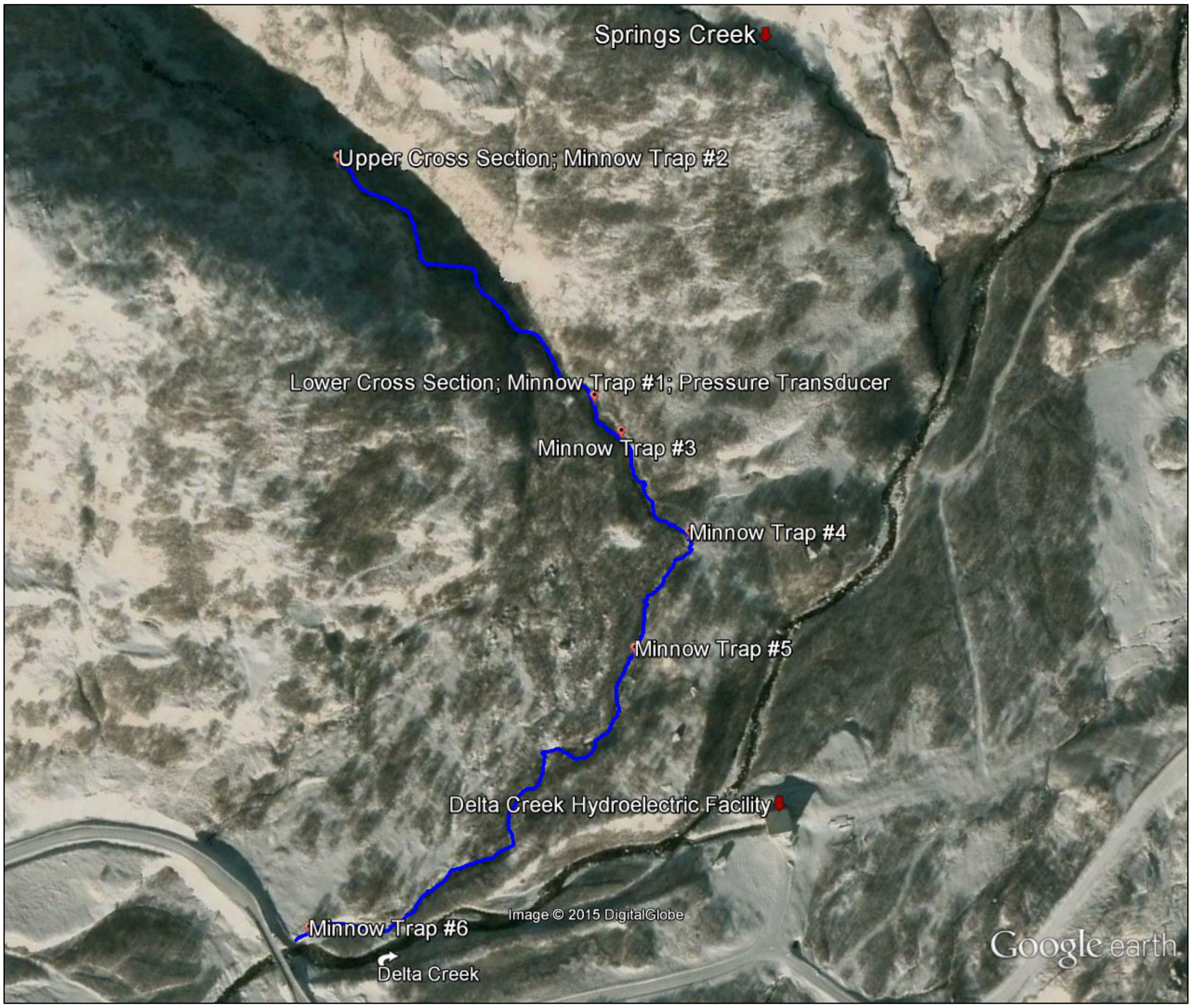

Figure 3.–Waterfall Creek study area, cross sections, and minnow trap locations. Minnow trap locations #1 and #2 were collocated with cross section sites. The pressure transducer was located at the lower cross section and minnow trap location #1.

ANALYSIS

We used 2 methods to identify minimum instream flow for Waterfall Creek. The fundamental difference in the 2 methods is in the way they view and define minimum instream flow. One method defines minimum instream flow as the flows below which the ability of fish to move throughout their range may be inhibited, while the second method defines the minimum instream flow as flows below which there would be a rapid decline in food production to support the fish population.

First, the R2CROSS method was used to identify instream flow values that would maintain fish passage. The R2CROSS software has been used in the western United States for establishing minimum instream flow (Anonymous 1974; Espegren 1996). The R2CROSS software provides an automated spreadsheet that was used to calculate discharge, hydraulic radius, and wetted perimeter. The method specifies that certain criteria be met for the discharge to be considered adequate to maintain fish passage. The 3 criteria are average water depth, percent of wetted perimeter, and average velocity. The thresholds for these criteria vary with the width of the stream at bankfull discharge. The R2CROSS requirements for different stream widths are shown in Table 1. For fish passage to be maintained, the R2CROSS method requires that spring and summer flow rates within the riffles satisfy all three criteria, while autumn and winter flows must meet two of the three criteria. For example, a stream with a bankfull width of 20 feet would require an average depth of 0.2 feet, need to maintain 50% wetted perimeter, and have an average velocity of 1.0 feet per second (ft/s) in order to maintain fish passage during the spring and summer.

Table 1. R2CROSS criteria.

Stream width (ft) at bankfull discharge	Average depth (ft)	Wetted perimeter (%)	Average velocity (ft/s)
1-20	0.2	50	1.0
21-40	0.2-0.4	50	1.0
41-60	0.4-0.6	50-60	1.0
61-100	0.6-1.0	≥70	1.0

Field measurements were taken within riffle habitats as described in the cross section methods above. Riffles are conducive to this type of analysis because they are controlled by channel geometry rather than a downstream flow control. They are also important habitats for fish passage, biological production, and cover for fish. Riffle habitats are also sensitive to streamflow changes. A slight reduction in streamflow may result in large reductions in water depth and wetted perimeter available for habitat (Nehring 1979). Field data were collected and input into R2CROSS for analysis. R2CROSS calculated a staging table that estimates flows needed to meet the average depth, percent wetted perimeter, and average velocity criteria. Seasonal instream flow recommendations can be made based on these criteria and information collected during the site visits.

Second, the California Department of Fish and Wildlife Instream Flow Program established standard operating procedures for the wetted perimeter method in California (CDFW 2013). This method uses the data collected in the field to establish a wetted perimeter-discharge curve and is designed to identify flows for maintaining productive riffle habitat. The curve is used to determine a range of flows that are critically important to food production. Flows above this range are considered at or near optimum for food production. Flows below this range indicate rapidly declining food production that can impact local fish populations.

This method uses a wetted perimeter-discharge curve to identify the flows at which there are significant changes in the slope of the curve (Figure 4). The first significant inflection point is called the breakpoint, which identifies the threshold flows below which habitat conditions (wetted perimeter, food production) rapidly decline. The second inflection point is called the incipient asymptote and identifies flows that create near optimum conditions for food production.

The range of flows between the breakpoint and the incipient asymptote are considered critical for food production and maintaining stream function.

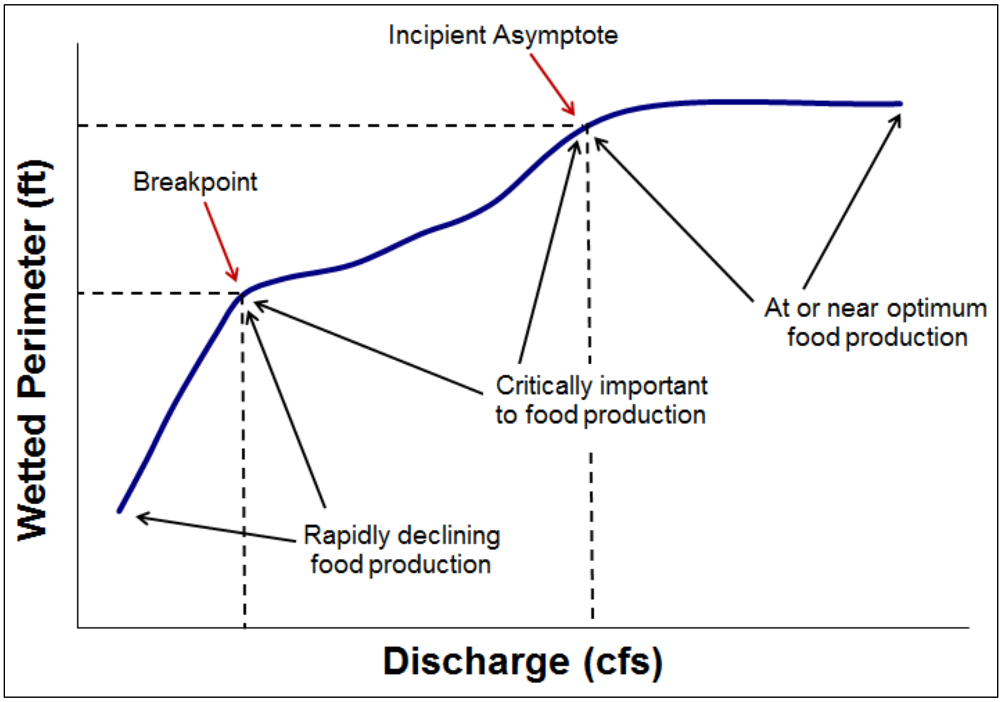

Figure 4.–Hypothetical wetted perimeter-discharge curve demonstrates breakpoint and incipient asymptote that define flows critical to food production (CDFW 2013).

FISH PRESENCE/ABSENCE

Baited minnow traps were set at each cross section described above to determine fish presence or absence in the middle reach of the bypass (Figure 3). Four additional minnow trap sites were sampled in the lower reach of Waterfall Creek to better understand fish distribution (Figure 3). The 4 lowermost sites were only sampled during September because of poor weather in July 2013. At each of the 6 minnow trap locations, only 1 minnow trap was set, except for location #2, where 2 traps were set during July. The minnow traps were 22.8 cm in diameter and constructed of 0.6 cm mesh. Each trap was baited using equal amounts of fresh or frozen salmon roe disinfected in a betadyne solution and packaged in Whirl-Paks or nylon stockings. Minnow traps were stabilized with a rock placed inside or tethered to riparian vegetation, or both. Target soak time for each minnow trap was 24 hours. All captured fish were identified to species, measured to the nearest millimeter (fork length), and released at the point of capture. Minnow trap sites were photographed prior to the traps being removed.

Water clarity in Waterfall Creek is good and allows for visual observation of fish. A GoPro® high-definition video camera was used to survey small pools where fish were observed, but no trapping effort was made. The camera was either placed in the pool or hand-held, depending on flow velocities and size of the pool. Images were reviewed on a computer each day to document the observations and habitat usage by fish. High definition images were used to identify the fish observed to species and obtain estimates of the number of fish present. Observational foot surveys were conducted in Waterfall Creek to determine the presence or absence of pink salmon in the lower reaches of the bypass study area.

Catch per unit effort (CPUE) was calculated for Dolly Varden by dividing the total catch (C_t) by the total number of hours fished (cumulative of all traps; H_t) and multiplied by 24 for a normalized trap catch of fish per day (equation below). Data analysis was performed using Microsoft Excel®.

$$CPUE = \frac{Ct}{Ht} \times 24$$

RESULTS

HYDROLOGY DATA

Continuous stage readings were recorded by the pressure transducer from July 16 to September 1, 2013 and from September 17 to September 18, 2013 (Figure 5). Waterfall Creek appears to have a relatively constant stage throughout the summer months; brief fluctuations in stage were recorded.

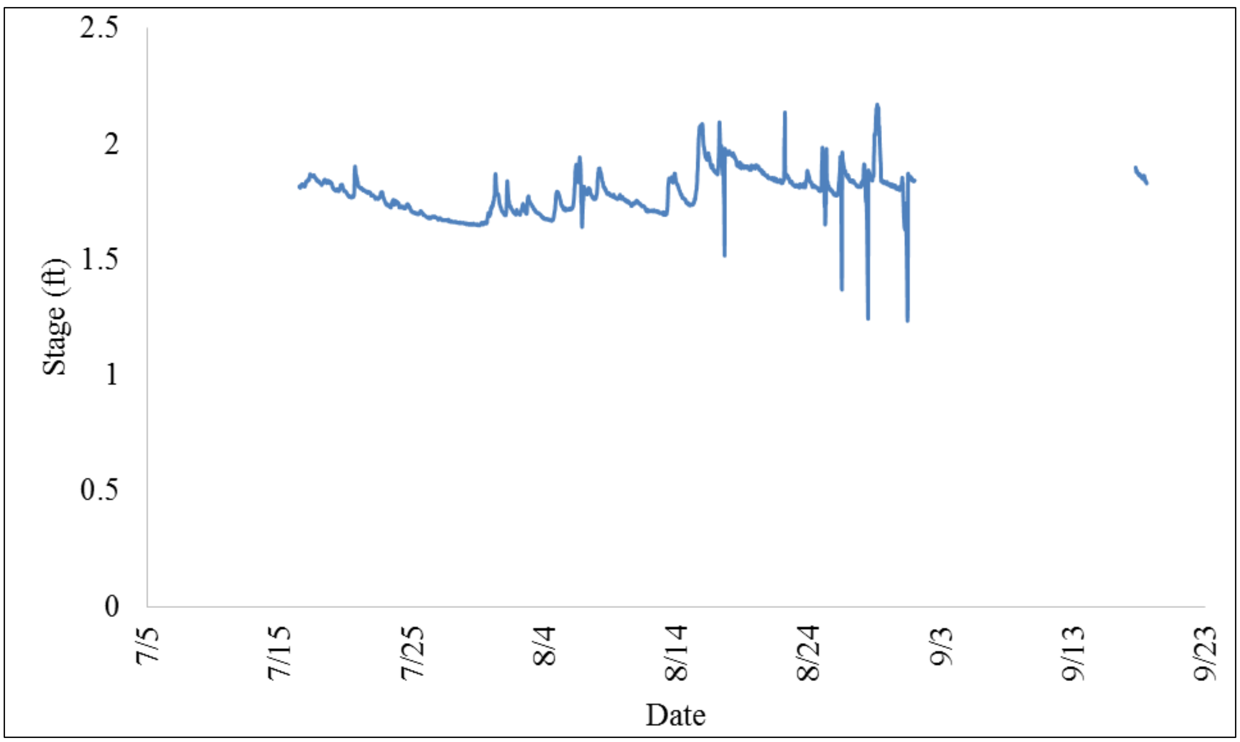

Figure 5.–Continuous stage data collected from the pressure transducer. Readings were taken every 30 minutes from July 16 to September 1, 2013 and from September 17 to September 18, 2013.

Pressure transducer stage data and cross section instantaneous flow measurements were used to calculate mean daily discharge in Waterfall Creek. Mean daily discharge rates ranged from 3.4 cfs in late July to 6.5 cfs in mid- and late-August (Table 2).

Table 2.–Mean daily flow (cfs) for Waterfall Creek. Data were extrapolated from the pressure transducer stage readings.

Day	July	August	September
1		3.8	4.7
2		4.1	
3		3.6	
4		4.5	
5		3.9	
6		4.7	
7		4.5	
8		4.4	
9		4.3	
10		4.2	
11		3.8	
12		3.7	
13		4.8	
14		4.0	
15		6.5	
16	4.9	5.2	
17	4.8	5.9	5.1
18	4.6	5.4	4.8
19	4.5	5.4	
20	4.7	5.0	
21	4.4	4.8	
22	4.2	4.7	
23	4.0	5.1	
24	3.8	5.4	
25	3.7	4.4	
26	3.6	5.0	
27	3.5	4.7	
28	3.4	6.5	
29	3.4	4.8	
30	4.0	4.7	
31	3.7	4.9	

The pressure transducer also recorded water temperature readings at 30 min intervals (Figure 6). Minimum water temperature was 5.8°C on September 18 at 2000; maximum water temperature was 13.4°C on July 24 at 1700. Water temperature followed a diel pattern throughout the season, with lowest temperatures generally recorded from 0000–0600 and daily temperature peaking typically between 1500 and 1700.

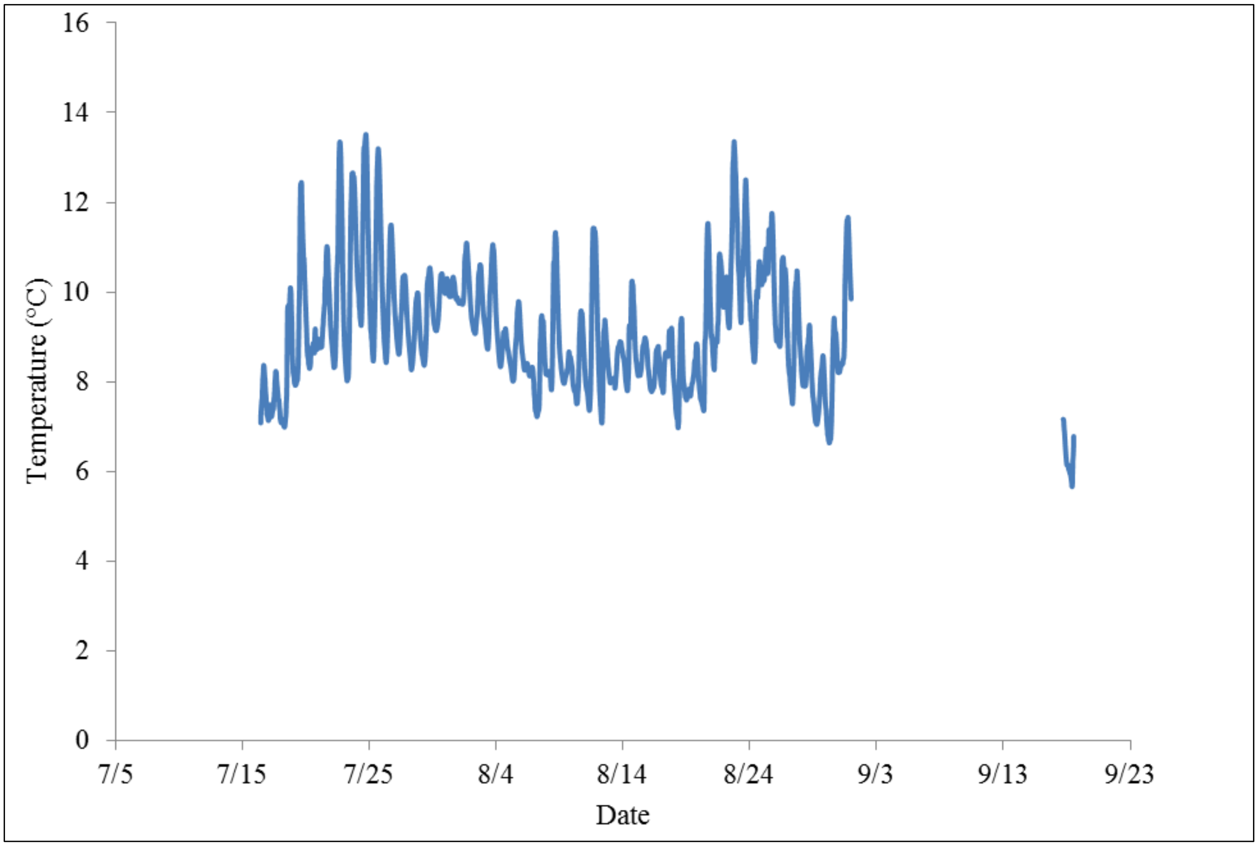

Figure 6.–Continuous temperature readings from the pressure transducer. Readings were taken every 30 minutes from July 16 to September 1, 2013 and from September 17 to 18, 2013.

The riffle cross section shows a streambed profile for the lower cross section site (Figure 7). The monthly wetted perimeter-discharge curves produced from the R2CROSS output for the 2 different months that discharge was measured are shown in Figure 8.

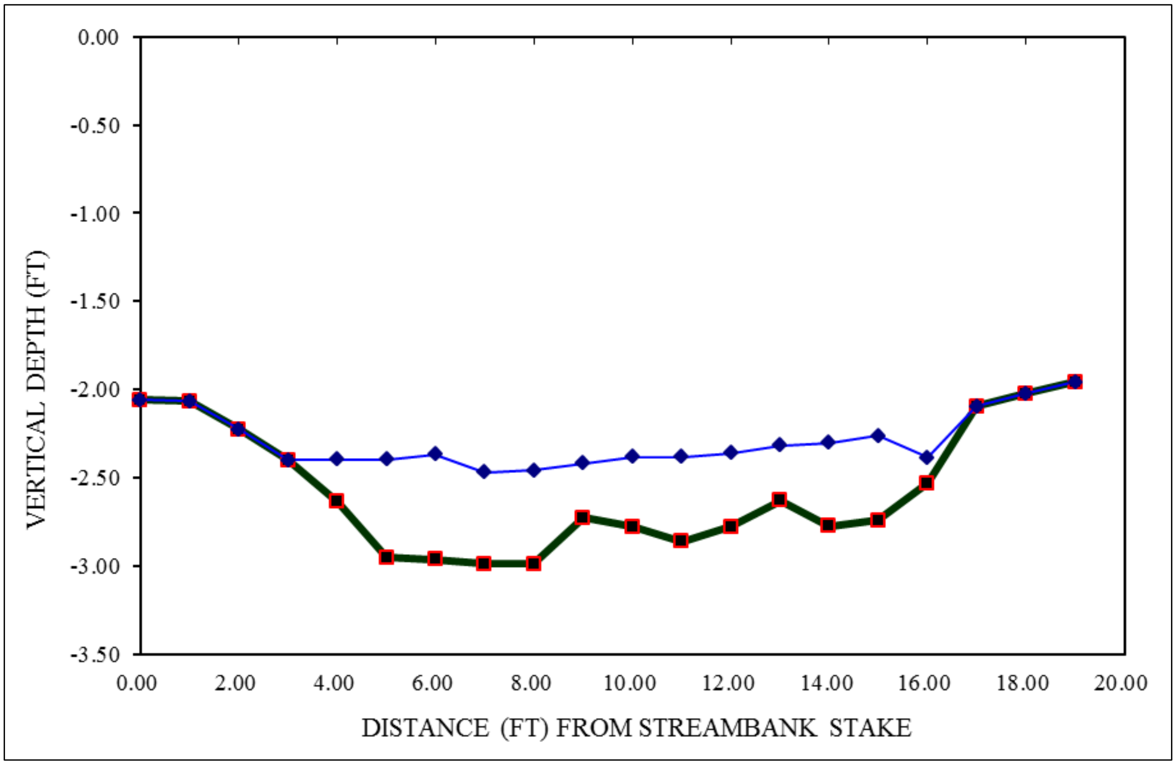

Figure 7.–September 2013 channel cross section at lower site near the pressure transducer site.

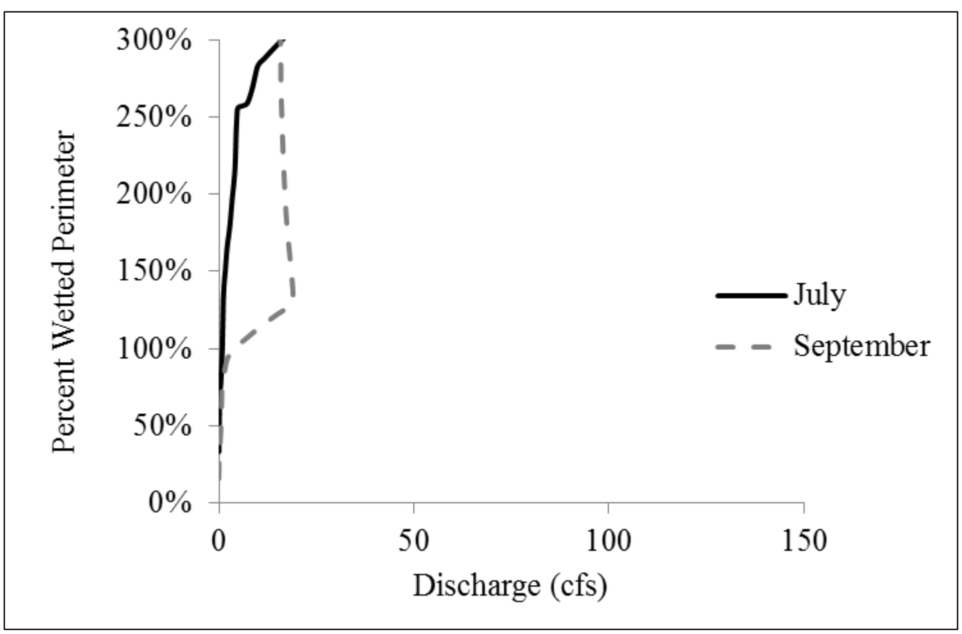

Figure 8.–Percent wetted perimeter versus discharge (cfs) at the lower cross section site.

Results of the R2CROSS calculations for the lower cross section site are presented in Table 3. R2CROSS evaluation criteria suggest that 0.87 cfs is required at the lower cross section site to maintain all 3 of the required fish passage criteria for the 2 months sampled.

Table 3.–R2CROSS evaluation criteria and calculated flows from Waterfall Creek lower cross section data.

Date	Bankfull width (ft)	Required average depth (ft)	Flow to meet average depth (cfs)	Required wetted perimeter (%)	Flow to meet wetted perimeter (cfs)	Required average velocity (ft/s)	Flow to meet velocity (cfs)
7/16/13	14	0.2	0.87	50	0.15	1.0	0.81
9/18/13	13	0.2	0.25	50	0.86	1.0	0.40

The wetted perimeter-discharge curve shows the breakpoint and incipient asymptote at the lower cross section site, based on the CDFW wetted perimeter method (Figure 9). Based on this method, a range of flows between 4.8 cfs and 10.0 cfs at the pressure transducer site are critical to food production in Waterfall Creek. Discharge below 4.8 cfs may result in a rapid decline in wetted perimeter and food production in Waterfall Creek (Figure 9).

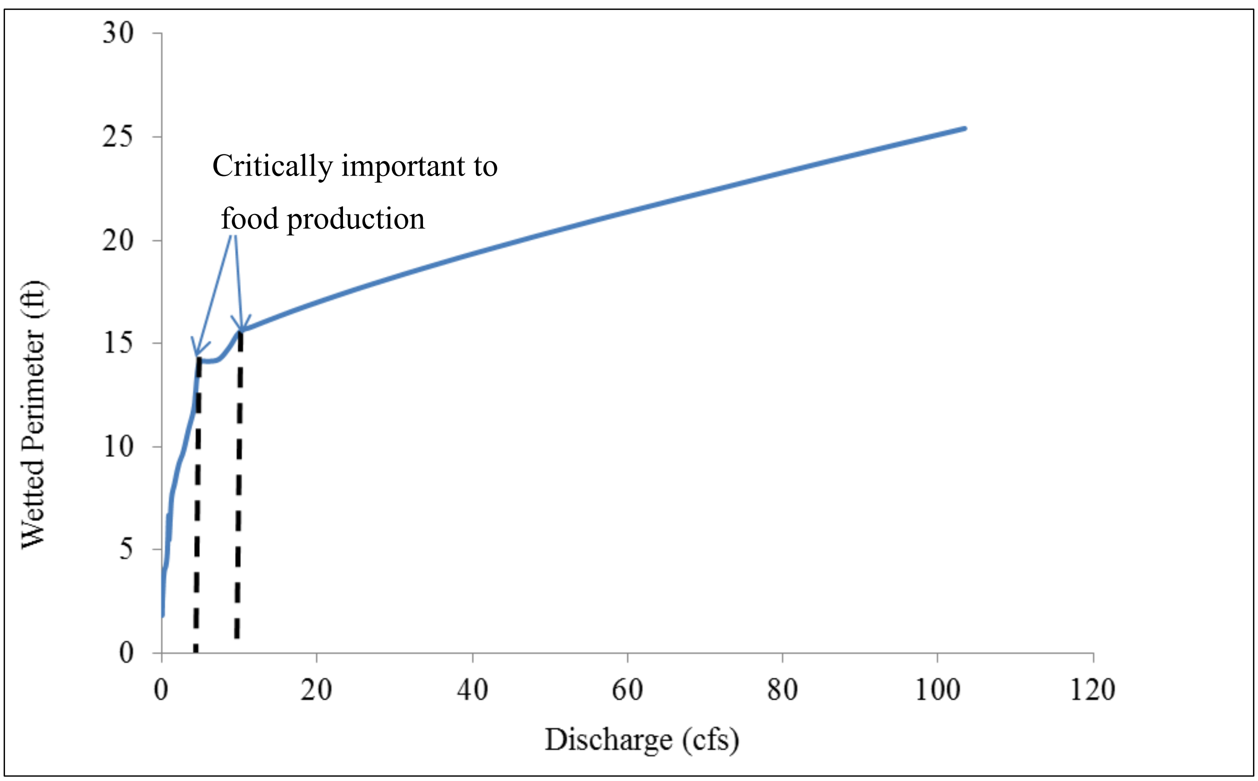

Figure 9.–Wetted perimeter-discharge curve for Waterfall Creek using the CDFW criteria.

The riffle cross section shows a streambed profile for the upper cross section site (Figure 10). The monthly wetted perimeter-discharge curves produced from the R2CROSS output for the 2 different months that discharge was measured are shown in Figure 11.

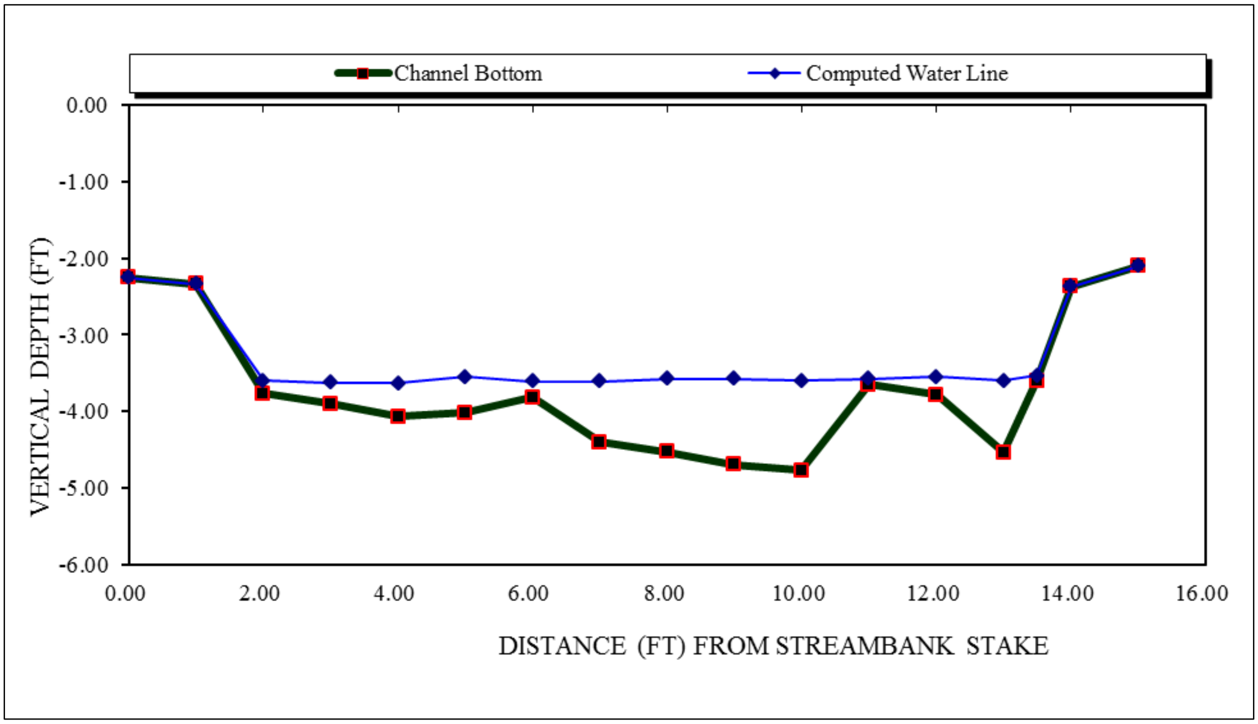

Figure 10.–September 2013 channel cross section at the upper site.

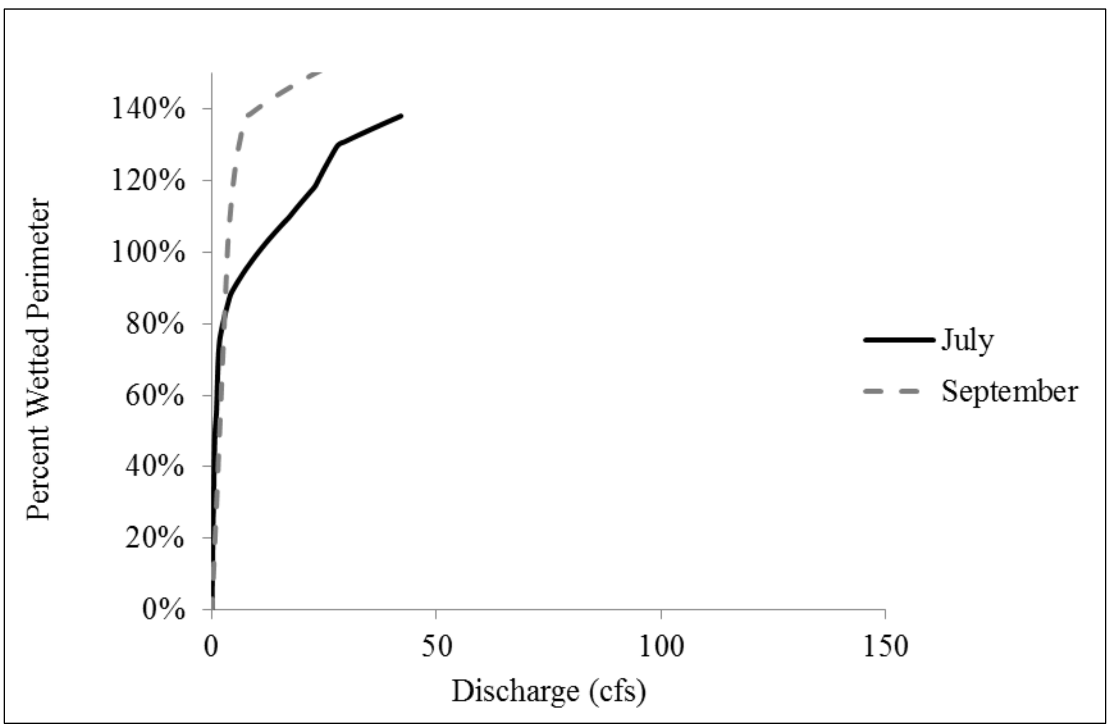

Figure 11.–Percent wetted perimeter versus discharge (cfs) at the upper cross section site.

Results of the R2CROSS calculations for the upper cross section site are presented in Table 4. R2CROSS evaluation criteria indicate that upper cross section flows of 2.11 cfs will satisfy all three required fish passage criteria in the two months sampled.

Table 4.–R2CROSS evaluation criteria and calculated flows from Waterfall Creek upper cross section data.

Date	Bankfull width (ft)	Required average depth (ft)	Flow to meet average depth (cfs)	Required wetted perimeter (%)	Flow to meet wetted perimeter (cfs)	Required average velocity (ft/s)	Flow to meet velocity (cfs)
7/16/13	14	0.2	2.11	50	0.57	1.0	0.81
9/18/13	13	0.2	1.72	50	1.72	1.0	0.52

Natural steps are present in the lower and middle reaches ranging in height from about 0.1 to 0.6 m (Figure 12). These steps provide fish passage at low notches between rock and slower water areas along the banks of the creek. Pools were present downstream of large boulders or other obstructions to flow. Two of the larger pools surveyed were about 1.5 m long by 0.6 m wide and had a maximum depth of 0.2 m. In the upper bypass reach, surveyed step heights range from about 0.3 m to over 0.9 m (Figure 13). Pool depths range from 0.2 to 0.4 m.

Figure 12.–Typical stream reach in the lower and middle reaches of Waterfall Creek.

Figure 13.–Typical stream reach and steps in upper Waterfall Creek.

FISH PRESENCE/ABSENCE

A total of 25 Dolly Varden were captured throughout the study (Figure 14; Table 5). Fork lengths ranged from 65 mm to 125 mm (Figure 15), with an average fork length of 87 mm and a median of 79 mm. During field observations, higher Dolly Varden concentrations were observed in small pools primarily in the middle and lower bypass reach.

Figure 14.–Dolly Varden captured in a minnow trap at the lower cross section site.

Table 5.–Mean fork length and CPUE for Dolly Varden from each minnow trap site.

Site	*n*	Mean Fork Length (mm)	CPUE
Upper bypass reach xsec (MT2)	7	92	4.8
Lower bypass reach xsec (MT1)	7	90	6.2
MT3 (25m DS of lower xsec site)	5	92	6.3
MT4 (60m DS of lower xsec site)	1	68*	1.3
MT5 (150m DS of lower xsec site)	4	72	5.1
MT6 (confluence with Delta Cr.)	1	79*	1.3

Note: DS = Downstream; xsec = cross section.

*Fork length reported for single fish captured; mean not calculated.

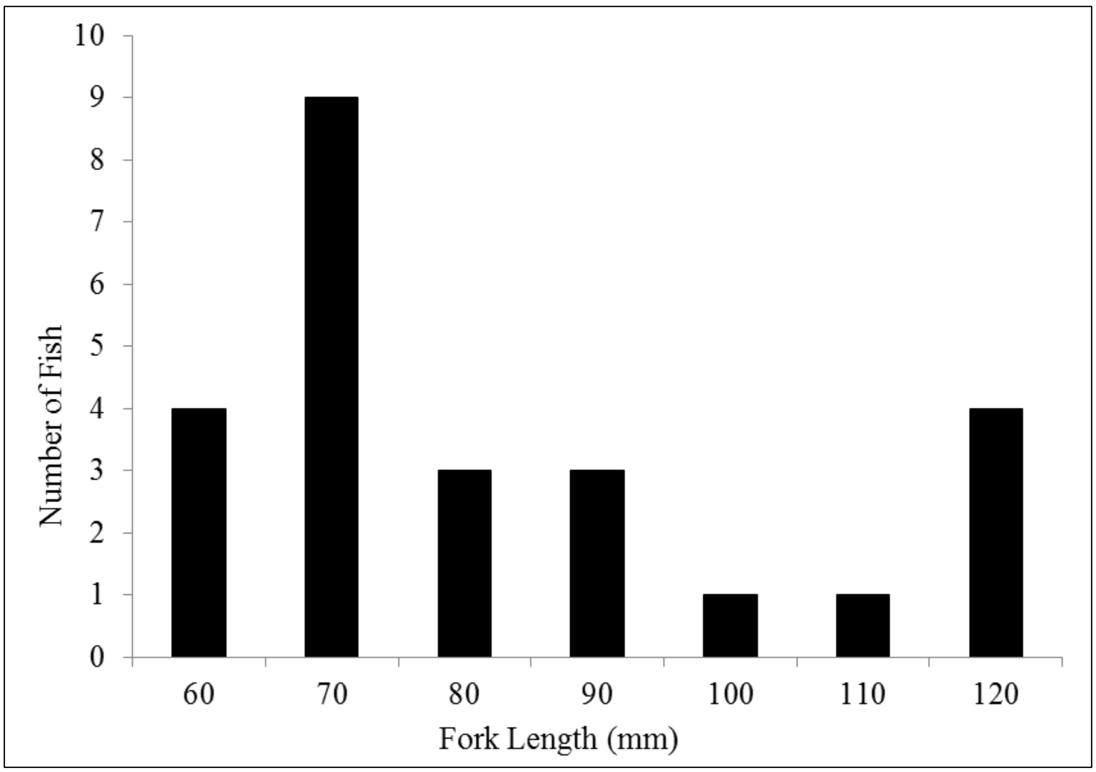

Figure 15.–Length frequency distribution of Dolly Varden.

During the September visit, pink salmon were observed in Waterfall Creek (Figure 16) from the confluence with Delta Creek upstream to a point about 50 meters downstream from the upper cross section location. On September 17, 211 pink salmon carcasses and 46 live adult pink salmon were observed in Waterfall Creek. Pink salmon were observed displaying spawning behavior, such as digging gravel and defending territories, in small gravel beds along the margins of Waterfall Creek. The GoPro® camera recorded these spawning behaviors. Two chum salmon (*O. keta*) were observed downstream of minnow trap location #6; this location is near the confluence with Delta Creek, which supports chum salmon.

Figure 16.–Video still of fish presence at the lower cross section site.
Pink salmon present (circled, left) and Dolly Varden present (circled, back right).

DISCUSSION

Under natural conditions, variability in discharge plays an important role in stream function and maintaining aquatic life. Seasonal cycles and periodic events of higher and lower water levels influence water temperature, sediment transport, and a host of other water quality and stream function parameters (Poff et al. 1997). When water management activities begin, the natural flow regime is disrupted and replaced by longer duration base flow levels, less frequent and less intense pulse flows, and temporal shifts in flow levels.

COMPARISON WITH EXISTING DATA

We compared our data to those collected during permitting (HDR 2008, 2010, 2011) to improve our understanding of the natural flow regime and fish resources in Waterfall Creek. Five components of a natural flow regime were considered: 1) the magnitude of discharge, 2) the frequency of pulse flow events, 3) the duration of flow conditions, 4) the timing of flow conditions, and 5) the rate of change between minimum and maximum flow conditions (i.e., the flashiness) (Poff et al. 1997). Magnitude is defined as the amount of water moving past a specified location per unit time. This is often reported as discharge in cubic feet per second or cubic meters per second. The frequency of pulse flow events relates to how often a flow above a given discharge recurs over some specified time interval. Flood classification (e.g., 5-year flood, 10-year flood) is a good example of frequency. Duration is the period of time associated with a specific flow condition. This can be expressed as the number of days a floodplain is inundated or days per year flows exceed a certain value. Timing refers to the regularity of occurrence of defined flows of a specific magnitude such as annual peak flows. The rate of change or flashiness reflects how quickly flows change from one magnitude to another (Poff et al. 1997). Comparing these metrics between data sets will enhance our understanding of baseline conditions prior to construction and operation of the diversion structure and allow future comparison to data collected during future project monitoring.

Magnitude of Discharge

Mean daily discharge reported for the lower cross section site from each study are shown in Table 6 and Figure 17. Lower cross sections in each study were in about the same location. Project permitting data were collected from May 20, 2005 to June 19, 2006. Discharge from May 20, 2005 to November 1, 2005 and February 23, 2006 to June 19, 2006 was calculated directly from hourly stream gauge data; discharge from November 1, 2005 to February 23, 2006 was extrapolated from periodic staff gauge readings. Calculated discharges from overlapping days (i.e., May 20 to June 19) were averaged to obtain one daily value in order to represent one calendar year (Figure 17). We collected discharge data from July 17 to September 1, 2013, and again on September 17-18, 2013.

In 2005–2006, mean daily discharge ranged from a low of 0.7 cfs on April 24 to a high of 21.3 cfs on September 19. Late summer and fall (August through October) discharge ranged from a low of 3.2 cfs (August 9) to a high of 21.3 cfs (September 19). During the winter months (November through March), mean daily discharge was 2.9 cfs at the gauge site. Fall peak flows and winter low flows may be important to Dolly Varden movements for spawning or overwintering within Waterfall Creek or between Waterfall and Delta creeks. Summer flow conditions influence annual adult pink salmon distribution.

During July and August, we recorded discharge values in 2013 similar to, but often lower than, 2005 (Figure 17). Data from 2005 showed substantial pulse events in July and August that are not present in the 2013 discharge data. In 2013, measured instantaneous discharge at the lower cross section site was 5.93 cfs in July and 7.82 cfs in September.

Table 6.–Overall and monthly comparison of mean daily discharge (cfs) at the lower cross section site from project permitting (2005–2006) and this study (2013).

	Mean Daily Discharge (cfs) Range*		
Study (Date)[+]	Overall	July	August
Project permitting (2005-06)	0.7-21.3	4.3-8.9 (5.8)	3.2-18.3 (6.3)
This study (2013)	3.4-6.5	3.4-4.9[#] (4.1)	3.6-6.5 (4.7)

*Monthly means are shown in parenthesis.

[+]Project permitting data were collected from May 20, 2005 to June 19, 2006. Data for this study were collected from July 16 to September 1, 2013 and September 17-18, 2013.

[#]Only 15 days of data were recorded (July 16 to July 31, 2013).

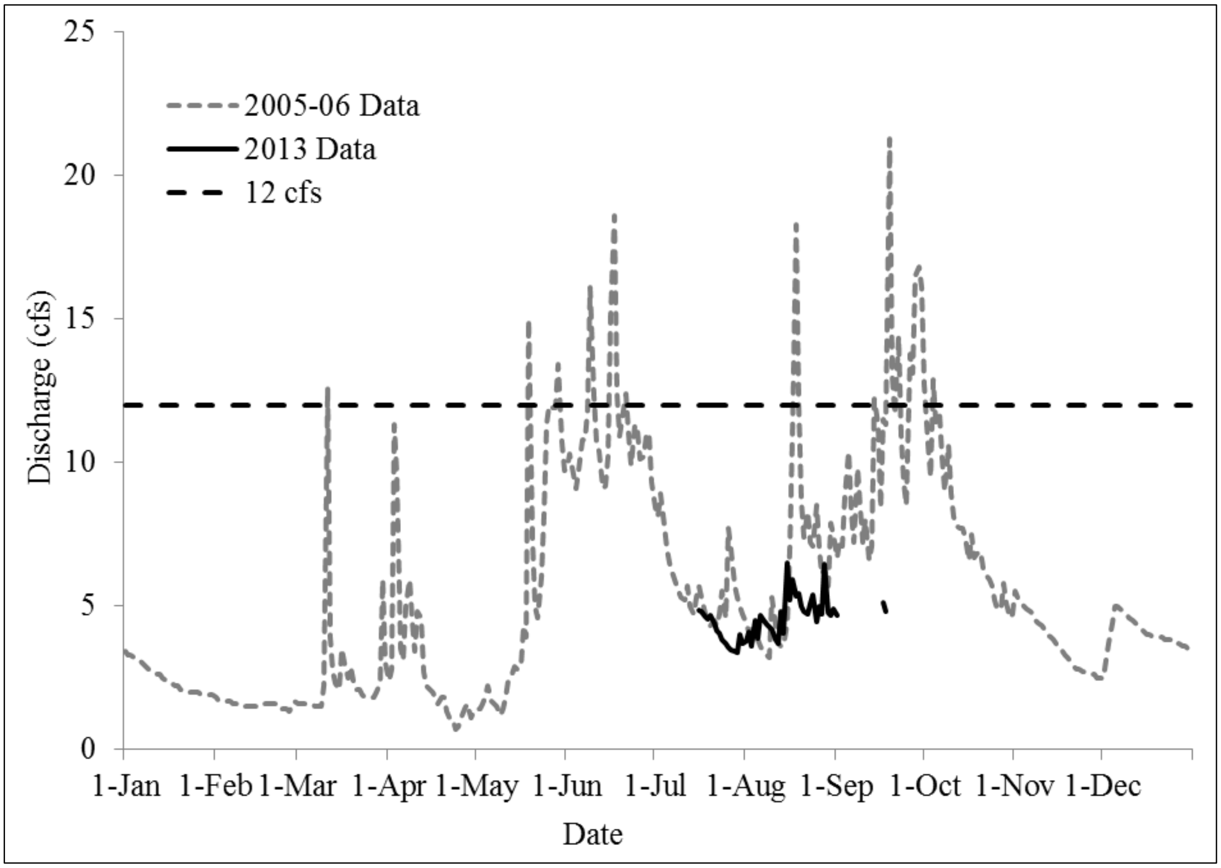

Figure 17.–Hydrograph comparison between project permitting data (2005–2006) and this study (2013). The 12 cfs water right line is shown for reference.

Frequency of Pulse Flows and Flow Duration

Waterfall Creek is a snowmelt-fed and precipitation-driven system. Data collected in 2005–2006 indicate that about 6 weeks of elevated water level occurs in the spring and early summer based on snowmelt. Intermittent pulses of higher water levels occurred in late winter and late summer/fall; these pulses are likely related to air temperature increases and/or precipitation events. Ten pulse flow events where discharge increased >5 cfs occurred throughout the 2005–2006 data collection period. Pulse discharge events were short-lived, returning to pre-pulse flows after about 3 days. Smaller pulse events up to 3 cfs of change occurred regularly throughout the year, excluding the mid-December to early March period when pulsed flows did not occur. In the 2013 study, pulse flow events where discharge increased >5 cfs in Waterfall Creek did not occur, although the limited timeframe of data collection was likely a factor. Small pulse events (about 3 cfs) did occur on August 15 and August 28, 2013, and vegetative debris and streambank water marks suggest recent pulse flow events (Figure 18). Duration of the small 2013 pulse events was ≤3 days.

Waterfall Creek discharge is influenced by the frequency and duration of precipitation events. Intense or prolonged precipitation events may rapidly raise discharge levels in Waterfall Creek; discharge appears to quickly return to pre-pulse flow once precipitation stops. Additional study is needed to understand the function of these regular pulse flow events on stream habitat and aquatic organisms in Waterfall Creek.

Timing of Flow

Based on the 2005-2006 data, mean daily discharge above 12 cfs (i.e., the appropriated water right) was recorded 21 times from March through October (Figure 17). Of these 21 days for the water year, 9 were in September and 6 in June. This timing of elevated stream discharge relates to the timing of fall precipitation events and snowmelt. Given the lack of frequency that Waterfall Creek flow is above the 12 cfs water right, post-construction flow for much of the year will be limited to the 1 cfs instream flow requirement, water diverted from Springs Creek, and accretion within the basin.

In July to September 2013, mean daily discharge was not above 12 cfs. Comparison of the different data sets for the brief overlap period (July 16–September 1) suggests a difference between water years.

It is important to distinguish that the water right is appropriated at the withdrawal point above the waterfall in the upper part of Waterfall Creek, while each study's discharge measurements were taken further downstream in the middle portion of the bypass reach. Because of the influence of basin size and accretion on flow volume, stream flow at any given time at the point of discharge measurement is expected to be higher than at the water withdrawal point in the upper part of the basin. Thus, the number of days that Waterfall Creek flow at the withdrawal point will exceed the appropriated water right will be less than what the existing data suggest.

Flashiness

The frequency, duration, and timing of flows in Waterfall Creek suggest that the natural flow regime in Waterfall Creek has a high rate of change or flashiness value. The 2005–2006 flow data show multiple short-duration high flow events distributed throughout the longer term hydrology pattern of low water in the winter and highest flows in the spring and fall (Figure 17). While data collected during 2013 generally show lower discharge rates and less flashiness, short pulse events were still recorded. More study is needed to understand how these short, intense pulse events influence Waterfall Creek stream habitat and aquatic organisms.

Figure 18.–Photo of debris about one foot above the current water level indicating previous high flow. Middle reach of Waterfall Creek, July, 2013.

Fish Resources

Fish presence was documented during project permitting. HDR (2008) reported 87 fish (77 Dolly Varden and 10 pink salmon) observed through visual foot surveys conducted in the summer and fall of 2007 and a backpack electrofishing survey in February 2006. Most of these fish were documented near the confluence with Delta Creek and near the lower cross section site. In 2006, 6 Dolly Varden were caught at the lower cross section site and 2 were caught at the upper cross section site. During later studies (HDR 2010), Dolly Varden presence throughout the proposed bypass reach was confirmed; Dolly Varden fork length ranged from 73 to 162 mm, with a mean of 155 mm. Although habitat appears suitable, Dolly Varden were not captured in Waterfall Creek above the waterfall near the proposed water withdrawal point (HDR 2011). Springs Creek does not appear to support substantial numbers of Dolly Varden; in 2 separate sampling events (October 2009 and February 2010), five Dolly Varden were captured at the same location in the lower reach near Delta Creek (HDR 2010). Dolly Varden were not captured elsewhere in Springs Creek.

In comparison, the 2013 study captured 25 Dolly Varden using minnow traps during 2 sampling events. Dolly Varden were the only fish captured in minnow traps. Mean fork length of captured fish was 87 mm. A total of 257 pink salmon (46 live pink salmon and 211 carcasses) were observed in Waterfall Creek in September 2013; spawning behavior and redds containing eggs were observed. The presence of spawning pink salmon likely influences the fall distribution of Dolly Varden in Waterfall Creek. Dolly Varden were observed following pink salmon in the creek and attacking pink salmon redds when eggs where present and available. Also, annual variability in Delta Creek run timing, run strength, and habitat availability may influence the annual pink salmon return to Waterfall Creek and the response of the local Dolly Varden population. Additional study of these fish populations and their distribution is needed to determine the potential impacts of water management on fish resources in Waterfall and Delta creeks.

HYDROLOGY AND HABITAT CONSIDERATIONS

Pulse flows from snowmelt and rain events are a regular occurrence in Waterfall Creek; the role of these flows in sediment/nutrient transport or maintaining fish habitat in Waterfall Creek is not well understood. Removal of the 12 cfs water right will remove these peak flow events; thus, whatever aquatic habitat function (or impact) these pulse flows provide will be lost under managed water conditions.

The diurnal cycle appears to be the primary driver of water temperature in Waterfall Creek; daily water temperature varied by as much as 4.5^{o} C in July (Figure 6). There does not appear to be a relationship between water stage (Figure 5) and water temperature (Figure 6), as was observed in another Alaska Peninsula stream (Dunker 2015). Under managed water conditions, water depth throughout the bypass reach will likely be reduced, which could increase water temperature and influence fish populations.

Winter flow rates were not collected during this field investigation. Based on the 2005–2006 data, water flow was ≤5 cfs from early November to mid-March (Figure 17). During this water year, multiple pulse flow events >5 cfs occurred in March and April, but otherwise, flows remained ≤5 cfs until snowmelt began in late May. There also was a summer low flow period in July and August. During these base flow periods, limited water will be available for power production while still providing the 1 cfs instream flow requirement below the diversion structure. Throughout the year, there are few occasions when Waterfall Creek flow exceeds 13 cfs (i.e., the 12 cfs water right and the 1 cfs instream flow requirement). Depending on the actual amount of the 12 cfs water right withdrawn at any given time, flow for much of the year in the Waterfall Creek bypass reach is expected to consist of the 1 cfs instream flow requirement, input from the Springs Creek diversion, and accretion. Fish passage, overwintering habitat, and connectivity to large pools in the bypass reach may be disrupted for long periods of time. Post-construction monitoring will be needed to understand the impact of a managed water regime on habitat connectivity and function.

R2CROSS

According to the R2CROSS method, spring and summer flow rates must satisfy all 3 model criteria, while fall and winter flows must meet 2 of the 3 criteria in order for fish passage to be maintained (see Table 1). The R2CROSS method is sensitive to site selection. The presence of exposed rocks that separate the bankfull channel, the presence of undercut banks, and other site features can lead to artificially high or low readings (Annear et al. 2004). This method was developed in Colorado where spring and summer flows are higher than fall and winter flows because of high rates of snowmelt and the resulting runoff. While this is true for portions of Alaska, the Alaska Peninsula typically sees 2 high flow periods: early summer from snowmelt and fall from rain events. Therefore, applying this method to the Alaska Peninsula may require some adjustment in the seasonal flow requirements and the number of criteria that must be met for fish passage to be maintained. For example, seasonal discharge criteria could be adjusted for fish run timing and coincide with spawning migrations or other important life stage events for the organisms that are present in the stream. We chose to analyze Waterfall Creek based on all 3 fish passage flow criteria being met during the months sampled to determine if favorable fish passage conditions were maintained. Additional study on Waterfall Creek fish movement, fish passage, and flow characteristics are needed to determine appropriate adjustments to the R2CROSS method.

Based on the R2CROSS method, the minimum flow required to meet all 3 fish passage criteria in both months sampled is 0.87 cfs at the lower cross section (Table 3) and 2.11 cfs at the upper cross section (Table 4). Based on flow data provided during permitting and data collected during this study, the natural flow regime in Waterfall Creek at the lower cross section is > 0.87 cfs for most of the year and the 1 cfs instream flow requirement will satisfy R2CROSS fish passage flow criteria at this location. However, the minimum flow recommendation from the R2CROSS model is suspect because the wetted perimeter versus discharge comparison (Figure 8 and Figure 11) resulted in discharge flows for fish passage that exceed 100% wetted perimeter. Nehgring (1979) noted that this discharge-wetted perimeter relationship can occur in creeks that have a more V-shaped channel, such as Waterfall Creek. Also, the presence of undercut banks can contribute to error during cross section measurements.

CDFW Wetted Perimeter Procedure

The California Department of Fish and Wildlife's Standard Operating Procedure for the Wetted Perimeter Method in California (2013) recommends identifying a range of flows to maintain critically important food production in order to protect fish populations. Under this method, the calculated wetted perimeter-discharge curve is used to identify flows below which food production rapidly declines and flows that provide near-optimal food production conditions. Maintaining food production is important to maintaining the indigenous fish populations in any creek.

Based on this method, a range of flows between 4.8 cfs and 10.0 cfs at the pressure transducer site (i.e., lower cross section) are critical to food production in Waterfall Creek. Discharge below 4.8 cfs may result in a rapid decline in wetted perimeter and food production in Waterfall Creek (Figure 9). The CDFW method recommended flow range seems like a reasonable breakpoint for critical food production; this flow range is similar to the natural flow regime observed in both the 2005–2006 and the 2013 studies (Figure 17).

Future Water Management

We used 2 distinct instream flow methods to assess the Waterfall Creek flow needed to maintain stream function, fish passage, and food production. In Waterfall Creek, the R2CROSS and CDFW wetted perimeter methods resulted in considerably different instream flow recommendations. The CDFW wetted perimeter method suggested a range of flows within observed flow values in 2005–2006 and 2013. While this suggested flow range (4.8–10.0 cfs) may maximize food production, the CDFW method does not address fish passage conditions. Given our observations of Waterfall Creek, we suspect fish passage will be maintained at flows below this CDFW-suggested flow range, but more study is needed to determine the specific flow level at which fish passage is compromised. Under the proposed future water management regime, water withdrawals up to the 12 cfs water right will likely affect food production but the specific impact to fish passage within Waterfall Creek remains unknown.

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APPENDIX A.–FISH EFFORT, CATCH, AND LENGTH DATA

Appendix A.– Fish effort, catch, and length data

Date	Location	Trap	Soak Time (Hr)	Fish Count	Fork Length (mm)
7/16/2013	1	1	8	1	75
7/16/2013	1	1	-	2	75
7/16/2013	1	1	-	3	88
7/16/2013	1	1	-	4	118
7/16/2013	2	1	8	1	90
7/16/2013	2	1	-	2	100
7/16/2013	2	2	8	1	65
9/18/2013	1	1	19	1	125
9/18/2013	1	1	-	2	75
9/18/2013	1	1	-	3	75
9/18/2013	2	1	19	1	125
9/18/2013	2	1	-	2	121
9/18/2013	2	1	-	3	76
9/18/2013	2	1	-	4	67
9/18/2013	3	1	19	1	125
9/18/2013	3	1	-	2	91
9/18/2013	3	1	-	3	92
9/18/2013	3	1	-	4	80
9/18/2013	3	1	-	5	72
9/18/2013	4	1	19	1	68
9/18/2013	5	1	19	1	71
9/18/2013	5	1	-	2	65
9/18/2013	5	1	-	3	82
9/18/2013	5	1	-	4	71
9/18/2013	6	1	19	1	79