Water Temperature, River Discharge, and Adult Sockeye Salmon Migration Observations for the Tahltan Watershed, 1959-2012

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WATER TEMPERATURE, RIVER DISCHARGE, AND ADULT SOCKEYE SALMON MIGRATION OBSERVATIONS FOR THE TAHLTAN WATERSHED, 1959-2012

by

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ABSTRACT

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Daily mean water temperature and adult Sockeye migration data were assembled for the Tahltan watershed, British Columbia. Regional air temperature data collected at Dease Lake were statistically related to intermittent water temperature time-series to hind-cast daily water temperature in Tahltan Lake/River for 1954-2012. Discharge data from the adjacent Tuya River watershed were used as an index of Tahltan flow conditions 1962-2011. Peak-over-threshold analyses were applied to reconstructed time-series to review long-term trends in temperature and flow by site.

The climatology remains cool in this northern watershed, with little evidence of high temperature or low flow impacts on adult Sockeye migration. However, high flow impacts may exist. Although approximately 73% of Tahltan Sockeye migration dates occur between discharges of 20-40 cms, highest daily migration rates (>3% per day) occur at ~40-80 cms. Moderate to high migration rates were distributed across the entire water temperature range during the normal migration interval (mid-Jul to late-Aug), with highest migration rates at 16-19°C. Low flow dates (defined as daily average flow < 18 cms) averaged < 20 per year but spiked to ~36 in the 1990s, though almost half were in September, when few Tahltan Sockeye were migrating. Since then, a regional reversion to cooler and “wetter” summers in the 2000s is evident in the frequency of high flow dates (daily average > 80 cms) in July and August, from an average of ~4 per year from the 1960s-1990s to ~8 per year in the 2000s. The length in days of continuous high flow periods currently remains within the long-term average, but the number of high flow periods escalated in the 2000s from a previous average of ~8 to 24 per year.

RÉSUMÉ

Stiff, H.W., Hyatt, K.D., Stockwell, M.M., Etherton, P.M., and Waugh, W.D. 2013. Water temperature, river discharge, and adult Sockeye salmon migration observations for the Tahltan watershed, 1959-2012. Can. Manuscr. Rep. Fish. Aquat. Sci. 3018: ix + 114 p.

Les données sur la température quotidienne moyenne de l'eau et la migration des saumons rouges adultes proviennent du bassin hydrographique de Tahltan, en Colombie-Britannique. Les données sur la température régionale de l'air recueillies à Dease Lake ont été liées statistiquement aux séries chronologiques intermittentes relatives à la température de l'eau afin de prévoir *a posteriori* la température quotidienne de l'eau du lac et de la rivière Tahltan de 1954 à 2012. Des données sur le débit du bassin hydrographique de la rivière Tuya adjacente ont été utilisées comme indice des conditions de débit de la rivière Tahltan de 1962 à 2011. Des analyses des pics de franchissement du seuil ont été appliquées afin de reconstituer les séries chronologiques pour passer en revue les tendances à long terme en matière de température et de débit par site.

La climatologie demeure fraîche dans ce bassin hydrographique situé dans le nord de la Colombie-Britannique et peu de signes indiquent des répercussions de la température élevée ou du faible débit sur la migration des saumons rouges adultes. Cependant, un débit élevé pourrait avoir des répercussions. Bien qu'environ 73 % des dates de migration des saumons rouges de Tahltan aient lieu lorsque le taux de déversement se situe entre 20 et 40 m^3/s, les taux de migration quotidiens les plus élevés (plus de 3 % par jour) se produisent quand le taux de déversement varie entre 40 et 80 m^3/s. Des taux de migration allant de modérés à élevés ont été répartis dans l'ensemble de la plage de températures de l'eau au cours de l'intervalle normal de migration (de la mi-juillet à la fin du mois d'août) avec les taux de migration les plus élevés lorsque la température de l'eau se situe entre 16 et 19 °C. Les jours de faible débit (lorsque le débit quotidien moyen est inférieur à 18 m^3/s) se produisaient en moyenne moins de 20 fois par année, mais ont connu un pic à environ 36 jours par année dans les années 1990, bien que près de la moitié de ces jours aient eu lieu en septembre alors que peu de saumons rouges étaient en migration. Depuis, un retour à des étés plus frais et pluvieux dans cette région au cours des années 2000 peut être constaté dans la fréquence des jours de débit élevé (moyenne quotidienne de plus de 80 m^3/s) en juillet et en août, qui sont passés d'environ 4 par année pendant les années 1960 jusqu'aux années 1990 à environ 8 par année dans les années 2000. La durée en jours des périodes de débit élevé continu demeure actuellement dans la moyenne à long terme, mais le nombre de périodes de débit élevé a augmenté au cours des années 2000, passant d'une moyenne d'environ 8 à une moyenne d'environ 24 par année.

INTRODUCTION

Maintaining healthy and diverse populations of salmon that will support sustainable fisheries in the present and for future generations is the key goal of the Department of Fisheries and Oceans' *Wild Salmon Policy* (Fisheries and Oceans Canada 2005). This goal is advanced by safeguarding the genetic diversity of wild salmon populations, maintaining habitat and ecosystem integrity, and managing fisheries for sustainable benefits.

However, management methods to meet sustainable fisheries and biodiversity objectives are likely to be affected by climate change impacts on the distribution, abundance, and productivity of wild salmon populations (Finney, Gregory-Eaves, Douglas, and Smol 2002). Therefore, conservation, restoration, and harvest management of many wild salmon populations will require improvements in knowledge of the extent to which human disturbance versus natural disturbance events control variations in salmon growth, survival, and production.

Within the general category of natural disturbance regimes or events, annual and seasonal variations in freshwater temperature and flow represent the most common factors exerting a major influence over salmon life history outcomes. Analyses of historical data indicate that significant changes in regional meteorological factors (such as air temperature and precipitation) that directly affect freshwater quantity and quality have already occurred in response to climate change in Canada's Pacific region (e.g., Whitfield and Cannon 2000; Whitfield 2001; Whitfield, Bodtker, and Cannon 2002), and regional climate model projections point to increased changes in these factors through the 21st century (Abdul-Aziz, Mantua, and Myers 2011; Littell et al. 2011).

Recent investigations in the Pacific Northwest and British Columbia have demonstrated regional temperature shifts of about 0.8°C over the past century, with projected temperature increases of 1.5-3.2°C in near-future decades (Mote et al. 2003). Seasonal precipitation has also changed markedly in the recent past (Walker and Sydneysmith 2008), and future projections point to wetter winters and drier summers, with a high likelihood that extreme events involving regional temperature and precipitation will become more frequent (Mantua, Tohver, and Hamlet 2010; IPCC 2007). These analyses also indicate that the magnitude, and, in some cases the direction, of historical and projected climate variability, exhibit sub-regional specificity due to the large and topographically complex areas involved (Walker and Sydneysmith 2008).

Temperature effects on migrating adult Sockeye (*Oncorhynchus nerka*) have been well documented in many river systems in the Pacific Northwest (Nelitz et al. 2007; Salinger and Anderson 2006). Lethal temperatures are reported in the range 21-24°C, and water temperatures in excess of 18°C may affect migration speed, cause timing delays, and alter spatial distribution of Sockeye salmon. Increased water temperature also may result in secondary effects such as increased disease, resulting in pre-spawn mortality (Cooke et al. 2004; Hinch and Martins 2011). Thermal stress has also been found to reduce salmon gamete viability, fertilization rates and decrease egg to fry survival rates (Jensen et al. 2004). Since Sockeye populations may also differ in their thermal tolerances, reflecting local adaptation to conditions over their historic evolution (Farrell 2009; Martins et al. 2012), stock-specific responses to climate variation and change impacts are also possible.

Stream discharge levels may also be associated with variations in migration timing, causing delays, affecting swimming speed, and inducing biological stress during upstream migration of adult salmonids (Hinch and Bratty 2000). The quantitative effects may differ between waterbodies due to unique physical stream attributes (rapids and falls, canyons, etc., but also man-made fishways and weirs) which influence water velocity in key locations along the migratory route. In some cases, low flows may result in physical limits to fish passage; in other cases, high flows may generate velocity barriers that reduce or prohibit upstream migration.

The current report is one of a series intended to consolidate and document historic observations on key life history events and associated environmental variables for relatively data-rich Sockeye and Chinook salmon populations distributed throughout their range in Canada's Pacific region. Although there are many potential uses for these data, the focus of our current work is to develop lifestage-specific models that identify potential associations between salmon production variations and climate variation effects in freshwater and marine ecosystems throughout the eastern rim of the north Pacific.

STUDY AREA

The Tahltan River is found in the 52,000 km^2 Stikine River watershed that arises in the Spatsizi Plateau of the BOREAL MOUNTAINS AND PLATEAU eco-region and NORTHERN CENTRAL UPLANDS hydrological region of northern British Columbia. The Tahltan drainage is situated on the north side of the Stikine valley, approximately 100 km southwest of the town of Dease Lake (Figure 1). The vegetation is a mixed forest of poplar, aspen, and pine; the wet river-bottom sites exhibit dense deciduous growth, but the forest rapidly becomes open pine stands on the slopes above the flood plain (Lough 1980). The soils of the area are a mix of clay and sand, with only a thin layer of topsoil. Evidence of slumps and slope failures exist throughout the drainage. A large slide (2 km across) occurred in 1965 on the Tahltan River, about 4 km from its mouth, where the east slope of the Tahltan valley slid down into the river-bottom.

Tahltan Lake (57°57'N x 131°37'W; 812 m above sea level) is the largest lake in the drainage. It is approximately 7 km long and 0.5–1.25 km wide and has a mean depth of 23 m, a maximum depth of 48 m, a surface area of 492 ha, and a volume of 113.4 x 10^6 m^3 (Hyatt et al. 2005). During Sockeye migration periods, DFO staff operate a counting weir at the lake outlet into the Tahltan River, associated with a flow control structure to retain water for maintenance of summer flows. The Tahltan River flows 55.5 km to the Stikine River, approximately 207 m above sea level at the confluence. The ~600 m drop varies between steep canyon sections and gentle meandering sections with an average gradient of 1.1% (Lough 1980).

Tahltan Lake has an endemic population of Sockeye salmon and has been stocked since 1990. It is an important producer of Stikine Sockeye salmon; wild stocks average

28,000 adults and make up between 17% (in 1988) and 62% (in 1982) of the total Stikine River Sockeye salmon population (Hyatt et al. 2005).[1]

METHODS

DATA SOURCES AND ASSEMBLY

Physical data, including air temperature, precipitation, and water temperature were assembled from existing electronic databases, published documents, unpublished reports and personal records from a variety of government agency sources (e.g., B.C. Ministry of Environment, Environment Canada (including the Water Survey of Canada), Fisheries and Oceans Canada (DFO), and the U.S. National Oceanic and Atmospheric Administration (NOAA).

Air Temperature and Precipitation

Environment Canada's Meteorological Services group maintains an archive of climate, hydrographic and water quality data gathered from both active and inactive stations distributed throughout British Columbia and the Yukon. Station locations and data descriptions can be found at the Environment Canada (EC) climate data archive[2]. This web site was accessed to identify potential sites of air temperature data within the area of interest (Figure 1) for statistical analyses with water temperature data.

For the majority of Canadian climate stations, air temperature measurements are taken from self-registering, maximum and minimum thermometers that record the extremes of each parameter within a 24-hour period. Daily mean temperature, where provided, is defined as the average of the maximum and the minimum temperatures attained during the 24-hour period. These datasets undergo detailed quality-control analysis before posting to the web site.

EC climate station 1192340 (Dease Lake) was selected for climate data retrieval on the basis of (i) the quantity and quality of data available and (ii) proximity to Tahltan watershed (<200 km) (Figure 1), and (iii) the potential to routinely update data from an "active" climate station. In addition, Environment Canada has refined the air temperature and precipitation time-series for this station, as part of the Adjusted and Homogenized Canadian Climate Data (AHCCD) group of climatological stations across Canada[3]. These data incorporate a number of adjustments applied to the original station data to address shifts due to changes in instruments and in observing procedures, thus optimizing their use for climate research, including climate change studies (Vincent et al. 2012).

Precipitation data are included in this compendium of physical data as they are generally correlated with discharge levels and, in some cases, water temperature. They may also be useful for downscaling projected changes in regional precipitation

[1] Other fish species known to be present in Tahltan Lake include bull trout, rainbow trout, coho salmon, longnose suckers *Catostomus catostomus*, slimy sculpin *Cottus cognatus*, and lake chub *Couesius plumbeus* (Hyatt et al. 2005).
[2] Environment Canada Climate Data: http://climate.weatheroffice.gc.ca/climateData/canada_e.html
[3] Adjusted and Homogenized Canadian Climate Data (AHCCD) – See http://www.ec.gc.ca/dccha-ahccd/default.asp?lang=En&n=B1F8423A-1

due to climate variation to the local level from climate model outputs.

Dease Lake daily air temperature (daily maximum, minimum, and mean) and total daily precipitation were made available from AHCCD datasets by ENVIRONMENT CANADA for the period September 1944 to December 2012.[4]

Water Temperature

Water temperature data from the Tahltan Lake weir at its outlet into the Tahltan River

Figure 1) were made available by DFO staff (unpub. data; Pete Etherton, DFO STOCK ASSESSMENT DIVISION, Whitehorse, Yukon), for the years 1984-2011.[5] Tahltan Lake water temperatures have been recorded hourly by automated data-loggers since 1999. Prior to that, water temperatures were taken both day and night at regular intervals using a hand-held alcohol thermometer; temperature estimates were based on the average of the daily minimum and maxima.[6] Due to the proximity of the instrumentation site to the lake outlet, it is assumed that lake surface temperatures are equivalent to Tahltan River temperatures downstream of the weir.

River Discharge Data

Flow data were not available for the Tahltan watershed. As an indicator of flow conditions in the Tahltan system, mean daily discharge data (m^3/s or cms) were obtained from the web archives of the WATER SURVEY OF CANADA (WSC)[7] for an active hydrological station in the adjacent watershed, Tuya River (Station 08CD001, 58°04'20"N x 130°49'27"W). The Tuya River drains an area of 3,550 km^2, and flows into the Stikine approximately 8 km upstream of the Tahltan (Figure 1). Tuya River discharge data were downloaded for the years 1962-2011.

Sockeye Migration Data

Daily Sockeye escapement estimates (1959-2012) stocks were provided by FISHERIES AND OCEANS CANADA (unpub. data; Pete Etherton, DFO STOCK ASSESSMENT DIVISION, Whitehorse, YK). These data are collected in-season as daily counts at the Tahltan Lake weir, and finalized post-season by DFO personnel.

Data issues identified in the daily migration data include:

1. No daily counts were available for 1963.
2. A landslide in the Tahltan River in 1965 blocked salmon migration; a helicopter was deployed to transport fish around barriers. Due to uncertainty in the daily counts, 1965 data were omitted from migration timing analyses.
3. In 1966 a velocity barrier in Tahltan River (Decheeka Falls at low flows) likely

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[4] AHCCD Licence Agreement: This work contains data licenced "as is" under the Government of Canada Open Data Licence Agreement. Such licensing does not constitute an endorsement by the Government of Canada of this product.

[5] Water temperature datasets for other locations in the Stikine drainage (e.g., Tahltan River near the Stikine (bridge crossing), Little Tahltan River, lower Stikine) not used in this analysis but documented in the FRESHWATER ENVIRONMENTAL VARIABLES DATABASE, are listed in Appendix A.

[6] Similar data were recorded for 1973-1983, but were not available in electronic format.

[7] ENVIRONMENT CANADA – WATER SURVEY OF CANADA website: http://www.wsc.ec.gc.ca/applications/H2O/HydromatD-eng.cfm.

delayed adult migration into the lake (pers. comm., P. Etherton, DFO).

4. The Tahltan Sockeye stock has been augmented by hatchery releases, with hatchery-origin adults arriving in return years after 1992 (Hyatt et al. 2005).

DATA ANALYSIS

Basic statistical analyses were used to document and describe the available data, establish relationships between regional air and site-specific water temperature datasets, and define inter-site relations for both water temperature and discharge to infill missing observations. STATISTICAL ANALYSIS SOFTWARE (SAS® Version 9.2) was used to assemble imported data from MICROSOFT EXCEL® spreadsheets, analyze the data, and export the data to the MICROSOFT ACCESS® FRESHWATER ENVIRONMENTAL VARIABLES DATABASE[8] for storage.

Migration Data

To standardize the annual adult migration time-series for inter-year and inter-stock comparisons, daily percentages of Tahltan Sockeye migrants were calculated relative to the total annual stock escapement. Annual plots of daily and cumulative migration rate (% relative to the annual total escapement) were generated, overlaid with historical mean and maximum daily migration rate by Julian day-of-year, for inter-annual migration pattern comparisons.

Univariate statistical analyses were used to characterize the distributions of migration effort by adult Sockeye. Properties examined included central tendency (mean, median, modal date of passage), scale (range, variance, extreme values and outliers), and shape (skewness, kurtosis) of annual migration effort distributions at the location of interest. Median (50^{th} percentile) and 75^{th} quartile values of the historical datasets were calculated to establish low ($0\text{-}75^{th}$ percentile), medium ($75\text{-}90^{th}$ percentile) and high ($90\text{-}100^{th}$ percentile) categories for daily migration rate classification. Quartiles of the Julian dates of migration in the historical data were used to categorize daily migrant data into early ($0\text{-}25^{th}$ percentile), middle ($25\text{-}50^{th}$ percentile), and late ($75\text{-}100^{th}$ percentile) observations. Daily migration rate (%) data were transformed using the arcsin function to normalize the percentage data where appropriate for parametric analyses (Sokal and Rohlf, 1969).

River Discharge

Univariate statistical analyses were used to characterize daily discharge data with respect to central tendency (mean, median, mode); scale (range, variance, extreme values and outliers), and shape (skewness, kurtosis) of the distributions from the Tuya River. Deciles and quartiles were derived for the migration months (July-September) to identify low ($< 25^{th}$ percentile), moderate ($25\text{-}75^{th}$ percentile) and high ($75\text{-}100^{th}$ percentile) categories for daily discharge. We used plots of the historic mean and variance of daily discharge to characterize the flow patterns during the principal adult migration period (July-September).

A forward lag of 10 days was applied to the discharge data before merging with migration timing data to match Sockeye weir counts with flow conditions existing when

[8] MICROSOFT ACCESS® relational database, available from the authors.

the fish first entered the Tahltan River, assuming a fish swimming speed of 5.9 km/day along the 55 km Tahltan River. Thus, Sockeye counts on August 11th at the weir would be matched with Tuya River mean daily discharge on August 1st, assuming no significant temporal differences between Tuya and Tahltan outflows since the Tuya WSC station is located a few kilometers from the Tuya/Stikine confluence.

Water Temperature

Observed water temperature data are classified as three categories based on temporal data resolution:

- Class 1: Automated date-specific data summarized from multiple samples evenly spaced over a 24-hour period;
- Class 2: Daily mean values, derived from automated data summarized from date-specific samples, though of unknown frequency and/or interval; and
- Class 3: Instantaneous and possibly routine date-specific “spot” samples, taken at a specified or unspecified time of day, but most likely during daylight hours, and therefore systematically biased.

Class 1 datasets provide the highest resolution and least potential bias, and are therefore the most appropriate data for statistical use in site-specific air-to-water and inter-site water-to-water temperature relationships. Class 2 and Class 3 data may be used to extend these Class 1 time-series, but only if the data are found to be statistically equivalent, using parametric comparisons tests (e.g., ANOVA, paired t-tests).

Water temperature data “cleanup” consisted of examining descriptive statistics and graphic output to identify anomalous data and outliers, in conjunction with a review of field notes regarding data-logger installation and removal dates and times. All anomalous data were retained in the database but flagged for omission (i.e., OMIT field = YES) from data analyses.

Water temperature data were pre-summarized by site and date[9], and organized for import into the MICROSOFT ACCESS® FRESHWATER ENVIRONMENTAL VARIABLES DATABASE for storage, and into SAS® programs for analysis.

Univariate statistical analyses were used to characterize the daily mean water temperature (MWT) observations by location of interest for the period of record with respect to central tendency (mean, median, mode, etc.), scale (range, variance, extreme values and outliers), and shape (skewness, kurtosis) of the associated distributions.

A subset of the selected daily MWT time-series was used with the selected mean air temperature (MAT) index to calibrate site-specific air-to-water temperature regression relations, described below. The remaining water temperature data were used as a validation dataset to test the goodness of fit of air-to-water temperature models.

A threshold exceedance analysis, tallying the decadal mean monthly frequency of

[9] MICROSOFT EXCEL® spreadsheet: Tahltan Lake Water Temperature Summary v12.08.21.xls (source: Pete Etherton, DFO Stock Assessment Division, Whitehorse YK).

dates for which the reconstructed MWT temperature index exceeded 18°C, was used to examine site-specific trends in water temperature conditions during adult migration.

Air Temperature

Although MWT records are available for Tahltan Lake back to the mid-1980s, the relatively short length of the dataset and discontinuities in the timeline render it inadequate for accurately assessing baseline conditions for climatological analysis. Reconstruction of a long-term freshwater temperature dataset suitable for climate analyses is contingent on a set of daily mean air temperature records spanning at least 30 years, and more for historic trend analyses.

Various studies have demonstrated that variations in local air temperature are generally sufficient to explain as much as 80% of the seasonal variations in local daily mean water temperature utilizing either linear or nonlinear regression models (Mohseni and Stefan 1999; Hyatt and Stockwell 2003; Pilgrim, Fang and Stefan 1998; Stefan and Preud'homme 1993; Webb and Nobilis 1997). Regression relations between air and water temperature are known to be accurate at moderate air temperatures (i.e. 10-20°C) (Mohseni and Stefan 1999). Because mean temperatures during adult Sockeye migration in the Tahltan watershed generally fall within this range, reasonable predictive relationships could be expected for freshwater temperatures as a function of regional air temperature.

The best predictive air-water relationships exist for associations between daily mean water and multi-day mean air temperature (Hyatt and Stockwell 2003; Webb and Nobilis 1997). Centered moving averages (i.e., mean temperatures from *Date – (n-1)/2* to *Date + (n-1)/2*, where *n* is the number of days) center the multi-day means such that peaks and troughs more accurately align with the flux in the original daily MAT time-series.

DEASE LAKE MULTI-DAY MEAN AIR TEMPERATURE INDEX

Adjusted and homogenized data from the *Dease Lake* AHCCD climate station were used as the reference air temperature time-series. Correlation analysis was used to identify the most appropriate multi-day moving average index (*n* = 3, 5, 7, 10 days), by comparing Pearson correlation coefficients for each index and the original regional air temperature variable (i.e., *n* = 1) with daily mean water temperatures from Tahltan Lake for a representative subset of the available years of water temperature data, designated as a calibration dataset. Selection of data for the calibration dataset was based on subjective and statistical examinations of the annual air and water temperature time-series plots and annual regression relationships. Years with consistent and apparently unbiased data-logger readings associated with a maximum range of temperature values for both warming and cooling periods[10] were preferred for characterizing the all-year air/water temperature relationship. The remaining data were used for validation of statistical relations.

The multi-day *Dease Lake* CMAT index with the lowest adjusted AKAIKE INFORMATION CRITERION (AICc) and the highest Pearson correlation coefficient for calibration data

[10] Derivation of the seasonal flux point between warming and cooling "seasons" is described in the text below.

was used for subsequent air/water temperature regression relations.

A threshold exceedance analysis, tallying the decadal mean monthly frequency of dates for which the original daily mean air temperature exceeded 20°C, was used to examine trends in high temperature events.[11]

Air/Water Temperature Relationships

Linear and logistic air/water temperature relations were derived from calibration data water temperature time-series against the selected Dease Lake multi-day air temperature index. Linear relations were derived based on the ordinary least-squares model:

Equation 1: $T_w = \alpha + \beta * T_a$; where

T_w is the estimated water temperature;

T_a is the air temperature index; and

α is the y-intercept and β is the regression coefficient.

However, due to the effects of freezing at low air temperatures and evaporative cooling at high temperatures (hysteresis[12]), the true air/water temperature relationship does not remain linear at the full range of regional air temperatures, and a linear model will therefore misrepresent site MWT at the both lower and upper temperature extremes, depending on certain waterbody characteristics. The large surface area and volume of lakes and large rivers has a major influence on the differential rates of seasonal heat exchange, whereas streams and creeks located upstream of major water bodies may exhibit little or no hysteresis effects, due to their small surface area and continuous flushing activity (Hyatt and Stockwell 2003).

An alternative approach involves fitting a nonlinear logistic curve to the air/water temperature data (Mohseni et al. 1998):

[11] Mote et al. (2003) suggest a monthly average air temperature of 20°C to be a dependable upper threshold for identifying suitable salmon habitat.

[12] Hysteresis: the heat storage properties of water. Hysteresis is a measure of the seasonal effect of the differential rates of heat exchange between air and water as the spring-to-summer period warms up and the fall-to-winter period cools down (Wetzel 1975). The observed pattern of hysteresis is related to the complex physics of air-water heat exchange processes. These involve evaporative cooling of the lake in the late summer-to-fall, thermal de-stratification in the fall-to-winter; rapid, wind-induced, mixing of surface and deep waters through the winter, and initiation of thermal stratification and evaporative cooling once again in the spring-to-summer season.

Equation 2*:* $T_w = \mu + (\alpha - \mu) / (1 + e^{\gamma (\beta - T_a)})$; *where*

T_w is the estimated water temperature;

T_a is the measured air temperature index;

α is the estimated maximum water temperature;

μ is the estimated minimum water temperature;

γ is a measure of the steepest slope of the function; and

β represents the air temperature at the inflection point.

When the function is derived from a comprehensive range of site air and water temperatures, and hysteresis is not a factor, the logistic regression method can integrate the full cycle of the seasons into a single mathematical relationship.

The most appropriate form of the logistic model may depend on the minimum temperature range (parameter μ) for the waterbody. For the large lakes and rivers in coastal ecosystems, which do not freeze in winter, minimum water temperatures remain above zero (i.e., $\mu \neq 0$), and parameter μ is estimated from the data, as in Equation *2* above. Where waterbodies freeze, minimum water temperatures can reach 0°C; thus the parameter μ, should be set to zero (Mohseni and Stefan 1999), as in *Equation 3* (other parameters are defined as in Equation *2*):

Equation 3*:* $T_w = \alpha / (1 + e^{\gamma (\beta - T_a)})$

In addition, the presence of significant hysteresis indicates that the relationship between air and water temperatures is not equivalent throughout the year, and that separate warming and cooling season equations are better suited for predictive purposes than a single function derived from the entire time-series. All-season model fits were therefore contrasted with models fit to the warming- and cooling-season components (as distinguished by the week of maximum air temperatures in the watershed), to determine the degree of hysteresis and whether separate seasonal models would provide the best estimates of site water temperatures.

For linear models, the significance of a season effect, and/or an interaction effect between the air temperature index and the season category in the all-season calibration dataset, was used to either indicate a significant difference in the slope or in intercept coefficients, which would be indicative of hysteresis, and the need for separate seasonal models.

For nonlinear models, goodness-of-fit is assessed based on the *Nash-Sutcliffe Coefficient* (NSC), calculated as (Mohseni and Stefan 1999):

Equation 4*:* $NSC = 1 - (\Sigma (T_{sim} - T_{obs})^2 / \Sigma (TBAR_{obs} - T_{obs})^2)$; *where*

T_{sim} = estimated water temperature;

T_{obs} = observed water temperature; and

$TBAR_{obs}$ = mean observed water temperature.

The degree of hysteresis in a waterbody is assessed from a comparison of the NSC value for the all-season model versus the (averaged) NSC values for the separate warming and cooling season models:

Equation 5: $Hysteresis = [(NSC_w + NSC_c) / 2 – NSC_{all}] \geq 0.01$; *where*

NSC_w = NSC for warming season;

NSC_c = NSC for cooling season;

NSC_{all} = NSC for all seasons combined;

If the averaged seasonal NSC is larger (i.e., ≥ $\underline{NSC_{all}}$ + 0.01) than the NSC of the one function fit to the entire dataset, hysteresis exists (Mohseni et al. 1998) indicating that separate warming and cooling season equations are better suited for predictive purposes than the single function derived from the entire time-series.

Employing two separate equations to model a waterbody's temperature may result in a discontinuous "step" event in the daily time-series at the seasonal transition date where the two equations "meet". This may be due to insufficient data in the upper thermal range for both seasonal models. The step effect may be reduced by selecting calibration data that contain representative observations at the upper end of the temperature range for both warming and cooling seasons, or by "tuning" the date of the seasonal transition to distribute available observations in the high temperature range more evenly between seasons. In extreme cases (where modeled seasonal water temperatures differ by 1°C or more at the transitional date), the average of the seasonal model estimates may be used to "smooth" the transition between the last date of the warming season, and the first date of the subsequent cooling season. Alternatively (for nonlinear models), it may be useful to bound the α coefficient (corresponding to the maximum water temperature) in one or both seasonal models to align predicted values at the upper temperature extreme.

Water Temperature Time-Series Reconstruction

Model Calibration

Linear and logistic regression relations described above were developed using site-specific daily mean water temperatures (MWTs) from the sub-daily (Class 1) dataset for Tahltan Lake as a function of the regional air temperature index (7d centered *Dease Lake* MAT variate).

Calibration data were selected based on examination of annual air and water temperature time-series and correlation plots. A minimum of 5 years of representative data including sufficient observations at the upper end of the temperature range for both warming and cooling seasons were obtained from source MWT datasets partitioned as follows:

Reference Site	Calibration Years	Validation Years
Tahltan Lake	1992, 1994, 1996, 1997, 1999, 2000, 2002, 2004-2006, 2008-2010	1984-1989, 1991, 1993, 1995, 1998, 2001, 2003, 2007, 2011, 2012

To determine whether seasonally-distinct regression relations were required, the air/water temperature data for each water body were checked for hysteresis. To detect hysteresis, separate functions were fitted to the air and water temperature data in each of the warming and cooling seasons. Since the Tahltan site experiences freezing temperatures, parameter µ was set to zero in the logistic models, as in Equation *3*.

The warming and cooling seasons were first distinguished from each other by determining the seasonal temperature "turn-around point" (the timing of the winter season turn-around point was not required for the purpose of this analysis)[13]. The seasonal transition dates were obtained by plotting weekly mean daily water temperatures as a function of weekly mean daily air temperatures, and connecting the points chronologically. The week associated with the maximum mean air temperature, indicating the ending of the warming season (and the starting point of the cooling season) was converted to day-of-year to pinpoint the seasonal turn-around date.

Site-specific hysteresis effects were then assessed as described above using all-year all-season data for both linear and logistic models. If hysteresis was detected in either case, linear and logistic models were then fitted to the all-year data for each of the warming and cooling seasons separately.

Model Validation

Site-specific linear and nonlinear air/water regression parameter estimates were tested for statistical significance, and applied to the *Dease Lake* air temperature index to estimate reference site daily MWT for the period of record of air temperature data. Modeled MWTs for the validation dataset were correlated with observed reference site water temperature data graphically and statistically as a measure of goodness-of-fit. The all-year Pearson and Spearman correlations for the validation years were compared between model types to determine whether linear or logistic outputs best simulated observed MWTs at the lower Tahltan River reference site.

Exceedance Analyses

Water Temperature

Modeled water temperature estimates were analyzed for the frequency of dates in each year and month (July-September) for which mean daily water temperature exceeded a threshold value of 18°C ($POT_{18°C}$; i.e., peak-over-threshold > 18°C), and summarized by decade.

In addition, the frequency of annual periods in which water temperature continuously exceeded this value, and the mean duration (days) of these periods, were derived for each year. These data were summarized by decade to review trends in the frequency and duration of continuous periods of potentially stressful temperature conditions.

River Discharge

For discharge, exceedance analyses for both low- and high-flow dates are of interest. Thus the frequency of dates for which the observed flow rate in the Tuya River was either less than the lower 25th percentile of summer flows, or greater than the upper 95th percentile of summer flows were calculated by year and month (July-September),

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[13] For linear models, an additional "winter" season was defined (November 25th to March 10th), encompassing the cold-weather months when changes in air temperature are not reflected in changes in water temperature due to hysteresis effects at low temperature extremes. These data were omitted from this analysis.

and summarized by decade. In addition, the frequency of annual periods in which flow levels continuously remained below/above the lower/upper thresholds, and the mean duration (days) of these periods was derived for each year. These data were summarized by decade to review trends in the frequency and duration of continuous periods of potential flow barriers to upstream migration.

Migration, Temperature and Discharge

Daily mean water temperature and discharge time-series were merged with daily Tahltan Sockeye migration rate data for co-variation analyses, after applying a date lag of 10 days to the discharge data (i.e., subtracting 5 days from the discharge date to capture the daily flow conditions experienced by the Sockeye that arrived at the weir 10 days later).

To characterize the temperature and discharge conditions during historical stock migration, frequency distributions of observed active migration dates (i.e., filtered for non-zero migration rates) at varying levels of temperature, discharge, and both temperature and discharge, were generated. By simply tallying the number of dates in the historical dataset at which some migratory activity occurred, these plots indicate the general distribution of temperature and discharge conditions that were available during the migratory period.

A similar frequency distribution of active migration dates, weighted by the daily migration rate, indicate how much migration occurred at a given temperature, discharge, or temperature-and-discharge combination. In contrast to the simple distribution of dates of migration, these plots indicate which temperature and discharge conditions are associated with highest migration rates (i.e., presumably most favourable to salmon migration), and, by extension, the thermal and hydrological limits (if any) that differentiate high versus low rates of migration.

Environmental “limits” derived from the weighted frequency analyses were used to set threshold values for calculation of daily deviations in the modeled water temperature and discharge time-series, and combined with deviations in daily Sockeye migration rate on annual anomaly plots to examine the pattern of daily variation in each time-series in relation to each other.

The 50th percentile migration rate was used to define whether a daily migration rate value is “high” (positive) or “low” (negative) in relation to the zero-line. Thus, the anomaly threshold (“zero-line”) for migration data was set to the 50th percentile of the historical daily migration rate (0.75% of annual total escapement). The migration threshold value was subtracted from the historical daily migration rates to derive the anomaly for daily migration.

The water temperature threshold was set to 17°C, based on known thermal barrier levels for migrating salmon. Values of 18 and 80 cms were used as the zero-line threshold for discharge to review patterns of migration in relation to low and high flows. The difference between these thresholds and the daily mean values were plotted on a common axis (discharge rates were factored by 0.1 to fit on the y-axis).

RESULTS

SOCKEYE MIGRATION DATA

Tahltan Sockeye salmon migration typically commences in mid-July and terminates by late August (
Table 1), with all-year time-to-50% (TT50%) occurring approximately July 28-30th (Figure 2). Run timing varies widely, however – early run timings in 1967, 1977, 1982, 1983, 2009, and 2011 were 90% complete by late July or early August, while some late runs (1960, 1972, 1978) were only 90% complete by the end of August. Non-zero migrant counts averaged approximately 587 ± 1122 fish per day; maximum daily counts have surpassed 10,000 fish (1985, 1996). The median fish passage over the years has been 155 fish per day.

The corresponding all-year mean daily migration rate is 2.3% of total annual escapement. Annual peak daily rates are typically in the range of 6-10%; as much as 33% of the annual escapement occurred on one day in August 1961 (
Table 1). Annual time-series of Tahltan Sockeye daily migration rates (%) are plotted in Appendix C, along with mean and maximum daily migration rates across all years 1959-2012.

DISCHARGE DATA

Observed daily mean discharge data obtained from WSC archives are summarized for the Tuya River station for the active migration period (July-September) in

Table 2 and plotted in Appendix C. Median flow rates during Sockeye migration periods (1962-2011) were ~28 cms, but ranged from a low of 10.5 cms in 1998 to a high of 62.5 cms in 2007 (Figure 3, Figure 4). Low flow years occurred in 1965, 1978, 1990, 1996, 1998, 2004, and 2010 (median flow < 18 cms, i.e., < 25th percentile). High flow years during Sockeye migration occurred in 1962 (peak flow 405 cms); 1980 (peak 259 cms) in addition to 2007 (peak 320 cms).

WATER TEMPERATURE DATA

Tahltan Lake and River

The annual time-series for water temperature data obtained at the Tahltan Lake weir are displayed in Appendix C, and condensed in Figure 5. and summarized for the months of peak migration (July-August) by year in Table 3. Average temperatures during migration were 15.3°C, with intermittent periods of 2-3 days duration surpassing 20°C throughout the month of August (Figure 6, Figure 7).

The warmest year on record was 2004 (mean water temperature 18.0°C; maximum 20.7°C). Water temperatures were also above average in 1987, 1990, 1994, and 2005.

WATER TEMPERATURE TIME-SERIES RECONSTRUCTION

Seasonal Turn-Around Point

The mid-year seasonal turn-around point for all reference sites was in week 30 – approximately day 210, or July 29th – based on maximum mean weekly air and water temperatures (Figure 8). The "warming season" therefore extends to July 29th, followed by the "cooling season" from day 211 – i.e., July 30th – to the end of the time-series in mid-to-late September.

Multi-Day Air Temperature Index

The multi-day *DEASE LAKE* air temperature index that best correlated with all-year daily mean water temperature was identified as the 7-day centered moving average air temperature index (7d-CMAT). The 7d-CMAT scored the highest correlation for lower Tahltan water temperatures in the cooling season, relative to the 3d-, 5d-, 10d-, and simple daily MAT air temperature indices (Figure 9). The 7D-MAT index provided the best trade-off between maximizing correlation and minimizing the effects of multi-day averaging on predictive power at longer period lengths. Thus, the *DEASE LAKE* 7d-MAT was used for subsequent air/water temperature analyses (Appendix C).

Model Calibration and Validation

Logistic and linear air/water temperature models were parameterized using a subset of the available data for calibration, and tested for goodness-of-fit against the remaining years for model validation. Calibration and validation data years, and the number of observations available for analyses by season, are identified for the Tahltan watershed reference site in Table 4.

Hysteresis was detected for logistic relations, indicating that the site-specific air/water temperature relationships were best modeled using separate seasonal models (Figure 10, bottom). Seasonal model parameters, 95% confidence limits, and NSC goodness-of-fit coefficients are listed in Table 5.

Linear regression model output for seasonal air/water temperature relationships and calibration data are provided in Table 6. Type III sum of squares for a season effect and a season/air temperature interaction effect are highly significant, indicating again, that hysteresis exists and that seasonal models provide the best fit to the data (Figure 11).

Predictive estimates of daily mean water temperature were generated for each model type and season for the extent of the air temperature record. Correlation analyses between observed and predicted daily MWT values for the validation years were used to compare the predictive skill of logistic versus linear models. Season-specific Pearson (least squares) and Spearman (rank) correlation coefficients for the validation data are contrasted in Table 7. Validation data correlations indicate that the two model types are statistically-equivalent in their skill at predicting Tahltan Lake water temperatures, likely due to short time-series, mostly in the linear range of air/water temperatures (e.g., logistic fit for the cooling season dataset appears virtually linear)..

As the nonlinear model has a predictive advantage at temperature extremes, the seasonal logistic model parameters were selected as the best estimators of daily mean water temperature at each site, and were used to reconstruct historical daily water temperature estimates for the period of available air temperature data. A subset of the validation data years with observed and modeled MWT output, along with daily MAT and the 7-d MAT index, are plotted in Figure 12 and Appendix C.

TEMPERATURE, DISCHARGE AND MIGRATION

Trends in Air and Water Temperature

Mean regional air and estimated Tahltan River water temperature during the Sockeye migratory period (July – September) have been trending in a slightly positive direction since 1959 (Figure 13). Average water temperature conditions during this period remain below 15°C, but are rising at a rate of 0.12ºC per decade ($b = 0.012$; $r = 0.09$, $P < .0001$).

Trends in Discharge

The long-term trend in observed daily mean discharge in Tuya River is also weakly significant ($b = 0.06$; $r^2 = 0.001$; $P = 0.04$) for the migratory months (Figure 14). This corresponds to an increase in average flows during the migratory period of approximately 0.6 cms per year.

Migration in Relation to Temperature and Discharge

An unweighted tally of non-zero migration dates indicated that approximately 73% of the historic migration dates occur at discharges of 20-40 cms (Figure 15). Weighting the frequency distribution by the daily migration rate, however, indicated that flow rates up to 30 cms are not associated with the highest rates of migration (> 2.8% per day). Ignoring rare events, the highest daily migration rates (>3% per day) occur at ~40-80 cms, are rare between 90-120 cms, and migration rates are significantly reduced above 120 cms (Figure 16).

The majority of migration dates (80%) were characterized by water temperatures of 14-17°C (Figure 17). As these temperatures are well within the biological preferences of migrating Sockeye, moderate to high migration rates were distributed across the available thermal range, with no significant differences attributable to temperature (Figure 18).

A weighted two-way frequency distribution based on combined flow and temperature ranges showed that highest migration rates for Tahltan Sockeye occurred between 16-19°C and at Tuya River station flow rates of 40-80 cms (Figure 19).

For anomaly plots (Appendix D), the 50th percentile of historical migration rates was used to define whether a daily migration rate value was “high” (positive) or “low” (negative) in relation to the zero-line. Thus, the anomaly threshold (“zero-line”) for migration data was set to 0.75% of annual total escapement, which was subtracted from the individual historical daily migration rates to derive the anomaly for daily migration. The water temperature threshold was set to 17°C, as temperatures above 18°C are rare. Since high flows may be more likely to impact adult migration than low flows in this system, a value of 80 cms (at Tuya River) was used as the zero-line threshold for discharge, corresponding to the upper 95th percentile of summer flows. The difference between these thresholds and the site-specific daily mean temperature and discharge estimates were plotted on a common axis (discharge rates were factored by 0.1 to fit on the y-axis).

Review of anomaly plots with zero-lines for temperature and discharge based on above results (Appendix D) indicates that insufficient data exist to determine what exact temperature level might constitute a critical threshold between low and high migration rates for Tahltan Sockeye. However, a few instances support the generally-accepted threshold of 17-18C, when higher temperatures appear to be associated with lower migration (e.g., 1962; 1971; 1976; 1984; 1989; 1990; 1994; 1999; 2004; 2005; 2009). However, none of these cases are clearly associated with insignificant migration – just reduced migration – and/or may also be equally the result of coincident high temperature and low migration rates near the end of the run (with the exception of 1962). Flows above 80 cms are rarely associated with high migration – many years indicate a coincident drop in discharge below that level and a commencement of migration (e.g., 1974; 1976; 1977; 1980; 1988, 2001; 2003). A few of these demonstrate high flows in the middle of the Sockeye run associated with a stop/start migration pairing (e.g., 1980; 2001). A notable exception to this rule occurred in 2007, where peak flows coincided with peak Sockeye counts.

Air Temperature Exceedance Analyses

A frequency analysis of regional daily mean air temperature indicates that the cumulative total number of $POT_{>20°C}$ dates per year has averaged less than 1 day per year in the past few decades, up from zero prior to the 1990s (Table 8, Figure 20). A continuous period of multiple $POT_{>20°C}$ dates was first recorded in 2009, from July 28th – 31st (Figure 21).

Water Temperature Exceedance Analyses

A similar frequency analysis based on estimated daily mean water temperature indicated that the cumulative total number of $POT_{>18°C}$ dates per year is also negligible, with no evident trend (Figure 22). The combined average number of $POT_{>18°C}$ dates across all migration months (July-September) has fluctuated around 0-2 days per year on average, mostly in August (Table 9).

The duration of $POT_{>18°C}$ events during Sockeye migration may be in flux. Average length of $POT_{>18°C}$ periods has increased slightly from an average of < 1 day up to the 1980s, to 1-2 days in the 1990s and 2000s; the total frequency of such $POT_{>18°C}$ periods is ~10-15 per decade, since the 1990s (Figure 23, Table 9).

Discharge Exceedance Analyses

Frequency analysis of the decadal mean number of “low flow” dates (flows below the 25th percentile, i.e., $POT_{<18\ cms}$) per month (July-September) in the Tuya River at Telegraph Creek displayed an anomalous jump in the 1990s, during August and September (Figure 24). The number of low flow dates was averaging < 20 per year for the previous three decades, but almost doubled to ~36 in the 1990s, though almost half were in September, when few Tahltan Sockeye were migrating (Table 10). The average length (days) of continuous $POT_{<18\ cms}$ periods beginning in July or August also rose in the 1990s from ~10 days up to the 1980s, to ~20 days in the 1990s and 2000s (Figure 25). The “drying” trend has not persisted into the 2000s, in which the frequency of $POT_{<18\ cms}$ dates fell back to an average of 13 days per year, and the frequency of extended $POT_{<18\ cms}$ periods fell to an average of 8 times per year (Figure 25).

The regional reversion to cooler and wetter summers in the 2000s is evident in the frequency of “high flow” (> 80 cms in Tuya River) dates (average ~4 per year from the

1960s-1990s) to almost 8 per year in the 2000s, at least half of the increase in July (relative to the 1990s) and August (Table 11, Figure 26). The length in days of high flow periods is within the long-term average, but the number of high flow periods per year escalated in the 2000s from an previous average of ~8 to 24 (Figure 27).

The 1990s were relatively dry and warm, and thus may provide a glimpse of potential environmental changes under climate scenarios that indicate warmer, drier conditions to come. On the other hand, the apparent increase in extended high flows in the 2000s may be an indicator of either a trend towards a wetter regional climate or of increased net annual inputs of melt-water in the highly glaciated rivers of the area.

DISCUSSION

Pacific salmon complete their life history within a nested set of freshwater and marine habitats stretching from the headwaters of streams and rivers to the high seas and back. Climate variation and change may be expected to exert impacts on annual production variations of salmon in association with one or more life-history and habitat combinations. Recent evidence (Hyatt et al. 2003; Cooke et al. 2004; Goniea et al. 2006) suggests that some adult salmon populations, returning through terminal marine and freshwater migration corridors, are especially sensitive to climate induced impacts on migration events (e.g. influence of temperature and flow conditions on migration delays, migration duration and migration success) that influence subsequent spawning success (Cooke et al. 2004; Fryer et al. 2011) and future production. Consequently, aquatic ecosystems support sustainable populations and economically viable fisheries for salmon only as long as they provide suitable conditions (e.g. suitable seasonal flow and temperature conditions for adult migration) for successful completion of critical life history events or processes. The greater the departure of conditions outside of this range, and the higher the frequency of such departures, the greater the vulnerability of a given ecosystem, population, and fishery to loss of its salmon. Consequently, assessing the historic to future frequency, magnitude, and production consequences of climate-induced migration impacts on salmon populations is highly relevant to a wide range of existing DFO programs organized around historically productive salmon stocks that have experienced or are likely to experience significantly altered conditions in terminal marine and freshwater migration corridors throughout BC and the Yukon.

The principal objective for assembling observations contained in the current report is to provide a foundation for further analysis and modeling to determine the potential impacts of climate variation and change effects on key life history events that may subsequently affect annual production variations of Sockeye salmon in Canada’s Pacific region. Assembly and analysis of observations of annual to seasonal variations of Tahltan Sockeye salmon migrations and associated environmental variables considered in this report support inferences regarding their potential vulnerability to climate variation and change events as follows:

THERMAL REGIMES AND MIGRATION

Returning adult Sockeye salmon enter freshwater near Wrangell Alaska, migrate upstream through the glacially turbid Stikine River for about 240 km at which point they may enter the Tahltan River in order to return to their spawning grounds located a further 55 km upstream within Tahltan Lake (Hyatt et al. 2005). Because the Stikine River basin is highly glaciated, peak runoff typically occurs in mid-summer, is highly turbid due to glacial silt and is relatively cold because of the dominant influence of glacial melt relative to smaller volume discharges from a few unglaciated tributaries and lakes. By contrast, the Tahltan Lake and River system are less glaciated, involve seasonal discharge of much smaller volumes of water, and consequently exhibit warmer thermal regimes than the Stikine mainstem. Therefore, the Tahltan River portion of adult Sockeye migration has the greatest potential, if any, to develop seasonal thermal barriers to disrupt Sockeye return migrations.

Reconstructions of aquatic thermal regimes over several decades for the Tahltan Lake and River system suggests years during the decade of the 1990s were anomalously warm exhibiting a 2-10 fold increase of $POT_{18^{o}C}$ in that decade relative to any other interval, including the 2000s. Moreover, the duration (in days) of these POT events increased to 2.3 days per episode in the 1990s relative to an average of <1 day per event in the 50-year interval (1940s-1980s) preceding or the 11-year interval (2000s) following the 1990s. However, despite earlier evidence of regional warming over the past century (BCMWLAP 2002, Walker and Sydneysmith 2008), and of pronounced warming in the 1990s (this report), the climatology of the Stikine and Tahltan region remains relatively cool by comparison with southern B.C. Moreover, adult Sockeye salmon migration rates exhibit little difference across the 10-19^{o}C range encountered during their principal migration interval in the Tahltan River (i.e. mid-July to late-August) with little evidence of acute high temperature impacts on timing or migration success. Having said this, there are several years (1971, 1991, 1996 and 1999; Appendices C and D) during which adult Sockeye migration rates appear noticeably suppressed below earlier or later seasonal values, as Tahltan River and Lake water temperatures climb above 18^{o}C. Although these incidents of apparent migration rate suppression, in response to increasing river temperature, are relatively rare (i.e. single events in only 4 years of a 50 plus year record), they are consistent with the general inference that temperatures >18^{o}C are increasingly stressful (McCullough et al. 2001) and are likely to influence the behaviour and outcomes for migrating adult salmon.

FLOW REGIMES AND MIGRATION

Given our focus on the potential influence of seasonal thermal regime variations on Sockeye migration behaviour through the Tahltan Lake and River portion of their return migration, we also wished to assess the potential role of variable discharge on Sockeye migratory behaviour and associated outcomes. Stage height and discharge are not continuously monitored for the Tahltan River. Consequently, discharge records from the nearby Tuya River were adopted as a proxy indicator for seasonal variations that we assumed would also occur in the Tahltan River. Unlike the instance above, where we were confident that any thermal impact on migration would be expressed in the Tahltan as opposed to Stikine portion of adult Sockeye migration, we cannot be certain that any association(s) between Tuya discharge and Sockeye migration behaviour reflect events in the Tahltan R., as opposed to Stikine R., because changes in our discharge indicator may reflect seasonal changes in discharge and potential velocity barriers to migration in either of these rivers.

Examination of adult Sockeye salmon migration behaviour across the spectrum of seasonal discharge values failed to identify any obvious associations between changes to migration behaviour and the low end of the range of observed discharge. Thus, lower than average seasonal discharge appears to exert little influence over Tahltan Sockeye migration timing or success (Appendices C & D). By contrast, there is evidence for an influence of the high-end of discharge on migratory timing. High flows (indexed at >100 cms in late July in the Tuya River) in 1980 (Appendix C & D) appear to have bisected the Sockeye return into an early and late timing component for arrival at the Tahltan enumeration weir. High flows (>100 cms at Tuya R) in mid-July 2001 and especially from early-July through early-August 2007, were also associated with unusual delays of average seasonal increases of Sockeye passage through the Tahltan weir (i.e. time to 50% returns in 2001 and 2007 were delayed to Aug 9th and Aug 16th respectively relative to the all-year average of July 29th). In addition, there appears to be a trend for an increase of high flow events (flows >80 cms lasting for 2.5 to 4 days) which are 3 times as common during the 2000s than during the previous 40 year period of record. Although this flow increase has not been accompanied by any noticeable delay in the average time to 50% migration dates for Tahltan Sockeye during the 2000s relative to the previous 40-year interval, it is conceivable that further increases in the magnitude, frequency or duration of such high flow events may create seasonal velocity barriers with the potential to produce such a change.

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TABLES

	Tahltan Lake Weir										
	Date			Daily Sockeye Migrants			Daily Migration Rate (%)				
	Days	Min	Max	Mean	Max	Tot Annual	Mean	Max	P50	P75	P95
Year											
1959	16	03AUG	20AUG	269	800	4,311	6.25	18.6	4.78	8.19	18.56
1960	19	02AUG	28AUG	336	1,258	6,387	5.26	19.7	3.96	8.27	19.70
1961	17	10AUG	27AUG	972	5,512	16,519	5.88	33.4	1.93	6.05	33.37
1962	18	03AUG	24AUG	806	2,900	14,508	5.56	20.0	1.46	10.20	19.99
1964	43	26JUL	07SEP	427	1,520	18,353	2.33	8.3	1.69	3.51	5.55
1966	33	04AUG	06SEP	654	2,585	21,580	3.03	12.0	1.41	5.51	8.66
1967	32	15JUL	25AUG	1,213	4,726	38,802	3.13	12.2	1.62	5.77	9.42
1968	27	21JUL	27AUG	731	4,576	19,726	3.70	23.2	1.03	4.40	13.05
1969	31	12JUL	18AUG	381	1,812	11,805	3.23	15.3	1.69	3.92	13.32
1970	28	26JUL	07SEP	301	1,216	8,430	3.57	14.4	2.00	4.89	11.66
1971	26	20JUL	17AUG	712	3,710	18,523	3.85	20.0	2.18	5.79	8.13
1972	40	12JUL	21AUG	1,311	8,107	52,454	2.50	15.5	0.94	3.66	9.49
1973	24	25JUL	01SEP	119	465	2,864	4.17	16.2	2.43	7.56	14.07
1974	41	29JUL	13SEP	198	1,910	8,101	2.44	23.6	0.41	1.60	15.10
1975	30	27JUL	28AUG	272	939	8,159	3.33	11.5	2.11	4.98	11.40
1976	23	29JUL	24AUG	1,048	4,940	24,111	4.35	20.5	0.75	5.40	16.83
1977	44	12JUL	25AUG	976	7,181	42,960	2.27	16.7	1.21	2.28	9.99
1978	36	11JUL	26AUG	633	2,402	22,788	2.78	10.5	1.17	4.76	9.99
1979	28	24JUL	31AUG	365	1,766	10,211	3.57	17.3	1.66	4.94	15.18
1980	34	16JUL	03SEP	324	1,558	11,018	2.94	14.1	1.38	5.23	8.15
1981	54	17JUL	08SEP	941	5,877	50,790	1.85	11.6	0.16	2.66	6.73

Table 1. Annual migration statistics for Tahltan Sockeye daily migrants, 1959-2012 (filtered for non-zero observations), including migration period and length, mean and maximum daily migrant count, total annual escapement, and mean, maximum, and 50th – 95th percentiles of daily migration rate (%) (Source: Pete Etherton, DFO Stock Assessment Division, Whitehorse YK).

	Tahltan Lake Weir										
	Date			Daily Sockeye Migrants			Daily Migration Rate (%)				
	Days	Min	Max	Mean	Max	Tot Annual	Mean	Max	P50	P75	P95
Year											
1982	54	11JUL	04SEP	523	4,049	28,257	1.85	14.3	0.22	2.22	11.65
1983	50	09JUL	07SEP	425	6,453	21,255	2.00	30.4	0.47	1.91	7.00
1984	37	21JUL	29AUG	886	5,909	32,777	2.70	18.0	0.52	4.31	12.92
1985	43	19JUL	05SEP	1,566	10,408	67,326	2.33	15.5	0.22	1.72	12.07
1986	38	28JUL	04SEP	534	3,560	20,280	2.63	17.6	0.28	3.17	15.55
1987	37	21JUL	27AUG	188	714	6,958	2.70	10.3	1.51	4.28	9.83
1988	45	16JUL	29AUG	56	316	2,536	2.22	12.5	1.30	2.72	6.27
1989	58	09JUL	04SEP	143	802	8,316	1.72	9.6	0.52	1.77	8.55
1990	40	15JUL	28AUG	373	3,076	14,927	2.50	20.6	0.31	2.60	11.61
1991	51	17JUL	05SEP	983	5,166	50,135	1.96	10.3	0.51	3.70	7.70
1992	47	18JUL	02SEP	1,275	8,933	59,907	2.13	14.9	0.36	1.91	10.74
1993	64	10JUL	11SEP	834	3,009	53,362	1.56	5.6	0.70	3.26	4.14
1994	54	14JUL	07SEP	859	5,944	46,363	1.85	12.8	0.39	1.48	8.99
1995	69	09JUL	16SEP	613	2,827	42,317	1.45	6.7	0.66	2.42	5.27
1996	58	14JUL	10SEP	905	10,653	52,500	1.72	20.3	0.42	1.34	9.89
1997	71	15JUL	26SEP	176	1,392	12,483	1.41	11.2	0.54	1.23	7.35
1998	67	11JUL	17SEP	189	1,577	12,658	1.49	12.5	0.48	1.86	5.89
1999	56	19JUL	15SEP	192	1,085	10,748	1.79	10.1	0.49	2.31	7.06
2000	41	21JUL	04SEP	148	1,230	6,076	2.44	20.2	0.54	1.45	11.14
2001	42	19JUL	14SEP	353	1,363	14,811	2.38	9.2	1.24	4.08	7.86

Table 1, continued.

	Tahltan Lake Weir										
	Date			Daily Sockeye Migrants			Daily Migration Rate (%)				
	Days	Min	Max	Mean	Max	Tot Annual	Mean	Max	P50	P75	P95
Year											
2002	59	12JUL	14SEP	301	1,888	17,740	1.69	10.6	0.73	3.03	6.36
2003	62	11JUL	16SEP	870	6,366	53,933	1.61	11.8	0.38	1.64	7.61
2004	61	12JUL	14SEP	1,039	7,816	63,372	1.64	12.3	0.38	1.85	7.83
2005	65	11JUL	15SEP	668	3,588	43,446	1.54	8.3	1.18	2.29	3.94
2006	62	12JUL	13SEP	869	9,178	53,855	1.61	17.0	0.55	1.61	6.01
2007	54	20JUL	15SEP	390	3,600	21,074	1.85	17.1	0.64	1.70	7.98
2008	51	22JUL	16SEP	206	1,239	10,516	1.96	11.8	0.36	3.25	9.10
2009	56	13JUL	08SEP	548	7,693	30,673	1.79	25.1	0.39	1.95	8.19
2010	56	10JUL	06SEP	408	2,593	22,860	1.79	11.3	0.77	2.78	6.12
2011	51	13JUL	01SEP	678	5,163	34,588	1.96	14.9	0.90	2.26	9.55
2012	44	16JUL	29AUG	311	2,164	13,693	2.27	15.8	0.99	3.07	10.31
All	2,287	03AUG	29AUG	587	10,653	1,342,142	2.27	33.4	0.75	2.83	9.64

Table 1, continued.

	Date		Discharge (cms)								
	Min Date	Max Date	N	Min Daily	Mean Daily	Max Daily	Std Dev	P25	P50	P75	P95
Year											
1962	01JUL	30SEP	92	21.9	71.9	405.0	74.1	35.3	46.1	71.3	240.0
1963	01JUL	30SEP	92	12.5	27.3	73.9	14.8	16.2	23.7	32.0	60.6
1964	01JUL	30SEP	92	17.8	31.4	56.4	10.3	22.1	29.5	39.6	46.7
1965	01JUL	30SEP	92	8.8	18.3	65.7	11.8	11.4	13.6	19.4	44.7
1966	01JUL	30SEP	20	24.0	32.0	52.1	7.3	27.3	29.9	33.9	49.3
1967	01JUL	30SEP	92	14.4	26.3	70.5	11.8	17.9	21.6	31.0	52.4
1968	01JUL	30SEP	92	10.8	30.9	89.8	21.7	13.3	21.6	45.3	76.7
1969	01JUL	30SEP	92	16.8	47.3	122.0	26.6	25.5	42.8	64.7	99.4
1970	01JUL	30SEP	92	16.4	28.2	92.9	12.2	19.9	24.6	33.1	46.7
1971	01JUL	30SEP	92	13.2	23.2	55.2	9.1	15.6	21.2	27.5	41.9
1972	01JUL	30SEP	92	20.6	37.2	93.4	14.5	26.9	32.3	42.2	62.0
1973	01JUL	30SEP	92	23.4	47.9	105.0	20.9	29.9	41.9	62.3	91.5
1974	01JUL	30SEP	92	18.9	50.0	175.0	37.8	20.8	29.9	70.8	135.0
1975	01JUL	30SEP	92	25.8	47.2	131.0	20.7	35.0	43.8	50.9	103.0
1976	01JUL	30SEP	92	11.4	43.4	210.0	37.1	17.5	28.3	54.1	121.0
1977	01JUL	30SEP	92	15.3	37.0	114.0	23.4	20.9	25.5	49.6	84.7
1978	01JUL	30SEP	92	8.8	14.1	26.1	3.6	11.1	13.8	15.9	20.7
1979	01JUL	30SEP	92	11.0	36.7	137.0	29.1	15.4	23.7	58.7	93.4
1980	01JUL	30SEP	92	20.0	52.7	259.0	33.0	35.9	45.6	58.8	102.0
1981	01JUL	30SEP	92	12.1	32.1	90.0	19.0	19.7	27.7	36.0	78.2

Table 2. Annual and overall discharge statistics for observed data from Tuya River (WSC Station 08CD001; July-September 1962-2011).

	Date		Discharge (cms)									
	Min Date	Max Date	N	Min Daily	Mean Daily	Max Daily	Std Dev	P25	P50	P75	P95
Year											
1982	01JUL	30SEP	92	10.5	23.3	57.4	11.0	15.8	19.5	28.8	48.7
1983	01JUL	30SEP	92	26.9	45.3	87.7	15.0	34.8	42.1	52.6	77.7
1984	01JUL	30SEP	92	16.3	27.2	59.3	10.0	20.0	24.3	29.4	48.1
1985	01JUL	30SEP	92	15.0	36.7	201.0	32.0	18.3	22.9	47.1	112.0
1986	01JUL	30SEP	80	16.9	31.2	96.4	16.3	20.7	25.3	34.2	68.1
1987	01JUL	30SEP	92	13.1	30.3	91.8	15.3	18.6	27.8	35.7	59.0
1988	01JUL	30SEP	92	19.5	39.5	138.0	20.1	25.7	38.2	44.8	88.2
1989	01JUL	30SEP	92	12.6	22.0	72.3	8.9	15.9	20.5	25.6	35.5
1990	01JUL	30SEP	92	10.6	21.0	54.1	12.0	12.7	15.2	27.1	46.8
1991	01JUL	30SEP	92	12.0	43.0	139.0	28.9	20.0	30.0	63.1	96.7
1992	01JUL	30SEP	92	10.6	24.0	69.0	13.7	14.5	18.3	32.5	53.2
1993	01JUL	30SEP	92	12.2	24.8	60.9	12.5	14.5	19.5	33.4	49.3
1994	01JUL	30SEP	92	15.6	42.7	211.0	34.5	21.3	26.8	50.4	105.0
1995	01JUL	30SEP	92	15.4	23.4	40.6	6.2	18.5	21.6	27.5	36.0
1996	01JUL	30SEP	92	12.5	20.6	56.9	10.8	14.4	15.5	23.2	48.2
1997	01JUL	30SEP	92	16.3	34.2	125.0	15.0	27.2	32.6	37.8	54.1
1998	01JUL	30SEP	92	7.7	11.8	20.1	3.4	9.3	10.5	13.7	19.4
1999	01JUL	30SEP	92	15.0	22.3	47.8	6.9	18.3	20.2	23.4	39.5
2000	01JUL	30SEP	92	22.3	49.7	215.0	31.4	30.1	39.7	58.8	96.1

Table 2, continued.

	Date		Discharge (cms)								
	Min Date	Max Date	N	Min Daily	Mean Daily	Max Daily	Std Dev	P25	P50	P75	P95
Year											
2001	01JUL	30SEP	92	20.3	41.2	126.0	23.6	23.1	32.0	53.9	82.3
2002	01JUL	30SEP	92	17.7	44.1	88.2	17.8	27.5	42.6	56.6	82.9
2003	01JUL	30SEP	92	15.3	41.5	111.0	24.4	19.5	37.6	55.0	95.4
2004	01JUL	30SEP	92	9.6	24.8	81.3	17.3	12.5	16.8	33.6	63.9
2005	01JUL	30SEP	92	27.2	46.9	91.5	14.1	37.6	43.7	53.4	74.7
2006	01JUL	30SEP	92	30.0	55.6	138.0	23.8	40.1	47.4	63.2	115.0
2007	01JUL	30SEP	92	31.7	75.6	320.0	47.6	46.2	62.5	84.3	174.0
2008	01JUL	30SEP	92	20.4	39.5	108.0	18.8	26.8	31.8	47.5	79.1
2009	01JUL	30SEP	92	15.6	34.5	110.0	22.4	19.3	26.3	38.4	87.7
2010	01JUL	30SEP	92	7.8	13.5	32.5	5.3	10.1	11.4	15.0	27.4
2011	01JUL	30SEP	92	23.5	53.6	142.0	25.4	34.9	48.1	66.2	110.0
All	01JUL	30SEP	5E3	7.7	35.7	405.0	27.0	18.7	27.6	44.2	82.1

Table 2, continued.

	Water Temperature						Percentiles			
	Dates	Min	Mean	Max	Std	Skew	P25	P50	P75	P95
Year										
1984	7	12.50	13.46	14.00	0.59	-0.64	13.0	13.5	14.0	14.0
1985	60	11.64	13.56	16.44	1.27	0.41	12.4	13.6	14.4	16.1
1986	53	12.12	14.22	16.75	0.99	0.56	13.6	14.1	14.8	16.3
1987	46	15.00	16.75	18.50	0.88	0.29	16.1	16.7	17.4	18.4
1988	60	11.96	13.19	14.91	0.65	0.47	12.7	13.1	13.6	14.4
1989	62	14.00	15.94	17.90	0.89	-0.29	15.4	16.0	16.5	17.3
1990	46	14.38	16.86	19.00	1.25	0.06	16.0	16.8	17.6	19.0
1991	58	12.40	14.88	16.83	1.14	-0.33	14.1	14.9	15.8	16.7
1992	54	12.50	14.96	16.80	1.08	-0.62	14.2	15.3	15.8	16.4
1993	54	13.70	15.40	17.42	0.83	0.31	14.7	15.4	15.9	16.9
1994	62	13.55	16.83	20.08	1.74	-0.06	15.8	16.8	18.1	19.8
1995	54	13.60	15.14	17.25	1.10	0.24	14.2	15.1	16.2	16.9
1996	52	13.00	14.81	18.00	1.33	1.16	14.0	14.4	15.1	17.9
1997	53	14.90	16.48	18.28	0.67	0.10	16.0	16.5	16.9	17.8
1998	51	13.00	15.28	16.90	1.24	-0.40	14.4	15.6	16.5	16.9
1999	52	13.30	15.99	19.80	1.50	0.41	15.0	15.9	16.9	19.0
2000	54	13.00	15.40	17.60	1.12	-0.32	14.5	15.6	16.0	17.4
2001	51	12.75	15.11	17.20	1.19	-0.21	14.3	15.2	15.9	17.1
2002	54	12.75	14.01	16.38	0.81	1.11	13.5	13.8	14.4	15.8
2003	52	13.50	15.76	18.00	1.04	-0.09	15.1	15.9	16.4	17.5
2004	54	15.88	18.02	20.70	1.16	0.07	17.2	18.0	18.9	19.9
2005	52	14.40	16.09	19.60	1.08	1.55	15.5	15.8	16.3	18.6
2006	50	12.90	14.62	16.20	0.73	0.18	14.2	14.6	15.1	15.9
2007	54	6.25	14.69	17.40	2.85	-1.84	15.0	15.6	16.2	17.1
2008	57	10.60	13.86	16.88	1.58	-0.05	13.0	13.7	14.9	16.7
2009	55	13.00	15.97	20.25	1.58	0.60	15.2	15.8	16.8	19.7
2010	52	12.80	15.19	18.30	1.36	0.21	14.0	15.0	16.4	17.3
2011	54	12.10	14.18	17.33	1.36	0.44	13.0	14.2	14.9	16.7
All	1463	6.25	15.27	20.70	1.69	-0.18	14.1	15.4	16.4	18.0

Table 3. Annual summary of Class 1 daily mean water temperature data for Tahltan Lake at the outlet weir during Sockeye migration (July-August) (Source: Pete Etherton, DFO Stock Assessment Division, Whitehorse YK, unpub. data). Mean is average of daily mean temperatures from datalogger readings for #Dates times per year. Min and Max are minimum and maximum of the daily mean temperatures (i.e., not observed extremes).

	Calibration		Validation	
	Warming	Cooling	Warming	Cooling
	Observations	Observations	Observations	Observations
Year				
1984			59	0
1985			62	36
1986			83	24
1987			83	18
1988			86	32
1989			85	33
1990	56	31		
1991			56	38
1992	53	38		
1993			71	44
1994	84	33		
1995			78	54
1996	73	31		
1997	68	54		
1998			72	33
1999	74	50		
2000	73	52		
2001			61	28
2002	67	31		
2003			71	31
2004	63	33		
2005	64	38		
2006	62	41		
2007			56	37
2008	65	42		
2009	59	32		
2010	59	32		
2011			61	33

Table 4. Number of annual water temperature observations available for Tahltan Lake air/water temperature analyses, partitioned into warming and cooling seasons for seasonal relationships. Air/water temperature model calibration data years were selected based on strength of association between air and water time-series and range of temperature observations.

Tahltan Air/Water Logistic (No-Intercept) Model - All Seasons 1984-2012 - Calibration

Source	DF	Sum of Squares	Mean Square	F Value	Approx Pr > F
Model	3	256182	85394.1	19689.3	<.0001
Error	1455	6310.5	4.3371		
Uncorrected Total	1458	262493			

Parameter	Estimate	Approx Std Error	Approximate 95% Confidence Limits		Skewness
alpha	20.1002	0.4674	19.1834	21.0171	0.3086
beta	8.2289	0.2107	7.8156	8.6422	0.3066
gamma	0.2412	0.0113	0.2189	0.2634	0.0534

Tahltan Air/Water Logistic (No-Intercept) Model - Warming Season 1984-2012 - Calibration

Source	DF	Sum of Squares	Mean Square	F Value	Approx Pr > F
Model	3	131723	43907.7	13195.5	<.0001
Error	917	3051.3	3.3275		
Uncorrected Total	920	134775			

Parameter	Estimate	Approx Std Error	Approximate 95% Confidence Limits		Skewness	Label
alpha	21.0000	0	21.0000	21.0000	.	
beta	9.5797	0.0582	9.4654	9.6940	-0.0259	
gamma	0.2285	0.00477	0.2192	0.2379	0.0319	

Tahltan Air/Water Logistic (No-Intercept) Model - Cooling Season 1984-2012 - Calibration

Source	DF	Sum of Squares	Mean Square	F Value	Approx Pr > F
Model	3	127162	42387.3	40767.5	<.0001
Error	535	556.3	1.0397		
Uncorrected Total	538	127718			

Parameter	Estimate	Approx Std Error	Approximate 95% Confidence Limits		Skewness	Label
alpha	21.0000	0	21.0000	21.0000	.	
beta	4.9651	0.1923	4.5874	5.3428	-0.1661	
gamma	0.1510	0.00460	0.1420	0.1601	0.0214	

Table 5. Logistic regression output for air/water temperature relationship between the DEASE LAKE 7d-CMAT (air temperature index) and calibration data for lower Tahltan Lake daily mean water temperatures: seasons combined (top); warming season (middle); cooling season (bottom). Intercept (μ parameter) set to zero, α parameter constrained to 21°C or less. Hysteresis detected ($NSC_{seasonal} - NSC_{all} = 0.075$).

Tahltan Air/Water Linear Model - Warming Season 1984-2012 - Calibration

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	10832	10832	3052.13	<.0001
Error	918	3258.01347	3.54903		
Corrected Total	919	14090			

Root MSE	1.88389	R-Square	0.7688
Dependent Mean	11.45333	Adj R-Sq	0.7685
Coeff Var	16.44839		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	0.60541	0.20595	2.94	0.0034
Dease_7DMAT	7d-MAT	1	1.04288	0.01888	55.25	<.0001

Tahltan Air/Water Linear Model - Cooling Season 1984-2012 - Calibration

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	1377.88029	1377.88029	1343.28	<.0001
Error	536	549.80677	1.02576		
Corrected Total	537	1927.68705			

Root MSE	1.01280	R-Square	0.7148
Dependent Mean	15.29088	Adj R-Sq	0.7143
Coeff Var	6.62354		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	8.29255	0.19588	42.34	<.0001
Dease_7DMAT	7d-MAT	1	0.59698	0.01629	36.65	<.0001

Tahltan Air/Water Linear Model - Season 1984-2012 - Calibration

TYPE III SS for interaction term significance - if P<.05, slopes are different (hysteresis)

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Dease_7DMAT	1	3356.972648	3356.972648	1281.85	<.0001
Season	1	1197.301524	1197.301524	457.18	<.0001
Dease_7DMAT*Season	1	553.777530	553.777530	211.46	<.0001

Table 6. Linear regression output for air/water temperature relationship between the Dease Lake 7d-CMAT (air temperature index) and calibration data for Tahltan Lake daily mean water temperatures: warming season (top); cooling season (middle). Type III sum of squares for season effect and season interaction effect are highly significant (bottom), indicating that hysteresis exists and that seasonal models provide the best fit to the data.

------------------- Site=Tahltan Dataset=Validation Season=Warming ---------------------

The CORR Procedure

1 With Variables: WaterT
2 Variables: LogisticModelWaterTemp LinearModelWaterTemp

Pearson Correlation Coefficients, N = 984
Prob > |r| under H0: Rho=0

	Logistic Model Water Temp	Linear Model Water Temp
WaterT Daily MWT	0.85508 <.0001	0.85206 <.0001

Spearman Correlation Coefficients, N = 984
Prob > |r| under H0: Rho=0

	Logistic Model Water Temp	Linear Model Water Temp
WaterT Daily MWT	0.84781 <.0001	0.84781 <.0001

------------------- Site=Tahltan Dataset=Validation Season=Cooling ---------------------

The CORR Procedure

1 With Variables: WaterT
2 Variables: LogisticModelWaterTemp LinearModelWaterTemp

Pearson Correlation Coefficients, N = 441
Prob > |r| under H0: Rho=0

	Logistic Model Water Temp	Linear Model Water Temp
WaterT Daily MWT	0.67428 <.0001	0.67802 <.0001

Spearman Correlation Coefficients, N = 441
Prob > |r| under H0: Rho=0

	Logistic Model Water Temp	Linear Model Water Temp
WaterT Daily MWT	0.68678 <.0001	0.68679 <.0001

Table 7. Comparison of Pearson (least squares) and Spearman (rank) correlation coefficients for observed (*WaterT*) versus estimated (from logistic and linear models) daily mean water temperature for validation data years: warming season (top); cooling season (bottom). Analysis indicates equal predictive power between linear and logistic model types.

Decadal Mean Monthly MAT Peaks > 20c

Site: Dease Air

	Years in Decade	Mean No. Days			Mean Annual Total
		Jul	Aug	Sep	
Decade					
1940s	6				
1950s	10	0.1			0.1
1960s	10				
1970s	10				
1980s	10				
1990s	10		0.4		0.4
2000s	13	0.3			0.3

Annual Frequency & Mean Duration (days) for POT20c Events

	POT Event Duration (days)				
	N	Min	Avg	Max	Std
Decade					
1950s	1	1	1.0	1	
1990s	3	1	1.3	2	0.6
2000s	1	4	4.0	4	
Total	5	1	1.8	4	1.3

Table 8. Frequency analysis of decadal mean number of dates per month (July-September) in which regional daily mean air temperature at DEASE LAKE weather station exceeded 20°C (top); min., mean and max. length (days) and total frequency of periods in which regional daily mean air temperature continuously exceeded 20°C (July-September), by decade (bottom).

Decadal Mean Monthly MWT Peaks > 18c

Site: Tahltan Lake/River

	Years in Decade	Mean No. Days			Mean Annual Total
		Jul	Aug	Sep	
Decade					
1940s	6				
1950s	10	1.1	0.1		1.2
1960s	10				
1970s	10	0.5	0.1		0.6
1980s	10		0.2		0.2
1990s	10	0.5	1.7		2.2
2000s	13	0.4	0.7		1.1

Annual Frequency & Mean Duration (days) for POT18c Events

	POT Event Duration (days)				
	N	Min	Avg	Max	Std
Decade					
1940s	6	0	0.7	4	1.6
1950s	10	0	1.6	8	2.7
1960s	10	0	0.8	8	2.5
1970s	11	0	0.5	5	1.5
1980s	10	0	0.1	1	0.3
1990s	10	0	2.3	8	2.6
2000s	15	0	1.5	9	2.8
Total	72	0	1.1	9	2.3

Table 9. Frequency analysis of decadal mean number of dates per month (July-September) in which estimated mean water temperature in the Tahltan River exceeded 18°C (top); min., mean and max. length (days) and total frequency of periods in which estimated mean water temperature continuously exceeded 18°C (July-September), by decade (bottom).

Decadal Mean Monthly Flow < 18 cms

Site: Tuya River

	Years in Decade	Mean No. Days			Mean Annual Total
		Jul	Aug	Sep	
Decade					
1960s	8	1.9	12.4	5.4	19.6
1970s	10	4.0	10.4	4.6	19.0
1980s	10	0.5	9.1	4.8	14.4
1990s	10	3.4	17.9	14.7	36.0
2000s	12	1.6	7.0	4.8	13.3

Annual Frequency & Mean Duration (days) for POT < 18 cms Events

	POT Event Duration (days)				
	N	Min	Avg	Max	Std
Decade					
1960s	14	1	11.7	34	13.3
1970s	15	1	9.5	28	8.1
1980s	15	1	9.7	29	9.6
1990s	22	1	20.7	151	35.6
2000s	8	1	21.3	89	31.3
Total	74	1	14.6	151	23.4

Table 10. Frequency analysis of decadal mean number of dates per month in which observed or estimated daily discharge in Tuya River did not exceed the 25th percentile of flows (18 cms) in July-September (top); min., mean and max. length (days) and total frequency of periods in which observed or estimated daily discharge remained continuously below 18 cms in July and August, by decade (bottom).

Decadal Mean Monthly Flow > 80 cms

Site: Tuya River

	Years in Decade	Mean No. Days			Mean Annual Total
		Jul	Aug	Sep	
Decade					
1960s	8	1.8	1.3	1.0	4.0
1970s	10	5.5		1.0	6.5
1980s	10	3.2		0.4	3.6
1990s	10		0.2	2.2	2.4
2000s	12	3.1	1.0	3.5	7.6

Annual Frequency & Mean Duration (days) for POT > 80 cms Events

	POT Event Duration (days)				
	N	Min	Avg	Max	Std
Decade					
1960s	6	1	2.7	5	1.9
1970s	9	1	3.4	8	2.4
1980s	7	1	4.0	9	2.9
1990s	8	1	3.0	7	2.5
2000s	24	1	3.5	17	3.9
Total	54	1	3.4	17	3.1

Table 11. Frequency analysis of decadal mean number of dates per month in which observed or estimated daily discharge at Tuya River exceeded the 95th percentile of flows (80 cms) in July-September (top); min., mean and max. length (days) and total frequency of periods in which observed or estimated daily discharge remained continuously above 80 cms in July - Sep, by decade (bottom).

FIGURES

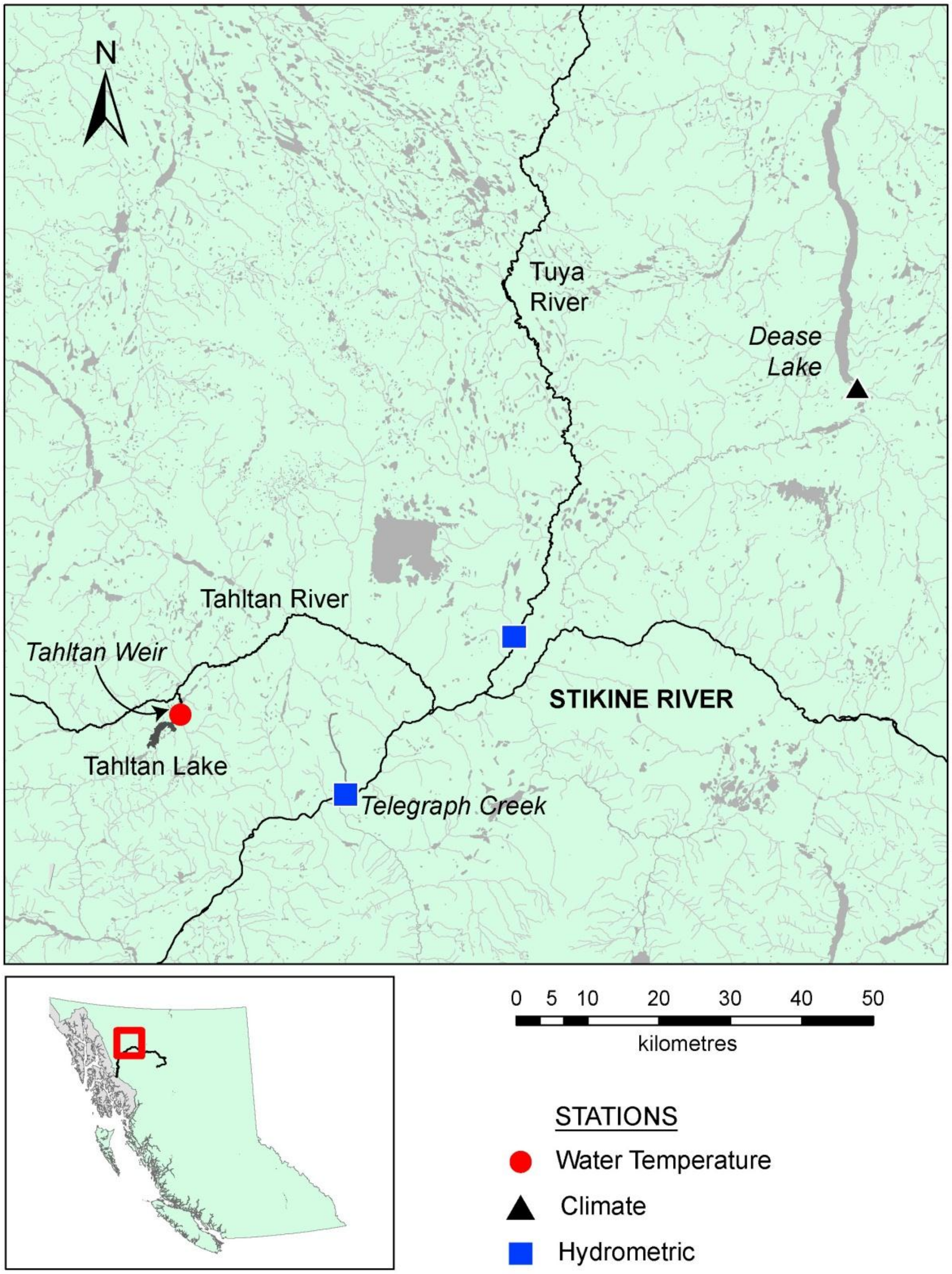


Figure 1. Tahltan watershed with key locations, ENVIRONMENT CANADA climate stations and CANADIAN HYDROGRAPHIC SURVEY water monitoring stations.

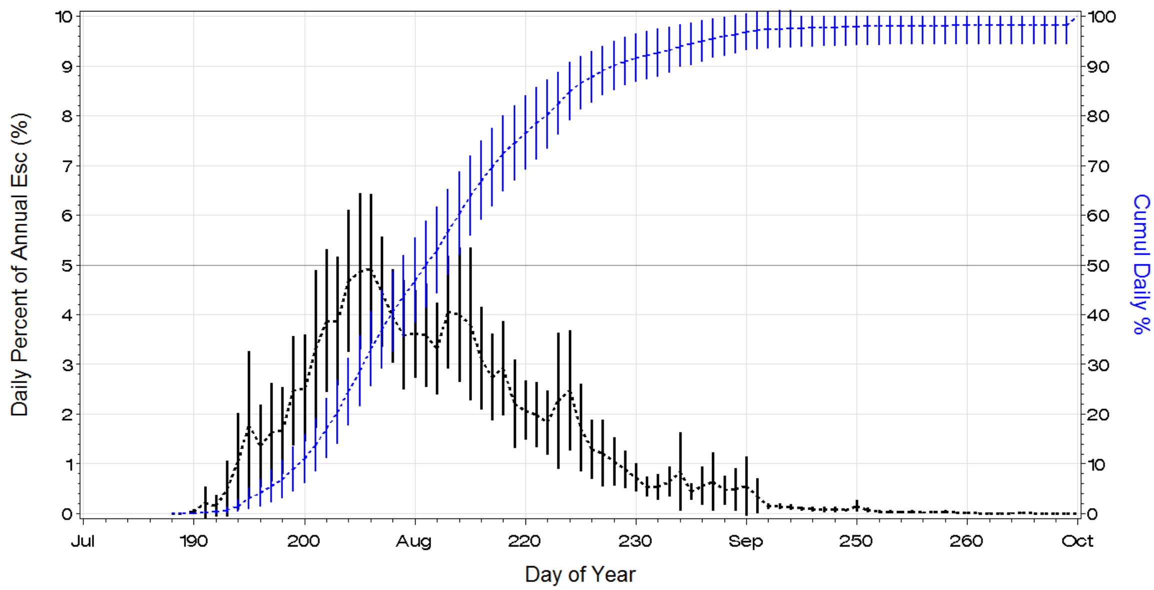


Figure 2. Historical migration timing. Mean daily and cumulative % of total annual escapement ± 2 standard errors of the mean (95% CI). Time-to-50% ~ day 211 ~ July 30th.

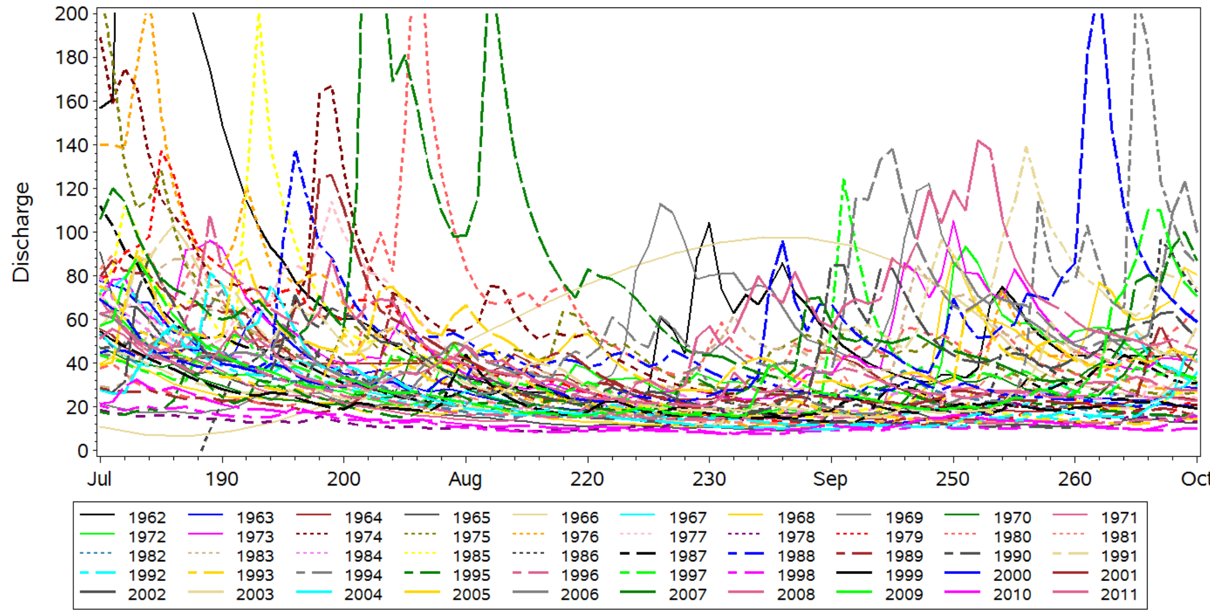


Figure 3. Observed annual daily mean discharge (m^3/s) for Tuya River (WSC Station 08CD001; July-September 1962-2011).

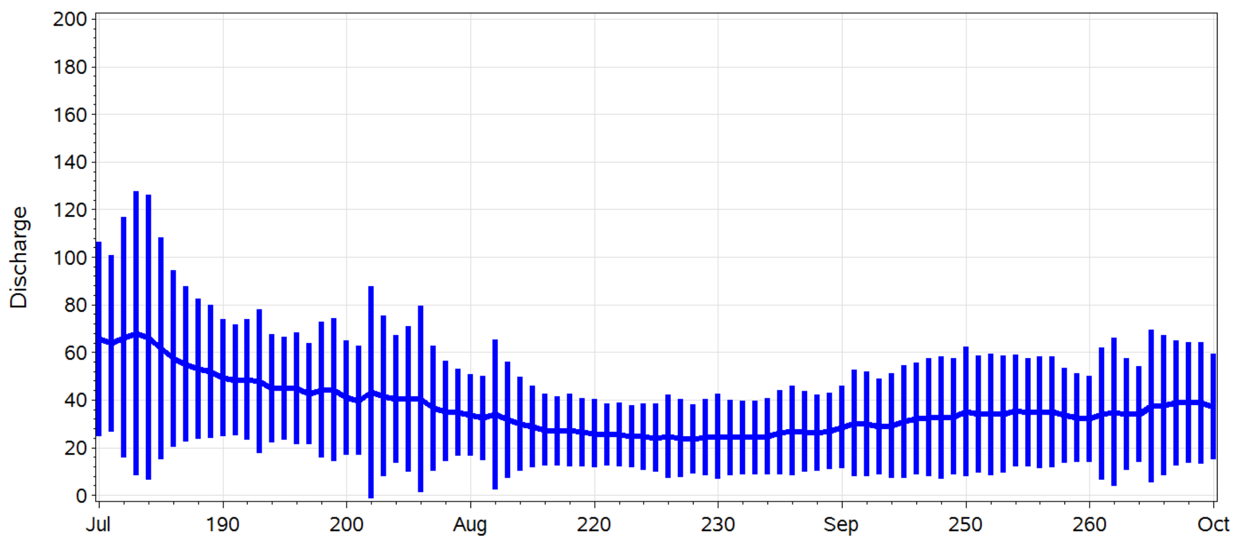


Figure 4. Observed daily mean discharge (m^3/s) ± 1 standard deviation for Tuya River (WSC Station 08CD001; July-September 1962-2011).

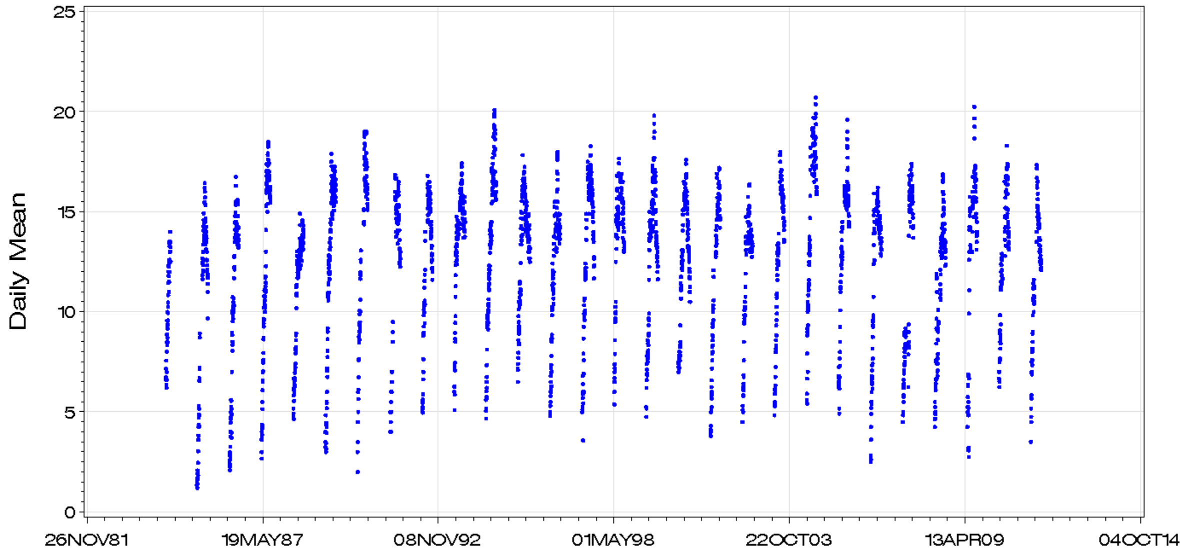


Figure 5. Water temperature data for Tahltan Lake at the outlet weir (Source: Pete Etherton, DFO Stock Assessment Division, Whitehorse YK, unpub. data).

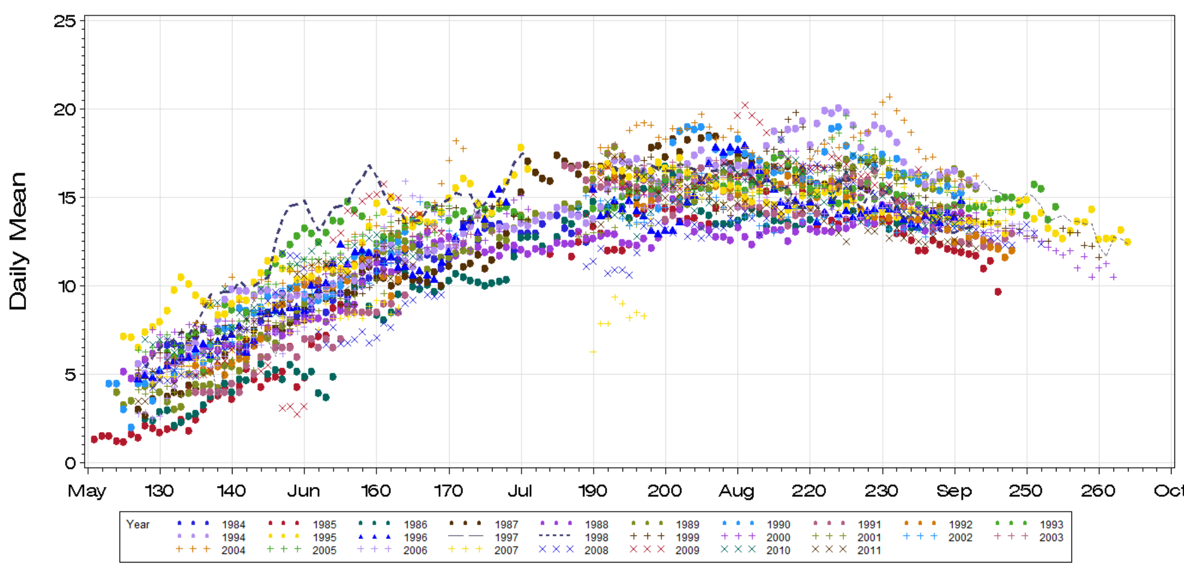


Figure 6. Annual thermograph of water temperature data for Tahltan Lake at the outlet weir (Source: Pete Etherton, DFO Stock Assessment Division, Whitehorse YK, unpub. data).

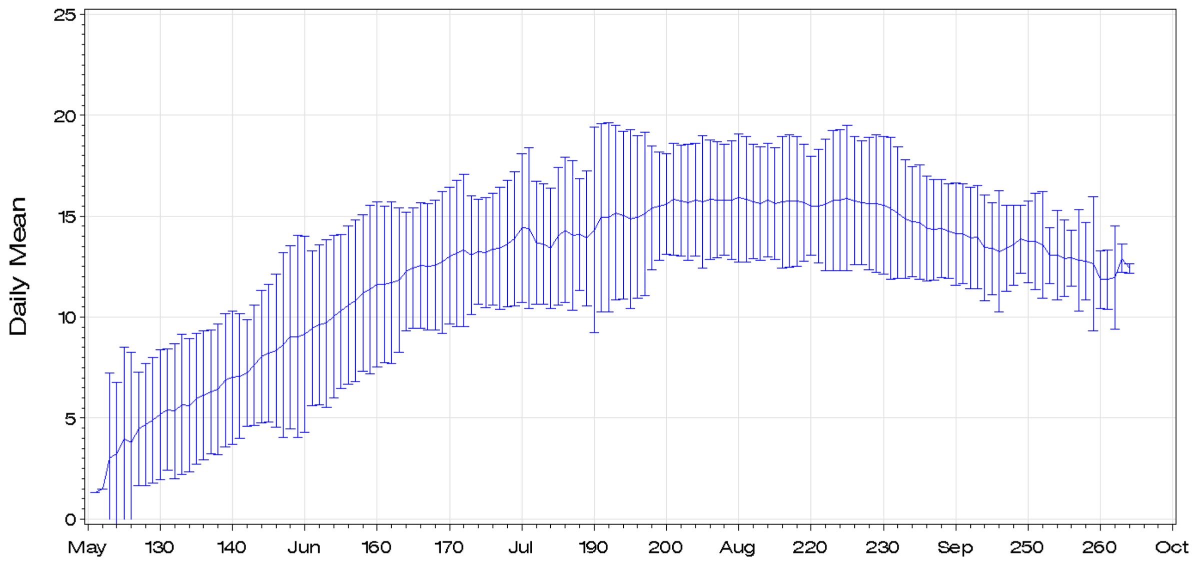


Figure 7. Annual thermograph of water temperature data ± two standard deviations for Tahltan Lake at the outlet weir (Source: Pete Etherton, DFO Stock Assessment Division, Whitehorse YK, unpub. data).

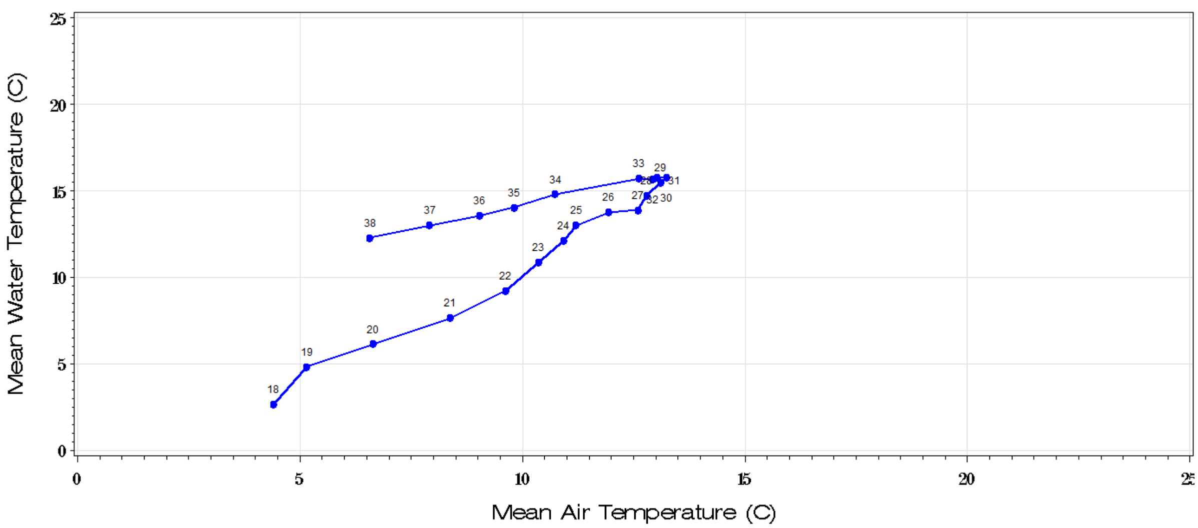
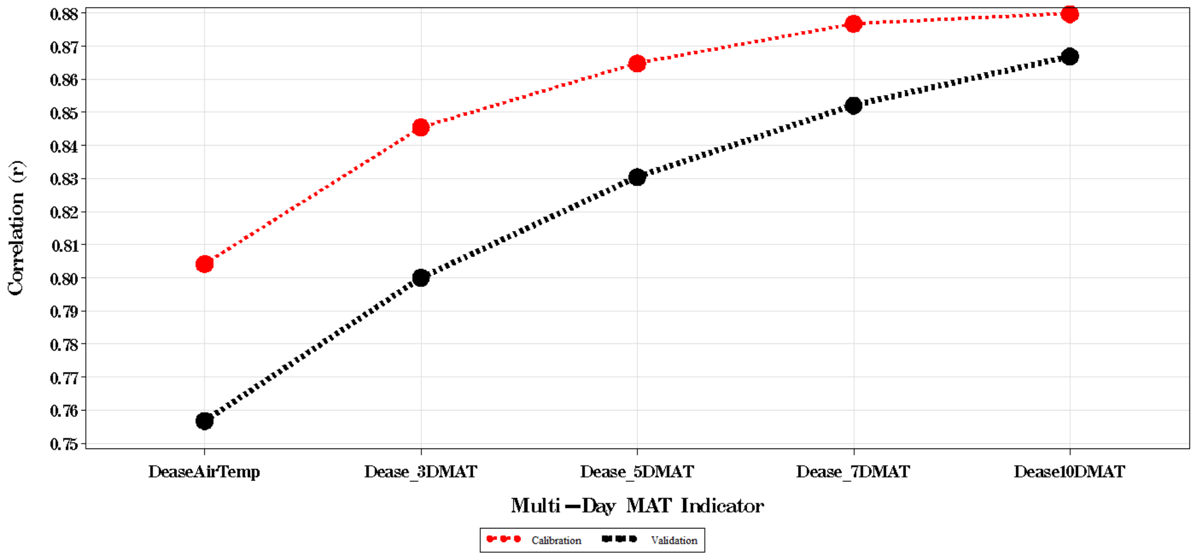


Figure 8. Derivation of seasonal turn-around point for lower Tahltan Lake, based on maximum weekly mean air and water temperature data. The seasonal turn-around point is in week 30 or day 210, approx July 29th. The "warming season" therefore extends from April 1 to July 29th, followed by the "cooling season" from day 211-329, i.e., July 30th – November 25th.



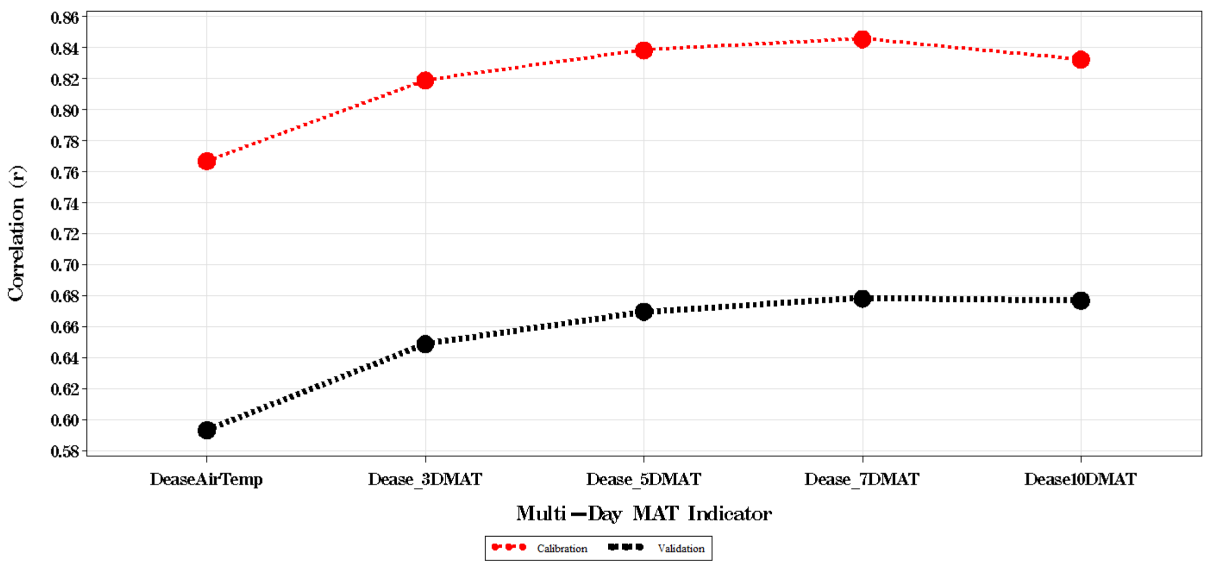


Figure 9. Derivation of optimum regional air temperature index for air/water temperature analyses, based on maximum all-year correlation between various DEASE LAKE multi-day mean air temperature indicators (MATs) with Tahltan daily mean water temperature (MWT) for calibration (red) and validation (black) data; warming season (top), cooling season (bottom). DEASE LAKE air temperature indicators include (l-r): Air Temp (same day mean); 3-day centered moving average air temperature (3D-MAT), 5D-MAT, 7D-MAT, and 10-DMAT. Overall, the 7D-MAT provides the best trade-off between correlation and multi-day averaging (which affects predictive power at longer period lengths).

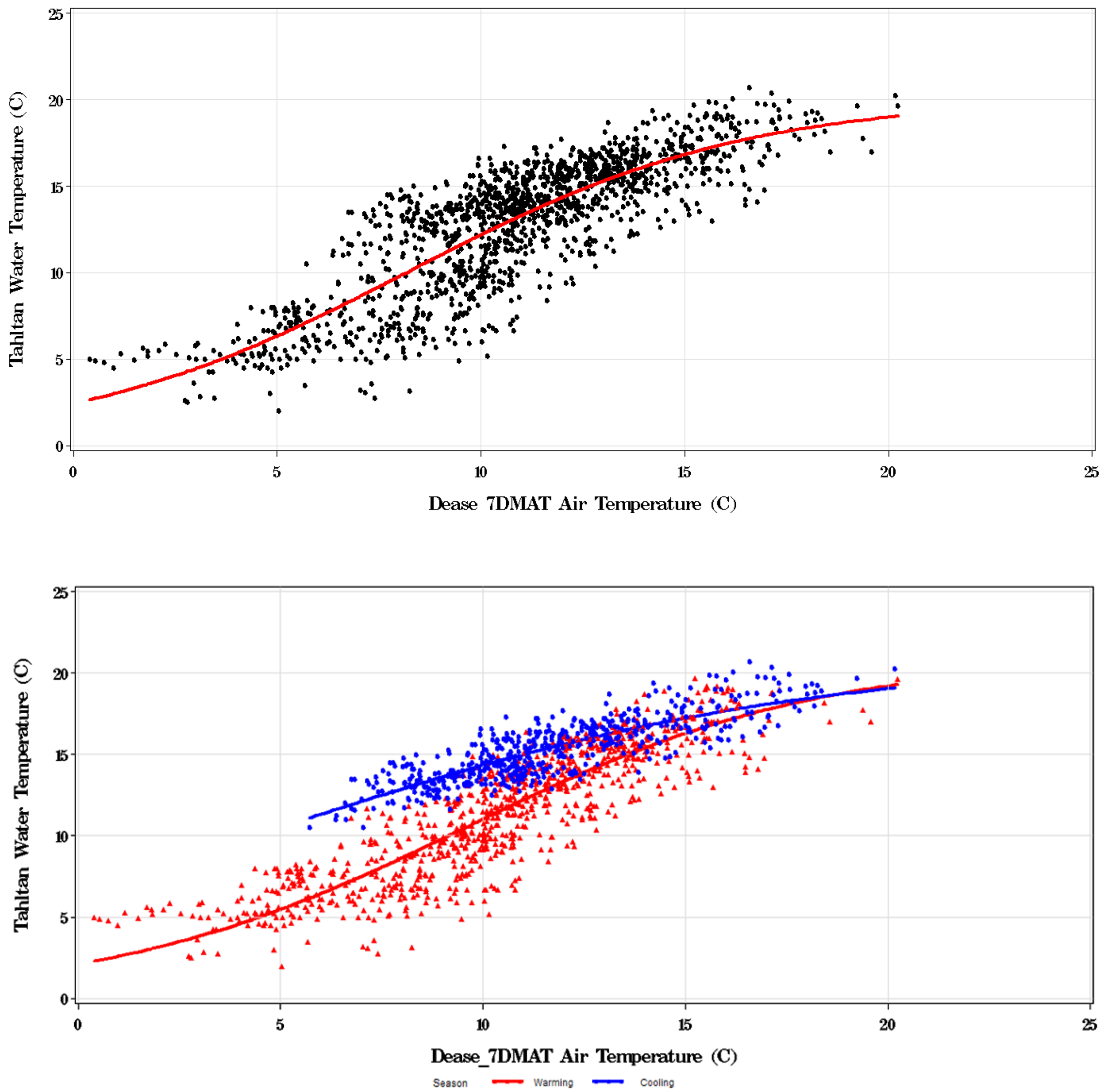


Figure 10. Logistic regression fits for air/water temperature relationship for Tahltan daily mean water temperatures as a function of the DEASE LAKE 7d-CMAT (air temperature index): seasons combined (top); separate warming season (red) and cooling seasons (blue)(bottom).

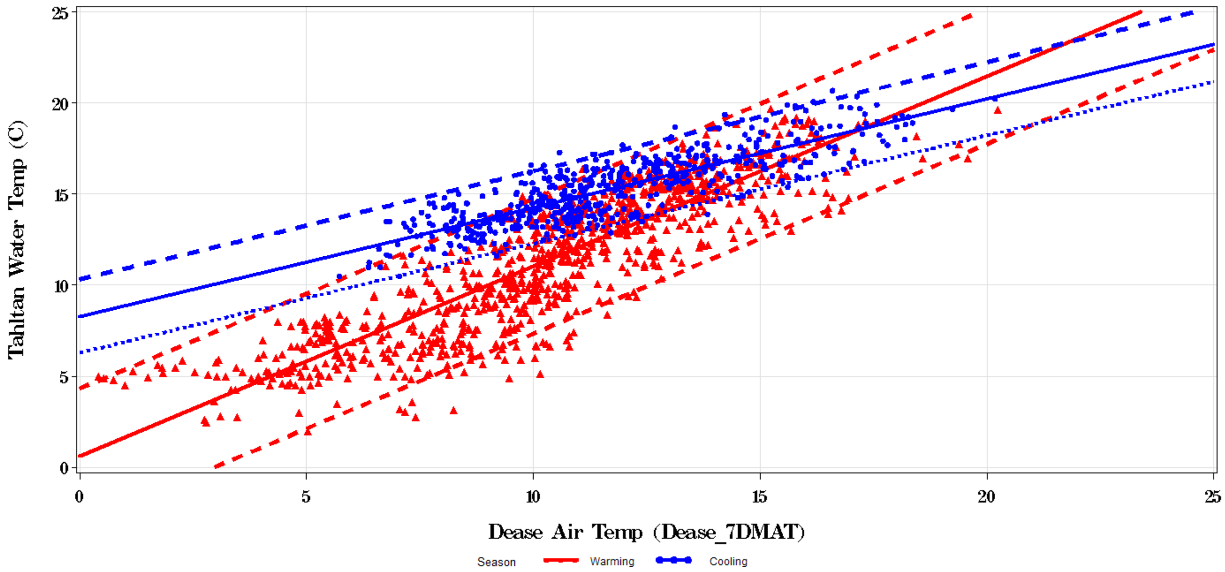


Figure 11. Linear regression fits for air/water temperature relationship for Tahltan Lake daily mean water temperatures as a function of the DEASE LAKE 7d-CMAT (air temperature index), by season (warming season (red) and cooling season (blue)).

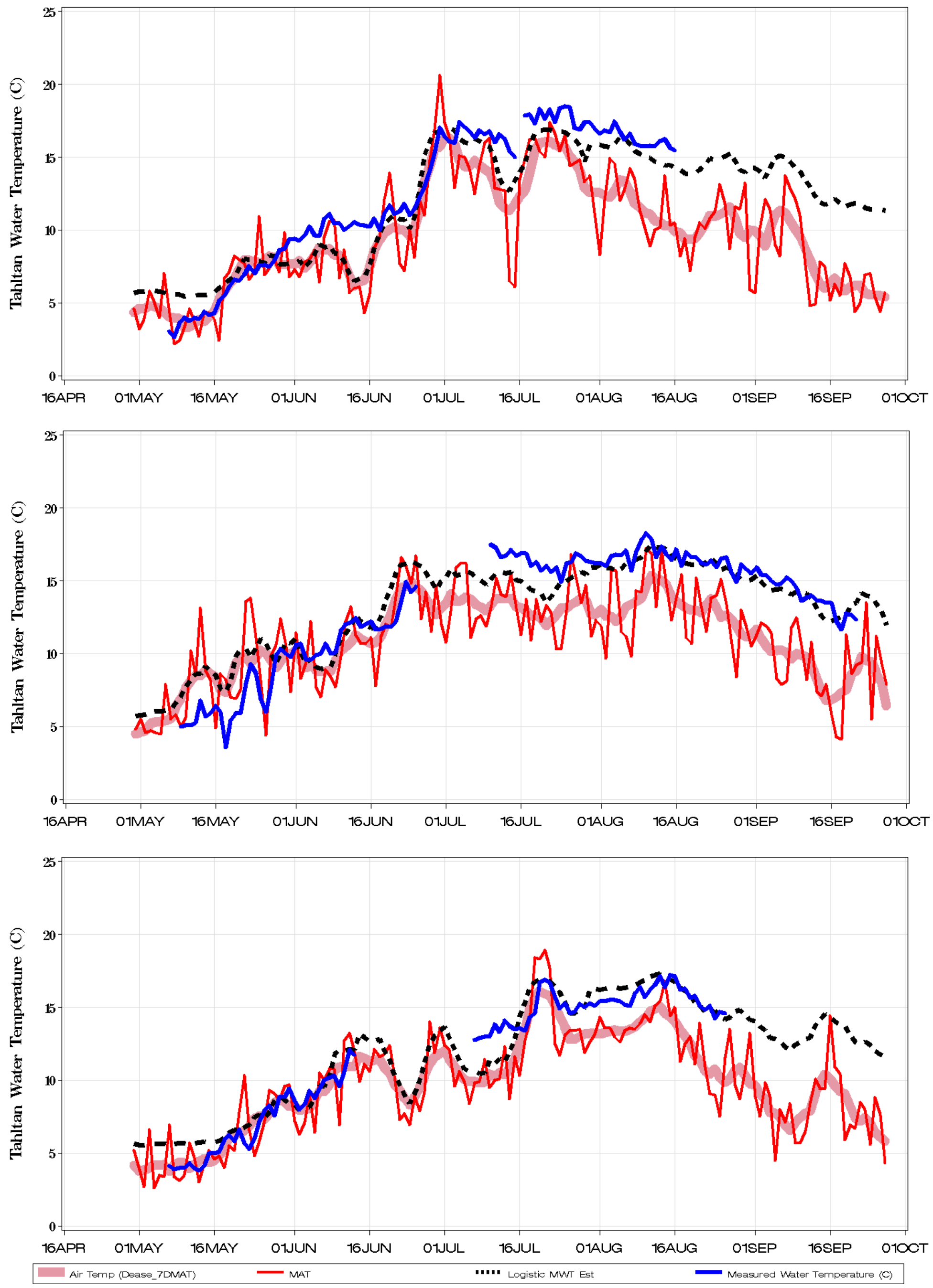


Figure 12. Sample validation plots of daily mean air temperature (red line), 7-day MAT index (broad pink line), and observed (blue solid line) and estimated (black dashed line, based on seasonal logistic regression models) daily mean water temperature for Tahltan Lake/River, May-Oct 1987 (top), 1997 (middle), 2001 (bottom).

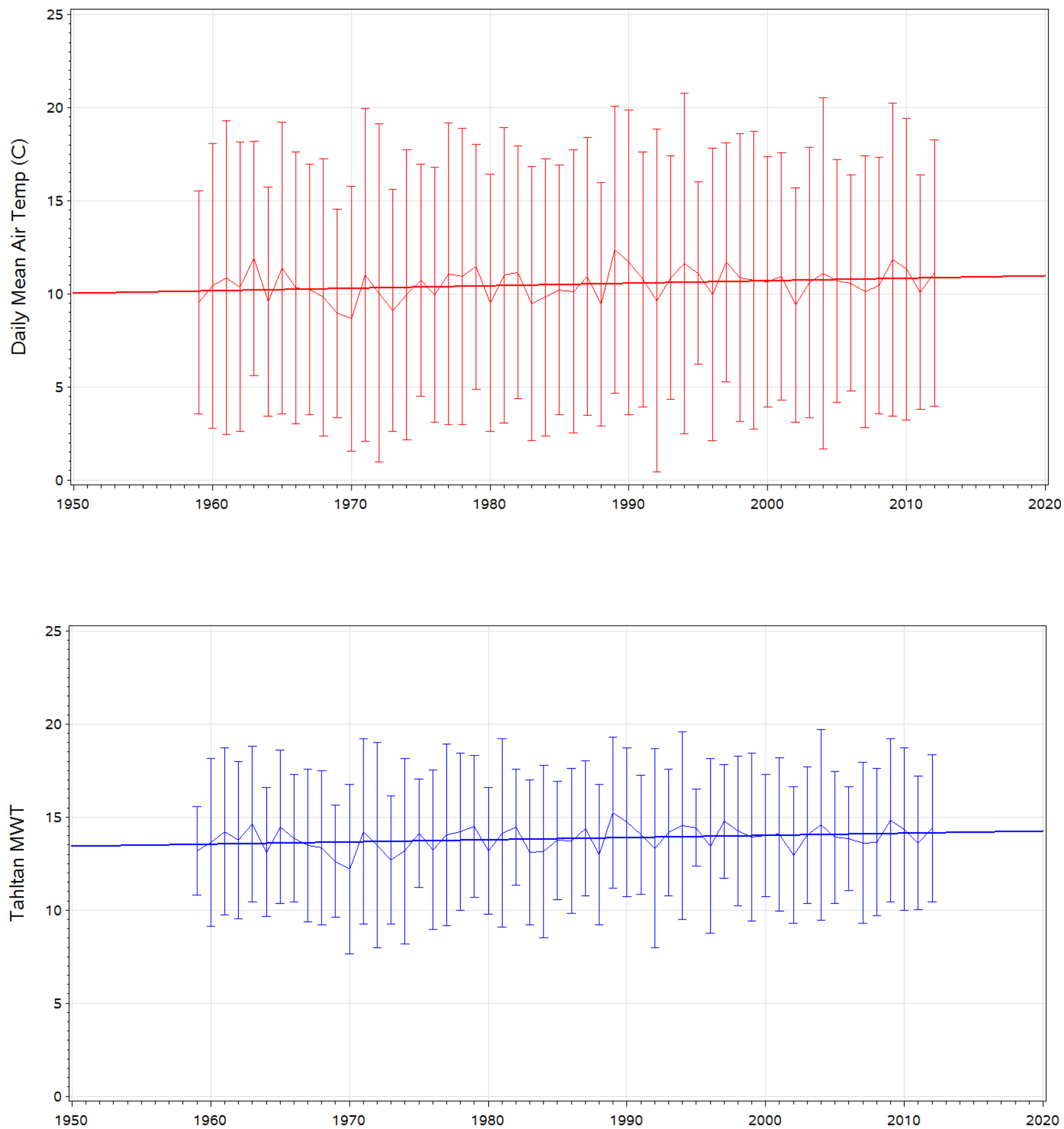


Figure 13. Dease Lake mean air temperature (top) and Tahltan River estimated mean water temperature (bottom) ± 2 std deviations, August-November 1959-2012. Trend: MWT = -9.75 + 0.012 * Year (r^2 = 0.008; $P < .0001$).

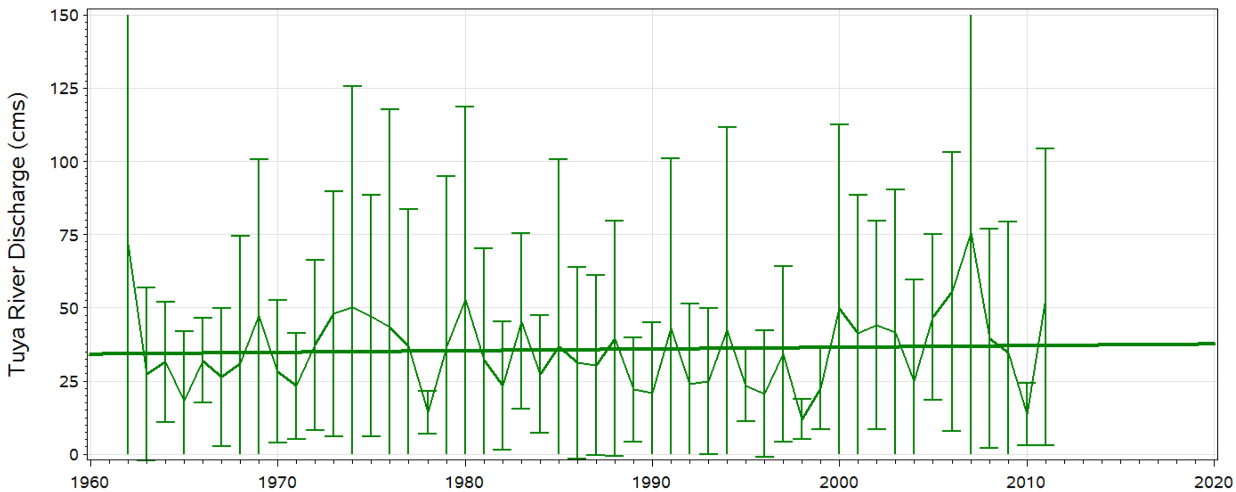


Figure 14. Observed Tuya River mean discharge ± 2 std deviations, July-September, 1962-2011. Trend: Discharge = -776 + 0.057 * Year (r^2 = 0.001; P = .04).

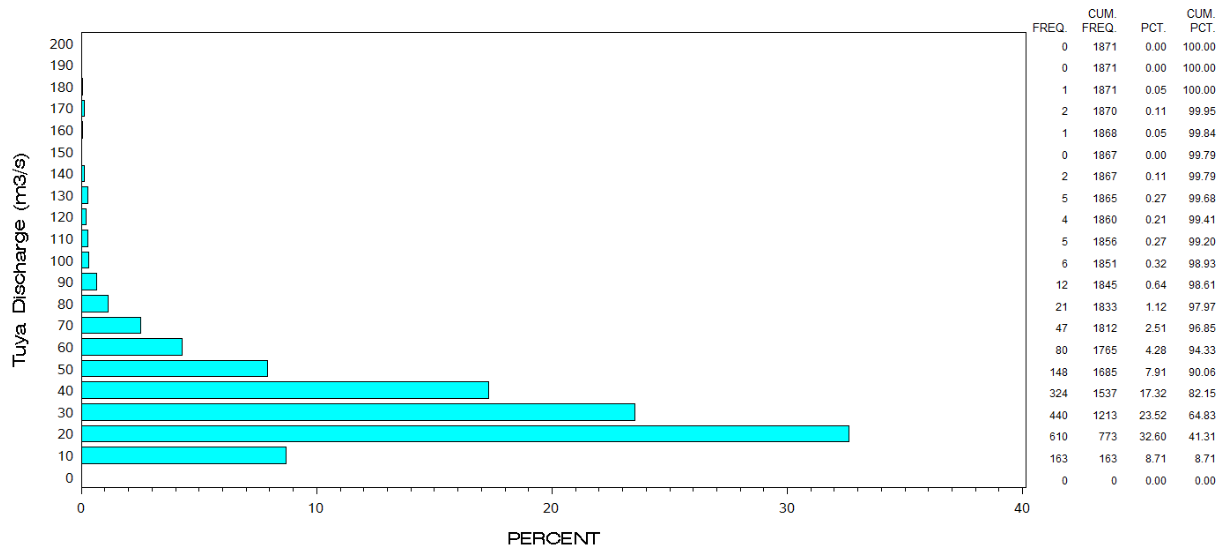


Figure 15. Frequency plot of historical Tahltan Sockeye non-zero migration (unweighted tally of non-zero migration dates), at varying levels of Tuya River discharge (lagged 10 days). Most dates (73%) of migration occur at 20-40 cms at Tuya.

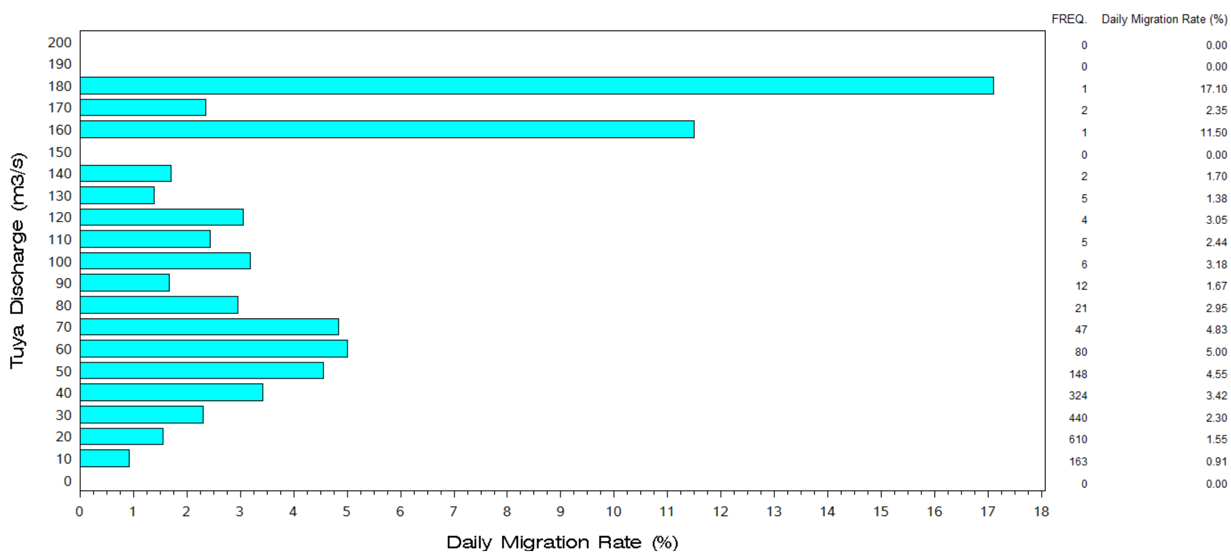


Figure 16. Frequency plot of historical Tahltan Sockeye non-zero migration dates (weighted by daily migration rate), at varying levels of Tuya River discharge (lagged forward 10 days to correspond with timing of Tahltan Sockeye entry into Tahltan River). Ignoring low-frequency occurrences (FREQ < 3), the highest daily migration rates (>3% per day) occur at ~40-80 cms.

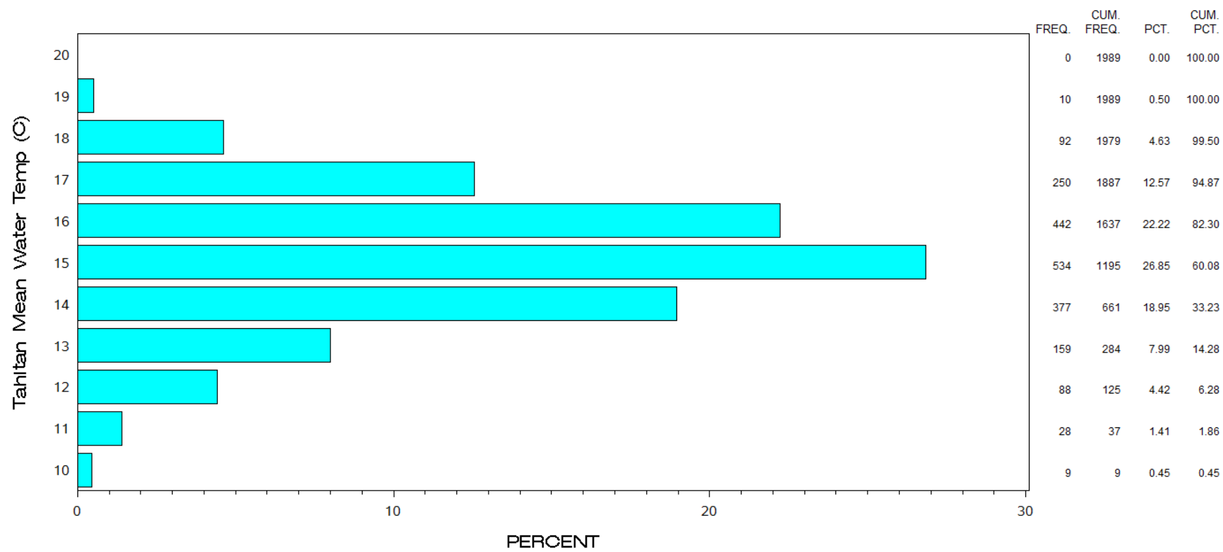


Figure 17. Frequency plot of historical Tahltan Sockeye migration (unweighted tally of non-zero migration dates), at varying levels of Tahltan Lake water temperature. ~80% of migration occurs at 14-17°C.

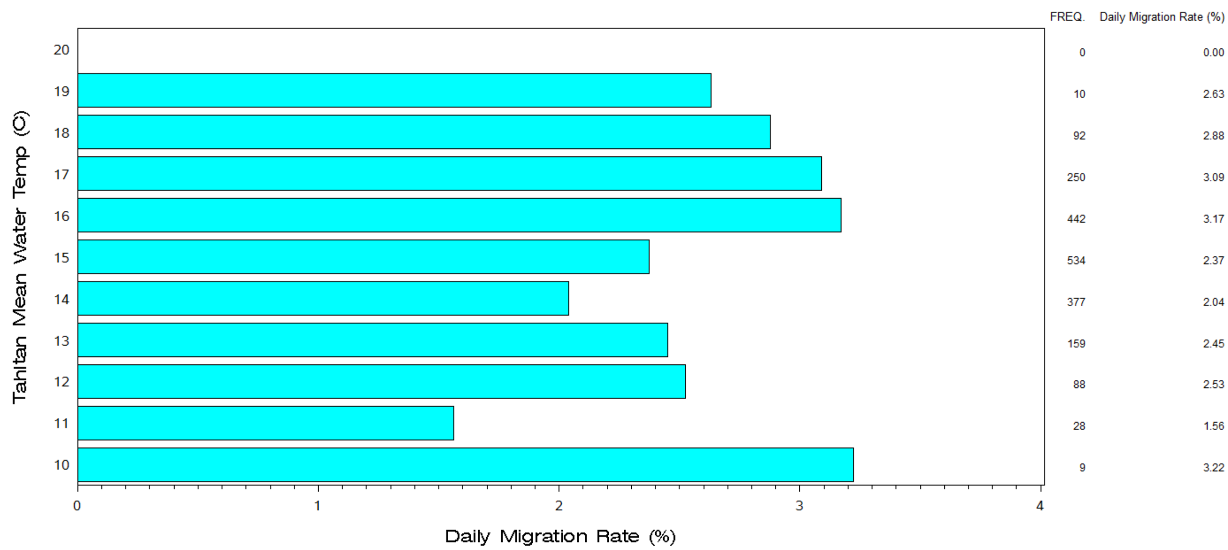


Figure 18. Frequency plot of historical Tahltan Sockeye non-zero migration dates (weighted by daily migration rate), at varying levels of lower Tahltan River water temperature. No significant difference in migration rates across water temperature levels.

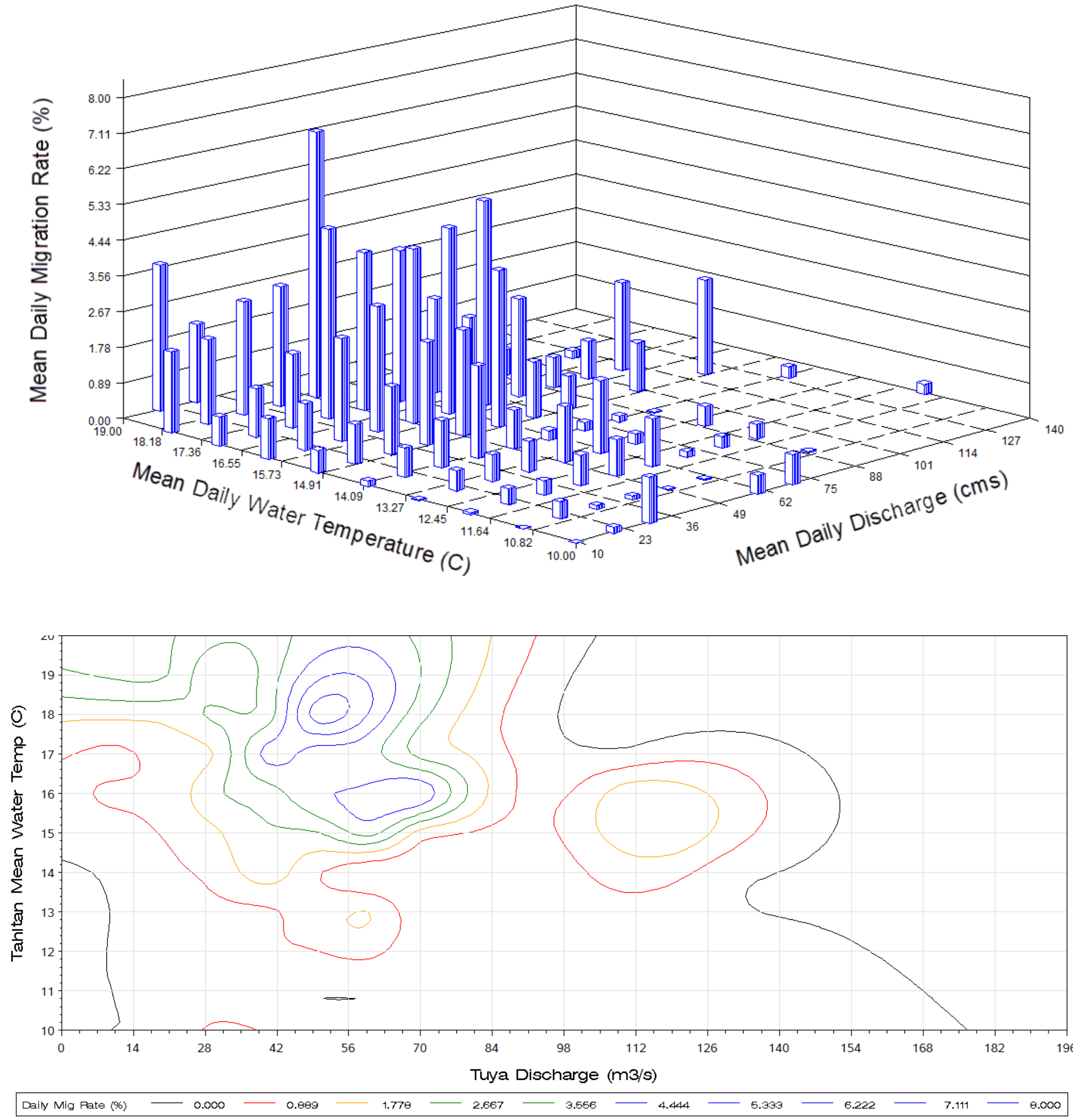


Figure 19. Distribution (top) and smoothed contour (bottom) of historical Tahltan Sockeye migration rates (daily %), at varying levels of Tahltan River water temperature and Tuya River discharge (filtered for a minimum of 3 observations at each MWT x Flow point). Maximum migration rate found at 16-19°C and 40-80 cms.

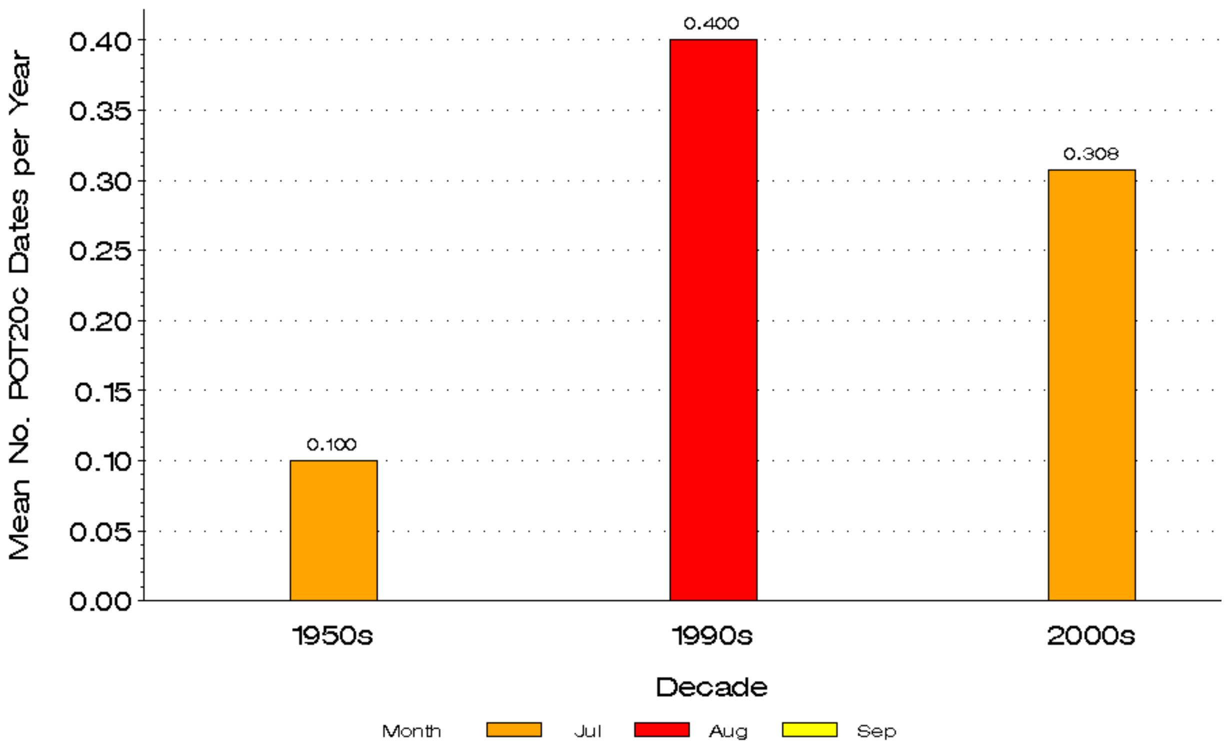


Figure 20. Frequency analysis of decadal mean number of dates per month in which regional daily mean air temperature (at DEASE LAKE) exceeded 20°C.

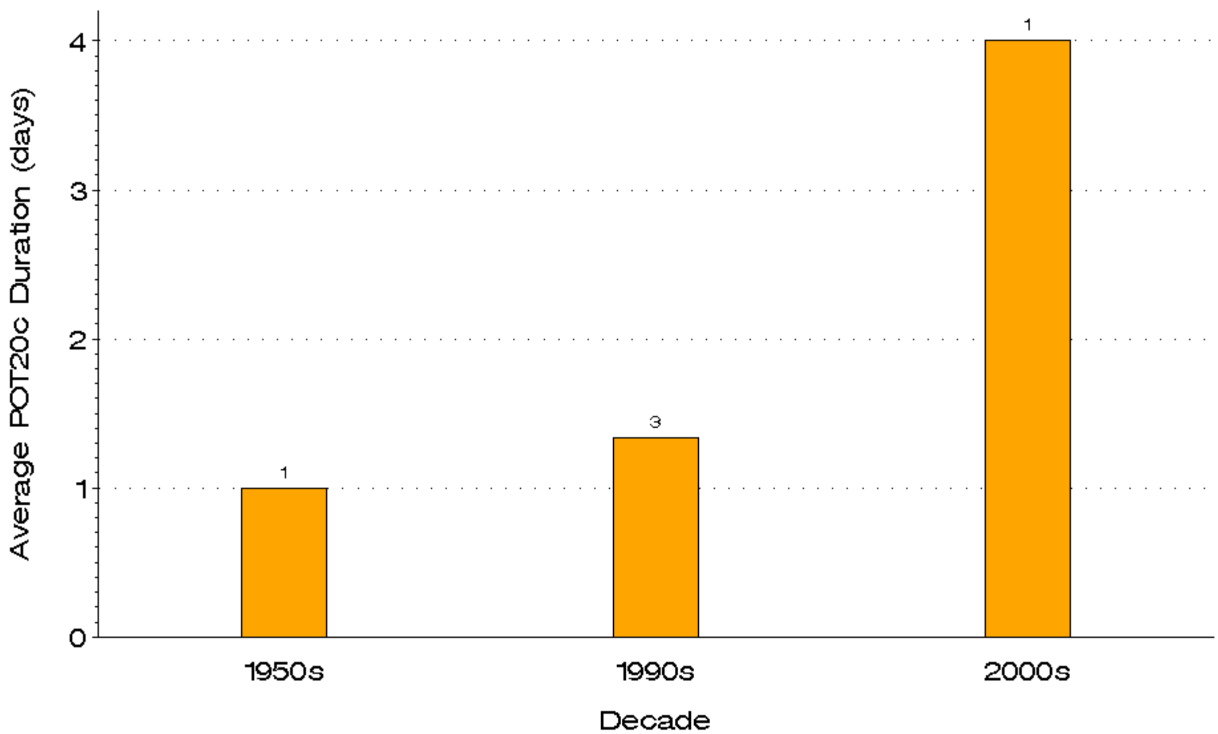


Figure 21. Mean length (days) and total decadal frequency of periods in which regional daily mean air temperature (at DEASE LAKE) exceeded 20°C.

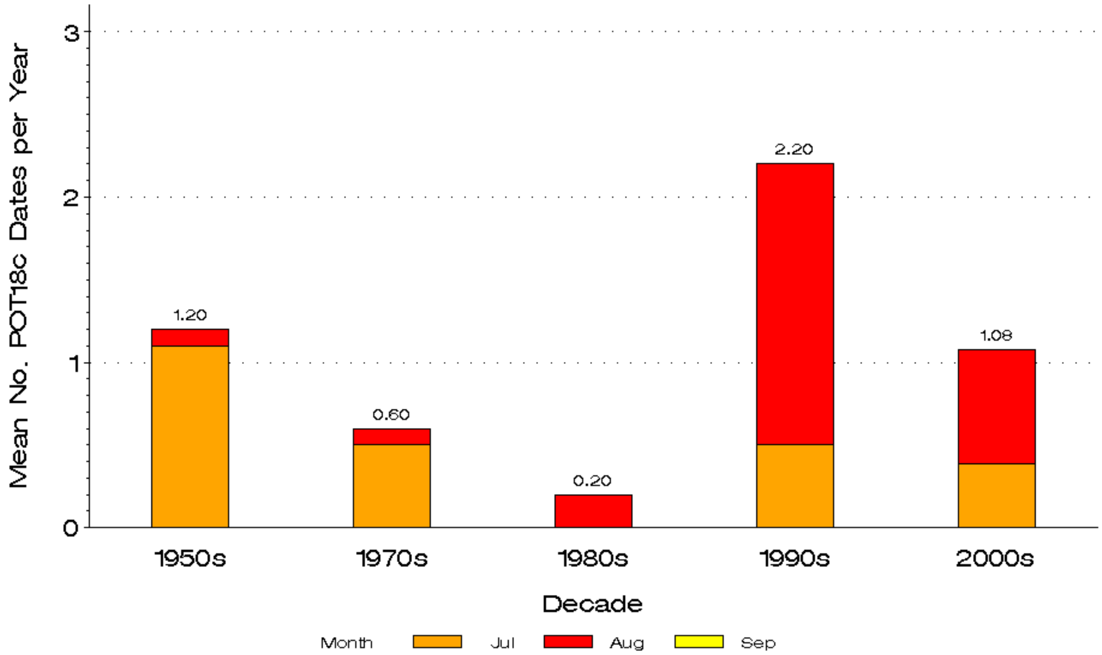


Figure 22. Frequency analysis of decadal mean number of dates per month (Jul-Sep) in which estimated mean water temperature in Tahltan River exceeded 18°C.

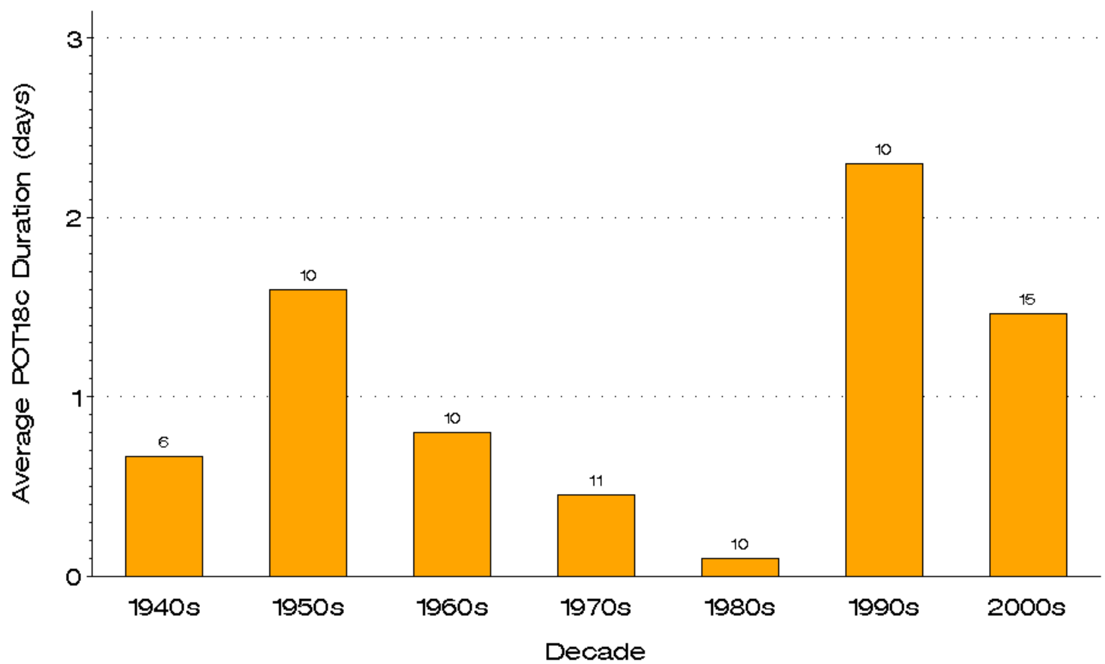


Figure 23. Mean length (days) and total decadal frequency of periods in which estimated daily mean water temperature (Jul-Sep) in Tahltan Lake/River continuously exceeded 18°C, by decade.

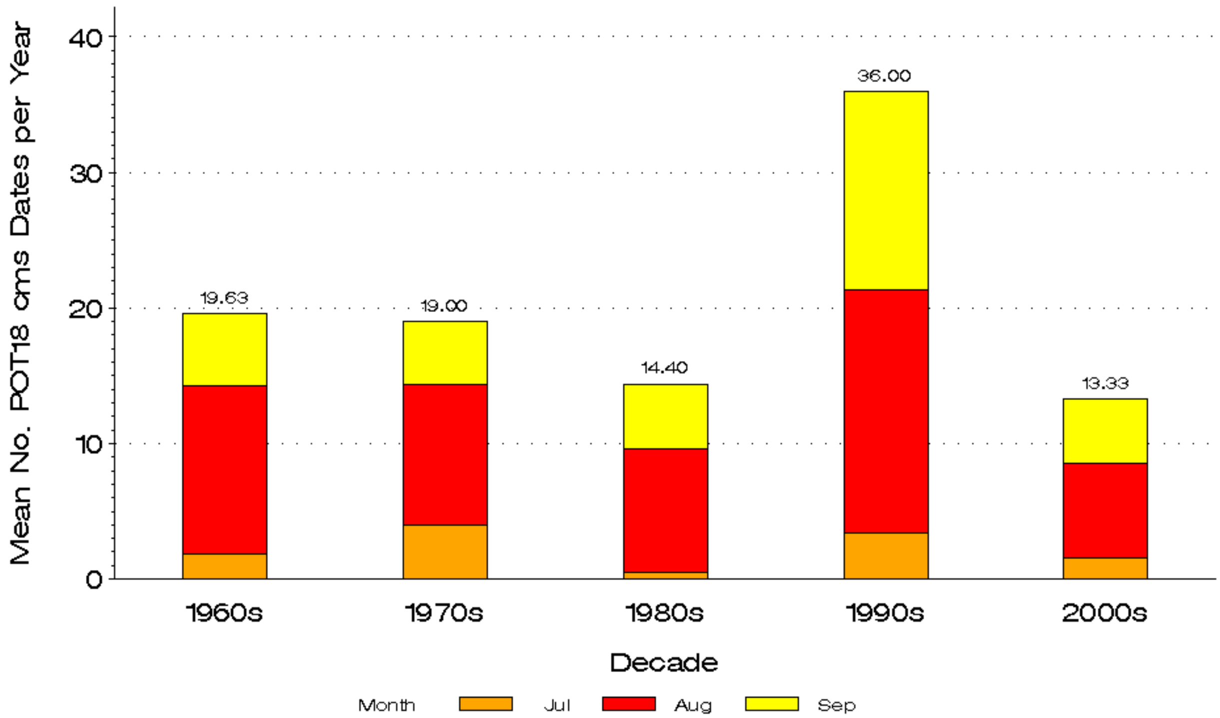


Figure 24. Frequency analysis of decadal mean number of "low flow" dates (below 25th percentile of summer flows, 18 cms) per month (July-September) in Tuya River.

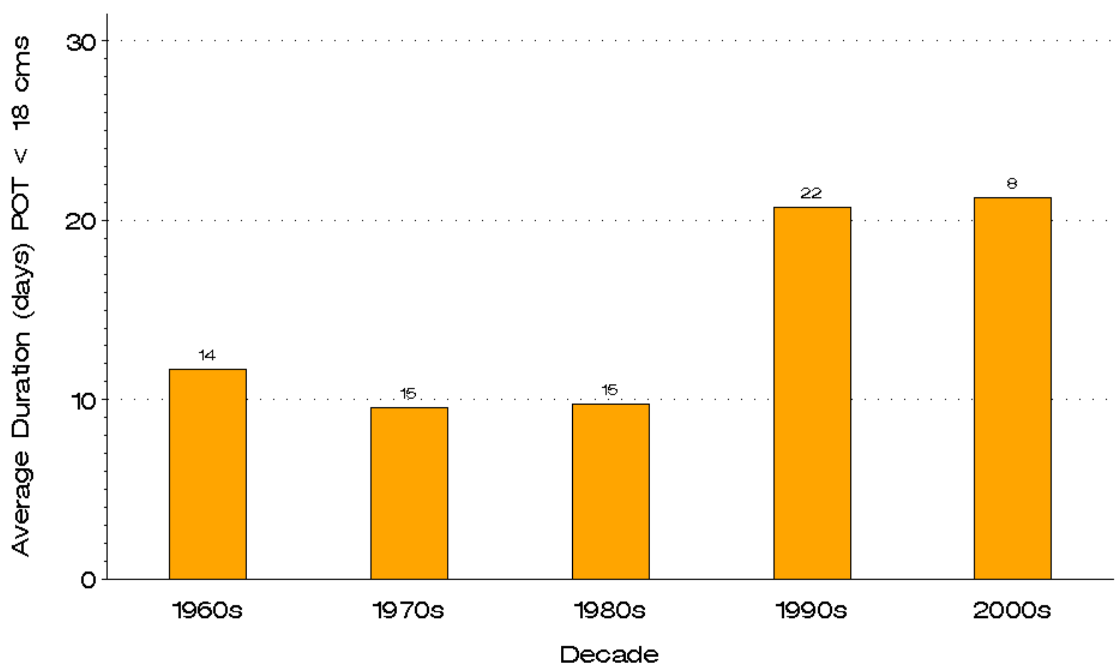


Figure 25. Mean length (days) and frequency of "low flow" periods in which Tuya River discharge continuously remained below the 25th percentile of summer flows (18 cms) in July-September.

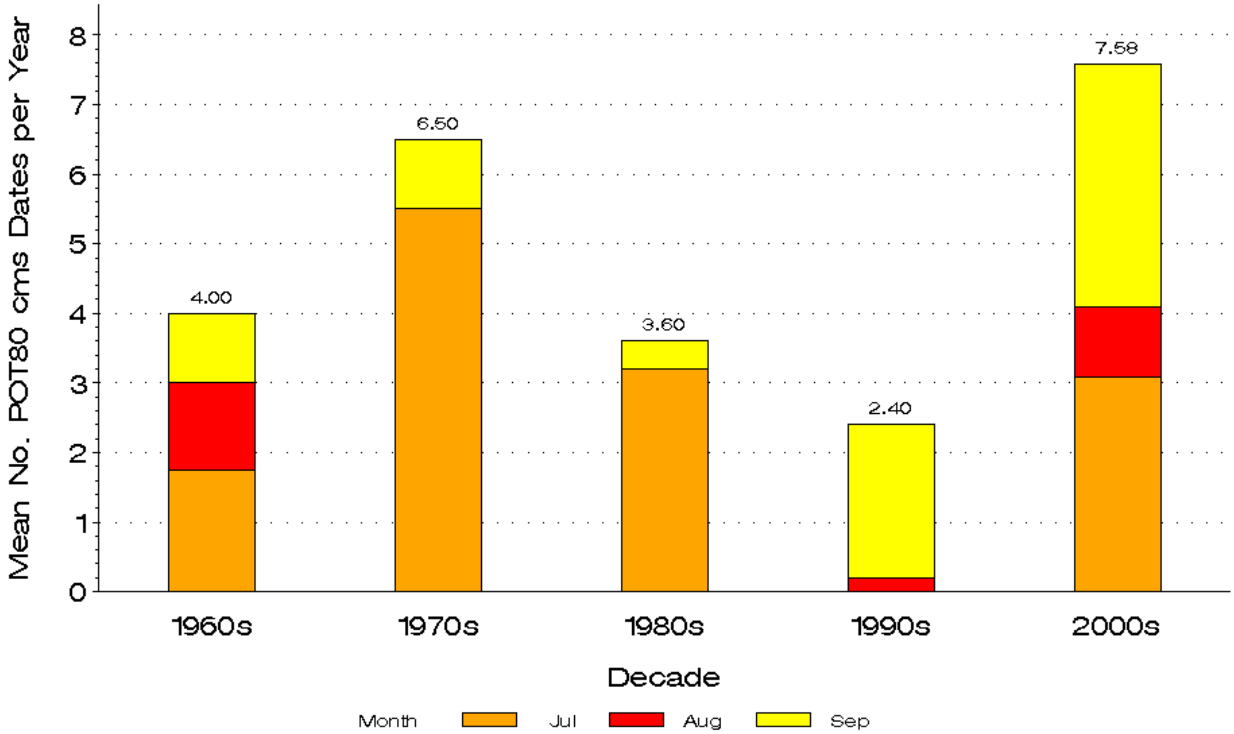


Figure 26. Frequency analysis of decadal mean number of "high flow" dates (> 95th percentile of July-September flows, ~80 cms) per month in Tuya River.

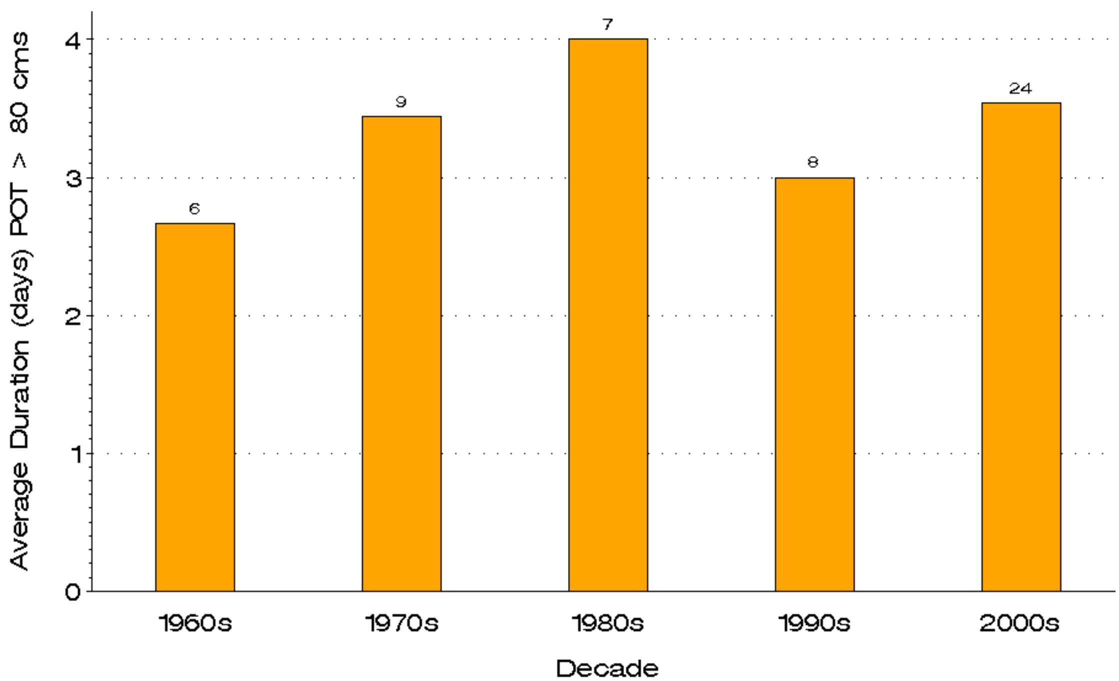


Figure 27. Mean length (days) and frequency of "high flow" periods in which Tuya River discharge continuously remained above 80 cms (i.e., 95th percentile of July-September flows).

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APPENDICES

Appendix A. Site water temperature and water level datasets documented in the FRESHWATER ENVIRONMENTAL VARIABLES DATABASE. Data are available from enclosed CD-ROM where DATA = YES; use CONTACT NAME to access data where DATA = NO.

DFO Mgmt Area: **Yukon Transboundary** Major Drainage: **Stikine** Joint Adaptive Zone: **Lower Stikine | Transboundary Fjords**

Watershed Group	Waterbody	Location	Contact Name	Type	Start	End	Years	Resolution	Status	Data
LOWER ISKUT	Verrett River	Unspecified	DFO - Peter Etherton	Water Temperature	1996	2011	16	Sub-Daily	A	No
LOWER STIKINE	Lower Stikine River	Unspecified	DFO - Peter Etherton	Water Temperature	1979	1998	20	Daily	U	No
	Lower Stikine River	Unspecified	DFO - Peter Etherton	Water Temperature	1999	2011	13	Sub-Daily	A	No
STIKINE	Stikine River	Telegraph Creek	DFO - Peter Etherton	Water Temperature	1999	2011	13	Sub-Daily	A	No
TAHLTAN	Little Tahltan River	Unspecified	DFO - Peter Etherton	Water Temperature	1985	2011	27	Sub-Daily	A	No
	Tahltan Lake	Outlet Weir	DFO - Kim Hyatt	Water Temperature	1944 Sep	2012 Dec	69	Daily	C	Yes
	Tahltan Lake	Outlet Weir	DFO - Kim Hyatt	Water Temperature	1944 Sep	2012 Dec	69	Daily	C	Yes
	Tahltan Lake	Outlet Weir	DFO - Peter Etherton	Water Temperature	1979	1983	5	Daily	U	No
	Tahltan Lake	Outlet Weir	DFO - Peter Etherton	Water Temperature	1984	2011	28	Sub-Daily	A	Yes
	Tahltan Lake	Outlet Weir	DFO - Peter Etherton	Water Level	1996 May	2012 Aug	17	Sub-Daily	A	Yes
	Tahltan River	Bridge Crossing	DFO - Peter Etherton	Water Temperature	2000	2011	12	Sub-Daily	A	No
TUYA	Tuya Lake	Unspecified	DFO - Peter Etherton	Water Temperature	2000	2011	12	Sub-Daily	A	No
	Tuya River	Bridge	DFO - Peter Etherton	Water Temperature	2000	2011	12	Sub-Daily	A	No

Appendix B. Climate reference station datasets documented in the FRESHWATER ENVIRONMENTAL VARIABLES DATABASE. Daily AHCCD data must be requested from ENV. CANADA CLIMATE RESEARCH DIVISION (ahccd@ec.gc.ca). Daily WSD discharge data are available online at the WATER SURVEY OF CANADA website: http://www.wsc.ec.gc.ca/applications/ H2O/HydromatD-eng.cfm.

Climate Reference Meta-Data — Adjusted and Homogenized Canadian Climate Data (AHCCD)

DFO Mgmt Area: **Yukon Transboundary** Major Drainage: **MacKenzie** Joint Adaptive Zone: **Upper Liard | Arctic Ocean**

Watershed Group	Waterbody	Location	Contact Name	Type	Start	End	Years	Resolution	Status	Data
DEASE LAKE	Dease Lake	DEASE LAKE	Climate Research Division - Lucie Vincent	Air Temperature	1944	2010	67	Daily	A	No
	Dease Lake	DEASE LAKE	Climate Research Division - Lucie Vincent	Precipitation	1945	2008	64	Daily	D	No
	Dease Lake	DEASE LAKE	-	Barometric Pressure	1953	2008	56	Daily	D	No
	Dease Lake	DEASE LAKE (AUT)	-	Barometric Pressure	1993	2008	16	Daily	D	No

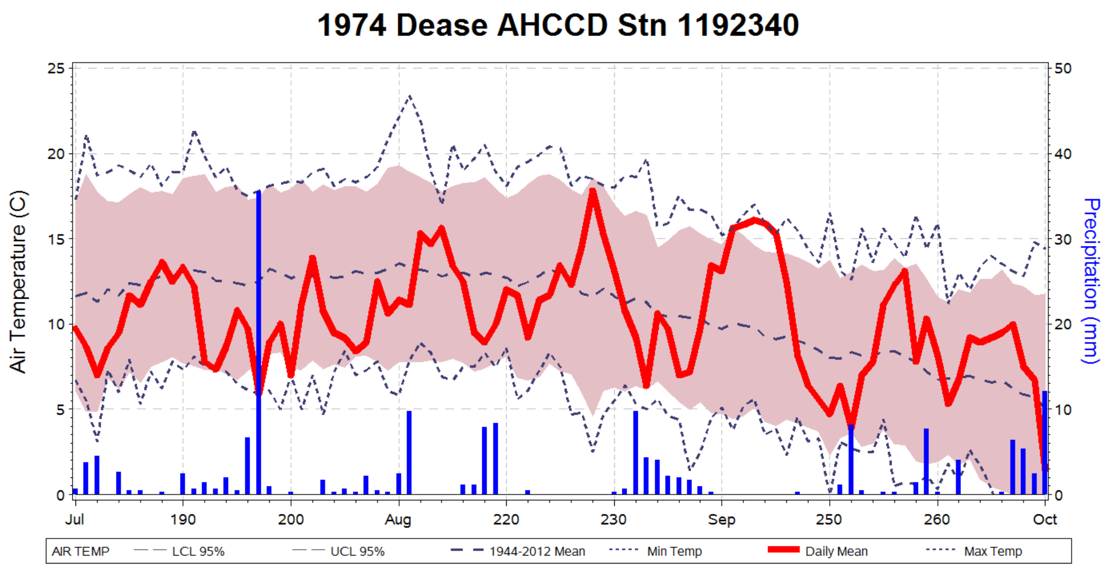
Climate Reference Meta-Data — Env Canada WSD - Non-RHBN Stations

DFO Mgmt Area: **Yukon Transboundary** Major Drainage: **Stikine** Joint Adaptive Zone: **Lower Stikine | Transboundary Fjords**

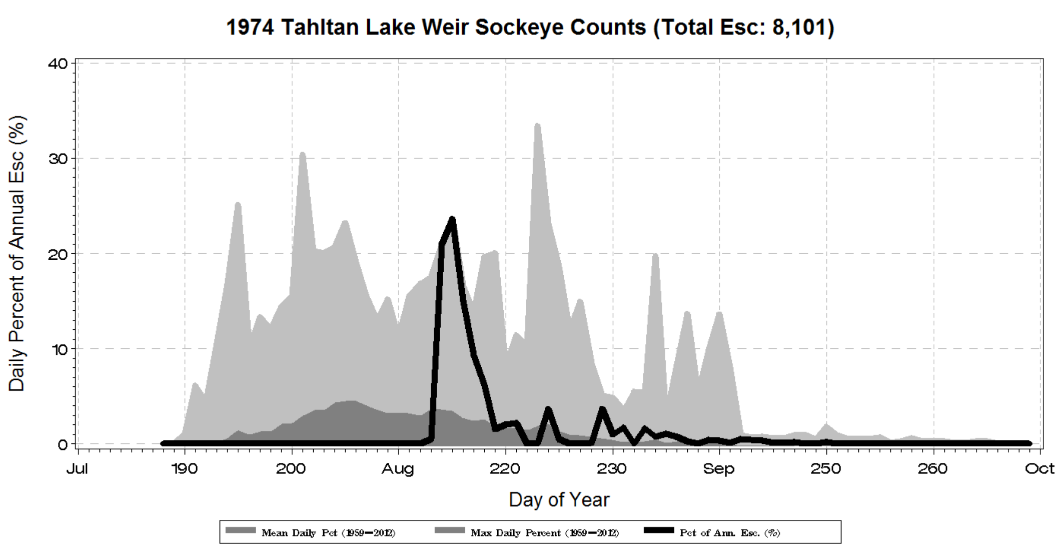
Watershed Group	Waterbody	Location	Contact Name	Type	Start	End	Years	Resolution	Status	Data
ISKUT	Iskut River	ISKUT RIVER BELOW JOHNSON RIVER	WSD -	Water Flow	1959	Current	55	Daily	A	No
LOWER STIKINE	Stikine River	STIKINE RIVER NEAR WRANGELL	USGS -	Water Temperature	1976 Jul	1981 Aug	6	Daily	A	No
	Stikine River	STIKINE RIVER NEAR WRANGELL	USGS -	Air Temperature	1984	Current	30	Daily	A	No
	Stikine River	STIKINE RIVER NEAR WRANGELL	USGS -	Water Flow	1984	Current	30	Daily	A	No
STIKINE	Stikine River	STIKINE RIVER AT TELEGRAPH CREEK	WSD -	Water Flow	1954	Current	60	Daily	A	Yes
TUYA	Tuya River	TUYA RIVER NEAR TELEGRAPH CREEK	WSD -	Water Flow	1962	Current	52	Daily	A	Yes

Appendix C. Multi-panel plots of daily Tahltan Sockeye daily migration in relation to environmental variables, by year, 1959-2012.

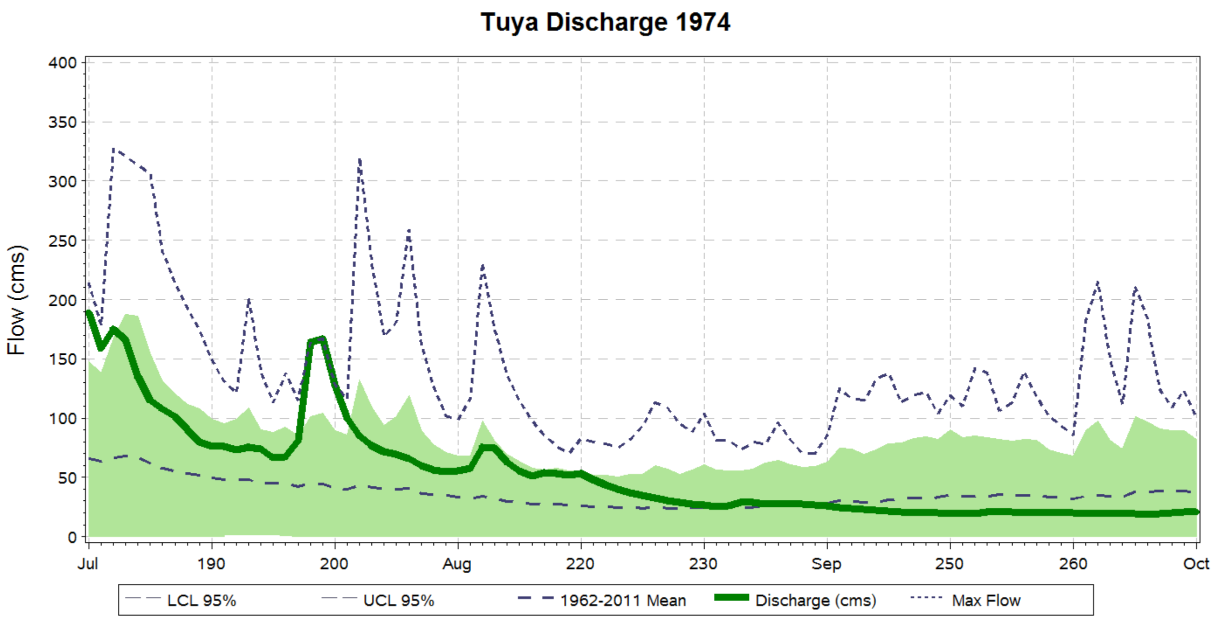
Sample plots for the year 1974 display legends with vertical axis variates and horizontal axis with day of year (month label is *approximate* start of each month). Annual plots (following pages) are organized in a multi-panel format for comparison of the following variates:



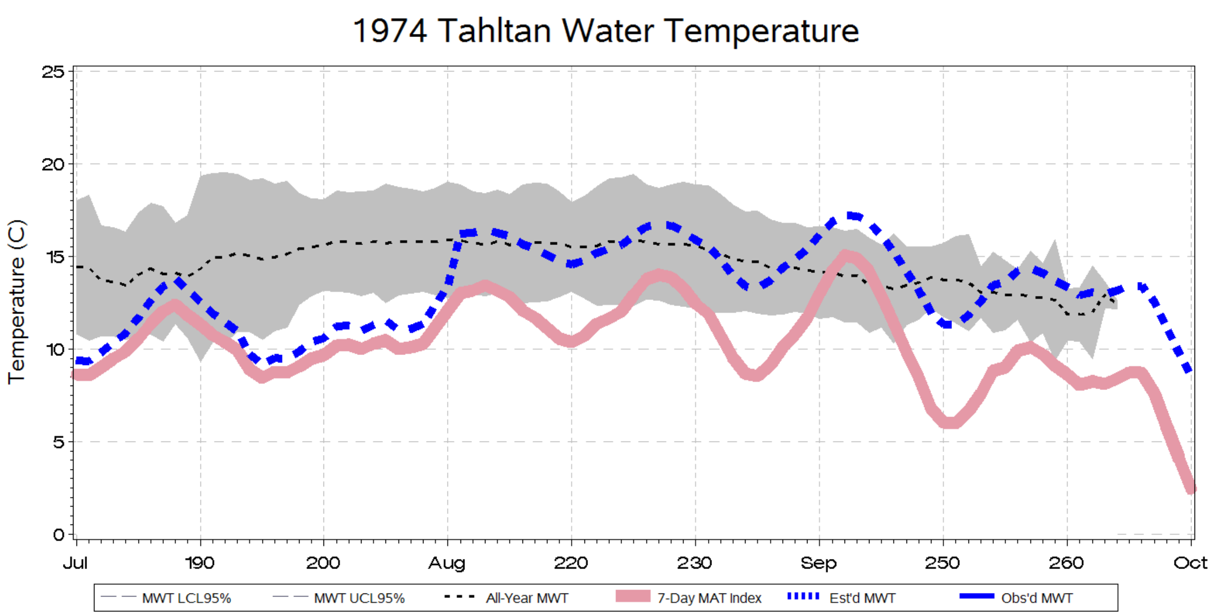
1. Precipitation (mm, blue bars) and daily mean air temperature (°C, red line) with historical (1944-2012) daily air temperature mean and variance (dashed line and red area), from EC meteorological station *Dease Lake*.



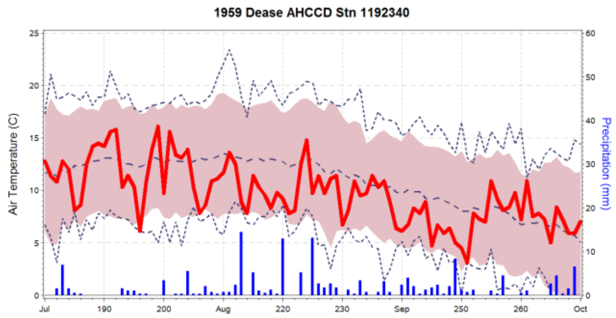
2. Daily migration rates as a percent (%) of annual stock escapement (black line), from daily sockeye (adult + jack) migrants counted at the Tahltan Lake weir, with historical mean (dark gray area) and maximum (light gray area) daily migration rate for 1959-2012.

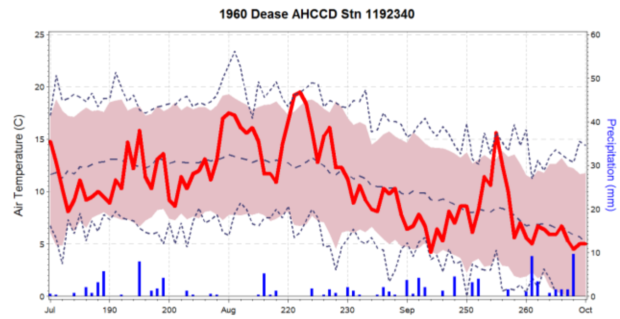


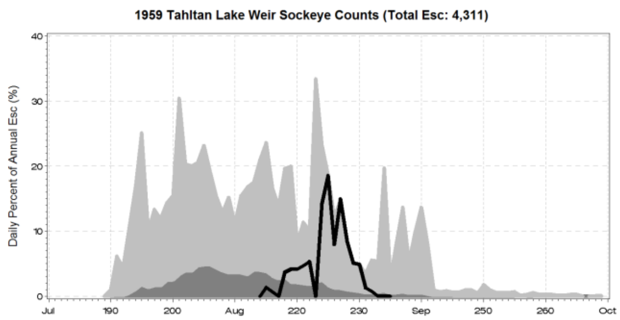
3. Daily mean discharge (cms) at WSC station *Tuya River* (green line), with historical daily mean and variance (dashed line and green area), 1962-2012.

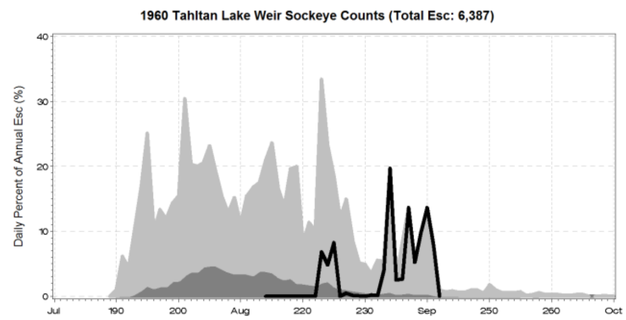


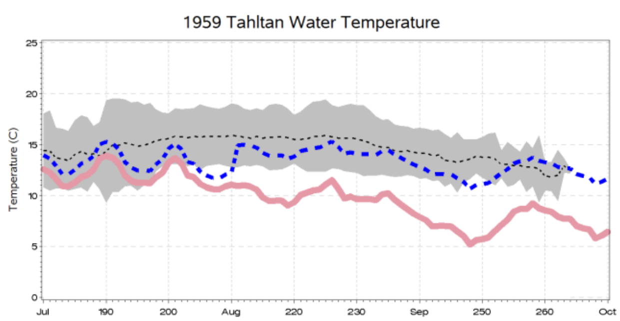
4. Observed (solid blue line) and estimated (dashed blue line) daily mean water temperature in Tahltan River, with historical daily MWT and variance (dashed gray line and gray area), 1984-2012; and daily 7-day MAT air temperature index (pink).

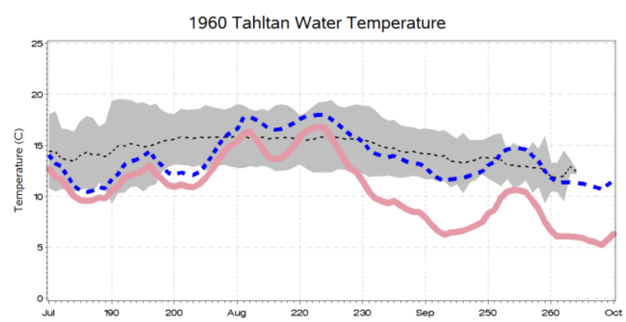

1959 Dease AHCCD Stn 1192340
Air Temperature (C)
Precipitation (mm)
Jul
190
200
Aug
220
230
Sep
250
260
Oct

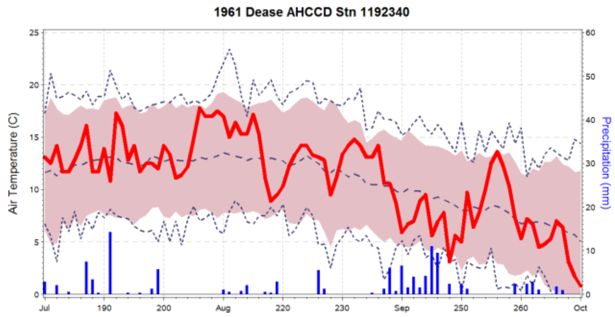

1960 Dease AHCCD Stn 1192340
Air Temperature (C)
Precipitation (mm)
Jul
190
200
Aug
220
230
Sep
250
260
Oct

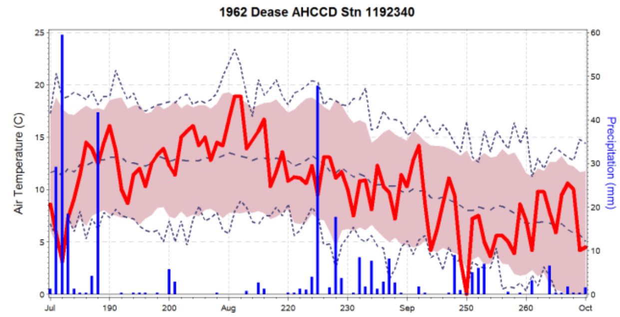

1959 Tahltan Lake Weir Sockeye Counts (Total Esc: 4,311)
Daily Percent of Annual Esc (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct

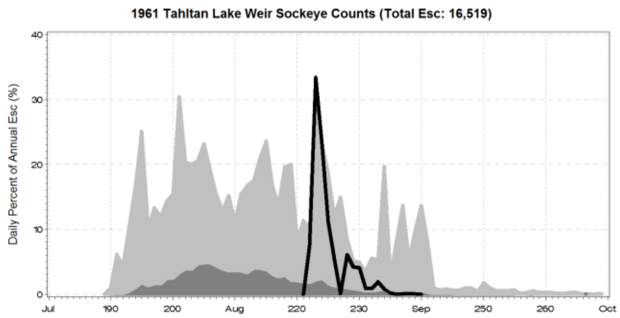

1960 Tahltan Lake Weir Sockeye Counts (Total Esc: 6,387)
Daily Percent of Annual Esc (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct

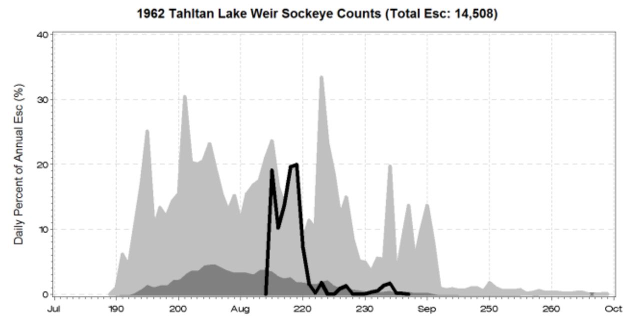

1959 Tahltan Water Temperature
Temperature (C)
Jul
190
200
Aug
220
230
Sep
250
260
Oct

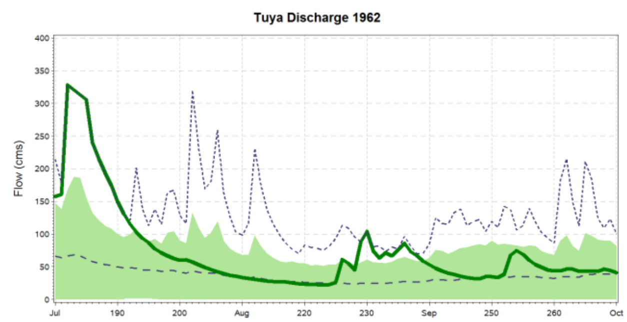

1960 Tahltan Water Temperature
Temperature (C)
Jul
190
200
Aug
220
230
Sep
250
260
Oct

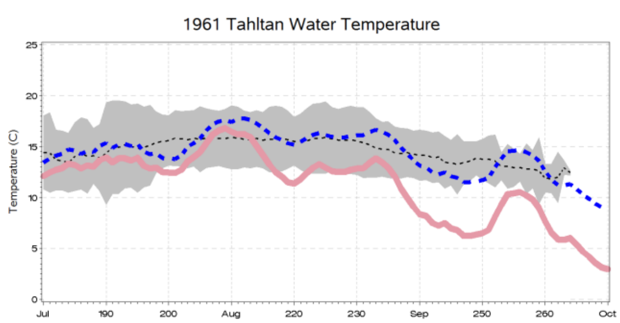

1961 Dease AHCCD Stn 1192340
Air Temperature (C)
Precipitation (mm)
Jul
190
200
Aug
220
230
Sep
250
260
Oct

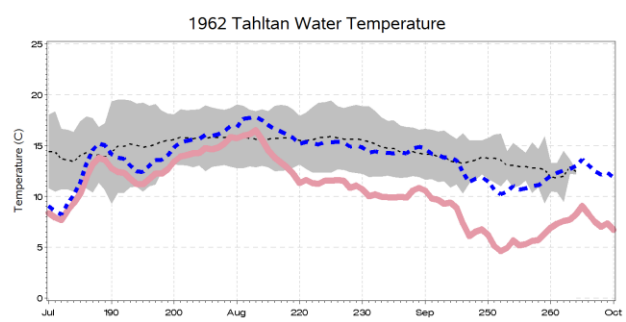

1962 Dease AHCCD Stn 1192340
Air Temperature (C)
Precipitation (mm)
Jul
190
200
Aug
220
230
Sep
250
260
Oct

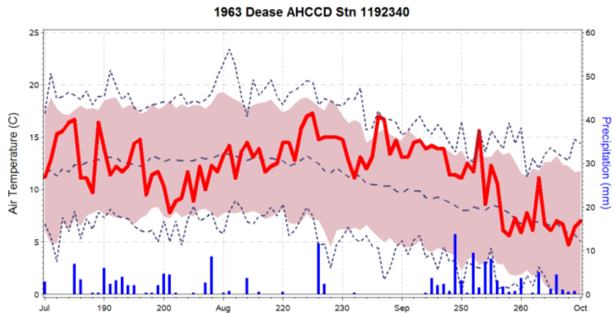

1961 Tahltan Lake Weir Sockeye Counts (Total Esc: 16,519)
Daily Percent of Annual Esc (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct

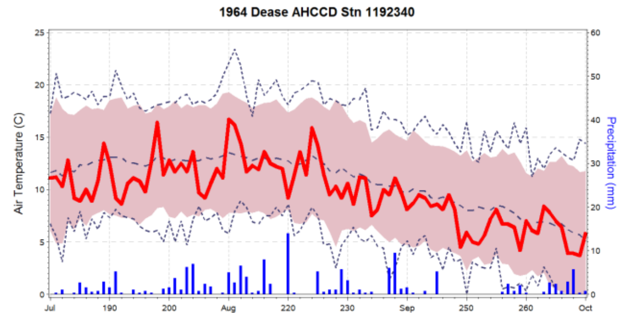

1962 Tahltan Lake Weir Sockeye Counts (Total Esc: 14,508)
Daily Percent of Annual Esc (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct

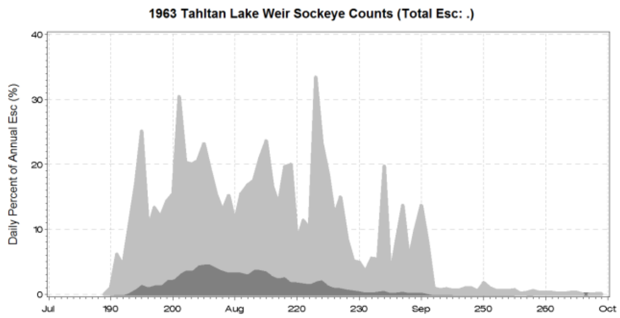

Tuya Discharge 1962
Flow (cms)
Jul
190
200
Aug
220
230
Sep
250
260
Oct

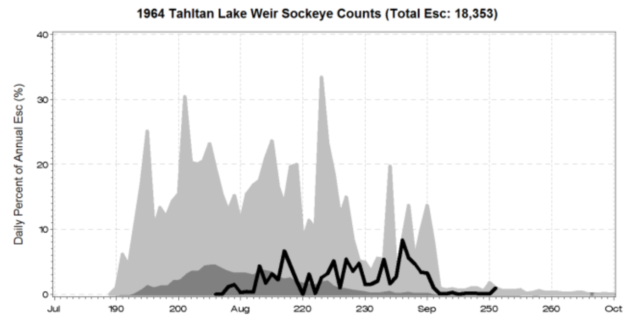

1961 Tahltan Water Temperature
Temperature (C)
Jul
190
200
Aug
220
230
Sep
250
260
Oct

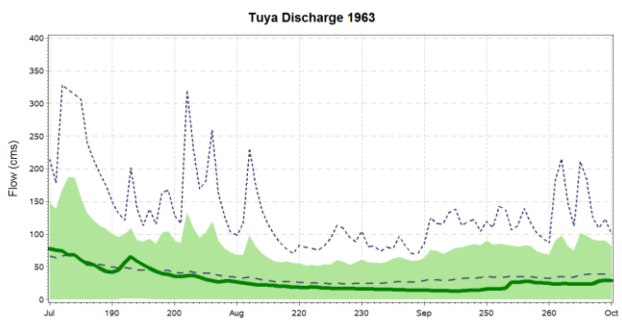

1962 Tahltan Water Temperature
Temperature (C)
Jul
190
200
Aug
220
230
Sep
250
260
Oct

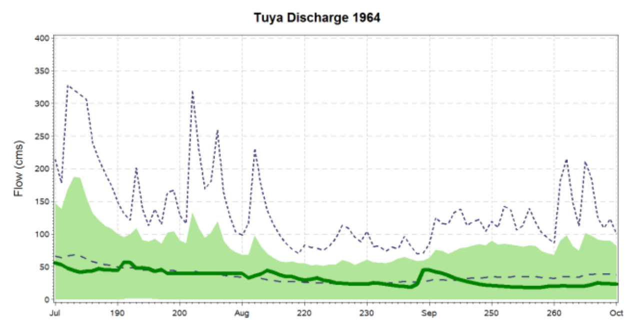

1963 Dease AHCCD Stn 1192340
Air Temperature (C)
Precipitation (mm)

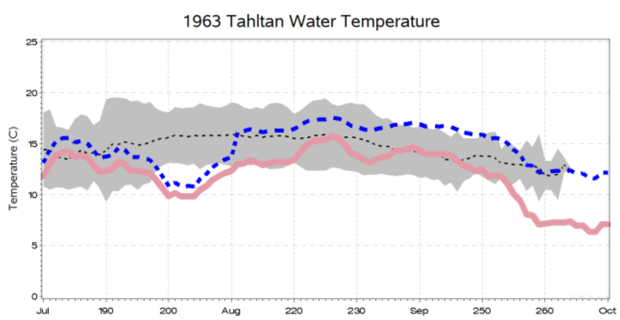

1964 Dease AHCCD Stn 1192340
Air Temperature (C)
Precipitation (mm)

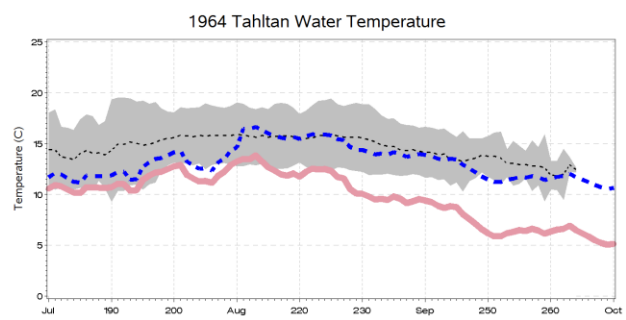

1963 Tahltan Lake Weir Sockeye Counts (Total Esc: .)
Daily Percent of Annual Esc (%)


1964 Tahltan Lake Weir Sockeye Counts (Total Esc: 18,353)
Daily Percent of Annual Esc (%)

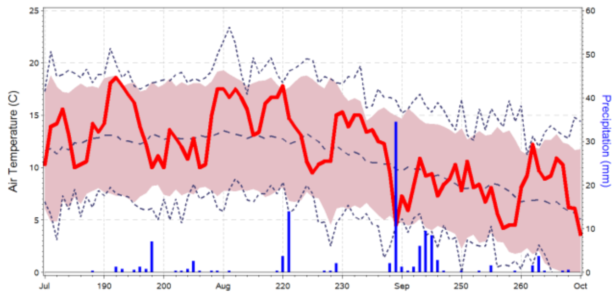

Tuya Discharge 1963
Flow (cms)


Tuya Discharge 1964
Flow (cms)

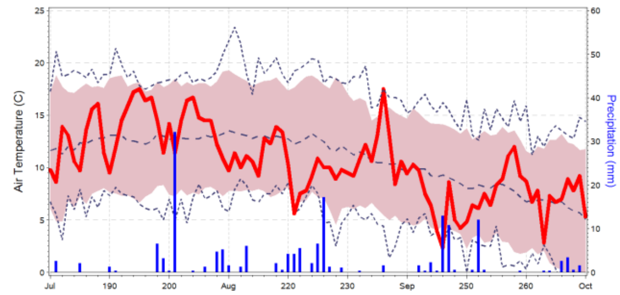

1963 Tahltan Water Temperature
Temperature (C)


1964 Tahltan Water Temperature
Temperature (C)

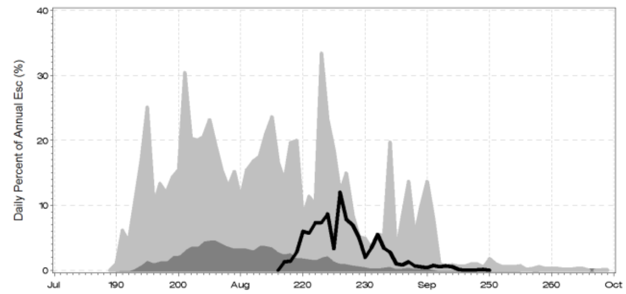
1965 Dease AHCCD Stn 1192340



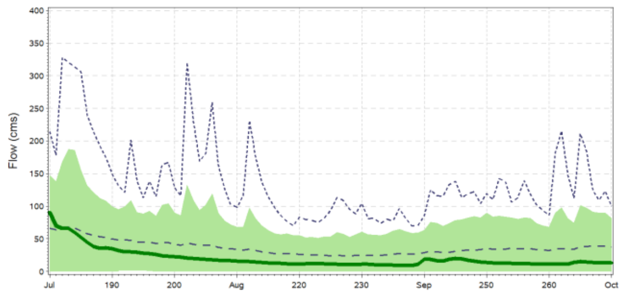
1966 Dease AHCCD Stn 1192340



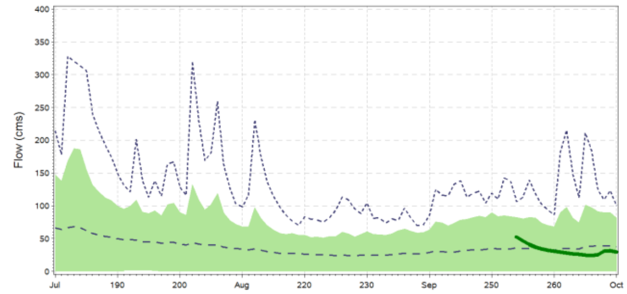
1966 Tahltan Lake Weir Sockeye Counts (Total Esc: 21,580)



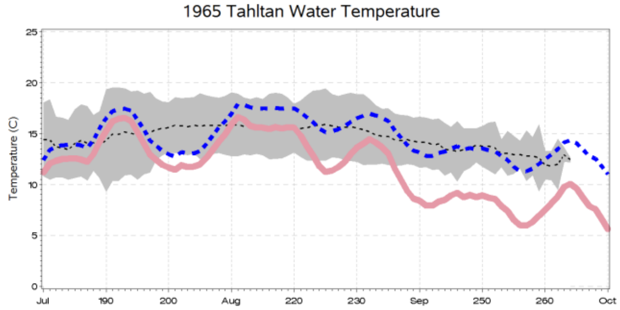
Tuya Discharge 1965



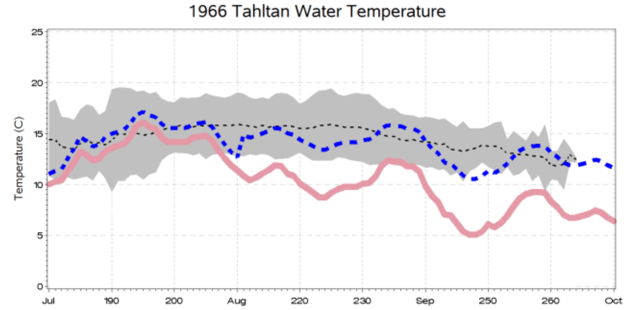
Tuya Discharge 1966

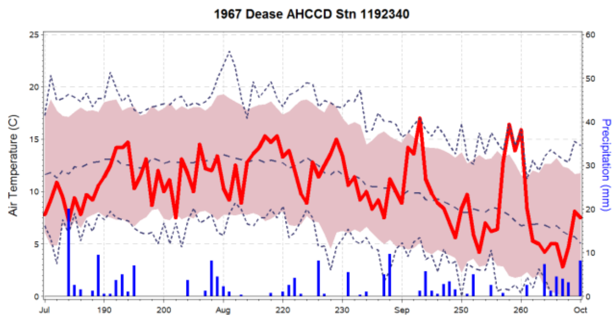


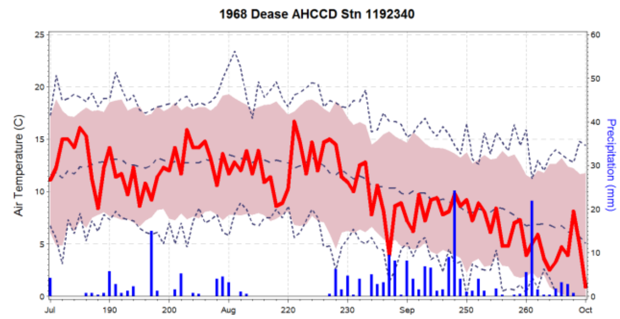
1965 Tahltan Water Temperature

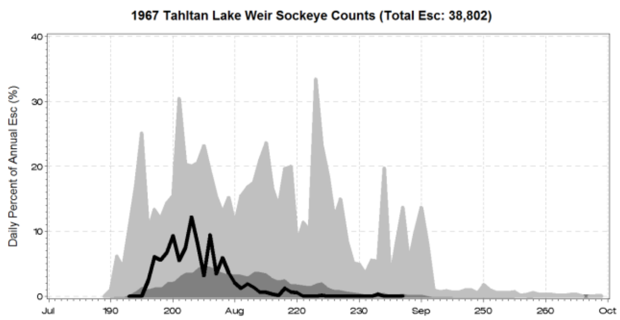


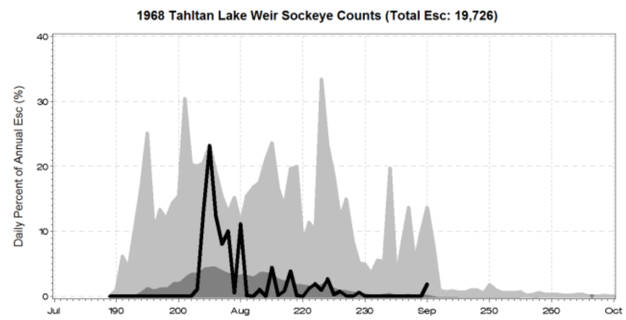
1966 Tahltan Water Temperature

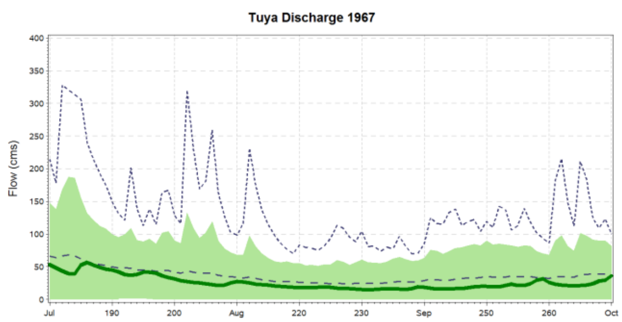


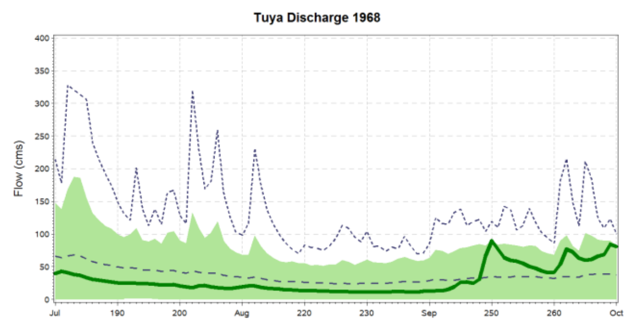

1967 Dease AHCCD Stn 1192340
Air Temperature (C)
Precipitation (mm)

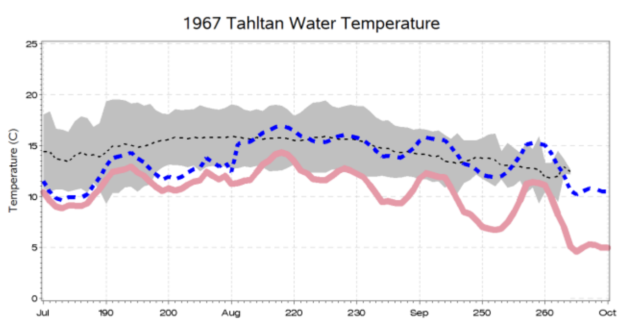

1968 Dease AHCCD Stn 1192340
Air Temperature (C)
Precipitation (mm)

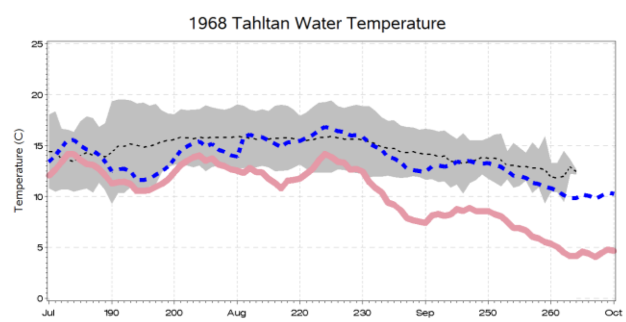

1967 Tahltan Lake Weir Sockeye Counts (Total Esc: 38,802)
Daily Percent of Annual Esc (%)


1968 Tahltan Lake Weir Sockeye Counts (Total Esc: 19,726)
Daily Percent of Annual Esc (%)

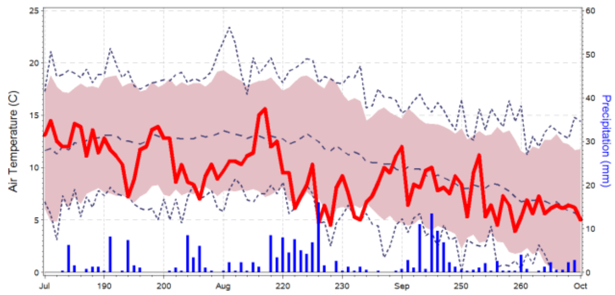

Tuya Discharge 1967
Flow (cms)


Tuya Discharge 1968
Flow (cms)

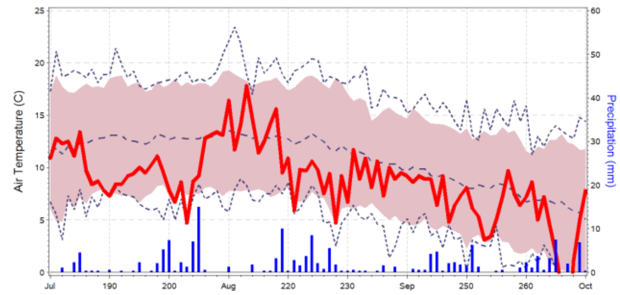

1967 Tahltan Water Temperature
Temperature (C)


1968 Tahltan Water Temperature
Temperature (C)

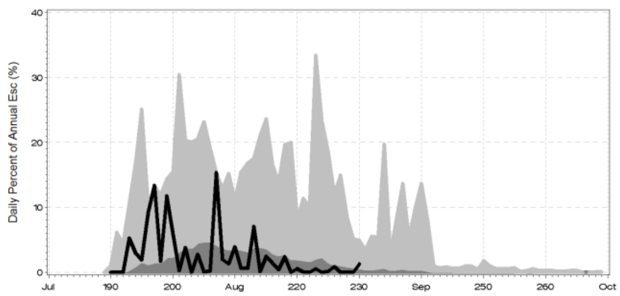
1969 Dease AHCCD Stn 1192340



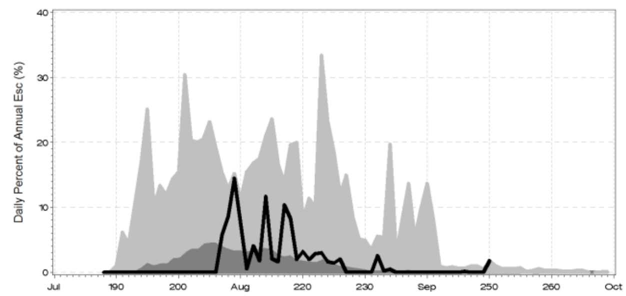
1970 Dease AHCCD Stn 1192340



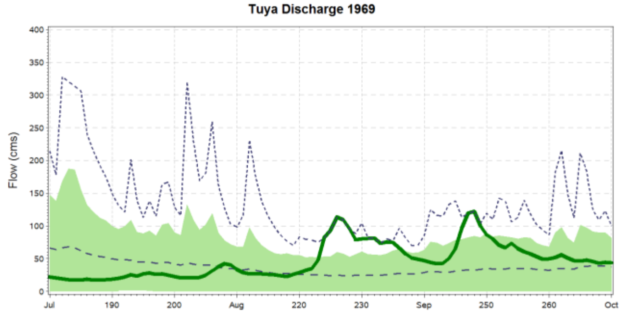
1969 Tahltan Lake Weir Sockeye Counts (Total Esc: 11,805)



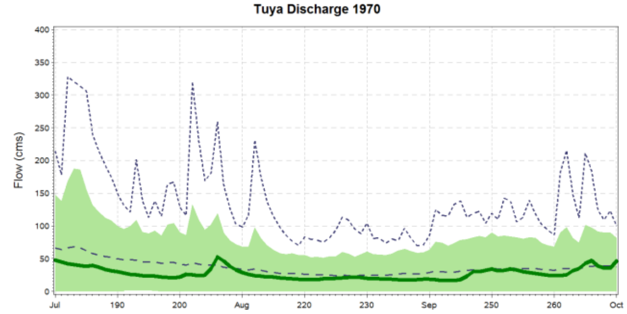
1970 Tahltan Lake Weir Sockeye Counts (Total Esc: 8,430)



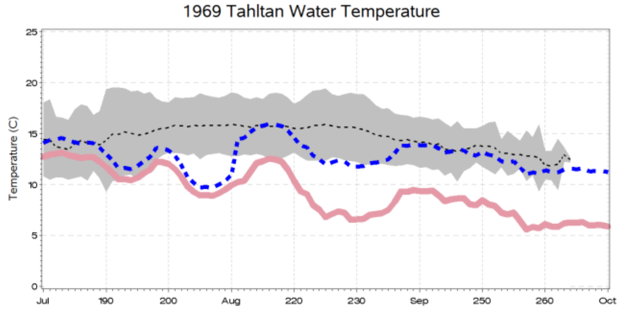
Tuya Discharge 1969



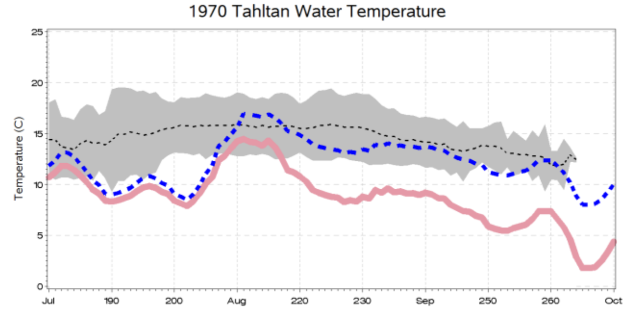
Tuya Discharge 1970



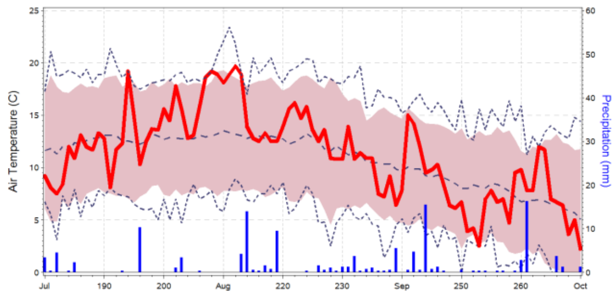
1969 Tahltan Water Temperature



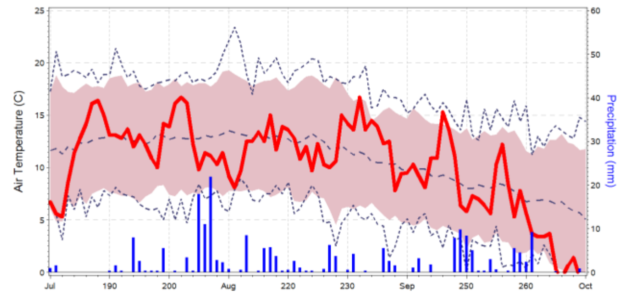
1970 Tahltan Water Temperature



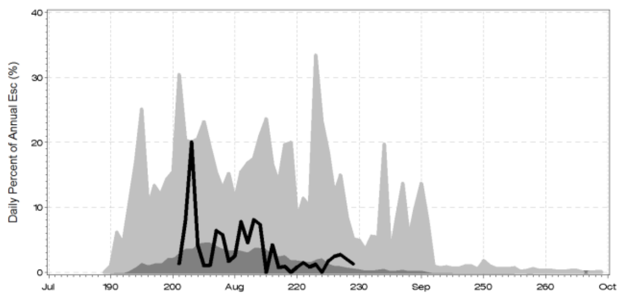
1971 Dease AHCCD Stn 1192340



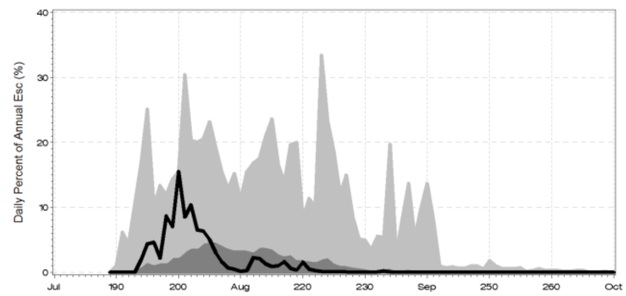
1972 Dease AHCCD Stn 1192340



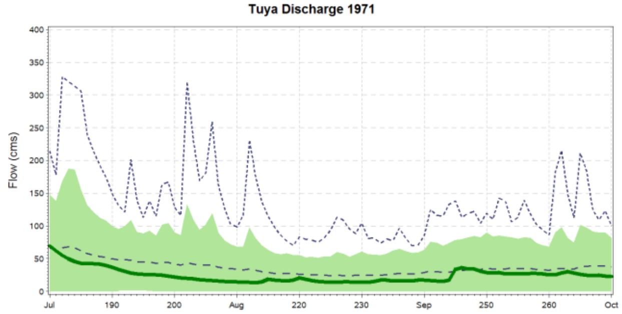
1971 Tahltan Lake Weir Sockeye Counts (Total Esc: 18,523)



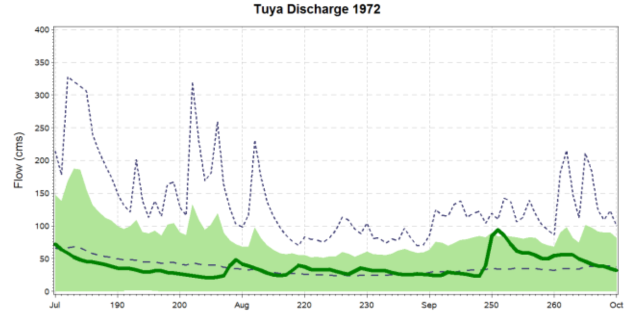
1972 Tahltan Lake Weir Sockeye Counts (Total Esc: 52,454)



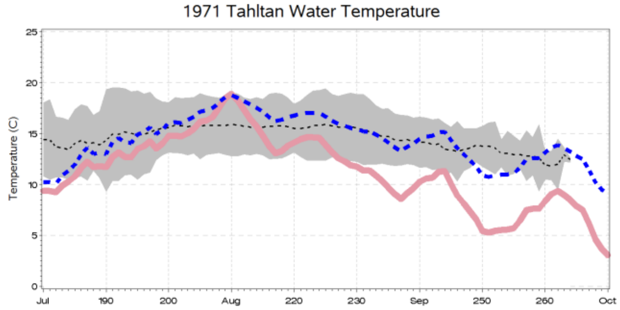
Tuya Discharge 1971



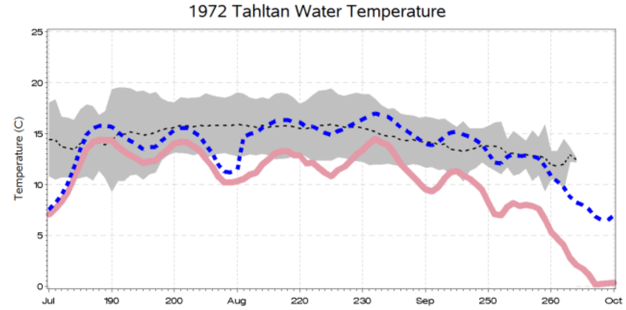
Tuya Discharge 1972



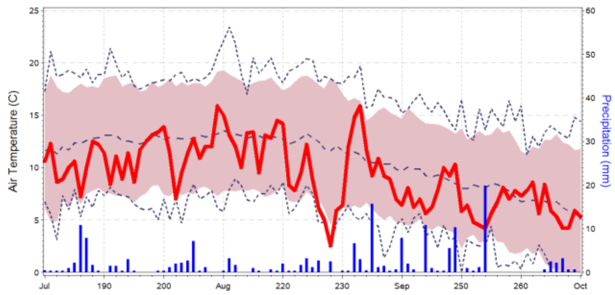
1971 Tahltan Water Temperature



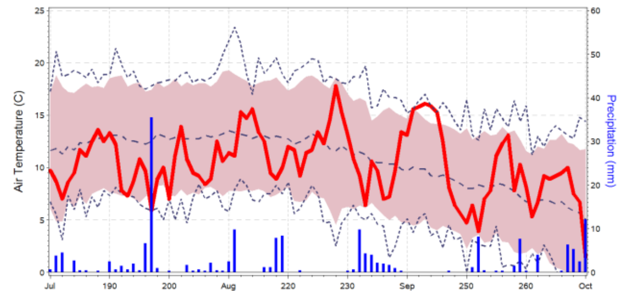
1972 Tahltan Water Temperature



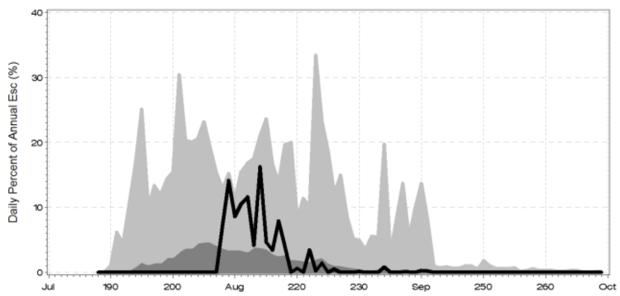
1973 Dease AHCCD Stn 1192340



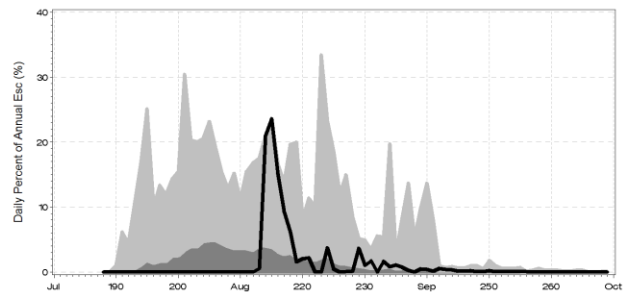
1974 Dease AHCCD Stn 1192340



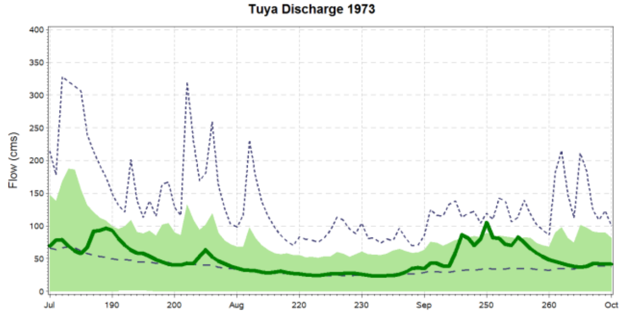
1973 Tahltan Lake Weir Sockeye Counts (Total Esc: 2,864)



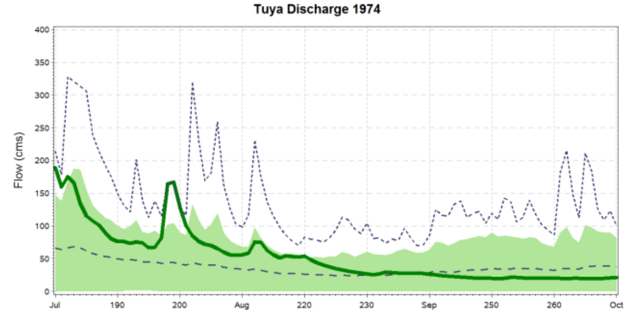
1974 Tahltan Lake Weir Sockeye Counts (Total Esc: 8,101)



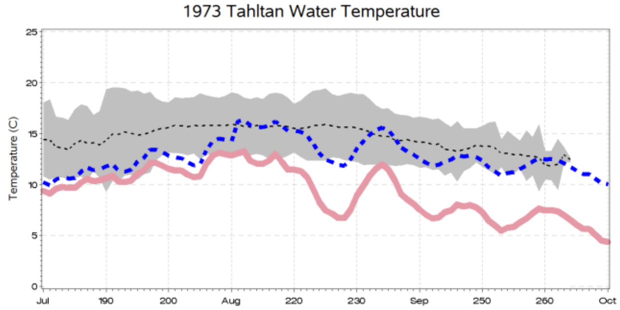
Tuya Discharge 1973



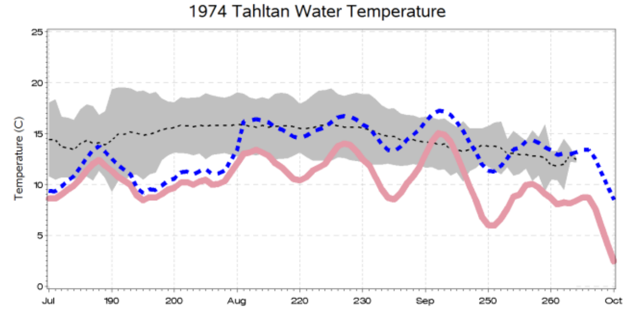
Tuya Discharge 1974



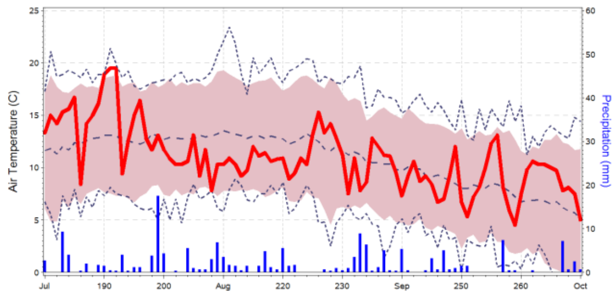
1973 Tahltan Water Temperature



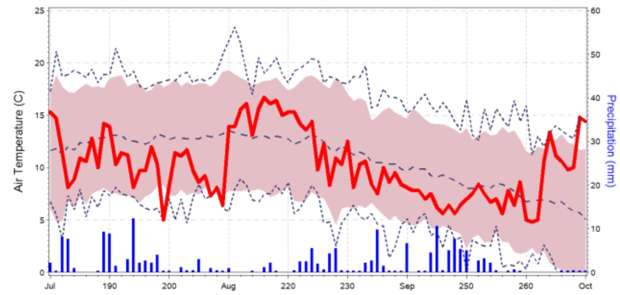
1974 Tahltan Water Temperature



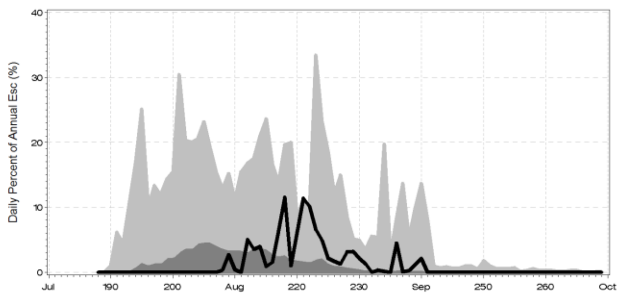
1975 Dease AHCCD Stn 1192340



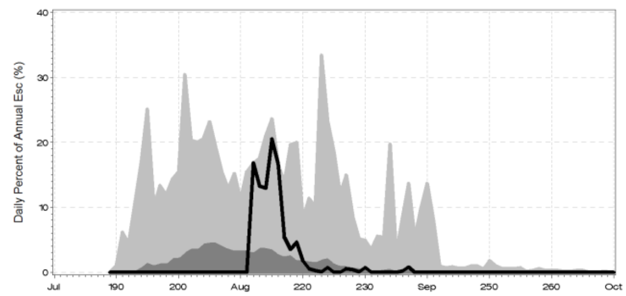
1976 Dease AHCCD Stn 1192340



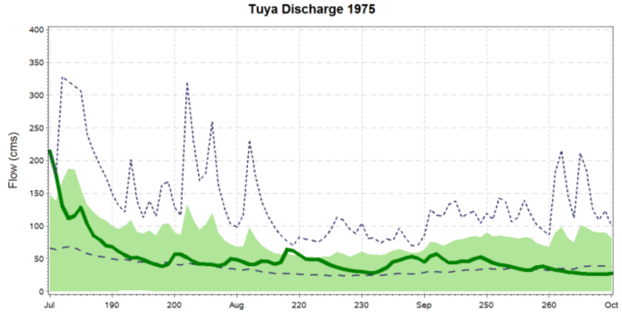
1975 Tahltan Lake Weir Sockeye Counts (Total Esc: 8,159)



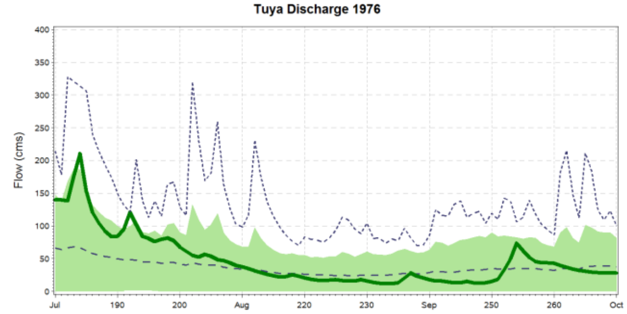
1976 Tahltan Lake Weir Sockeye Counts (Total Esc: 24,111)



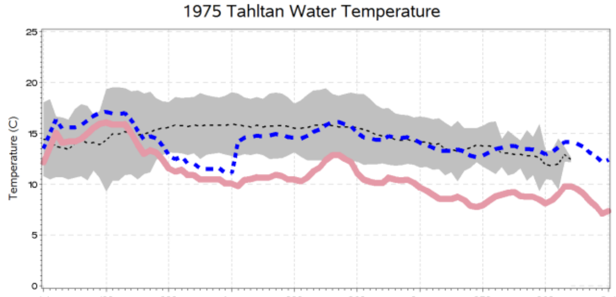
Tuya Discharge 1975



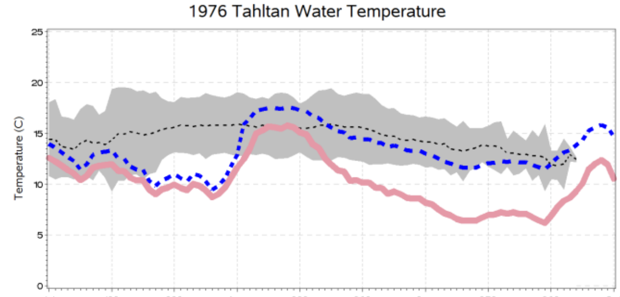
Tuya Discharge 1976



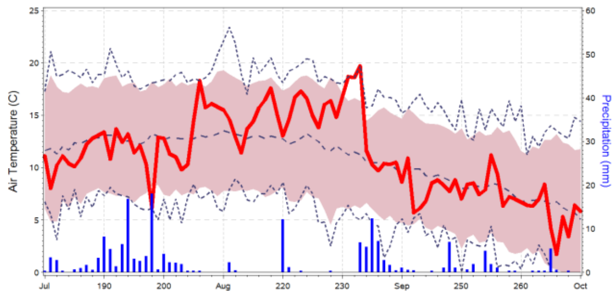
1975 Tahltan Water Temperature



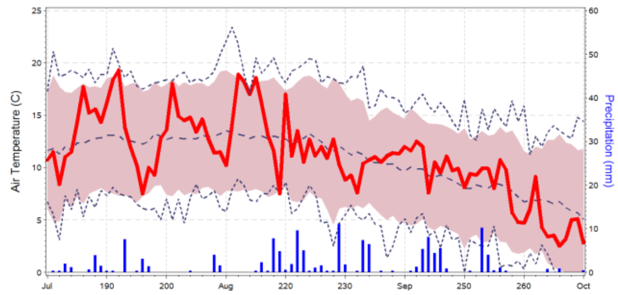
1976 Tahltan Water Temperature



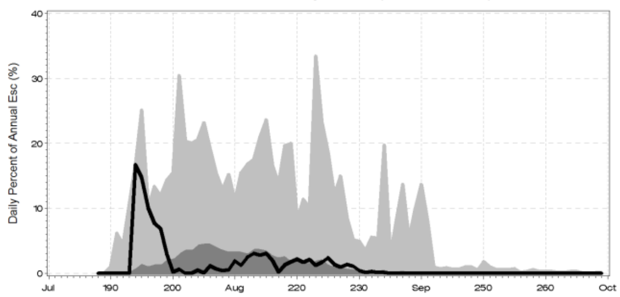
1977 Dease AHCCD Stn 1192340



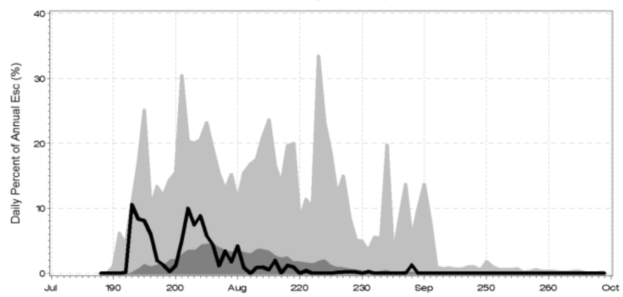
1978 Dease AHCCD Stn 1192340



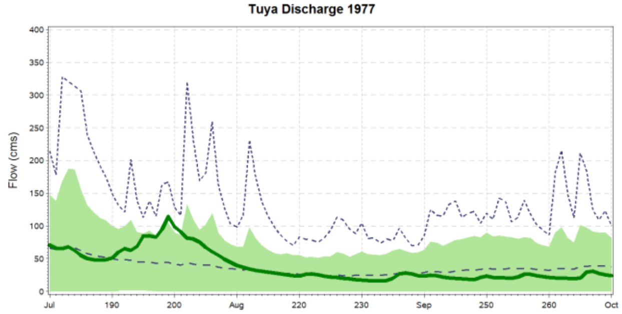
1977 Tahltan Lake Weir Sockeye Counts (Total Esc: 42,960)



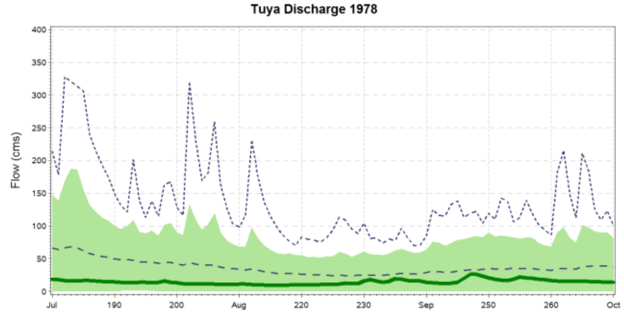
1978 Tahltan Lake Weir Sockeye Counts (Total Esc: 22,788)



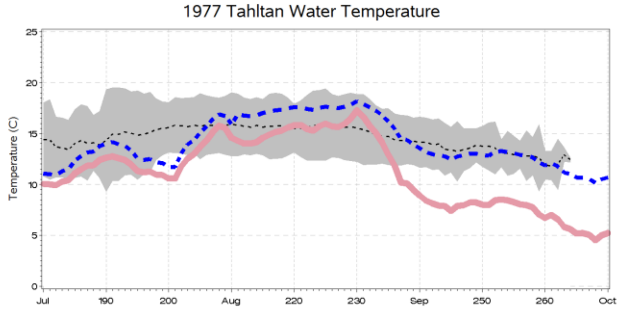
Tuya Discharge 1977



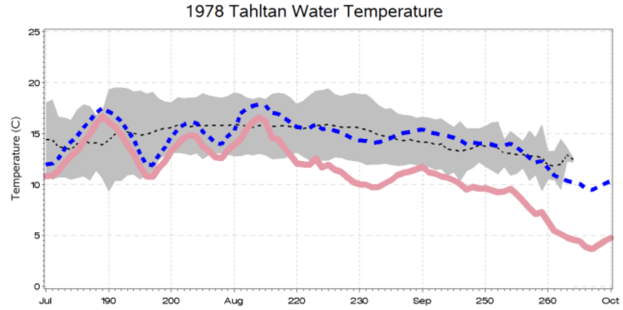
Tuya Discharge 1978

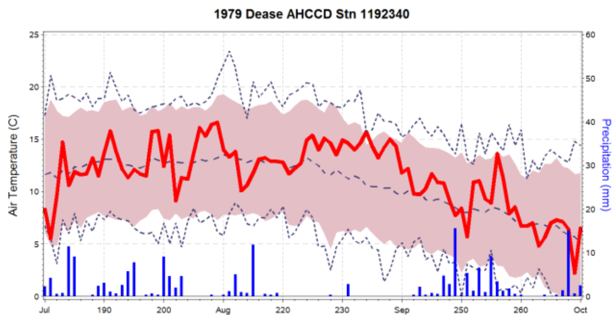


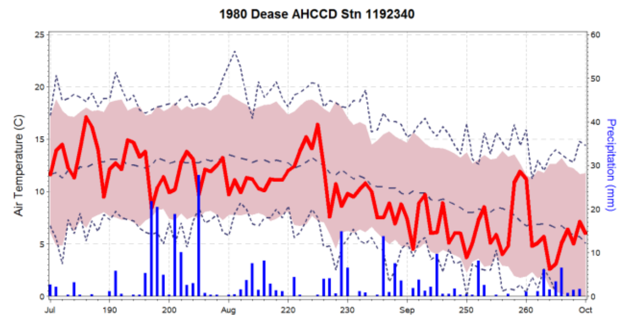
1977 Tahltan Water Temperature

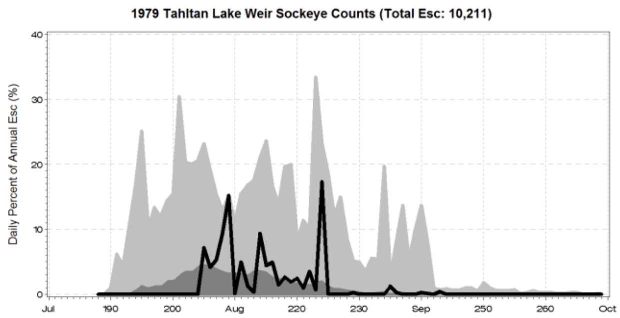


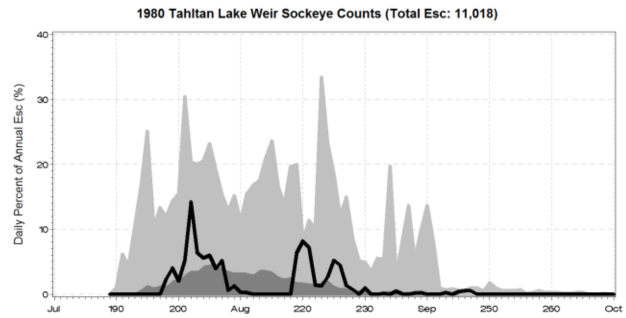
1978 Tahltan Water Temperature

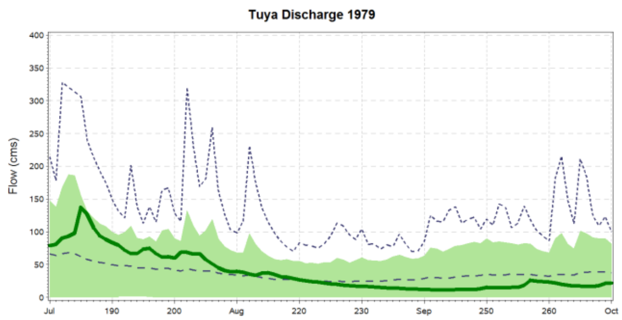


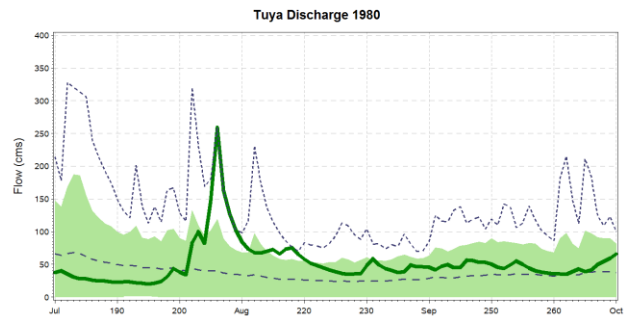

1979 Dease AHCCD Stn 1192340
Air Temperature (C)
Precipitation (mm)
Jul
190
200
Aug
220
230
Sep
250
260
Oct

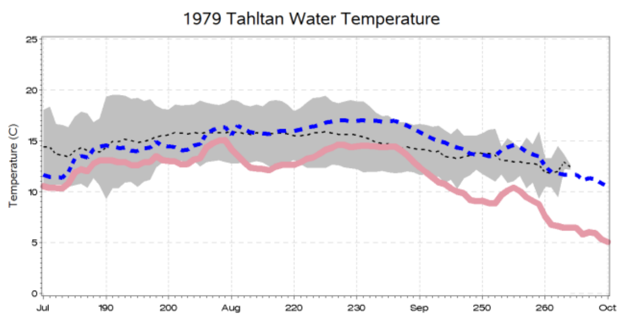

1980 Dease AHCCD Stn 1192340
Air Temperature (C)
Precipitation (mm)
Jul
190
200
Aug
220
230
Sep
250
260
Oct

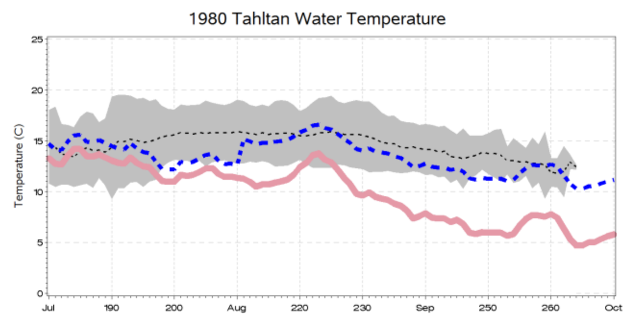

1979 Tahltan Lake Weir Sockeye Counts (Total Esc: 10,211)
Daily Percent of Annual Esc (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct

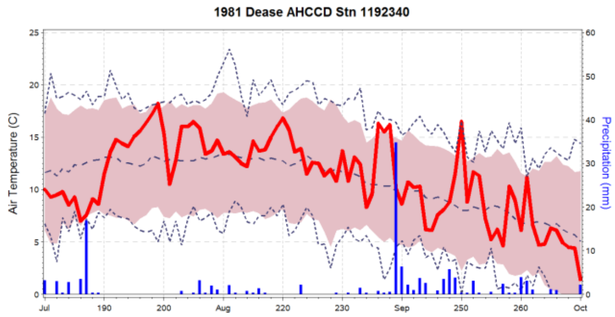

1980 Tahltan Lake Weir Sockeye Counts (Total Esc: 11,018)
Daily Percent of Annual Esc (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct

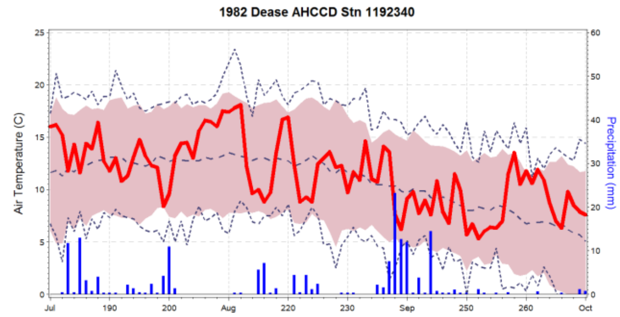

Tuya Discharge 1979
Flow (cms)
Jul
190
200
Aug
220
230
Sep
250
260
Oct

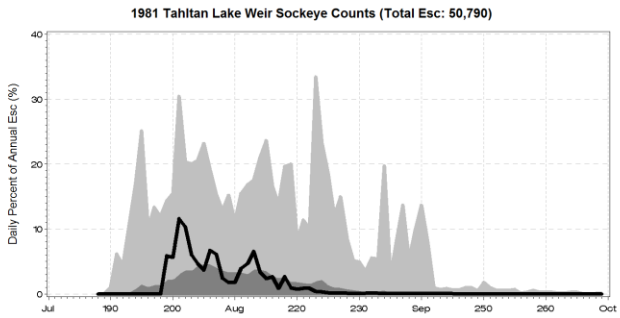

Tuya Discharge 1980
Flow (cms)
Jul
190
200
Aug
220
230
Sep
250
260
Oct

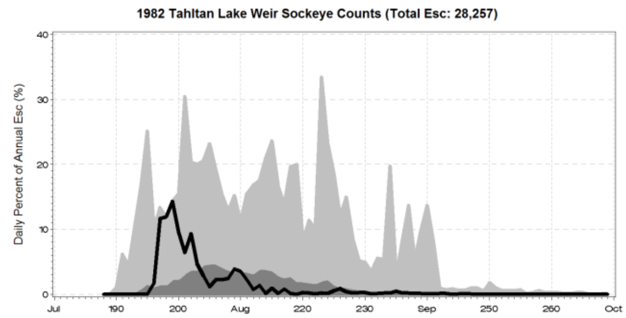

1979 Tahltan Water Temperature
Temperature (C)
Jul
190
200
Aug
220
230
Sep
250
260
Oct

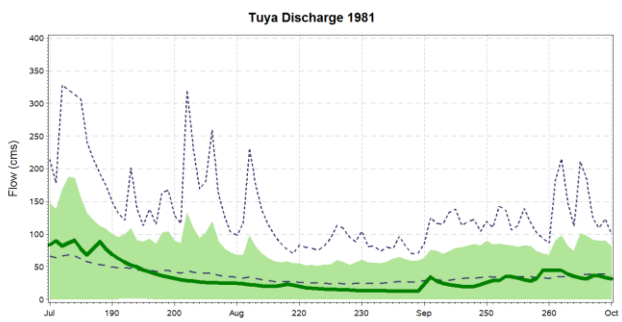

1980 Tahltan Water Temperature
Temperature (C)
Jul
190
200
Aug
220
230
Sep
250
260
Oct

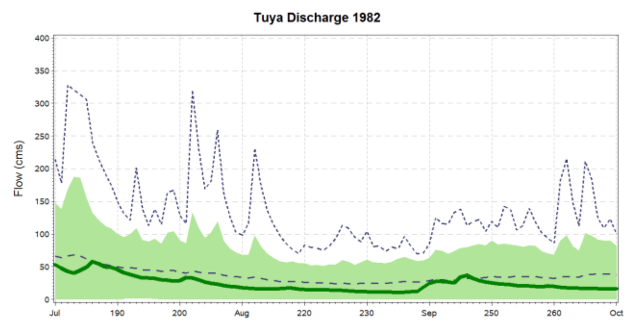

1981 Dease AHCCD Stn 1192340
Air Temperature (C)
Precipitation (mm)
Jul
Aug
Sep
Oct

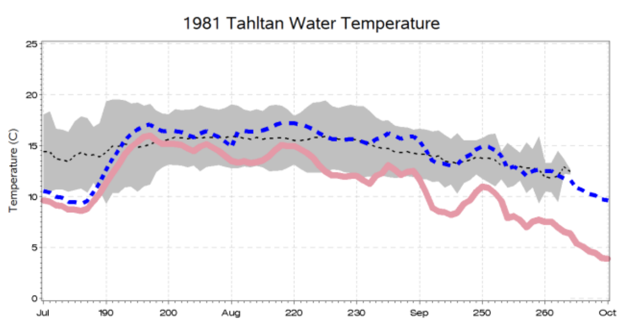

1982 Dease AHCCD Stn 1192340
Air Temperature (C)
Precipitation (mm)
Jul
Aug
Sep
Oct

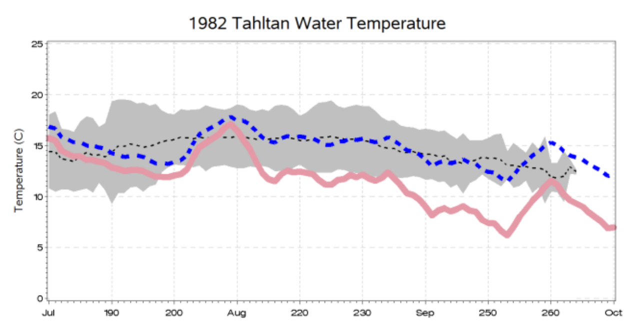

1981 Tahltan Lake Weir Sockeye Counts (Total Esc: 50,790)
Daily Percent of Annual Esc (%)
Jul
Aug
Sep
Oct


1982 Tahltan Lake Weir Sockeye Counts (Total Esc: 28,257)
Daily Percent of Annual Esc (%)
Jul
Aug
Sep
Oct

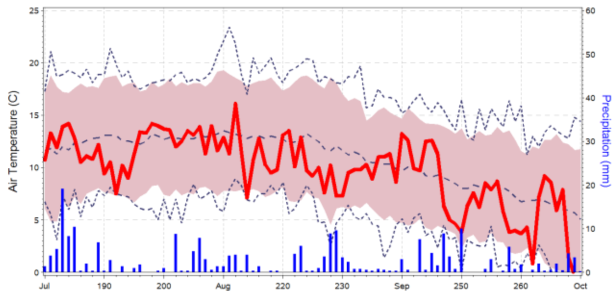

Tuya Discharge 1981
Flow (cms)
Jul
Aug
Sep
Oct


Tuya Discharge 1982
Flow (cms)
Jul
Aug
Sep
Oct

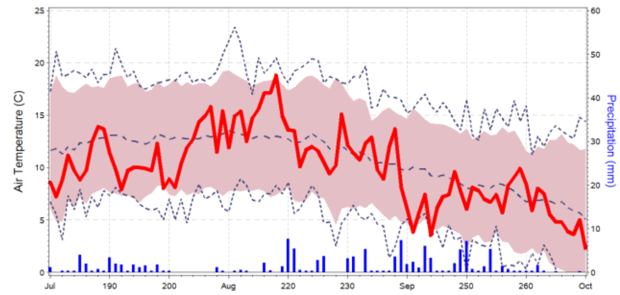

1981 Tahltan Water Temperature
Temperature (C)
Jul
Aug
Sep
Oct


1982 Tahltan Water Temperature
Temperature (C)
Jul
Aug
Sep
Oct

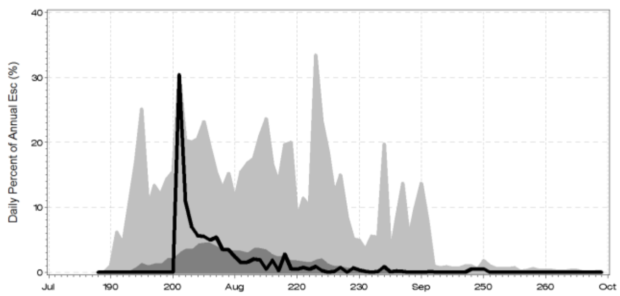
1983 Dease AHCCD Stn 1192340



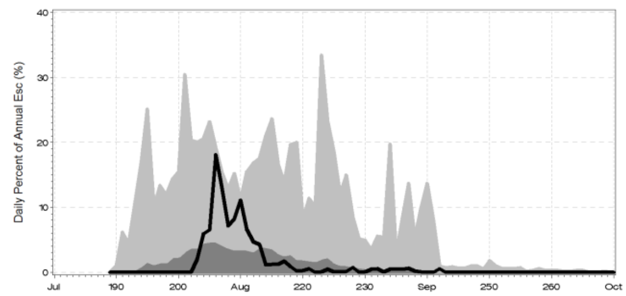
1984 Dease AHCCD Stn 1192340



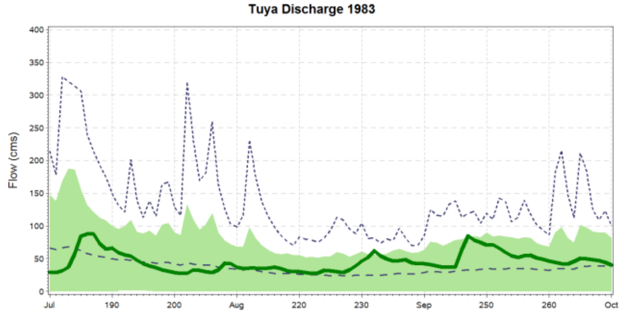
1983 Tahltan Lake Weir Sockeye Counts (Total Esc: 21,255)



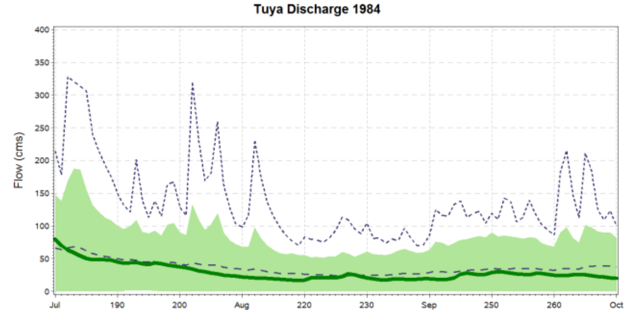
1984 Tahltan Lake Weir Sockeye Counts (Total Esc: 32,777)



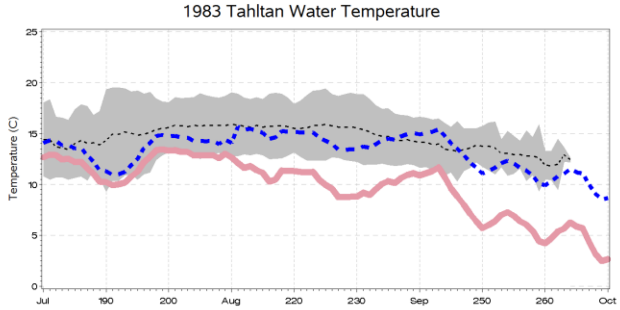
Tuya Discharge 1983



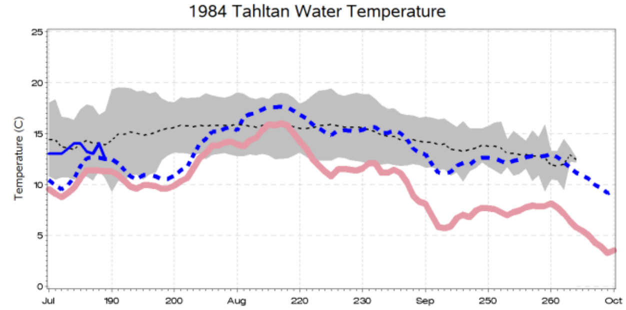
Tuya Discharge 1984



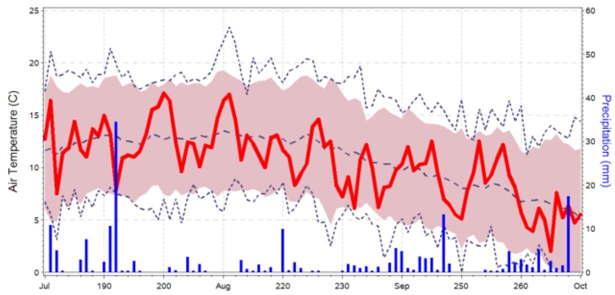
1983 Tahltan Water Temperature



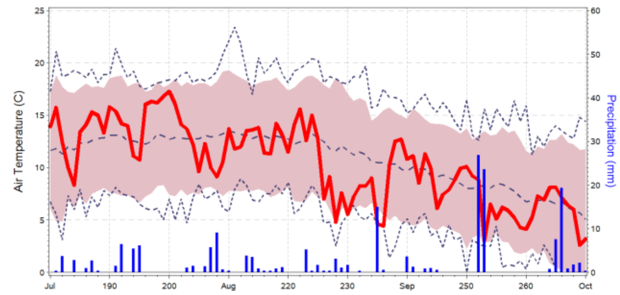
1984 Tahltan Water Temperature



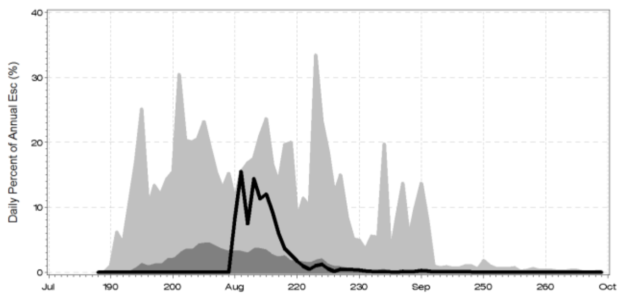
1985 Dease AHCCD Stn 1192340



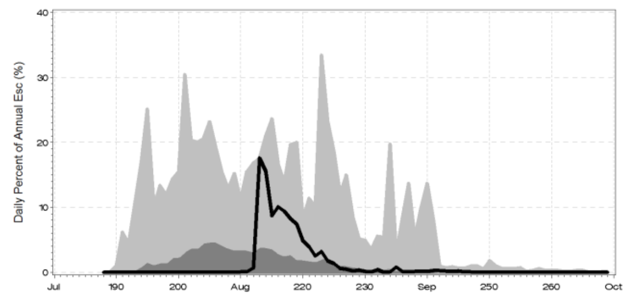
1986 Dease AHCCD Stn 1192340



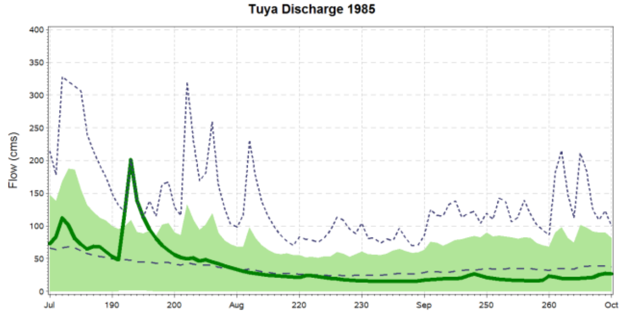
1985 Tahltan Lake Weir Sockeye Counts (Total Esc: 67,326)



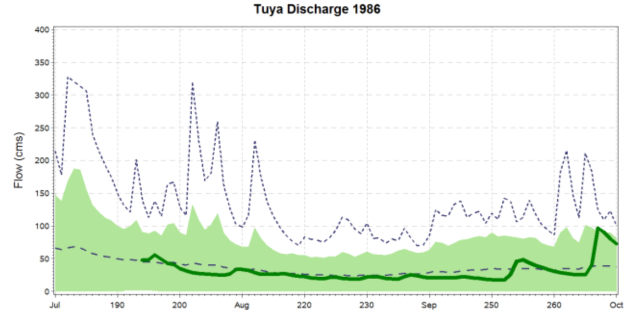
1986 Tahltan Lake Weir Sockeye Counts (Total Esc: 20,280)



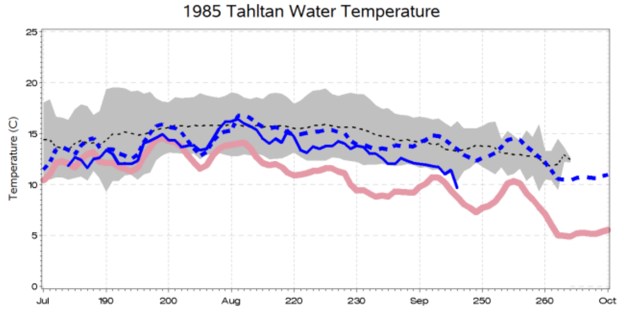
Tuya Discharge 1985



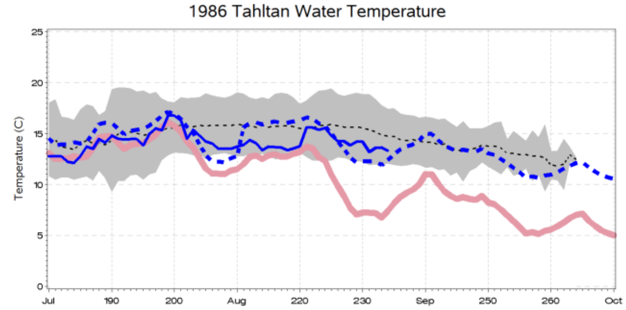
Tuya Discharge 1986

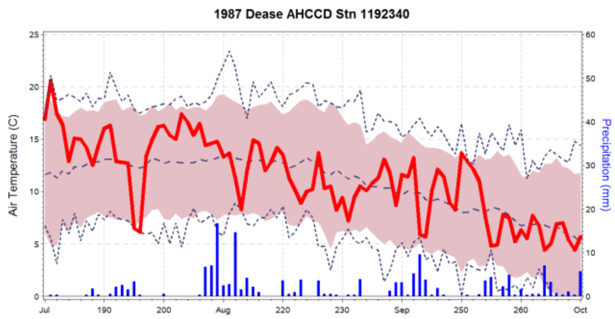


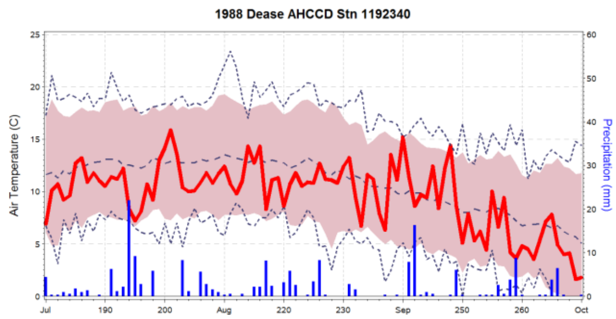
1985 Tahltan Water Temperature

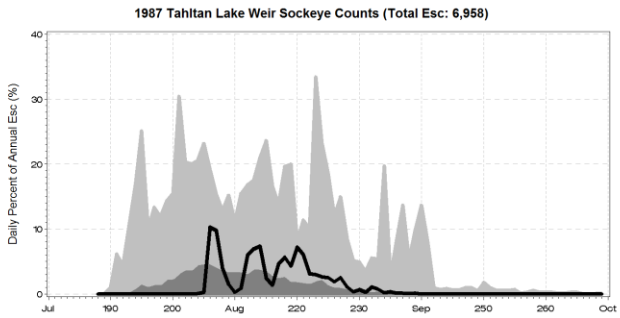


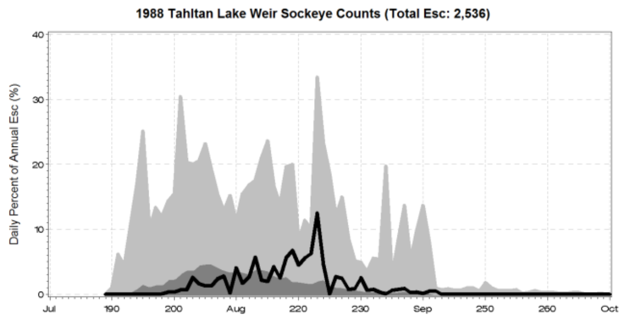
1986 Tahltan Water Temperature

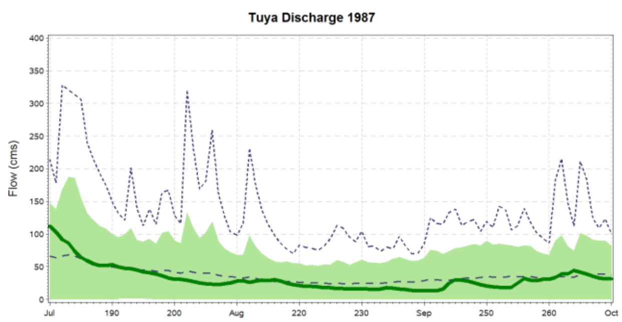


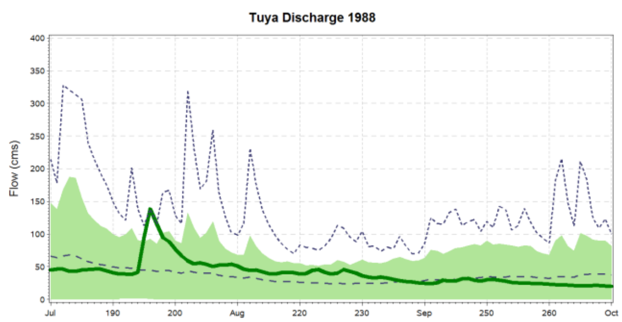

1987 Dease AHCCD Stn 1192340
Air Temperature (C)
Precipitation (mm)
Jul
190
200
Aug
220
230
Sep
250
260
Oct

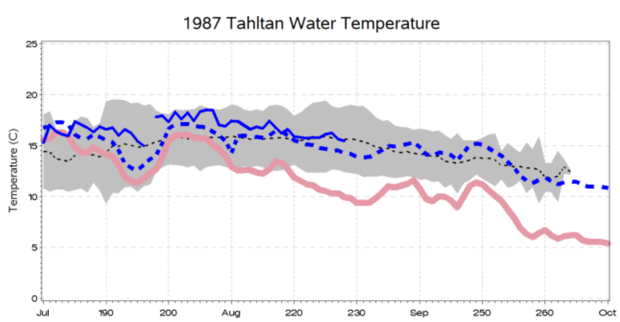

1988 Dease AHCCD Stn 1192340
Air Temperature (C)
Precipitation (mm)
Jul
190
200
Aug
220
230
Sep
250
260
Oct

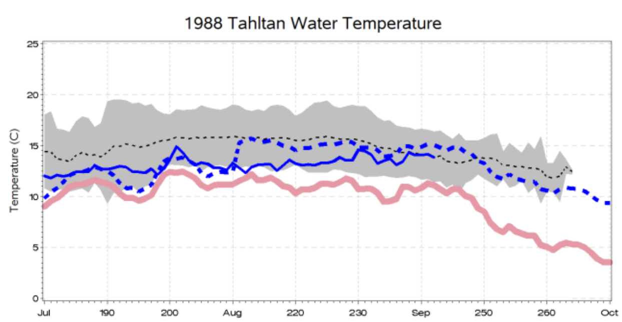

1987 Tahltan Lake Weir Sockeye Counts (Total Esc: 6,958)
Daily Percent of Annual Esc (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct


1988 Tahltan Lake Weir Sockeye Counts (Total Esc: 2,536)
Daily Percent of Annual Esc (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct

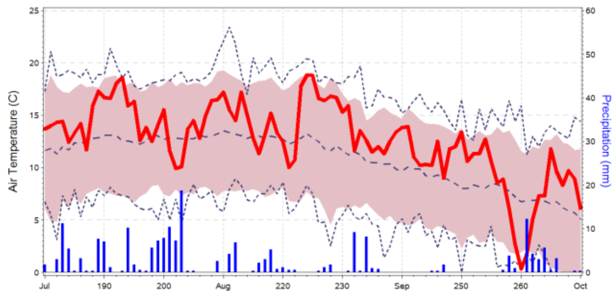

Tuya Discharge 1987
Flow (cms)
Jul
190
200
Aug
220
230
Sep
250
260
Oct


Tuya Discharge 1988
Flow (cms)
Jul
190
200
Aug
220
230
Sep
250
260
Oct

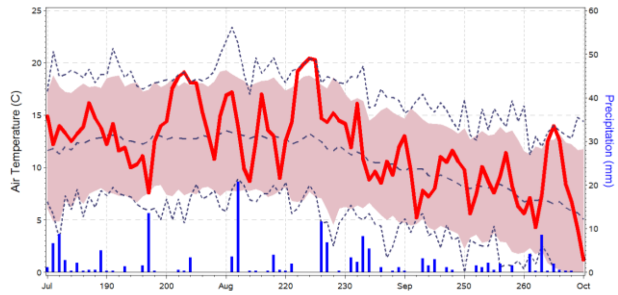

1987 Tahltan Water Temperature
Temperature (C)
Jul
190
200
Aug
220
230
Sep
250
260
Oct


1988 Tahltan Water Temperature
Temperature (C)
Jul
190
200
Aug
220
230
Sep
250
260
Oct

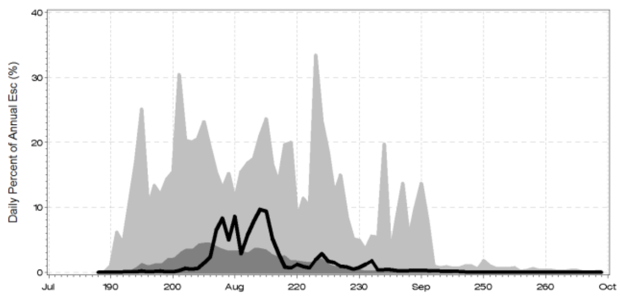
1989 Dease AHCCD Stn 1192340



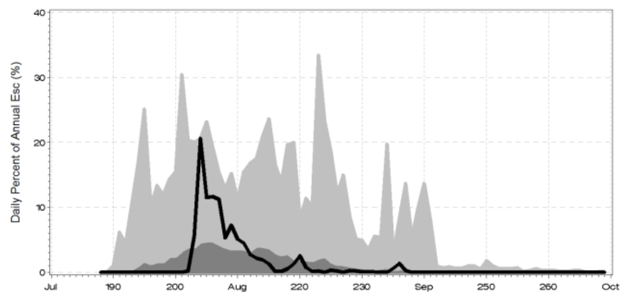
1990 Dease AHCCD Stn 1192340



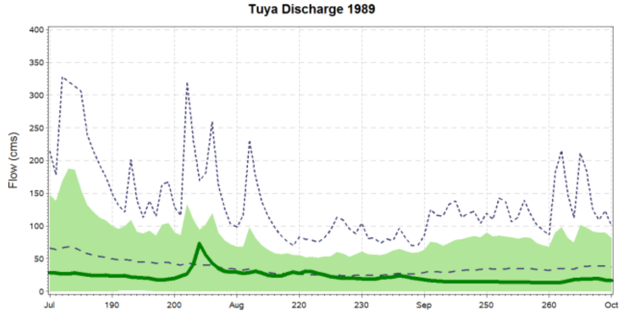
1989 Tahltan Lake Weir Sockeye Counts (Total Esc: 8,316)



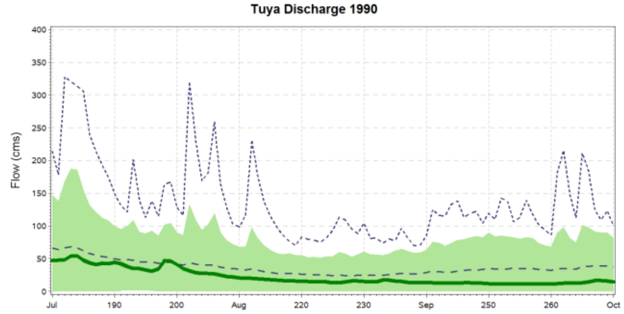
1990 Tahltan Lake Weir Sockeye Counts (Total Esc: 14,927)



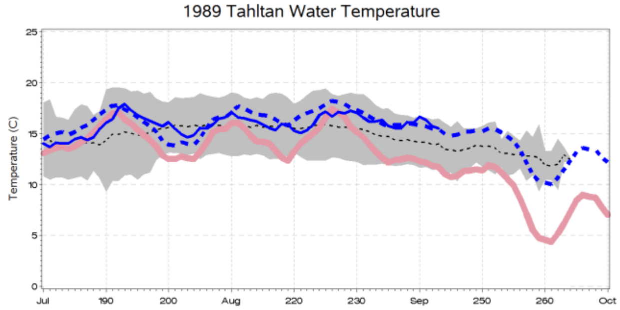
Tuya Discharge 1989



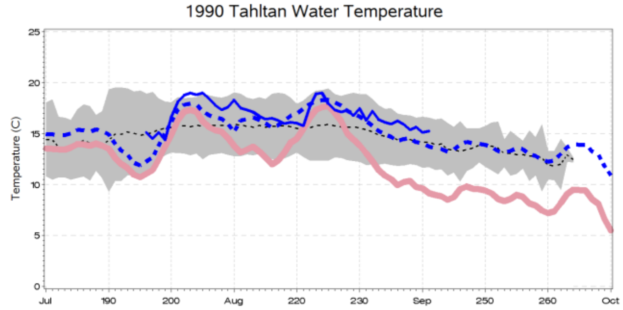
Tuya Discharge 1990

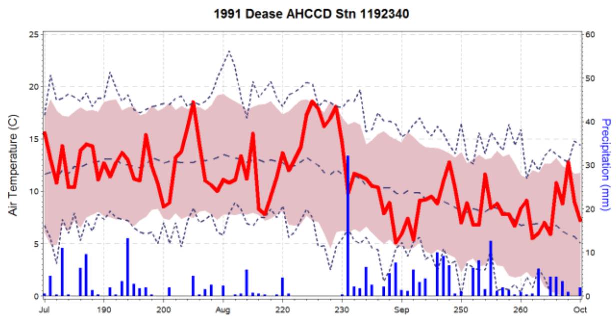


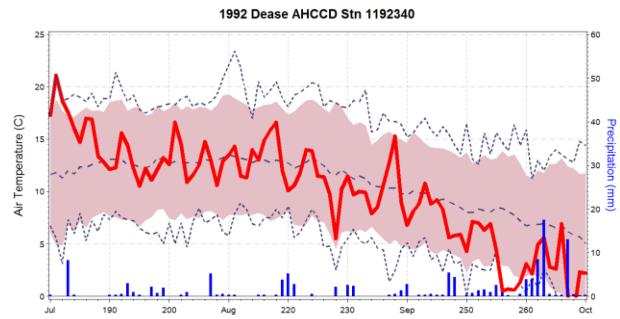
1989 Tahltan Water Temperature

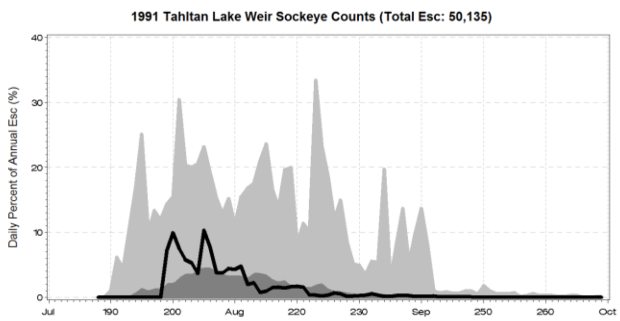


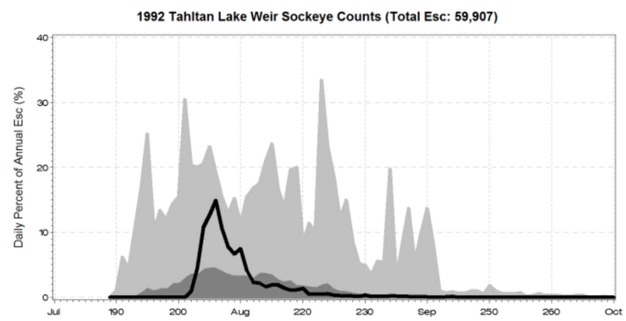
1990 Tahltan Water Temperature

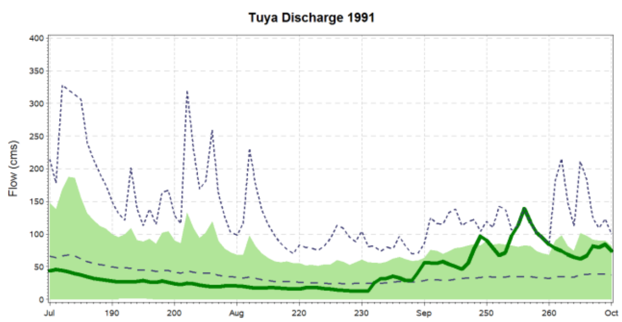


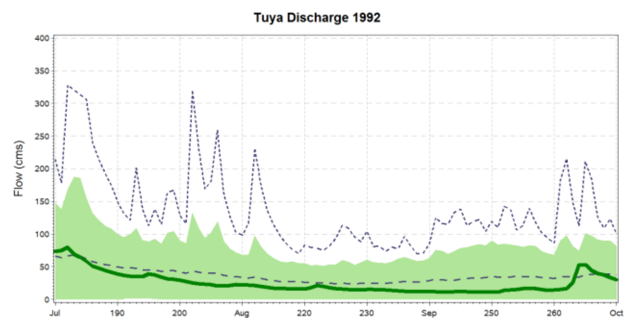

1991 Dease AHCCD Stn 1192340
Air Temperature (C)
Precipitation (mm)

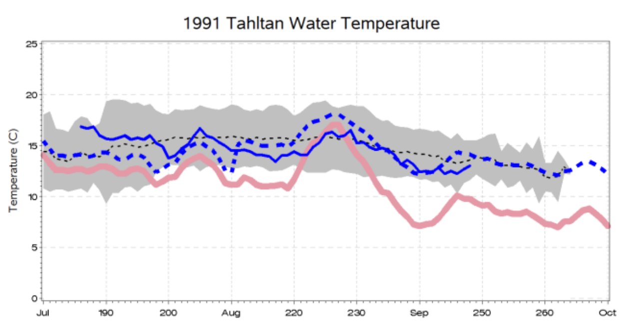

1992 Dease AHCCD Stn 1192340
Air Temperature (C)
Precipitation (mm)

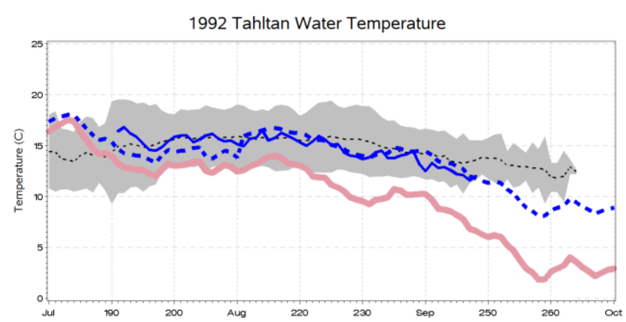

1991 Tahltan Lake Weir Sockeye Counts (Total Esc: 50,135)
Daily Percent of Annual Esc (%)

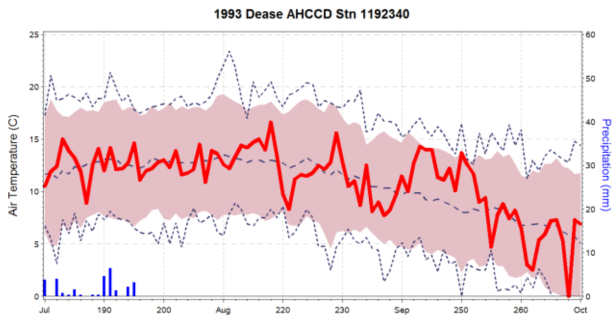

1992 Tahltan Lake Weir Sockeye Counts (Total Esc: 59,907)
Daily Percent of Annual Esc (%)

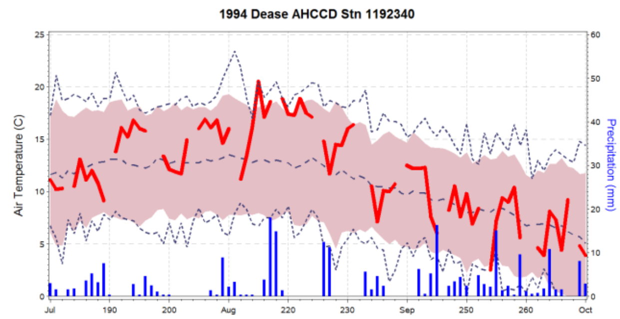

Tuya Discharge 1991
Flow (cms)

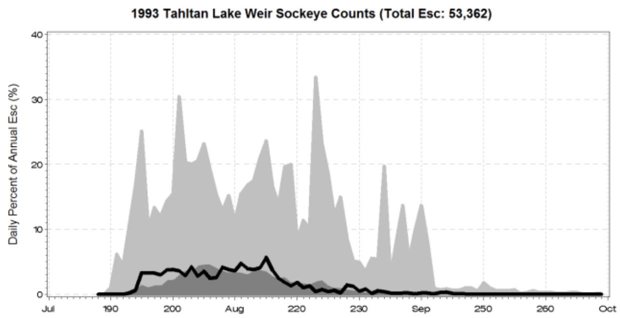

Tuya Discharge 1992
Flow (cms)

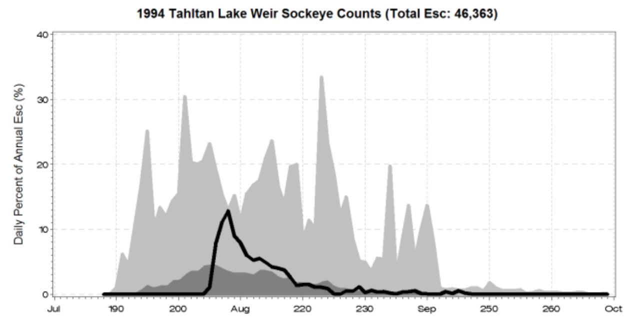

1991 Tahltan Water Temperature
Temperature (C)

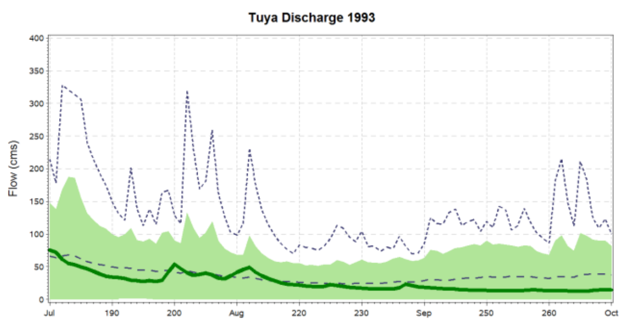

1992 Tahltan Water Temperature
Temperature (C)

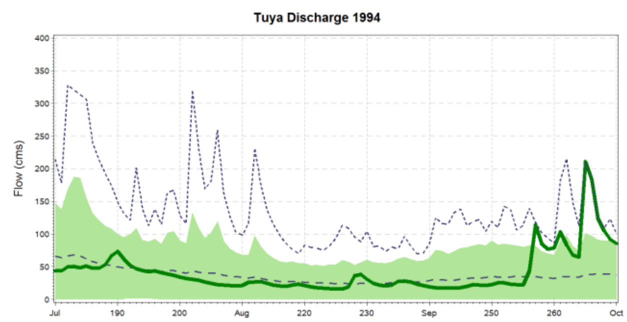

1993 Dease AHCCD Stn 1192340
Air Temperature (C)
Precipitation (mm)
Jul
190
200
Aug
220
230
Sep
250
260
Oct

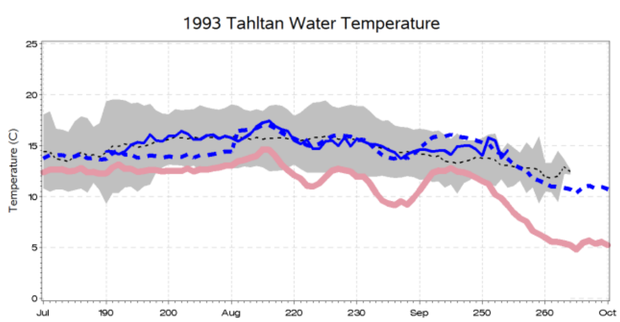

1994 Dease AHCCD Stn 1192340
Air Temperature (C)
Precipitation (mm)
Jul
190
200
Aug
220
230
Sep
250
260
Oct

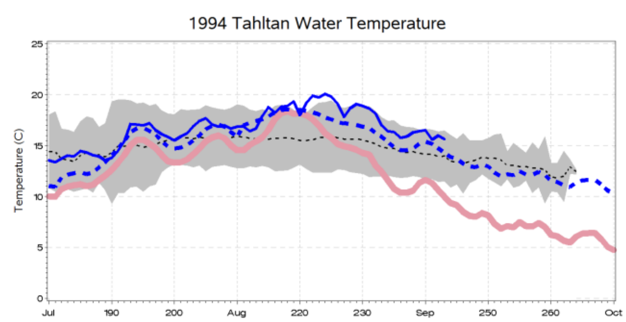

1993 Tahltan Lake Weir Sockeye Counts (Total Esc: 53,362)
Daily Percent of Annual Esc (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct


1994 Tahltan Lake Weir Sockeye Counts (Total Esc: 46,363)
Daily Percent of Annual Esc (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct

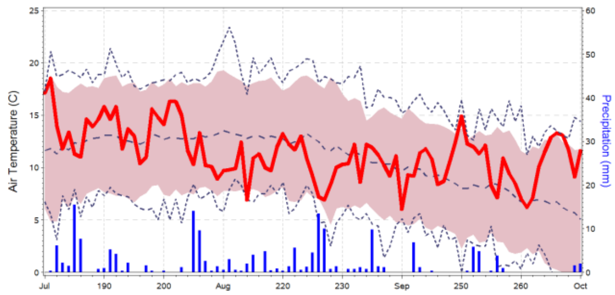

Tuya Discharge 1993
Flow (cms)
Jul
190
200
Aug
220
230
Sep
250
260
Oct


Tuya Discharge 1994
Flow (cms)
Jul
190
200
Aug
220
230
Sep
250
260
Oct

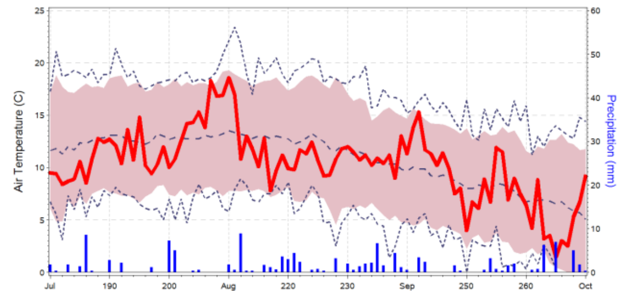

1993 Tahltan Water Temperature
Temperature (C)
Jul
190
200
Aug
220
230
Sep
250
260
Oct


1994 Tahltan Water Temperature
Temperature (C)
Jul
190
200
Aug
220
230
Sep
250
260
Oct

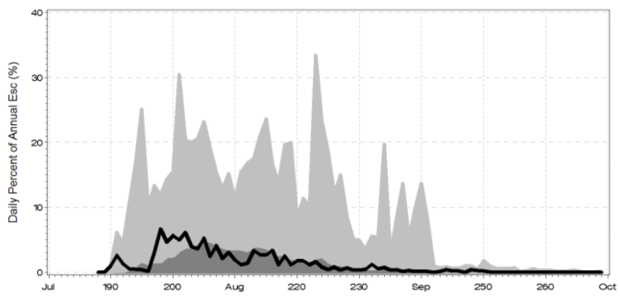
1995 Dease AHCCD Stn 1192340



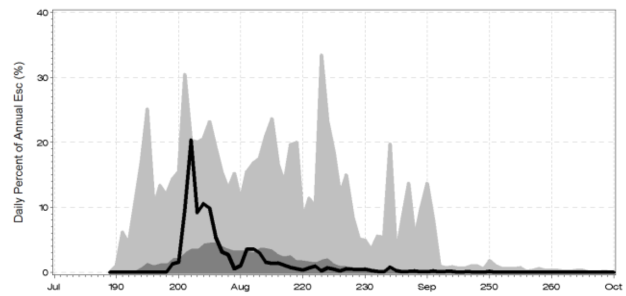
1996 Dease AHCCD Stn 1192340



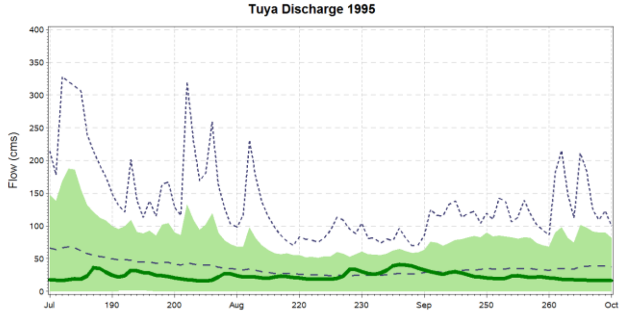
1995 Tahltan Lake Weir Sockeye Counts (Total Esc: 42,317)



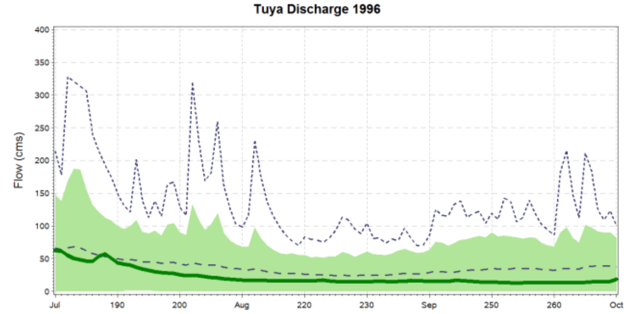
1996 Tahltan Lake Weir Sockeye Counts (Total Esc: 52,500)



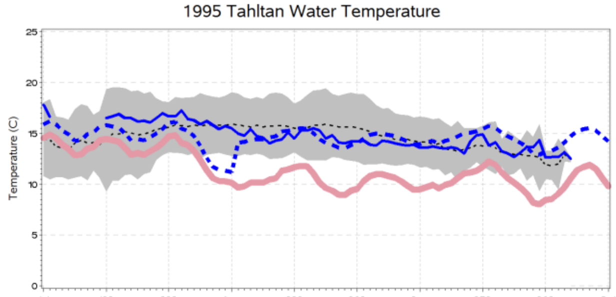
Tuya Discharge 1995



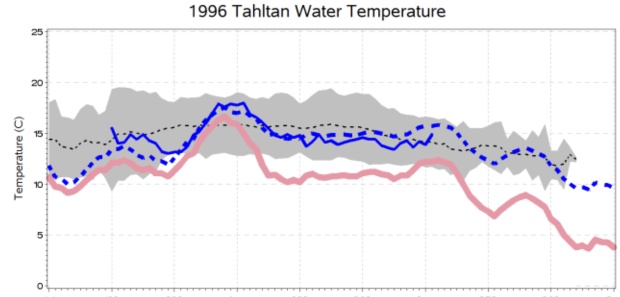
Tuya Discharge 1996



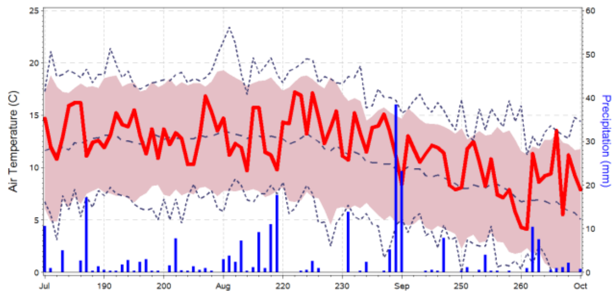
1995 Tahltan Water Temperature



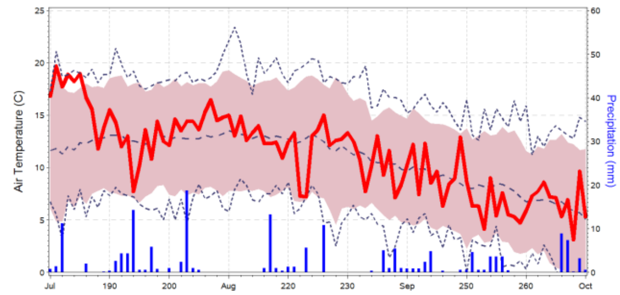
1996 Tahltan Water Temperature



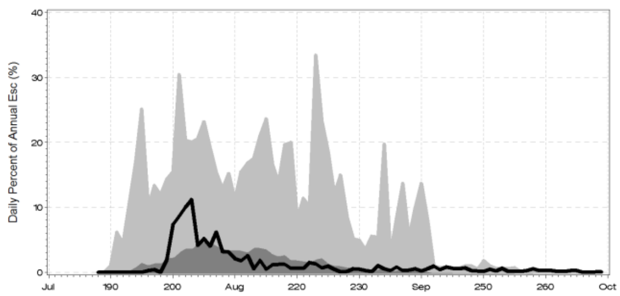
1997 Dease AHCCD Stn 1192340



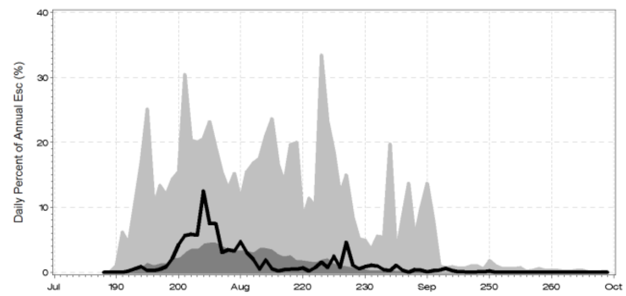
1998 Dease AHCCD Stn 1192340



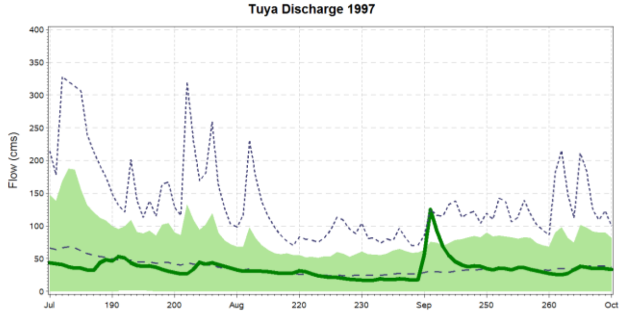
1997 Tahltan Lake Weir Sockeye Counts (Total Esc: 12,483)



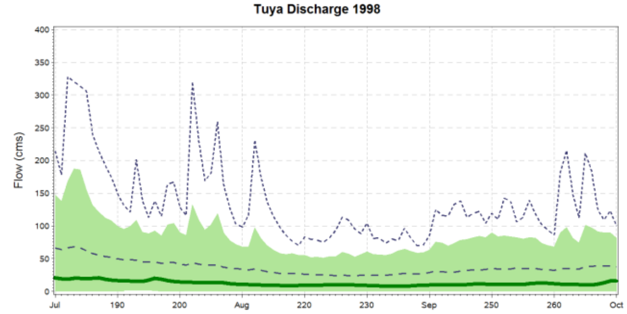
1998 Tahltan Lake Weir Sockeye Counts (Total Esc: 12,658)



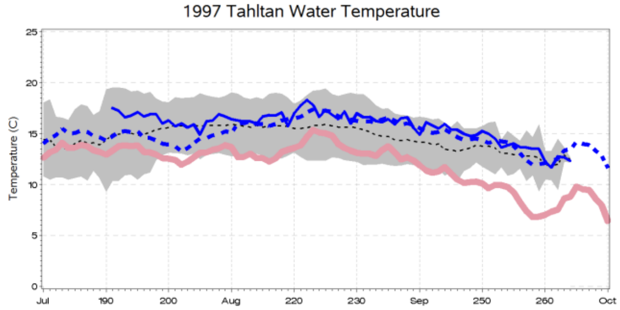
Tuya Discharge 1997



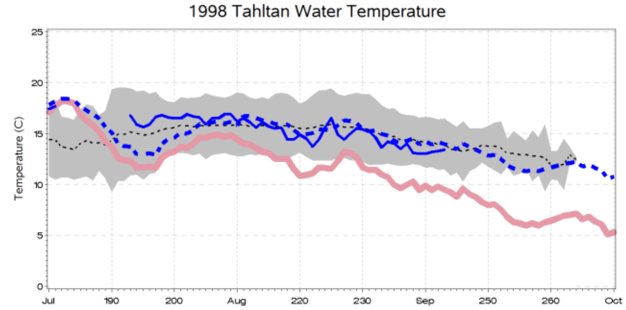
Tuya Discharge 1998



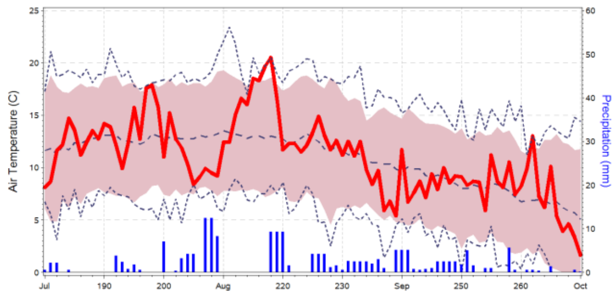
1997 Tahltan Water Temperature



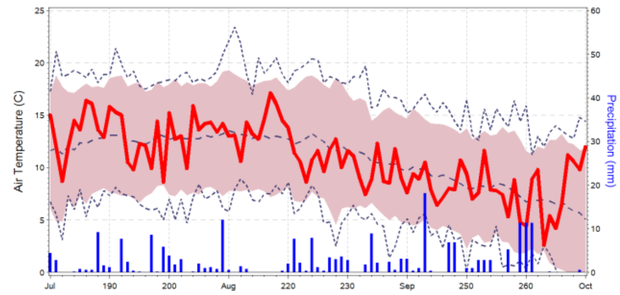
1998 Tahltan Water Temperature



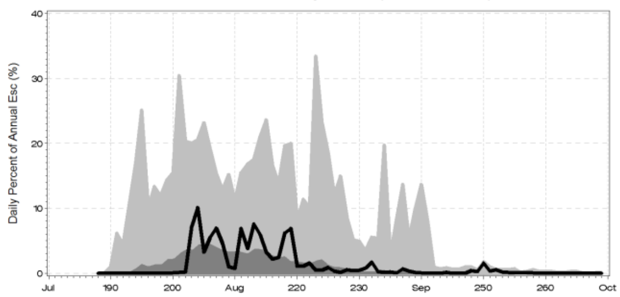
1999 Dease AHCCD Stn 1192340



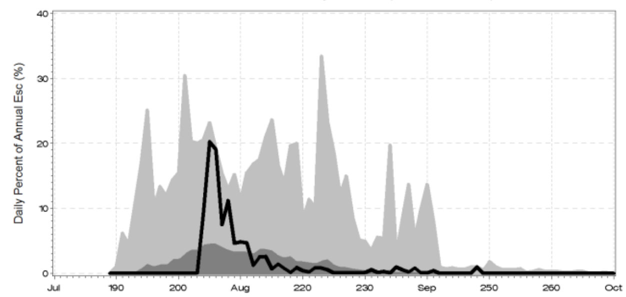
2000 Dease AHCCD Stn 1192340



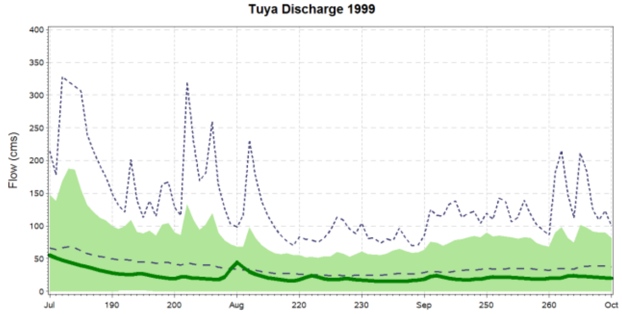
1999 Tahltan Lake Weir Sockeye Counts (Total Esc: 10,748)



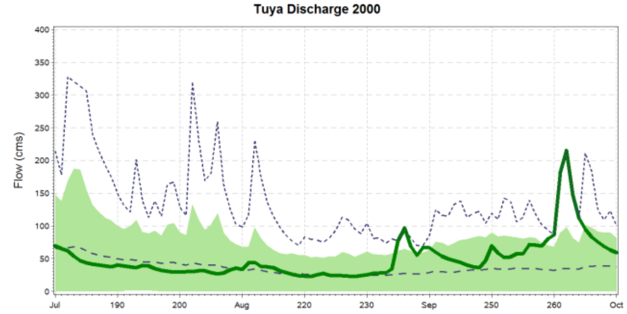
2000 Tahltan Lake Weir Sockeye Counts (Total Esc: 6,076)



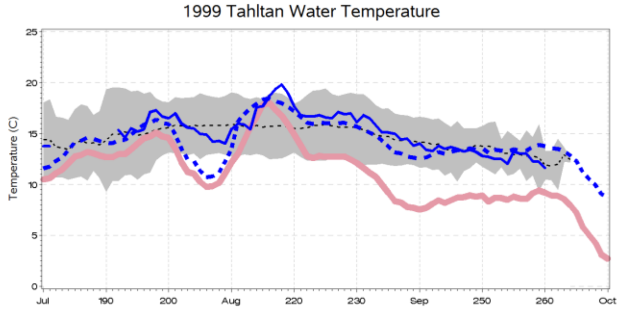
Tuya Discharge 1999



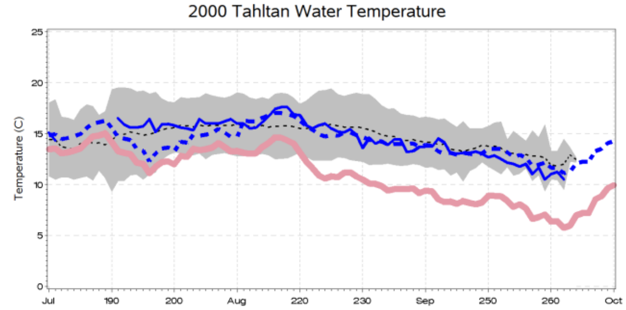
Tuya Discharge 2000



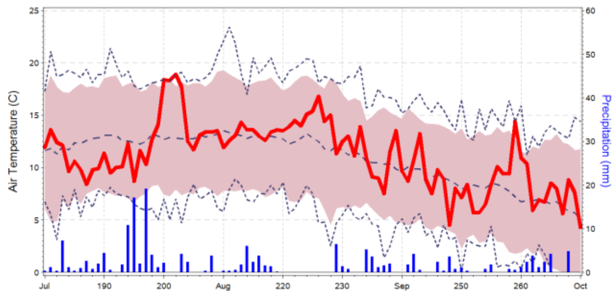
1999 Tahltan Water Temperature



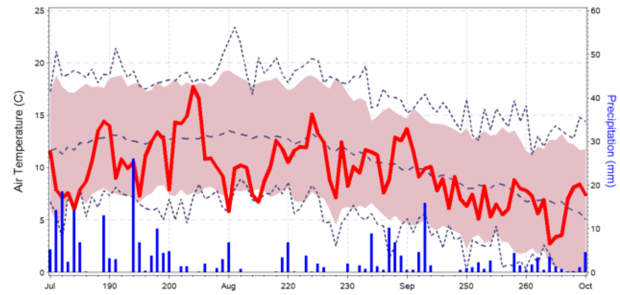
2000 Tahltan Water Temperature



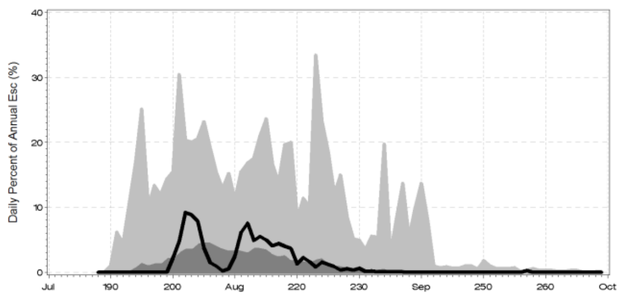
2001 Dease AHCCD Stn 1192340



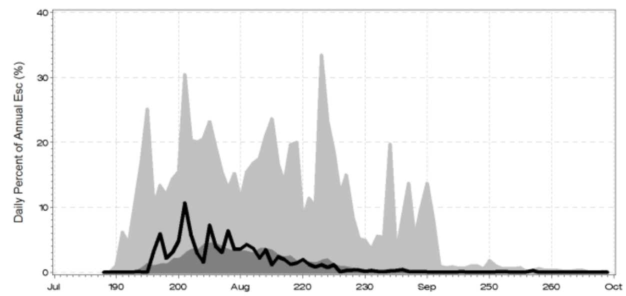
2002 Dease AHCCD Stn 1192340



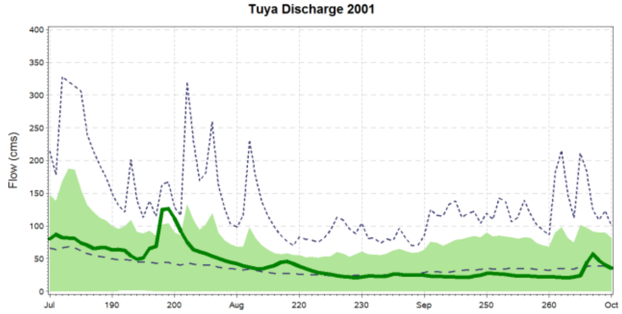
2001 Tahltan Lake Weir Sockeye Counts (Total Esc: 14,811)



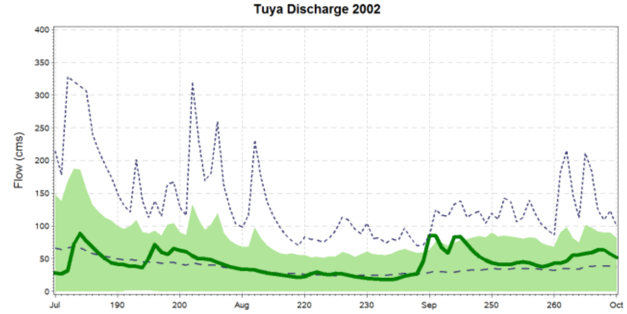
2002 Tahltan Lake Weir Sockeye Counts (Total Esc: 17,740)



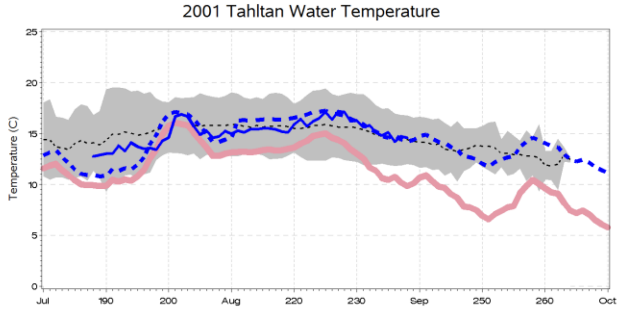
Tuya Discharge 2001



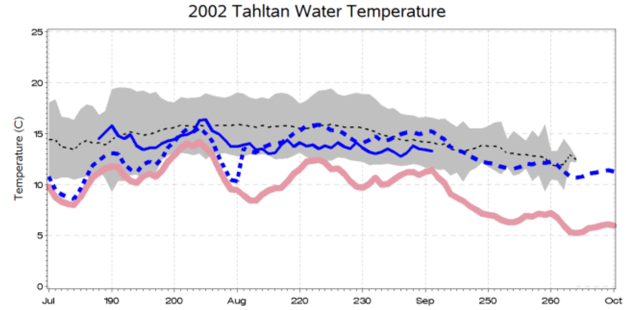
Tuya Discharge 2002

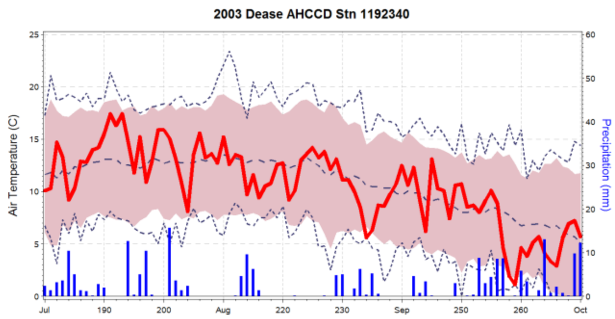


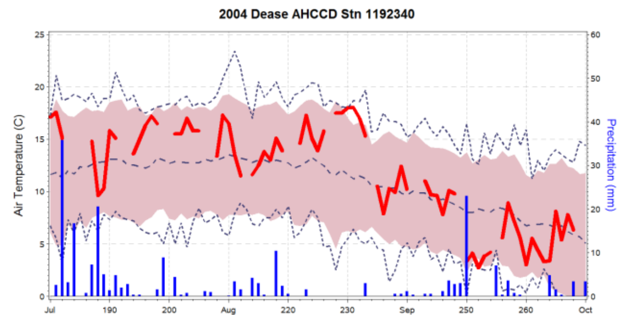
2001 Tahltan Water Temperature

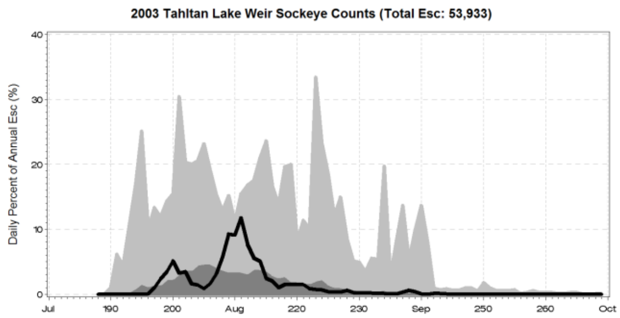


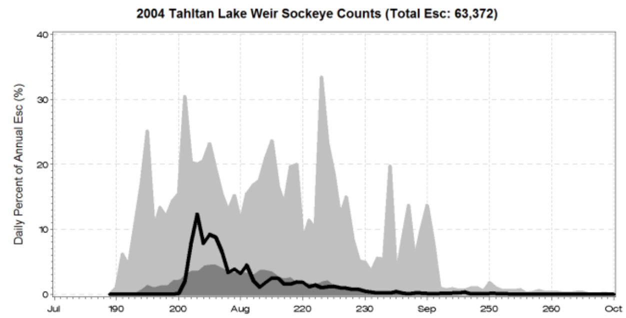
2002 Tahltan Water Temperature

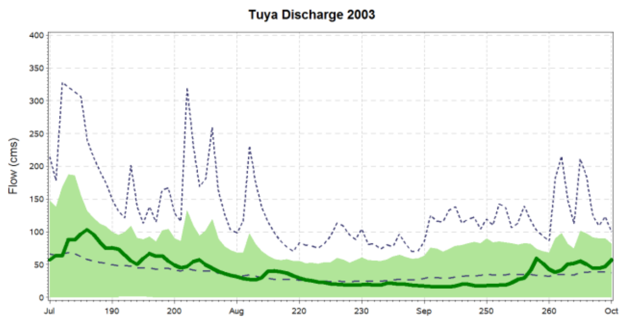


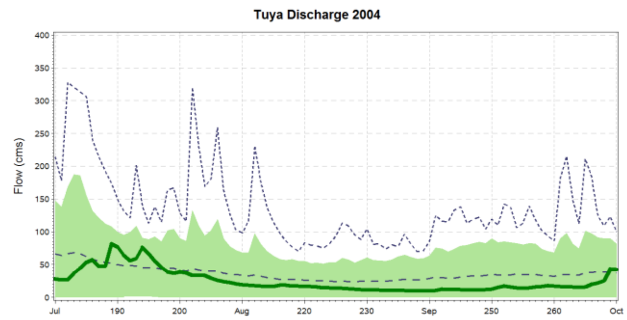

2003 Dease AHCCD Stn 1192340
Air Temperature (C)
Precipitation (mm)

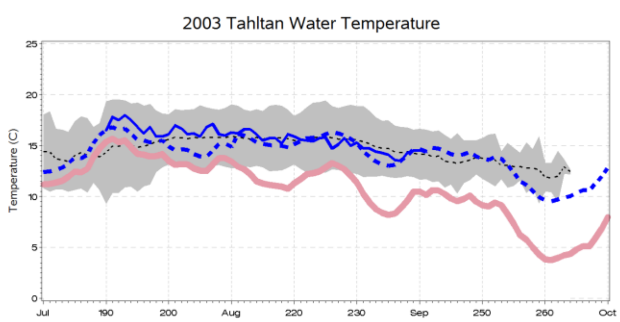

2004 Dease AHCCD Stn 1192340
Air Temperature (C)
Precipitation (mm)

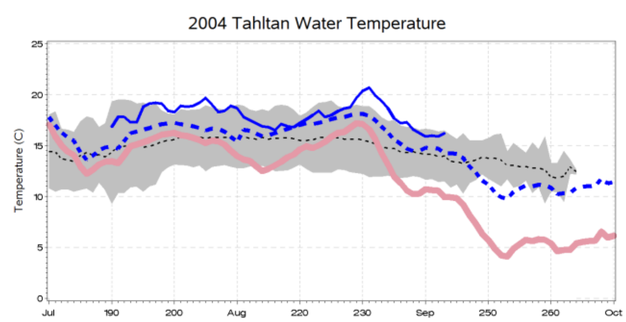

2003 Tahltan Lake Weir Sockeye Counts (Total Esc: 53,933)
Daily Percent of Annual Esc (%)

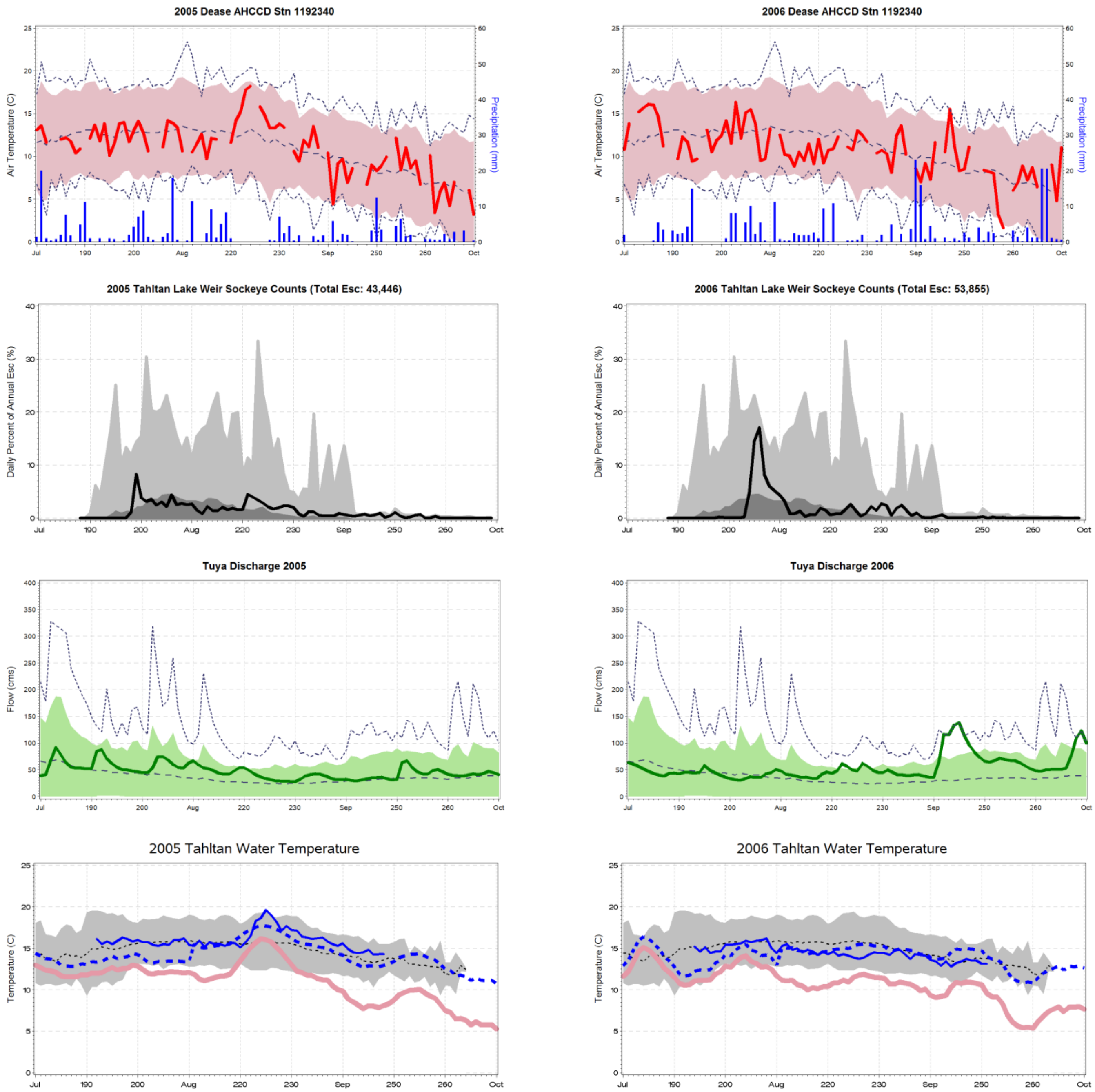

2004 Tahltan Lake Weir Sockeye Counts (Total Esc: 63,372)
Daily Percent of Annual Esc (%)

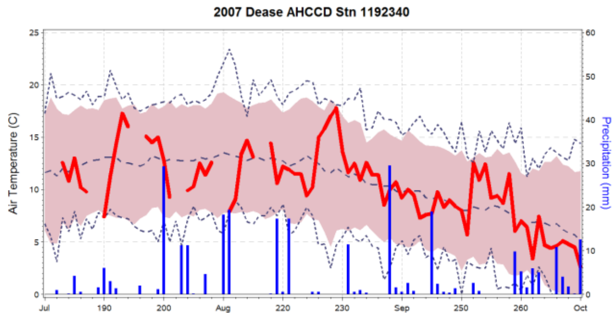

Tuya Discharge 2003
Flow (cms)

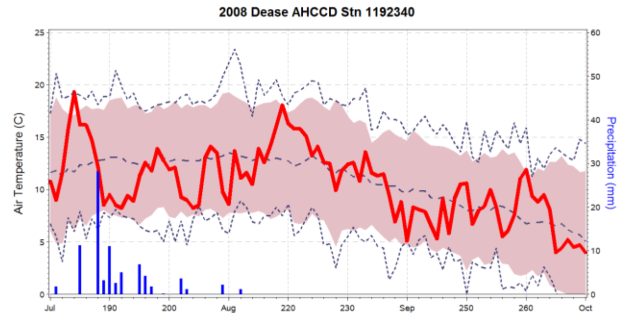

Tuya Discharge 2004
Flow (cms)

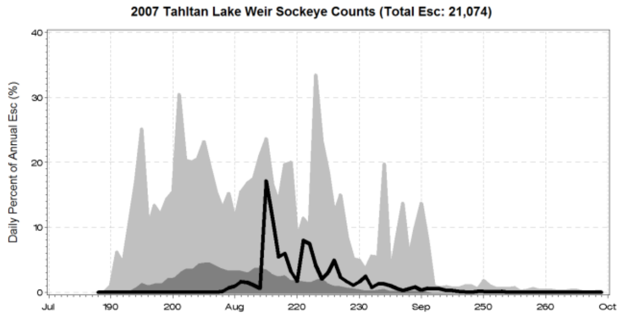

2003 Tahltan Water Temperature
Temperature (C)

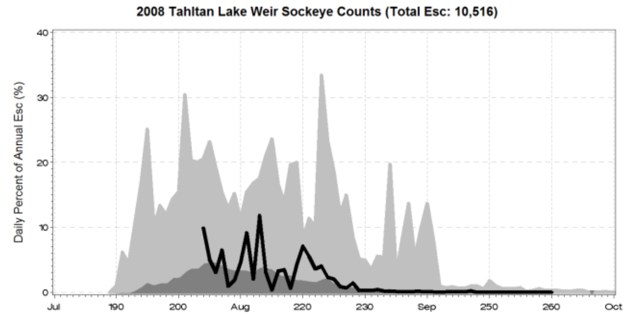

2004 Tahltan Water Temperature
Temperature (C)

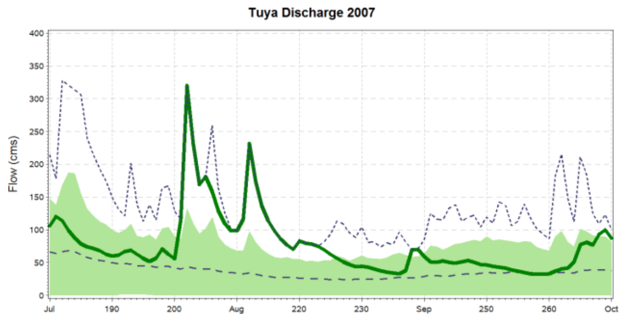

2005 Dease AHCCD Stn 1192340
2006 Dease AHCCD Stn 1192340
Air Temperature (C)
Precipitation (mm)
2005 Tahltan Lake Weir Sockeye Counts (Total Esc: 43,446)
2006 Tahltan Lake Weir Sockeye Counts (Total Esc: 53,855)
Daily Percent of Annual Esc (%)
Tuya Discharge 2005
Tuya Discharge 2006
Flow (cms)
2005 Tahltan Water Temperature
2006 Tahltan Water Temperature
Temperature (C)
Jul
190
200
Aug
220
230
Sep
250
260
Oct

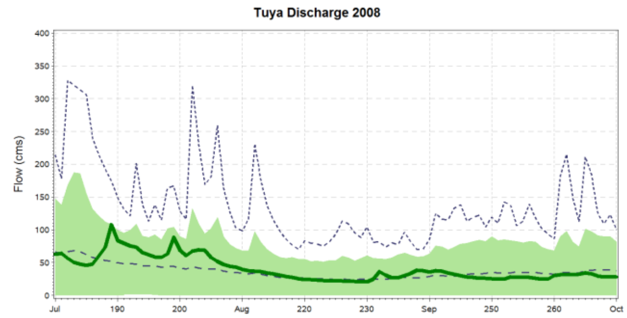

2007 Dease AHCCD Stn 1192340
Air Temperature (C)
Precipitation (mm)
Jul
190
200
Aug
220
230
Sep
250
260
Oct

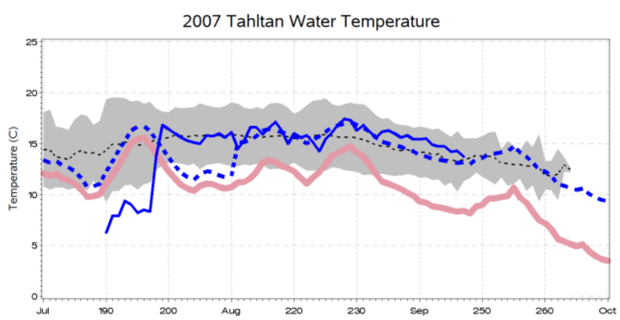

2008 Dease AHCCD Stn 1192340
Air Temperature (C)
Precipitation (mm)
Jul
190
200
Aug
220
230
Sep
250
260
Oct

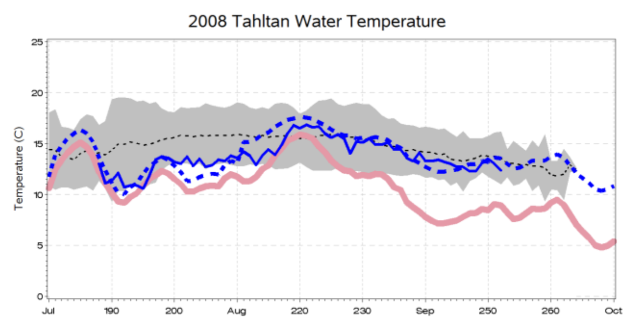

2007 Tahltan Lake Weir Sockeye Counts (Total Esc: 21,074)
Daily Percent of Annual Esc (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct

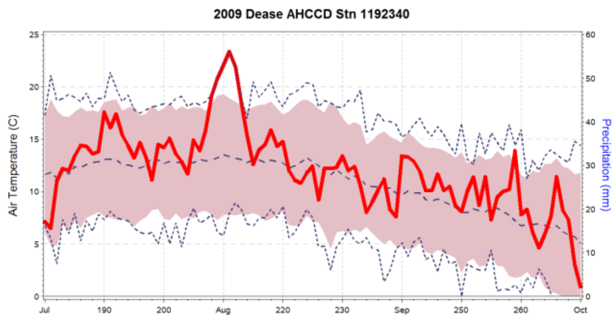

2008 Tahltan Lake Weir Sockeye Counts (Total Esc: 10,516)
Daily Percent of Annual Esc (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct

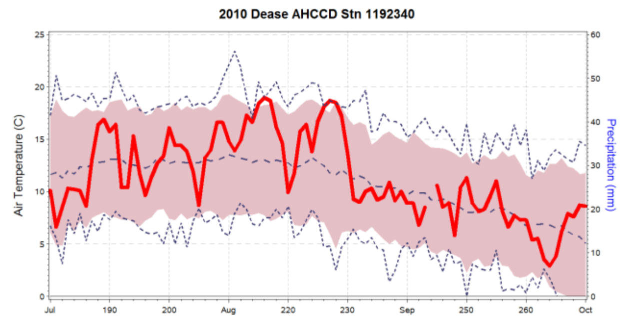

Tuya Discharge 2007
Flow (cms)
Jul
190
200
Aug
220
230
Sep
250
260
Oct

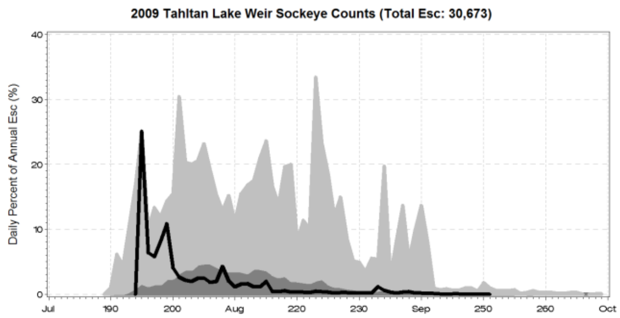

Tuya Discharge 2008
Flow (cms)
Jul
190
200
Aug
220
230
Sep
250
260
Oct

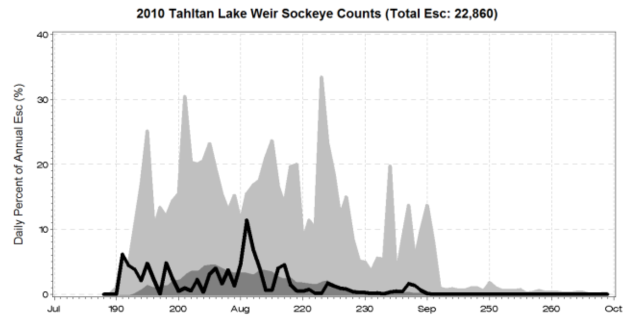

2007 Tahltan Water Temperature
Temperature (C)
Jul
190
200
Aug
220
230
Sep
250
260
Oct

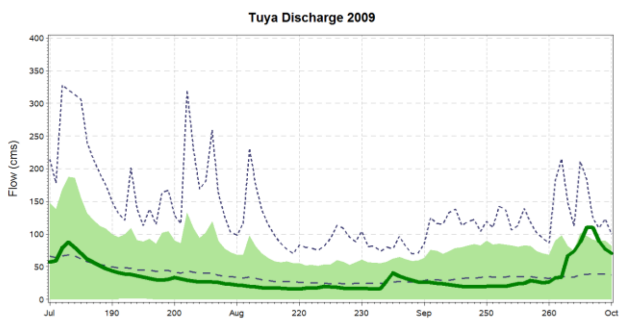

2008 Tahltan Water Temperature
Temperature (C)
Jul
190
200
Aug
220
230
Sep
250
260
Oct

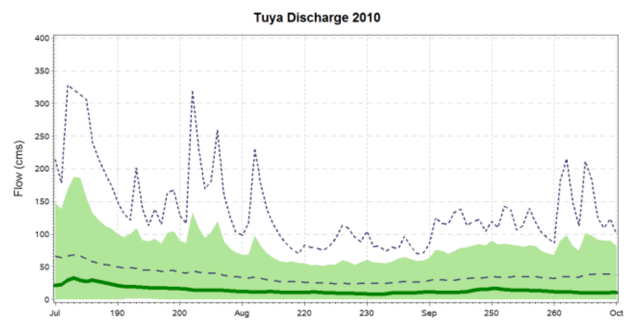

2009 Dease AHCCD Stn 1192340
Air Temperature (C)
Precipitation (mm)

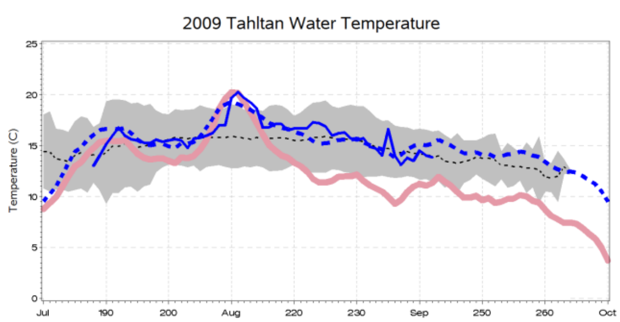

2010 Dease AHCCD Stn 1192340
Air Temperature (C)
Precipitation (mm)

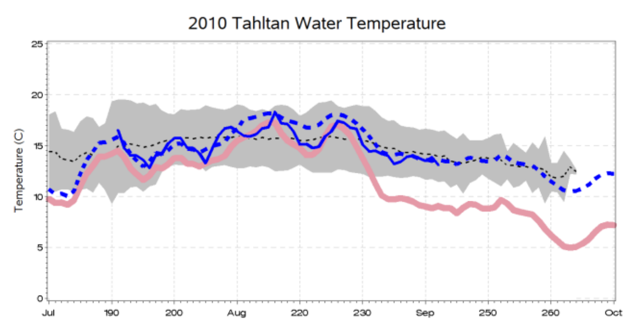

2009 Tahltan Lake Weir Sockeye Counts (Total Esc: 30,673)
Daily Percent of Annual Esc (%)


2010 Tahltan Lake Weir Sockeye Counts (Total Esc: 22,860)
Daily Percent of Annual Esc (%)

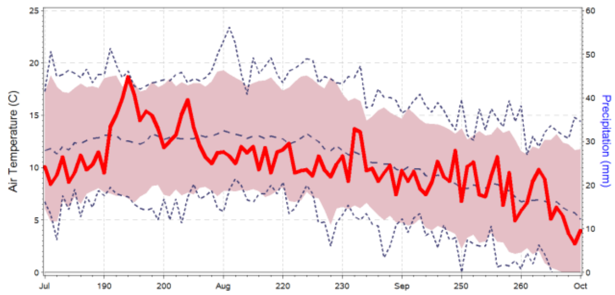

Tuya Discharge 2009
Flow (cms)


Tuya Discharge 2010
Flow (cms)

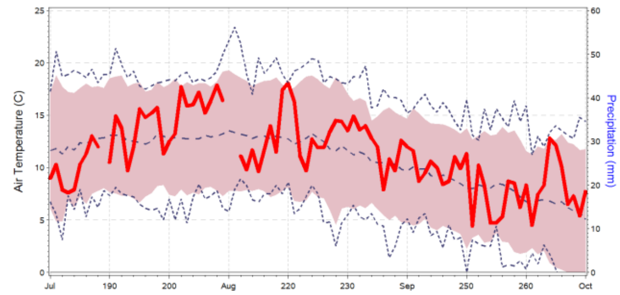

2009 Tahltan Water Temperature
Temperature (C)


2010 Tahltan Water Temperature
Temperature (C)

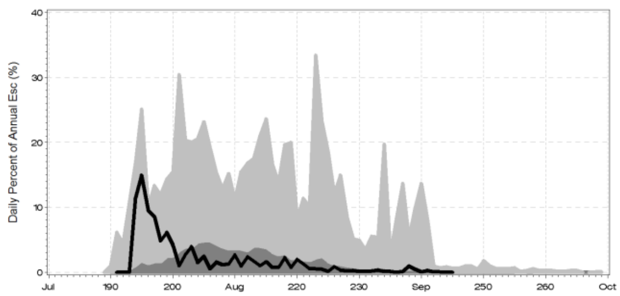
2011 Dease AHCCD Stn 1192340



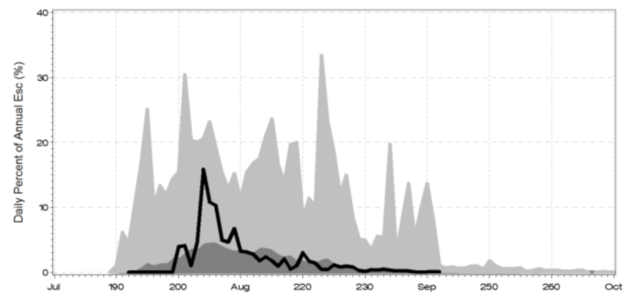
2012 Dease AHCCD Stn 1192340



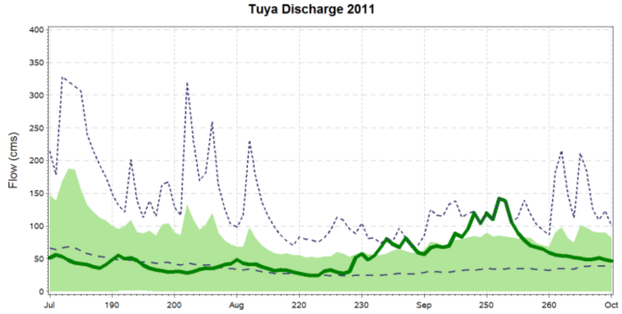
2011 Tahltan Lake Weir Sockeye Counts (Total Esc: 34,588)



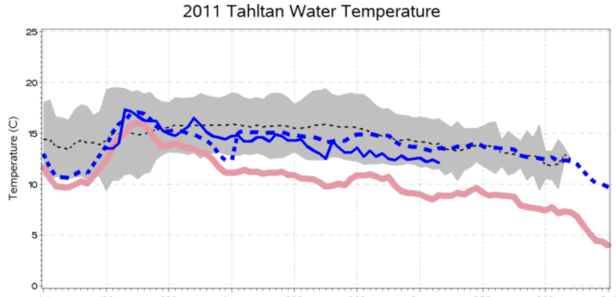
2012 Tahltan Lake Weir Sockeye Counts (Total Esc: 13,693)



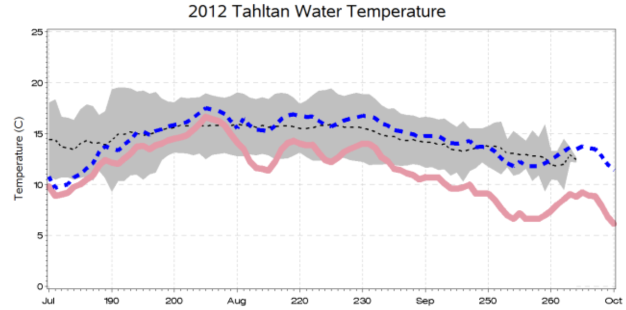
Tuya Discharge 2011



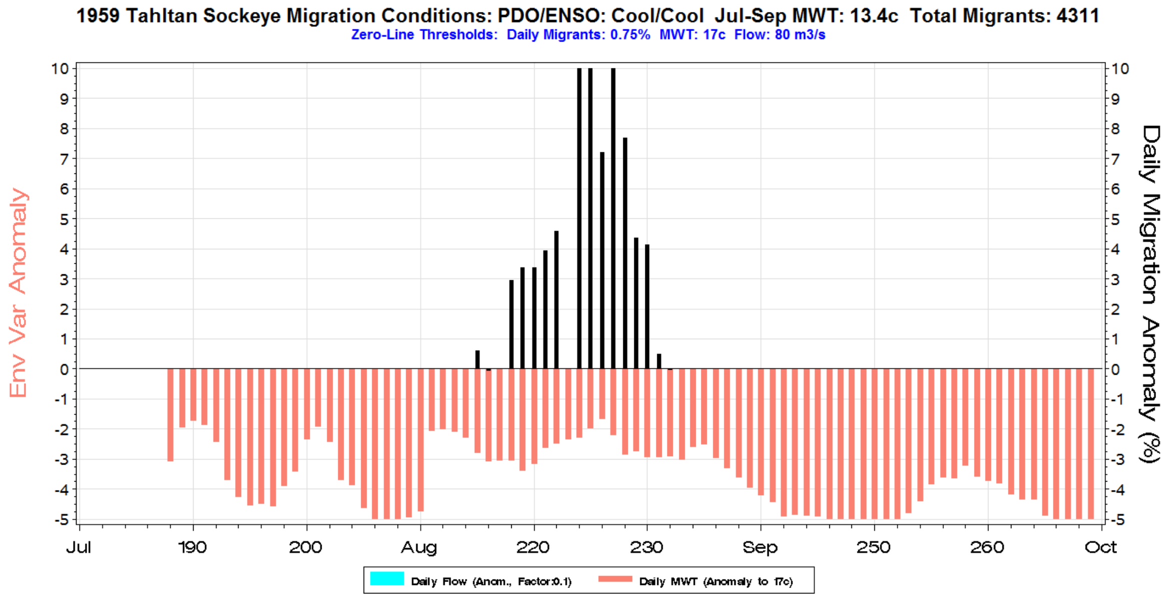
2011 Tahltan Water Temperature

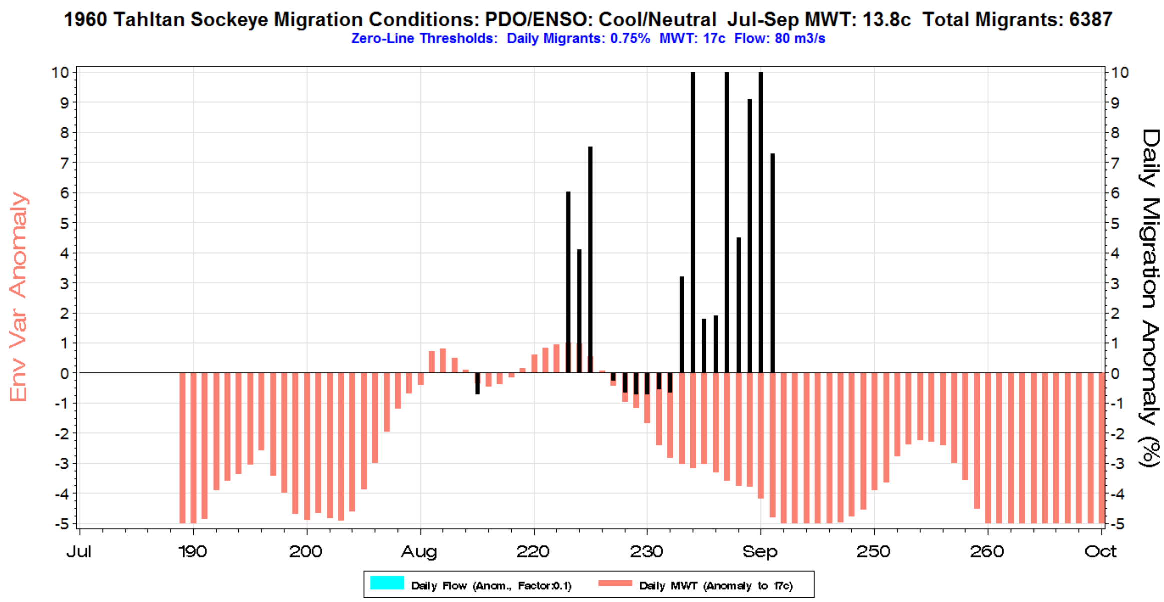


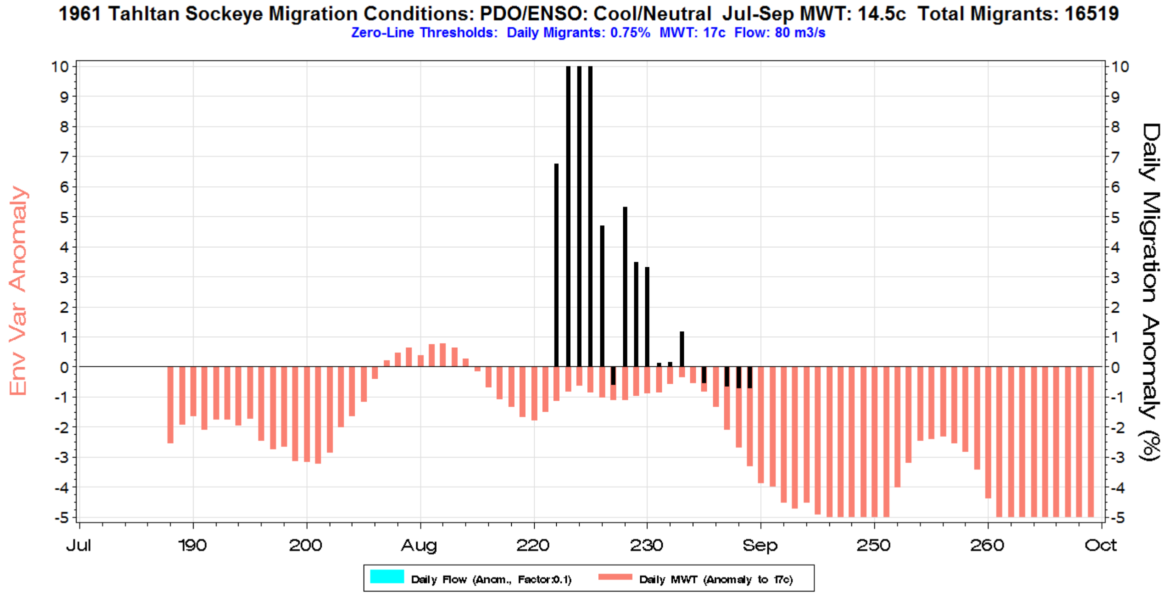
2012 Tahltan Water Temperature

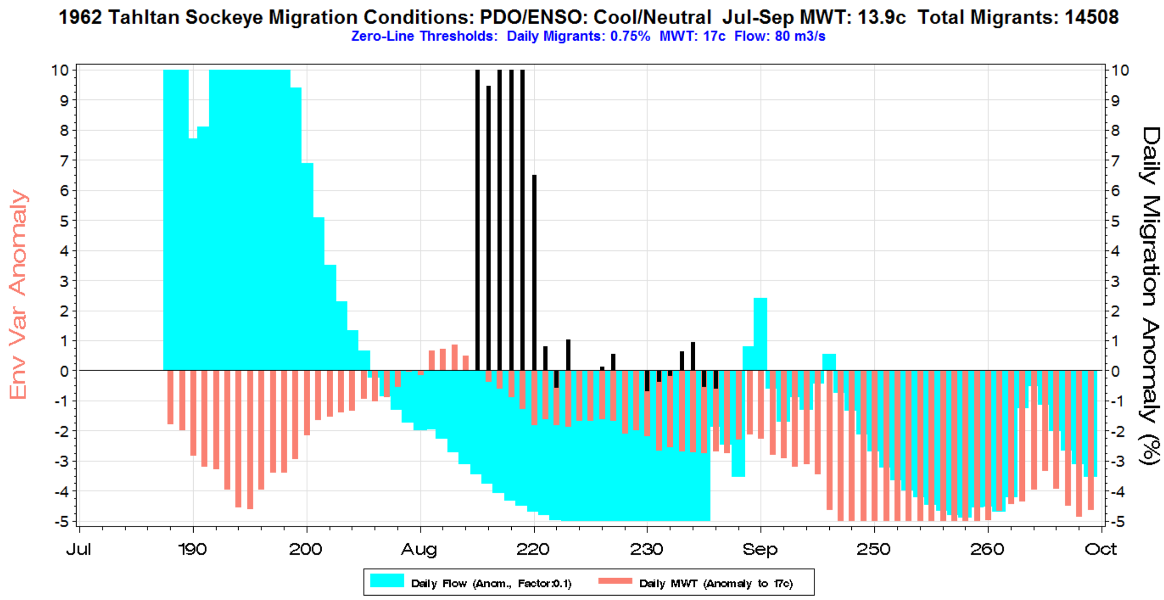


Appendix D. Annual anomaly plots for Tahltan Sockeye migration, Tahltan Lake water temperature (estimated), and Tuya River discharge (flow factored by 0.1 to fit on y-axis). Zero-line thresholds: (a) Daily migration rate = 2.8% (75th percentile of non-zero daily migration rates (1959-2012); (b) water temperature = 17°C; discharge = 80 cms.

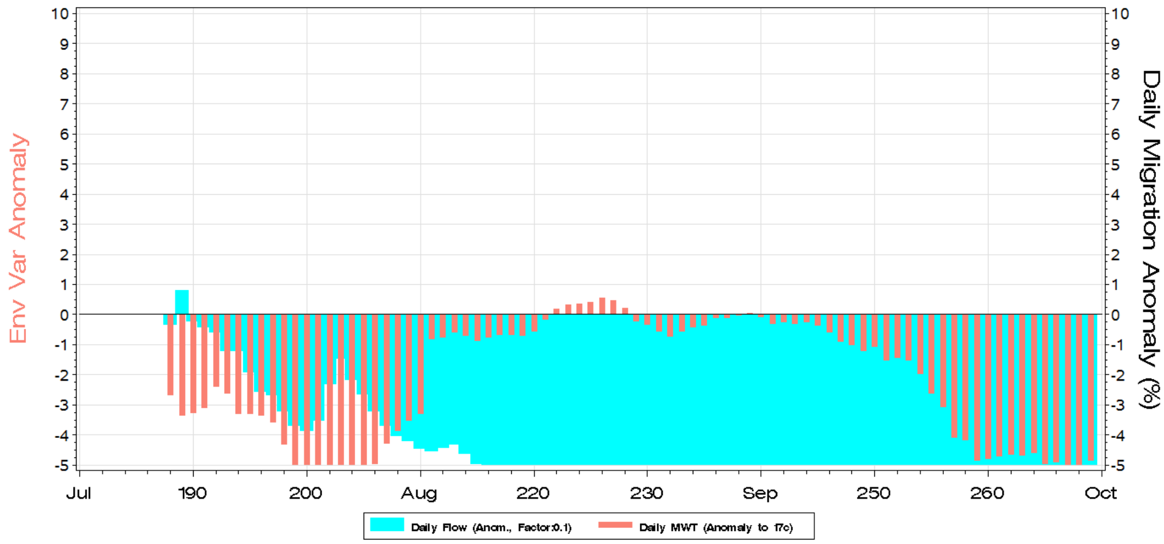




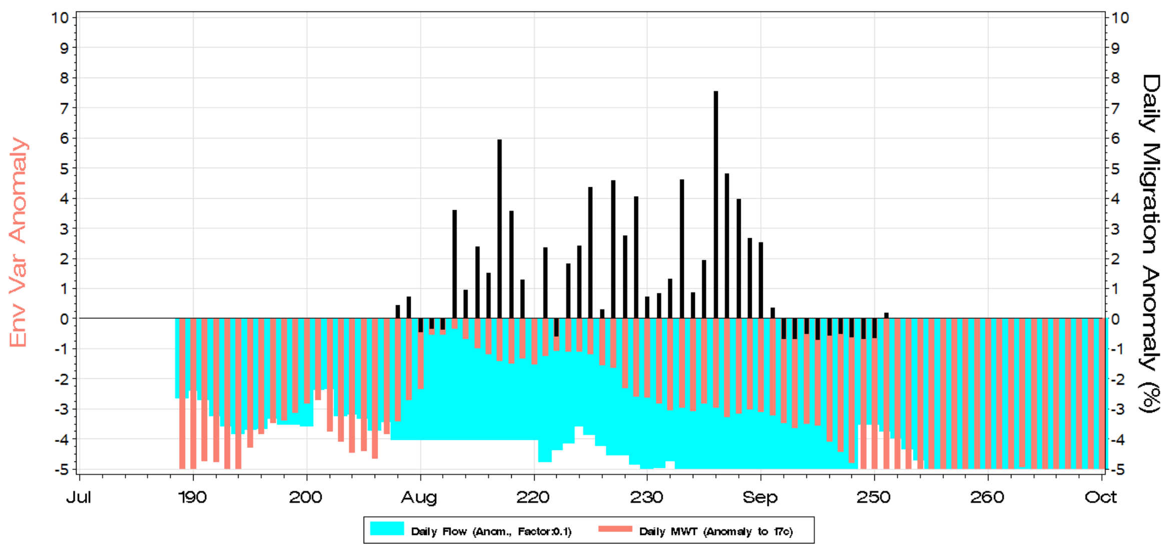

1961 Tahltan Sockeye Migration Conditions: PDO/ENSO: Cool/Neutral Jul-Sep MWT: 14.5c Total Migrants: 16519
Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct
Daily Flow (Anom., Factor:0.1)
Daily MWT (Anomaly to 17c)

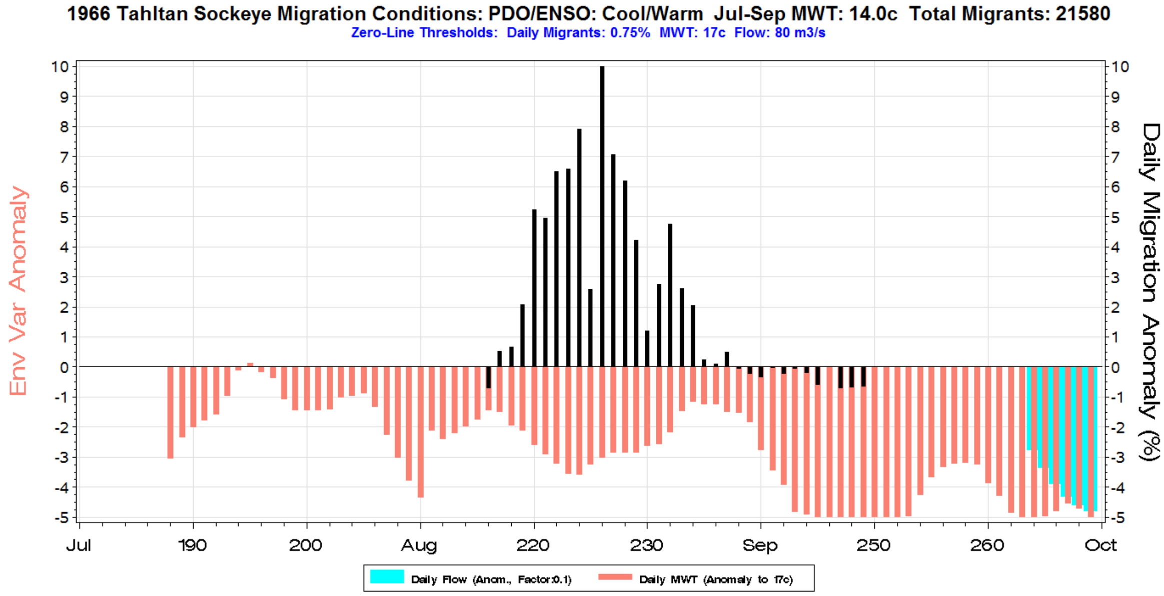

1962 Tahltan Sockeye Migration Conditions: PDO/ENSO: Cool/Neutral Jul-Sep MWT: 13.9c Total Migrants: 14508
Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct
Daily Flow (Anom., Factor:0.1)
Daily MWT (Anomaly to 17c)

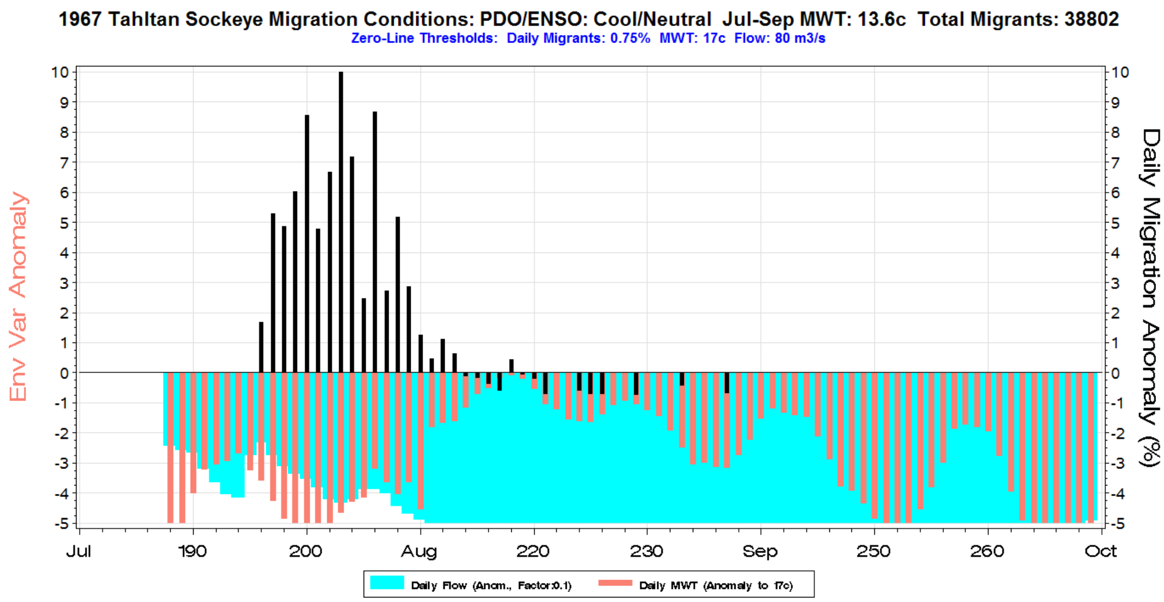
1963 Tahltan Sockeye Migration Conditions: PDO/ENSO: Cool/Neutral Jul-Sep MWT: 14.8c Total Migrants: .
Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s



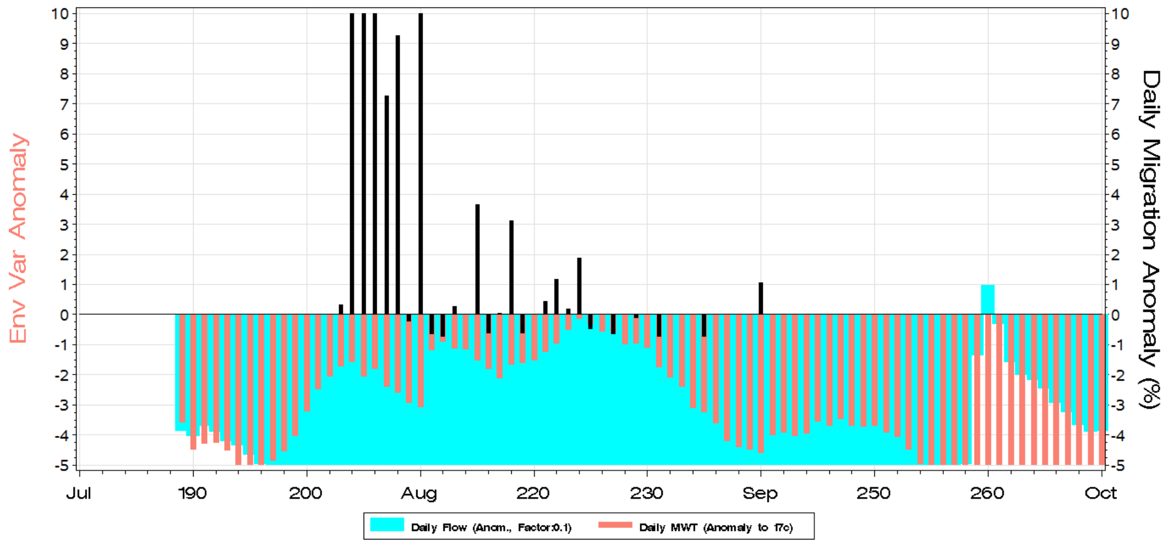
1964 Tahltan Sockeye Migration Conditions: PDO/ENSO: Cool/Warm Jul-Sep MWT: 13.3c Total Migrants: 18353
Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s



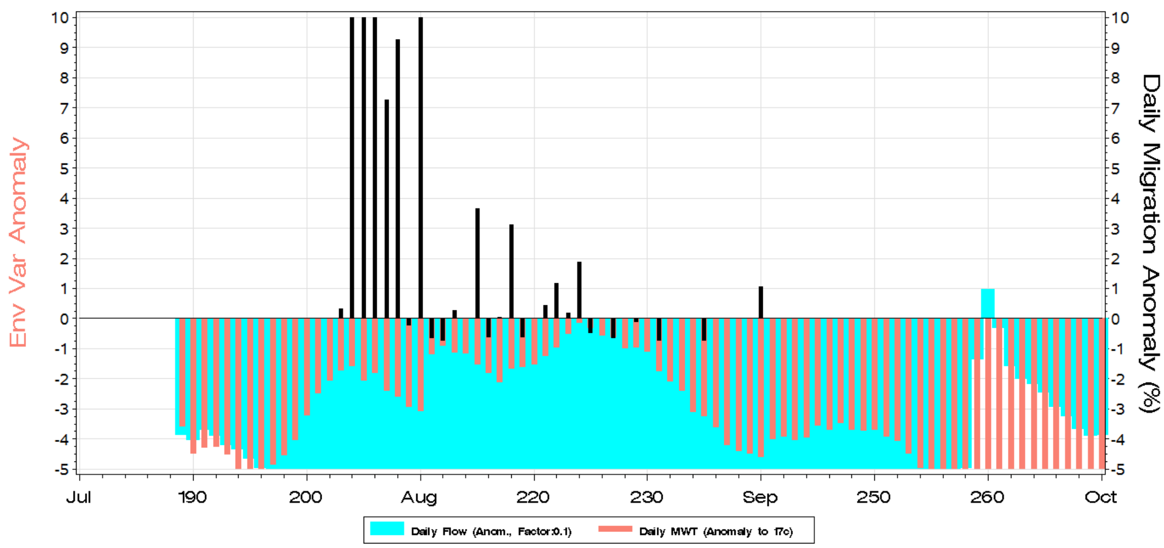

1966 Tahltan Sockeye Migration Conditions: PDO/ENSO: Cool/Warm Jul-Sep MWT: 14.0c Total Migrants: 21580
Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct
Daily Flow (Anom., Factor:0.1)
Daily MWT (Anomaly to 17c)

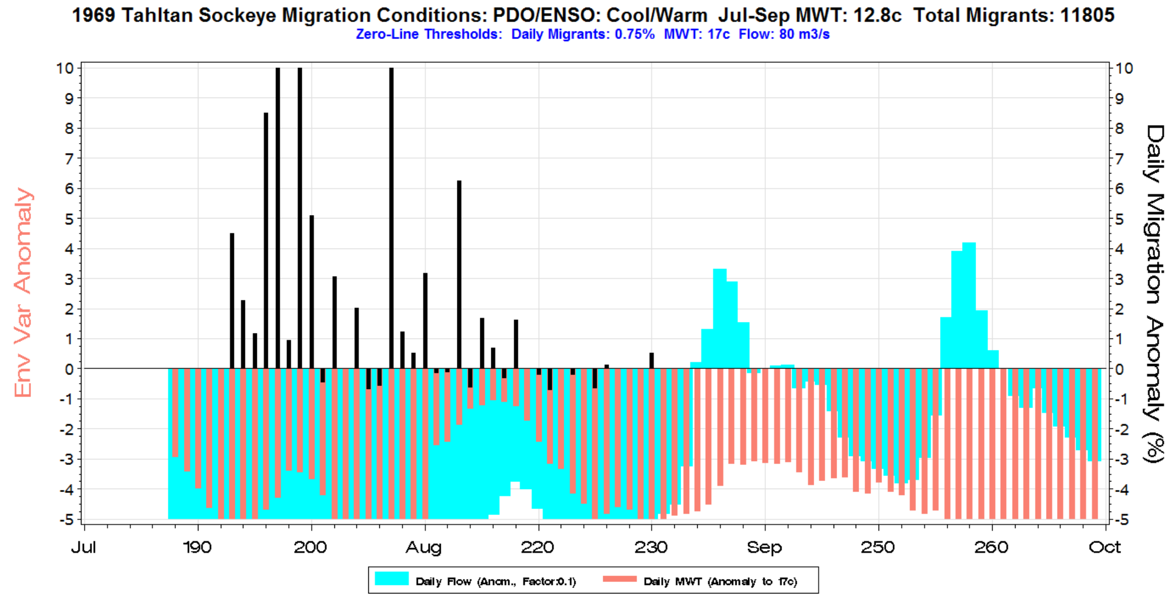

1967 Tahltan Sockeye Migration Conditions: PDO/ENSO: Cool/Neutral Jul-Sep MWT: 13.6c Total Migrants: 38802
Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct
Daily Flow (Anom., Factor:0.1)
Daily MWT (Anomaly to 17c)

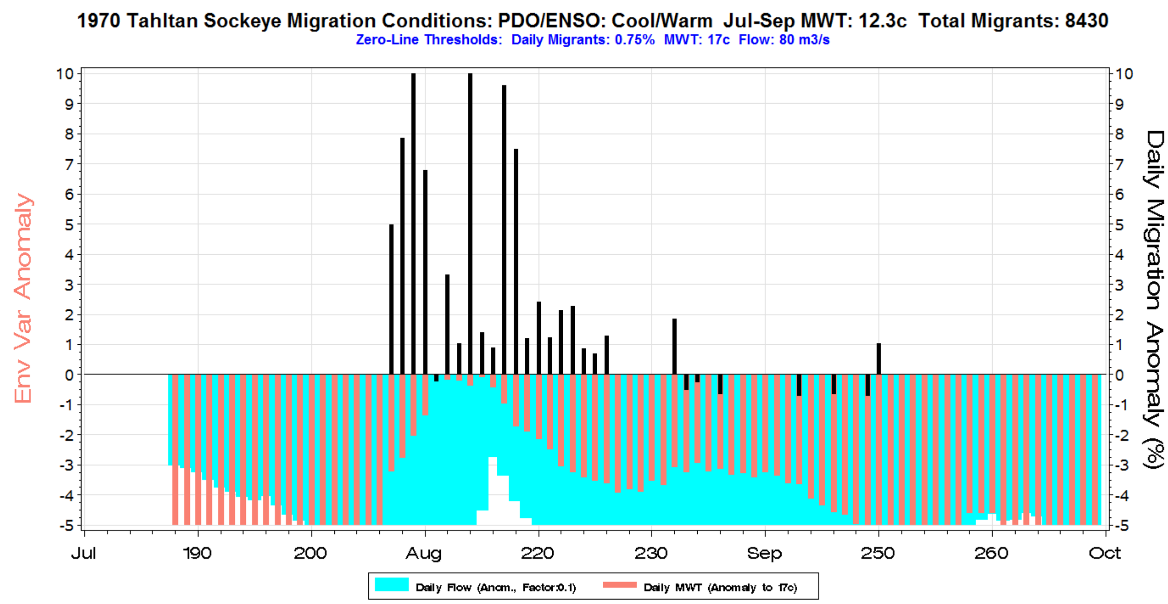
1968 Tahltan Sockeye Migration Conditions: PDO/ENSO: Cool/Cool Jul-Sep MWT: 13.8c Total Migrants: 19726
Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s

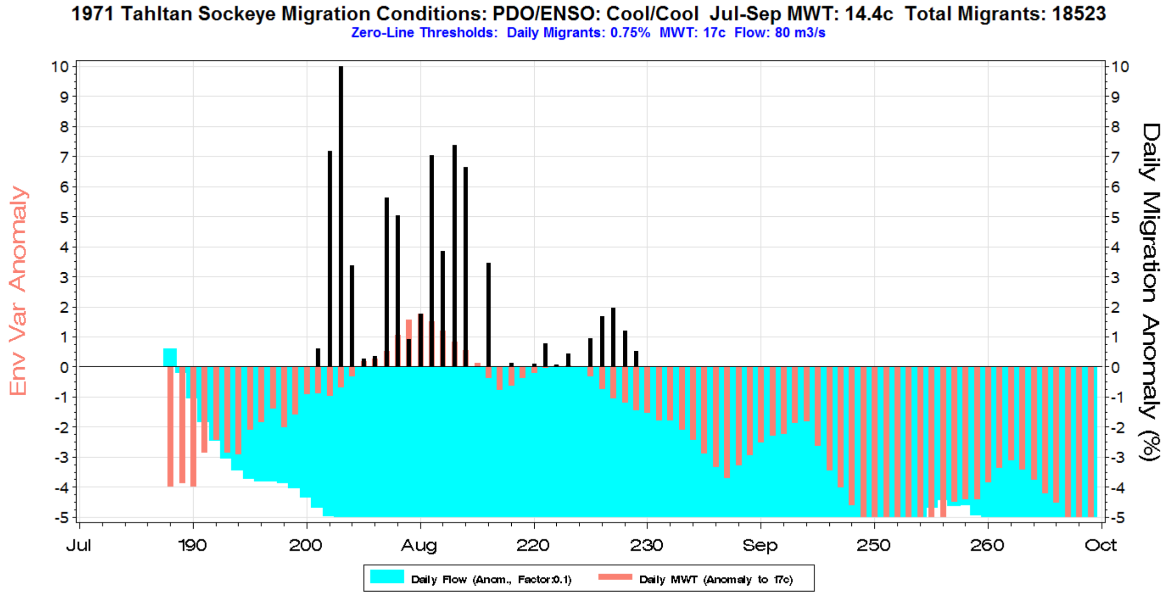


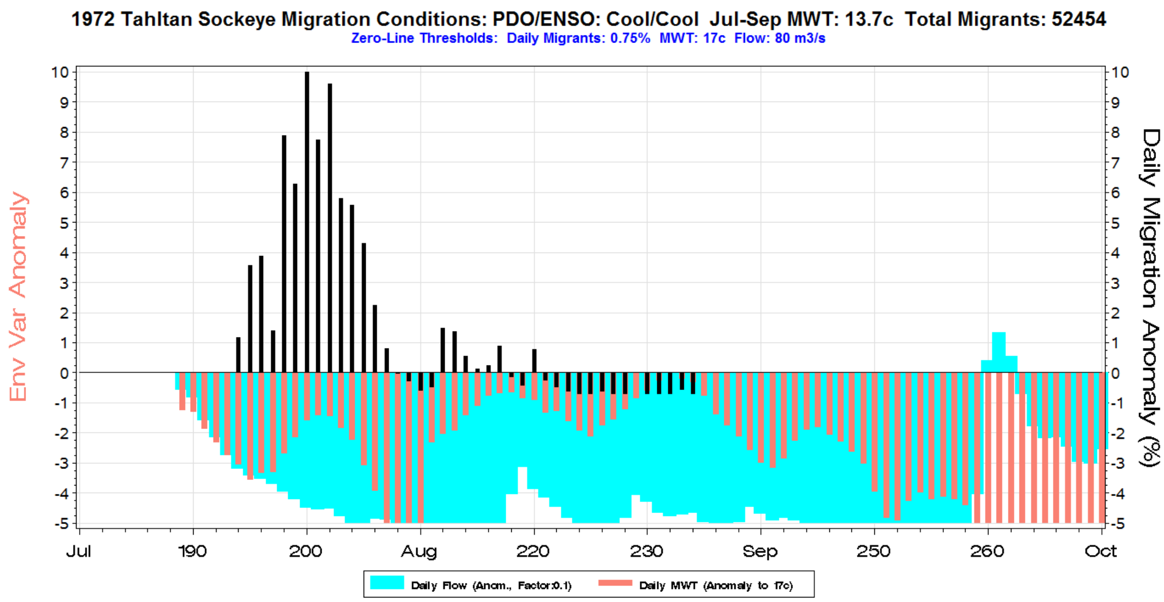
1968 Tahltan Sockeye Migration Conditions: PDO/ENSO: Cool/Cool Jul-Sep MWT: 13.8c Total Migrants: 19726
Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s



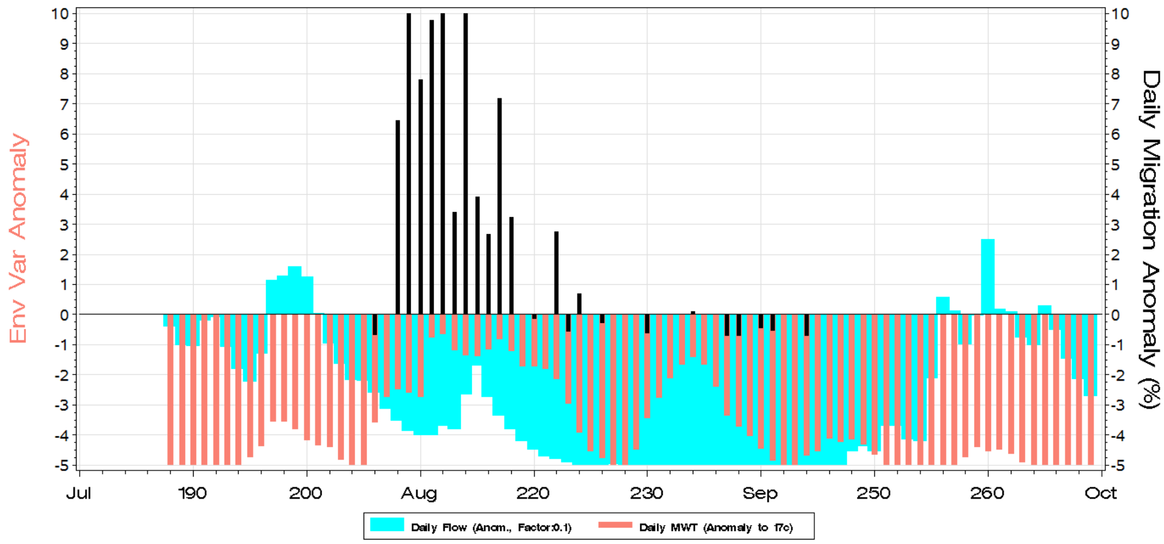

1969 Tahltan Sockeye Migration Conditions: PDO/ENSO: Cool/Warm Jul-Sep MWT: 12.8c Total Migrants: 11805
Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct
Daily Flow (Anom., Factor:0.1)
Daily MWT (Anomaly to 17c)


1970 Tahltan Sockeye Migration Conditions: PDO/ENSO: Cool/Warm Jul-Sep MWT: 12.3c Total Migrants: 8430
Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct
Daily Flow (Anom., Factor:0.1)
Daily MWT (Anomaly to 17c)

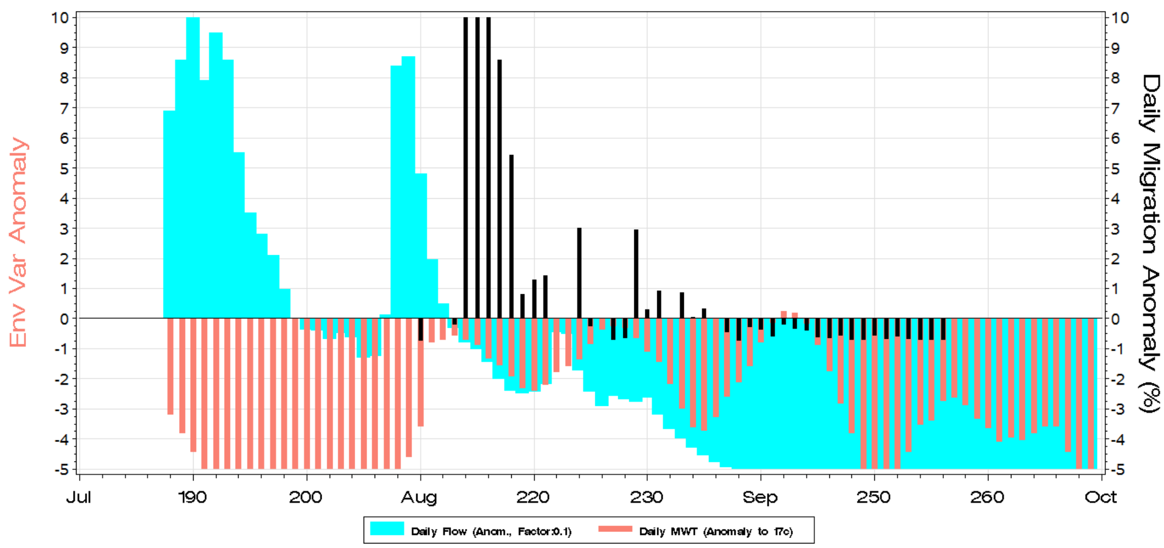

1971 Tahltan Sockeye Migration Conditions: PDO/ENSO: Cool/Cool Jul-Sep MWT: 14.4c Total Migrants: 18523
Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct
Daily Flow (Anom., Factor:0.1)
Daily MWT (Anomaly to 17c)

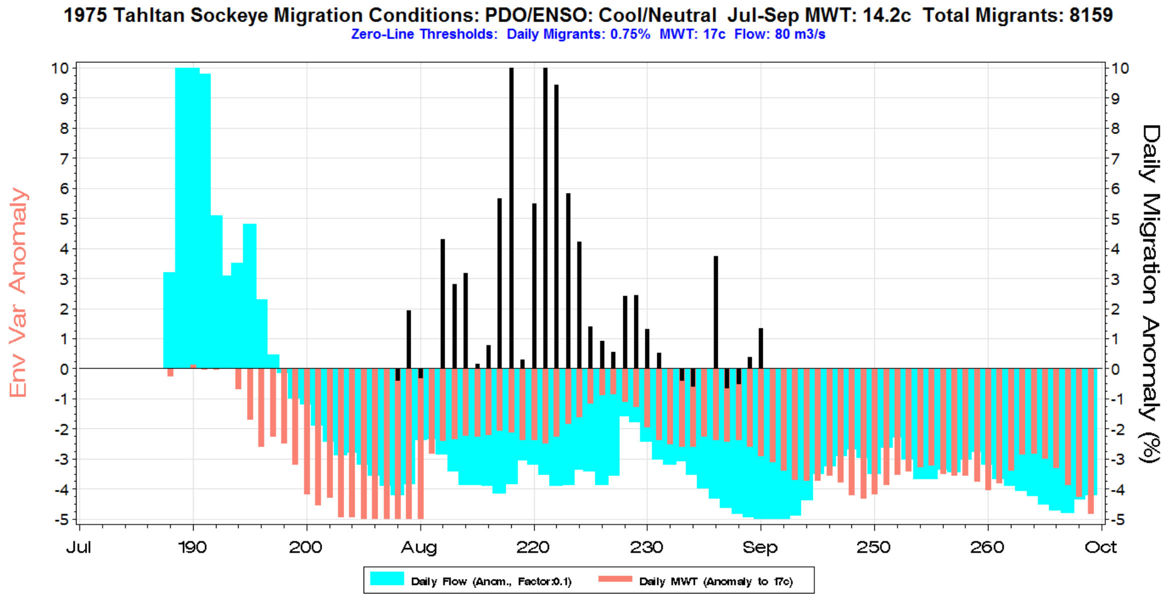

1972 Tahltan Sockeye Migration Conditions: PDO/ENSO: Cool/Cool Jul-Sep MWT: 13.7c Total Migrants: 52454
Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct
Daily Flow (Anom., Factor:0.1)
Daily MWT (Anomaly to 17c)

1973 Tahltan Sockeye Migration Conditions: PDO/ENSO: Cool/Warm Jul-Sep MWT: 12.9c Total Migrants: 2864
Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s

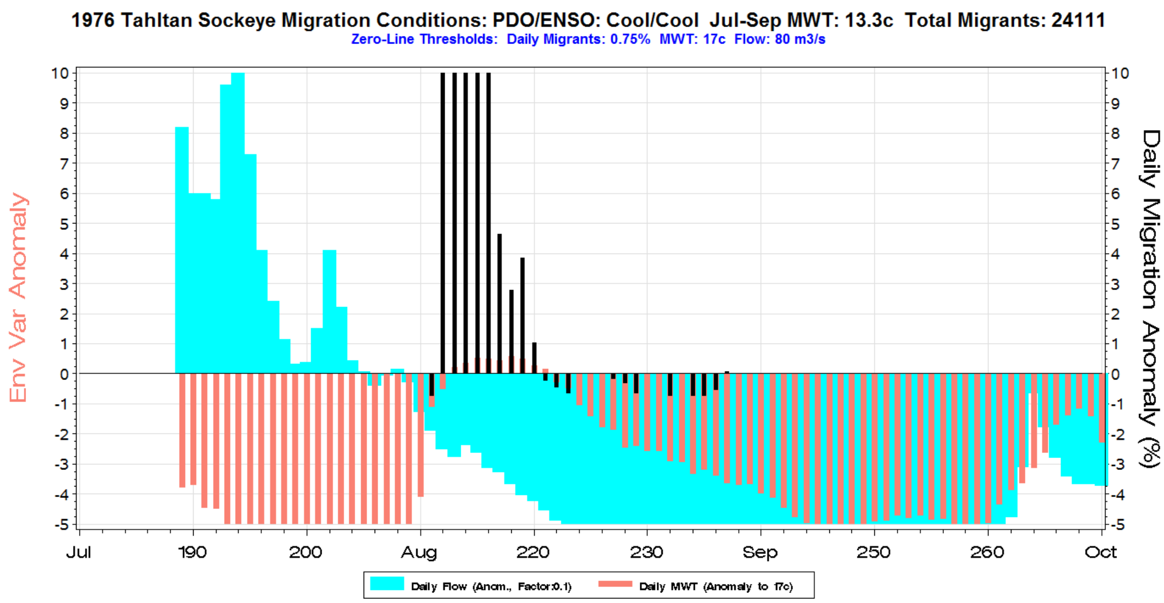


1974 Tahltan Sockeye Migration Conditions: PDO/ENSO: Cool/Cool Jul-Sep MWT: 13.3c Total Migrants: 8101
Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s



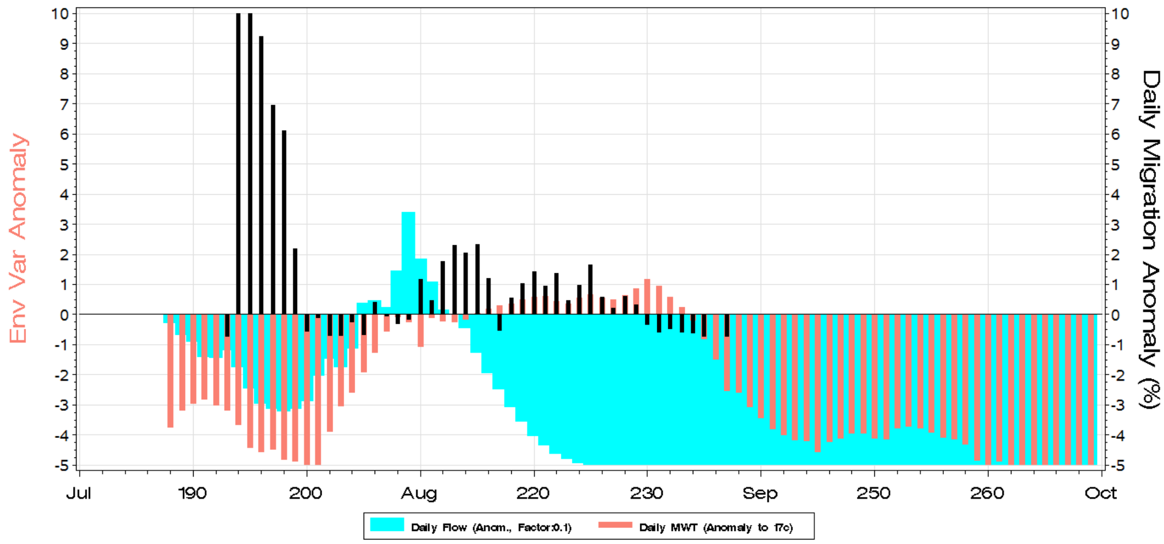


1975 Tahltan Sockeye Migration Conditions: PDO/ENSO: Cool/Neutral Jul-Sep MWT: 14.2c Total Migrants: 8159
Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct
Daily Flow (Anom., Factor:0.1)
Daily MWT (Anomaly to 17c)

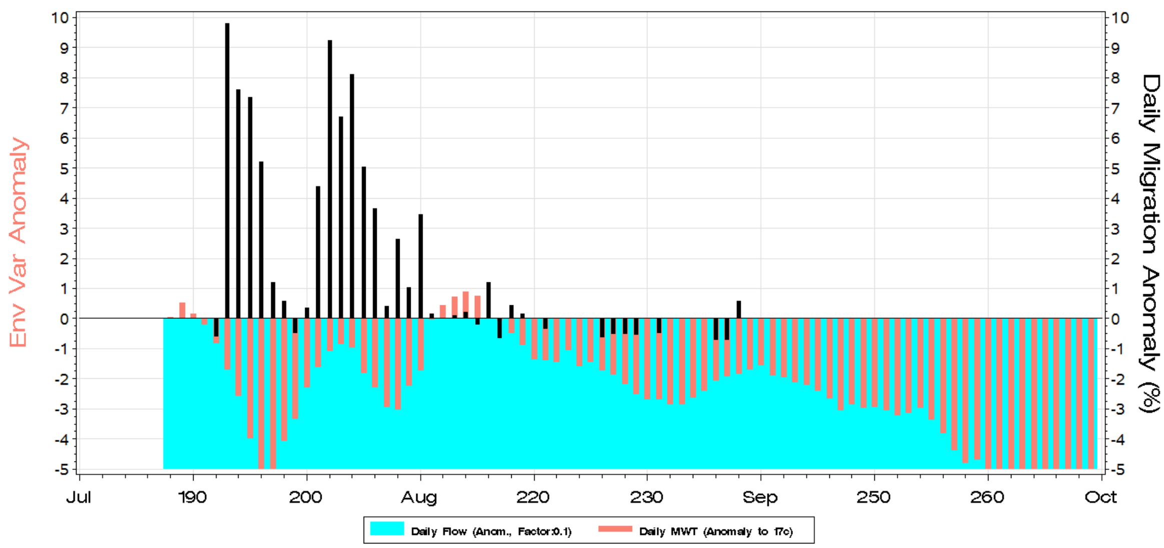


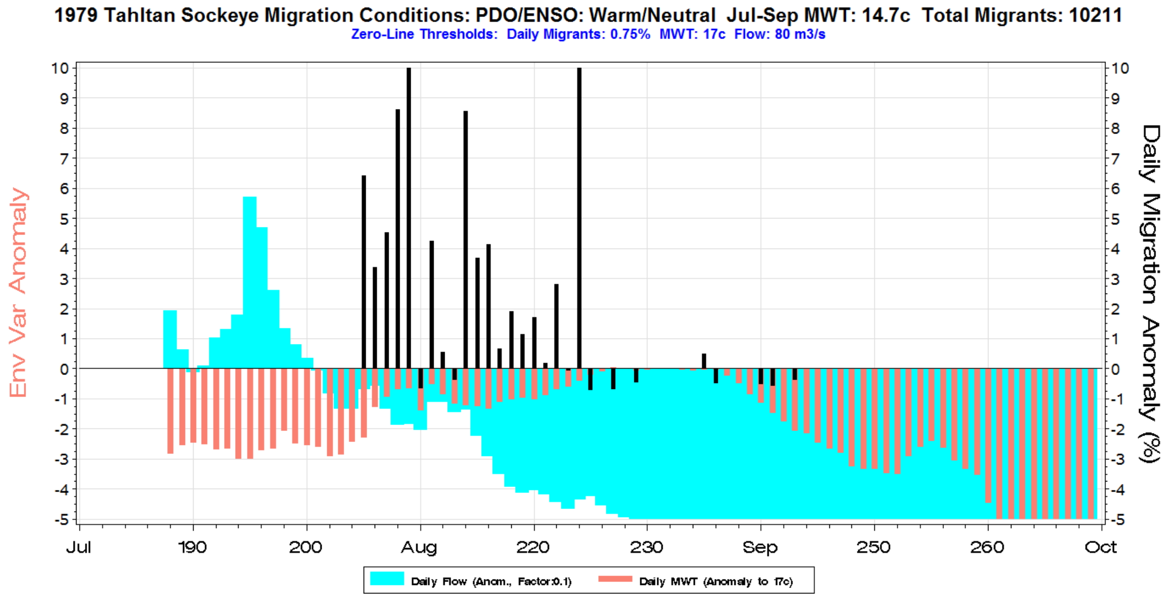
1976 Tahltan Sockeye Migration Conditions: PDO/ENSO: Cool/Cool Jul-Sep MWT: 13.3c Total Migrants: 24111
Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct
Daily Flow (Anom., Factor:0.1)
Daily MWT (Anomaly to 17c)

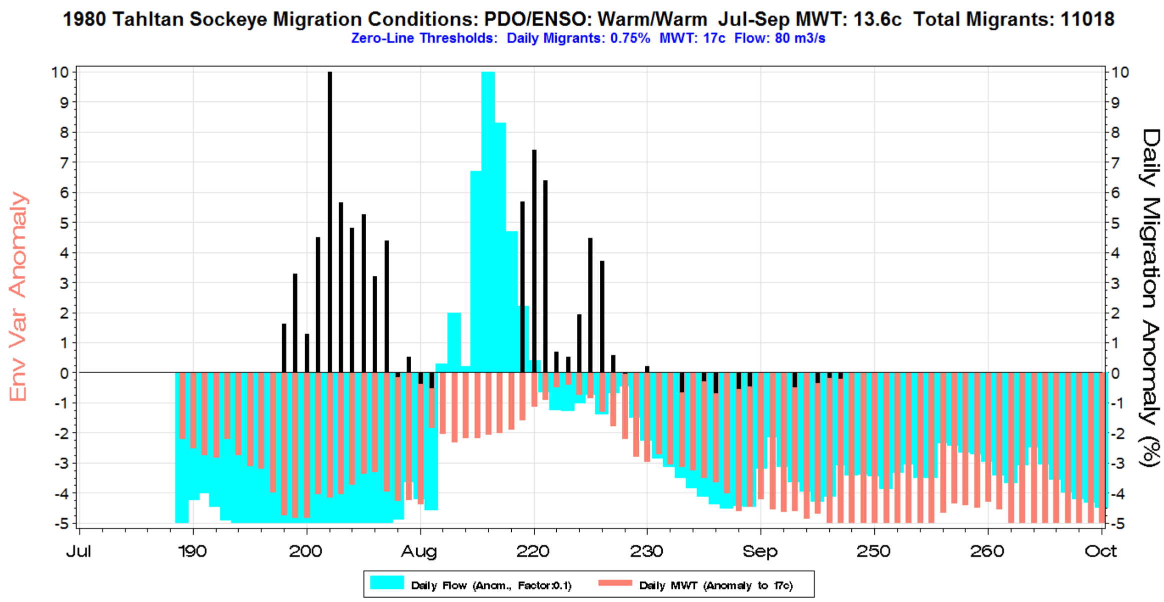
1977 Tahltan Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Jul-Sep MWT: 14.3c Total Migrants: 42960
Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s

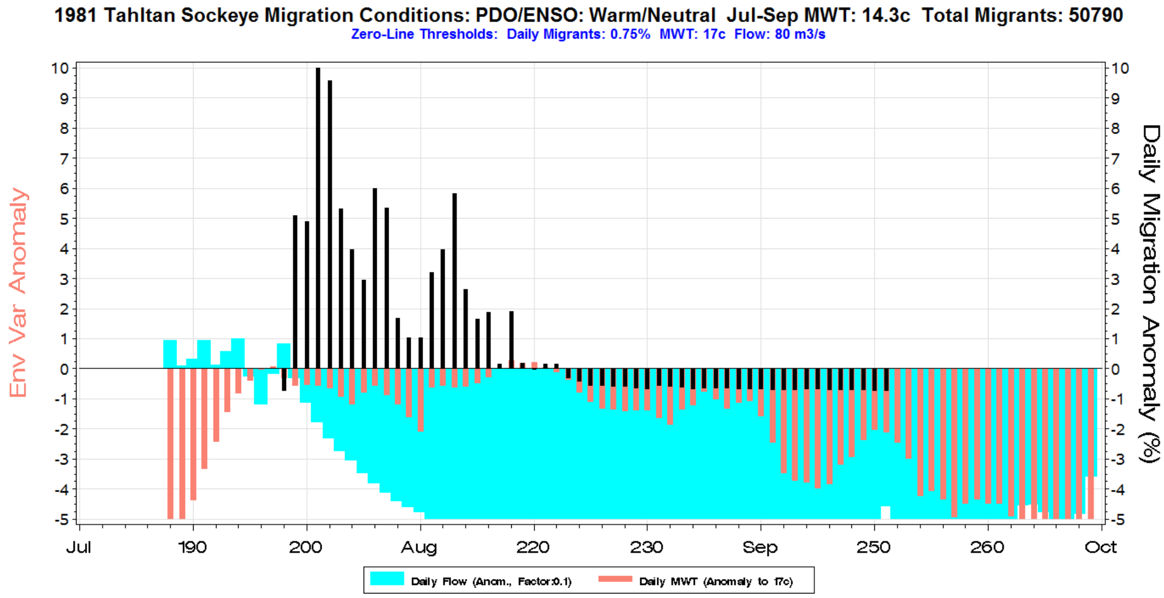


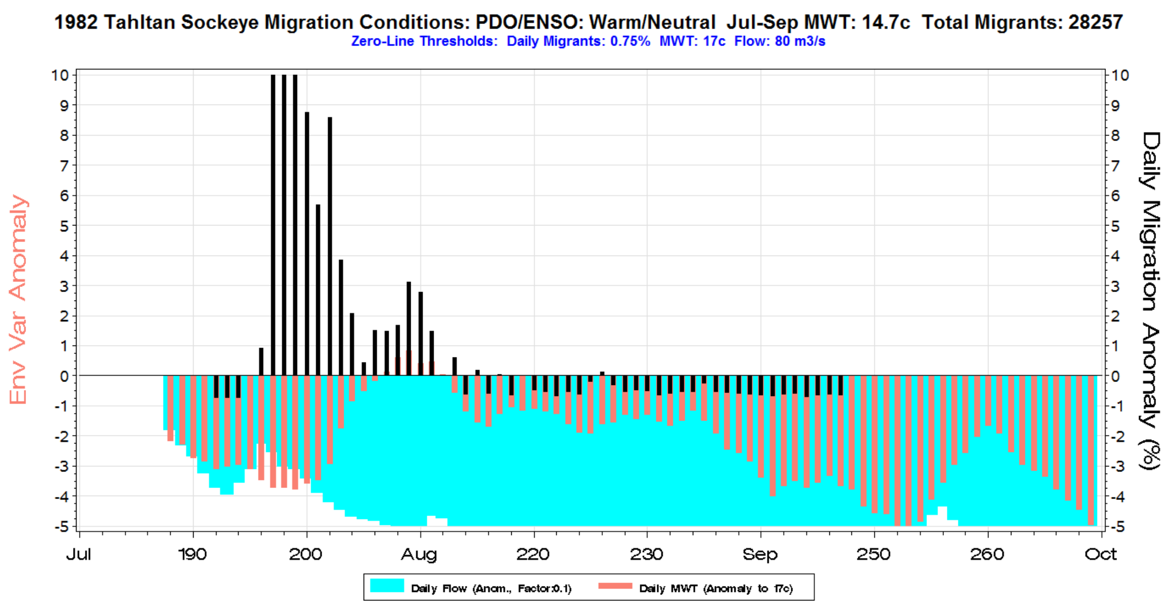
1978 Tahltan Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Jul-Sep MWT: 14.4c Total Migrants: 22788
Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s




1979 Tahltan Sockeye Migration Conditions: PDO/ENSO: Warm/Neutral Jul-Sep MWT: 14.7c Total Migrants: 10211
Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct
Daily Flow (Anom., Factor:0.1)
Daily MWT (Anomaly to 17c)


1980 Tahltan Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Jul-Sep MWT: 13.6c Total Migrants: 11018
Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct
Daily Flow (Anom., Factor:0.1)
Daily MWT (Anomaly to 17c)


1981 Tahltan Sockeye Migration Conditions: PDO/ENSO: Warm/Neutral Jul-Sep MWT: 14.3c Total Migrants: 50790
Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct
Daily Flow (Anom., Factor:0.1)
Daily MWT (Anomaly to 17c)


1982 Tahltan Sockeye Migration Conditions: PDO/ENSO: Warm/Neutral Jul-Sep MWT: 14.7c Total Migrants: 28257
Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
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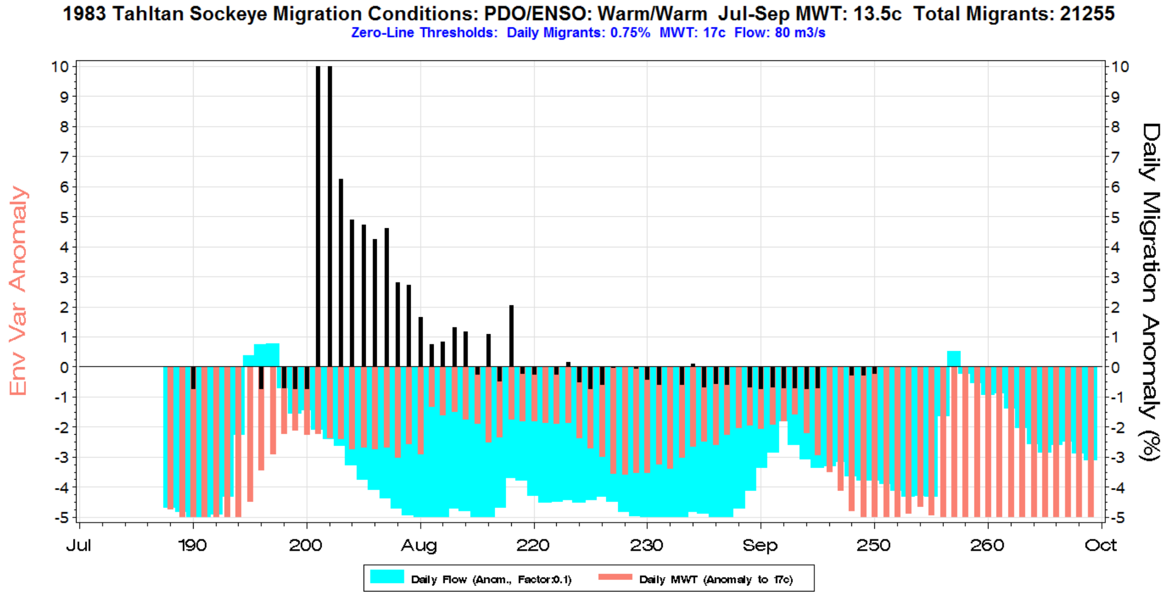
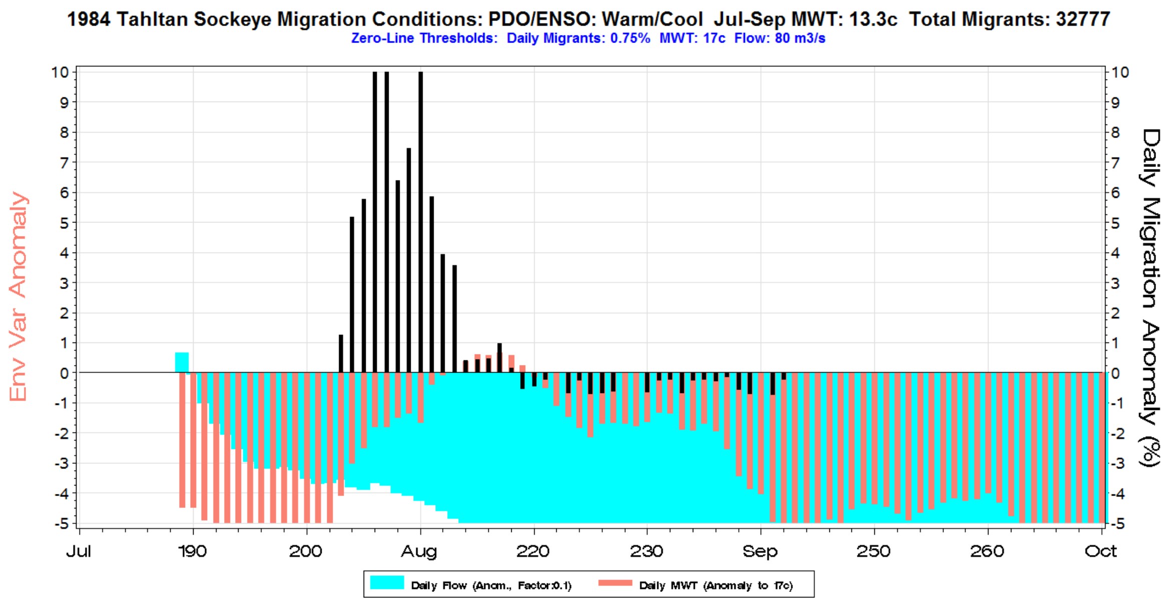
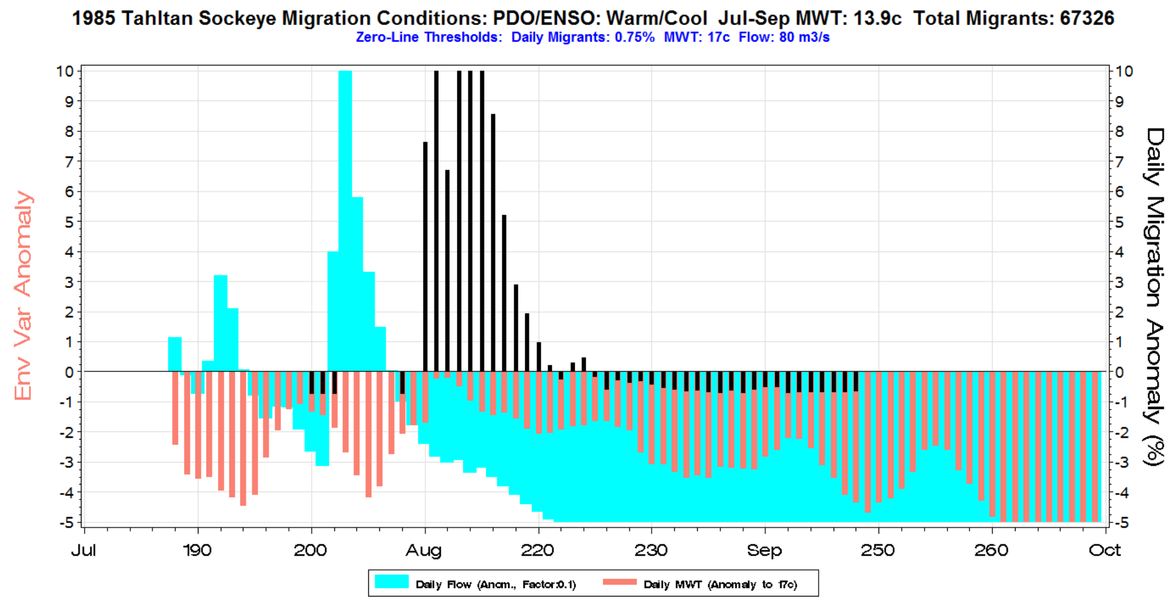
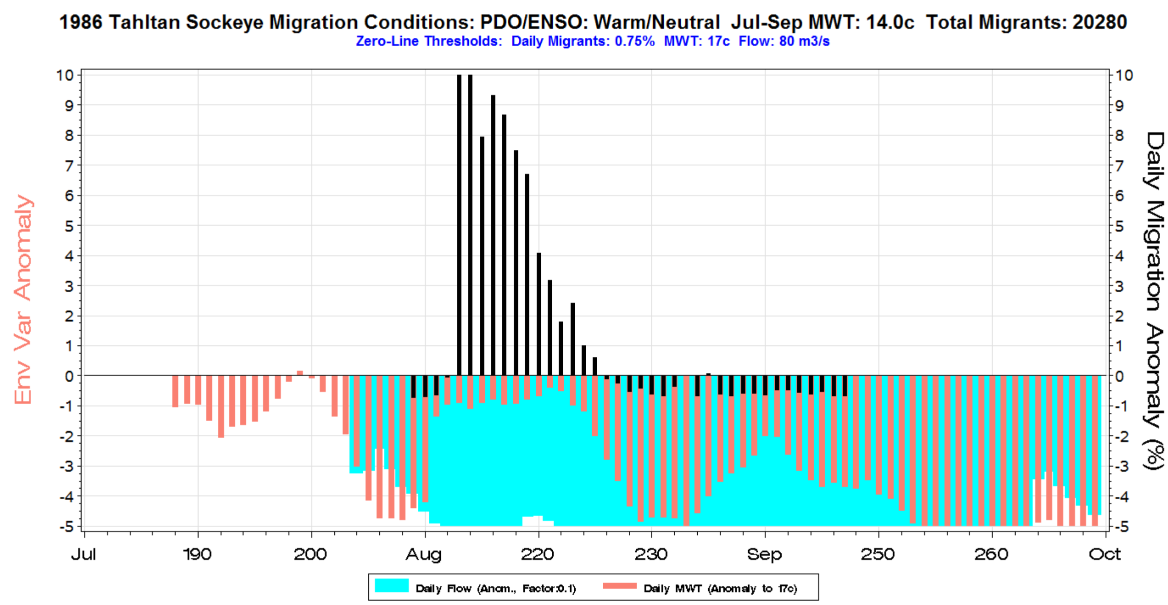
200
Aug
220
230
Sep
250
260
Oct
Daily Flow (Anom., Factor:0.1)
Daily MWT (Anomaly to 17c)


1983 Tahltan Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Jul-Sep MWT: 13.5c Total Migrants: 21255
Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct
Daily Flow (Anom., Factor:0.1)
Daily MWT (Anomaly to 17c)

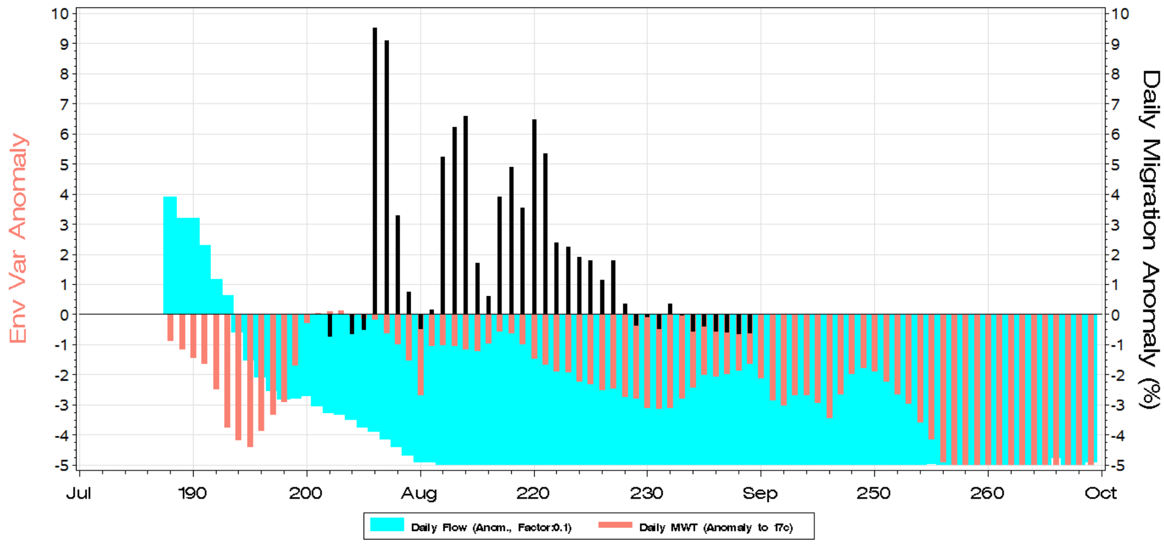

1984 Tahltan Sockeye Migration Conditions: PDO/ENSO: Warm/Cool Jul-Sep MWT: 13.3c Total Migrants: 32777
Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct
Daily Flow (Anom., Factor:0.1)
Daily MWT (Anomaly to 17c)


1985 Tahltan Sockeye Migration Conditions: PDO/ENSO: Warm/Cool Jul-Sep MWT: 13.9c Total Migrants: 67326
Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct
Daily Flow (Anom., Factor:0.1)
Daily MWT (Anomaly to 17c)


1986 Tahltan Sockeye Migration Conditions: PDO/ENSO: Warm/Neutral Jul-Sep MWT: 14.0c Total Migrants: 20280
Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct
Daily Flow (Anom., Factor:0.1)
Daily MWT (Anomaly to 17c)

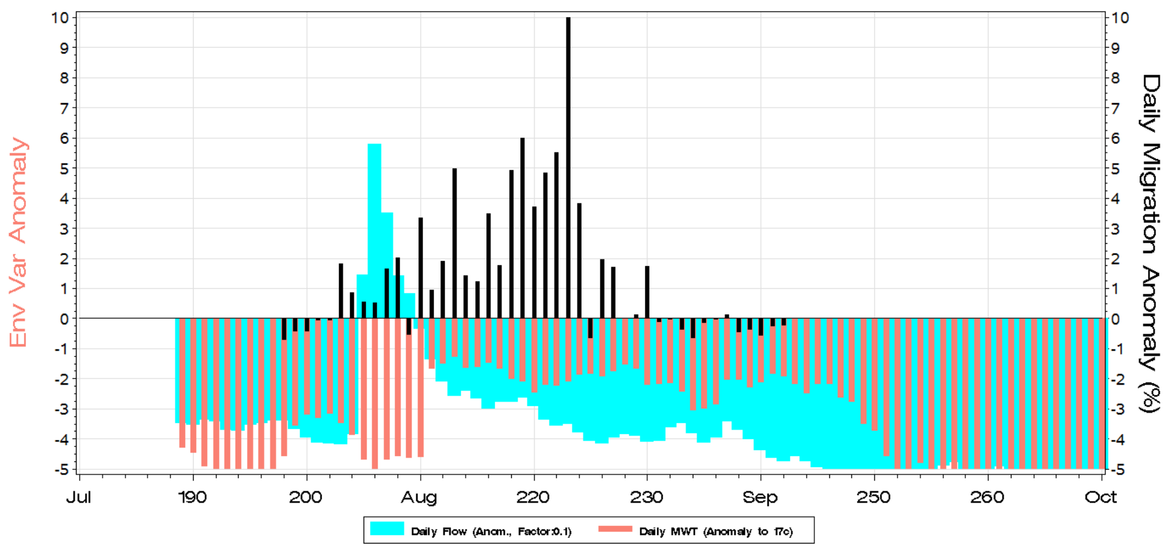
1987 Tahltan Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Jul-Sep MWT: 14.6c Total Migrants: 6958

Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s



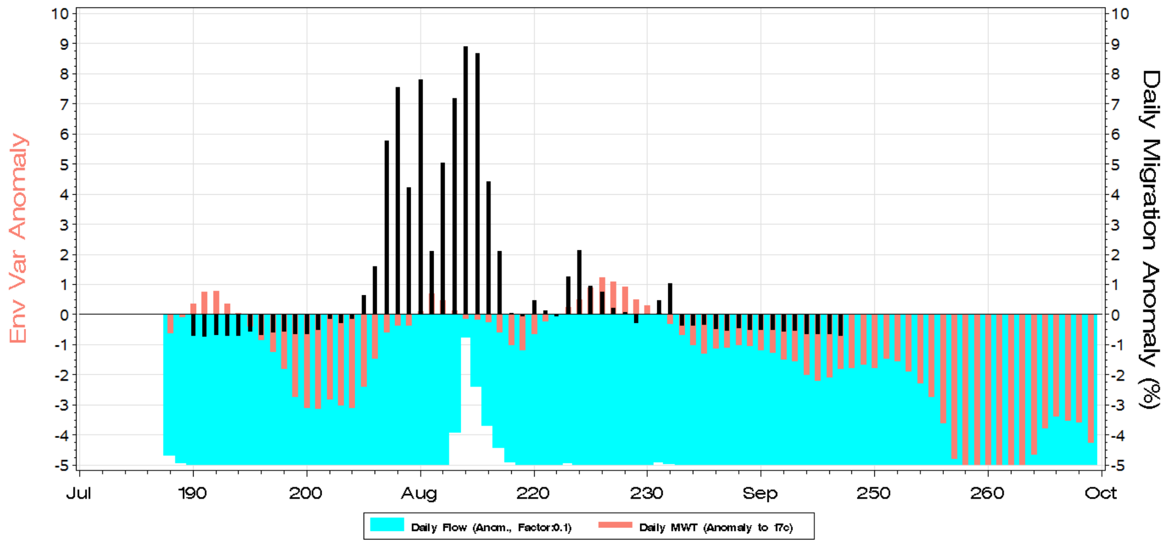
1988 Tahltan Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Jul-Sep MWT: 13.1c Total Migrants: 2536

Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s



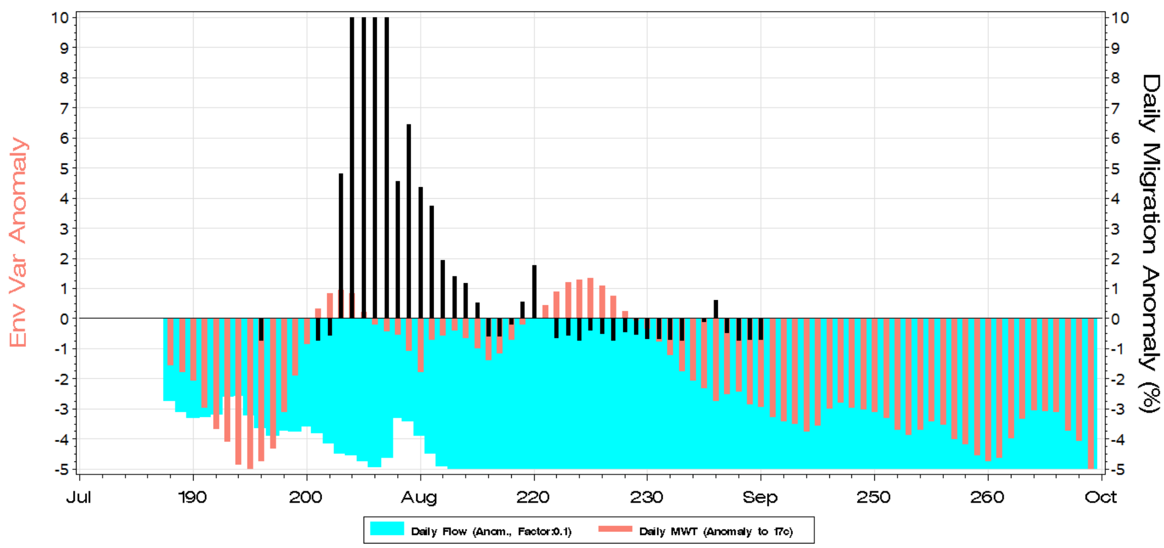
1989 Tahltan Sockeye Migration Conditions: PDO/ENSO: Warm/Cool Jul-Sep MWT: 15.4c Total Migrants: 8316

Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s



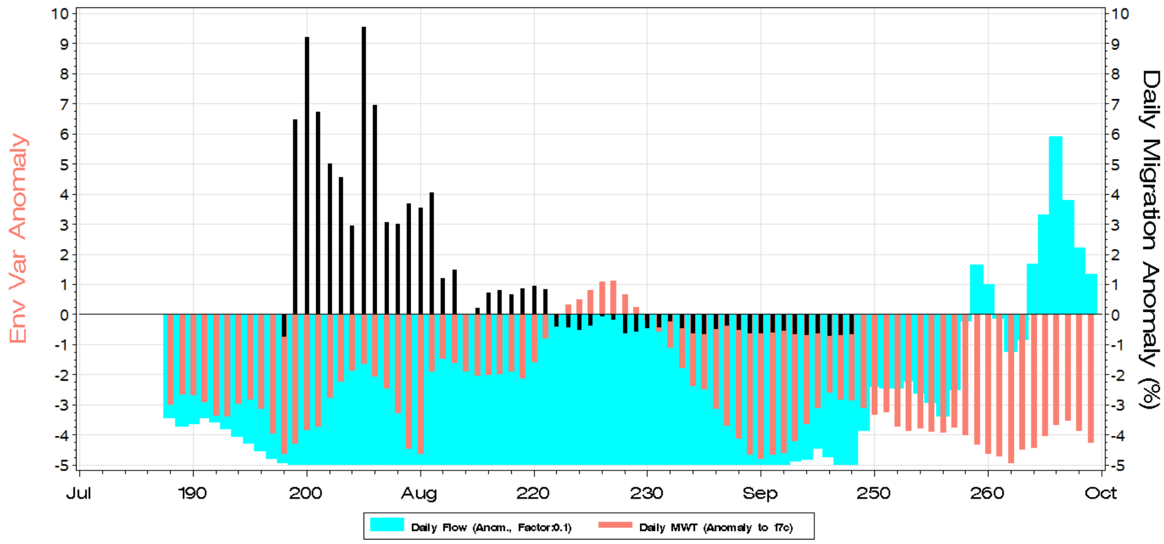
1990 Tahltan Sockeye Migration Conditions: PDO/ENSO: Warm/Neutral Jul-Sep MWT: 15.0c Total Migrants: 14927

Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s



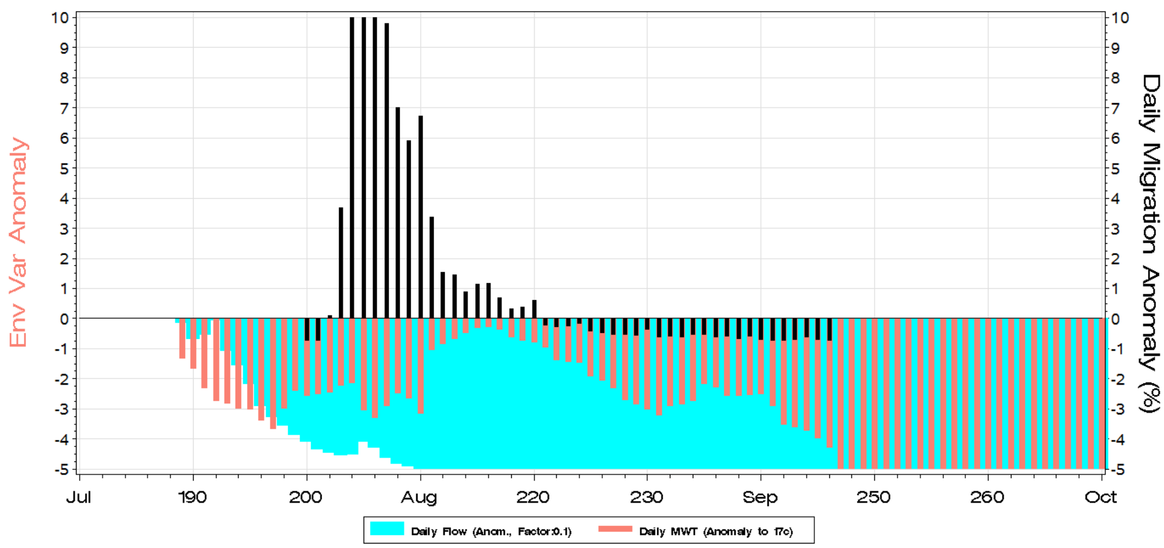
1991 Tahltan Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Jul-Sep MWT: 14.3c Total Migrants: 50135

Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s



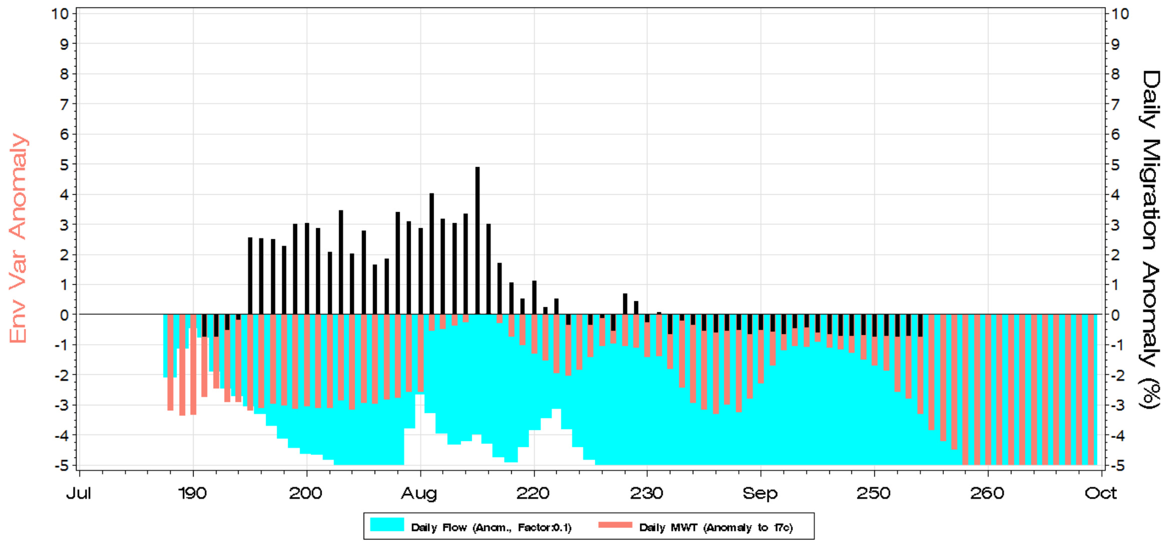
1992 Tahltan Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Jul-Sep MWT: 13.8c Total Migrants: 59907

Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s



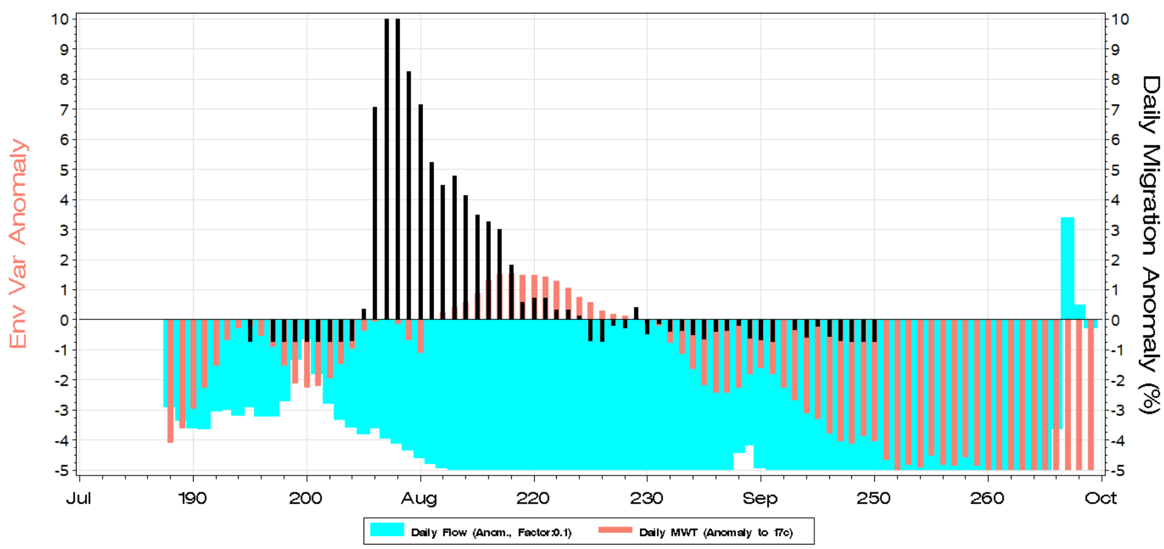
1993 Tahltan Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Jul-Sep MWT: 14.4c Total Migrants: 53362

Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s

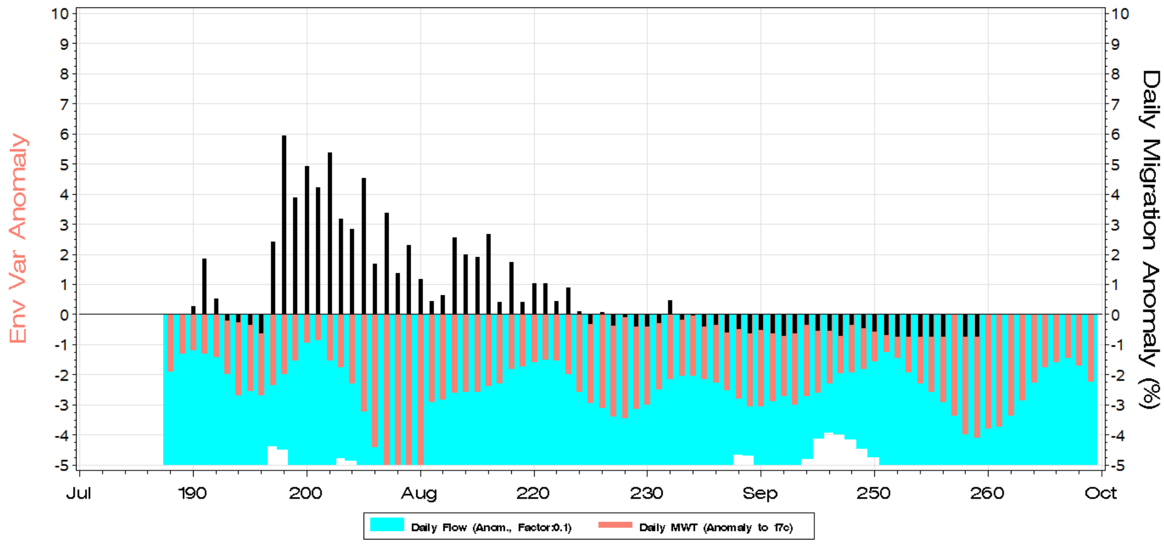


1994 Tahltan Sockeye Migration Conditions: PDO/ENSO: Warm/Neutral Jul-Sep MWT: 14.8c Total Migrants: 46363

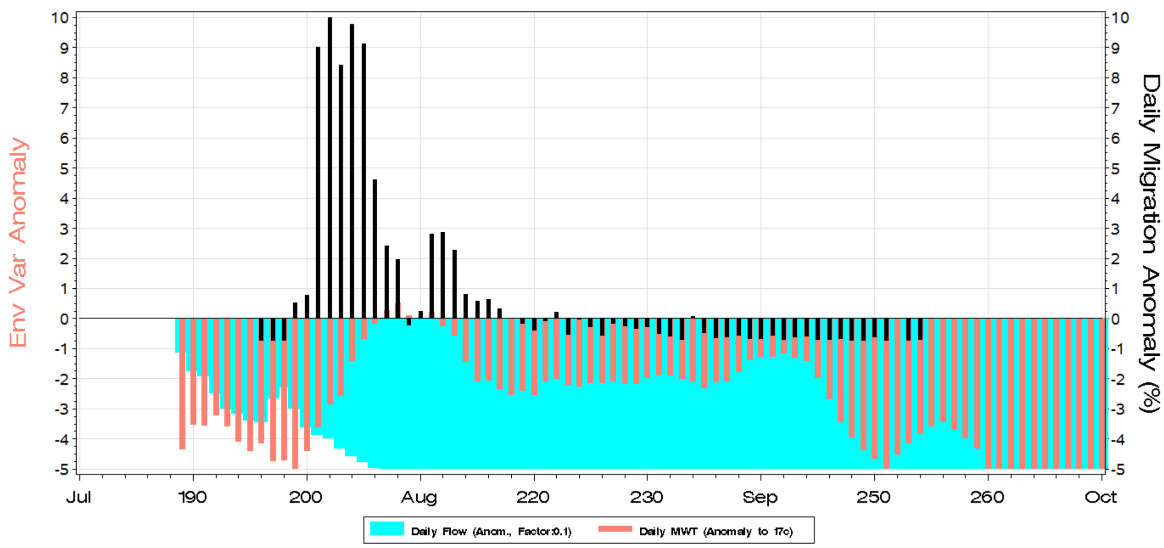
Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s

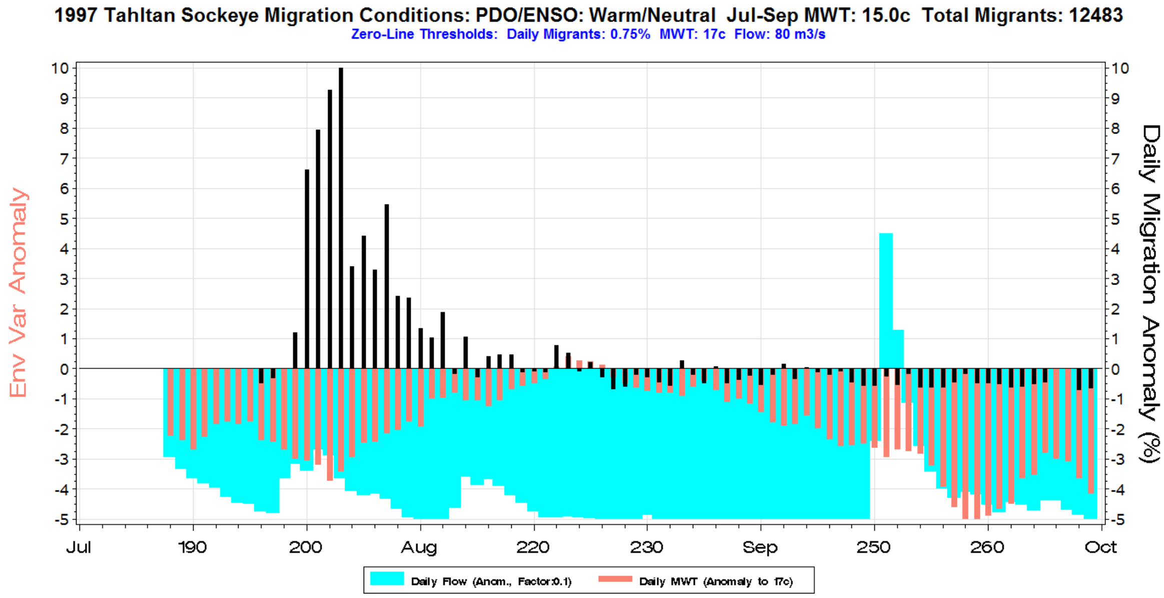


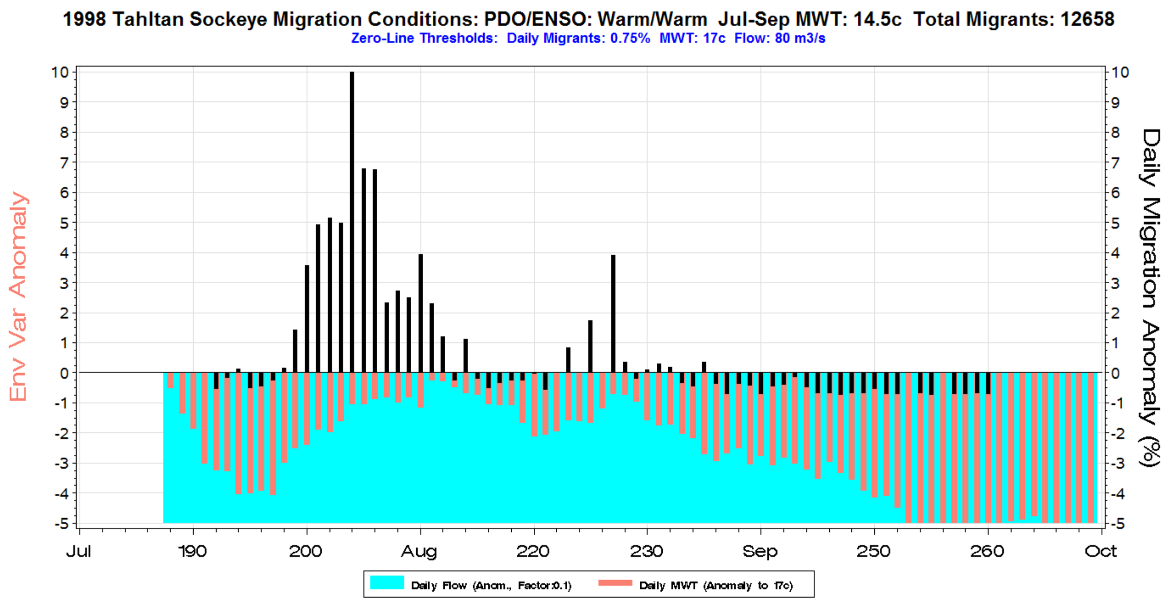
1995 Tahltan Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Jul-Sep MWT: 14.6c Total Migrants: 42317
Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s

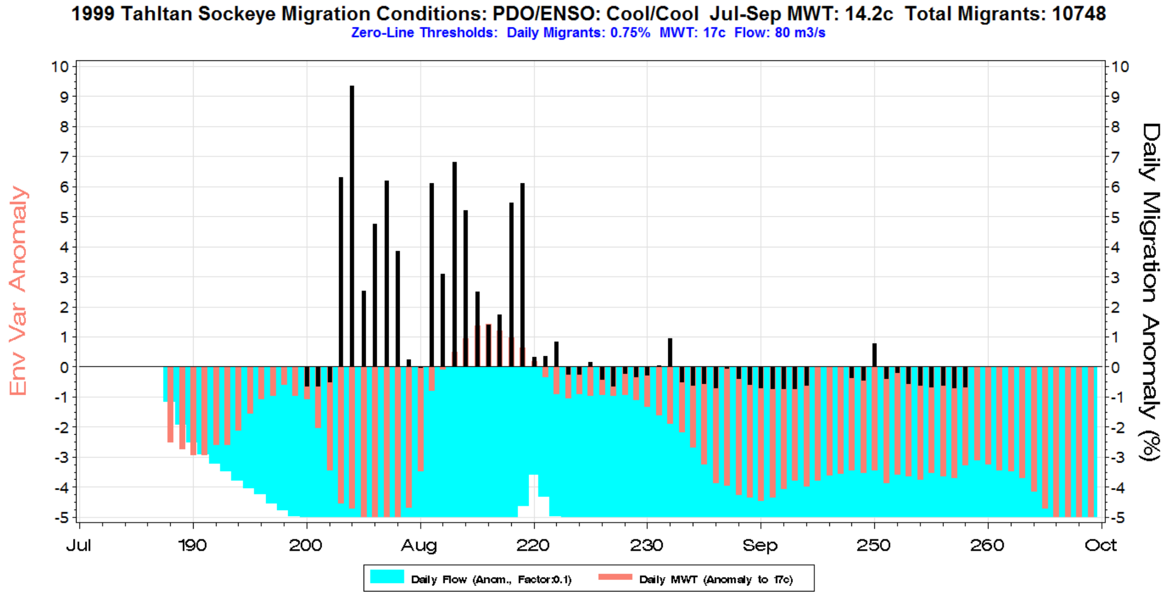


1996 Tahltan Sockeye Migration Conditions: PDO/ENSO: Warm/Neutral Jul-Sep MWT: 13.7c Total Migrants: 52500
Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s

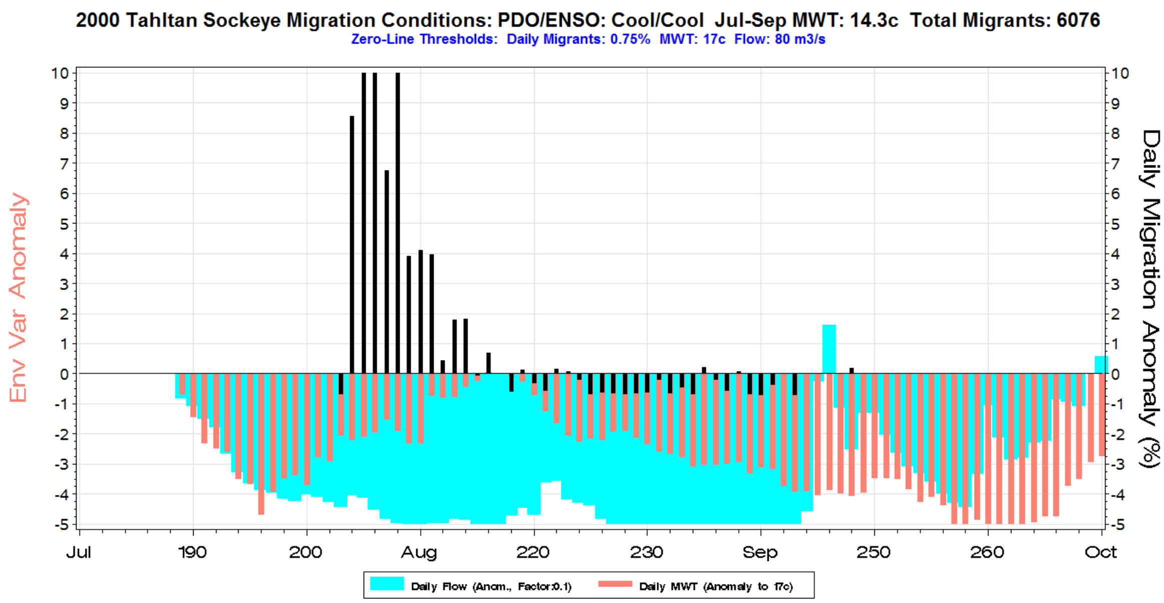



1997 Tahltan Sockeye Migration Conditions: PDO/ENSO: Warm/Neutral Jul-Sep MWT: 15.0c Total Migrants: 12483
Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct
Daily Flow (Anom., Factor:0.1)
Daily MWT (Anomaly to 17c)

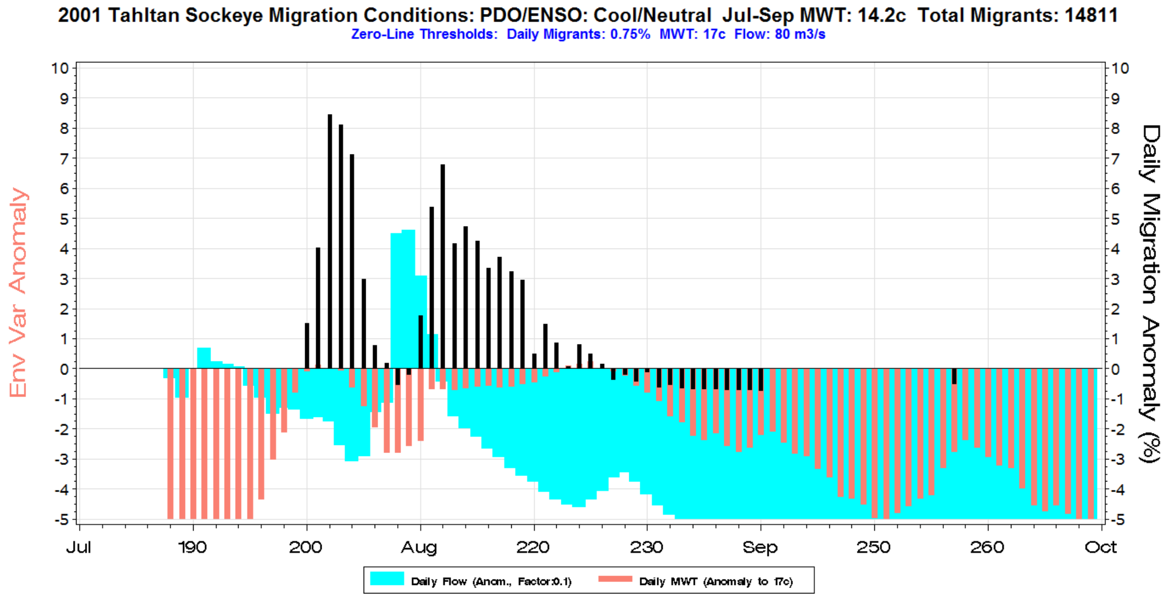

1998 Tahltan Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Jul-Sep MWT: 14.5c Total Migrants: 12658
Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct
Daily Flow (Anom., Factor:0.1)
Daily MWT (Anomaly to 17c)

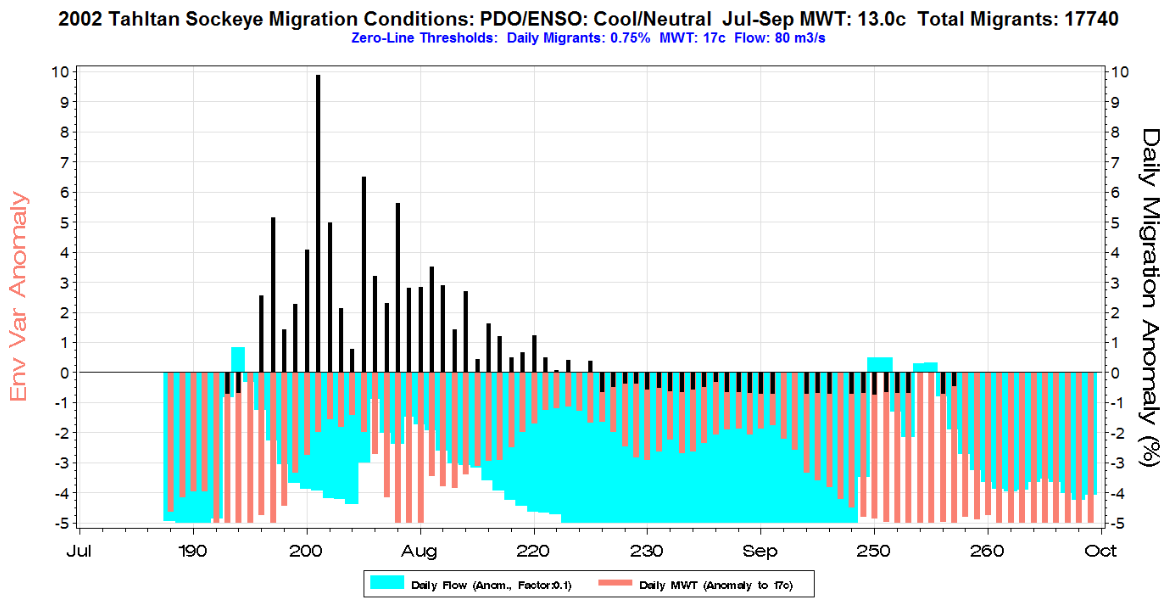


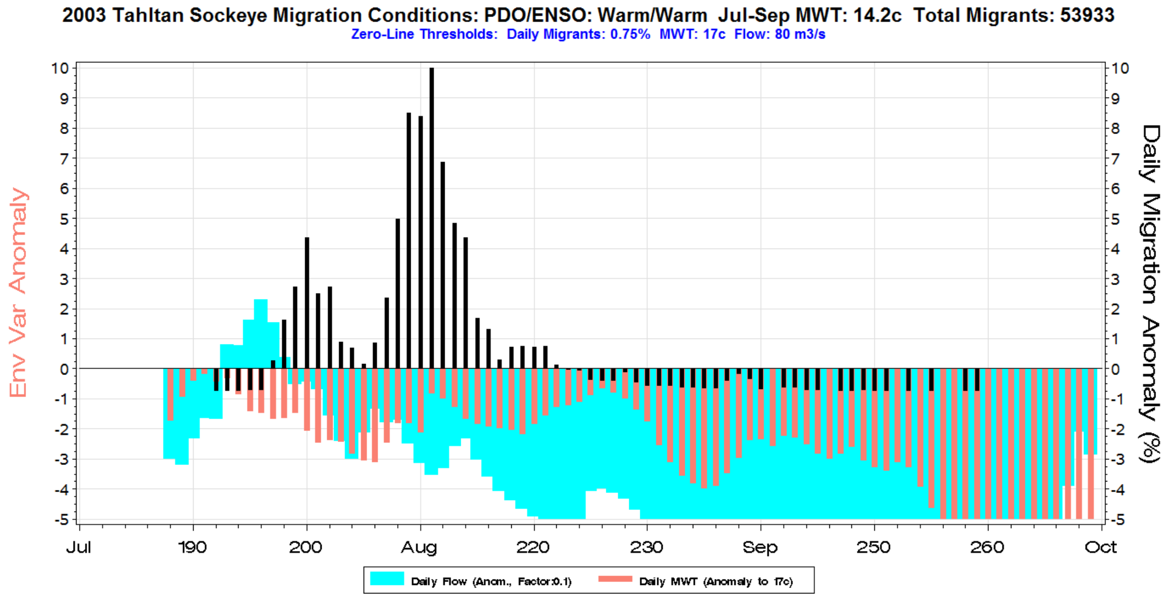
1999 Tahltan Sockeye Migration Conditions: PDO/ENSO: Cool/Cool Jul-Sep MWT: 14.2c Total Migrants: 10748
Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct
Daily Flow (Anom., Factor:0.1)
Daily MWT (Anomaly to 17c)

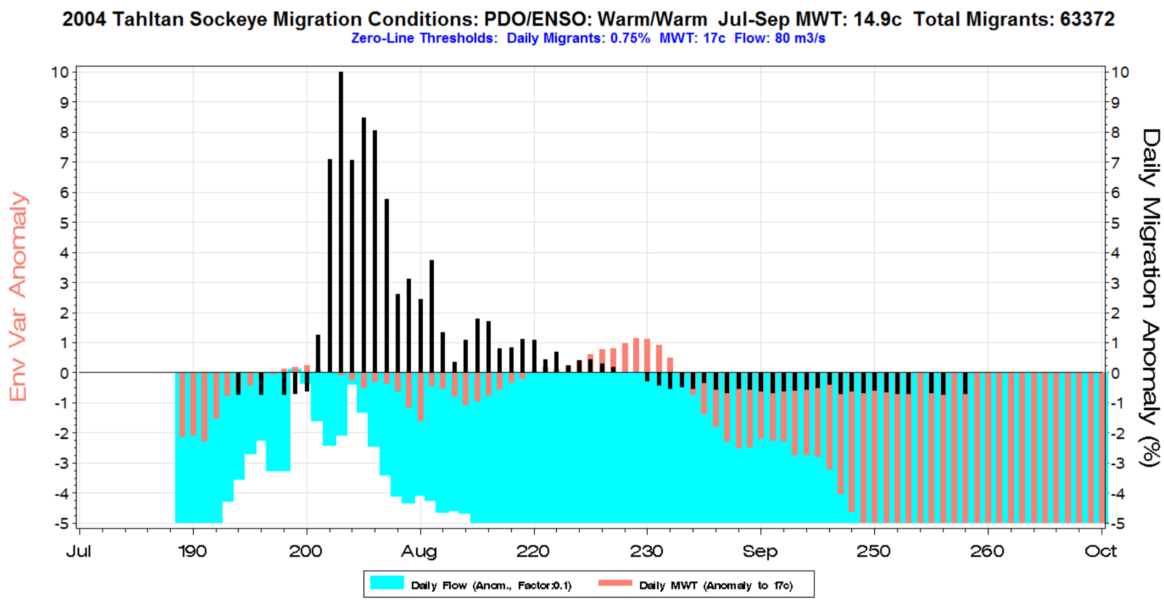


2000 Tahltan Sockeye Migration Conditions: PDO/ENSO: Cool/Cool Jul-Sep MWT: 14.3c Total Migrants: 6076
Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct
Daily Flow (Anom., Factor:0.1)
Daily MWT (Anomaly to 17c)

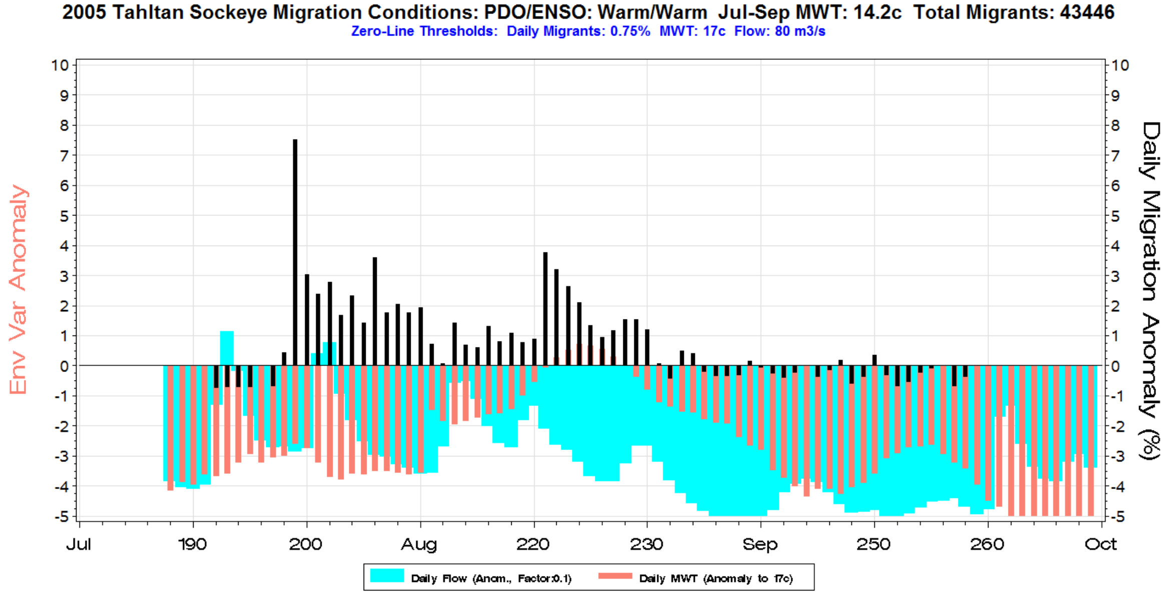

2001 Tahltan Sockeye Migration Conditions: PDO/ENSO: Cool/Neutral Jul-Sep MWT: 14.2c Total Migrants: 14811
Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct
Daily Flow (Anom., Factor:0.1)
Daily MWT (Anomaly to 17c)


2002 Tahltan Sockeye Migration Conditions: PDO/ENSO: Cool/Neutral Jul-Sep MWT: 13.0c Total Migrants: 17740
Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct
Daily Flow (Anom., Factor:0.1)
Daily MWT (Anomaly to 17c)

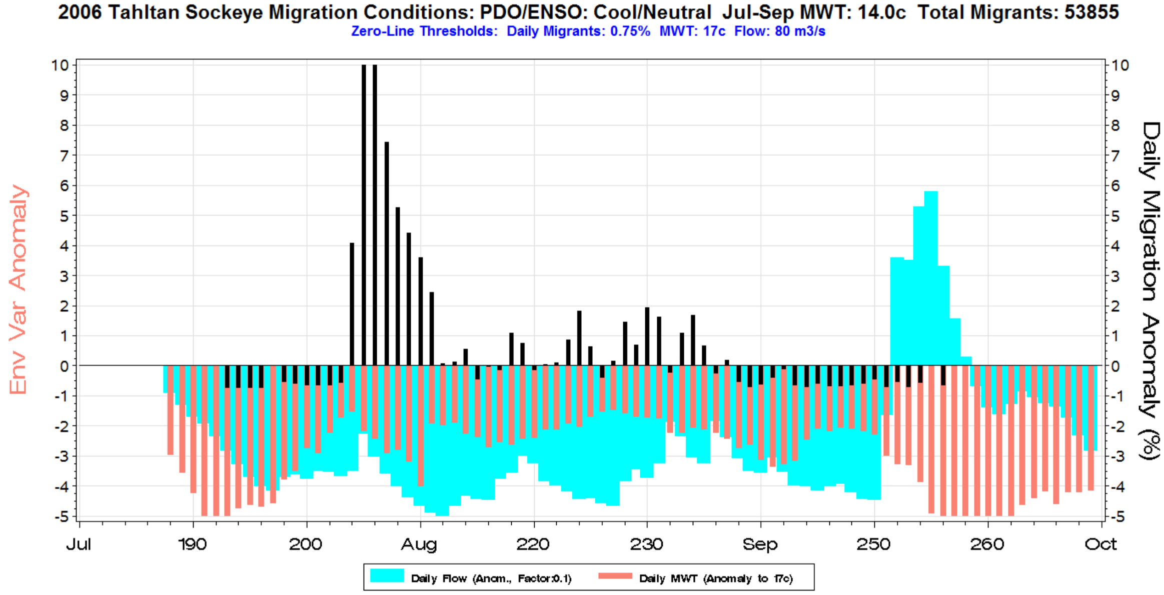

2003 Tahltan Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Jul-Sep MWT: 14.2c Total Migrants: 53933
Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct
Daily Flow (Anom., Factor:0.1)
Daily MWT (Anomaly to 17c)

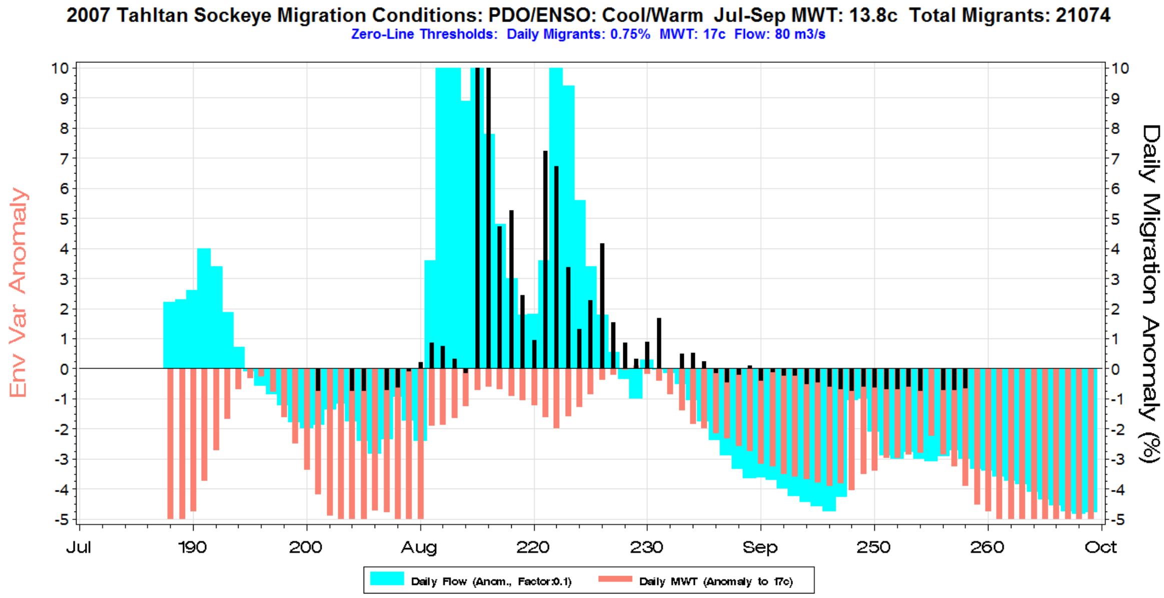

2004 Tahltan Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Jul-Sep MWT: 14.9c Total Migrants: 63372
Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct
Daily Flow (Anom., Factor:0.1)
Daily MWT (Anomaly to 17c)

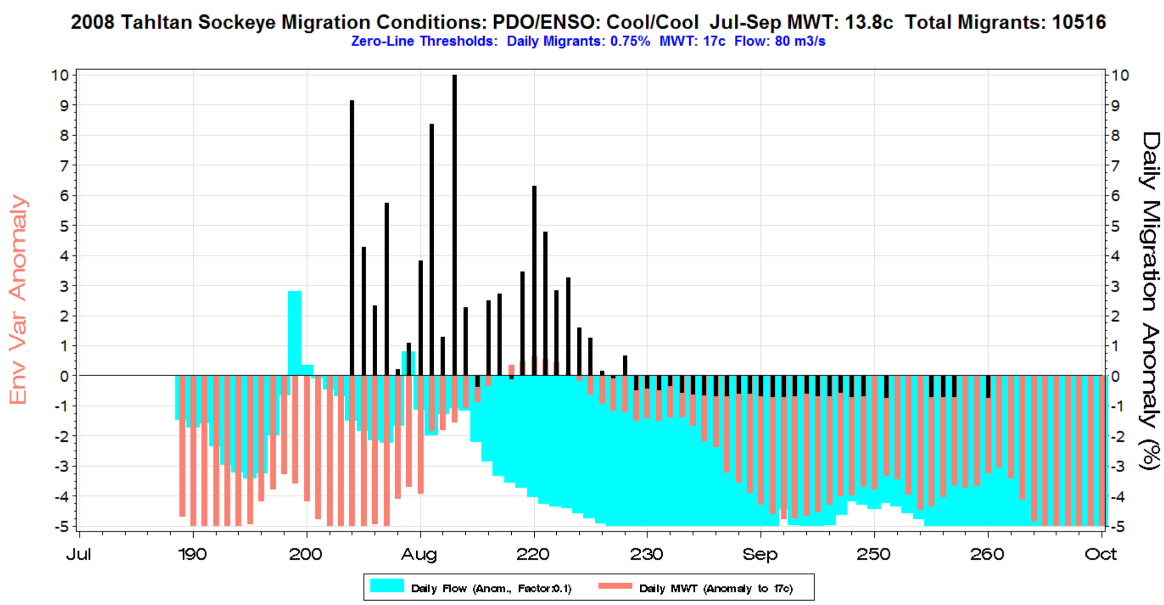
2005 Tahltan Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Jul-Sep MWT: 14.2c Total Migrants: 43446



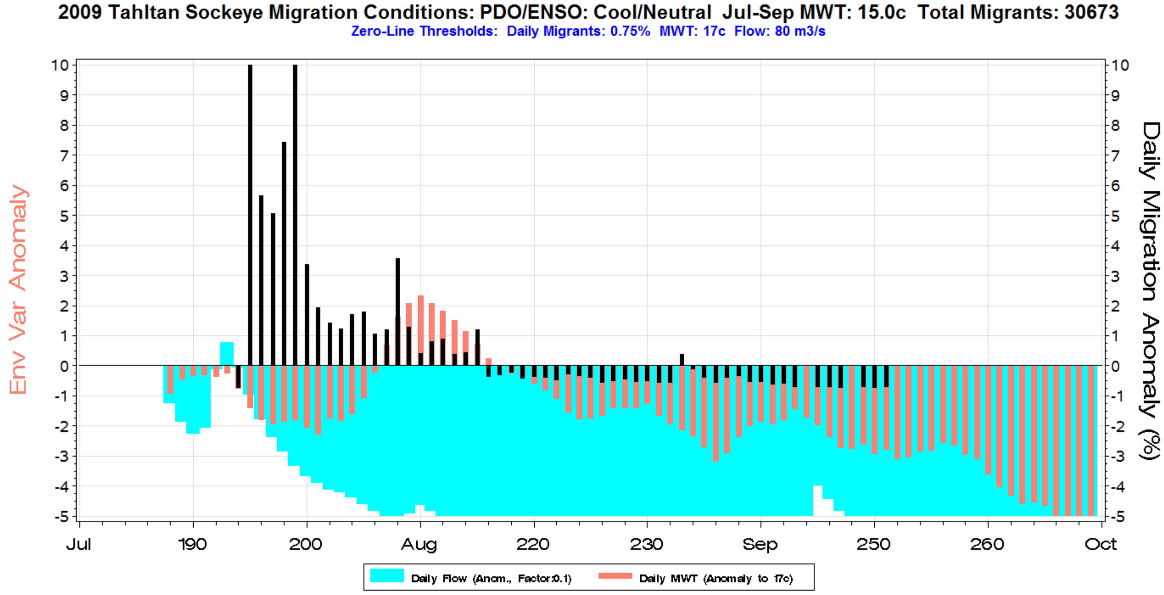
2006 Tahltan Sockeye Migration Conditions: PDO/ENSO: Cool/Neutral Jul-Sep MWT: 14.0c Total Migrants: 53855



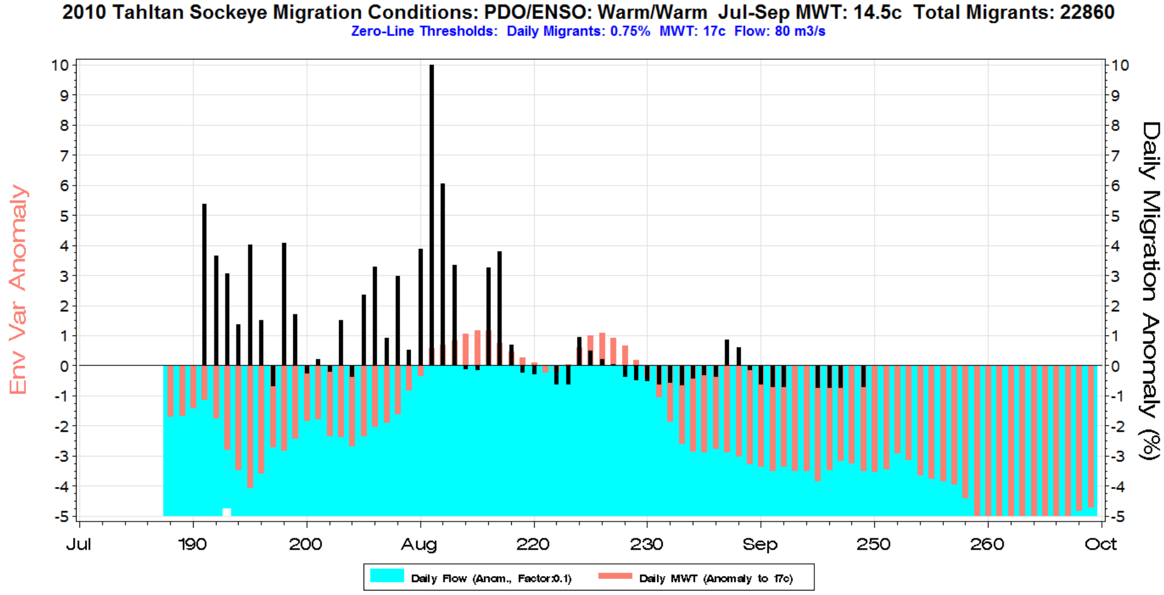

2007 Tahltan Sockeye Migration Conditions: PDO/ENSO: Cool/Warm Jul-Sep MWT: 13.8c Total Migrants: 21074
Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct
Daily Flow (Anom., Factor:0.1)
Daily MWT (Anomaly to 17c)


2008 Tahltan Sockeye Migration Conditions: PDO/ENSO: Cool/Cool Jul-Sep MWT: 13.8c Total Migrants: 10516
Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct
Daily Flow (Anom., Factor:0.1)
Daily MWT (Anomaly to 17c)

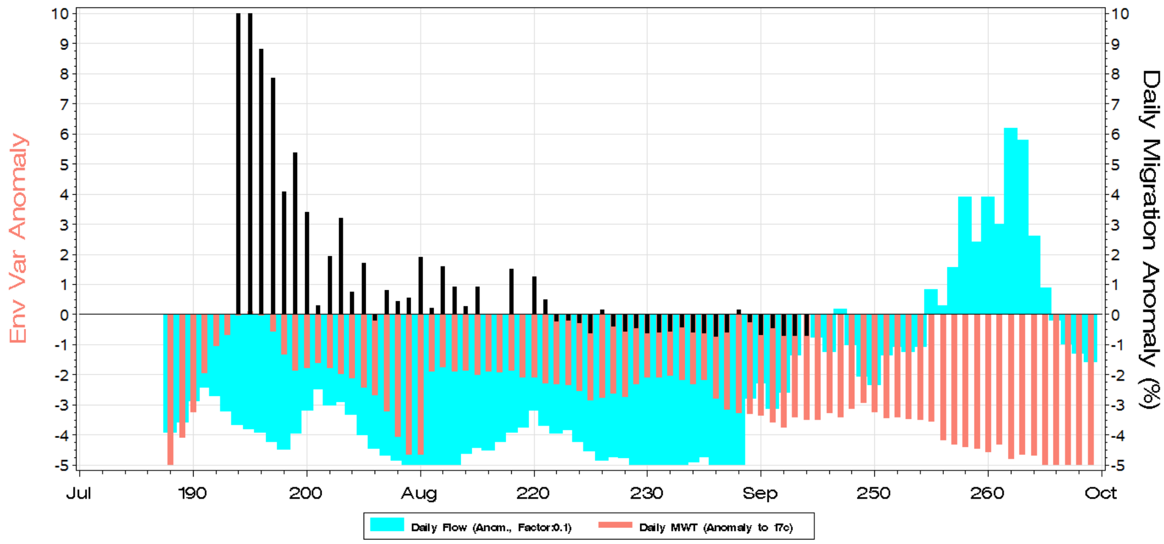
2009 Tahltan Sockeye Migration Conditions: PDO/ENSO: Cool/Neutral Jul-Sep MWT: 15.0c Total Migrants: 30673



2010 Tahltan Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Jul-Sep MWT: 14.5c Total Migrants: 22860



2011 Tahltan Sockeye Migration Conditions: PDO/ENSO: 2011/Unknown Jul-Sep MWT: 13.8c Total Migrants: 34588
Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s



2012 Tahltan Sockeye Migration Conditions: PDO/ENSO: 2012/Unknown Jul-Sep MWT: .c Total Migrants: 13693
Zero-Line Thresholds: Daily Migrants: 0.75% MWT: 17c Flow: 80 m3/s