DRAFT REPORT

EVALUATION OF CHANGE IN BLUE LAKE HYDROELECTIC PROJECT INTAKE LOCATION ON WATER TEMPERATURES AND ANADROMOUS SALMONID UTILIZATION IN SAWMILL CREEK

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EXECUTIVE SUMMARY

The City and Borough of Sitka is investigating options for expansion of the Blue Lake Hydroelectric Project to increase power generation capacity. The proposed expansion involves raising the dam spillway 83 feet and relocating the water intake, which could change water temperatures downstream in Sawmill Creek. This change in elevation has potential effects on salmonid egg incubation and emergence in the creek. These analyses utilized historic data on water temperatures in Blue Lake and spawning timing in Sawmill Creek to model temperatures at the proposed relocation of the water intake and subsequent effects on salmonid fry emergence timing in Sawmill Creek. Temperature predictions were based on data from a sensor array measuring water temperatures in Blue Lake at 15-foot intervals of depth during 2005 and 2008. Spawning timing for species of interest (primarily pink and chum salmon, and secondarily coho salmon) was based on data collected in Sawmill Creek 2001-2005. Emergence timing was based on Accumulated Temperature Units (ATUs) gathered from literature on the species of interest in Alaska. The proposed relocation of the intake, with invert at El 320, and dam spillway raised to El 425, is predicted to raise typical summer intake temperatures by 1°C to 3°C (June-September), with an average annual increase in water temperatures of 0.5°C. Effect on winter temperatures would be minimal (<1°C November-April). Utilizing the median spawning timing for pink and chum salmon, and the peak of spawning for coho salmon, fry emergence in Sawmill Creek with the proposed intake ranges from 1 day earlier to 5 days later than the existing condition. Predictions suggest a 1-day difference in emergence timing for chum salmon with a spawning date of September 4, and a 3-day difference for pink salmon with a spawning date of September 8.

INTRODUCTION and BACKGROUND

The City and Borough of Sitka Electric Department (City) has recently analyzed energy needs and determined that in order to assure continued delivery of low-cost electrical power in the face of rising energy needs in Sitka, it must expand its hydroelectric generating base. The City's preferred alternative would involve: 1) installing a new powerhouse with three new, larger generating turbines near the existing Project powerhouse, and 2) raising the height of the Project dam. These actions are referred to as the Blue Lake Project Expansion (Expansion).

As part of the dam raising component of the Expansion, the City is also evaluating relocation of the Project water intake structure. The new intake location, in association with raised reservoir elevation, could alter seasonal water temperatures at the intake (and consequently in Sawmill Creek), with potential effects on salmonids downstream of the Project powerhouse. This report addresses the potential effects of these intake changes in terms of water temperature at the intake and in Sawmill Creek, and in terms of effects on salmonid populations.

STUDY OBJECTIVE

The overall objective of this study was to determine the effect of Expansion-related water temperature changes on salmonids in Sawmill Creek. Results of this analysis will assist project engineers in determining the depth of the repositioned water intake for the Project.

DESCRIPTION of the EXISTING PROJECT and EXPANSION-RELATED CHANGES

EXISTING PROJECT FEATURES

(Throughout this report, elevations are feet (ft) above mean sea level, and are denoted "El," as in El 342).

The existing Project has a concrete arch dam 211 ft high, with a spillway at El 342 (Figure 1). The dam impounds the 1,225-acre surface of Blue Lake Reservoir (called "Blue Lake" in this report), which is 3.25 mi long, with an average width of 0.63 miles. The reservoir's deepest point is at El -126 (126 feet below mean sea level) at a depth of 468 ft below the spillway lake surface elevation. Blue Lake has a gross storage capacity of 145,200 acre-feet (af), and a usable storage of 102,200 af at spill level.

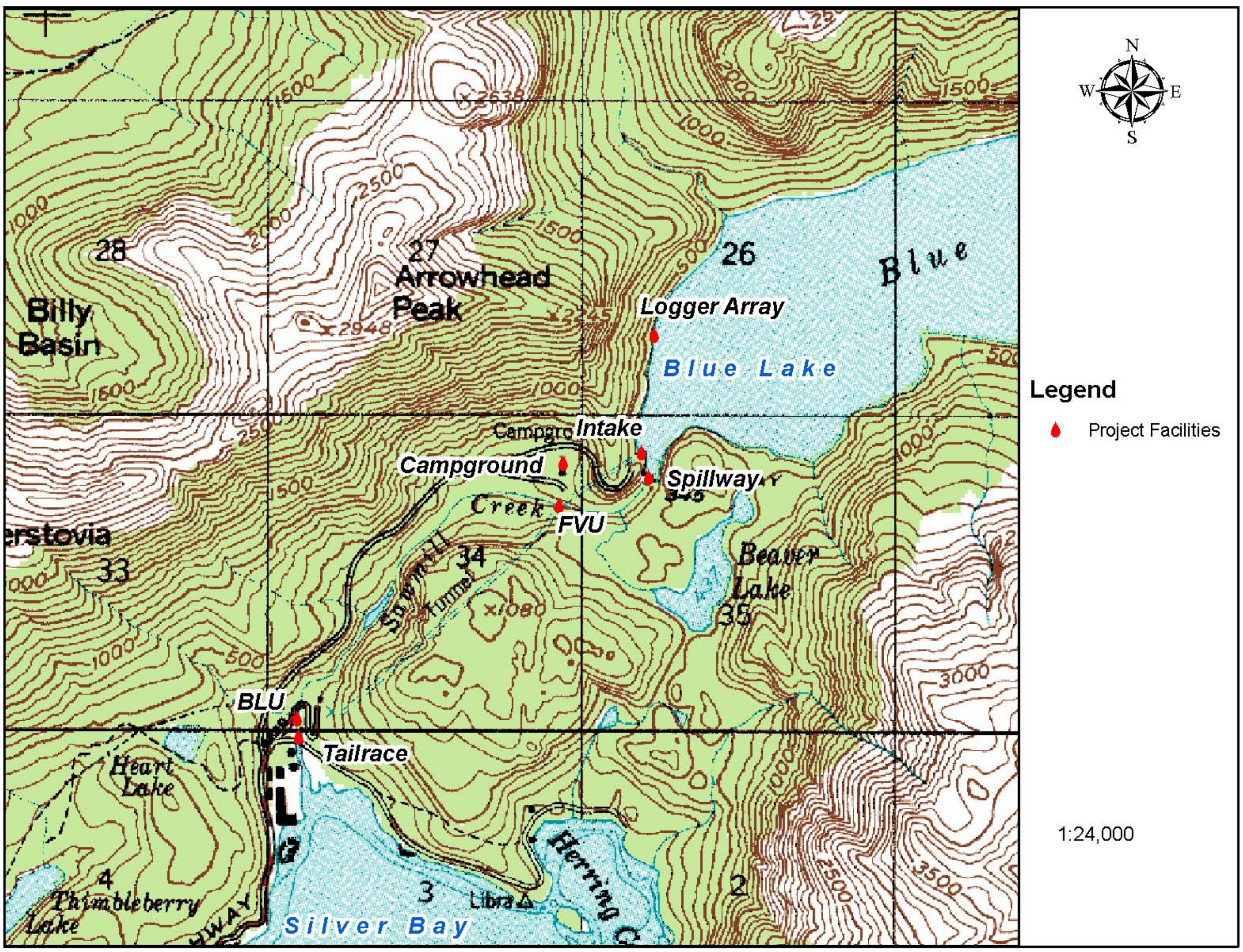

Figure 1. Locations of temperature loggers and other key features in Blue Lake and Sawmill Creek.

FVU is the Fish Valve Unit on Sawmill Creek. BLU is the Blue Lake Unit powerhouse.

A submerged concrete intake structure is located approximately 400 ft north of the dam at El 209 (Figure 2). This structure features a trash rack and moveable gate, which is operated from a gate house onshore. Water from the intake flows through an unlined 1,500-ft long 11.5-ft diameter horseshoe tunnel to the Fish Valve Unit (FVU), where a minimum flow of 50 cfs is released for Sawmill Creek aquatic resources (Figure 2). Water continues 4,650 ft through the power conduit to the Blue Lake Unit (BLU), the Project's main powerhouse. The BLU discharges into Sawmill Creek at stream mile 0.32 (SM, upstream of low mean tide level) (Figure 2).

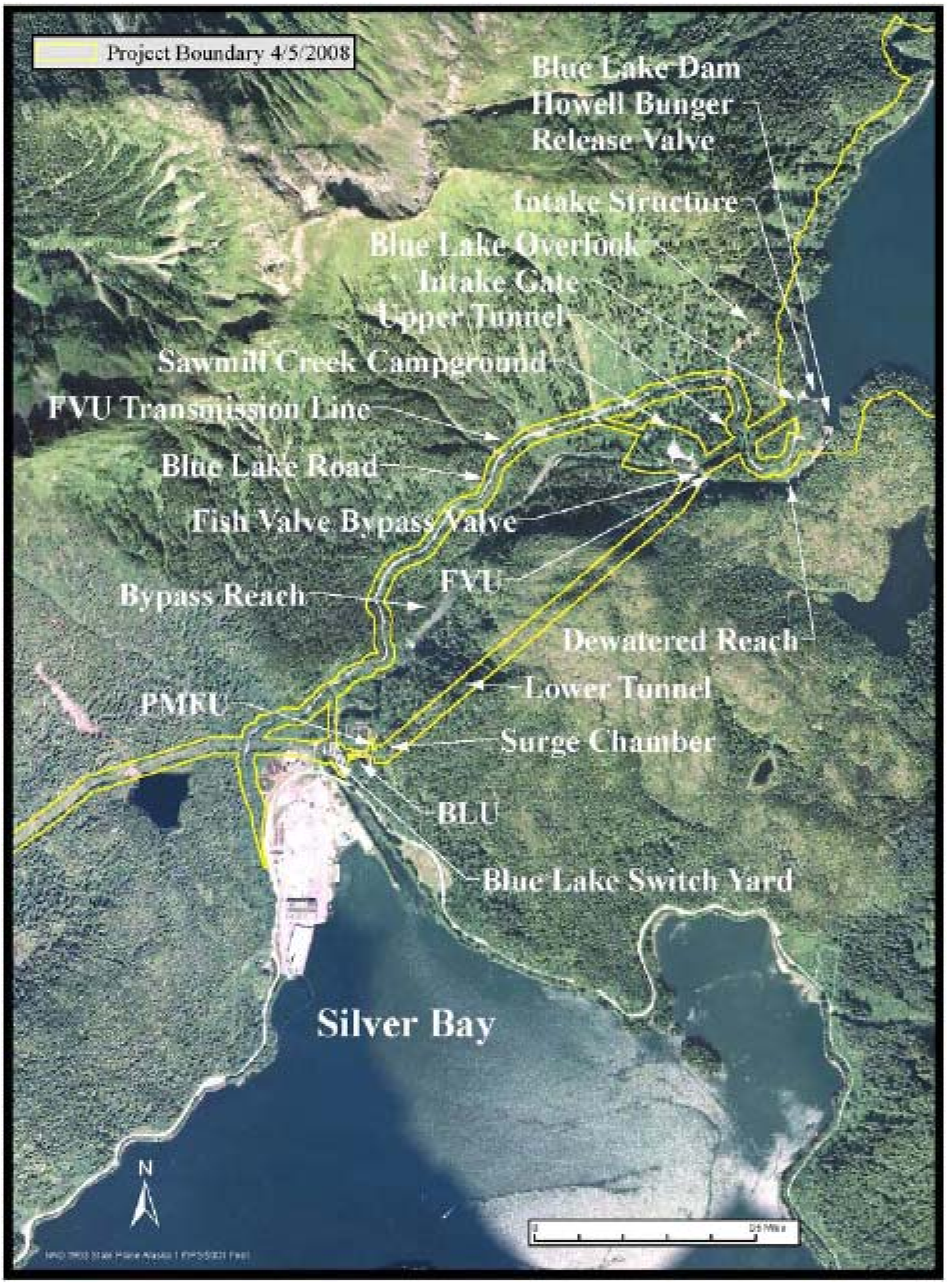

Figure 2. Additional detail of key features in Blue Lake and Sawmill Creek.

EXPANSION-RELATED INTAKE CHANGES

Project engineers have considered new intake arrangement(s) to avoid debris accumulation issues associated with the current structure. The proposed intake would draw water from a 14-ft high intake structure with centerline at El 327 and invert at El 320. The intake structure would be relocated, and the gate would be located in the power conduit and operated via a vertical shaft.

STUDY APPROACH and METHODS

STUDY APPROACH

The overall study approach involved data analyses and predictions in two areas: 1) temperature regime prediction, and 2) biological effects of predicted temperature regimes.

Temperature Regime Prediction

- Determine the temperature regime at the existing intake (El 209) and in Sawmill Creek, using existing water temperature data from Blue Lake and Sawmill Creek;
- Predict water temperatures at the proposed intake elevation (invert El 320)[1], and
- Evaluate the effects of these changes on water temperatures in Sawmill Creek.

Biological Effects of Predicted Temperature Regimes

- Review the run, incubation, and emergence timing of anadromous salmonids utilizing Sawmill Creek, and
- Evaluate potential effects on emergence timing due to changes in the water temperature regime based on water temperature predictions at the proposed intake elevation.

STUDY and ANALYSIS METHODS

Temperature Regime Prediction

EES Consulting (EESC) used several data sources to predict Expansion-related water temperatures in Blue Lake and Sawmill Creek. These included: 1) continuous water temperature monitoring in Blue Lake and Sawmill Creek; 2) Blue Lake reservoir elevation records; 3) air temperature records, and 4) water temperatures measured at the City of Sitka water treatment plant.

Blue Lake and Sawmill Creek Temperature Monitoring

Temperature monitoring in these locations was conducted by the City during the Blue Lake Project relicensing (City 2006; City 2008). The City's temperature monitoring included

[1] Prior investigations (not reported herein) also examined potential centerline intake elevations at El 332 and El 345.

extensive measurements from various Blue Lake and Sawmill Creek locations. From these, EESC extracted data from two Blue Lake sites and three Sawmill Creek sites to support the analyses in this report: 1) the Blue Lake logger array and boom log logger, and 2) three temperature monitoring sites in Sawmill Creek, as described in the following sections.

All continuous temperature monitoring in both Blue Lake and Sawmill Creek was conducted using Optic StowAway temperature loggers (Model 3, Version 5) manufactured by Onset Computer Corporation. These loggers were capable of measuring and recording temperatures between -4 and +38°C. All loggers were set to record temperatures at 2-hour intervals. Data from the loggers were downloaded approximately every two months using a data shuttle, and transferred to the server in Sitka.

Blue Lake Logger Array

An array of Onset loggers was suspended on a cable attached to a cliff located approximately 0.5 miles north along the shoreline from Blue Lake dam (Figure 1). The array consisted of several loggers set at elevation intervals of 15 ft. Loggers remained at fixed elevations regardless of water surface elevation of the lake.

The logger array was active during two periods: 1) from January 1, 2005, to December 31, 2005, and 2) from May 1, 2008, to May 7, 2009. During both measurement periods, the uppermost logger was at approximately El 327, 15 ft below the elevation of the existing spillway at El 342. In 2005, the array consisted of nine loggers that extended down to El 207, approximately the elevation of the current intake (which is at El 209). During the 2008/2009 period, the array was expanded to fifteen loggers extending down to El 117.

Boom Log Logger

To continuously measure surface water temperature, another logger was fixed to a floating log boom near the dam spillway (Figure 1). The logger was suspended on a 2-foot cable, and therefore measured the surface water temperature at the west end of Blue Lake. Data employed from this sensor consisted of daily average water temperatures for the periods of January 1, 2005 to December 31, 2005 and May 15, 2008 to May 1, 2009.

Sawmill Creek Temperature Records

From relicensing studies, EESC retrieved continuous temperature monitoring data at three locations in Sawmill Creek. These were at: 1) the Sawmill Creek campground, just downstream of the FVU, which reflected stream temperatures after inputs from the FVU, Beaver Lake, and reservoir spill; 2) The BLU logger, which reflected temperature just upstream of the BLU, and 3) the BLU tailrace logger, which reflected water temperature discharging from the BLU.

Blue Lake Reservoir Elevation Records

The City supplied daily lake level records for 2005 and 2008 (calendar years) and 2009 (partial year). These data allowed determination of the depths of individual loggers on the logger array during the 2005 and 2008/2009 measurement periods.

The City also supplied proposed lake levels for average, wet, and dry years. These data were the result of lake level modeling completed by the City. Inputs to the model to determine lake levels were the average, 80^{th} percentile (wet year), and 20^{th} percentile (dry year) of the annual records of streamflow into the lake. Lake outflows in the model were regulated according to the proposed "rule curve." The result of the rule curve is that lake outflows for power generation capability are adjusted in such a way as to ensure the reservoir is capable of refilling again in the fall. The wet year (80^{th} percentile) and dry year (20^{th} percentile) lake levels allowed an analysis of expected variability in the temperature analysis results.

Sawmill Creek streamflow records were also obtained from the USGS web site (station #15088000, Sawmill Creek).

Temperature Analysis Methods

EESC used data from the above sources to predict intake and Sawmill Creek temperature regimes. Data from the Blue Lake logger array had to be corrected for water depth (i.e., the temperature at the fixed elevation loggers would become a function of depth, which is a function of the water surface elevation of the lake). Next, different prediction scenarios were considered. In each case, it was assumed that the new spillway would be at El 425, with the invert located at El 320. For each scenario, predictions were made for three different lake levels:

- Proposed rule curve lake operating levels (as provided by the City)
- Lake levels in a wet year, based on 80^{th} percentile stream flows (provided by the City)
- Lake levels in a dry year, based on 20^{th} percentile stream flows (provided by the City)

Finally, intake water temperatures were predicted for each combination of recorded temperatures (2005 and 2008) and lake level (rule curve, wet year, dry year).

Variability Assessment

Air Temperature Records

Air temperatures at the Sitka airport were obtained from the National Weather Service web site. These data consisted of monthly average air temperatures at the Sitka airport from 1949 to the present. These data allowed evaluation of air temperature variability.

Air temperatures at Sitka airport were evaluated to determine the range of variability and to compare to years 2005 and 2008. Mean air temperatures and standard deviations were computed from monthly data for the period 1950-2008.

Water Treatment Plant Temperatures

The City supplied daily water temperatures as measured at the water treatment plant for 2001 through 2008. The water treatment plant is located near the downstream end of the power conduit. These data were used in a correlation analysis to confirm that the temperature logger at El 207 was an accurate measure of water temperature at the Blue Lake intake (El 209). These data also allowed an assessment of intake temperature variability.

Daily measured temperatures at El 207 on the logger array were compared to daily water temperatures measured at the water treatment plant. If these two measurements are closely correlated, then it can be concluded that the temperature logger at El 207 is an accurate measure of water temperature being transported to the treatment plant and the powerhouse. This in turn would provide perspective on the potential variability of intake temperatures, because daily water treatment plant temperatures were available for an eight-year period of record (2001-2008). These data could potentially be used to extend the record of water temperatures at the intake at El 207. A linear correlation was performed between these two measured temperatures for 2005 and 2008.

Biological Effects

A series of fisheries investigative reports had been prepared as relicensing studies for the Blue Lake Hydroelectric Project (City 2002; 2003; 2004; 2005; 2006); additional information is also found in the Affected Environment section of the License Amendment. Information relative to Sawmill Creek utilization is derived from these reports (in particular City 2006). Primary target species were determined from the information in these reports. The primary target species for this analysis were pink (*Oncorhynchus gorbuscha*) and chum (*O. keta*) salmon, with a secondary target species of coho salmon (*O. kisutch*). Pink and chum salmon were selected as the primary target species because they comprise the overwhelming majority of the salmonids that spawn in Sawmill Creek. Coho salmon were selected as a secondary target species due to the presence of the hatchery; its water supply is Sawmill Creek, and changes in temperature could affect growth rates of coho juveniles while at the hatchery.

The purposes of these analyses were to:

- Establish a baseline of existing incubation and emergence timing,
- Simulate water temperatures for rule curve lake levels and proposed invert at El 320, and
- Determine the changes in emergence timing, if any, from the current conditions.

Review Periodicity of Anadromous Salmonids Utilizing Sawmill Creek

EESC relied on data summarized in a series of reports issued by the City for fish runs from 2001-2005 (City 2002; 2003; 2004; 2005; 2006). EESC used the periodicity timing for target species as presented in City (2006).

Evaluate Potential Effects on Emergence Timing

Existing and Predicted Temperature Regimes

EESC examined the water temperature scenarios for the target species:

- The current temperature regime, noting the median, 12th percentile, and 88th percentile water temperatures at the existing intake, and
- The predicted rule curve water temperatures for the proposed invert at El 320.

Since there were only two years of record for temperature at different depth levels (2005 and 2008), compared to eight years of data at the water treatment plant (where exceedance bands could be established), direct comparisons between the two data sets are not possible.

Accumulated Temperature Units

One of the primary variables that affects the rate of development of incubating salmon and trout eggs is Accumulated Temperature Units (ATU) (Piper et al. 1986). ATU is defined as the sum of water temperatures over a period of time. A temperature unit is the number of degrees (in °C) above freezing for a 24-hour period. For example, if the average temperatures for three consecutive days are 4°C, 7°C, and 5°C, the ATU for those three days would be 16. ATU required for egg development for various species in Alaska were obtained from Piper et al (1986), the Alaska Department of Fish and Game (ADFG) web site, Sheridan (1962), and Medvejie Creek. Although fairly consistent between data sources, where discrepancies existed, temperature units developed in Alaska were used.

Calculation of Emergence Timing

EESC used the following methodology to calculate emergence timing of the target species:

- Spawning timing for the target species was determined from the periodicity tables and spawning timing curves developed for Sawmill Creek. The mean run timing curve was used to determine when 50% of the spawning had occurred. For purposes of this analysis, it was assumed that the 50% date would represent the central 80% of the target species spawning timing (i.e., ±40% of the mean).
- Daily water temperatures were calculated for the existing condition (i.e., spillway at El 342 and the intake at El 209) using the median, 12th percentile, and 88th percentile data sets developed.[2]
- For the proposed new invert (El 320), daily water temperatures were calculated using the "rule curve predicted temperatures." *[Note: Rule curve predicted temperatures are represented by predictions for proposed rule curve lake levels and averages between 2005 and 2008 measured temperatures. Strictly speaking, these are not directly comparable to the existing intake median temperatures, because the existing intake*

[2] The only exceedance bands that could be established were the 12th and 88th percentiles, because there were only eight years of temperature records available from the water treatment plant.

temperatures are computed from eight years of data (2001-2008), while the predicted rule curve temperatures are based on only two years of data (2005 and 2008)].

- ATUs for the target species were then used to determine the timing of emergence, based upon:
  - The time when, on average, 50% of the spawning had occurred for each target species;
  - water temperature, and
  - temperature units
- Emergence timing of target species under existing conditions was then compared to predicted temperatures under the Expansion scenarios.

RESULTS

TEMPERATURE REGIME

Blue Lake and Sawmill Creek Temperature Monitoring

All data obtained from the Blue Lake logger array, boom log logger, and Sawmill Creek locations were coordinated in a spreadsheet for subsequent analysis. Recorded temperatures were reduced to daily average temperatures (^{o}C) for each location. As an example, Figure 3 illustrates temperatures recorded in 2008 at selected elevations along the logger array (only selected sensors on the logger array are shown in the figure, because showing all 16 sensors would render the graph hopelessly incomprehensible).

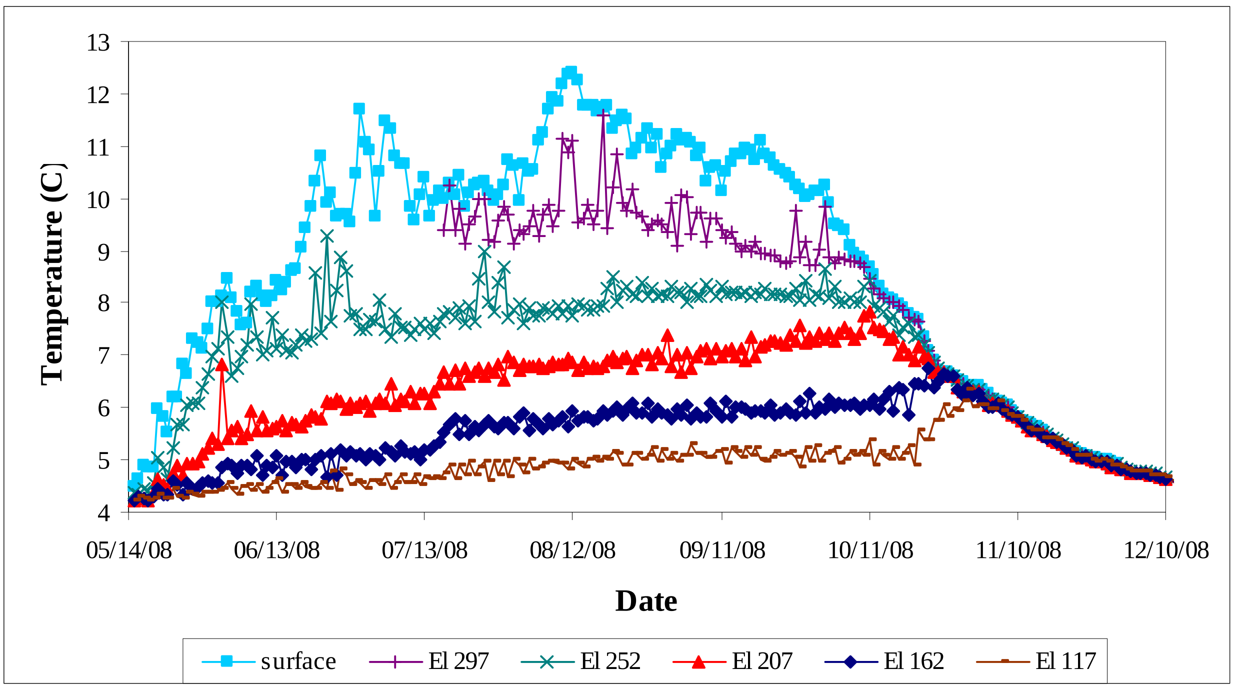

Figure 3. Blue Lake logger array temperatures, 2008.
Each line represents a different elevation on the logger array.

Blue Lake Reservoir Elevation

The various lake levels considered for prediction scenarios are illustrated in Figure 4. It can be seen from Figure 4 that 2005 was at relatively high lake levels throughout the year. Overall, 2008 was relatively low to average lake level; however, 2008 snowmelt appears to have come off later than normal, resulting in a springtime lake level that was quite low. Lake levels then increased dramatically through the summer of 2008 to near maximum in the fall. This observation is consistent with streamflow records from Sawmill Creek, below Blue Lake dam (Figure 5). Sawmill Creek saw relatively high flows in 2005, but substantially lower than average flows in 2008 until later in the summer. Note also in Figure 4 that lake levels in a dry year are actually higher than in an average (rule curve) year. This is because the proposed Expansion would be operated in such a way as to ensure refilling of the reservoir in the fall. The result is that in a dry year power generation capability would be reduced to conserve water in the reservoir.

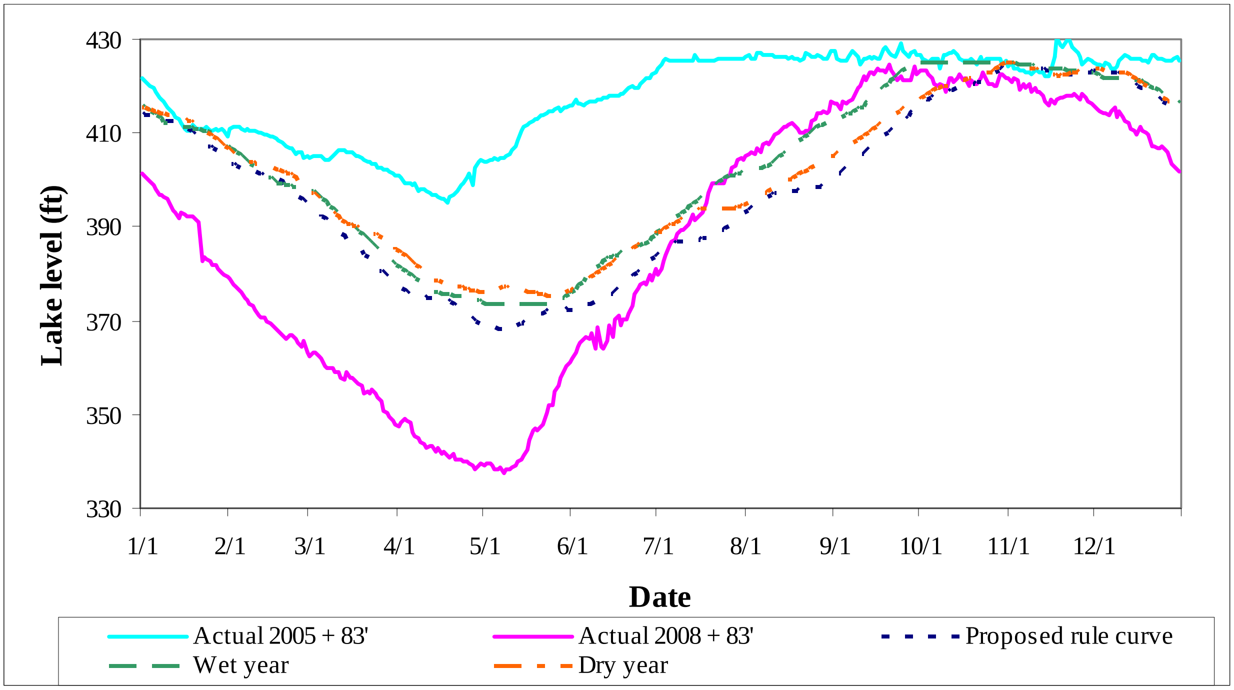

Figure 4. Lake level comparisons with the proposed spillway at El 425.

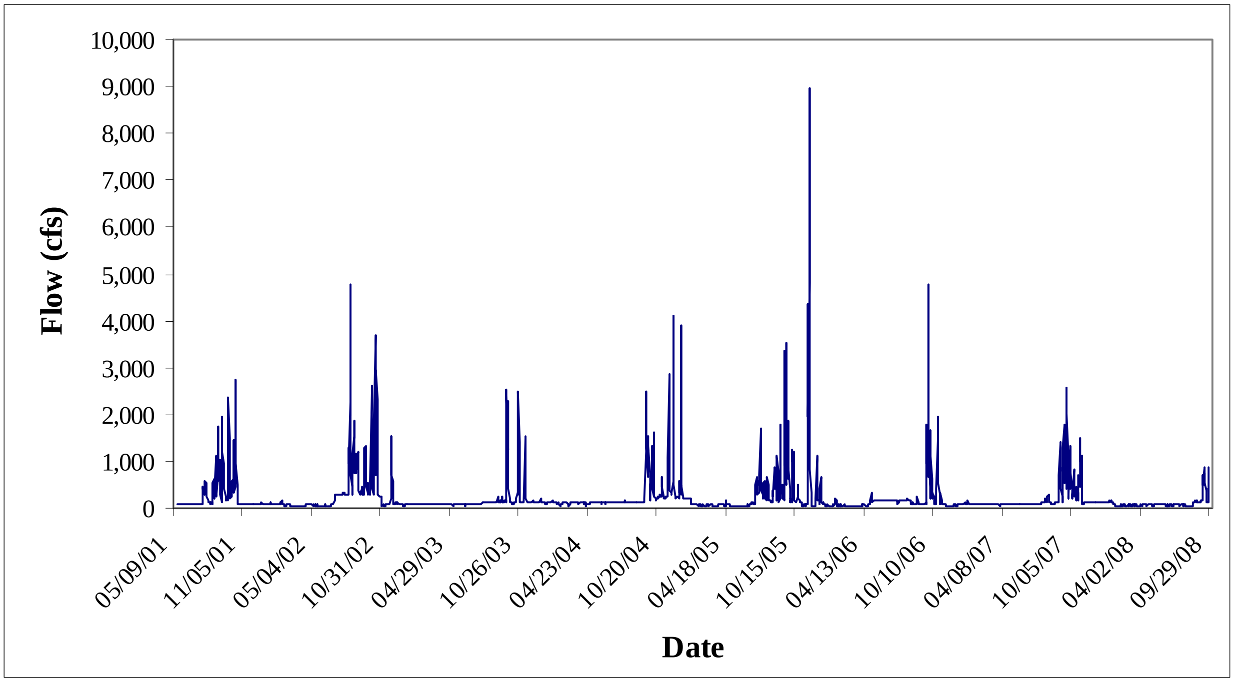

Figure 5. Sawmill Creek discharge 2001-2008.
(source: USGS Station 15088000).

TEMPERATURE PREDICTION

Elevation Correction

The nature of the logger array temperature data (loggers at fixed elevations) necessitated interpolation of the data for the prediction methods. Therefore, to facilitate expedient data analysis, results were tabulated for 24 discrete days throughout the year (i.e., for days of the year of 1/15, 1/31, 2/15, etc.). This interpolation involved several steps.

First, the logger array data was corrected for lake surface elevation. For any given day, the depth of each temperature logger was determined by taking its fixed elevation and subtracting it from the lake surface elevation on that day. For example, on 8/1/2008, the lake surface was El 322. Therefore, the uppermost logger (El 327) was out of the water by 5 ft; the next highest logger (El 312) was in 10 ft of water, etc. In this way, the recorded temperature from each logger on a given date becomes a function of depth. These computations resulted in a series of temperature profiles over various depths on the selected dates for 2005 and 2008. These results are illustrated in Figures 6 and 7 (these figures are for illustrative purposes; 10 dates of interest were selected, because showing all 24 dates would render the graphs hopelessly incomprehensible). Note that the depths are not consistent throughout the year, because the lake level changes over time. Temperatures were then interpolated at 1-ft increments for each of the 24 days of interest, resulting in a lookup table for 24 dates at 1-ft increments of depth below the water surface.

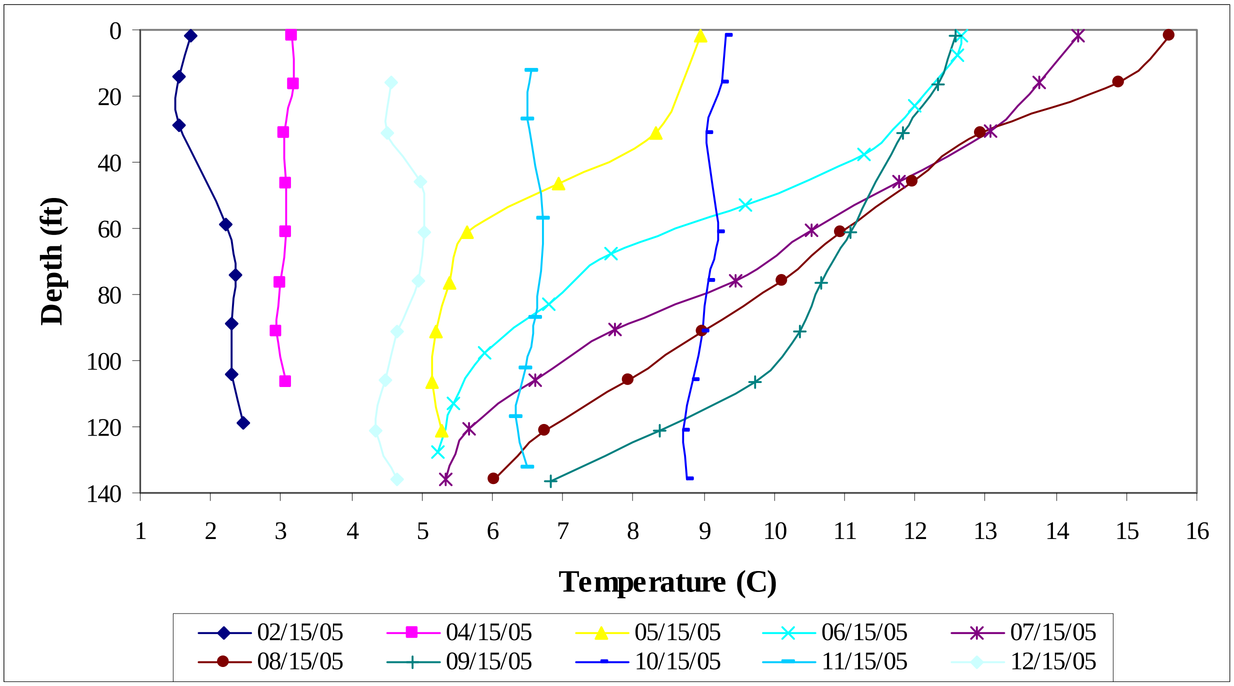

Figure 6. Blue Lake daily average water temperatures, 2005.

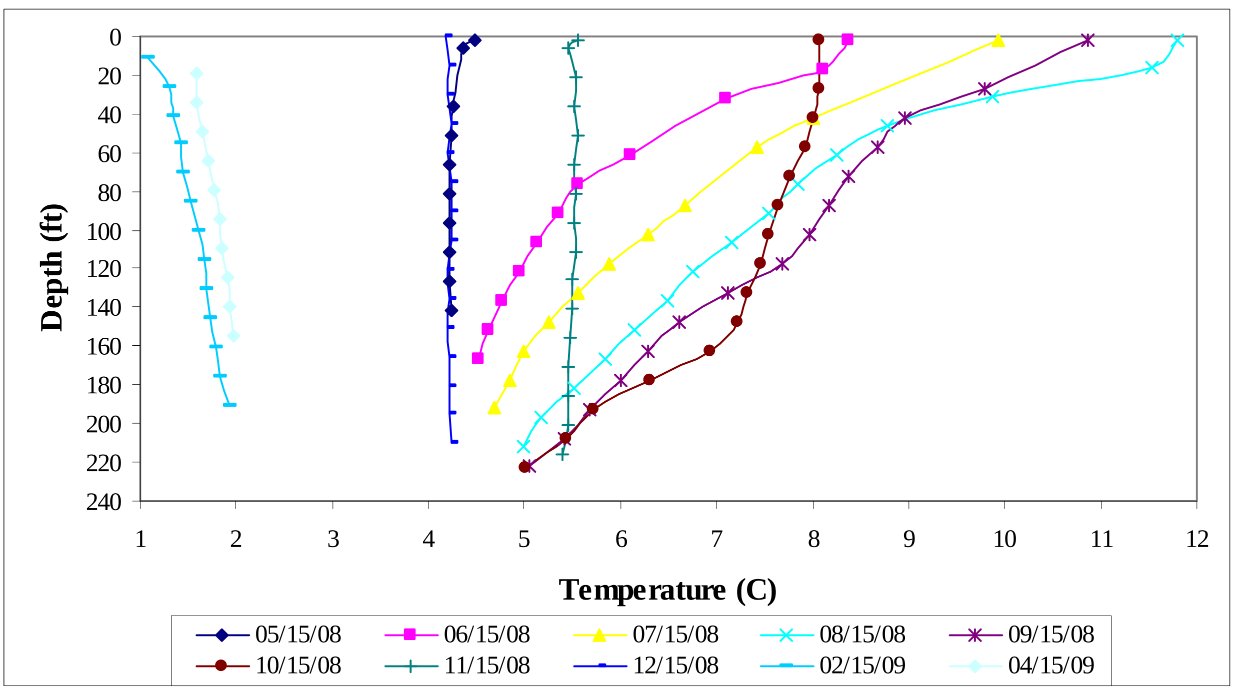

Figure 7. Blue Lake daily average water temperatures, 2008.

Figures 6 and 7 show a distinct temperature stratification in the lake that begins by late May and lasts into October. These figures also show, however, an interesting phenomenon of wintertime "reverse stratification." For at least a few months (from as long as February to April in 2008), the temperature in the lake is actually warmer at depth than it is at the surface. This is due to the cold air temperatures at that time of year, and the fact that water density decreases from 4°C to 0°C, causing warmer water to sink within this temperature range. This effect, however, is short-lived (1 to 3 months), and of much lowers magnitude (about 1°C) than the summertime stratification.

Intake water temperatures were predicted for each combination of recorded temperatures (2005 and 2008) and lake level (proposed rule curve, wet year, and dry year). First, for a given date, the elevation of the intake was subtracted from the lake surface elevation, yielding the depth of the intake on that date. This date and depth were then looked up in the data table (data illustrated in Figures 6 and 7) to determine the temperature at that depth on that given date.

For example, on August 15, the rule curve lake level is El 397. This puts the El 320 invert (El 327 intake centerline) at a water depth of 70 ft. Referring to 2008 recorded temperature data (Figure 7) on August 15, 2008, the (interpolated) lookup table yields a water temperature of 8.0°C at a depth of 70 ft. This process was repeated for all the various combinations of year and lake level.

Figures 8 and 9 illustrate the results of the intake temperature predictions for the various scenarios. For comparison purposes, actual measured temperatures from the El 207 logger on the logger array are included for the year in question (lowest line in each graph). The other three lines in each graph represent predicted temperatures at the intake based on the different lake level scenarios as outlined above.

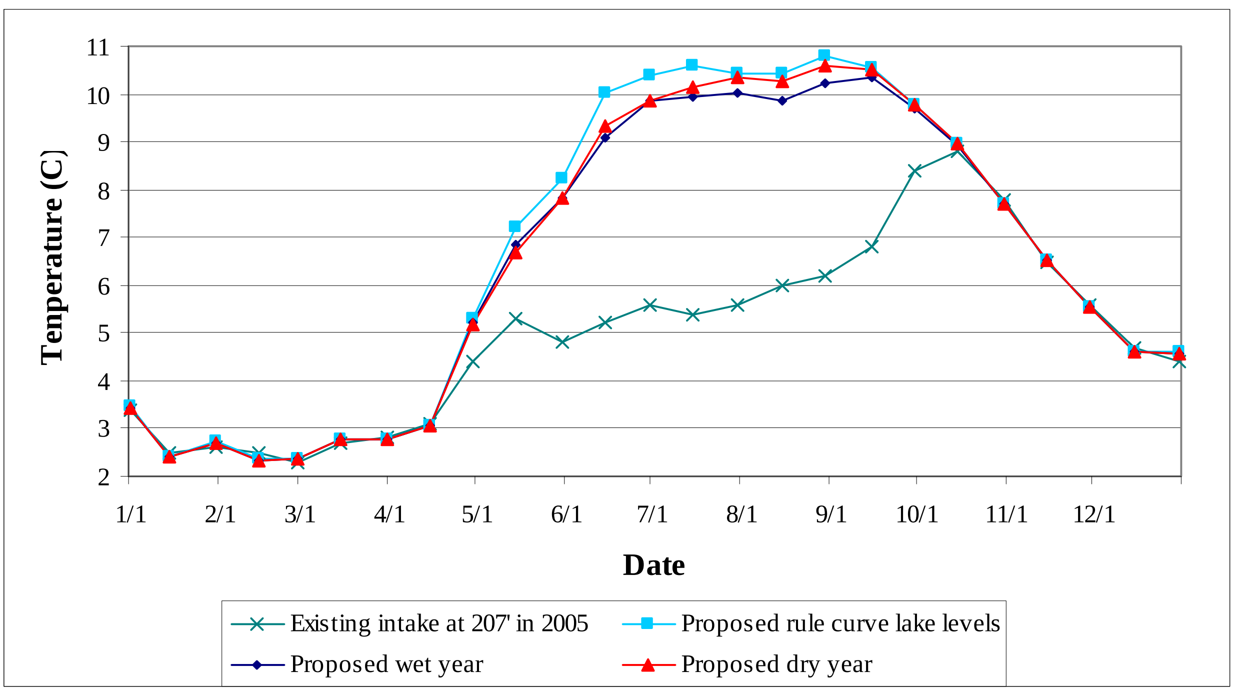

Figure 8. Predicted intake water temperatures based on 2005 water temperature data using spillway at El 425 and proposed invert at El 320.

Water temperatures at the existing intake at El 207 in 2005 provided for reference.

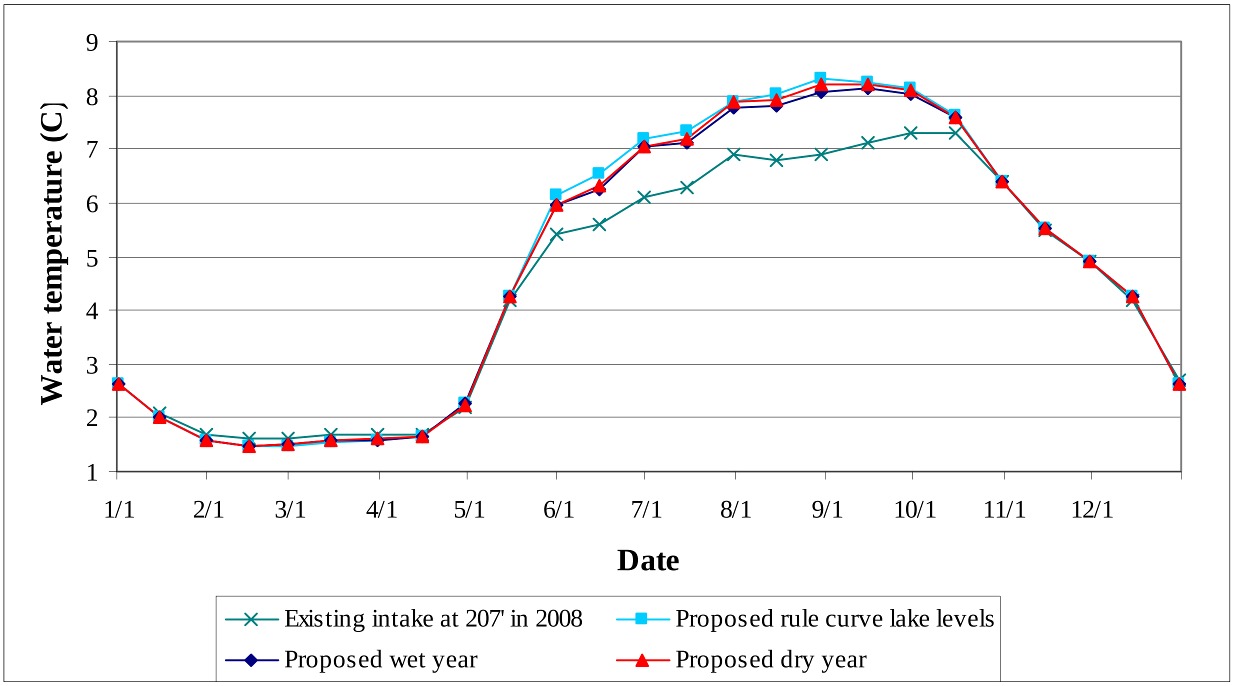

Figure 9. Predicted intake water temperatures based on 2008 water temperature data using spillway at El 425 and proposed invert at El 320.
Water temperatures at the existing intake at El 207 in 2008 provided for reference.

The difference between predicted temperatures and existing conditions is minimal in the winter and early spring (approximately November through March); water temperatures in the lake are nearly uniform during this time, so changes in the depth of the intake do not affect the temperature of the intake water. From spring through late summer, lower lake levels result in warmer intake temperatures. This finding is consistent, considering lower lake levels mean the intake will be at shallower depths, resulting in warmer water temperatures due to the stratification in the lake.

Looking at Figure 8 for 2005, the predictions for the three different lake levels are very close together, varying by less than 1°C between them, because the lake level variation is kept to a minimum through regulation of outflows for power generation (refer to Figure 4). Figure 9 for 2008 parallels that of Figure 8 (for 2005). There is less variability, however, because 2008 was a cooler year; therefore it demonstrated a smaller range in temperature stratification in the lake (7°C versus 10°C; compare Figures 6 and 7). Predicted temperature patterns are similar, with predicted temperatures following the same progression from warmer to cooler with the same sequence of lake levels.

Variability Assessment

Air Temperatures

Monthly average air temperatures recorded at Sitka airport are illustrated in Figure 10. 2005 generally had above average air temperature throughout the year. 2008 had a relatively cool spring and summer, which explains the late snowmelt in 2008.

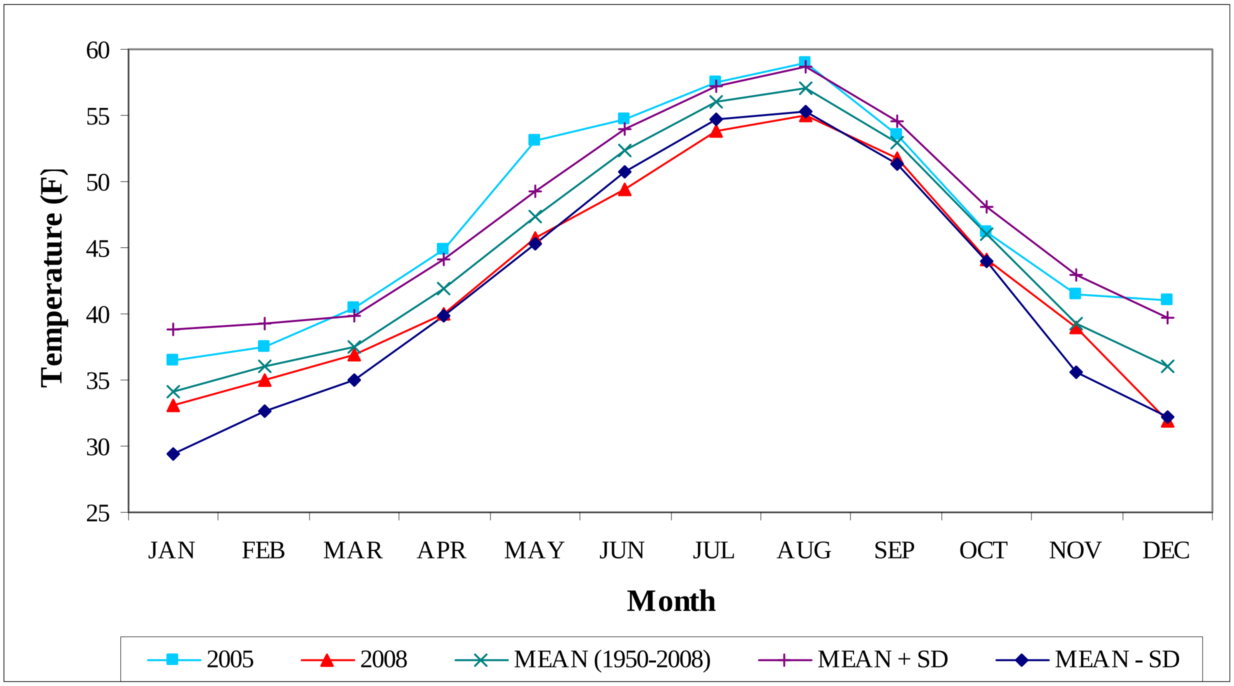

Figure 10. Monthly average air temperatures at the Sitka Airport with standard deviations.
Standard deviations represent approximately 16th and 84th percentiles.
(source: National Weather Service).

Water Treatment Plant Temperatures

Figure 11 illustrates the distribution of water treatment plant temperatures for 2001 through 2008, indicating the median, 12th and 88th percentiles for the 8-year record. These values are compared to the temperatures recorded at the water treatment plant during 2005 and 2008.

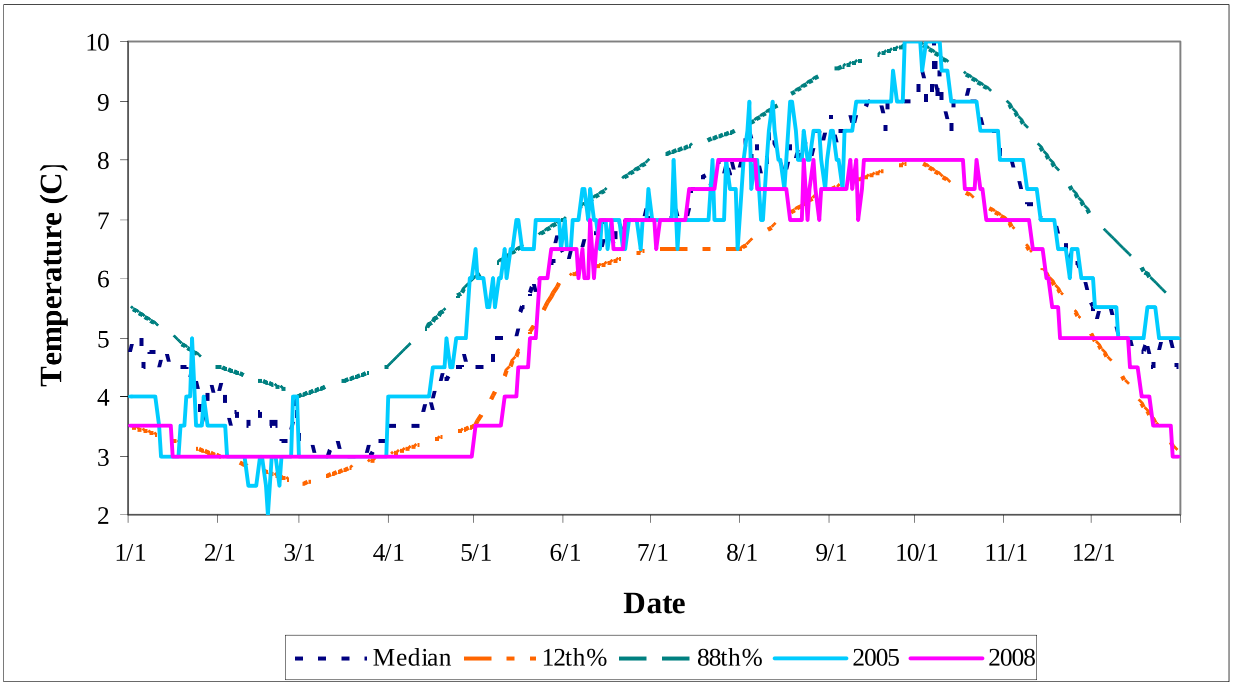

Figure 11. Distribution of water treatment plant temperatures 2001-2008.

As a verification step, daily measured temperatures at El 207 on the logger array were compared to daily water temperatures measured at the water treatment plant. A linear correlation was performed between these two measured temperatures for 2005 and 2008. Figures 12 and 13 illustrate the results of the temperature correlations between the logger at the existing intake elevation at El 207 and the water treatment plant.

The correlation between temperatures measured at El 207 and the water treatment plant is very good (Figures 12 and 13). There does, however, appear to be a fairly consistent offset of about 0.5°C to 1.0°C (treatment plant temperature warmer than intake elevation). Several factors may account for this apparent discrepancy. The El 207 temperature logger is located approximately 0.5 miles above the actual lake intake, while the water treatment plant is located downstream of the lake intake. Therefore, there is some distance between these two temperature measurement locations. Also, typical temperature loggers, such as Onset Tidbit sensors, have an inherent uncertainty of 0.2-0.3°C. Finally, the resolution of the treatment plant temperature measurements is 0.5°C. Combination of these different factors could easily account for a discrepancy of 0.5°C to 1.0°C. Therefore, the water treatment plant temperatures provide a good representation of variability in intake water temperatures, and the range of variability of intake temperatures should be well illustrated by Figure 11.

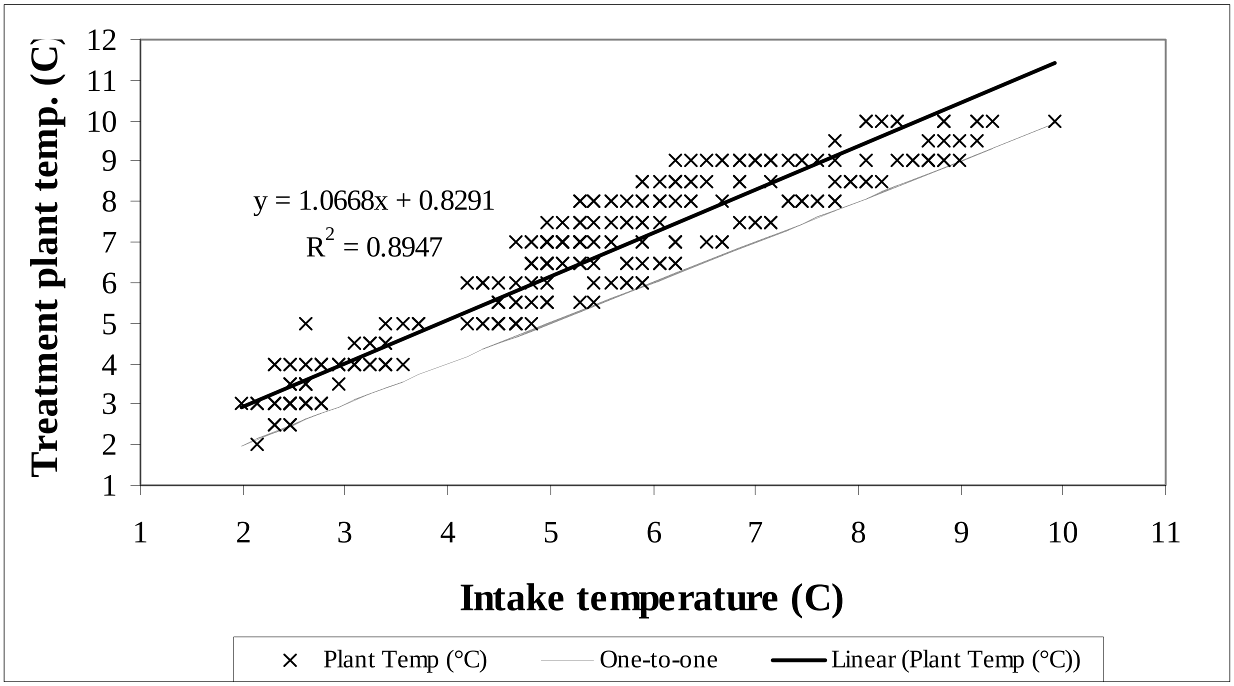

Figure 12. 2005 treatment plant temperatures vs. temperature logger at El 207.

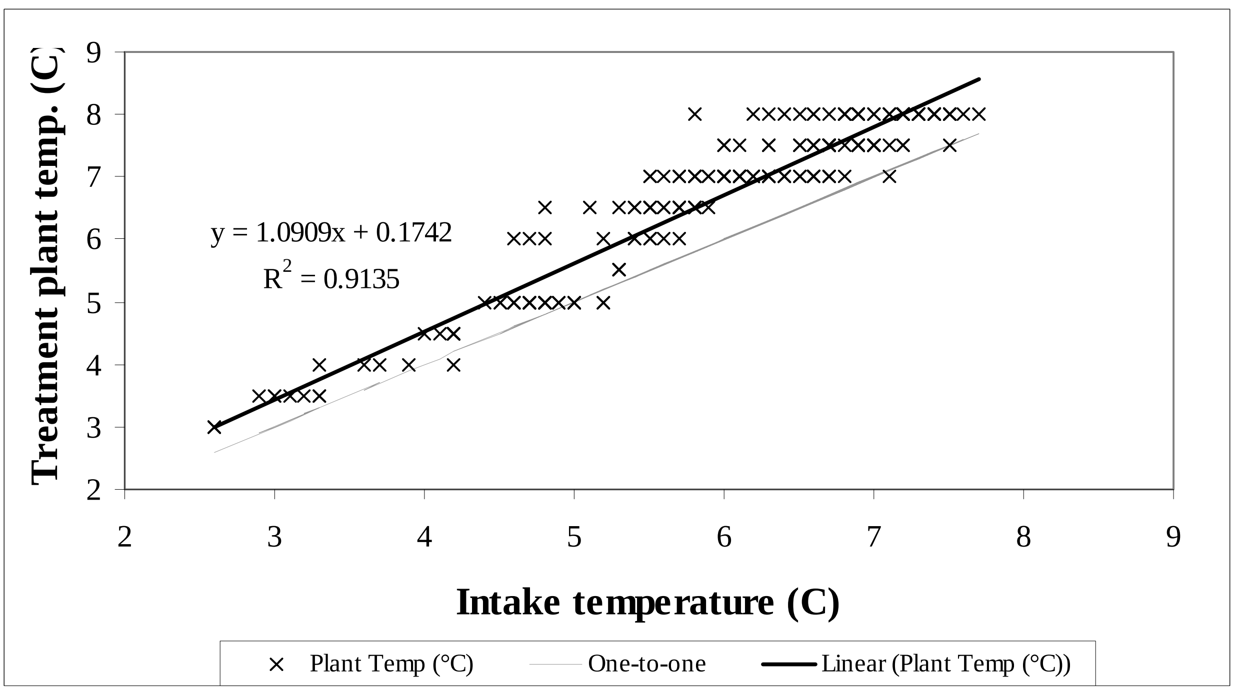

Figure 13. 2008 treatment plant temperatures vs. temperature logger at El 207.

The average difference between the water treatment plant temperature and the El 207 logger is 1.0°C for 2005 and 2008 combined (Figures 12 and 13). Therefore, to represent historical variation in intake temperatures, the measured water treatment plant temperatures were adjusted (downward) by 1.0°C for inclusion in Table 1.

Table 1. Existing Intake Temperatures and Predicted Temperatures with Proposed Project

Date	Existing intake (°C)[1]			Proposed invert at El 320 (°C)		
	12th perc.	Median	88th perc.	Min	Average[2]	Max
1/1	2.5	3.8	4.5	2.6	3.0	3.5
1/15	2.3	3.5	4.0	2.0	2.2	2.4
2/1	2.0	3.0	3.5	1.6	2.1	2.7
2/15	1.8	2.8	3.3	1.5	1.9	2.4
3/1	1.5	2.3	3.0	1.5	1.9	2.4
3/15	1.7	2.0	3.2	1.6	2.2	2.8
4/1	2.0	2.5	3.5	1.6	2.2	2.8
4/15	2.2	3.0	4.2	1.7	2.4	3.1
5/1	2.5	3.5	5.0	2.2	3.7	5.3
5/15	3.7	4.0	5.5	4.2	5.6	7.2
6/1	5.0	5.3	6.0	6.0	6.9	8.2
6/15	5.2	6.0	6.5	6.3	7.7	10.0
7/1	5.5	6.0	7.0	7.0	8.4	10.4
7/15	5.5	6.5	7.2	7.1	8.5	10.6
8/1	5.5	7.0	7.5	7.8	8.9	10.4
8/15	6.0	7.0	8.0	7.8	8.8	10.4
9/1	6.5	7.8	8.5	8.1	9.1	10.8
9/15	6.7	8.0	8.7	8.1	9.2	10.6
10/1	7.0	8.0	9.0	8.0	8.9	9.8
10/15	6.5	8.0	8.5	7.6	8.2	9.0
11/1	6.0	7.0	8.0	6.4	7.0	7.7
11/15	5.1	6.0	7.1	5.5	6.0	6.5
12/1	4.0	4.5	6.0	4.9	5.2	5.6
12/15	3.1	3.8	5.3	4.2	4.4	4.6

[1] Existing intake temperatures are represented by 2001-2008 water treatment plant temperatures (Figure 10), adjusted for the correlation between water treatment plant and El 207 logger for 2005 and 2008 (Figures 12 and 13).

[2] Average predicted temperatures are represented by averages between 2005 and 2008 predictions for proposed rule curve lake levels. Strictly speaking, these are not directly comparable to the existing intake median temperatures tabulated in the third column of the table, because the existing intake temperatures are computed from eight years of data (2001-2008), while the predicted average temperatures are based on only two years of data (2005 and 2008).

In summary, the proposed invert at El 320, with the dam spillway raised to El 425, could be expected to raise typical summer intake temperatures by 1°C to 3°C (June-September). The greatest increases would be expected in July or August. Changes in intake temperatures would increase with higher summer air temperatures. The effect on winter temperatures would be minimal (<1°C November-April).

Variability is well represented in these results. 2005 was a relatively high lake level year (Figure 4), and a warm year in terms of air temperature (96th percentile; Figure 10). 2008 was a low to average lake level year (Figure 4), and a relatively cool year in terms of air temperatures (11th percentile; Figure 10). In terms of measured intake temperatures at the water treatment plant, the measured data from 2005 was near average, and 2008 was below average (Figure 11).

BIOLOGICAL EFFECTS

Fish Species Observed in Sawmill Creek

Eight salmonid species were observed in Sawmill Creek during surveys extending from 2001-2005. These species, including the stream miles (SM) utilized, were (City 2009):

- Pink salmon (*Oncorhynchus gorbuscha*) (SM 0.0 – 0.73)
- Chum salmon (*O. keta*) (SM 0.0 – 0.73)
- Chinook salmon (*O. tshawytscha*) (SM 0.0 – 0.73)
- Coho salmon (*O. kisutch*) (SM 0.0 – 0.73)
- Steelhead trout (*O. mykiss*) (SM 0.0 – 0.73)
- Resident Rainbow trout *(O. mykiss)* (considered resident if lengths were between 250 mm and 490 mm) (SM 0.0 – 2.03).
- Dolly Varden char (*Salvelinus malma*) (SM 0.0 – 0.73)
- Arctic Grayling (*Thymallus arcticus*) (SM 1.74 – 1.84)

Non-salmonid species include:

- Staghorn sculpin (*Leptocottus armatus*) (SM 0.0 – 0.73)
- Prickly sculpin (*Cottus asper*) (SM 0.0 – 0.73)

Species Distribution Within Sawmill Creek

A waterfall (Falls) exists at SM 0.73, which is believed to be a barrier to upstream migration of anadromous fish. The Alaska Department of Fish & Game (ADFG) Atlas shows the uppermost extent of anadromous fish to be the Falls (ADFG 2009).

Sawmill Creek fish distribution varies in an upstream direction from tidewater. From tidewater to the Project Powerhouse, pink and chum salmon are the most abundant species; about 83% of the pink salmon spawning occurs in the intertidal area upstream to BLU. Directed studies in 2009 indicate that 53% of the spawning during the first part of the chum salmon run occurred in the intertidal area, with 71% of the spawning occurring in this area during the later part of the run.

Pink salmon are the most abundant species to utilize Sawmill Creek. Peak intertidal ground counts from 2002 in the intertidal area (e.g. downstream of the BLU tailrace) ranging from 18,500 – 160,000 pinks. ADFG escapement counts occur in the intertidal area and have ranged from 11,000 to 48,000 pinks. Peak ground counts upstream of the BLU tailrace have ranged from 10,740 to 172,070 pinks with no comparative ADFG counts due to aerial sampling difficulties.

Pink salmon tend to enter the stream some time before spawning commences; chum salmon, however, tend to begin spawning soon after entering Sawmill Creek (City 2009).

Chum salmon are the second most abundant species to utilize Sawmill Creek with peak intertidal ground counts during the early portion of the run ranging from 250-669 chum and peak late portion ground counts ranging from 200-3,350 chum. Peak ground counts above the BLU have ranged from 61-993 chum for the early portion of the run, and from 190 to 7090 during the late portion of the run.

Chinook and coho salmon and steelhead trout were more often found in the reaches between the powerhouse and the Falls. Compared to numbers of pink and chum salmon, numbers of coho salmon were small; this is most likely due to limitations in juvenile rearing habitat and lack of access above the Falls at SM 0.73. Steelhead numbers are likewise limited by juvenile habitat. Adult Chinook salmon numbers varied widely; it appears there is an inverse correlation between adult Chinook salmon numbers in Sawmill Creek with flow levels in Medeveje Creek. Juvenile Chinook habitat (e.g., large river, low-gradient areas) does not exist in Sawmill Creek and has precluded the species from becoming naturalized. Studies completed for the Blue Lake Hydroelectric Project Relicensing documented 30 to 50 steelhead trout, 10 to 60 coho salmon, and 42 to 573 Chinook salmon. Sawmill Creek steelhead and coho salmon are thought to be native to the stream, while Chinook salmon are considered strays from nearby hatchery operations based at Medeveje Creek (City 2009). More detailed descriptions of these fish, their habitat, and observed population numbers are available in City (2002, 2003, 2004, 2005, 2006).

Target Species

As stated previously, pink and chum salmon were selected as the primary target species, since these two species comprise the overwhelming majority of the salmonids that spawn in Sawmill Creek. Coho salmon were selected as a secondary target species due to the presence of the hatchery; its water supply is Sawmill Creek, and changes in temperature could affect growth rates of coho juveniles while at the hatchery.

Species Periodicity

Sawmill Creek anadromous salmonids varied in their typical in-migration, spawning, incubation, and rearing times (Table 2). The information in this section was gleaned from City (2006).

Pink Salmon

Pink salmon have been observed milling in the intertidal area as early as July; true migration to the terminal area of Sawmill Creek begins in early August. Peak numbers occur in the upper stream (the Powerhouse and above) during the first and second weeks of September, while peak numbers occur in the intertidal areas in mid- to late August. In all areas of Sawmill Creek (both above the Powerhouse and below in the intertidal area), spawning begins in mid- to late August, with the peak occurring in the upper area during the first or second week of September (see Figure 14). *[Note: this curve represents the "average" condition in Sawmill Creek. Pink salmon spawning timing has exhibited a great deal of variability since 2002, with timing both* *earlier and later than the mean run timing depicted in this figure]*. This curve indicates "middle" run timing for pink salmon in Southeast Alaska (Sheridan 1962). Pink salmon eggs incubate over the winter, and fry emerge the next year from late March through May. Pink salmon do not exhibit an extended fresh water rearing phase; fry leave the stream soon after emergence to rear in brackish water. All juvenile pink salmon spend about two seasons (i.e., 16 to 18 months) in salt water before returning to their natal stream to spawn.

Table 2. Stream Periodicity Table for Salmonids Utilizing Sawmill Creek

Species	Life Stage	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Pink	Inmigration												
	Spawning												
	Incubation												
	Outmigration[1]												
Chum	Inmigration												
	Spawning												
	Incubation												
	Outmigration[1]												
Chinook	Inmigration												
	Spawning												
	Incubation												
	Rearing	Unknown											
	Outmigration	Unknown											
Coho	Inmigration												
	Spawning												
	Incubation												
	Rearing												
	Outmigration[2]												
Steelhead	Inmigration												
	Spawning												
	Incubation												
	Rearing												
	Outmigration[2]												
Rainbow	Spawning												
	Incubation												
	Rearing												

[1] Based on stream observations, local trends and professional judgment due to photo negative behavior. The black color indicates peak timing of a life stage, if known.

[2] Based on similar local systems due to limited observations

Chum Salmon

Chum salmon migrate to Sawmill Creek from mid-July through mid-September, and begin to spawn as soon as they enter the creek through early October. Chum eggs incubate over the winter, and fry emerge the following year from late February through May. Like pink salmon, chum salmon exhibit no extended fresh water rearing phase, with fry leaving the stream soon after emergence to rear in brackish water where they feed on increasing plankton levels (Halupka et al 2000; Sheridan 1962). Chum salmon spend from 3 to 5 years in salt water, with most chum in Sawmill Creek appearing to return at four years.

Chum salmon exhibit bi-modal spawning timing, with the second peak being larger than the first (Figure 15). *[Note: this curve represents the "average" condition in Sawmill Creek. Chum salmon spawning timing has exhibited a great deal of variability since 2002, with timing both earlier and later than the mean spawning timing depicted in this figure]*.

Chinook Salmon

King salmon enter the stream in July with the early chum, and spawn during late summer. Incubation lasts until the following spring, and all emergent fry observed soon perished due to lack of suitable rearing habitat. In Sawmill Creek, it is believed that Chinook salmon are hatchery strays.

Coho Salmon

Coho salmon enter Sawmill Creek from early September through mid-November; the peak migration to the stream occurs from late September through mid-October. Spawning begins in early October, peaking from late October through early November, and extending until late November. Coho eggs incubate over the winter, and fry emerge from the gravels the following year, presumably in April and May. Coho juveniles rear in fresh water for one to two years (most rearing for two years), and typically smolt in May or early June. Coho in southeast Alaska typically spend 16 months in saltwater before returning to spawn.

Steelhead Trout

Earliest to migrate to Sawmill Creek are steelhead, which enter the stream as early as late March and continuing through mid-June. Steelhead spawn soon after migrating, with the peak occurring in late May and early June; steelhead eggs incubate until mid- to late summer. Steelhead in Southeast Alaska have complex life histories, spending anywhere from two to five years in fresh water, and two to three years in salt water. Steelhead also have the capability of repeat spawning, the adults known as kelts as they migrate back to salt water.

Rainbow Trout

Rainbow trout are the resident, non-anadromous form of steelhead. Since the resident and anadromous forms are indistinguishable, *O. mykiss* is considered resident if lengths are between

250 mm and 490 mm. It is not known whether rainbow trout were native to the Sawmill Creek watershed prior to stocking by the U.S. Forest Service in 1938 and 1939. During this period, 9,000 fry, 200 adult rainbow trout, and 50,000 eggs from Sashin Lake were planted in Blue Lake (Der Hovanisian 1994). After this initial planting, 8,800 rainbow trout from the Willamette River in Oregon were released in Blue Lake. It is assumed that fish from these plantings spilled over the dam, creating resident rainbow trout populations in Sawmill Creek (ADFG 2002).

Figure 14 depicts the pink salmon spawning timing in Sawmill Creek for 2002-2009. Over this time period, approximately half of the pink spawning occurred during the week of September 3 – 9. For analysis purposes, the date of September 8 was selected for modeling to determine any changes in pink salmon incubation and emergence timing

Figure 15 shows chum salmon spawning timing for the 2002-2009 period in Sawmill Creek. Spawning timing for chum salmon is bimodal; on average, about 50% of the spawning occurs during the week of September 3 – September 9. For analysis purposes, the date of September 4 was selected for modeling to determine any changes in chum salmon incubation and emergence timing.

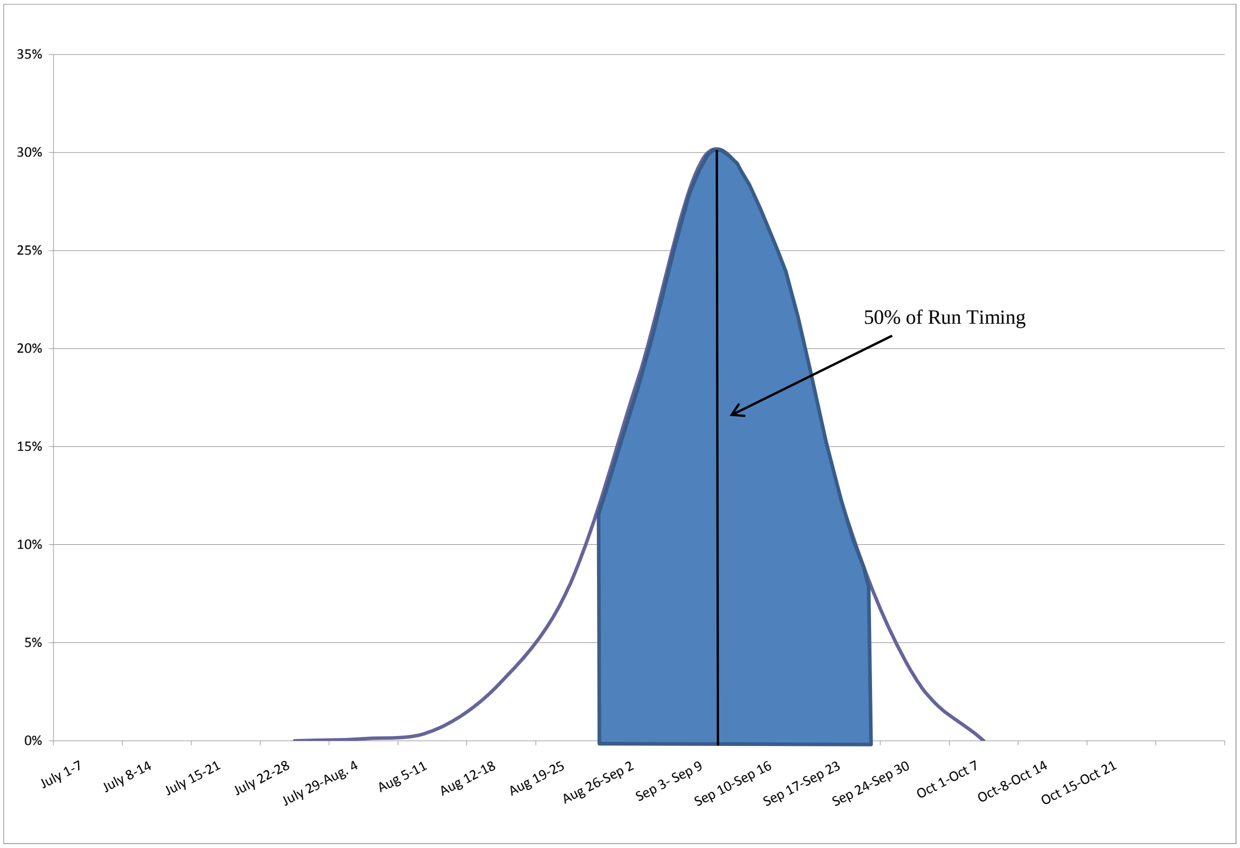

Figure 14. Percentage of pink salmon entering Sawmill Creek by week, 2002-2009. Black line denotes the average date when 50% of spawning has occurred; blue shading represents the central 80% of average spawning timing.

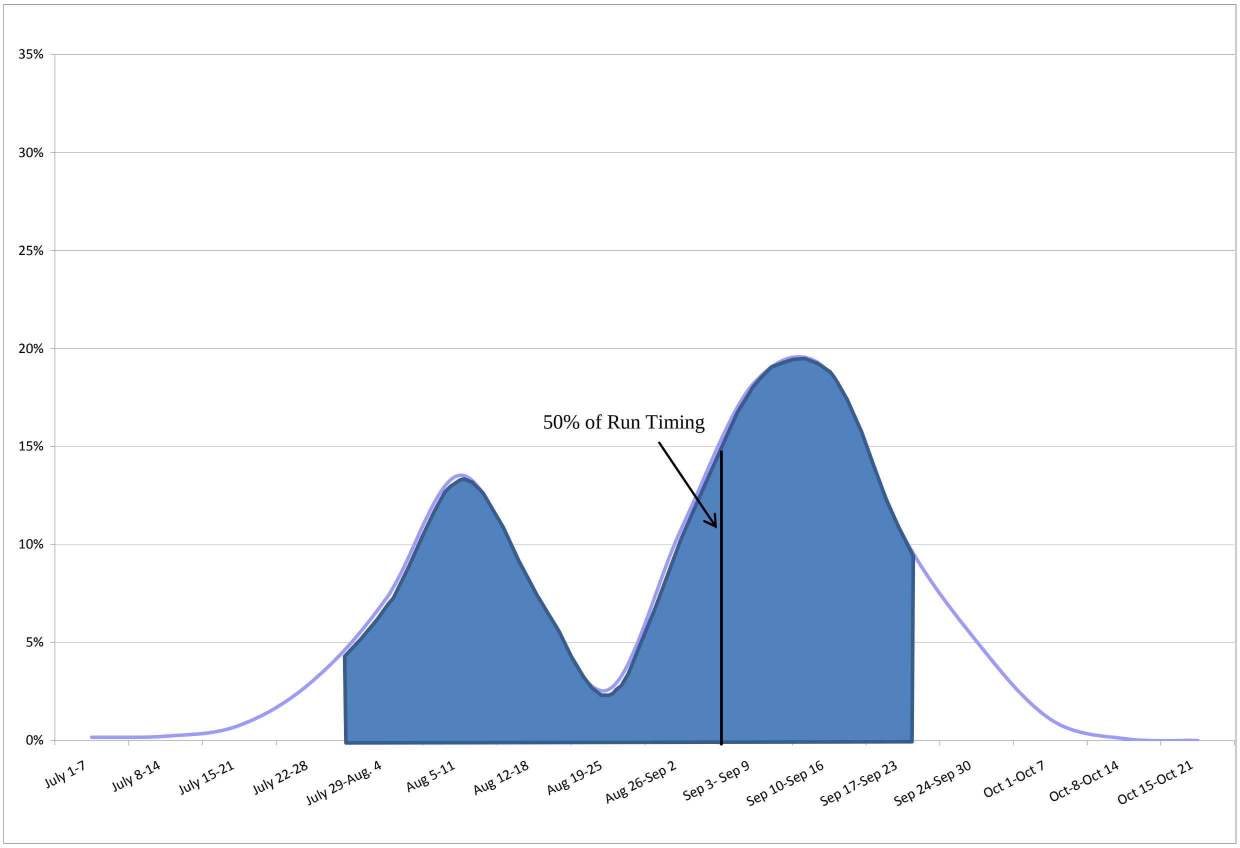

Figure 15. Percentage of chum salmon entering Sawmill Creek, 2002-2009. Black line denotes the average date when 50% of spawning has occurred; blue shading represents the central 80% of average spawning timing.

Effects on Emergence Timing

Water Temperatures

Using the above data, EESC selected three or four parts of each curve to examine the effect of different temperature regimes on egg incubation. These were:

- Pink Salmon: spawning timing of August 1 – October 7 inclusive; selected September 8 as the date for analysis (median of the spawning timing).
- Chum Salmon: spawning timing of July 15 – October 7 inclusive. Selected September 4 as the date for analysis (median of the spawning timing).
- Coho Salmon: spawning timing of October 1 – November 30, inclusive. Selected October 30 (peak of the spawning run) as the date for analysis.

Accumulated Temperature Units

Table 3 provides ATUs for the target and non-target species egg development in Alaska (ADFG; Medvejie 2005; Piper et al. 1986; Sheridan 1962). Although fairly consistent between data sources, where discrepancies existed, temperature units developed in Alaska were used.

Table 3. Accumulated temperature units required to reach important embryonic development stages for common salmonids in Alaska (°C).

Species	Stage	ATU [1/]	ATU [2/]
Chinook Salmon	To eyed stage	280	250
	To hatch	480-540	417
	To emergence	900-1000	889
Chum Salmon	To eyed stage	300-350	417
	To hatch	475-525	611
	To emergence	900-1100	806
Coho Salmon	To eyed stage	220	250
	To hatch	400-500	417
	To emergence	700-800	972
Pink Salmon	To eyed stage	350-400	417
	To hatch	550-650	500
	To emergence	900-1000	806
Sockeye Salmon	To eyed stage	230	500
	To hatch	500-550	667
	To emergence	900-1000	1000
Arctic Char	To eyed stage	200	
	To hatch	475	
	To emergence	700	
Rainbow Trout	To eyed stage	210-240	
	To hatch	300-320	
	To emergence	500-580	
Steelhead	To eyed stage	250-270	
	To hatch	360	
	To emergence	600	

[1/] http://www.sf.adfg.state.ak.us/region2/ie/eggcam/atu.cfm; Sheridan (1962) (for pink salmon), and Medvejie Hatchery data for chum salmon.
[2/] Piper et al. (1986)

Emergence Timing

Table 4 summarizes the results of the analysis of water temperature effects on emergence of pink, chum, and coho salmon fry in Sawmill Creek. **An important assumption in the development of this analysis is that spawning timing would remain the same under the existing and Expansion scenarios. This assumption may not be valid, in that salmon may adjust their spawning timing in response to differences in temperature (Sheridan 1962).**

Figures 16-18 graphically depict ATUs to emergence for pink, chum, and coho salmon, respectively, given the median spawning timing statistic.

Table 4. Summary of spawning timing and fry emergence timing by species for different operational scenarios.

Species	**Spawn Date**	**Existing Project Temperatures (median)**	**Proposed Project Temperatures (invert El 320)**
Pink Salmon	September 8	3/24 – 4/13	3/25 – 4/16
Chum Salmon	September 4	3/9 – 5/4	3/8 – 5/5
Coho Salmon	October 30	5/16 – 6/6	5/21 – 6/5

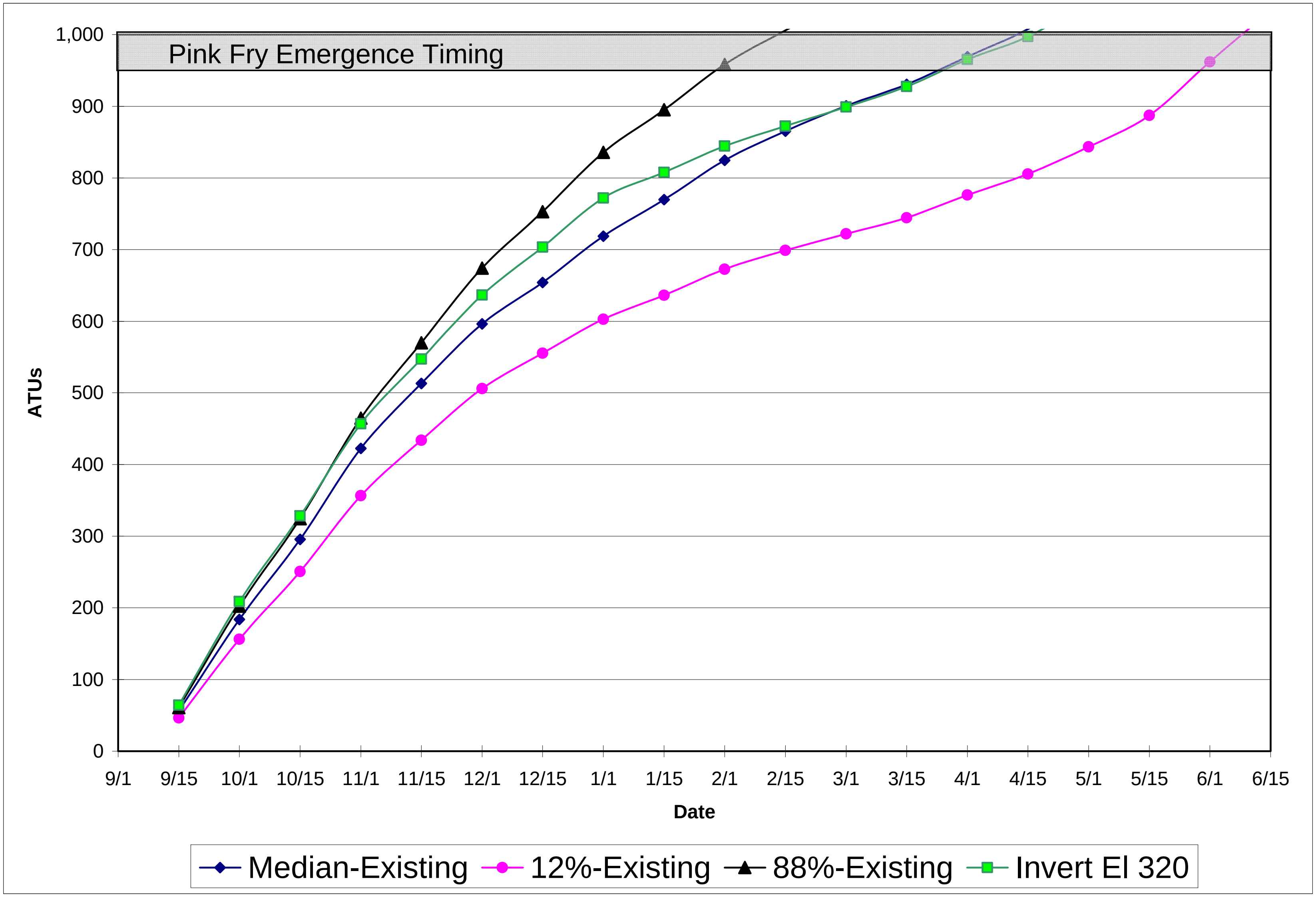

Figure 16. Emergence timing of pink salmon that spawned on September 8 under existing and proposed scenarios. Shaded area is the range of emergence timing (950-1000 ATUs) for pink salmon).

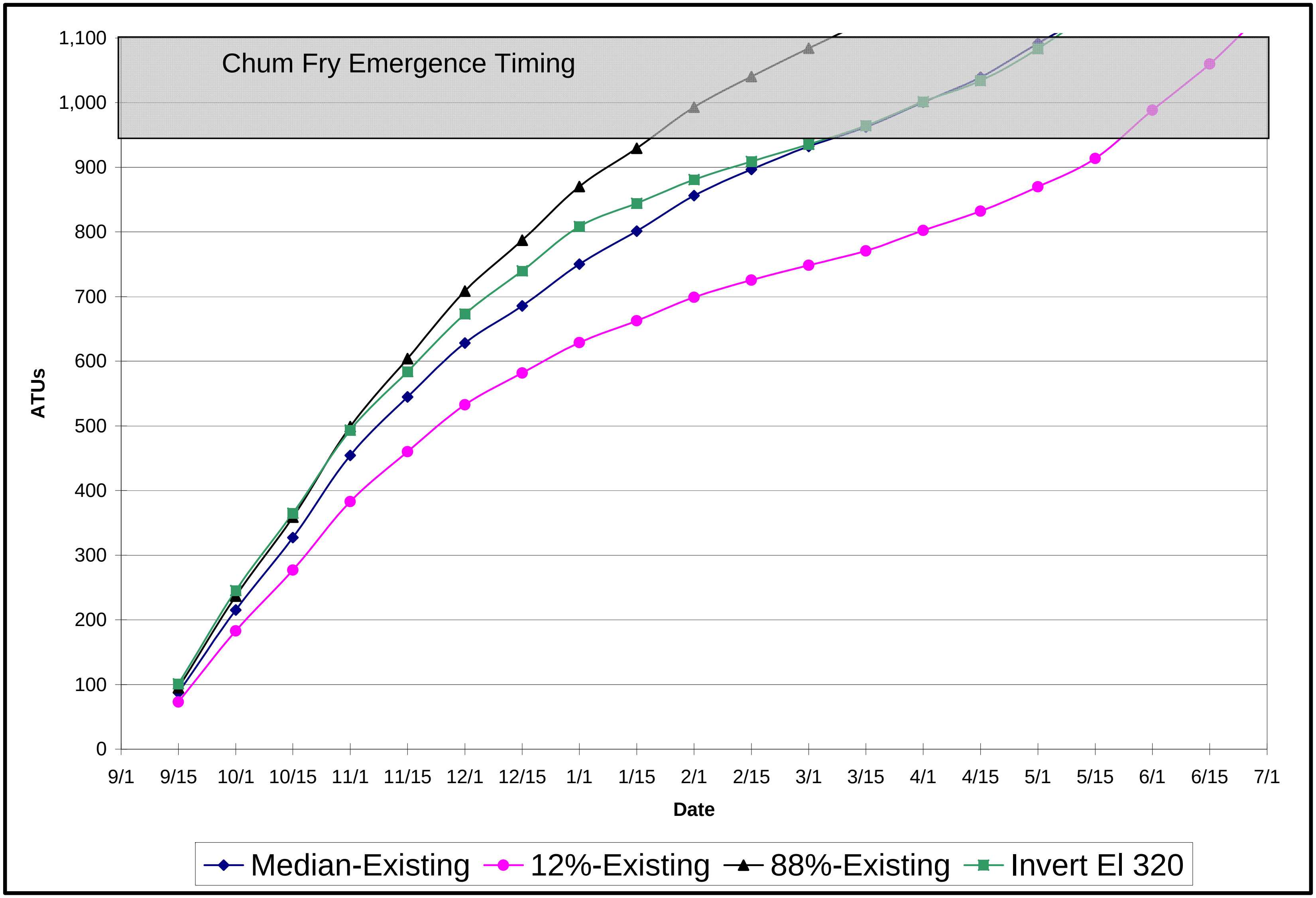

Figure 17. Emergence timing of chum salmon that spawned on September 4 under existing and proposed scenarios. Shaded area is the range of emergence timing (950-1100 ATUs) for chum salmon).

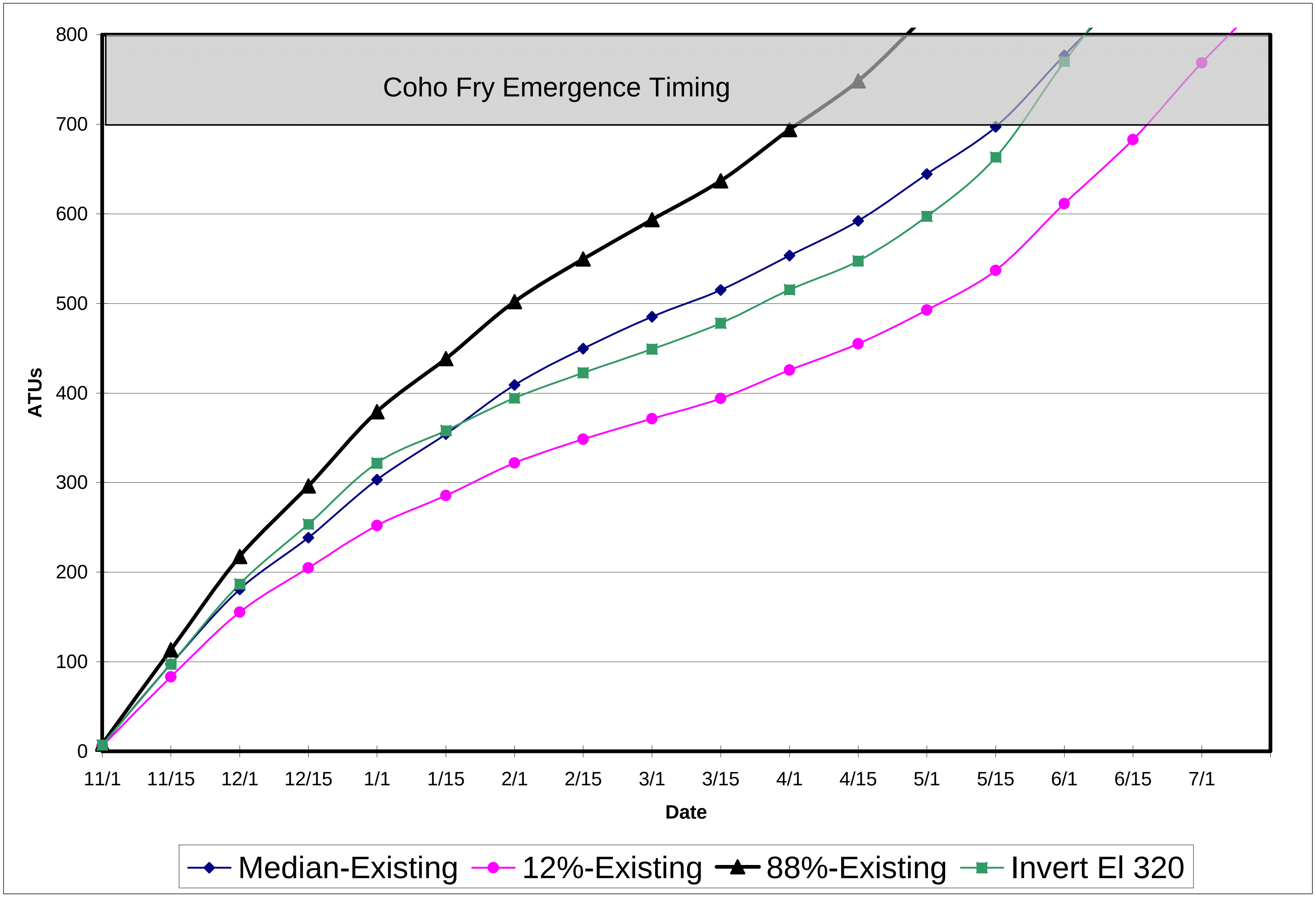

Figure 18. Emergence timing of coho salmon that spawned on October 30 under existing and proposed scenarios. Shaded area is the range of emergence timing (700 – 800 ATUs) for coho salmon).

DISCUSSION AND CONCLUSIONS

The results indicated several trends:

- Given the variability of temperatures found in Sawmill Creek over the past eight years, the median, as well as 12^{th} and 88^{th} percentiles, were modeled. The proposed invert location (at El 320) falls within the range between the 12^{th} and 88^{th} percentile of the current conditions.
- Water temperatures are slightly warmer during the summer months (i.e., prior to November when the lake mixes) for the proposed new invert at El 320 compared to the current condition (median value) with the "rule curve" lake elevation scenario. This accelerates the incubation of any salmonid eggs deposited earlier in the spawning season (i.e., the earlier parts of the pink and chum runs). On average, temperatures were approximately 0.5^{o}C warmer at the Invert El 320 than the existing intake.
- The later that spawning occurs in Sawmill Creek, the less the difference in emergence timing. This is due to decreased water temperatures in September and October, resulting in less difference in ATUs among the scenarios modeled. Using the median spawning timing for pink and chum salmon, and the peak of spawning for coho salmon, the difference between the existing intake and the proposed intake (invert at El 320) ranges from 1 – 5 days. This is well within the natural variability found within the data set for the past eight years. For example, there is one day difference in emergence timing for chum salmon with a spawning date of September 4; there is 3 days difference for pink salmon with a spawning date of September 8.

There are several major assumptions built into the development of these analyses:

- Sawmill Creek temperatures, for purposes of this analysis, are consistent with intake temperatures.
- An investigation of tidal influence and its effect on temperatures at and above the redds and incubating eggs is ongoing. For purposes of this analysis, EESC assumed that there was no effect on water temperature or ATU at this time. If the results of this investigation indicate that the effects of temperature at and above the redds is significant, then EESC will re-run the analysis.
- Comparisons were made by: 1) adjusting water treatment plant temperatures and using these data as a surrogate for existing intake temperatures. This allowed EESC to extend the record of existing temperatures at the intake, and develop median, 12^{th} percentile, and 88^{th} percentile temperature statistics; and 2) averaging the results of the 2005 and 2008 lake temperature data, adjusted for "rule curve" lake operational levels, for proposed intake conditions. There are only two years of data in this analysis; it is assumed that these two years are a fair representation of the variance in annual temperatures. It is also assumed that the rule curve lake elevation scenario is comparable to the synthesized, eight-year record using treatment plant water temperatures.
- 12^{th} and 88^{th} percentile temperatures were not necessarily from the same year; they encompassed the temperatures recorded for that particular date over the 2001-2008 period. These statistics are provided to demonstrate the variability in water temperatures over that period, and to present the potential range in emergence timing from low to high

water temperatures. Given the variability in natural systems, this method appeared appropriate for modeling uncertainty.

- The modeling of incubation and subsequent emergence timing is based upon the assumption that spawning timing would remain the same, regardless of changes in the temperature regime of Sawmill Creek. That may not be the case. Sheridan (1962) notes that a change of 1°F in water temperature will result in a three-day shift in spawning timing; i.e., the warmer the water, the later that spawning would occur, while colder temperatures would result in earlier spawning. When reviewing the spawning timing data of pink and chum salmon in Sawmill Creek, it is notable that spawning timing varied somewhat from year to year. Given the variability in water temperatures during the eight year period of record, empirically it makes sense that the spawning timing of salmon in Sawmill Creek may be the result of adapting to differences in water temperatures.
- ATUs used in this analysis are based upon the temperature units observed in various hatcheries in Alaska and the Pacific Northwest. These ATUs may underestimate the time to emergence in naturally-spawned and incubated stocks, where the fry may stay longer in the gravel before emerging to the stream.

Salmon have been known to alter their spawning timing in response to thermal regimes presented in their natal streams. Sockeye salmon (*O. nerka*) have shown that when temperatures reach critical thresholds, the adult salmon either migrate before the high temperatures and wait to spawn until temperatures have decreased, or wait until the streams cool prior to entering and spawning (Hodgson and Quinn 2002). In the Columbia River, mean and median migration rates of spring Chinook slow significantly when water temperatures increased (Goniea et al 2006). Pink salmon populations can vary considerably in their arrival timing at spawning grounds (Sheridan 1962; WDFW 1992), and some evidence exists for substantial differences in spawn timing within a single river system. Smoker et al (1988) suggest that pink salmon spawn over a period of time, and that strategy of dispersion is used to increase the probability of survival of the species.

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