Technical Report No. 17-01

# Pink Salmon Use of the Tyee Lake Hydro Tailrace

by

Katrina M. Kanouse and Jackie Timothy

December 2018

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 reports by the Divisions of Habitat, Sport Fish, and Commercial Fisheries. 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 figures 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 |
| megawatt | MW |
| 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) |

**Measures (fisheries)**

| | |
|---|---|
| fork length | FL |
| mideye-to-fork | MEF |
| mideye-to-tail fork | METF |
| standard length | SL |
| total length | TL |

**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, $\chi^2$, 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 | $\geq$ |
| harvest per unit effort | HPUE |
| less than | $<$ |
| less than or equal to | $\leq$ |
| logarithm (natural) | ln |
| logarithm (base 10) | log |
| logarithm (specify base) | $log_{2,}$ etc. |
| minute (angular) | ' |
| not significant | NS |
| no data | ND |
| null hypothesis | $H_O$ |
| percent | % |
| probability | P |
| probability of a type I error (rejection of the null hypothesis when true) | $\alpha$ |
| probability of a type II error (acceptance of the null hypothesis when false) | $\beta$ |
| second (angular) | " |
| standard deviation | SD |
| standard error | SE |
| variance | |
| population | Var |
| sample | var |

*TECHNICAL REPORT NO. 17-01*

# PINK SALMON USE OF THE TYEE LAKE HYDRO TAILRACE

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Cover: Upstream view of the Tyee Lake hydroelectric facility tailrace and powerhouse, August 2018.

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# EXECUTIVE SUMMARY

The Southeast Alaska Power Agency (SEAPA) owns and operates the Tyee Lake hydroelectric facility near Wrangell. The lake-tap project was constructed in the early 1980s and discharges fresh water from the powerhouse into Tailrace Creek—a channel carved into the tidal flat and filled with gravel to support pink salmon *Oncorhynchus gorbuscha* spawning. To evaluate pink salmon embryo survival in the constructed habitat, biologists embedded fertilized pink salmon embryos in incubation chambers in the gravel near the powerhouse, of which 95% survived to the alevin stage. While post-construction Tailrace Creek habitat studies documented declining spawning habitat quality, pink salmon[a] continued reproducing when the facility was generating less than 10 MW of its 25 MW design capacity.

In 2010, to meet increasing regional power needs, SEAPA completed a hydropower transmission line intertie; the Tyee Lake and Swan Lake hydroelectric facilities are now operating at capacity and the Swan-Tyee intertie provides clean energy to Wrangell, Petersburg, and Ketchikan. To assess long-term tailrace stability and condition, and to evaluate the effect of increased discharge on pink salmon habitat, SEAPA contracted with the Alaska Department of Fish and Game (ADF&G) Division of Habitat to conduct studies similar to those completed in the 1980s. Our studies reveal that without a source for transport and recruitment, Tailrace Creek is starved for spawning gravel, and what gravel remains provides only low quality intertidal spawning habitat for pink salmon. Most spawning takes place in the upper half of the channel less often influenced by salt water.

The intent of the experimental spawning channel was to mitigate anadromous fish habitat loss in Hidden Creek after water was diverted for hydropower generation. Hidden Creek continues to flow year-round nearly four decades later, despite annual Tyee Lake drawdown (C. Hammer, Operations Manager, SEAPA, Wrangell, personal communication), and provides low quality intertidal spawning habitat for anadromous fish. Tyee Lake continues to support resident fish. While Tailrace Creek also provides spawning habitat for a few pink salmon, it will not continue to provide spawning habitat without a new source of gravel. Therefore, we recommend against constructing future spawning channels in the intertidal unless tailrace discharge scour will expose tidal flat gravel suitable for spawning, or manual gravel replenishment is guaranteed.

In the case of the Tyee Lake hydroelectric facility, we now have the benefit of time and hindsight to understand the *de minimis* impact the project had on anadromous fish habitat and fish populations. Had we known then what we know now, ADF&G biologists would not have required fisheries mitigation for this project that is now sustainably powering the region.

# INTRODUCTION

The Tyee Lake hydroelectric facility is located at the head of Bradfield Canal in the Tongass National Forest, about 63 km southeast of Wrangell and 33 km west of the U.S./Canada border by air (Figure 1).

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[a] And a few chum salmon *O. keta*.


Figure 1.–Tyee Lake hydroelectric facility map.

The Federal Energy Regulatory Commission (FERC) licensed the hydroelectric facility in 1981, the Alaska Power Authority (APA) developed and began operating the project in January 1984 (Kelly 1987), and SEAPA, a non-profit State of Alaska joint action agency, purchased the facility in 2002.[b]

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[b] Formerly known as the Four Dam Pool Power Agency.

The facility generates power by withdrawing water through a lake-tap at about 375 m elevation[c] and transporting the water though a drop shaft, a 2,500 m power tunnel, and a 400 m penstock to a powerhouse (FERC 1981) equipped with two turbines near tidewater on the south side of the Bradfield River delta (Figure 2). The turbines discharge water into a 350 m tailrace designed as an experimental salmon spawning channel known as Tailrace Creek. Between 1984 and 2010, the facility provided power to Petersburg and Wrangell and generally produced less than 10 MW of power. Since completing construction of the Swan–Tyee transmission line intertie in 2010 to provide hydroelectric power to Ketchikan, the facility now operates up to the design capacity of 25 MW.[d]

Figure 2.–Bradfield River (left) and Tyee Lake hydroelectric facilities (right).

In 1980, fishery biologists documented Arctic grayling *Thymallus arcticus* in Tyee Lake, and chum salmon, coho salmon *O. kisutch*, pink salmon, Dolly Varden char *Salvelinus malma*, cutthroat trout *O. clarkii*, and rainbow trout *O. myskiss* in Hidden Creek, the Tyee Lake outlet stream (Dwight 1980). Article 43 of the FERC project license (Permit No. 3015) required APA to develop a plan to mitigate potential adverse effects to fishery resources caused by Tyee Lake drawdown and reduced flow in Hidden Creek during project operation. In 1983, resource agencies and FERC approved the Revised Fisheries Mitigation Plan (Kelly 1983), which included constructing an experimental salmon spawning channel as the tailrace to mitigate the potential loss of pink and chum salmon spawning habitat in Hidden Creek.

In 1983, the APA constructed the tailrace according to the mitigation plan design (Dwight 1980, Wilson et al. 1981; Table 1) and documented basic water quality, discharge, spawning habitat quality, and juvenile and adult fish use between 1984 and 1987, and pink salmon embryo survival 1986–1987, during operating loads less than 10 MW. Following is a summary of the Tailrace Creek study results described in the final monitoring report (Kelly 1987):

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[c] Maximum lake level elevation is 425 m.

[d] SEAPA's Swan Lake and Tyee Lake hydroelectric facilities provide wholesale power to its member utilities after member existing hydro has been fully utilized, except Wrangell, which is powered solely by these facilities (E. Wolfe, Special Projects Director, SEAPA, Wrangell, personal communication).

- mean daily surface water temperatures ranged 2.8–5.6 ºC;
- discharge ranged 35–40 $ft^3/s$ during low tide;
- mean proportion of sand in streambed substrate increased from 0% to 15%;
- more pink salmon spawned than chum salmon;
- juvenile coho salmon, Dolly Varden char, threespine stickleback *Gasterosteus aculeatus*, and sculpin *Cottus* sp. were captured in the creek; and
- 95% of the artificially fertilized pink salmon embryos embedded in incubation chambers in the gravel near the upper extent of the creek survived to alevin stage.

Table 1.–Tailrace Creek design specifications.

| Criteria | Preferred Range |
|---|---|
| Length | 335 m |
| Bed width | 7.6–9.1 m |
| Bed gradient | 0.001% |
| Water depth | 0.15–0.75 m |
| Water velocity | 1.0–2.0 ft/s |
| Substrate size | 6.35–101.6 mm diameter river rock having < 10% fines and < 2% rock measuring > 63.5 mm |
| Substrate depth | 0.51–0.76 m |

The Tailrace Creek studies occurred during low operating loads due to reduced electrical demand at the time, and the final monitoring report (Kelly 1987) recommended resuming the tailrace monitoring studies when the operating load increased, as the additional fresh water input could change fish habitat conditions.[e] In 1994, FERC determined the final monitoring report (Kelly 1987) fulfilled the Article 43 reporting requirements for the project license.[f]

In 2010, the same year the Swan-Tyee transmission line intertie was completed, SEAPA partnered with the Division of Habitat to document channel morphology, discharge, basic water quality, spawning habitat quality, and fish use during increased operating loads up to 25 MW. We collected the data between August 2010 and May 2011, August 2015 and May 2016, and in August 2018.

## PURPOSE

The purpose of this investigation is to assess long-term tailrace stability and evaluate the effect of increased discharge on pink salmon habitat.

[e] Additionally, the feasibility analysis (Wilson et al. 1981) suggests the APA consider constructing a second tailrace channel when the facility operates at maximum capacity to avoid disrupting productive salmon spawning habitat in the tailrace, if successful.

[f] J. Mark Robinson, Director, Division of Project Compliance and Administration, FERC, to Stanley E. Sieczkowski, AEA. Letter: Project No. 3015-008 Tyee Lake Project; dated 2/24/1994. Unpublished document, can be obtained from the Operations Manager, Southeast Alaska Power Agency, 100 First Ave., Suite 318, Ketchikan, AK.

## AQUATIC STUDIES

We completed the following studies in Tailrace Creek:

- channel morphology;
- stream discharge;
- surface water quality;
- intragravel water quality;
- spawning substrate quality;
- pink salmon use; and
- juvenile fish use.

## STUDY AREA

### Tyee Lake

Tyee Lake is southeast of Wrangell near the head of the Bradfield Canal at 425 m elevation in subalpine terrain (Figure 3). The 434 acre lake measures about 4 km long, less than 0.6 km wide, 100 m deep, and is surrounded to the east and west by steep rock cliffs that rise to 1,500 m peaks (Dwight 1980). The main inlet creek drains into the lake from the southeast, and the outlet drains to the northwest. The Tyee Lake drainage area is about 37 $km^2$ and mean annual precipitation is about 406 cm (Dwight 1980).

ADF&G biologists planted eyed Arctic grayling eggs in the main inlet stream in 1962,[g] and 20,000 grayling fry in the lake in 1967 and 1968 (Dwight 1980). In 1980, during the FERC licensing review, contract biologists estimated the Tyee Lake grayling population at about 5,000 fish, identified primary spawning habitats in several inlet streams at the head of the lake, documented spawning activity and fry development, and discovered many Arctic grayling were infected with bacterial kidney disease and enteric red mouth (Dwight 1980). While not a part of the study, we opportunistically fished for Arctic grayling in Tyee Lake on August 27, 2015 for about 20 min using a spinning rod and reel at the mouth of the main inlet stream on the south side of the lake and captured one 200 mm Arctic grayling (Figure 4). During that time, we also observed one 250 mm Arctic grayling in the lake.[h]


Figure 3.–Tyee Lake, looking upstream.


Figure 4.–Tyee Lake Arctic grayling.

[g] ADF&G Division of Sport Fish lake survey record. Unpublished document, can be obtained from the Ketchikan Division of Sport Fish Area Management Biologist, 2030 Sea Level Drive #205, Ketchikan, AK.

[h] Nicole Legere, Habitat Biologist, to Jackie Timothy, Southeast Regional Supervisor, ADF&G Division of Habitat. Memorandum: Tyee Hydro trip report August 27–28, 2015; dated 9/25/2015. Unpublished document, can be obtained from the Southeast Regional Supervisor, ADF&G Division of Habitat, 802 3rd Street, Douglas, AK.

## Hidden Creek

Tyee Creek, the Tyee Lake outlet stream, begins on the northwest side of the lake at 425 m elevation, flows for about 1.7 km through a series of cascades and waterfalls, joins Hidden Creek[i] at about 30 m elevation, below which Hidden Creek flows northeast for about 1 km and into Bradfield Canal. About 140 m upstream of the mouth near the extent of tidal influence, a 5.5 m waterfall prevents upstream fish passage (Figures 5–8).[j]

During project planning and licensing in the early 1980s, fishery biologists documented spawning pink and chum salmon,[k] Dolly Varden char, cutthroat trout, and sculpin below the Hidden Creek waterfall. Above the waterfall, they found steelhead (Dwight 1980).[l] Stream widths downstream of the falls range 15–33 m, and we observed dense algae growth on the streambed, which included bedrock and boulders near the waterfall and cobble, gravel, sand, and mud near the stream mouth.

On April 28, 2010, we set three minnow traps baited with disinfected salmon roe in Hidden Creek at the base of the waterfall overnight and captured 1 rainbow trout (130 mm FL) and 8 sculpin.[m] On August 18, 2010, we set four baited minnow traps in Hidden Creek pools for about 6 h during low tide and captured 3 sculpin, no salmonids. We also surveyed Hidden Creek for adult pink and chum salmon during low tides; on August 18, 2010, we observed 3 pink salmon near the mouth, none in the creek, and between August 28 and August 30, 2018, we surveyed three times and did not find adult salmon or evidence of salmon spawning, though observed a school of juvenile coho salmon and a few sculpin near the mouth.[n]

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[i] Stream No. 107-40-10538 provides habitat for chum, coho, and pink salmon (Johnson and Blossom 2018).

[j] Evan Fritz, Habitat Biologist, to Jackie Timothy, Southeast Regional Supervisor, ADF&G Division of Habitat. Memorandum: Tailrace and Hidden Creek spawning surveys; dated 9/21/2018. Unpublished document, can be obtained from the Southeast Regional Supervisor, ADF&G Division of Habitat, 802 3rd Street, Douglas, AK.

[k] Dwight (1980) reports observing nearly 600 chum salmon in Hidden Creek on 8/8/1980, and 250 pink salmon in Hidden Creek on 9/9/1980. In 2018, we observed Hidden Creek substrates generally unsuitable for chum and pink salmon spawning.

[l] Dwight (1980) reports observing at least two age classes of steelhead, less than 130 mm FL, in Hidden Creek above the waterfall. We documented the waterfall is an anadromous fish barrier that prevents upstream steelhead migration, so the fish are from a self-sustaining rainbow trout population, of which some individuals may drop below the waterfall barrier and become steelhead.

[m] Kate Kanouse and Katie Eaton, Habitat Biologists, to Jackie Timothy, Southeast Regional Supervisor, ADF&G Division of Habitat. Memorandum: Tyee Hydro facility trip report; dated 6/23/2010. Unpublished document, can be obtained from the Southeast Regional Supervisor, ADF&G Division of Habitat, 802 3rd Street, Douglas, AK.

[n] Evan Fritz, Habitat Biologist, to Jackie Timothy, Southeast Regional Supervisor, ADF&G Division of Habitat. Memorandum: Tailrace and Hidden Creeks spawning surveys; dated 9/21/2018. Unpublished document, can be obtained from the Southeast Regional Supervisor, ADF&G Division of Habitat, 802 3rd Street, Douglas, AK.

Figure 5.–Hidden Creek waterfall.

Figure 6.–Hidden Creek at low tide, downstream view from the waterfall.

Figure 7.– Hidden Creek at low tide, downstream view of the mouth.

Figure 8.–Hidden Creek at mid-tide, upstream view of the waterfall.

## Tailrace Creek

Tailrace Creek[o] begins at the hydroelectric powerhouse and flows through about 350 m of tidal wetlands into Hydro Creek[p] (Figures 9, 10). After Tailrace Creek construction, biologists captured juvenile coho salmon, Dolly Varden char, and sculpin in Tailrace Creek and observed spawning chum and pink salmon (Kelly 1987).

Figure 9.–Tailrace Creek at –1.5 ft tide, downstream view from the powerhouse.

Figure 10.–Tailrace Creek at +18.5 ft tide, downstream view from the powerhouse.

[o] Stream No. 107-40-10537-2008 provides habitat for chum, coho, and pink salmon (Johnson and Blossom 2018).

[p] Stream No. 107-40-10538 provides habitat for chum, coho, and pink salmon (Johnson and Blossom 2018).

# METHODS

## CHANNEL MORPHOLOGY

In 1983, gravel was placed uniformly at 0.45 m depth in Tailrace Creek (Kelly 1987). In 2010,[q] we observed riffles and pools and marked the riffles with rebar stakes and flagging on both streambanks to designate five transects for sampling (Figure 11; Table 2).

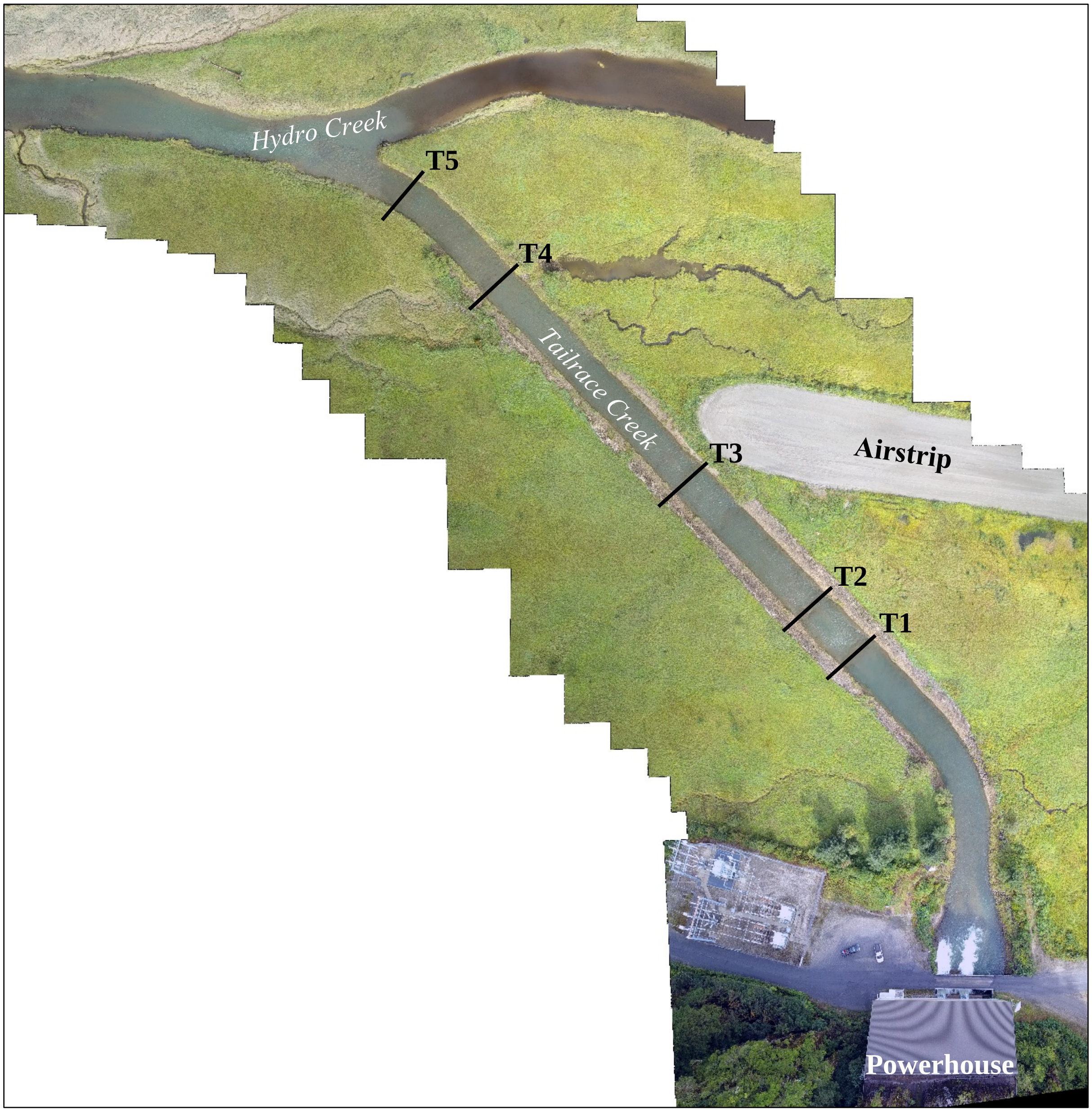


Figure 11.–Tailrace Creek sample sites map.
*Note:* Drone photo taken 122 m above ground.

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[q] Kate Kanouse and Katie Eaton, Habitat Biologists, to Jackie Timothy, Southeast Regional Supervisor, ADF&G Division of Habitat. Memorandum: Tyee Hydro facility trip report; dated 6/23/2010. Unpublished document, can be obtained from the Southeast Regional Supervisor, ADF&G Division of Habitat, 802 3rd Street, Douglas, AK.

Table 2.–Tailrace Creek transect sampling locations.

| Site | Latitude | Longitude |
|---|---|---|
| T1 | 56.21750 | -131.48969 |
| T2 | 56.21757 | -131.48993 |
| T3 | 56.21778 | -131.49082 |
| T4 | 56.21812 | -131.49210 |
| T5 | 56.21825 | -131.49271 |

*Note:* WGS84 datum.

### Data Collection

During low tide,[r] we measured a long profile of the channel at the tailrace center[s] at about 0.6 m increments using a stadia rod and GPS. We measured channel bed wetted width (m) and bankfull width (m) using a measuring tape strung tightly perpendicular to the stream at each of the five transects. We measured channel bed slope (%) between the center of each transect with a clinometer.

### Data Presentation

We summarize the data in a table and figure and compare the data with the design specifications (Wilson et al. 1981) and 1980s monitoring results (Kelly 1987).

## STREAM DISCHARGE

### Data Collection

During low tide, we measured stream flow to estimate discharge at T2, where stream bottom elevation and water velocity were generally continuous across the channel, using a Global Water Flow Probe Model FP101 meter and a SonTek FlowTracker acoustic doppler velocimeter. We attempted to record at least 20 measurements, and collected additional measurements where we observed changes in the stream bottom elevation and water velocity.

To estimate discharge using the flow probe, we strung a measuring tape tightly across the stream perpendicular to flow and recorded stream depth (*d*), width (*w*), and velocity[t] (*v*) at equidistant subsections. We calculated discharge[u] ($Q$) in ft$^3$/s using the equation in Platts et al. (1983),

$$Q = \sum_{i=1}^{n} (w_{i+1} - w_i)\left(\frac{d_i + d_{i+1}}{2}\right)\left(\frac{v_i + v_{i+1}}{2}\right)$$

To estimate discharge with the SonTek FlowTracker, we strung a fiberglass measuring tape tightly across the stream perpendicular to flow and followed the methods described in SonTek (2007).

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[r] Using the National Ocean and Atmospheric Administration's Bradfield Canal, Ernest Sound, AK tide prediction data, Station ID No. 9451012.

[s] Which was not necessarily the thalweg.

[t] We recorded mean water velocity by slowly moving the flow meter through the water column, top to bottom, for 30–60 s until the mean velocity value was stable.

[u] We present discharge data and tide stage in Imperial units for convention.

### Data Presentation

We report velocity and discharge data in a table with powerhouse generation and discharge data (unpublished data, SEAPA, Wrangell), and compare the data with the 1980s monitoring results (Kelly 1987). Appendix A contains the field survey data collected using the flow probe.

## SURFACE WATER QUALITY

### Data Collection

We measured surface water temperature (°C), conductivity (µS/cm), salinity (ppm), pH, and dissolved oxygen (mg/L) at each transect in Tailrace Creek during low and high tides using a variety of instruments, including a YSI Model 85, YSI Model Pro 2030, Oakton PS2000, and Extech Instruments Exstik EC400. During high tides, we accessed sample sites using SEAPA's jet boat, and measured water quality at the surface and the bottom. We calibrated the YSI and Oakton instruments onsite per the manufacturer's instructions.

### Data Presentation

We report the April 7, 2016 sample data in a table and generally compare the data with the 1980s monitoring results (Kelly 1987). Appendix B contains the raw data.

## INTRAGRAVEL WATER QUALITY

### Data Collection

We installed two YSI Sonde Model 600OMS data loggers in the center of Tailrace Creek, one at T2 and one at T5, for two pink salmon reproduction years: October 2010–May 2011 and August 2015–April 2016.[v] Prior to installing the instrument each season, the manufacturer calibrated each instrument and we calibrated the dissolved oxygen sensors again onsite per manufacturer recommendation.

We built a housing for each data logger using 5 cm x 1.57 m galvanized well points equipped with 60 cm of stainless steel mesh (Figure 12). We sealed the upper 33 cm of mesh with 100% silicone auto/marine sealant and PVC tape to encourage intragravel water flow in the lower 28 cm of mesh screen, the expected pink salmon redd depth (Groot and Margolis 1991). We installed both well points in the stream bed using a post pounder until the steel mesh was no longer visible. We placed rocks in the well points so the bottoms of the data loggers were level with the bottom of the open mesh, lowered the data loggers into the well points, wrapped Teflon tape around well point cap threads, capped the well points, and taped the caps with PVC tape to prevent inundation during high tide.

Figure 12.–Well point housing for the intragravel water quality data logger.

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v Except, we only installed one data logger in Tailrace Creek at T2 in October 2010 to test data logger and well point performance; we installed the second data logger at T5 in January 2011.

We programmed the data loggers to record dissolved oxygen (mg/L), temperature (°C), conductivity (µS/cm), and salinity (ppt) at 90 min intervals, and the sensor wiper rotation at 180 min intervals. These settings afforded a 100-day battery life, after which we returned to the site, retrieved each data logger, downloaded the data, reprogrammed, and reinstalled each unit in the well point until study completion.

We used EcoWatch software provided by the data logger manufacturer to download and export the data to Excel spreadsheets.

### Data Presentation

We summarize the data, present figures illustrating data trends from select data sets, and compare the data with the 1980s monitoring results (Kelly 1987).

## SPAWNING SUBSTRATE QUALITY

### Data Collection

We collected one substrate sample each from T1, T2, and T5 using a McNeil sediment sampler, which has a 15 cm basal core diameter and 25 cm core depth. We pushed the McNeil sampler into the substrate until the sample core was buried, then transferred the sediments to a bucket. We wet-sieved samples onsite using sieve sizes 101.6, 50.8, 31.75, 19.05, 2.38, and 0.0635 mm, the same sieve sizes used in the 1980s (Kelly 1987). We measured the contents of each sieve to the nearest 10 mL by the volume of water displaced in 600 mL and 1 L plastic beakers. We transferred the fines that pass through the 0.15 mm sieve to Imhoff cones, allowed 10 min settling time, and measured the sediment volume to the nearest 1 mL using the Imhoff cone gradations.

For the fines that passed through the 0.0635 mm sieve, we converted wet weights to dry weights using standards identified by Zollinger (1981). For all other sediments, we converted the wet weights to dry weights using a correction factor derived from Shirazi et al. (1981), assuming a gravel density of 2.6 g/cm$^3$. We calculated the geometric mean particle size (GMPS)[w] ($d_g$), sorting coefficient[x] ($S_o$), and Fredle index[y] ($F_i$) for each sediment sample using methods developed by Lotspeich and Everest (1981). To calculate GMPS for each sample, we raised the midpoint diameter of particles retained in each sieve ($d$) to a power equal to the decimal fraction of volume retained by that sieve ($w$), and multiplied the products of each sieve size to obtain the final product,

$$d_g = d_1^{w1} \times d_2^{w2} \times d_3^{w3} \ldots d_n^{wn}$$

We graphed the decimal fraction of volume retained in each sieve for each sample, assigned a linear relationship between points, and used the linear line equation to determine the 25th and 75th

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[w] The geometric mean particle size estimates the midpoint diameter of the distribution of particles, but does not provide information about pore size or permeability, which directly influence salmon embryo survival to emergence by regulating intragravel water flow, dissolved oxygen transport, and alevin movement (Lotspeich and Everest 1981).

[x] The sorting coefficient provides information about the distribution of grain sizes. Substrate composed of one particle size has a $S_o$ value of 1, while values greater than 1 suggest pore spaces between particles are occupied with smaller particles. $S_o$ is inversely proportional to permeability (Lotspeich and Everest 1981).

[y] The Fredle index provides a qualitative measure of salmon spawning habitat. The magnitude of the Fredle index is a measure of particle size and relative permeability, both of which increase as the Fredle index value increases (Lotspeich and Everest 1981). The Fredle index value for substrate composed of one particle size would be equal to $d_g$, and decreases as $S_o$ increases.

percentiles. We calculated the sorting coefficient by taking the square root of the quotient of the grain size at the 75th percentile divided by the grain size at the 25th percentile,

$$S_o = \sqrt{\frac{d^{75}}{d^{25}}}$$

We calculated the Fredle index value for each sample by dividing $d_g$ by $S_o$,

$$F_i = \frac{d_g}{S_o}$$

### Data Presentation

We present the data in a table and compare the data with the 1980s monitoring results (Kelly 1987). Appendix C contains the raw data.

## PINK SALMON USE

### Data Collection

We documented the number and location of spawning pink salmon and redds during low tide in Tailrace Creek. We identified pink salmon redds based on species return timing and a 1–2 $m^2$ depression area lacking macroalgae with bed material moved into a tailspill mound (Groot and Margolis 1991).

We searched for salmon eggs and alevins in Tailrace Creek substrate and focused our effort in areas where we observed spawning pink salmon or redds earlier in the spawning season. We used a hand shovel, attempted to use a Smithroot LR-24 backpack electrofisher without success, and placed a 0.5 mm mesh net set downstream of the sample area to capture unearthed eggs and alevins.

### Data Presentation

We compare the adult salmon and embryo development observations with the 1980s observation data (Kelly 1987) in a table and include a map of pink salmon redd locations.

## JUVENILE FISH USE

### Data Collection

We set 10 two-piece galvanized steel minnow traps having 6.35 mm mesh, baited with disinfected salmon roe and containing cobble for stability, at low tide along the banks of each transect, one trap on each side of the channel, for 12–24 h. We identified salmonids to species using Pollard et al. (1997), measured FL to the nearest 5 mm for each fish, and released fish at the capture site.

### Data Presentation

We summarize fish capture data in a table and compare the results with the 1980s monitoring results (Kelly 1987). Appendix D contains the capture data.

# RESULTS

## CHANNEL MORPHOLOGY

A comparison of the historic and recent Tailrace Creek channel measurements is shown in Table 3. Since 1987, the channel bed has widened 2–3 m while the bankfull width remains similar. Mean bed gradient remains less than 1% though Tailrace Creek bed material has redistributed forming shallow riffles and scouring pools (Figure 13). Rip rap is exposed in the pools. Water depths during low tide ranged 0.18–0.76 m, deeper than the 1980s monitoring results and within the design specification range. Increased discharge, the decline of bed material in the absence of new gravel recruitment, and the absence of lateral sediment inputs may explain channel morphology changes.

Table 3.–Tailrace Creek morphological data.

| | Design Spec. | Results by Study Years | | |
|---|---|---|---|---|
| Condition | 1982 | 1984–1987 | 2010–2011 | 2015–2016 |
| Operating loads (MW) | 25 | 4–6 | 9.5–20.2 | 3.0–22.6 |
| Bankfull width (m) | ND | 22.9 | 17.0–22.9 | 17.5–22.9 |
| Bed width (m) | 7.6–9.1 | 9.1 | 11.3–12.8 | 11.4–12.5 |
| Bed gradient (%) | 0.001 | ND | < 1 | < 1 |

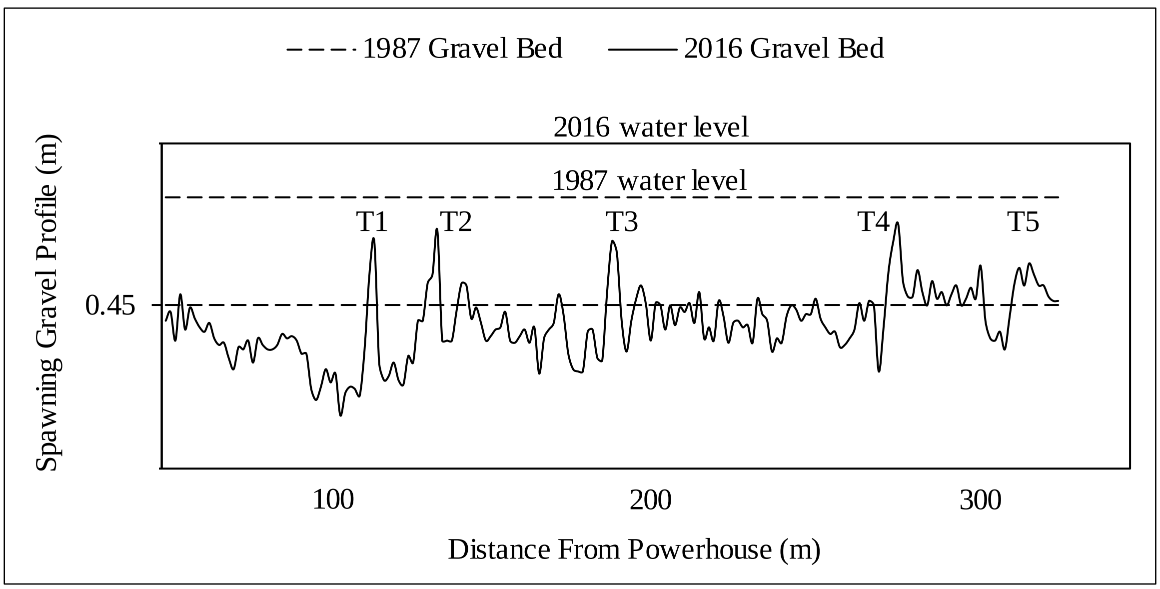


Figure 13.–Long profile of the channel measured at low tide.

## STREAM DISCHARGE

Table 4 presents the water velocity and discharge data we collected during low tide, and SEAPA's daily powerhouse generation and discharge data. Water velocities were lowest at riffles near the channel margins providing suitable habitat for spawning pink salmon use (Groot and Margolis 1991, Reiser and Bjornn 1979, Wilson et al. 1981).

Our discharge measurements were generally greater than the daily power generation record. We attribute the variation to sample timing,[z] input from drainages between the powerhouse and the T2 sampling location,[aa] groundwater input, influence from the incoming tide, and the different streamflow measurement equipment we used.

Table 4.–Tailrace Creek water velocity and discharge data.

| Date | Location | Estimate Tide Height (ft) | Water Velocity (ft/s) | Measured Discharge ($ft^3/s$) | Tyee Plant Discharge ($ft^3/s$) | Operating Load (MW) |
|---|---|---|---|---|---|---|
| 08/17/10 | T5 | +6.0 | 0.84–5.63 | 120 | 79 | 11.4 |
| 01/06/11 | T2 | 0.0 | 0.56–4.90 | 223 | 146 | 19.8 |
| 05/18/11 | T2 | -3.8 | 0.73–3.92 | 109 | 93 | 11.4 |
| 10/26/11 | T2 | +0.3 | 0.20–4.70 | 160 | 98 | 12.5 |
| 08/27/15 | T2 | +7.0 | 1.60–3.80 | 209 | 148 | 18.7 |
| 12/09/15 | T2 | +0.1 | 1.05–3.29 | 89 | 128 | 15.8 |
| 04/07/16 | T2 | -2.7 | 1.43–4.40 | 97 | 77 | 8.5 |
| 1984–1987 Monitoring Results: | | | 1.0–2.0 | ND | 35–40 | 4–6 |
| Low Tide Design Specifications: | | | 1.0–2.0 | ND | 107 | 25 |

## SURFACE WATER QUALITY

The surface water quality data we collected during low and high tides 2010–2011 and 2015–2016 mimic the 1980s monitoring data with the expected colder fresh water measurements at low tide, warmer brackish water measurements at high tide, and seasonal variation. These data are presented in Table 5.

[z] SEAPA records the daily powerhouse discharge and operating load data once in the morning when production peaks at about 0700. Our 10/26/11, 08/27/15, and 04/07/16 field discharge measurements were recorded at about the same time as SEAPA's data, while others were different due to low tide time.

[aa] Such as Stream No. 107-40-10537-2008-3008, which provides habitat for coho salmon and Dolly Varden char.

Table 5.–Tailrace Creek surface water quality data at +19.0 ft tide, April 7, 2016.

| Transect No. | Water Column Location | Tide Stage (ft) | Temperature (°C) | Dissolved Oxygen (mg/L) | Conductivity (µS/cm) | Salinity (ppm) |
|---|---|---|---|---|---|---|
| T1 | Surface | -2.6 | 4.1 | 12.0 | 1.3 | 0.0 |
| T1 | Surface | 19.0 | 5.3 | 11.2 | 281 | 0.2 |
| T1 | Bottom | 19.0 | 7.6 | 8.8 | 18,100 | 16.6 |
| T2 | Surface | -2.6 | 4.1 | 12.1 | 5.0 | 0.0 |
| T2 | Surface | 19.0 | 5.6 | 10.8 | 199 | 0.1 |
| T2 | Bottom | 19.0 | 7.7 | 9.9 | 7,136 | 4.1 |
| T3 | Surface | -2.6 | 4.1 | 12.3 | 1.2 | 0.0 |
| T3 | Surface | 19.0 | 5.4 | 11.2 | 223 | 0.2 |
| T3 | Bottom | 19.0 | 7.7 | 9.4 | 14,107 | 12.5 |
| T4 | Surface | -2.6 | 4.1 | 12.7 | 29.2 | 0.0 |
| T4 | Surface | 19.0 | 5.3 | 11.4 | 103 | 4.2 |
| T4 | Bottom | 19.0 | 7.8 | 9.4 | 16,710 | 15.2 |
| T5 | Surface | -2.6 | 4.1 | 13.0 | 1.7 | 0.0 |
| T5 | Surface | 19.0 | 5.2 | 12.3 | 1300 | 3.8 |
| T5 | Bottom | 19.0 | 8.3 | 9.5 | 17,952 | 16.2 |

Throughout the Tailrace Creek water column:

- water temperatures ranged 3.5–8.3 ºC and were lowest during low tides;
- dissolved oxygen concentrations ranged 8.8–17.0 mg/L, were greatest at the surface among all tide stages, and lowest along the channel bottom during high tide;
- pH ranged 6–7.6;
- conductivity ranged 1–19,000 µS/cm, was greatest along the channel bottom during high tide, and generally increased downgradient during high tide; and
- salinity ranged 0–17 ppt, was greatest along the channel bottom, and generally increased downgradient during high tide.

These data are within the natural range of variability and provide suitable habitat for spawning pink salmon use (Helle et al. 1964, Reiser and Bjornn 1979, Weber Scannell 1991, Wilson et al. 1981).

## Intragravel Water Quality

We experienced several equipment malfunctions while measuring intragravel water quality, as did biologists who completed the 1980s monitoring studies (Kelly 1987). We suspect the errors were caused by instrument failure, corrosion, biofouling, or unintentional placement in fine substrate (Kondolf et al. 2008). Unknown factors, such as variable powerhouse discharge, precipitation, and storm surges could also explain data anomalies. Nonetheless, portions of the T2 and T5 intragravel water quality data sets appear valid, and like Kelly (1987):

- water temperatures ranged 4.3–9.8 ºC at both sites and were lowest during low tides (Figure 14);

- dissolved oxygen concentrations were greatest at T2, ranged 6–13 mg/L, and were lowest during high tides, while concentrations at T5 ranged 0–12 mg/L and were greatest during high tides (Figure 15); and
- salinity concentrations ranged 0–29 ppt at both sites (Figure 16).

Intragravel water temperatures and salinity concentrations at T2 and T5 were within the optimal range for pink salmon embryo and alevin development (Groot and Margolis 1991, Raleigh and Nelson 1985, Reiser and Bjornn 1979, Weber Scannell 1991). Intragravel temperatures were slightly warmer than surface water during low tide and fluctuated as much as 5 °C during one tide cycle, similar to other intertidal pink salmon spawning habitat study results (Helle et al. 1964).

Intragravel dissolved oxygen concentrations were suitable for pink salmon embryo and alevin development at T2 where concentrations mirrored surface water concentrations, similar to the 1980s study results (Kelly 1987); concentrations at T5 were low and may not support developing pink salmon embryos and alevins.

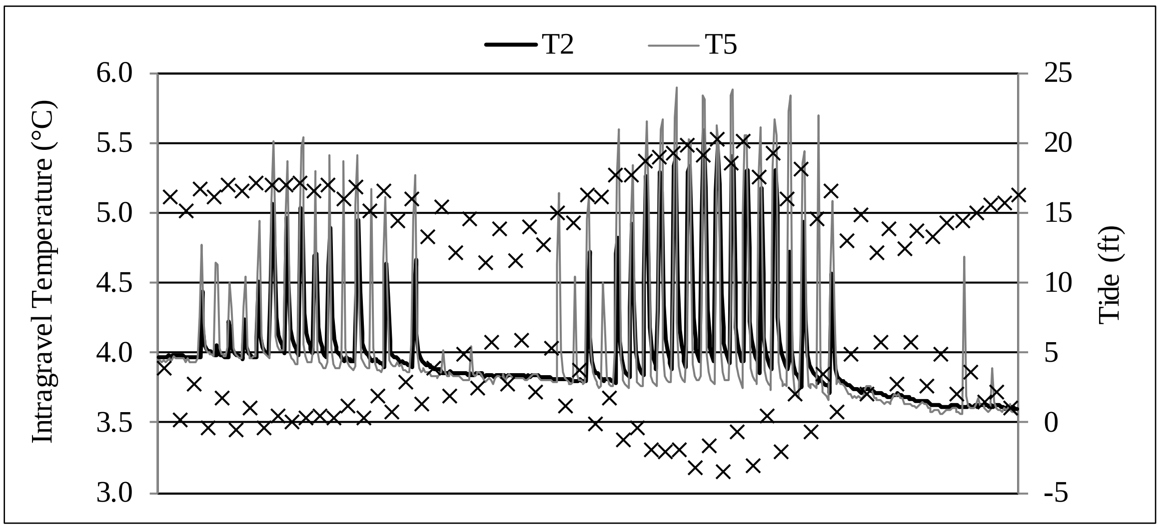


Figure 14.–Tailrace Creek intragravel temperature and tidal stage (×) data, March 1–31, 2011.

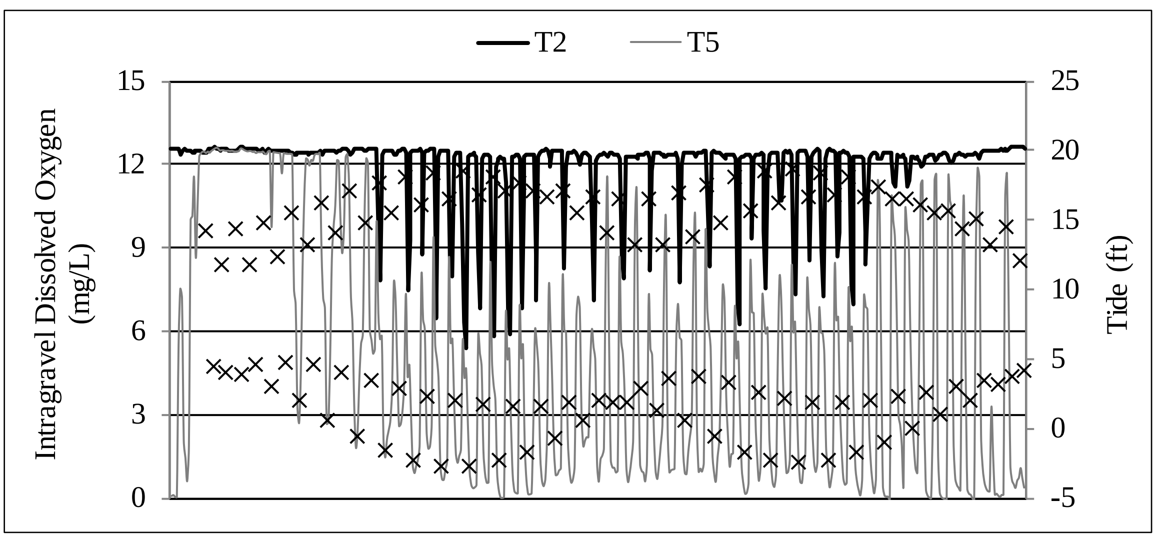


Figure 15.–Tailrace Creek intragravel dissolved oxygen and tidal stage (×) data, January 1–31, 2016.

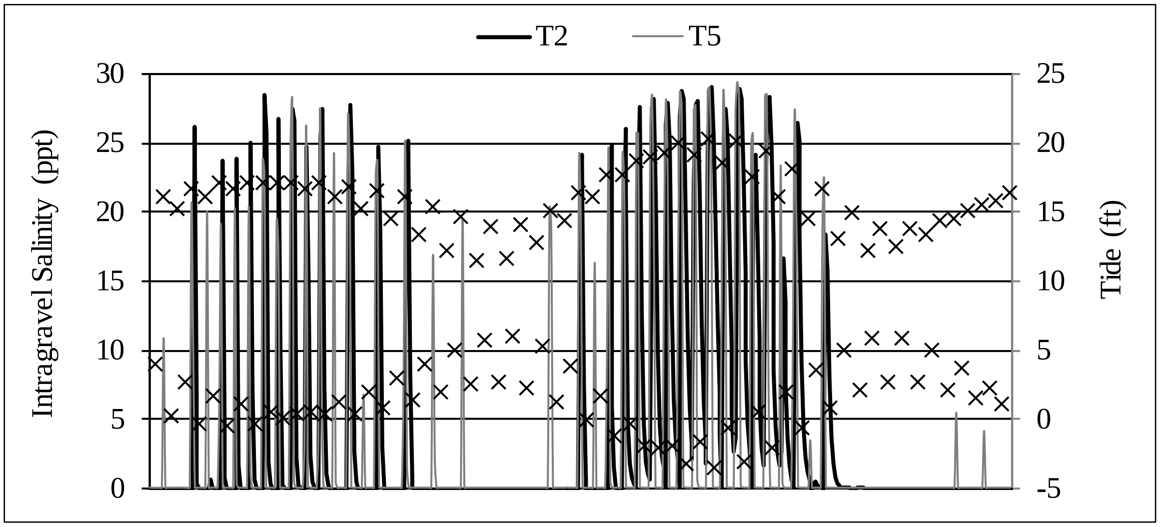

Figure 16.–Tailrace Creek intragravel salinity and tidal stage (×) data, March 1–31, 2011.

Tidal influence affected intragravel water quality at T5 during tides greater than about 14.5 ft, causing water temperature, dissolved oxygen and salinity concentrations to increase. During tides less than 14.5 ft, intragravel temperature mirrored the T2 data while dissolved oxygen concentration was lower, usually less than 3 mg/L.

Tidal influence affected intragravel water quality at T2 during tides greater than about 16 ft, causing water temperature and salinity concentration to increase and dissolved oxygen concentration to decrease. During tides less than about 16 ft, water temperature and dissolved oxygen concentrations mirrored surface water quality data.

## SPAWNING SUBSTRATE QUALITY

Table 6 presents the 2011 and 2016 substrate sample data. T5 samples contained up to 17% fines (< 2.38 mm) while samples from T1 and T2 contained less than 10% fines. These results are reflected in the GMPS and Fredle index values, which were lowest among T5 samples (more fines) where we found the greatest sorting coefficients (less permeability).[bb]

Kelly (1987) documented spawning habitat quality decreasing over time and attributed the change to an increasing proportion of sand transported by tide from the Bradfield River delta.[cc,dd] We found fewer fines present (Figure 17). Both studies show salmon spawning habitat quality is best in the upper half of Tailrace Creek.

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[bb] We did not sample between transects, where substrate included rip rap, more fines, and less gravel.

[cc] Based on the data in Kelly (1987), we could not replicate most of the Fredle index values previously reported.

[dd] The 1980s substrate sample location data were not published in Kelly (1987).

Table 6.–Tailrace Creek substrate sample data.

| | Particle Size | T1 | | T2 | | T5 | |
|---|---|---|---|---|---|---|---|
| Classification | (mm) | 2011 | 2016 | 2011 | 2016 | 2011 | 2016 |
| Small cobble | 50.8 – 101.6 | 25% | 18% | 23% | 19% | 11% | 15% |
| Coarse gravel | 31.75 – 50.8 | 30% | 56% | 43% | 44% | 34% | 34% |
| Medium gravel | 19.05 – 31.75 | 34% | 23% | 30% | 29% | 31% | 34% |
| Fine gravel | 2.38 – 19.05 | 3% | 0% | 0% | 0% | 7% | 6% |
| Sand | 0.0635 – 2.38 | 6% | 1% | 0% | 1% | 8% | 5% |
| Silt and clay | < 0.0635 | 3% | 2% | 4% | 7% | 9% | 7% |
| | GMPS (mm) | 26.6 | 35.6 | 30.7 | 23.0 | 13.9 | 17.8 |
| | Sorting coefficient | 1.9 | 1.3 | 1.5 | 1.6 | 3.0 | 2.2 |
| | Fredle index | 14.3 | 28.0 | 20.6 | 14.5 | 4.7 | 8.2 |

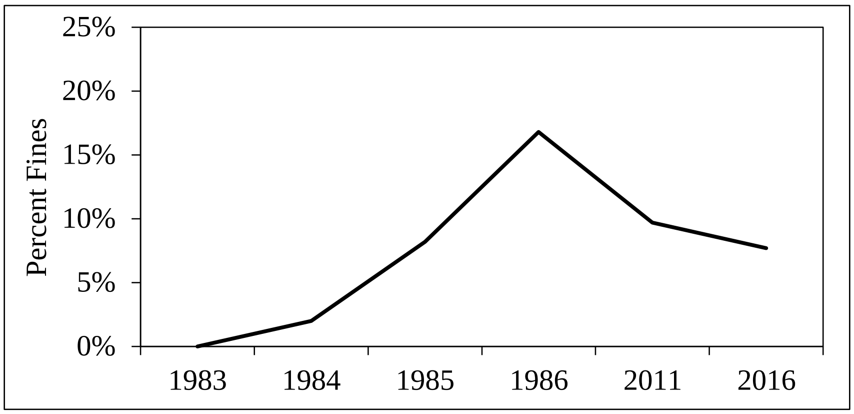


Figure 17.–Mean proportion of fines in Tailrace Creek substrate.

## PINK SALMON USE

Kelly (1987) estimated up to 9,050 pink salmon could spawn in Tailrace Creek based on mean pink salmon redd size and streambed area, and documented as many as 200 pink salmon in 1985. On August 18, 2010, we observed 13 spawning pink salmon and 16 redds in Tailrace Creek, on August 27, 2015, we did not find spawning pink salmon and observed 5 redds, and on August 28–30, 2018, we observed 2 pink salmon and 7 redds (Table 7; Figure 18). We found most spawning pink salmon and redds within the upper half of Tailrace Creek, similar to the 1980s monitoring results (Kelly 1987).

Table 7.–Tailrace Creek adult salmon use.

| Survey Date | Pink Salmon | Redds |
|---|---|---|
| 1984 | 0 | ND |
| 8/28/1985 | 200 | ND |
| 8/28/1986 | 50 | ND |
| 8/18/2010 | 13 | 16 |
| 8/27/2015 | 0 | 5 |
| 8/28/2018 | 2 | 7 |

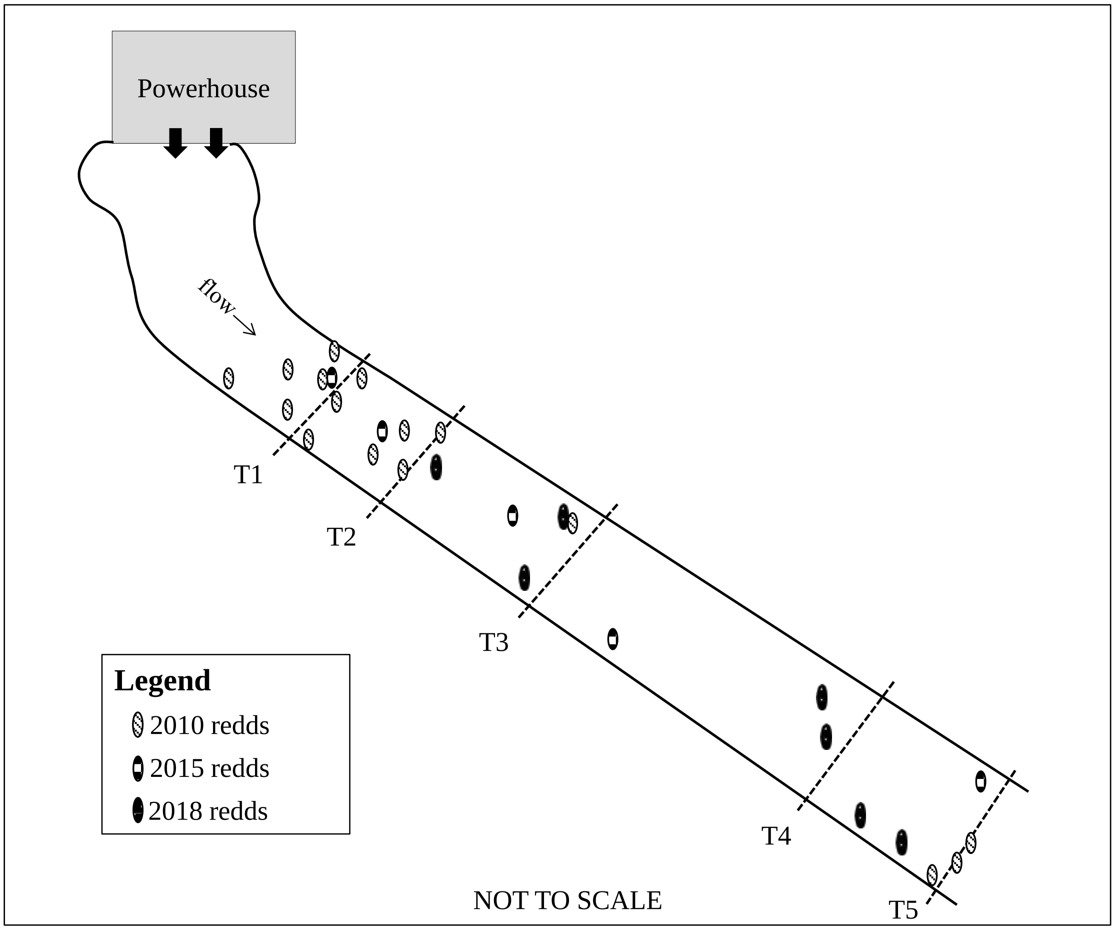


Figure 18.–Tailrace Creek pink salmon redd locations.

ADF&G's 2010 pink salmon return index for Southern Southeast Alaska District 7 was about average and within the goal range (Davidson et al. 2012).[ee] Despite meeting the District 7 escapement index goal in 2015, pink salmon returns varied by system and several water bodies did not receive expected escapements (Gray et al. 2017). The 2018 pink salmon harvest data were not available before publication of this report. ADF&G's 2010 and 2015 pink salmon return information may explain the differences we observed in Tailrace Creek adult pink salmon and redd counts those years.

We sampled gravel substrate for salmon embryos and alevins three times following three salmon spawning seasons. We found developing salmon eggs and newly hatched alevins at T2 on January 5, 2011, developing salmon eggs at T1 on October 26, 2011, and no eggs or alevins on December 9, 2015. The January 5, 2011 mid-hatch timing was consistent with pink salmon egg hatch timing results from the 1986–1987 Tailrace Creek egg incubation study (Kelly 1987).

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[ee] District 7 includes Bradfield Canal.

## JUVENILE FISH USE

Similar to the 1980s results (Kelly 1987), we captured juvenile coho salmon, Dolly Varden char, and sculpin in Tailrace Creek (Table 8). Fork lengths of the coho salmon (50–110 mm) and Dolly Varden char (50–150 mm) suggest at least two age classes of each species use the water body.

Table 8.–Tailrace Creek juvenile fish captures.

| Date | Dolly Varden char | Coho salmon | Sculpin |
|---|---|---|---|
| 08/08/10 | 23 | 21 | 0 |
| 01/06/11 | 16 | 4 | 153 |
| 05/20/11 | 5 | 0 | 19 |
| 10/27/11 | 7 | 3 | 15 |
| 08/28/15 | 52 | 10 | 58 |
| 12/10/15 | 21 | 5 | 138 |
| 04/07/16 | 7 | 1 | 27 |

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# APPENDIX A: DISCHARGE DATA

Appendix A.1.–Tailrace Creek discharge.

**Date:** 8/17/2010 **Time:** 1345
**Tide:** +6.0 ft
**Instrument:** Global Water Flow Probe

| Distance (ft) | Depth (ft) | Velocity (ft/s) | Increment Dis. ($ft^3/s$) |
|---|---|---|---|
| 0.0 | 0.00 | 0.00 | 0.04 |
| 1.0 | 0.20 | 0.84 | 0.45 |
| 2.0 | 0.35 | 2.46 | 1.45 |
| 3.0 | 0.60 | 3.65 | 2.22 |
| 4.0 | 0.70 | 3.18 | 2.33 |
| 5.0 | 0.60 | 3.99 | 2.48 |
| 6.0 | 0.70 | 3.64 | 3.10 |
| 7.0 | 0.70 | 5.23 | 3.79 |
| 8.0 | 0.80 | 4.87 | 4.46 |
| 9.0 | 0.90 | 5.63 | 4.64 |
| 10.0 | 0.80 | 5.29 | 3.80 |
| 11.0 | 0.70 | 4.83 | 2.91 |
| 12.0 | 0.70 | 3.48 | 2.66 |
| 13.0 | 0.80 | 3.62 | 4.16 |
| 14.0 | 1.20 | 4.69 | 5.79 |
| 15.0 | 1.20 | 4.96 | 6.11 |
| 16.0 | 1.20 | 5.22 | 5.22 |
| 17.0 | 1.00 | 4.27 | 4.81 |
| 18.0 | 1.10 | 4.89 | 5.58 |
| 19.0 | 1.30 | 4.41 | 6.19 |
| 20.0 | 1.30 | 5.12 | 5.74 |
| 21.0 | 1.10 | 4.45 | 5.58 |
| 22.0 | 1.20 | 5.25 | 6.38 |
| 23.0 | 1.20 | 5.38 | 5.33 |
| 24.0 | 1.00 | 4.31 | 4.86 |
| 25.0 | 1.10 | 4.94 | 5.48 |
| 26.0 | 1.10 | 5.03 | 5.37 |
| 27.0 | 1.10 | 4.73 | 3.79 |
| 28.0 | 0.90 | 2.85 | 2.52 |
| 29.0 | 0.60 | 3.87 | 1.83 |
| 30.0 | 0.40 | 3.44 | 1.13 |
| 31.0 | 0.30 | 3.01 | 0.23 |
| 32.0 | 0.00 | 0.00 | 0.00 |
| Estimate total discharge ($ft^3/s$)= | | | 120.4 |
| Plant discharge ($ft^3/s$) at 0702= | | | 79.2 |

**Date:** 1/6/2011 **Time:** 1830
**Tide:** 0 ft
**Instrument:** Global Water Flow Probe

| Distance (ft) | Depth (ft) | Velocity (ft/s) | Increment Dis. ($ft^3/s$) |
|---|---|---|---|
| 0.0 | 0.00 | 0.00 | 0.01 |
| 1.0 | 0.10 | 0.56 | 0.20 |
| 2.0 | 0.60 | 0.57 | 1.40 |
| 3.0 | 1.00 | 2.94 | 3.42 |
| 4.0 | 1.20 | 3.28 | 4.24 |
| 5.0 | 1.30 | 3.50 | 4.62 |
| 6.0 | 1.30 | 3.60 | 4.81 |
| 7.0 | 1.40 | 3.53 | 5.20 |
| 8.0 | 1.40 | 3.90 | 5.33 |
| 9.0 | 1.30 | 4.00 | 5.33 |
| 10.0 | 1.30 | 4.20 | 6.02 |
| 11.0 | 1.50 | 4.40 | 6.31 |
| 12.0 | 1.40 | 4.30 | 5.74 |
| 13.0 | 1.30 | 4.20 | 5.46 |
| 14.0 | 1.30 | 4.20 | 5.33 |
| 15.0 | 1.30 | 4.00 | 5.33 |
| 16.0 | 1.40 | 3.90 | 5.58 |
| 17.0 | 1.50 | 3.80 | 5.58 |
| 18.0 | 1.40 | 3.90 | 5.46 |
| 19.0 | 1.40 | 3.90 | 5.80 |
| 20.0 | 1.50 | 4.10 | 6.38 |
| 21.0 | 1.50 | 4.40 | 6.82 |
| 22.0 | 1.60 | 4.40 | 7.36 |
| 23.0 | 1.60 | 4.80 | 7.92 |
| 24.0 | 1.70 | 4.80 | 7.84 |
| 25.0 | 1.60 | 4.70 | 8.16 |
| 26.0 | 1.80 | 4.90 | 8.31 |
| 27.0 | 1.70 | 4.60 | 7.82 |
| 28.0 | 1.70 | 4.60 | 8.28 |
| 29.0 | 1.90 | 4.60 | 8.10 |
| 30.0 | 1.70 | 4.40 | 7.65 |
| 31.0 | 1.70 | 4.60 | 7.88 |
| 32.0 | 1.80 | 4.40 | 7.10 |
| 33.0 | 1.50 | 4.20 | 5.87 |
| 34.0 | 1.40 | 3.90 | 5.60 |
| 35.0 | 1.30 | 4.40 | 5.59 |
| 36.0 | 1.30 | 4.20 | 4.86 |
| 37.0 | 1.10 | 3.90 | 3.94 |
| 38.0 | 1.00 | 3.60 | 3.35 |
| 39.0 | 1.00 | 3.10 | 2.16 |
| 40.0 | 0.60 | 2.30 | 0.35 |
| 41.0 | 0.00 | 0.00 | 0.00 |
| Estimate stream discharge ($ft^3/s$)= | | | 222.5 |
| Plant discharge ($ft^3/s$) at 0725= | | | 146.0 |

**Date:** 5/18/2011 **Time:** 0838
**Tide:** -3.8 ft
**Instrument:** Global Water Flow Probe

| Distance (ft) | Depth (ft) | Velocity (ft/s) | Increment Dis. (ft$^3$/s) |
|---|---|---|---|
| 0.00 | 0.00 | 0.00 | 0.05 |
| 1.00 | 0.25 | 0.87 | 0.75 |
| 2.00 | 0.60 | 2.67 | 2.09 |
| 3.00 | 0.90 | 2.89 | 2.57 |
| 4.00 | 1.00 | 2.51 | 2.71 |
| 5.00 | 1.00 | 2.90 | 2.81 |
| 6.00 | 1.00 | 2.71 | 2.52 |
| 7.00 | 0.90 | 2.59 | 2.63 |
| 8.00 | 0.95 | 3.09 | 2.85 |
| 9.00 | 0.95 | 2.92 | 2.93 |
| 10.00 | 1.00 | 3.08 | 2.50 |
| 11.00 | 0.95 | 2.05 | 2.41 |
| 12.00 | 0.95 | 3.03 | 3.06 |
| 13.00 | 1.00 | 3.24 | 3.02 |
| 14.00 | 1.05 | 2.66 | 3.06 |
| 15.00 | 1.20 | 2.78 | 3.46 |
| 16.00 | 1.20 | 2.99 | 3.47 |
| 17.00 | 1.05 | 3.18 | 3.42 |
| 18.00 | 1.02 | 3.43 | 3.75 |
| 19.00 | 1.18 | 3.38 | 4.11 |
| 20.00 | 1.20 | 3.53 | 3.98 |
| 21.00 | 1.20 | 3.10 | 4.21 |
| 22.00 | 1.30 | 3.63 | 4.91 |
| 23.00 | 1.30 | 3.92 | 4.79 |
| 24.00 | 1.25 | 3.59 | 4.13 |
| 25.00 | 1.12 | 3.38 | 4.02 |
| 26.00 | 1.25 | 3.40 | 4.40 |
| 27.00 | 1.33 | 3.42 | 4.35 |
| 28.00 | 1.26 | 3.30 | 3.83 |
| 29.00 | 1.22 | 2.87 | 3.30 |
| 30.00 | 1.32 | 2.33 | 3.41 |
| 31.00 | 1.30 | 2.88 | 3.30 |
| 32.00 | 1.12 | 2.58 | 2.85 |
| 33.00 | 1.10 | 2.55 | 1.91 |
| 34.00 | 0.80 | 1.48 | 1.02 |
| 35.00 | 0.70 | 1.25 | 0.54 |
| 36.00 | 0.40 | 0.73 | 0.07 |
| 37.00 | 0.00 | 0.00 | 0.00 |
| | | Estimate stream discharge (ft$^3$/s)= | 109.2 |
| | | Plant discharge (ft$^3$/s) at 0633= | 93.0 |

**Date:** 10/26/2011 **Time:** 0700
**Tide:** 0.3 ft
**Instrument:** Global Water Flow Probe

| Distance (ft) | Depth (ft) | Velocity (ft/s) | Increment Dis. (ft$^3$/s) |
|---|---|---|---|
| 17.00 | 0.00 | 0.00 | 0.03 |
| 18.00 | 0.30 | 0.40 | 0.15 |
| 19.00 | 0.68 | 0.20 | 1.22 |
| 20.00 | 0.84 | 3.00 | 2.82 |
| 21.00 | 1.04 | 3.00 | 3.64 |
| 22.00 | 1.10 | 3.80 | 4.72 |
| 23.00 | 1.20 | 4.40 | 5.28 |
| 24.00 | 1.20 | 4.40 | 5.51 |
| 25.00 | 1.22 | 4.70 | 6.16 |
| 26.00 | 1.40 | 4.70 | 6.28 |
| 27.00 | 1.30 | 4.60 | 6.20 |
| 28.00 | 1.52 | 4.20 | 6.45 |
| 29.00 | 1.48 | 4.40 | 6.71 |
| 30.00 | 1.50 | 4.60 | 6.71 |
| 31.00 | 1.48 | 4.40 | 6.51 |
| 32.00 | 1.48 | 4.40 | 6.41 |
| 33.00 | 1.50 | 4.20 | 5.68 |
| 34.00 | 1.34 | 3.80 | 5.02 |
| 35.00 | 1.30 | 3.80 | 4.79 |
| 36.00 | 1.36 | 3.40 | 4.49 |
| 37.00 | 1.36 | 3.20 | 4.12 |
| 38.00 | 1.30 | 3.00 | 3.54 |
| 39.00 | 1.06 | 3.00 | 3.24 |
| 40.00 | 1.10 | 3.00 | 3.19 |
| 41.00 | 1.10 | 2.80 | 3.19 |
| 42.00 | 1.10 | 3.00 | 3.34 |
| 43.00 | 1.20 | 2.80 | 3.48 |
| 44.00 | 1.20 | 3.00 | 3.75 |
| 45.00 | 1.30 | 3.00 | 3.94 |
| 46.00 | 1.24 | 3.20 | 3.93 |
| 47.00 | 1.14 | 3.40 | 4.10 |
| 48.00 | 1.20 | 3.60 | 4.38 |
| 49.00 | 1.30 | 3.40 | 4.48 |
| 50.00 | 1.26 | 3.60 | 4.32 |
| 51.00 | 1.14 | 3.60 | 3.82 |
| 52.00 | 1.04 | 3.40 | 3.37 |
| 53.00 | 1.00 | 3.20 | 2.56 |
| 54.00 | 0.60 | 3.20 | 1.80 |
| 55.00 | 0.60 | 2.80 | 1.25 |
| 56.00 | 0.34 | 2.50 | 0.00 |
| | | Estimate stream discharge (ft$^3$/s)= | 160.3 |
| | | Plant discharge (ft$^3$/s) at 0717= | 97.7 |

**Date:** 8/27/2015 **Time:** 0845
**Tide:** 7.0 ft
**Instrument:** Global Water Flow Probe

| Distance (ft) | Depth (ft) | Velocity (ft/s) | Increment Dis. ($ft^3/s$) |
|---|---|---|---|
| 4.70 | 0.00 | 0.00 | 0.27 |
| 6.00 | 0.52 | 1.60 | 1.22 |
| 7.00 | 0.92 | 1.80 | 2.14 |
| 8.00 | 0.98 | 2.70 | 2.79 |
| 9.00 | 1.05 | 2.80 | 6.47 |
| 11.00 | 1.18 | 3.00 | 7.72 |
| 13.00 | 1.35 | 3.10 | 9.06 |
| 15.00 | 1.67 | 2.90 | 10.28 |
| 17.00 | 2.00 | 2.70 | 11.56 |
| 19.00 | 2.13 | 2.90 | 12.56 |
| 21.00 | 2.20 | 2.90 | 12.77 |
| 23.00 | 2.13 | 3.00 | 13.02 |
| 25.00 | 2.07 | 3.20 | 12.63 |
| 27.00 | 1.94 | 3.10 | 11.93 |
| 29.00 | 1.97 | 3.00 | 11.28 |
| 31.00 | 1.67 | 3.20 | 11.52 |
| 33.00 | 1.77 | 3.50 | 12.04 |
| 35.00 | 1.67 | 3.50 | 11.35 |
| 37.00 | 1.44 | 3.80 | 11.18 |
| 39.00 | 1.71 | 3.30 | 10.94 |
| 41.00 | 1.71 | 3.10 | 9.52 |
| 43.00 | 1.41 | 3.00 | 8.02 |
| 45.00 | 1.31 | 2.90 | 6.81 |
| 47.00 | 1.08 | 2.80 | 1.66 |
| 49.20 | 0.00 | 0.00 | 0.00 |
| Estimate stream discharge ($ft^3/s$)= | | | 208.8 |
| Plant discharge ($ft^3/s$) at 0722= | | | 148.0 |

# APPENDIX B: SURFACE WATER QUALITY DATA

Appendix B.1.–Tailrace Creek low tide surface water quality.

| Date | Location | Tide Stage (ft) | Temp (°C) | Conductivity (µS/cm) | Salinity (ppt) | DO (mg/L) |
|---|---|---|---|---|---|---|
| 08/28/15 | T1 | 0.7 | 4.7 | 14.9 | 0.0 | 14.2 |
| 08/28/15 | T2 | 0.7 | 4.8 | 14.9 | 0.0 | 14.5 |
| 08/28/15 | T3 | 0.7 | 4.8 | 14.8 | 0.0 | 14.5 |
| 08/28/15 | T4 | 0.7 | 4.7 | 11.6 | 0.0 | 14.4 |
| 08/28/15 | T5 | 0.7 | 4.8 | 10.6 | 0.0 | 14.7 |
| 12/10/15 | T1 | 2.9 | 5.2 | 41.5 | 0.0 | 11.8 |
| 12/10/15 | T2 | 2.9 | 5.2 | 41.4 | 0.0 | 11.8 |
| 12/10/15 | T3 | 2.9 | 5.2 | 32.9 | 0.0 | 12.0 |
| 12/10/15 | T4 | 2.9 | 5.2 | 29.3 | 0.0 | 13.2 |
| 12/10/15 | T5 | 2.9 | 5.4 | 16.9 | 0.0 | 14.3 |
| 04/07/16 | T1 | -2.6 | 4.1 | 1.7 | 0.0 | 13.0 |
| 04/07/16 | T2 | -2.6 | 4.1 | 29.2 | 0.0 | 12.7 |
| 04/07/16 | T3 | -2.6 | 4.1 | 1.2 | 0.0 | 12.3 |
| 04/07/16 | T4 | -2.6 | 4.1 | 5.0 | 0.0 | 12.1 |
| 4/7/2016 | T5 | -2.6 | 4.1 | 1.3 | 0.0 | 12.0 |

Appendix B.2.–Tailrace Creek high tide surface water quality.

| Date | Location | Tide Stage (ft) | Temp (°C) | Conductivity (µS/cm) | Salinity (ppt) | DO (mg/L) | pH |
|---|---|---|---|---|---|---|---|
| 10/08/10 | T1 | 19.3 | 7.2 | 4,067 | 3.2 | 10.8 | ND |
| 10/08/10 | T2 | 19.3 | 7.8 | 4,570 | 3.7 | 10.4 | ND |
| 10/08/10 | T3 | 19.3 | 6.4 | 2,626 | 2.5 | 11.3 | ND |
| 10/08/10 | T4 | 19.3 | 6.0 | 2,268 | 2.0 | 11.5 | ND |
| 10/08/10 | T5 | 19.3 | 6.8 | 2,490 | 2.1 | 11.3 | ND |
| 10/26/11 | T1 | 18.4 | 6.4 | ND | ND | ND | 7.35 |
| 10/26/11 | T2 | 18.4 | 6.3 | ND | ND | ND | 7.42 |
| 10/26/11 | T3 | 18.4 | 6.3 | ND | ND | ND | 7.44 |
| 10/26/11 | T4 | 18.4 | 6.3 | ND | ND | ND | 7.45 |
| 10/26/11 | T5 | 18.4 | 6.3 | ND | ND | ND | 7.64 |
| 08/28/15 | T1 | 15.3 | 4.9 | 8.9 | 0.0 | 17.0 | ND |
| 08/28/15 | T2 | 15.3 | 4.8 | 7.7 | 0.0 | 15.1 | ND |
| 08/28/15 | T3 | 15.3 | 4.9 | 7.8 | 0.0 | 15.3 | ND |
| 08/28/15 | T4 | 15.3 | 5.2 | 8.3 | 0.0 | 14.8 | ND |
| 08/28/15 | T5 | 15.3 | 4.8 | 7.6 | 0.0 | 15.1 | ND |
| 04/07/16 | T1 | 19.0 | 5.2 | 1,300 | 3.8 | 12.3 | ND |
| 04/07/16 | T2 | 19.0 | 5.3 | 103 | 0.2 | 11.4 | ND |
| 04/07/16 | T3 | 19.0 | 5.4 | 223 | 0.2 | 11.2 | ND |
| 04/07/16 | T4 | 19.0 | 5.6 | 199 | 0.1 | 10.8 | ND |
| 04/07/16 | T5 | 19.0 | 5.3 | 281 | 0.2 | 11.2 | ND |

Appendix B.3.–Tailrace Creek high tide bottom water quality.

| Date | Location | Tide Stage (ft) | Temp (°C) | Conductivity (µS/cm) | Salinity (ppt) | DO (mg/L) | pH |
|---|---|---|---|---|---|---|---|
| 10/08/10 | T1 | 19.8 | 7.5 | 5,390 | 4.5 | 10.4 | ND |
| 10/08/10 | T2 | 19.8 | 7.5 | 5,360 | 4.5 | 10.5 | ND |
| 10/08/10 | T3 | 19.8 | 7.6 | 5,300 | 4.4 | 10.4 | ND |
| 10/08/10 | T4 | 19.8 | 7.8 | 5,310 | 4.4 | 10.5 | ND |
| 10/08/10 | T5 | 19.8 | 7.8 | 5,340 | 4.4 | 10.6 | ND |
| 10/26/11 | T1 | 18.4 | 7.0 | ND | ND | ND | 6.3 |
| 10/26/11 | T2 | 18.4 | 7.0 | ND | ND | ND | 7.5 |
| 10/26/11 | T3 | 18.4 | 7.0 | ND | ND | ND | 7.1 |
| 10/26/11 | T4 | 18.4 | 7.0 | ND | ND | ND | 7.2 |
| 10/26/11 | T5 | 18.4 | 7.1 | ND | ND | ND | 6.9 |
| 08/28/15 | T1 | 15.3 | 4.9 | 7.7 | 0.0 | 15.0 | ND |
| 08/28/15 | T2 | 15.3 | 5.1 | 8.3 | 0.0 | 14.9 | ND |
| 08/28/15 | T3 | 15.3 | 5.0 | 8.0 | 0.0 | 15.2 | ND |
| 08/28/15 | T4 | 15.3 | 4.8 | 7.8 | 0.0 | 15.1 | ND |
| 08/28/15 | T5 | 15.3 | 5.1 | 8.3 | 0.0 | 14.9 | ND |
| 04/07/16 | T1 | 19.0 | 7.6 | 18,100 | 16.6 | 8.8 | ND |
| 04/07/16 | T2 | 19.0 | 7.7 | 7,136 | 4.1 | 9.9 | ND |
| 04/07/16 | T3 | 19.0 | 7.7 | 14,107 | 12.5 | 9.4 | ND |
| 04/07/16 | T4 | 19.0 | 7.8 | 16,710 | 15.2 | 9.4 | ND |
| 04/07/16 | T5 | 19.0 | 8.3 | 17,952 | 16.2 | 9.5 | ND |

# APPENDIX C: SPAWNING SUBSTRATE DATA

Appendix C.1.–Tailrace Creek spawning substrate.

| Sample | | Volume (mL/L) Retained Each Sieve (mm) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Date | Location | 101.6 | 50.8 | 31.75 | 19.05 | 2.38 | 0.064 | Imhoff | GMPS |
| 10/27/11 | T1 | 0 | 750 | 900 | 1,050 | 100 | 350 | 114.0 | 26.6 |
| 10/27/11 | T2 | 0 | 600 | 1,125 | 800 | 0 | 0 | 144.5 | 30.7 |
| 10/27/11 | T5 | 0 | 300 | 975 | 900 | 225 | 500 | 342.5 | 13.9 |
| 04/07/16 | T1 | 0 | 500 | 1,575 | 650 | 0 | 50 | 35.0 | 35.6 |
| 04/07/16 | T2 | 0 | 475 | 1,150 | 775 | 0 | 75 | 257.0 | 23.0 |
| 04/07/16 | T5 | 0 | 375 | 900 | 900 | 175 | 275 | 266.0 | 17.8 |

# APPENDIX D: JUVENILE FISH DATA

Appendix D.1.–Tailrace Creek juvenile fish captures.

| Date | Species | Number | FL (mm) |
|---|---|---|---|
| 08/18/10 | Dolly Varden char | 23 | 80–120 |
| 08/18/10 | Coho salmon | 21 | 60–110 |
| 01/06/11 | Dolly Varden char | 16 | ND |
| 01/06/11 | Coho salmon | 4 | ND |
| 01/06/11 | Sculpin | 153 | ND |
| 05/20/11 | Dolly Varden char | 5 | 110–150 |
| 05/20/11 | Sculpin | 19 | ND |
| 10/27/11 | Dolly Varden char | 7 | 110–125 |
| 10/27/11 | Coho salmon | 3 | 90 |
| 10/27/11 | Sculpin | 15 | ND |
| 08/28/15 | Dolly Varden char | 52 | 50–120 |
| 08/28/15 | Coho salmon | 10 | 50–90 |
| 08/28/15 | Sculpin | 58 | ND |
| 12/10/15 | Dolly Varden char | 21 | 60–135 |
| 12/10/15 | Coho salmon | 5 | 60–90 |
| 12/10/15 | Sculpin | 138 | ND |
| 04/08/16 | Dolly Varden char | 7 | 80–120 |
| 04/08/16 | Coho salmon | 1 | 80 |
| 04/08/16 | Sculpin | 27 | ND |