Water Temperature, River Discharge, and Adult Sockeye Salmon Migration Observations in the Chilko-Chilcotin Watershed, 1975-2012

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WATER TEMPERATURE, RIVER DISCHARGE, AND ADULT SOCKEYE SALMON MIGRATION OBSERVATIONS IN THE CHILKO/CHILCOTIN WATERSHED, 1975-2012

by

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ABSTRACT

Stiff, H.W., Hyatt, K.D., Patterson, D.A., Benner, K., Cone, T.E., Grinder, P. and Billyboy, R. 2017. Water temperature, river discharge, and adult Sockeye salmon migration observations in the Chilko-Chilcotin watershed, 1975-2012. Can. Manuscr. Rep. Fish. Aquat. Sci. 3114: vii + 183 p.

Historical meteorological, water discharge and water temperature data were assembled to review the influence of changes in these environmental factors on daily migration patterns of adult Sockeye *en route* to their Chilko River spawning grounds (1975-2012), a major tributary to the Chilcotin River, British Columbia. Air temperature data, adjusted and homogenized for climate analyses, were obtained for a regional meteorological station (at Williams Lake), and statistically related to intermittent water temperature time-series (spanning 1996-2012) in the Chilko and Chilcotin rivers to hind-cast daily mean water temperature for 1940-2012 at key sites along the migration route. Flow data from two hydrometric stations in the watershed were statistically-related to construct continuous daily discharge time-series for 1927-2012 at the same sites. A stratified categorical frequency analysis of daily water temperature and flow levels versus standardized daily migration lagged 0-20 days earlier was used to discern the most likely combination of threshold values for temperature, discharge, and time lag contributing to daily migration rate variation. The resulting critical thresholds were applied in exceedance analyses to review trends in flow & temperature events pertinent to Chilko Sockeye migration.

Though trending slowly upward (0.1°C per decade) since the 1940s, mean August-September air temperatures and associated water temperatures during Sockeye migration in the Chilcotin in this high altitude (elev. 338-1,170 m) watershed remain cool at 14°C. A weak downward trend in discharge since 1927 was punctuated intermittently by years with extreme high summer flows (>240 cms in the lower Chilko) commonly lasting up to 17 days (maximum 29-33 days). Statistics from a non-parametric test of association between migration rate and environmental factors (water temperature and discharge) suggested that discharge conditions approximately 7-12 days prior to enumeration were most highly associated with categorical changes in migration rates at the counter site. Though elevated water temperatures (>18°C) were rare and do not appear to be limiting Sockeye migration within the Chilcotin system, reductions in migration from high to moderate levels as temperatures approached 15-16°C were evident for some years, most likely attributable to prior exposure to stressful water temperatures in the Fraser River mainstem where same-day temperatures were typically 2-3°C higher. When daily migration data were lagged back 12 days to align with conditions monitored in the lower Chilcotin River, the most evident environmental impact on Sockeye migration was a delay in the arrival of early migrants in the event of persistent high discharge levels in August: high daily migration rates were generally inhibited until daily mean discharge dropped below 270-300 cms in the lower Chilcotin River. Preliminary statistical analysis points to the continued existence of an intermittent velocity barrier at Farwell Canyon limiting Sockeye migration at high (90th percentile) Chilcotin River flows. The associated impacts are likely disproportionately affecting the weak early-run Chilko and Taseko Sockeye stocks.

RÉSUMÉ

Stiff, H.W., Hyatt, K.D., Patterson, D.A., Benner, K., Cone, T.E., Grinder, P. et Billyboy, R. 2017. Observations sur la température de l'eau, le débit fluvial et la migration du saumon sockeye adulte dans le bassin hydrographique des rivières Chilko et Chilcotin, de 1975 à 2012. Rapp. manus. can. sci. halieut. aquat. 3114 : vii + 183 p.

Des données météorologiques et historiques sur le débit fluvial et la température de l'eau ont été recueillies afin d'étudier l'influence de changements dans ces facteurs environnementaux sur les habitudes migratoires quotidiennes du saumon sockeye adulte en route vers ses frayères de la rivière Chilko (1975-2012), un affluent majeur de la rivière Chilcotin, en Colombie-Britannique. Des données sur la température de l'air, ajustées et homogénéisées pour permettre des analyses du climat, ont été obtenues pour une station météorologique régionale (à Williams Lake) et rapprochées statistiquement à une série chronologique intermittente sur la température de l'eau (s'étendant de 1996 à 2012) dans les rivières Chilko et Chilcotin afin de produire une simulation rétrospective de la température moyenne quotidienne de l'eau pour la période allant de 1940 à 2012 en des points clés le long de la route de migration. Les données sur le débit recueillies à deux stations hydrométriques dans le bassin versant ont été rapprochées statistiquement à une série chronologique continue sur le débit d'eau quotidien de 1927 à 2012 aux mêmes points. Une analyse par fréquence des catégories de la température de l'eau et des débits quotidiens par rapport à la migration quotidienne (décalage de 0 à 20 jours plus tôt) a servi à déterminer la combinaison la plus probable des valeurs de seuil de la température, de l'écoulement et des décalages connexes contribuant à la variation du taux de migration quotidien. Les seuils critiques obtenus ont été appliqués dans des analyses des dépassements afin d'étudier les tendances concernant le débit et la température qui peuvent être pertinentes à la migration du saumon sockeye de la rivière Chilko.

Malgré une lente tendance à la hausse (0,1 °C par décennie) depuis les années 1940, les températures moyennes de l'air d'août à septembre et les températures de l'eau qui y sont associées durant la migration du saumon sockeye dans la rivière Chilcotin, dans ce bassin de haute altitude (élévation allant de 338 à 1 170 m), demeurent fraîches, soit 14 °C. Une faible tendance à la baisse dans l'écoulement depuis 1927 a été ponctuée de façon intermittente par des années de débits très élevés en été (>240 cm/s dans la partie inférieure de la Chilko) pouvant durer jusqu'à 17 jours (maximum de 29 à 33 jours). Les statistiques tirées d'un test d'association non paramétrique entre le taux de migration et les facteurs environnementaux (température de l'eau et écoulement) laissent entendre que les conditions d'écoulement qui prévalaient de 7 à 12 jours environ avant le dénombrement sont principalement associées à des changements catégoriques dans le taux de migration au site de dénombrement. Même si les températures élevées de l'eau (>18 °C) étaient rares et ne semblent pas limiter la migration du saumon sockeye à l'intérieur du système de la Chilcotin, les réductions de la migration, passant de niveaux élevés à des niveaux modérés, à mesure que les températures approchaient 15 à 16 °C ont été évidentes pour certaines années, et sont très probablement attribuables à une exposition antérieure à des températures de l'eau éprouvantes dans le cours principal du fleuve Fraser, où les températures pour les mêmes journées étaient généralement plus élevées de 2 à 3 °C. Lorsque les données quotidiennes sur la migration ont été décalées de 12 jours pour correspondre aux conditions observées dans la partie inférieure de la rivière Chilcotin, la conséquence environnementale la plus évidente sur le saumon sockeye a été un retard dans l'arrivée des premiers migrants dans l'éventualité de taux d'écoulement constamment

élevés en août : les taux de migration quotidienne élevés ont été généralement freinés jusqu’à ce que l’écoulement quotidien moyen descende sous la barre des 270 à 300 cm/s dans la partie inférieure de la rivière Chilcotin. Les analyses statistiques préliminaires pointent vers l’existence continue d’un obstacle intermittent à la vitesse du courant au canyon Farwell, qui limite la migration du saumon sockeye quand le débit de la rivière Chilcotin est élevé (90^e percentile). Les conséquences connexes influent probablement de manière disproportionnée sur les faibles stocks de saumon sockeye de montaison hâtive des rivières Chilko et Taseko.

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 et al. 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 British Columbia and the U.S. Pacific Northwest have demonstrated regional air 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 direction of historical and projected climate variability exhibit sub-regional specificity due to the large and topographically complex areas involved (Walker and Sydneysmith 2008; Fleming and Whitfield 2010; Fleming et al. 2016).

Water temperature effects on migrating adult Sockeye (*Oncorhynchus nerka*) have been well documented in many river systems in the Pacific Northwest (Hyatt et al. 2003; Nelitz, Alexander, and Wieckowski 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 (Hyatt et al. 2015; Pellett et al. 2015). 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; Hyatt et al. 2016 in: Chandler et al. 2016). Adult thermal stress has also been found to reduce salmon fecundity and gamete viability, fertilization rates and decrease egg to fry survival rates (Braun et al. 2013; Jensen et al. 2004). Since Sockeye populations may also differ in their thermal tolerances, reflecting local adaptation to conditions over their historic evolution (Eliason et al. 2011; Martins et al. 2012; Farrell 2009), 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 (Pellett et al. 2015). 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.

Trend analyses to date have identified increases of 2-3°C in the mean, minimum and maximum water temperatures of the Fraser River during the adult Sockeye migration period since the 1950s (e.g. Patterson et al. 2007). These changes are having associated impacts on Fraser Sockeye population health (Hinch and Martins 2011; Macdonald et al. 2000), fish condition (Hinch et al. 2008), and fisheries management (Hague and Patterson 2007). Further studies show that adult migrants encounter a range of temperature and flow conditions in the remote tributaries of their freshwater migration route that may not be consistently well-correlated with lower Fraser conditions – especially for populations returning to spawning grounds in excess of 500 km from the marine environment (Hague, Patterson, and Macdonald 2008). As Hague et al. state (2008, p. vii): *“These results provide a rationale for further exploration into the use of multi-site, alternate-site, and cumulative exposure models to better reflect the full impact of freshwater conditions on the health and spawning success of Fraser River Sockeye salmon populations.”*

This report documents the data assembled for derivation of historic water temperature and flows affecting Sockeye salmon on the final leg of their migration to the spawning grounds in the terminal areas of the Chilcotin watershed. It is one of a series of manuscripts 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 (Hyatt et al. 2015; Stiff et al. 2013; 2015a; 2015b; 2015c; Damborg et al. 2015). 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

Location

The Chilcotin watershed drains the Chilcotin Plateau of British Columbia into the Fraser River (Figure 1). The Chilko subsystem, consisting of Chilko and Taseko lakes and rivers, originates high in the eastern edge of the Coast Mountain range within the Central Interior eco-province, surrounded by sub-alpine fir and montane spruce vegetation (Figure 2). The Central Chilcotin mountains at the head of the system are among the highest in the province (2,500-2,975 m). The Chilko system flows northward to meet the 241-km Chilcotin River flowing south out of Itcha Lake in the Western Chilcotin Uplands section (elevation 1600 m). The two watersheds merge in the center of the Chilcotin Plateau, where their combined flows cut east through glacial till to the Fraser River (Figure 2, Figure 3). Vegetation is dominated by the Interior Douglas-Fir zone in the south, the Sub-Boreal Pine-Spruce zone in the centre and the Sub-Boreal Spruce zone in the north.

Cultural Importance

The Chilko/Chilcotin River system lies within the traditional territories and title lands of the Tsilhqot’in peoples, and Sockeye salmon have been an integral component of Tsilhqot'in culture for centuries. The TSILHQOT'IN NATIONAL GOVERNMENT (TNG) fisheries department co-manages field operations and data management with the DEPARTMENT OF FISHERIES AND OCEANS (DFO) under an ABORIGINAL FISHERIES STRATEGY agreement.

Communities of the Tsilhqot'in Nation harvest salmon from the Fraser River mainstem and the Chilcotin River and its tributary streams. The majority of harvesting is conducted in the Chilcotin River and the primary species harvested is Sockeye, although all anadromous salmon species in the region support unique fisheries and cultural practices (Toth and Tung 2013b). In 2010, the TNG initiated an inland commercial fishery – managed by the FIRST NATIONS RIVER SELECT COOPERATIVE – harvesting Sockeye salmon where sustainable between mid-August and early-September using traditional dip net techniques. In 2014, two fish-wheels were also tested in the Chilcotin River downstream of Alexis Creek.

Chilko Sockeye stocks also comprise a large proportion of British Columbia’s commercial, recreational, and First Nation fisheries long before the fish arrive in the Chilcotin watershed. Since 1952, an average of more than one million Chilcotin-bound Sockeye was harvested annually in all fisheries (DFO Stock Assessment).

Physiography

The Chilko/Chilcotin watershed basin spans three eco-sections of the Central Interior eco-province (Demarchi 2010). The entire eco-province was glaciated by the last Cordilleran Ice Sheet. For the most part, the Chilcotin Ranges display a combination of high, serrated snow peaks (up to 3,000 m) rising above lower rounded summits and gently sloping areas of upland. The Chilcotin Plateau ranges from flat to gently rolling, with upland areas between 1,200 m and 1,500 m elevation. Glacial drift covers much of the upland plateau overlying lava flow remnants and dotted by wetlands and lakes. The Fraser River and lower Chilcotin River have cut into the plateau surface forming numerous riverine canyons characterized by steep escarpments (ibid).

Climate

The Chilcotin Plateau has a sub-continental climate, characterized by cold winters, warm summers, and peak precipitation in late spring or early summer (Demarchi 2010). Annual precipitation may exceed 1,000 mm where moist coastal air reaches the western slopes of the Coast Mountains. The rain-shadow area in the eastern lee of this range experiences typical annual precipitation of 350-450 mm.

Average annual precipitation at the regional reference meteorological station at Williams Lake[1], located in the slightly drier Fraser Basin to the east (Figure 1), is 450 mm, including 177 cm of snow (i.e. a roughly 143 mm snow-water equivalent), and mean annual temperature is 4.5°C (Table 1). During the winter and early spring, Arctic air frequently stalls on the eastern edge of these ranges. Snow accumulation in the Coast Mountains results in peak stream flows in early summer. Slower glacier melt and attenuation by the numerous lakes in the region contribute to stable summer stream discharges. Summer may be characterized by strong surface heating and convective showers, while frequent outbreaks of cold Arctic air may occur throughout winters. Late summer air temperatures during peak Sockeye migration periods averaged 10-15°C, with typical maximums of 22-23°C, and total monthly precipitation of 10-15 mm (Figure 7). Peak monthly precipitation occurs in June, averaging 58 mm.

Hydrology

The hydrology of the Chilko/Chilcotin watershed is dominated in the southern portion of the basin by two large glacier-fed head-water lakes – Chilko and Taseko Lakes –, which stabilize the flow regime, with lesser inputs from the Itcha wilderness via the upper Chilcotin River (Figure 3). The Chilko glacial valley opens onto a broad lava plateau. In the forested floodplains downstream of the lakes, the rivers alternate between wandering gravel-bed channels punctuated by gravel-bar islands and entrenched bedrock channels (Garber 2011).

The oligotrophic[2] Chilko Lake is 65 km long, 184 km² in area, with an average depth of 108 m and a maximum depth of 366 m.[3] At 1,176 m elevation, it is British Columbia's largest lake above 1,000 m, with a gross drainage area of 2,130 km². Glacially-turbid inflows contribute to cooler lake temperatures historically, in addition to low water clarity in the southern portion of the lake during the summer months. The lake's north-south orientation and proximity to the Coast Mountains result in frequent strong southerly winds and an unstable thermal regime (Grant et al. 2011).

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[1] ENVIRONMENT CANADA meteorological station 1078939 WILLIAMS LAKE (elevation 614 m) climate normals 1981-2010 (Table 1, Figure 7).

[2] Experimentation with lake fertilization to increase fish production occurred between 1988-1993 (Bradford et al. 2000).

[3] Chilko Lake, Wikipedia the Free Encyclopedia (downloaded: January 2016).

Chilko River drains the lake northward (average discharge 42.2 cms)[4] through 89 km of sub-boreal pine-spruce forests of the Chilcotin Plateau where its clear waters are joined by the silt-laden waters from the Taseko tributary, doubling the discharge levels downstream (combined drainage area: 6,880 km²; combined average discharge: 89 cms; Table 2; Figure 3).

Chilko River then joins the smaller slow-moving (upper) Chilcotin River[5] (originating about 72 km upstream around the swamp-like Itcha Lake). The combined waters of the lower Chilcotin River flow eastward for 88 km, carving canyons through the glacial till of the Chilcotin Plateau to the Fraser River (Figure 3, Figure 6). Maximum freshet in the Chilko/Chilcotin river system occurs in June and July following spring precipitation and upper elevation snowmelt. The naturalized 7-day summer mean low flow is relatively high in Chilko River at 33% of mean annual discharge, and 43% of mean annual discharge in the Chilcotin River (Nener and Wernick 1998). Mean monthly flows typically decline over the summer, reaching a minimum in September. A secondary discharge peak can occur in October in some years due to heavy autumn rainfall.

Water velocity barriers associated with canyon rapids may be a hindrance to passage for adult migrants at certain discharge levels (Hinch and Bratty 2000). Rapids in the Chilcotin River encountered by adult salmonid migrants can be found at (Figure 4, Figure 5): Farwell Canyon (about 16 km above the Chilcotin/Fraser confluence); Big Creek Canyon (another 13 km upstream, at the Chilcotin/Big Creek confluence); and Bull Canyon (60 km further upstream, about 7 km below the Chilko/Chilcotin confluence). In the Chilko River, Lava Canyon is located 54 km upstream of the confluence, 35 km downstream of the outflow of Chilko Lake (Figure 3). Of these, Farwell Canyon is the only site empirically observed to negatively impact upstream migration via delays or mortality due to high water velocity conditions (IPSFC 1946a; 1946b; 1948).

Within Farwell Canyon, the river has eroded through the soft gravel and clay banks to a depth of ~100 m into a channel constricted by granite bedrock (see Figure 6). The result is a 5 m drop in elevation over 300 m of canyon (IPSFC 1946a). IPSFC staff reviewed observations in the canyon in the 1930s, and found migration stoppages at flows ranging from 240-300 cms at WSC station CHILKO AT REDSTONE (ibid, Table I). Subsequent tagging experiments in the 1940s indicated that water levels of 90.1 feet (27 m) or more, as measured at the staff gauge at site 4-L in Farwell Canyon formed a “partial obstruction” to Sockeye migration (ibid).[6] These

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[4] 1928–2003 data; Water Survey of Canada website accessed on 2 February 2005.

[5] The Chilko/Chilcotin confluence is unique in the sense that Chilko flows comprise >80% of the water volume the lower Chilcotin, yet the Chilko is considered tributary to the Chilcotin.

[6] “The fall or drop through the [Farwell] Canyon creates water velocities in excess of 16 feet per second [4.9 m/s] or beyond the ability of the Sockeye salmon to swim in the central part of the channel. The salmon make their way upstream adjacent to the shorelines. The fast moving water impinges upon the banks at certain locations creating drops and turbulence which form points of difficult passage for the salmon. These points of difficult passage have been found to be on the right bank at approximately 375 and 550 feet upstream in the Canyon end and on the left bank at

thresholds translate to flows of ~173 cms for partial obstruction, and 239 cms for full obstruction, as measured at the WSC station CHILKO AT REDSTONE. The IPSFC recommended that "the Farwell Obstruction be removed" due to the potential for fish mortalities (IPSFC 1946a).

The intermittent velocity barrier in Farwell Canyon was mitigated by the construction of five vertical slot fishways "designed to function at discharges of 5,000 - 11,000 cfs" (IPSFC 1946b), or 140-300 cms, as measured at WSC station CHILKO AT REDSTONE. The Farwell fishway began operations in 1948 (IPSFC 1948; Delaney et al. 1982). No empirical data are available regarding Farwell fishway efficacy during subsequent years. Over time, the installation fell into disrepair, though it is unclear exactly when maintenance was discontinued. High early summer flows in 1948 through 1955 contributing to stream erosion and minor landslides[7] in the area may have been a factor (Roos 1991), rendering the fishway chutes impassable or inaccessible to fish.[8]

By the late 1990s, the reduced utility of the fishway for fish passage was overshadowed by the hazard to human safety.[9] At the request of TNG community members, the fishway was ultimately 'capped' with metal grates by DFO personnel and decommissioned for safety purposes in 2004.[10]

As no recent field studies assessing the impacts of high flows through Farwell Canyon are available, it is unknown to what extent this potential velocity barrier currently limits Sockeye migration.

Sockeye Migration

The Chilcotin system supports three Sockeye populations with distinct spawning locations and timing, including two in the Chilko subsystem and another in the Taseko tributary to the Chilko (Holtby and Ciruna 2007):[11] [12]

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approximately 300 feet, 420 feet and 830 feet upstream in the Canyon. In accordance with the Biological finding the period of difficult passage for the fish in this Canyon begins above discharges of 6100 cfs to 7300 cfs [i.e.173-207 cms] at Siwash Bridge, Station MA1, Dominion Water and Power Bureau [i.e.WSC Station 08MA001, CHILKO AT REDSTONE]." (see: IPSFC 1946b, pp. 2-3)

[7] Including significant mudslides on August 19th, 1964 and August 29th, 2004. The 2004 event dammed the river and blocked upstream migration for 12-20 hours (Source: BC MFLNRO Water Mgmt Branch – Public Safety Information).

[8] There is anecdotal evidence of a relatively sudden change in the hydrology at the site at an unspecified time soon after full installation, resulting in an undocumented change in the elevation of the fishways relative to the streambed to the point where the entrances were inaccessible to fish at most water levels (J. Hillaby, DFO Fish Habitat Restoration Biologist, pers. comm., Nov. 2016).

[9] Farwell Canyon is an important dip-net fishing site for First Nations individuals and families. (Paul Grinder, Fisheries Manager, TNG Fisheries, pers. comm., Jan. 2016).

[10] Steve Ratko, Fisheries Technician, DFO Resource Mgmt – BC Interior, pers. comm., Jan. 2016.

[11] A third Sockeye conservation unit (CU) is located in Taseko Lake (Holtby & Ciruna 2007). The status of the TASEKO-ES Sockeye is currently designated provisionally RED ZONE and DATA DEFICIENT by DFO and RED-LISTED by the IUCN in 2011 (http://www.iucnredlist.org/details/201448/0). The Taseko Lake stock spawns in mid-September (DFO 1995).

- The Chilko-S Conservation Unit (CU) spawns predominantly in Chilko River, upstream of Henry’s Bridge, and along submerged beaches at the north end of Chilko Lake near the outlet (Schubert and Fanos 1997). Peak migration timing is centered around September 2nd (Figure 8; Table 3), and peak spawn timing occurs in late September (ibid). The Chilko-S CU comprises at least 85-90% of annual Chilko escapement abundance, and was found to be 98% of total escapement in years where ‘south-lake’ and north-end/Chilko River spawners were estimated separately (Toth and Tung 2013a).
- The Chilko-ES population arrive earlier than the Chilko-S CU (with some overlap) and spawn along the lakeshore and in tributaries at the south end of Chilko Lake in mid-to-late September (Schubert and Fanos 1997), and comprise up to 15% of annual escapement abundance (Schubert and Scarborough 1997). These fish were first recognized as a distinct stock in 1971 (Saito and Woodey 1973, in: Schubert and Fanos 1997), though, due to data collection methodologies, insufficient independent data exist to classify stock status; therefore the status-health is currently designated Data Deficient (Grant et al. 2011).
- The Taseko-ES population is another ‘Early Summer’ timed stock that co-migrates with Chilko-ES Sockeye, ahead of but with some overlap with the predominant Chilko-S ‘Summer’ stock (Grant et al. 2011). The status-health of the Taseko Sockeye is provisionally[13] considered poor (red zone), however, due to both short- and long-term declining trends in abundance (Toth and Tung 2013).

Sockeye salmon bound for the Chilcotin watershed leave marine waters and enter the Fraser River beginning in late July (peak entry ~August 2nd)[14] on a 725 km journey to the spawning grounds (Killick 1955). Migrating up the Fraser at approximately 40 km/d (range 32-52 km/d (Killick 1955; Hague, Patterson and Macdonald 2008)), these fish swim the first 548 km from the Fraser estuary to Farwell Canyon (in the lower Chilcotin River) over an elevation rise of approximately 338 m at an average climb ratio of 0.6 m/km (Idler and Clemens 1959).

Chilko-bound Sockeye then ascend approximately 850 vertical meters over the next 177 km to the upper Chilko River spawning grounds at an average climb ratio of 4.8 m/km (Idler and Clemens 1959). Tag studies performed in two moderate flow years (1944 and 1945) indicated 12 days on average for Sockeye to cover this distance (IPSFC 1946a). Approximately half the distance (and elevation gain) in this leg of the journey occurs in the lower Chilcotin – from the Fraser to the Chilko confluence (distance: 88 km; elevation at confluence: ~738 m; mean rise: 4.5 m/km) – and half

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[12] Chinook, Coho and Steelhead Salmon species, Bull Trout, Rainbow Trout, and Dolly Varden are also found in the Chilko watershed.

[13] Provisional due to data deficiencies associated with challenging carcass survey conditions in the glacially-turbid Taseko Lake (Grant and Pestal 2012).

[14] Time-to-50% at Hell’s Gate: ~August 17th (Patterson et al. 2007).

in the 89 km Chilko River tributary (final elevation: 1,170 m; mean rise: 4.8 m/km).

Both Chilko-ES and Chilko-S conservation units are currently enumerated as they pass by an acoustic imaging system deployed in the Chilko River near the lake outlet (2009-present). Prior to 2009, an index of daily escapement was obtained from visual surveys from a nearby bridge spanning the Chilko River. Taseko-ES Sockeye divert into the Taseko watershed 60 km downstream (Figure 3) and are not tallied on a daily basis.

METHODS

CHILKO SOCKEYE MIGRATION

Daily observations of Chilko-bound Sockeye salmon passage historically occurred at Henry's Bridge, located about 12 km downstream of the Chilko Lake outlet and the lower limit of known Sockeye salmon spawning in the river.

Migrating Sockeye salmon are shore-oriented and swim close to the bottom within 5 m of the banks of the Chilko River at Henry's Bridge and are easily visible to an observer stationed above the shoreline (Holmes et al. 2005). Adult Sockeye migrants have been visually tallied at Henry's Bridge since 1965, and reliably from 1975-2008, with total daily estimates expanded from 15-minute counts at each river bank for each hour between 09:00 and 15:00 hr.[15] The number of 15-minute counts typically ranged from 12-18 per day (mode: 14), though during periods of low migration at the start and end of the run, estimates may have been based on as few as 4 counts per day (Appendix C).[16] The daily sums from the counting effort at Henry's Bridge were considered comprehensive enough to retain for analysis for 30 years between 1975 and 2008, omitting: 1977, 1978, 1981, and 1985.

Since 2009, two acoustic imaging systems (ARIS and/or DIDSON) have been deployed to tally adult migrants in Chilko River, installed approximately 4 km upstream of Henry's Bridge, downstream of Lingfield Creek (Figure 3)[17]. The units operate independently on left and right river banks, sampling 10-15 min each hour, 24 hr/day for the entire migration period. Total daily estimates (Appendix D) are based on manual counts of digital data that are expanded for time not sampled (Holmes et al. 2005).

Though daily estimates based on counts at Henry's Bridge were based only on a partial daily count and therefore are not directly comparable to DIDSON total daily

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[15] Pers. comm., Keri Benner, Program Head, DFO Fraser Sockeye Stock Assessment, Sep 2012.

[16] During feasibility studies for DIDSON system implementation, it was noted that fish movement past Henry`s Bridge slowed but did not stop between sunset (21:00) and sunrise (6:00). Night-time movements consisted of individual fish rather than groups as observed during the day. The majority of these fish are moving within 5 m of the transducer and are probably sockeye salmon if daylight observations are representative of nighttime conditions (Holmes, Cronkite and Enzenhofer 2005).

[17] Pers. comm., Keri Benner, Program Head, DFO Fraser Sockeye Stock Assessment, Feb 2014.

estimates in absolute numbers, the seasonal pattern of abundance can be considered roughly comparable between the two sources.[18]

To standardize the annual adult migration time-series for inter-site, inter-year and inter-stock comparisons, the percentage of total daily adult + jack Chilko Sockeye were calculated relative to the annual total stock escapement. Annual plots of daily and cumulative migration rate (i.e. percent relative to the annual total escapement) were overlaid with historical mean and maximum daily migration rate by Julian day-of-year, for inter-annual migration pattern comparisons. Daily migration rate data (%) were further transformed using the arcsin function to normalize the percentage data where appropriate for parametric analyses (Sokal and Rohlf 1969).

Univariate statistical analyses were used to characterize the historical stock migration data (number of observations, central tendency (mean, median, mode, etc.), scale (range, variance, extreme values and outliers), and shape (skewness, kurtosis)). Median (50th percentile) and 75th quartile values of the historical datasets were calculated to establish categories of "insignificant" or "negligible" daily migration rates (0-50th percentile) versus "significant-but-moderate" (50-75th percentile) and "significant-and-high" (75-100th percentile) migration activity.

ENVIRONMENTAL DATA

Meteorological, hydrographic, and water temperature data necessary for derivation of long-term (30+ years) time-series of water temperature and flow conditions were assembled from online databases, published documents, unpublished reports, and personal records from government agencies (e.g. ENVIRONMENT CANADA, WATER SURVEY OF CANADA (WSC), ENVIRONMENTAL WATCH PROGRAM, FISHERIES AND OCEANS CANADA (DFO)).

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 9.3) was used to assemble data from MICROSOFT EXCEL® spreadsheets and analyze the data. The resulting datasets were stored in a relational FRESHWATER ENVIRONMENTAL VARIABLES DATABASE (Hyatt and Stiff, DFO; unpublished data) and are available from DFO upon request.[19]

HYDROLOGY

The WATER SURVEY OF CANADA (WSC, ENVIRONMENT CANADA)[20] maintains active hydrometric gauging stations at multiple locations in the Chilcotin/Chilko watershed (Figure 1 - Figure 5). Meta-data for select stations, including elevation and mean

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[18] Total annual tallies at Henry's Bridge were linearly correlated with annual total escapement estimates from mark recapture methods, 1975-2015 ($r^2 = 0.82$; $P < 0.01$; $N = 32$; unpub. data).

[19] Contact Howard.Stiff@dfo-mpo.gc.ca or Kim.Hyatt@dfo-mpo.gc.ca for information on the MICROSOFT ACCESS® database.

[20] ENVIRONMENT CANADA – WATER SURVEY OF CANADA website: http://www.ec.gc.ca/rhc-wsc/default.asp?lang=En&n=894E91BE-1.

annual discharge, are available in Table 2. Mean daily discharge data were obtained from the web archives for the following stations:

- Chilko River at the outlet of Chilko Lake (WSC station 08MA002; 51°37'31"N x 124°08'31"W; gross drainage area 2,130 km^2), with mean annual discharge ~47 cms (1928-2012), elevation 1,888 m.
- Chilko River at Redstone (WSC station 08MA001; 52°04'12"N x 123°32'12"W; gross drainage area 6,880 km^2), with mean annual discharge ~89 cms (1927-2012). This station is located near Siwash Rock (bridge), 13 km below the confluence of the Chilko and Taseko rivers, approximately 8 km above the confluence of the Chilko and Chilcotin rivers, elevation 1,756 m.
- Chilcotin below Big Creek (WSC station 08MB005; 51°50'55"N x 122°39'12"W; gross drainage area 19,200 km^2), with mean annual discharge ~97 cms (1970-2012). This station is located 79 km below the Chilko confluence, 3 km downstream of Big Creek, approximately ~10 km upstream of Farwell Canyon, at an elevation of 1,528 m.

Simple least-squares regression models (linear: $y = a + bX$; loglinear: $y = aX^b$; and polynomial curvilinear: $y = a + bX + cX^2$) were derived for estimating missing or historical daily Chilcotin River below Big Creek discharge as a function of the more extensive time-series for Chilko River at Redstone. Model calibration was based on July-Aug-Sep data (to capture observations at peak mid-summer flows) constrained to every 10th observation, to reduce the influence of autocorrelation effects. Model selection was based on highest correlation and lowest root mean square error or adjusted Akaike Information Criterion (AICc). Goodness-of-fit was assessed using correlation of observed versus predicted Chilcotin River at Big Creek data and subjective examination of time-series plots.

Univariate statistical analyses were used to characterize station discharge data (number of observations, central tendency (mean, median, mode, etc.), scale (range, variance, extreme values and outliers), and shape (skewness, kurtosis)). Deciles and quartiles were derived for the migration months (August-September) to identify drought (< 10th percentile), moderate (10-90th percentile) and flood (90-100th percentile) categories, plus low and high thresholds relevant to migration activity. Plots of the historic mean and variance of daily discharge were used to characterize the flow patterns during the adult Sockeye migration period (August-September).

WATER TEMPERATURE

Water temperature data were supplied courtesy of DFO Environmental Watch Program (EWP) which maintains an extensive environmental monitoring network of temperature data-logger stations at key locations in the Fraser Basin (Figure 1 - Figure 5) for salmonid research and management purposes (Hague, Patterson and MacDonald 2007)[21]. Quality-controlled daily mean water temperatures based on either daily minimum and maximum values (pre-2000), or hourly readings (2000-

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[21] DFO Environmental Watch Program: http://www.pac.dfo-mpo.gc.ca/science/habitat/frw-rfo/index-eng.html

present), were extracted from the FRESHWATER WATER TEMPERATURE DATABASE[22] (Thompson et al. 2010) for the following years[23]:

- CHILCOTIN RIVER BELOW BIG CREEK – 2006-2012 – an active real-time monitoring station closely associated with WSC hydrometric station 08MB005, approximately 10 km upstream of Farwell Canyon. Daily mean water temperatures derived exclusively from hourly data-logger readings.
- CHILCOTIN RIVER AT ALEXIS CREEK – 1996-2008 – site of the original Chilcotin real-time temperature monitoring site (CR50, located 50 km upstream of the Chilcotin/Fraser confluence), approximately 31 km upstream of the Chilcotin temperature station near Big Creek. Deactivated due to high flow impacts.
- CHILKO RIVER AT THE DFO STOCK ASSESSMENT SITE – 1990-1997 (daily), 1999-2000 (hourly), 2005-2009 (hourly), 2012. Daily mean temperatures were sourced from EWP data loggers at the DFO camp near the outlet of Chilko Lake.
- FRASER RIVER AT QUALARK – 1941-present – Fraser system reference station approximately 339 km below the Fraser/Chilcotin confluence. Daily mean water temperatures between June 1 and September 30 were intermittently available from 1941-1950, and consistently from 1951-1999 and 2008-2011. Daily means were derived from hourly data, where available, from 1995-2007. The QC/QA time-series of daily mean water temperature data associated with the lower Fraser at Qualark extends over 60 years (Patterson et al. 2007; Brown et al. 1998).

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. Anomalous data were corrected, or retained in the database but flagged for omission (i.e. OMIT field = YES) from data analyses.

Univariate statistical analyses were used to characterize the daily mean water temperature (MWT) time-series for the period of record (i.e. number of observations, central tendency (mean, median, mode, etc.), scale (range, variance, extreme values and outliers), and shape (skewness, kurtosis)).

Lower Chilcotin River (Reference Site)

Water temperature datasets were aligned by date and cross-correlated for assessment of linear relations. To extend the water temperature time-series at the reference locations in the lower Chilcotin (near Big Creek and Farwell Canyon), linear, log-linear, and quadratic regression relations were assessed to derive water temperature transfer functions between CHILCOTIN RIVER AT BIG CREEK (2006-2012) as a function of CHILCOTIN RIVER AT ALEXIS (1996-2008) based on all available data

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[22] Temperature collection methods and site descriptions for network locations are detailed elsewhere (Barnes & Magnusson 2000; Brown et al. 1998; Barnes & Walthers 1997; Lauzier et al. 1995).

[23] Water temperature data were made available by David Patterson, DFO EWP, 2012.

for the overlapping years (2006-2008). The most parsimonious model was selected based on maximized R-squares and goodness of fit, and used to reconstruct estimated daily mean water temperatures for the reference site CHILCOTIN RIVER AT BIG CREEK (1996-2012). This reference site dataset was then used in air/water temperature relations – described below – to develop a site water temperature dataset suitable for retrospective and future climate modelling studies.

Chilko River

Water temperature data obtained at the DFO STOCK ASSESSMENT site were used in air/water temperature relations – described below – to develop a Chilko River water temperature dataset suitable for retrospective and future climate modelling studies.

AIR TEMPERATURE

Studies have demonstrated that variations in regional air temperature (which often span the 19th century) are generally sufficient to explain as much as 80% of the variation in local daily mean water temperature (Mohseni and Stefan 1999; Hyatt and Stockwell 2003; Pilgrim, Fang and Stefan 1998; Stefan and Preud'homme 1993; Webb and Nobilis 1997). Linear and nonlinear regression models are known to be accurate at moderate air temperatures typical of adult Sockeye migration periods (i.e. 10-20°C), while water temperature "extremes" (<5°C or >20°C) are more appropriately modeled nonlinearly (Mohseni, Stefan, and Erickson 1998). The resulting time-series spanning the period of record of meteorological observations can be used as a consistent index of local water temperature conditions at the daily time-scale, and summarized to examine trends and shifts in water temperature regimes at longer time-scales (e.g. decadal).

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.[24] Air temperature measurements are taken from self-registering, maximum and minimum thermometers that record parameter extremes over a 24-hour period. These datasets undergo detailed quality-control analysis before posting to the web site.

In addition, ENVIRONMENT CANADA provided adjusted and homogenized daily climate data specifically for use in Canadian climate research and climate change studies, based on existing meteorological datasets.[25] AHCC data incorporate a number of adjustments applied to the original station data to address shifts due to changes in instruments and in observing procedures. Sometimes the observations from several stations were joined to generate a long time series.

The ENVIRONMENT CANADA (EC) web site was accessed to identify potential sites of air temperature data within the area of interest for statistical relationships with water temperature data (Figure 1). EC climate AHCCD station WILLIAMS LAKE (1098939;

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[24] ENVIRONMENT CANADA Climate Data: http://climate.weatheroffice.gc.ca/climateData/canada_e.html

[25] ADJUSTED AND HOMOGENIZED CANADIAN CLIMATE DATA (AHCCD) – Daily AHCCD air temperature data may be obtained by request to AHCCD@ec.gc.ca. See the ENVIRONMENT CANADA website for monthly AHCCD values.

52°08’N x 122°10’W; elev. 614 m) was selected for climate data retrieval for Chilko/Chilcotin watershed sites based on:

(i) the quantity and quality of data available (1940-present);

(ii) proximity to water temperature sites (~60 km to the lower CHILCOTIN AT BIG CREEK; ~160 km to upper CHILKO RIVER site); and

(iii) the potential to routinely update the time-series from an “active” climate station.

Gaps in the daily meteorological record at WILLIAMS LAKE during the Sockeye migration period were limited to August 1942 and September 1947, which were estimated from linear relations with nearby AHCCD EC station TATLAYOKO LAKE – nestled in the higher, wetter Coast Mountain Range approximately 50 km west of Chilko Lake.[26]

MULTI-DAY MEAN AIR TEMPERATURE INDEX

The best predictive air-to-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 (Hyatt et al. 2015).

For each EC meteorological dataset, correlation analysis was used to identify the multi-day moving average air temperature index with the lowest *n*-value (for *n* = 1, 3, 5, 7, 10 days)[27] while retaining a high Pearson correlation coefficient with a representative subset of data from the associated daily mean water temperature site. The multi-day centered moving average temperature CMAT index with the lowest adjusted AKAIKE INFORMATION CRITERION (AICc) and the highest Pearson correlation coefficient for the calibration data was used for subsequent air/water temperature regression relations.[28]

AIR/WATER TEMPERATURE RELATIONSHIPS

Hyatt et al. (2015) describe the basic methodology used to estimate missing or historical daily MWTs based on statistical relations with the regional multi-day CMAT index. For comparison purposes, the authors calibrated linear (Equation 1) and logistic (Equation 2) air-to-water temperature relations using a subset of the site daily MWTs as a function of the regional multi-day air temperature indices (WILLIAMS LAKE STANDARD):

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

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[26] Williams Lake Daily Mean Air Temp = 1.024 * Tatlayoko Daily Mean Air Temp + 0.675; r = 0.84; SE = 0.01; P = 0.001; n = 3,223 (summer months July-Aug-Sep only).

[27] *n* = 1 corresponds to the “observed” mean daily air temperature time-series.

[28] Although the 10-d CMAT index was included in this assessment, and (usually) generated the maximum correlation, this index was ultimately discarded due to the undesired trade-off between high correlation versus the damping effect on daily air temperature variation (Hyatt et al. 2015).

T_w is the *estimated mean water temperature*;

T_a is the *multi-day mean air temperature index*;

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

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

T_w *is the estimated mean water temperature;*

T_a *is the multi-day mean 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;*

β *represents the air temperature at the inflection point.*

The existence of hysteresis[29] in a water body requires separate warming and cooling season regression models to describe air/water temperature relations at a particular site (Mohseni et al. 1998; Hyatt et al. 2015). Hysteresis was evaluated for both linear and logistic models.

For the linear analysis, an additional categorical "season" predictor was tested for significance (signifying different seasonal model intercepts), as was an air temperature interaction effect, indicating potentially significant differences in seasonal model slopes (i.e. $P < 0.05$ for the Type III model sum of squares (SAS 1987).

For the logistic analysis, hysteresis was assessed by comparison of the *Nash-Sutcliffe Coefficient* (NSC) value for the all-season model versus the averaged NSC values for the separate warming and cooling season models (Mohseni et al. 1998):

Equation 3*:* $Hysteresis = [(NSC_w + NSC_c) / 2 - NSC_{all}] \geq 0.01$; where

NSC_w = NSC for warming season;

NSC_c = NSC for cooling season;

NSC_{all} = NSC for all seasons combined.

WATER TEMPERATURE TIME-SERIES RECONSTRUCTION

MODEL CALIBRATION

Linear and logistic regression relations described above were developed using site-specific daily mean water temperature (MWT) as a function of the regional air temperature index (7-day centered WILLIAMS LAKE CMAT variate) for two locations in the watershed: (upper) CHILKO RIVER (near the DFO stock assessment site), and

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[29] 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.

(lower) CHILCOTIN RIVER (BELOW BIG CREEK).

Selection of data for the calibration dataset was not randomly determined, but based on subjective and statistical examinations of individual annual air and water temperature time-series plots and correlations. A minimum of 5 years of temperature data across multiple decades, including sufficient observations at the upper end of the range for both warming and cooling seasons is generally necessary to define a truly representative air/water temperature relationship (Hyatt et al. 2015; Stiff et al. 2015a; 2015b; 2015c).

Years with consistent and apparently unbiased water temperature observations associated with a maximum range of temperature values for both warming and cooling periods were preferred for characterizing the all-year air/water temperature relationship. Years of evident bias or excessive anomalies in the water temperature observations were not evident in EWP's FRESHWATER WATER TEMPERATURE DATABASE, but some incomplete years were excluded from the calibration dataset (e.g. 2012). Data not used for model calibration were used for validation of statistical relations via correlation.

To determine whether seasonally-distinct regression relations were required, the air/water temperature data for each site 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.

The warming and cooling seasons were first distinguished from each other by determining the summer season temperature "turn-around point".[30] 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 air temperature indices 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

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[30] The timing of the winter season turn-around point was not required for the purpose of the logistic analysis. 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.

compared between model types to determine whether linear or logistic outputs best simulated observed MWTs at the Chilcotin River reference site.

PRECIPITATION

Precipitation data are correlated with discharge levels and water temperature. They may also be useful for downscaling projected changes in regional precipitation from global or regional climate models to specific sites at the local level.

Daily precipitation records for the Chilcotin/Chilko watershed were obtained for WILLIAMS LAKE station (1940-2012) from Environment Canada.[31] Due to the highly localized and non-normal distribution of precipitation data, missing values were not interpolated, nor were time-series extended based on parametric statistical relations with other stations.[32]

TREND AND EXCEEDANCE ANALYSES

AIR TEMPERATURE

Historic regional air temperature data (based on WILLIAMS LAKE STANDARD daily CMAT, 1940-2012) were summarized by year to obtain the mean value during the summer months (August-September), and plotted to review the long-term time trend in regional air temperature conditions during the migratory period.

Monthly mean air temperatures of 20°C are considered an upper threshold for salmonid life history stages in freshwater (Mote et al. 2003). Historic mean daily air temperature data (based on WILLIAMS LAKE STANDARD climate data; 1940-2012) were analyzed for the frequency of dates in each year and month (August-September) for which mean daily air temperature exceeded this threshold value, and summarized by decade as a trend indicator. In addition, the frequency of annual periods in which water temperature continuously exceeded 20°C, and the mean duration (days) of these periods, was derived for each year, and summarized by decade to review trends in the frequency and duration of continuous periods of potentially stressful temperature conditions.

WATER TEMPERATURE

Reconstructed daily mean temperature data were summarized by site and year in the Chilko/Chilcotin watershed to determine mean values during the summer months (August-September), and plotted to review the long-term time trend in site-specific water temperature conditions during the migratory period.

An exceedance analysis, similar to that performed for air temperature, was used to examine site-specific trends in water temperature conditions during the adult migration period (August-September), after tallying the decadal mean monthly frequency of dates for which the reconstructed MWT temperature index exceeded

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[31] ADJUSTED AND HOMOGENIZED CANADIAN CLIMATE DATA (AHCCD) – Daily AHCCD precipitation data may be obtained by request to AHCCD@ec.gc.ca. See the ENVIRONMENT CANADA website for monthly AHCCD values.

[32] An alternative approach, not attempted here, may be to obtain daily precipitation data for multiple regional meteorological stations to derive an appropriate area average. Source: NATIONAL CLIMATE DATA AND INFORMATION ARCHIVE (March 2013).

16°C (POT$_{16°C}$; i.e. peak-over-threshold > 16°C).[33]

In addition, the frequency of annual periods in which water temperature continuously exceeded this value, 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 potentially stressful water temperature conditions.

RIVER LEVEL / DISCHARGE

For trend analyses, observed daily discharge data were summarized by site and year in the Chilko/Chilcotin watershed to determine mean values during the summer months (August-September), and plotted to review the long-term time trend in site-specific water temperature conditions during the migratory period. For the lower Chilcotin reference site, flow data from the highly correlated and more extensive CHILKO RIVER AT REDSTONE site (1930-2012) were utilized as a proxy, to obtain the longest discharge time-series while avoiding the issue of 'regression towards the mean' of extreme values pre-1975 when calculating flows at CHILCOTIN RIVER AT BIG CREEK via predictive regression. Trends in the monthly maximum values for pre-migration (June-July) and migration months (Aug-Sep) were also examined.

For exceedance analyses, both "low flow" and "high flow" dates are of potential interest, since, conceivably, either flow extreme may influence upstream migration. The frequency of dates for which observed water levels in the lower CHILKO RIVER AT REDSTONE were less than the lower 10th percentile (~100 cms), or the lower bound of flows associated with significant Sockeye migration (whichever is greater) was calculated by year and month (August-September), and summarized by decade. Similarly, the frequency of dates for which observed water levels were greater than the upper 90th percentile (~220 cms, roughly equivalent to 240 cms in the lower Chilcotin) or the upper bound of significant Sockeye migration (whichever is lesser), was calculated by year and month (August-September), and summarized by decade. From these data, the frequency of annual periods in which discharge continuously remained below/above the lower/upper thresholds, and the mean duration (days) of these periods was derived for each year, and summarized by decade to review trends in the frequency and duration of continuous periods of potential flow barriers to upstream migration.

MIGRATION, WATER TEMPERATURE AND DISCHARGE

Daily mean water temperature and discharge estimates were merged with daily Sockeye migration rate data to test the null hypothesis that daily migration rates (percent of annual escapement by date) were not associated with changes in water temperature and discharge.

To that end, we attempted to detect whether water temperature and discharge levels were significantly associated with differences in daily percent of migration, and identify where that might occur over the 177 km of the Chilko/Chilcotin system, from the immediate vicinity of the counter sites, to the confluence with the Fraser River.

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[33] Insufficient data existed to contrast inter-annual results at higher thresholds (e.g.POT$_{16°C}$).

The existence of a potential velocity barrier in Farwell Canyon pointed to the lower Chilcotin as an analytical starting point (applying appropriate time lags for migrant data), using environmental estimates associated with the CHILCOTIN RIVER BELOW BIG CREEK reference site as the independent variables. Inferences regarding the lag time (in days) to align daily migration data with lower Chilcotin environmental conditions were derived from several sources.

Applying the lower end of the observed range in Chilko Sockeye swimming speeds in the Fraser River (32 km/d; Killick 1955) – due to the energetic requirements of the steeper ascent in the Chilcotin – Sockeye would take a minimum of 6 days to traverse the Chilcotin and Chilko sections. Idler and Clemens (1959, Table 1) support this estimate – they calculated 7 days in a 1956 study – but tag studies in 1944 and 1945 found Sockeye took 12 days on average to get from Farwell to the Chilko spawning grounds, averaging 13.8 km/d (IPSFC 1946a). Given the distance and elevation change between Farwell and the upper Chilko, plus the annual variability in Chilcotin River flows and annual variability in fish condition and numbers after exposure to heat and flow challenges in the lower Fraser and Hells Gate, a wide range of travel times (7-12 days) was deemed reasonable.

Incidental support for a time lag closer to the upper end of the range was derived from the aftermath of a rain-induced land-slide at Farwell Canyon that dammed the lower Chilcotin for the day on August 29th, 2004. Counts at Henry's Bridge fell to near-zero eleven days later (September 9th) (Appendix G). Counts remained negligible for about 3 days, likely due to the flood of water and debris sweeping away migrants pooling below the dam and beyond to the confluence with the Fraser.[34]

To address some of the statistical limitations associated with skewed and/or truncated data distributions (i.e. in migration rate and discharge), non-parametric categorical methods were utilized, based on the COCHRAN-MANTEL-HAENSZEL test statistic of GENERAL ASSOCIATION (CMH-GA; SAS 1987). The CMH-GA statistic provides a stratified test of association between a response variable – migration rate (daily % of annual total migrants) – versus multiple environmental variables after controlling for stratum level in the environmental factors.[35]

For the multi-way contingency tables, the continuous variates were classified according to thresholds based on percentiles (i.e. for migration and discharge) or assumed upper limits (for water temperature). For migration rate data, the 50th percentile was used as a threshold to exclude dates of 'negligible' migration (<50th percentile) in the tails of the run timing, while the 75th percentile was used as the threshold to define whether a daily migration rate value was a negative anomaly ("low" migration) versus a positive anomaly ("high" migration).

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[34] According to the BC Water Management Branch (MFLNRO): "*Debris that washed into the Fraser River posed a potential hazard to fishing gear and boats from Lillooet to Hope*." See also footnote 6.

[35] The stratified analysis provides a way to adjust for the possible confounding effects of water temperature and discharge without being forced to estimate parameters for them (SAS 1987).

To attempt to infer the “statistically-optimum lag time” (days) for which migration rates were most associated with lower Chilcotin conditions – the CMH-GA analysis was repeated at each integer temperature threshold (13-16°C) and flow decile (100-300 cms), for migration data merged with time-lags of 0 days (corresponding to environmental effects occurring at the counter sites) to 20 days (corresponding to effects acting on migrants downstream). A heat map of the resulting CMH GENERAL ASSOCIATION statistics was used to identify the discharge, temperature, and date lag threshold combinations that generated local maxima of significant association with categorical changes in migration rate. This was used to help identify the most likely time lag and, by extension, the potential location of the corresponding environmental influence contributing to variation in daily migration rates at the counter sites.

For water temperature in this high-altitude tributary, a high frequency of observed values near the upper tolerances of Sockeye salmon were rare, thus the only Chilcotin temperature thresholds available for statistical testing were well below known thermal impact levels (i.e. <18°C; Hyatt et al. 2015). However, the fact that Chilko migrants must previously experience temperatures 2-3°C higher as they ascend the Fraser River suggested that a Chilcotin temperature threshold of 15-16°C might serve as a local indicator or proxy for Fraser temperature levels known to affect Sockeye migration rates and patterns. Thus, a local temperature threshold of 15°C – akin to 18-19°C downstream in the Fraser – was used to classify Chilcotin daily mean temperature data as “low” (negative) or “high” (positive). This presumes that any significant ‘temperature effects’ apparent in the analysis would be an artifact of temperature co-variation associated with conditions downstream in the Fraser.

For discharge, the 90th percentile (~260 cms) of daily flow levels in the lower Chilcotin River during the Sockeye migratory period was used as a threshold to classify “low” (negative anomaly) versus “high” (positive anomaly) flow events. Previous studies indicated partial obstruction to migration corresponding to 200-220 cms in the lower Chilcotin (Farwell Canyon), and full obstruction above 260 cms (IPSFC 1946a; 1946b).

An unweighted frequency distribution of observed migration dates (i.e. filtered for non-zero migration rates) at varying levels of temperature and discharge was then generated for the selected lag, to indicate the general distribution of temperature and flow conditions that were available during the migratory period.

A similar frequency distribution of active migration dates, *weighted by the daily migration rate*, was also generated to quantify *how much* migration occurred at a given temperature and discharge level. In contrast to the simple distribution of dates of migration (which leave *amount* of fish out of the equation), these plots displayed the water temperature and flow conditions associated with highest migration rates (presumably most favourable to salmon migration), and, by extension, possible thermal and hydrological limits (if any) that differentiate high versus low rates of migration.

Environmental thresholds derived from the above analyses were used to calculate daily deviations in the modeled water temperature and discharge time-series. These were combined with deviations in daily migration rate (from the 75th percentile of the historical daily migration rate) on annual anomaly plots to examine the pattern of daily variation in each time-series in relation to each other.

RESULTS

CHILKO SOCKEYE MIGRATION

Total annual escapement estimates for Chilko-S and –ES stocks between 1975 and 2015 averaged 555,000 fish, and ranged from a low of 36,000 in 1982 to over 2.4 million in 2010 (Appendix A). Escapement totals were estimated via mark-recapture up to 2008 and via acoustic counters since 2009 (Grant et al. 2011). Quadrennial cyclic dominance, apparent prior to 1990, disappeared coincident with lake fertilization in 1988 and 1990-1993 and improved marine survival in the 1990s, which eradicated the weak cycle line ending in 1989 (Bradford et al. 2000).

Adult migrant fish counts at the Chilko River counter sites typically commenced in early-to-mid August and terminated by mid-October, with time-to-50% (TT50%) occurring approximately September 2nd (Figure 8). An annual average of ~71,566 Sockeye were tallied returning to the Chilko watershed at the Henry's Bridge count site over the 32 years of complete data from 1975-2008 (1975-1976, 1979-1980, 1982-1984, 1986-2008), ranging from a low of 6,583 (in 2004) to 170,284 (1991) fish in annual estimates (Table 3). Non-zero migrant counts at Henry's Bridge averaged ~2,000 fish per day; maximum daily counts surpassed 15,000 fish in multiple years, including 1997 and 2000.

With the installation of acoustic imaging systems in 2009, total annual counts ranged from ~217,000 to over 2 million (2010), with an average of 961,652 adults. Non-zero migrant counts averaged ~4,000 fish per day in 2009 and 2012, up to 43,982 per day in the exceptional 2010 return year. Maximum daily totals surpassed 132,000 fish in 2010, and ranged from 11,000 – 56,000 fish per day in 2009, 2011, 2012 (Table 3). Annual dates of time-to-50% are listed in Appendix E.

The corresponding all-year mean daily migration rate was 2.12% of total annual escapement. Annual peak daily rates were typically in the range of 10-15%, though 25% of the annual escapement appeared to occur on one day in 1989 (Table 3). Mean and maximum daily migration rates were generally lower for the years 2009-2012, likely due to the increased density of the counting effort available via the acoustic image systems. Total annual escapements are also charted in Appendix F.

The daily median (50th percentile) migration rate distinguishing "negligible" versus "low" migration was 1.2% of annual migration; the P75 value indicating "significant" migration was ~3% of annual migration, and the 95th percentile characterizing the threshold between "moderate" and "high" migration was ~7%.

Summarized across all years, a primarily unimodal pattern spanning 10-12 days emerged, centered in early September (Figure 8).

Annual time-series of Chilko Sockeye daily migration rates (%) were plotted in Appendix K, along with mean and maximum daily migration rates across all complete years, displaying, in some years, late onset of migration or time-to-50%

(e.g. 1976, 1991, 1993, 1997, 2005) and/or multi-modal migration pulses separated by periods of relatively low migration (e.g. 1979, 1990, 1998, 1999, 2004, 2008) which might be evidence of environmental factors influencing migration patterns.

HYDROLOGY

Chilko River / Chilcotin River

The typical Chilko/Chilcotin annual hydrograph displays a gradual diminishing of discharge levels from early August through the migratory period (Figure 9). Though different in scale, the highly correlated patterns of discharge within any given year between hydrometric stations in the upper and lower Chilko River[36,37] and lower Chilcotin River[38] (Figure 10 - Figure 15) indicated common meteorological and hydrological mechanisms (i.e. precipitation, temperature, and snow-melt patterns) driving seasonal changes across the region (Figure 16, Figure 17, Figure 18). For example, all hydrometric station time-series were characterized by high discharge events in 1976, 1991, and 1999 (Figure 14).

Furthermore, it was evident that the Chilko system (with inputs from its Taseko tributary) comprised about 90% of the seasonal discharge volumes for the lower Chilcotin and therefore largely determined the annual flow regime for Chilko-bound Sockeye upon entry into the Chilcotin watershed (Figure 16; Table 4 - Table 5). Though the high level of covariance in the system suggested that any one of the stations could be utilized as a suitable index of flow, the most logical place to look for potential impacts during high flow years was in the lower Chilcotin River, where cumulative discharge volumes were hydraulically concentrated at Farwell Canyon.

For the reference station in the lower CHILCOTIN AT BIG CREEK, a unimodal peak in discharge near 500 cms occurred in mid-August 1976 before returning to average flows by early September (Figure 15; similarly at other stations: Figure 13, Figure 11). Bi-modal peaks characterized 1991, and to a lesser degree, 1999. In late September 2011, higher than average flows (~200 cms) for that time of year occurred. Other years of relatively high discharge, where the median flow was over 200 cms or the extreme flow (P95) was ~300 cms or more included: 1978, 1981, 1982, 1992, 1998, 2004, and 2012.

At the other extreme, low water years, characterized by median flows below the all-year 25th percentile (i.e. < 127 cms at CHILCOTIN AT BIG CREEK) or P25 values below the all-year 10th percentile (i.e. < 99 cms) during peak migration, were not in evidence. The years 1975, 1983, and 1985 came closest (Table 4; Figure 15), but even in the upper Chilko River, minimum flows always exceeded 30 cms, while extreme lows (5th - 10th percentiles) generally exceeded ~50 cms until late September (Table 6; Figure 11).

High log-linear correlation (r = 0.99, n = 342) between the lower CHILCOTIN AT BIG CREEK and the lower CHILKO AT REDSTONE time-series (Figure 18) enabled extension and/or estimation of missing values in the lower Chilcotin time-series. Estimated

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[36] CHILKO RIVER AT CHILKO LAKE - WSC station 08MA002.
[37] CHILKO RIVER AT REDSTONE – WSC station 08MA001.
[38] CHILCOTIN RIVER (AT BIG CREEK) – WSC station 08MB005.

CHILCOTIN AT BIG CREEK discharge was well-correlated with observed data (r = 0.96, P < 0.001), though predicted values underestimated observed values for some high flow events (> 250 cms) by as much as 10% (Figure 19). As a consequence, reconstructed lower Chilcotin daily discharge estimates, prior to 1975, must be considered conservative regarding peak flows, theoretically missing 10% of high flow dates (e.g. peak-over-threshold = 250 cms) during certain years. Usefully, the reference station in the lower Chilcotin had continuous non-missing data that encompassed the entire Sockeye migration time-series; for the purposes of covariance analyses between Chilcotin flows and Sockeye daily migration, no infilling was required.

The CHILKO AT REDSTONE dataset provided additional utility via the length of its time-series (1927-present; Figure 12 (top)), which demonstrated a long-term negative trend in mean August-September discharge, despite an apparent significant positive trend in discharge in the Chilko system in more recent years (1975-2012; Figure 12 (bottom), and Figure 10). The recent trend appeared to be a result of several anomalously high flow summers in 1991 and 1999.

WATER TEMPERATURE DATA

Chilko River / Chilcotin River

Chilko River water temperatures during the migratory period (August-September, 1990-2012) averaged 12.8 ±1.7°C, with 95% of temperatures below 15.6°C (Table 8). Chilko River water temperatures typically reached their maximum in mid-August where daily mean temperatures briefly averaged 13-14°C (Figure 22).

Water temperatures warmed with progress downstream: the upper Chilcotin contributed as much as 1-2°C, and the Chilcotin River typically accrued another half-degree centigrade by the time flows reached the Fraser River. Observed water temperatures in the Chilcotin near Alexis warmed for longer beginning in late July, but still averaged less than 15°C (Figure 23). Downstream, near Big Creek, water temperatures tended to average slightly more than 15°C for the same period (Figure 24).

Chilcotin River water temperatures at Alexis and Big Creek were linearly correlated (r = 0.99; P < 0.001; n = 340; Figure 25). The statistical relation was used to infill missing data and extend the water temperature reference dataset at Big Creek from 1996-2012. This consolidated temperature dataset was used in air/water regression analyses for the Chilcotin River. Mean temperature during Sockeye migration for the resulting time-series was 13.8 ± 2.0°C, with 95% of water temperatures less than 16.8°C (Table 9). 1998 and 2004 were consistently represented in the warmest years of observed data for various temperature indices (e.g. mean, maximum, 75-95th percentiles).

The annual time-series of available water temperature data were plotted by year and site for CHILCOTIN RIVER (at BIG CREEK) in Appendix H, CHILCOTIN RIVER (at ALEXIS) in Appendix I, and CHILKO RIVER (at the DFO CAMP) in Appendix J. The annual plots were condensed for each site in Figure 22 - Figure 24.

Fraser River at Qualark

FRASER RIVER AT QUALARK water temperatures during the migratory period (July-September, 1941-2012) averaged 16.0 ± 2.0°C, with 95% of temperatures below 19.0°C (Table 10). Water temperatures typically reached their maximum in mid-August where daily mean temperatures averaged 17-18 ± 2°C at their peak in early-to-mid-August (Figure 21), coinciding with peak Sockeye migration at that location. Decadal averages during migration indicated an increase in temperatures since the 1980s (Table 10).

Covariation between the lower CHILCOTIN RIVER and the FRASER RIVER AT QUALARK ($r = 0.83$; $n=630$) indicated that temperatures in the Fraser were generally 2-3°C warmer than the Chilcotin during Sockeye migration (Figure 26). This would suggest that Sockeye encountering the upper extreme (16-18°C) of Chilcotin temperatures likely had already been exposed to temperatures exceeding 18°C while traversing the lower Fraser.

WATER TEMPERATURE TIME-SERIES RECONSTRUCTION

Chilcotin River (at Big Creek) – Reference Site

The logistic and linear air/water temperature models were parameterized using a calibration dataset composed of 8 years of data between 1997 to 2009 (Table 11).

SEASONAL TURN-AROUND POINT

The mid-year seasonal turn-around point for the Chilcotin was derived as week 30 – day 210, approximately August 2nd – based on maximum mean weekly air and water temperatures for the calibration data years (Figure 27). The “warming season” therefore extended from April 1 to August 2nd, followed by the “cooling season” from day 211-329, i.e. August 3rd – November 25th.

MULTI-DAY AIR TEMPERATURE INDEX

The multi-day WILLIAMS LAKE STANDARD air temperature index that best correlated with all-year daily mean water temperature in the lower Chilcotin was identified as the 7-day centered moving average air temperature index (7d-CMAT). Daily MWTs from the calibration dataset were about equally correlated with the 5d-CMAT and 7d-CMAT indices for the warming season (Figure 28 (top); $r_{5d\text{-}CMAT} = r_{7d\text{-}CMAT} = 0.82$; $P < .0001$; $n = 439$), but slightly more correlated with the 7d-CMAT for the cooling season (Figure 28 (bottom); $r_{7d\text{-}CMAT} = 0.89$; $r_{5d\text{-}CMAT} = 0.88$; $P < .0001$; $n = 531$), thus, the WILLIAMS LAKE STANDARD 7d-CMAT index was used for subsequent air/water temperature analyses.

MODEL CALIBRATION AND VALIDATION

Hysteresis was detected for logistic relations based on the difference between seasonal and all-season goodness-of-fit (NSC) coefficients (Table 12), as well as for linear relations based on significance tests for equal intercepts and equal slopes (Table 13), indicating that air/water temperature relationships were best modeled using separate seasonal components (logistic models: Figure 29; linear models: Figure 30). Logistic model parameters, 95% confidence limits, and NSC goodness-of-fit coefficients are listed in Table 12. Linear regression model output for seasonal air/water temperature relationships and calibration data are provided in Table 13.

Season-specific Pearson (least squares) and Spearman (rank) correlation coefficients between modeled estimates and validation data are contrasted in Table 14. Correlation coefficients for validation data indicated that linear and logistic model types were essentially equivalent in their skill at predicting Chilcotin River water temperatures. Both model-types estimated cooling seasons (r ~ 0.86, P < 0.0001) slightly better than warming seasons (r ~ 0.80, P < 0.0001).

A subset of the validation data years were plotted in Figure 31 with observed and logistically-modeled MWT output, along with daily MAT and the 7-d CMAT index (linear output not shown). Average conditions were estimated reasonably well (e.g. 1996, 2003, 2008), as were non-extreme monthly statistics such as the median and other percentiles (10th, 75th, 95th) (Table 15). Both model-types tended to underestimate water temperatures in warm years (e.g. 2004), thereby yielding conservative estimates of the frequency and duration of the warm water periods. Rapid drops in water temperature (e.g. 1997, 1999) were generally not modelled well either.

For the purposes of establishing a long-term water temperature index, and for consistency with analyses in other studies (e.g. Hyatt et al. 2015), the seasonal logistic model parameters were selected as the best estimators of daily mean water temperature for Chilcotin River, and were used to reconstruct historical daily water temperature estimates for the period of available air temperature data (1940-2012: Table 15).

Chilko River

The logistic and linear air/water temperature models were parameterized using a calibration dataset composed of ten years of data between 1990 to 2009 (Table 16).

SEASONAL TURN-AROUND POINT

The mid-year seasonal turn-around point for Chilko River was derived as week 30 – day 210, approximately August 2nd – based on maximum mean weekly air temperature at WILLIAMS LAKE and Chilko water temperatures for the calibration data years (Figure 32). The “warming season” therefore extended from April 1 to August 2nd, followed by the “cooling season” from day 211-329, i.e. August 3rd – November 25th.

MULTI-DAY AIR TEMPERATURE INDEX

The multi-day WILLIAMS LAKE air temperature index that best correlated with all-year daily mean water temperature in Chilko River was identified as the 10-day centered moving average air temperature index (not shown) (warming season: r = 0.90; cooling season: r = 0.94). However, the 7d-CMAT index was selected for subsequent air/water temperature analyses based on similar high correlations (warming season: r = 0.89, n = 1173; cooling season: r = 0.93, n = 1107), and for consistency with air-water temperature relations for the Chilcotin River reference site.

MODEL CALIBRATION AND VALIDATION

Hysteresis was detected for logistic relations based on the difference between seasonal and all-season goodness-of-fit (NSC) coefficients. Logistic model parameters, 95% confidence limits, and NSC goodness-of-fit coefficients are listed in Table 17. Hysteresis was also detected for linear relations based on significance tests for equal intercepts and equal slopes (Table 18), indicating that air/water temperature relationships were best modeled using separate seasonal components (logistic models: Figure 33; linear models: Figure 34).

A subset of the validation data years were plotted in Figure 35 with observed and logistically-modeled MWT output (linear output not shown), along with daily MAT and the 7-d MAT index. Rapid drops in water temperature (e.g. 1997, 1999) that occasionally characterize Chilko outflows were not modelled well, but average conditions were reasonably estimated (e.g. 1996, 2000). Season-specific Pearson (least squares) and Spearman (rank) correlation coefficients between modeled estimates and validation data are contrasted in Table 19. Correlation coefficients for validation data (r ~ 0.87) indicated that logistic model types were marginally more skillful at predicting Chilko River water temperatures.

TEMPERATURE, FLOW, AND MIGRATION

Trends in Temperature

As a weak long-term warming trend in the regional air temperature index was evident for the summer months (August-September) over the period of record (1940-2012) (Figure 39), the dependent long-term Chilcotin River mean water temperature estimate signaled an analogous warming trend in the slope as well ($r = 0.06$, $P < 0.001$) (Figure 40). However, the trend was less than a tenth of a degree per decade, and the mean summer water temperature has not differed significantly from 14°C over the time span (Table 15).

Trends in Discharge

The extended time-series of observed discharge in the lower CHILKO RIVER AT REDSTONE (serving as a long-term index of flows in the Chilcotin system) suggested a weak decline in mean flows during the Aug-Sep migratory period since 1927 (slope = -0.31, $P < 0.001$), amounting to an average decline of ~3 cms per decade or approximately 24 cms (10%) over the last eight decades (see Figure 12, top).

It is informative to segregate these data by month, since annual maximum flows in July and August almost invariably transition to low flows by September (with a few notable exceptions: 1991 and 1999) (see Figure 13, Figure 16). While September flows have declined (-4.0 cms per decade), July flows have increased (+3.6 cms per decade), and August flows are intermediary (trending downward -1.4 cms per decade; Figure 41).

Installation of fishway structures to facilitate fish passage through Farwell Canyon at high flows was completed in 1950, however the utility of these structures was negatively impacted by extreme flows in late-spring / early-summer between 1948 and 1955, which significantly altered both channel width and stream depth (Roos 1991). Maximum discharge values of 400+ cms at Chilko River at Redstone for June-July indicate the discharge levels associated with these changes – equivalent to ~600 cms in the lower Chilcotin River (Figure 42). The hydrological record indicated that these events were followed by 2-3 decades of relatively moderate flow levels; however, there have been four years in recent decades (1991, 1999, 2005, and 2012) when pre-migration discharge reached similar magnitudes (Figure 42). Whether these recent events altered, channel morphology is, however, unknown.

For the adult migration season (Aug-Sep), the period of relatively moderate flows beginning in the mid-1950s ended abruptly in 1976 (Figure 43). Although the fishways were likely inoperative during these years (Roos 1991), it is of interest to note the frequency of years when discharge levels were once again in the zone of potential impedance to upstream migration (at least under the historical IPSFC assessment in the 1940s), including: 1976, 1981, 1982, 1991, 1998, 1999, and 2012 (Figure 43). If any of these high-flow years were marked by hydraulic changes to Farwell Canyon channel morphology detrimental to fish passage, functional fishway structures may have again provided some utility.

Migration in Relation to Temperature and Discharge

A heat map of the distribution of 462 CMH-GA[39] statistics was used to help identify, for each environmental variable, the time lags and threshold levels most associated with large changes in migration rate at the Chilko Sockeye counter site. Graphic outputs were generated for migration in relation to discharge, stratified by water temperature category (Figure 44), and for migration in relation to water temperature, stratified by discharge category (Figure 45). There was little discernible effect between temperature thresholds in the range of 13-15°C, and insufficient data at 16°C or more, thus only the 15°C threshold analysis is displayed.

The temperature-stratified distribution in Figure 44 indicated highly significant statistical association ($P < 0.001$) for migration in relation to discharge level at the 15°C water temperature threshold, across a range of lower Chilcotin River[40] discharge thresholds. Maximum significance varied with both discharge level and migration data lag, ranging from 220 cms seven days prior to being counted in the upper Chilko River, to 280 cms twelve days prior. This posits the existence of a discharge effect at relatively high flow levels (typically occurring at the front of the run) influencing migration rates 7-12 days later. The lag effect appears to be proportional to the discharge level, as might be expected given the higher energetic demands on the fish as flow levels increase. Contingency tables at coordinates typical of the highly significant threshold values[41] indicated the greatest frequency of high migration activity (>3% per day) occurred at discharges < 260 cms and temperatures < 15°C (Table 20).

Interestingly, a similar pattern in the CMH-GA statistic is apparent at lower discharge thresholds (140-180 cms) extending ~6 to 16 days prior (Figure 44). This apparently distinct pattern might point to an unidentified factor, such as a seasonal effect,

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[39] The COCHRAN-MANTEL-HAENSZEL GENERAL ASSOCIATION statistic provides a stratified analysis of the level of association between the migration rate response variable and independent environmental variables to control for confounding effects of water temperature and discharge.

[40] Note: At CHILCOTIN AT BIG CREEK, NOT CHILKO AT REDSTONE

[41] Specifically: Discharge 260 cms; MWT 15°C; Migration data lag: 12 days.

associated with a time period characterized by lower flow conditions, as is more typical later in the season (Figure 9; Figure 15). If that is the case, it might be speculated that the wider range of lags (up to 16 days) – despite the lower discharge levels – might be indicative of weaker fish condition, perhaps due to prior stressful conditions (e.g. elevated temperatures in the Fraser).

The CMH-GA distribution in Figure 45 indicated highly significant statistical association ($P < 0.001$) between migration data lagged 10-12 days and lower Chilcotin River water temperature (at threshold level of 15°C), stratified across a range of discharge thresholds. This suggests a significant temperature effect associated with changes in migration 10-12 days later at a wide range of discharge levels, with maximum statistical significance at 180 cms and 260 cms thresholds (which might also denote a seasonal effect).[42] Contingency tables at 260 cms versus 12 day lag thresholds indicated highest frequency of high migration activity (>3% per day) occurred at temperatures < 15°C when discharge < 260 cms, though no effect when discharge > 260 cms (possibly due to low overall frequencies; Table 21). The CMH-GA statistic, which takes both tables into account, still found a significant temperature effect overall.

Taken together, these stratified frequency analyses seem to indicate that conditions in the lower Chilcotin River, approximately 7-12 days prior, were at times significantly associated with variation in daily migration rates at the counter site. Of particular interest is the upper discharge threshold of 260 cms – approximating the 90th percentile of lower Chilcotin River daily discharge – and equivalent to the historic flows associated with 'full blockage' of upstream migration (IPSFC 1946a; IPSFC 1946b). Migration variation associated with flows of 260 cms was also linked with lag times of approximately 12 days (Figure 44, Figure 45).

It should be noted that, based on a swim speed of 14 km/d estimated for Chilko Sockeye in the Chilcotin system (IPSFC 1946a), 12 days' swim would place the location of the corresponding environmental influences 168 km downstream, in the area of Farwell Canyon (Figure 5), the site of a potential physical mechanism of covariation. Thus, a backwards lag of 12 days was selected for Chilko Sockeye daily migration data for subsequent covariation analyses with environmental variables.

An un-weighted tally of non-zero migration dates indicated that approximately 70% of the historic migration dates occurred when lower Chilcotin flows twelve days earlier were ~140-240 cms (Figure 46). Weighting the frequency distribution by the daily migration rate indicated that, ignoring infrequent occurrences, significant daily migration rates (>3%) occurred at a similar range of discharge levels (160-260 cms) (Figure 47).

Dates of migration activity were approximately normally-distributed around 15°C, with the majority of dates (~80%) characterized by water temperatures of 13-16°C (Figure 48). Highest mean daily migration rates (i.e. > 75th percentile, i.e. >3% per

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[42] A lesser effect appears to be associated with relatively high discharges (200-240 cms) between 2-4 days prior to counts, likely related to intermittent velocity barriers occurring in Chilko River (e.g.Siwash Rock or Lava Canyon).

day) were also associated with estimated water temperatures of 13-15°C (Figure 49). A weighted two-way frequency distribution based on combined flow and temperature ranges showed that high migration rates were found at a range of discharge and temperature levels, with maxima at 13-15°C and 170-240 cms (Figure 50).

Anomaly plots of migration versus water temperature and discharge deviations based on lower Chilcotin environmental thresholds of 15°C and 260 cms 12 days earlier (Appendix L) indicated that the most consistent environmental impact in the historical data was the delay in the onset of migration due to high discharge levels. When high Chilcotin flows persisted into the migratory period, high migration rates (> 7% per day) were generally inhibited until daily mean discharge dropped below 270-300 cms. This effect appeared evident in 1976 (< 300 cms); 1990 (< 260); 1991 (< 300); 1992 (< 240); 1998 (< 250); 1999 (< 260); 2000 (< 250); 2007 (< 240); 2009 (< 240); 2010 (< 240); 2012 (< 260). In 1976, 1991 and 1999, persistent high discharge levels into late August / early September were associated with migratory delays of 2-3 weeks, with annual time-to-50% dates of 04-Sep-76, 12-Sep-91, and 11-Sep-99, respectively, all greater than or equal to the multi-year time-to-50%.

One exception to this “high-flow rule” was apparent, in 1991, when high migration rates occurred despite flow levels of 300 cms (Appendix L). This could reasonably be explained if the lag times were in error by one or two days.

At the low end of the Chilcotin flow spectrum, it was observed that high migration rates were not evident in the data below ~150 cms (~30th percentile); however, this is most likely because the lowest water levels only occurred late in September, near the end of the Sockeye run.

Direct effects of high temperature resulting in low migration rates were also not in evidence since Chilcotin water temperatures rarely reached 18°C; the 95th percentile of observed/estimated values was only 16.5°C. Apparent reductions in migration from high to moderate levels as temperatures approached 15-16°C were evident for some years (e.g. 1988; 1996; 1998; 2002; 2003); most likely an indirect effect of water temperatures several degrees warmer affecting the migrants while in the Fraser a few days earlier.

Temperature Exceedance Analyses

A frequency analysis of regional daily mean air temperature indicates that the annual cumulative total number of $\mathrm{POT}_{>20°C}$ dates has averaged less than 3 days per year since the 1940s, with no statistically detectable difference between decades (Table 22, Figure 51). While the duration of continuous $\mathrm{POT}_{>20°C}$ periods has remained less than 2-3 days on average over the past six decades, warmer temperature conditions since the 1960s have resulted in a tripling in the frequency of such periods (Figure 52).

A similar frequency analysis based on estimated daily mean water temperature exceeding 16ºC during migration (August-September) indicated that the cumulative total number of $\mathrm{POT}_{>16°C}$ dates per year fluctuated from 2-3 days per year on average in the 1940s and 1950s, but averaged closer to 7-8 days since the 1960s

(Figure 53; Table 23).[43] However, none of these differences are statistically significant ($P > 0.05$).

The average length of $\text{POT}_{>16°C}$ periods was less than 6 days for most decades, with no apparent trend, though in the last two decades, the frequency of such periods has increased (Figure 54, Table 24). Maximum period length over this temperature threshold has, on occasion, extended more than a week, but likely posed little threat to Sockeye. Years with extended periods of elevated water temperature included most of the usual warm years: 1941 (14 days); 1967 (15); 1977 (19); 1981 (20); 1990 (16), 1997 (11), and 2004 (10) (Table 25).

In the 1990 case, the 16-day $\text{POT}_{>16°C}$ event occurred in early August, likely associated with above-average temperatures in the Fraser; Sockeye migration did not pick up until the last 10 days of the month (Appendix K; Appendix L). A similar event occurred in 1997, 2001 and 2003, during which high migration seemed to coincide with Chilcotin temperatures falling below 15°C (equivalent to Fraser temperatures < 18°C).

Discharge Exceedance Analyses

Low flow periods ($\text{POT}_{<90\ \text{cms}}$), based on the 10th percentile of flow data from the CHILKO AT REDSTONE hydrometric station, have occurred almost exclusively in September (Figure 55; Table 26). The mean decadal frequency of low flow dates peaked in the 1970s and 1980s at an average of about 10 days per year.

This coincided with the period between 1970-1990; when (excluding 1976) Chilcotin discharge was generally lower than the long-term average (Figure 12). During that period, continuous $\text{POT}_{<90\ \text{cms}}$ events of ~10 days in length occurred on average once a year (Figure 56; Table 27). The longest stretch (20 days) occurred in 1970 (Table 26). More recently, during the 1990s and 2000s, the average frequency and duration of low flow events has returned towards the long-term average.

Migration activity is almost non-existent at discharges < 90 cms in the lower CHILKO RIVER AT REDSTONE[44]. However, that outcome is more likely related to the *timing* of low flows (in late September, after the Chilko run is virtually complete), rather than direct impacts on fish passage. There appears to be sufficient water available to Sockeye migrants in this lake-headed watershed. In the upper Chilko, above the Taseko junction, at the outlet of the headwater lake, minimum annual flow levels ranged from 33 cms and up (Table 6).

Extreme high flow dates (>240 cms at CHILKO AT REDSTONE[45]) have generally occurred about 10 or less times per year – principally in August – with no obvious trends in the long-term annual frequency (Figure 57). The 1990s exhibited the highest frequencies of $\text{POT}_{>240}$, at ~12 dates per year, largely driven by 1991 (29

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[43] A $\text{POT}_{>18°C}$ analysis yielded no tallies, and a $\text{POT}_{>17°C}$ analysis yielded no tallies prior to the 1960s, and less than 2 tallies per year for all decades since then, with no trends.

[44] Corresponding to ~100 cms in the lower Chilcotin River (Figure 50).

[45] Corresponding to ~260 cms in the lower Chilcotin River.

days) and 1999 (31 days) when high flows persisted through August into September. The overall frequency of high flows decreased in the 2000s to about one week per year, though that average obscures some years of relatively high flow frequencies (2010: 19 days; 2011: 13 days; 2012: 22 days).

The average duration of continuous $POT_{>240}$ dates in the 1970s and 1990s was ~12 days (Figure 58; Table 27). The persistence record was set in 1999 at 32 days, which entailed all of August and the first few days of September, followed by 1991 (28 days) (Table 28). Years in which the first 3-4 weeks of migration were met with extreme high flows included 1976, 1991, 1992, 1998, 1999, 2010, 2012), some of which showed strong evidence of delay in the onset of migration (e.g. 1976, 1991 and 1999).

DISCUSSION

The influence of environmental factors on upstream migration of Fraser salmon has been widely documented. Water temperatures have been found to be correlated with metabolic stress, impaired swimming capacity, and susceptibility to disease (Macdonald et al. 2000a; 2000b), resulting in increased *en route* mortality (Patterson et al. 2007). Furthermore, water temperatures in the Fraser have been rising steadily (Martins et al. 2010; 2012; Patterson et al. 2007) and are projected to continue to rise (Whitfield 2001; Whitfield et al. 2002), escalating the likely impacts on Sockeye population sustainability (Hinch and Martins 2011) and fisheries management (Hague and Patterson 2007; Young et al. 2006).

An increase in the frequency of flow extremes is another outcome of climate variation in the Fraser watershed (Whitfield and Cannon 2001), which can exacerbate thermal impacts on fish condition and survival (Rand et al. 2006). High water velocity associated with river discharge has been correlated with higher energy expenditures (Salinger and Anderson 2006), slower migration rates, and migration delays (Fenkes et al. 2016). Migrants are more likely to succumb to pre-spawn mortality after high-flow-induced ‘burst swimming’ efforts to traverse hydraulically-challenging locations (Burnett et al. 2014; Hinch et al. 2002), such as at Hell’s Gate in the Fraser River, ~250 km downstream of the Chilcotin River confluence.

As is the case for other Fraser salmon stocks, Chilko Sockeye that survive the Fraser leg of freshwater migration must have sufficient energy reserves to meet the physical demands associated with the unique environmental conditions in the terminal tributaries *en route* to their natal spawning grounds (Hinch and Rand 1998). For example, from the Fraser/Chilcotin confluence to the spawning grounds (177 km), Chilko Sockeye must climb 850 m to a final elevation 1,170 m while traversing multiple ‘canyons’ of rapids. This energetically-demanding leg of the journey represents the last 25% of their freshwater migration distance but accounts for 70% of the total vertical ascent from sea level (Idler and Clemens 1959). Though temperatures in the Chilcotin/Chilko system are generally cooler by 2-3°C relative to the Fraser, Chilcotin water temperatures may still exceed optimum migration temperatures for Chilko Sockeye (16-19°C; Eliason et al. 2011) during peak migration in August (Figure 23, Figure 24). For Sockeye, the cumulative thermal impacts to this point are likely exacerbated by concentrated flow impacts at hydrological focal points (Burnett et al. 2014) such as Farwell Canyon (IPSFC 1946a). A comprehensive assessment of the cumulative exposure to environmental challenges is necessary to understand the full impact of freshwater conditions on the health and spawning success of Chilko Sockeye salmon (Hague, Patterson and Macdonald 2008).

Sockeye Migration and Water Temperature Conditions

As environmental impacts – especially thermal effects – on Chilko migration attributable to Fraser River conditions (e.g. in the lower and mid-Fraser and/or at Hell's Gate, briefly outlined above) are explored elsewhere (Patterson et al. 2007; MacDonald et al. 2000a, 2000b; Martins et al. 2011), this section will focus specifically on the additional potential impacts in the Chilcotin/Chilko watershed.

Chilko River does not appear to currently impose any limitations on Sockeye migration due to water temperature. Water temperatures during the migratory period (August-September, 1990-2012) averaged 12.8 ±1.7°C, with 95% of temperatures below 15.6°C, and typically reached their maximum in mid-August where daily mean temperatures briefly averaged 13-14°C, ideal for Sockeye migration. Therefore, no review of Sockeye migration patterns in relation to water temperatures was deemed useful for Chilko River.

The warmest water temperatures in the Chilcotin watershed were observed 150 km downstream, near Big Creek in the lower Chilcotin River, averaging slightly more than 15°C during the migratory period. Hence, the lower Chilcotin was selected as the most logical location in the watershed to assess for thermal impacts on Sockeye migration, and to evaluate long-term trends in temperature conditions. Maximum daily mean water temperatures observed at this location between 1996 and 2012 were 18-19°C (in 1998 and 2004), but 95% of observations fell below 17°C.

A strong statistical relation (r = 0.99) between Chilcotin River temperature datasets was used to infill missing data in the limited time-series in the lower CHILCOTIN AT BIG CREEK (2006-2012) and to extend it back to 1996. The resulting temperature dataset was used in logistic regression analyses to generate an index of Chilcotin River daily mean water temperature from regional air temperature encompassing the record of daily Sockeye migration (1975-present) – and back to 1939 for trend analyses. This water temperature index[46] provides a standardized estimator across all years which reasonably reproduces observed temperatures in most years (e.g. 1996, 1999-2003, 2006-2008, etc.).

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[46] Like other multi-day moving air temperature means, the CMAT indicator tends to bias extreme air temperatures towards the mean, thus under-estimating the amplitude and frequency of peak thermal events that may affect fish behaviour. Therefore, this index, and, by extension, any water temperatures estimated as a function of this index, should be treated as a conservative indicator of extreme events. The 7D-CMAT index provided the best trade-off between maximizing correlation and minimizing the effects of multi-day averaging on predictive power at longer period lengths.

However, since the regression analysis is based on a wide variety of years, the estimates tend to underestimate occasional rapid changes (e.g. 1997, 1998) and/or persistent extremes (e.g. 2004) in water temperature in some years.[47] Thus, the results of analyses regarding average and peak temperatures, including exceedance analyses of frequency and duration over temperature thresholds (Figure 53; Figure 54), must be considered conservative, though inter-annual and decadal trends should be consistent.

Given these qualifications, it appears that estimated mean water temperatures in the lower Chilcotin River during the Sockeye migratory period are currently 13 ± 2°C, and have been rising at a rate of less than 0.1°C per decade since the 1940s (Figure 40). Review of historical Chilko Sockeye daily migration patterns – lagged back to the lower Chilcotin based on an estimated swim speed of 14 km/day (IPSFC 1946a) – in relation to estimated water temperatures indicated little difference in the frequency distribution of dates of migration activity versus the distribution of dates weighted by the amount of fish migrating: both distributions were approximately normally-distributed around a mode of 14-15°C (Figure 48 vs Figure 49). In other words, the temperatures associated with the highest daily migration rates overlapped closely with the temperature distribution of available dates, suggesting no real influence of Chilcotin water temperature on daily migration patterns. As temperatures in this range are hospitable to migrating Sockeye, this is not surprising.

Exceedance analyses indicate that the frequency and duration of periods in which conditions would be thermally-stressful to Sockeye migrants (18°C or more) is negligible, due to insufficient data at higher temperature thresholds. Even temperatures exceeding 16°C occurred less than 10 days per year on average (Figure 53), and persisted for less than a week (Figure 54), with no evident trend over the past seven decades.

However, $\text{POT}_{>16°\text{C}}$ periods in the Chilcotin may be associated with elevated water temperatures in the Fraser (usually 2-3°C higher than the Chilcotin) exerting thermal stress on Chilko migrants. Indeed, the COCHRAN-MANTEL-HAENSZEL test strongly suggests a "temperature effect" on migration rate occurring at virtually all levels of discharge approximately 10-12 days prior to Sockeye arrival on the spawning grounds (Figure 45), in the lower Chilcotin River at Farwell Canyon. Though water temperatures at that location cannot be considered limiting to adult Sockeye, it could be hypothesized that this "temperature effect" signifies the impact of encountering hydrologically-challenging waters after exposure to stressful water temperatures in the Fraser. Known years of Sockeye migration impacts due to elevated temperatures in the Fraser River include: 1992, 1994, 1998, and 2004[48] (Patterson et al. 2007). Extended $\text{POT}_{>16°\text{C}}$ periods of 10 or more days were associated with

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[47] See Appendix K, 1996-2012 for estimated vs observed water temperatures.

[48] In 2004, less than 7,000 Chilko migrants were counted at Henry's Bridge.

apparent delays and reduced migration in some of these years, especially 2004 (Appendix L).[49]

Sockeye Migration and Flow Conditions

Summer mean flows in the Chilcotin have exhibited a weak long-term decline since 1927 (slope = -0.31, P < 0.001), amounting to an average decline of ~3 cms per decade, or approximately 24 cms (10%) over the last eight decades (Figure 41). Despite the downward trend, some of the highest early summer discharge volumes of any year on record have occurred in recent decades, notably in 1991 and 1999, during which high flows persisted throughout August and into September, clearly delaying the onset of migration for several weeks (Appendix K) and offsetting the date-to-50% one week later than the multi-year average (Appendix E). High discharge levels persisting into mid-August also appear to be coincident with negligibly low migration rates in several other years, including: 1976, 1996, 1998, 2007, and 2009-2012.

When partitioned by month, it appears that falling September flow levels are responsible for most of the decline during the migratory period (Figure 41). August flows impacting Sockeye migration are of course correlated with flow levels in July, which appear to be trending upward at almost 4 cms per decade. Both July and August are characterized by increased variability since the late 1970s, which may be a function of changes in snow-pack depth and earlier timing of snow-melt over recent decades (Littell et al. 2011; Whitfield 2001; Zwiers et al. 2011). Associated hydrological regime shifts would also be implicated in the declining trend in September discharge levels, as the distribution of flows is skewed earlier in the summer season in a warming climate.

The confluence of warmest water temperatures in the Chilcotin watershed in association with a documented velocity barrier pointed to Farwell Canyon in the lower Chilcotin as the logical first place to assess impacts of environmental conditions on Chilko Sockeye in the final leg of the stock's freshwater migration route. The appropriate lag in days to align daily Chilko Sockeye migrant counts with conditions 160 km downstream depends on presumed swim speed in this final 850 meter ascent. Recent estimates for Chilko Sockeye swim speed – ranging from 32-52 km/day – were available only for distances in the Fraser River (e.g. Hague et al. 2008), which likely do not apply to the Chilko/Chilcotin segment, where hydrological conditions are different (cooler, but steeper) from the mainstem. However, these swim rates do provide a minimum time length of 6-7 days from Farwell Canyon to the spawning grounds. Tag studies performed in two moderate flow years (1944 and 1945), indicating 12 days on average for Sockeye to cover the same distance, provide an upper bound. Migration delays associated with the obstructive slide at Farwell in 2004 suggested about 10 days of travel time (Appendix G). Both stratified CMH-GA tests signified strong environmental influences on migration rate when daily Sockeye migration was lagged back in time 10-12 days, particularly at

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[49] In 1977, a 19-day POT>16°C event occurred in mid-August, and a 20-day event occurred in 1981 (Table 24). However, daily Chilko migration data were incomplete for these years.

discharge levels above 250 cms (Figure 44, Figure 45). These analyses tend to support the slower swim speed estimates at higher flows, and raise the possibility that Farwell Canyon may still be an important influence on Chilko migration activity.

When daily Sockeye migration counts in Chilko River are lagged back twelve days to match up with discharge levels in the lower Chilcotin (i.e. near Farwell Canyon), it appears that significant migration rates (>3% per day) were generally inhibited until daily mean discharge dropped below ~270-300 cms (Appendix L). Interestingly, this coincided with the flow threshold associated with ‘full blockage’ of Chilko-bound migrants at the Farwell Canyon velocity barrier, at least under the historical hydrological assessment empirically determined by IPSFC staff in the 1940s (IPSFC 1946a, 1946b). For the daily migrant counts assembled for this study (1975-2012), only one exception to this “high-flow rule” was evident – in 1991 – when a significant 4-day pulse of fish was tallied between bi-modal peaks of discharge in excess of 270 cms (see Appendix L). The coincidence of peak migration with discharges of ~300 cms is most likely explained by probable errors in the applied lag time, which was assumed constant at 12 days for all years despite large variations in Chilko/Chilcotin flows.

At the other extreme, significant *low flow* impacts on Sockeye migration were not detected and are generally not considered an issue in the Chilko/Chilcotin, since relatively stable late-summer flows characterize this lake-fed watershed (Rood and Hamilton 1995). High migration rates were not evident in the data below ~150 cms (~30th percentile); however, that is most likely because these water levels only occurred late in the season, near the end of the Sockeye run. In the upper Chilko, at the outlet of the headwater lake, minimum seasonal flow levels were 33 cms, generally sufficient for migrants and spawners, as long as temperatures remain cool.

This may change with expected climate shifts towards warmer, drier summers, which will reinforce the current trends towards lower September flows and higher water temperatures, especially with diminishing supplies of winter snow-pack in the near-future decades, followed by glacial retreat over the long-term (Whitfield 2000; Whitfield and Cannon 2000). However, to this point, water quality and quantity in the Chilcotin system appear to be sufficient for Sockeye migration and reproduction, provided the fish can cope with the thermal stresses accrued prior in the Fraser River approach.

The more significant threat to Chilko Sockeye is therefore conferred by high melt-water flooding in early summer that persists well into the migration period in August. Out of the 34 years of complete migrant data since 1975, high discharge events appear to be associated with delayed or impeded August migrants for 3-4 weeks in a minimum of 3 years, and 1-3 weeks in as many as 11 years. Warmer periods (e.g. 1940s, 1970s, and 1990s) were most often associated with higher frequency and duration of early summer flows exceeding 260-270 cms in the lower Chilcotin River, which exceeds flow levels associated with ‘partial obstruction’ to migrants at Farwell Canyon, and corresponds to the threshold associated with stopped migration (IPSFC 1946a, 1946b). July flows have been trending upwards over the past century, with increased variability (higher highs, and lower lows) since the 1970s.

Regional climate change is expected to alter the hydrologic flow regime in potentially unexpected ways. Despite anticipated reductions in summer precipitation and reduced winter snow thickness, earlier glacial ice- and snow-melt, combined with increased rain-on-snow events, may increase the risk of early summer floods in the region, at least until Coast Mountain glaciers significantly recede (Shrestha et al. 2012; Stahl et al. 2008).

Critical to the biodiversity of Sockeye salmon in this watershed is the fact that high early summer flows disproportionately impact the earliest migrants, specifically the small but distinct CHILKO-ES and TASEKO-ES conservation units (Holtby and Ciruna 2007). The CHILKO-ES CU has been designated as DATA DEFICIENT under WILD SALMON POLICY objectives and Taseko Sockeye have been flagged provisionally in the RED ZONE due to long- and short-term declines in the escapement index (Grant et al. 2011). Since both stocks co-migrate to some extent with the prevalent CHILKO-S CU, they are therefore also likely to be suppressed or declining due to mixed-stock fisheries from marine to Chilcotin areas[50]. However, neither minor stock is actively managed towards specific sustainability objectives within the existing aggregate Fraser sockeye management framework administered by DFO (Toth and Tung 2013b)[51]. Even the prevalent CHILKO-S population is classified as abundant but declining in the short-term (Grant et al. 2011). Assessment of high flow impacts on Chilko- and Taseko-bound Sockeye, and mitigation as appropriate, could be vital to maintaining biodiversity and resilience while sustaining fish productivity in the face of ongoing and anticipated environmental changes.

Farwell Canyon

Delays are costly to salmon migrating long distances and surviving on finely-tuned energy reserves (Hinch and Bratty 2000) and may impair fish condition (Idler and Clemens 1959; Salinger and Anderson 2006) and reproductive success (Rand et al. 2006). An intermittent delaying effect on Chilko Sockeye at Farwell Canyon was originally demonstrated by extensive tagging programs carried out in the 1940s by IPSFC biologists. Obstruction to migration was found to occur at a narrow range of high water levels, which in occasional years coincided with the time of arrival of the first Sockeye (IPSFC 1948). IPSFC studies found that Chilko Sockeye mortalities likely occurred if delays due to flows exceeding 260 cms persisted for more than 25 days (IPSFC 1946a). Combined with earlier research, the IPSFC concluded that “moderate to serious mortality” likely occurred in 7 of 18 years of observation (ibid., Table VI).

The Farwell Canyon fishway, installed in 1948-1950, was originally designed to provide safe passage for fish at discharges of 150-300 cms (as measured at CHILCOTIN AT BIG CREEK) (IPSFC 1946b). IPSFC annual reports indicated that

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[50] Recent trends in Fraser harvest data indicate Chilko Sockeye can represent up to 50% of downstream harvests, depending on the year and/or run-timing management unit, exerting added pressure on both minor and major Chilcotin Sockeye stocks (Toth and Tung 2013b).

[51] Selective terminal harvest methods are currently being implemented by Tsilhqot’in Fisheries to ensure commercial harvests protect weak stocks (pers. comm., P. Grinder, TNG Fisheries Manager).

between 1950 and 1956, the Farwell fishways were regularly maintained and operating normally, despite ongoing issues related to terrestrial instability[52]. However, a literature search in the DFO library archives did not reveal any post-installation studies regarding the overall efficacy of the fishway.[53] The last reference to the Farwell fishways found in IPSFC annual reports was in 1956.[54]

The subsequent lack of information on the status and function of the Farwell fishways was likely a result of their relatively-sudden reduced utility, as a consequence of significant bathymetric changes at the site, reportedly due to early summer extreme flows in 1948, 1950 and 1955 (Roos 1991). These flood events not only altered the channel width, but allegedly lowered the stream bed as well, rendering the fishway structures “high and dry” during most Sockeye migration periods, while simultaneously ameliorating the velocity barrier impeding upstream migration.[55]

Given the changes in hydraulic conditions at the Farwell site apparently soon after installation, and the lack of reliable daily migration data over the functional years of fishway operation, it is not possible to assess actual fishway efficacy (i.e. proportion of run affected by high flows, proportion benefitting from fishway, etc.). Even without a moving hydrological baseline, it would be difficult to gauge fishway utility from the available data, given the errors and assumptions associated with count data, hydrological conditions, swim speeds, and time lags. Rigorous experimental field studies would be required to reduce the associated uncertainties.

Furthermore, the hydrologically-induced structural changes at the Farwell site in the early 1950s (Figure 42)[56] were followed by two decades of relatively moderate flows during adult migration (Figure 43), likely cementing the general perception that the

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[52] “In the spring of 1950, the fifth and final fishway at Farwell Canyon was completed. Further slides occurred in the construction area but the first four fishways were functioning properly and sockeye were observed using them. Later that same spring, the lower right bank fishway was partially closed by a small rock slide into the outlet tunnel and the fishway channel. The material was removed and all five fishways were operative in the 1950 migratory period. In the spring of 1955, a slide occurred in the fractured rock of the canyon wall above the lower fishway on the right bank. Large rocks fell on the deck gratings and partially filled the entrance to the fishways, but they were once again operational during the 1955 season. In 1956 the trash racks at the upper end of the lower and middle left bank fishways had to be fitted with stop logs to prevent rocks and gravel from accumulating in the fishway during freshets.” (Roos 1991, p.105)

[53] Anne Lomas, DFO Library Services, pers. comm., November 2016.

[54] “…the fish exit trash racks of the lower and middle left bank fishways at Farwell Canyon were fitted with stop logs in an attempt to prevent river and bank gravel from being deposited in the fishway during freshet period, and if successful, these stop logs will be left in place except during the period of salmon migration upstream.” (IPSFC 1956; p.32)

[55] J. Hillaby, pers. comm., DFO Fish Habitat Restoration Biologist, November 2016.

[56] “Following the hydrological events in 1948 and 1955, it was determined that the 1948 flood had changed river flow patterns to such an extent in the area above the fishways that fishways were no longer required (M. Bell personal communication). The fishways have not been maintained and were not operative through 1985.” (Roos 1991; p.105).

fishways were not functional in terms of facilitating upstream fish passage. As the dysfunctional fishway structures fell further into disrepair under the impacts of ongoing bank erosion and minor landslides, the rational solution for safety and liability purposes was to seal the chutes in 2004.

Two inter-related factors might reasonably promote a review of the current situation.

In the first place, hydrological conditions in this glacial watershed are in flux. Hydrological flux was noted as early as 1991: “Changes in the flow pattern in recent years have reportedly increased the possibility that the fishways may again be required (F.J. Andrew, pers. comm.)”, (Roos 1991; p.105). The hydrological record for the Chilcotin system indicates a higher frequency of high flows during the migration period (Aug-Sep) since 1976 (figure2). The 1970s and 1990s experienced the longest decadal *average* duration (12 days) of continuous flows exceeding 240 cms over the past nine decades (Figure 58). The 1940s – which stimulated construction of the fishways – registered a decadal average of only 9 days (Figure 58).

Secondly, hydraulic conditions at the Farwell site are also in constant flux. Significant rain-driven landslides have occurred in Farwell Canyon at least twice during Sockeye migration (August 19th, 1964 and August 29th, 2004),[57] [58] creating temporarily impassable and/or hazardous conditions for fish passage, potentially introducing short-term[59] and long-term effects.[60] [61] Evidently, the terrestrial instability

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[57] On August 29, 2004 [at 10:30 am], a landslide occurred near Riske Creek about 15 km upstream of the junction of the Chilcotin and Fraser rivers. The mudslide in Farwell Canyon temporarily blocked the Chilcotin River [just downstream of the old Farwell Canyon trestle bridge crossing]. The water level rose to 20 m [by 9 pm]. *Overnight August 29-30, the water pooling behind the natural dam in the river, which was made up mostly of sand and silt, worked its way around it*. *Floodwaters undercut the banks in some areas, leaving them unstable. Debris that washed into the Fraser River posed a potential hazard to fishing gear and boats from Lillooet to Hope*. The Farwell Canyon bridge remained closed for several days to allow crews to remove debris. *Fisheries officials believe that up to 80% of summer Sockeye salmon in the Chilcotin River escaped the effects of the mudslide. The bulk of the run had already passed when the slide dammed the river*. [Note: the multi-year TT50% is roughly September 2nd at Henry’s Bridge (corresponding to first arrivals in mid-August, as was the case in 2004), suggesting peak migration in the lower Chilcotin around ~August 20th. Thus it is possible that just less than half of the Chilko run was still downstream at the time of the slide.]

On August 19, 1964, a similar slide happened at the same Farwell Canyon location. Source: BC MFLNRO Water Mgmt Branch – Public Safety Information August 2004.

[58] In 2004, the slide occurred near the outlet of Farwell Canyon, damming flows to a depth of 20 meters at the Farwell Road bridge trestle before the debris dam broke 12 hours later. See: 2004 Farwell Slide photos: http://jnblog.typepad.com/provocations/2004/08/farwell_canyon_.html

[59] Although direct impacts to the 2004 Chilko Sockeye spawning escapement were considered minimal by officials, it should be noted that the 2004 record of visual counts at Henry’s Bridge exhibited a one-week gap characterized by near-zero migration following the slide, ended with the lowest total visual counts (6,583 fish) of any year of comparable counting effort (Table 3, Appendix K), and one of the lowest total escapement estimates (92,143 fish) since the weak cycle line which ended in 1989 (Appendix A).

[60] Furthermore, total Chilko escapements of ~250,000 fish in 2008 and 2012 (and a preliminary estimate of 180,000 in 2016 [source: Tsilhqo’tin Fisheries]) were below the minimum (366,000) and

surrounding Farwell Canyon can result in episodic changes to lower Chilcotin River channel morphology: modifying depth, cross-sectional area, and water velocity at the site, rendering pre- and post-event hydrometrics discontinuous[62]. Also evidently, in terms of safe fish passage, these episodes may be positive (as in 1948-1955) or negative (as in 2004). The point is that, without monitoring, the direction of impact on fish passage may not be immediately obvious.

A comprehensive hydrological assessment (e.g. Richter et al. 1996) to statistically characterize seasonal and inter-annual hydrologic variation in Farwell Canyon (and updated as appropriate after future slides) would advance existing knowledge and provide further insight into the cumulative environmental impacts facing Chilko Sockeye migrants. These data would also be useful in conjunction with tag-based field studies designed to assess current hydrological impacts on migrant salmonids, and supplement cost-benefit analyses of the utility of restoring the Farwell Canyon fishway to facilitate fish passage in this dynamic watershed.

CONCLUSIONS

The goal of the WILD SALMON POLICY (WSP) is “to restore and maintain healthy salmon populations and their habitats for the benefit and enjoyment of the people of Canada in perpetuity” (Fisheries and Oceans Canada 2005). However, two weak Sockeye populations in the Chilko/Chilcotin watershed have been identified (Holtby and Ciruna 2007) for which monitoring methods are currently insufficient for scientific assessment and identification of benchmarks of biological or population status (Grant et al. 2011; Toth and Tung 2013a), and a third Sockeye population, though relatively abundant, is also of concern due to recent significant declines (ibid). As with other Fraser Sockeye stocks, exact reasons for these production declines are elusive but likely associated with human impacts (fisheries, development) overlaid with the cumulative effects of climate change acting across freshwater and marine life history stages, including adult migration and spawning (Campbell et al. 2014).

In the Chilcotin watershed, historic research coupled with more recent monitoring indicates that high discharge levels in August have the potential to disrupt and delay Sockeye migrants and possibly other anadromous fish at the Farwell Canyon velocity barrier. The level of impact on fish survival and reproductive success on the three Sockeye stocks in the Chilcotin is unknown, but is likely to be affecting the minor stocks of concern disproportionately, based on their early timing of arrival. In

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less than half the average abundance (585,000) of this cycle line between 1976 and 2000 (Appendix A), suggesting a potential new ‘weak cycle line’ initiated in 2004. A similar pattern may be observed in total Taseko escapement for this cycle line since 2004 (Appendix B).

[61] It must also be noted that Fraser River conditions in 2004 were characterized by low flows and record high temperatures of 21.5°C at Hell’s Gate between August 17th – 23rd which were estimated to have caused 50% fish mortality (Williams 2005). Therefore it is not possible to attribute low Chilko escapement estimates to conditions in the lower Chilcotin alone.

[62] The Babine River Slide (1951) also altered site hydrometrics (Godfrey et al. 1954).

addition, flow impacts on migrant stocks in the Chilcotin system are likely accentuated after periods of high water temperatures in the mainstem of the Fraser River (Salinger and Anderson 2006).

Based on the coarse alignment of fish migration data and environmental conditions in this study, it may be concluded that, once the fish have accomplished the Fraser River portion of their upstream journey, high Chilcotin River flows extending into the month of August present the largest environmental challenge to adult Sockeye migrants. The direct and indirect biological impacts of energetically-demanding high-flow reaches in the Chilcotin River, requiring burst-speed swimming efforts and resulting in energy-depleting delays, invites further study as climate change projections point to increases in the frequency and duration of high flow events in near future decades.

Since an increase in the frequency and duration of elevated water temperatures and persistent high flow events is consistent with anticipated climate change in this watershed, threatening fish productivity and biological diversity, it is recommended that fisheries authorities (DFO in collaboration with TNG Fisheries) comprehensively identify and assess the level of impacts for adaptation response planning (e.g. enhanced harvest management and environmental monitoring to maintain sustainable fisheries) and mitigation to control risk of extirpation of stocks at risk (Campbell et al. 2014) in keeping with WILD SALMON POLICY.

RECOMMENDATIONS

Statistical Re-Analysis

Review and improve statistical analyses between Chilcotin migration and environmental factors:

- Chilko salmon migrate a great distance and are therefore exposed to multiple physical and biological stressors, besides extreme temperatures and flows, affecting *en route* survival, including: fisheries, pathogens, predators, and pollution. A quantitative multi-variable assessment of the cumulative effects of interacting stressors on fish survival would provide a rigorous and potentially more realistic representation of the factors influencing migration success (Johnson et al. 2012).[63]
- Subjective review of anomalies based on results of the non-parametric CMH-GA analysis here provide one simple test of association between categories of migration rate and environmental factors, but does not explicitly address additive versus synergistic or antagonistic interactions amongst the factors. Other techniques, such as geographically-weighted regression allow model

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[63] For example, quantile regression (QR) provides a useful extension to regression techniques, that estimates the median response and other quantiles instead of the mean. Estimating multiple regression quantiles can reveal distinct rates of change between predictor and response variables, therefore providing a more realistic (nonlinear) relationship between fish migration success and ecological stressors or limiting factors (Johnston et al. 2012).

parameters to vary spatially (Johnson et al. 2012), and could be used to model the effects of stressors by sequential location (e.g. weighting the water temperature effect in the Fraser portion, and weighting the discharge effect in the Chilcotin portion of the migration route). See Johnson et al. (2012) for parametric and non-parametric multi-variable techniques for data re-analysis.

Environmental Impact Assessment - Field Studies

Re-assess biological impacts of high flow events at Farwell Canyon in the lower Chilcotin on all Sockeye stocks using current technology:

- Hydrological Surveys: Complete a comprehensive stream survey throughout the canyon area to document the longitudinal channel profile, bank-full channel widths, wetted widths and water velocity at various stage heights to determine the locations of potential velocity barriers at various water levels. The burst swim speed of Sockeye (approximately 2 m/s; Hinch et al. 2002), might serve as a key hydrological threshold for analysis. Rating curves could be developed for each location, and statistically-related to discharge levels at CHILCOTIN RIVER AT BIG CREEK for reconstruction of the historic, current, and future time-series under various climate change scenarios. For unstable sites, specific baseline hydrological indicators can assist in post-slide assessments, and measuring progress toward conservation/restoration goals (Richter et al. 1996).
- Tag Experiments: Employ archival IBUTTON® tags on Sockeye migrants in the lower Chilcotin downstream of Farwell Canyon to obtain information on temperature exposure, fish coping behaviour, and stock-, age- and size-specific travel time to the spawning grounds.
- Bio-Sampling: Develop sampling program to characterize biological condition of Sockeye pre- and post-passage at Farwell Canyon at various discharge levels to assess impacts on energy reserves and reproductive viability.
- Utilize biological sampling to identify, to stock level, the ‘early’ run component of the escapement to determine the distribution and extent of the impact of variable discharge rates on stock-specific migration success.

Climate Risk Assessment

- Climate model downscaling should be employed to project future hydrological scenarios at key sites in the watershed (i.e. Farwell Canyon and other sites if warranted), incorporating information on temperature, precipitation, snow-pack, ice-melt and glacial recession into the hydrological model.

Cost-Benefit Analysis

- Use all of the above in a COST-BENEFIT ANALYSIS regarding restoration of the fishways at Farwell Canyon.

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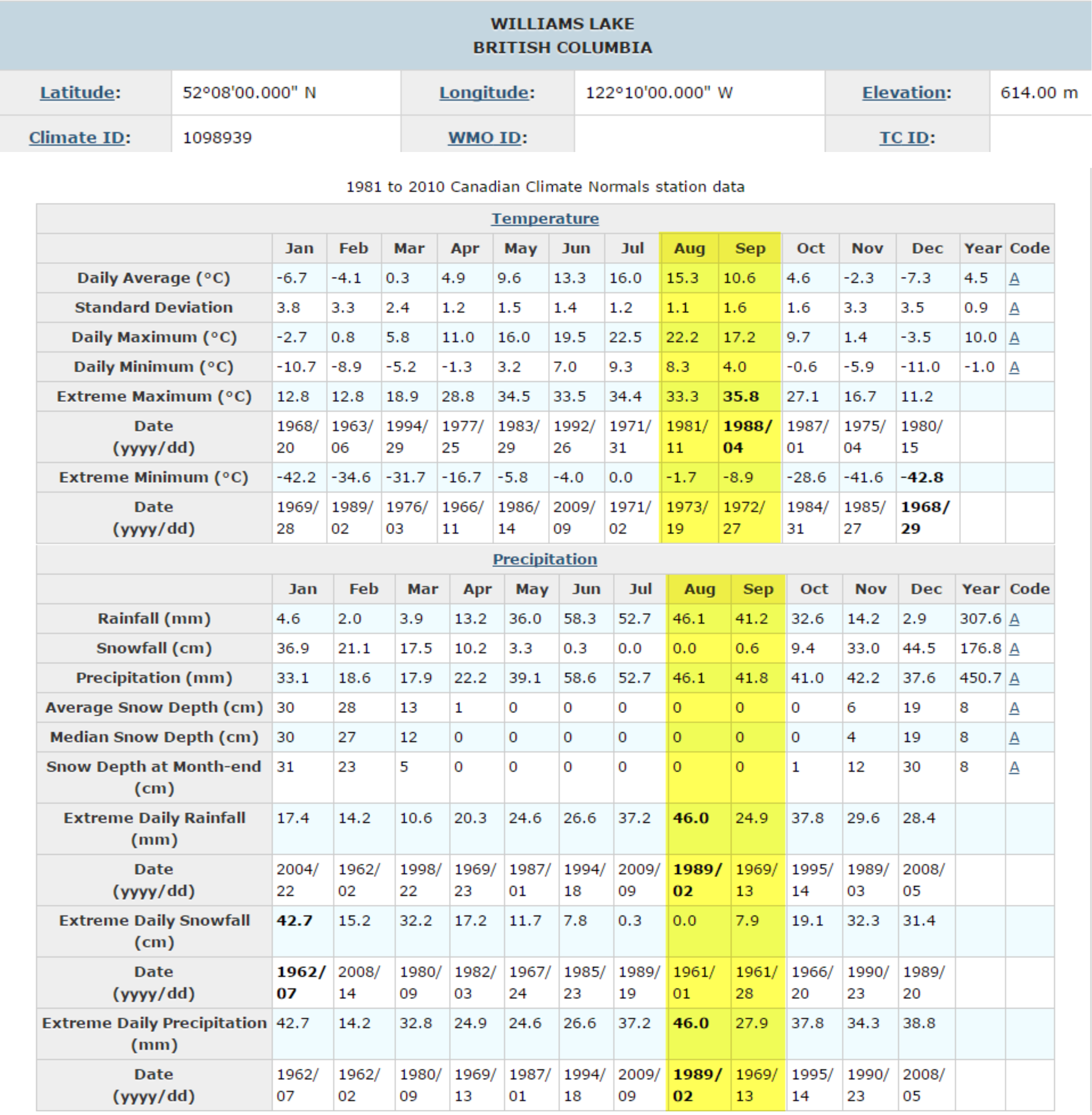


WILLIAMS LAKE
BRITISH COLUMBIA

Latitude:	52°08'00.000" N	**Longitude:**	122°10'00.000" W	**Elevation:**	614.00 m
Climate ID:	1098939	**WMO ID:**		**TC ID:**	

1981 to 2010 Canadian Climate Normals station data

Temperature

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Code
Daily Average (°C)	-6.7	-4.1	0.3	4.9	9.6	13.3	16.0	15.3	10.6	4.6	-2.3	-7.3	4.5	A
Standard Deviation	3.8	3.3	2.4	1.2	1.5	1.4	1.2	1.1	1.6	1.6	3.3	3.5	0.9	A
Daily Maximum (°C)	-2.7	0.8	5.8	11.0	16.0	19.5	22.5	22.2	17.2	9.7	1.4	-3.5	10.0	A
Daily Minimum (°C)	-10.7	-8.9	-5.2	-1.3	3.2	7.0	9.3	8.3	4.0	-0.6	-5.9	-11.0	-1.0	A
Extreme Maximum (°C)	12.8	12.8	18.9	28.8	34.5	33.5	34.4	33.3	**35.8**	27.1	16.7	11.2		
Date (yyyy/dd)	1968/20	1963/06	1994/29	1977/25	1983/29	1992/26	1971/31	1981/11	**1988/04**	1987/01	1975/04	1980/15		
Extreme Minimum (°C)	-42.2	-34.6	-31.7	-16.7	-5.8	-4.0	0.0	-1.7	-8.9	-28.6	-41.6	**-42.8**		
Date (yyyy/dd)	1969/28	1989/02	1976/03	1966/11	1986/14	2009/09	1971/02	1973/19	1972/27	1984/31	1985/27	**1968/29**		

Precipitation

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Code
Rainfall (mm)	4.6	2.0	3.9	13.2	36.0	58.3	52.7	46.1	41.2	32.6	14.2	2.9	307.6	A
Snowfall (cm)	36.9	21.1	17.5	10.2	3.3	0.3	0.0	0.0	0.6	9.4	33.0	44.5	176.8	A
Precipitation (mm)	33.1	18.6	17.9	22.2	39.1	58.6	52.7	46.1	41.8	41.0	42.2	37.6	450.7	A
Average Snow Depth (cm)	30	28	13	1	0	0	0	0	0	0	6	19	8	A
Median Snow Depth (cm)	30	27	12	0	0	0	0	0	0	0	4	19	8	A
Snow Depth at Month-end (cm)	31	23	5	0	0	0	0	0	0	1	12	30	8	A
Extreme Daily Rainfall (mm)	17.4	14.2	10.6	20.3	24.6	26.6	37.2	**46.0**	24.9	37.8	29.6	28.4		
Date (yyyy/dd)	2004/22	1962/02	1998/22	1969/23	1987/01	1994/18	2009/09	**1989/02**	1969/13	1995/14	1989/03	2008/05		
Extreme Daily Snowfall (cm)	**42.7**	15.2	32.2	17.2	11.7	7.8	0.3	0.0	7.9	19.1	32.3	31.4		
Date (yyyy/dd)	**1962/07**	2008/14	1980/09	1982/03	1967/24	1985/23	1989/19	1961/01	1961/28	1966/20	1990/23	1989/20		
Extreme Daily Precipitation (mm)	42.7	14.2	32.8	24.9	24.6	26.6	37.2	**46.0**	27.9	37.8	34.3	38.8		
Date (yyyy/dd)	1962/07	1962/02	1980/09	1969/13	1987/01	1994/18	2009/09	**1989/02**	1969/13	1995/14	1990/23	2008/05		

Table 1. WILLIAMS LAKE Climate Normals (1981-2010). Source: Environment Canada (http://climate.weather.gc.ca/climate_normals/index_e.html)

Station ID	Name	Regulated/Natural Flow	Active	Area	Period	Mean Basin Elevation	Mean Annual Discharge (MAD)	Mean Annual Runoff (MAF)	Fishflow (15% of MAF)
				km^2		m	m^3/s	$m^3/s/km^2$	m^3/s
08MA001	CHILKO RIVER NEAR REDSTONE	NATURAL	Y	6,940	1927-2005	1756	88.58	0.01	13.287
08MA002	CHILKO RIVER AT OUTLET OF CHILKO LAKE	NATURAL	Y	2,110	1928-2005	1868	42.75	0.02	6.412
08MA003	TASEKO RIVER AT OUTLET OF TASEKO LAKES	NATURAL	Y	1,520	1929-2005	2128	37.26	0.02	5.589
08MA006	LINGFIELD CREEK NEAR THE MOUTH	NATURAL	Y	98	1974-2005	1888	0.76	0.01	0.115
08MB005	CHILCOTIN RIVER BELOW BIG CREEK	NATURAL	Y	19,300	1970-2005	1528	102.14	0.01	15.320

Table 2. Hydrometric station data from the Chilko/Chilcotin watershed for January-December. (Source: BC Hydro Integrated Resource Plan - Appendix 3A-29, 2013 Resource Operations Update, Run-Of-River Report.)

	Chilko										
	Date			Sockeye Migrants			Migration Rate (%)				
	Date Count	Min Date	Max Date	Mean Daily	Max Daily	Annual Total	P50	P75	P95	Mean Daily	Max Daily
Year											
1975	33	12AUG	13SEP	1,014	6,369	33,473	1.43	3.25	10.50	3.03	19.03
1976	35	12AUG	20SEP	1,691	8,484	59,198	1.61	4.34	13.07	2.86	14.33
1977	10	19AUG	08SEP	87	162	871	12.00	15.04	18.60	10.00	18.60
1978	21	23AUG	27SEP	388	1,519	8,151	1.56	7.51	15.20	4.76	18.64
1979	29	14AUG	13SEP	658	2,198	19,071	2.57	3.47	9.71	3.45	11.53
1980	38	19AUG	25SEP	1,982	9,158	75,297	1.16	5.10	8.17	2.63	12.16
1982	31	21AUG	22SEP	784	2,516	24,302	2.46	5.25	10.27	3.23	10.35
1983	39	12AUG	25SEP	1,215	5,810	47,372	1.65	3.06	11.54	2.56	12.26
1984	63	06AUG	10OCT	1,187	6,541	74,777	0.78	2.02	6.76	1.59	8.75
1986	38	12AUG	01OCT	1,319	3,817	50,129	2.33	3.97	7.39	2.63	7.61
1987	44	09AUG	01OCT	1,284	5,673	56,475	1.94	3.34	6.12	2.27	10.05
1988	40	09AUG	18SEP	859	5,245	34,356	0.60	3.53	10.99	2.50	15.27
1989	27	23AUG	01OCT	352	2,452	9,500	0.87	6.58	12.23	3.70	25.81
1990	40	11AUG	27SEP	1,921	11,073	76,820	1.32	3.31	8.54	2.50	14.41
1991	56	15AUG	10OCT	3,041	14,522	170,284	1.57	2.62	5.29	1.79	8.53
1992	42	16AUG	29SEP	2,015	7,453	84,630	1.81	3.95	7.05	2.38	8.81
1993	46	16AUG	04OCT	1,545	8,318	71,070	0.70	3.99	7.33	2.17	11.70
1994	45	07AUG	25SEP	1,056	8,510	47,514	1.33	2.83	7.99	2.22	17.91
1995	47	06AUG	24SEP	981	6,942	46,114	0.71	2.22	10.47	2.13	15.05
1996	44	10AUG	22SEP	3,251	9,414	143,023	2.16	3.66	5.60	2.27	6.58

Table 3. Annual migration statistics for Chilko Sockeye daily migrants, 1975-2012 (filtered for non-zero observations), including migration period, mean and maximum daily migrant count, total annual escapement, and daily migration rate (%) statistics. Incomplete years omitted: 1977, 1978, 1981, 1985.

	Chilko										
	Date			Sockeye Migrants			Migration Rate (%)				
	Date Count	Min Date	Max Date	Mean Daily	Max Daily	Annual Total	P50	P75	P95	Mean Daily	Max Daily
Year											
1997	64	11AUG	14OCT	2,147	15,543	137,392	0.93	1.59	7.33	1.56	11.31
1998	60	01AUG	03OCT	1,720	7,002	103,225	0.72	3.09	5.67	1.67	6.78
1999	57	18AUG	14OCT	2,875	10,148	163,876	1.66	2.54	4.88	1.75	6.19
2000	53	08AUG	29SEP	2,797	15,464	148,219	0.39	2.54	8.13	1.89	10.43
2001	43	14AUG	25SEP	3,166	13,695	136,118	1.90	3.48	7.09	2.33	10.06
2002	46	16AUG	30SEP	1,563	5,439	71,909	1.59	3.12	6.65	2.17	7.56
2003	53	11AUG	02OCT	2,627	10,204	139,228	1.39	3.04	5.51	1.89	7.33
2004	51	15AUG	08OCT	129	904	6,583	0.68	2.35	9.63	1.96	13.73
2005	58	18AUG	14OCT	1,786	9,220	103,593	0.98	2.49	6.09	1.72	8.90
2006	51	11AUG	01OCT	1,662	5,796	84,765	1.61	2.70	5.80	1.96	6.84
2007	41	15AUG	27SEP	1,051	4,351	43,095	1.59	3.63	6.90	2.44	10.10
2008	49	09AUG	26SEP	586	2,335	28,720	1.01	3.41	6.72	2.04	8.13
2009	60	09AUG	07OCT	3,630	11,325	217,778	0.83	3.39	4.64	1.67	5.20
2010	56	08AUG	02OCT	43,982	132,941	2,462,975	1.51	2.78	4.95	1.79	5.40
2011	65	06AUG	09OCT	14,142	55,796	919,254	0.83	2.94	4.93	1.54	6.07
2012	57	06AUG	01OCT	4,326	19,671	246,602	0.58	2.94	6.79	1.75	7.98
1975-2012	1,601	12AUG	01OCT	3,833	132,941	6,136,737	1.21	3.09	7.05	2.12	25.81

Table 3 (continued). Annual migration statistics for Chilko Sockeye daily migrants, 1975-2012 (filtered for non-zero observations), including migration period, mean and maximum daily migrant count, total annual escapement, and daily migration rate (%) statistics. Incomplete years omitted: 1977, 1978, 1981, 1985.

Chilcotin at Big Creek,
08MB005,
Discharge (m3/s)

	Discharge (cms)						Percentiles					
	Dates	Min	Mean	Max	Std	Skew	P5	P10	P25	P50	P75	P95
Year												
1975	61	81.8	141.4	252.0	48.2	0.6	87.8	90.9	99.4	135.0	174.0	234.0
1976	61	141.0	254.3	493.0	113.6	0.7	142.0	144.0	149.0	197.0	365.0	453.0
1977	61	75.6	184.2	286.0	77.1	-0.0	82.7	92.0	106.0	180.0	264.0	281.0
1978	61	73.1	174.8	306.0	78.1	0.4	77.9	80.4	113.0	152.0	245.0	297.0
1979	61	120.0	184.8	229.0	34.8	-0.4	132.0	138.0	146.0	192.0	217.0	225.0
1980	61	92.1	161.9	243.0	52.1	0.3	97.0	101.0	122.0	141.0	217.0	237.0
1981	61	90.5	207.8	349.0	75.3	0.2	102.0	123.0	145.0	176.0	285.0	308.0
1982	61	125.0	189.1	336.0	53.2	1.2	131.0	135.0	148.0	178.0	207.0	311.0
1983	61	66.1	148.4	230.0	52.6	-0.1	74.6	75.8	92.6	155.0	194.0	224.0
1984	61	79.2	155.1	245.0	59.4	0.3	81.7	86.3	102.0	144.0	206.0	244.0
1985	61	61.8	152.6	266.0	62.2	0.1	65.2	70.6	94.4	159.0	197.0	253.0
1986	61	73.0	173.3	243.0	55.6	-0.7	77.9	85.8	120.0	194.0	214.0	239.0
1987	61	86.6	159.2	245.0	45.6	0.2	97.5	99.8	136.0	149.0	211.0	229.0
1988	61	72.5	165.7	242.0	49.2	-0.4	78.9	84.9	132.0	169.0	202.0	236.0
1989	61	93.2	178.7	253.0	51.3	-0.4	93.7	96.4	138.0	192.0	220.0	243.0
1990	61	109.0	187.5	285.0	62.4	0.3	116.0	119.0	136.0	155.0	252.0	278.0
1991	61	131.0	297.5	487.0	115.1	0.0	133.0	144.0	180.0	313.0	376.0	471.0
1992	61	80.8	183.2	323.0	77.8	0.2	82.7	87.7	103.0	175.0	251.0	314.0
1993	61	75.1	164.6	232.0	45.5	-0.5	78.8	91.3	139.0	165.0	199.0	226.0

(Continued)

Table 4. Discharge statistics for observed WSC station data from the lower CHILCOTIN RIVER AT BIG CREEK, during the peak adult Sockeye migration period, August-September 1975-2012.

Chilcotin at Big Creek,
08MB005,
Discharge (m3/s)

	Discharge (cms)						Percentiles					
	Dates	Min	Mean	Max	Std	Skew	P5	P10	P25	P50	P75	P95
Year												
1994	61	113.0	178.1	268.0	54.9	0.3	115.0	120.0	126.0	158.0	232.0	262.0
1995	61	95.6	152.2	241.0	43.3	0.8	105.0	112.0	121.0	132.0	188.0	231.0
1996	61	99.2	189.8	313.0	54.3	0.1	101.0	112.0	152.0	187.0	228.0	284.0
1997	61	92.3	163.8	224.0	44.6	-0.2	96.5	101.0	124.0	167.0	205.0	221.0
1998	61	101.0	201.0	361.0	65.6	0.6	114.0	121.0	149.0	190.0	248.0	322.0
1999	61	109.0	251.3	401.0	97.0	0.0	123.0	135.0	145.0	266.0	335.0	396.0
2000	61	104.0	168.6	279.0	58.4	0.9	107.0	110.0	124.0	150.0	201.0	276.0
2001	61	107.0	164.9	258.0	46.4	0.1	109.0	110.0	115.0	168.0	203.0	239.0
2002	61	87.5	161.3	250.0	41.9	-0.2	95.4	98.9	123.0	177.0	193.0	214.0
2003	61	80.7	172.3	252.0	54.3	-0.4	83.9	86.8	122.0	178.0	220.0	243.0
2004	61	96.8	194.8	256.0	51.0	-0.7	102.0	112.0	157.0	214.0	236.0	251.0
2005	61	88.2	166.8	255.0	48.9	-0.0	89.8	97.9	126.0	170.0	208.0	238.0
2006	61	82.8	136.4	229.0	34.5	0.3	85.1	87.1	115.0	138.0	156.0	191.0
2007	61	84.9	165.1	295.0	55.5	0.7	90.8	100.0	127.0	157.0	181.0	266.0
2008	61	72.3	140.8	208.0	37.1	-0.1	83.3	93.3	109.0	152.0	171.0	193.0
2009	61	127.0	190.4	298.0	47.6	0.8	130.0	138.0	161.0	175.0	215.0	293.0
2010	61	89.3	181.8	296.0	71.2	0.2	94.8	98.5	114.0	176.0	248.0	289.0
2011	61	119.0	204.1	292.0	48.2	-0.0	133.0	148.0	155.0	208.0	247.0	270.0
2012	61	95.7	184.2	330.0	79.9	0.4	96.8	100.0	106.0	157.0	246.0	317.0
All	2318	61.8	179.8	493.0	69.0	1.0	89.2	99.4	127.0	170.0	221.0	298.0

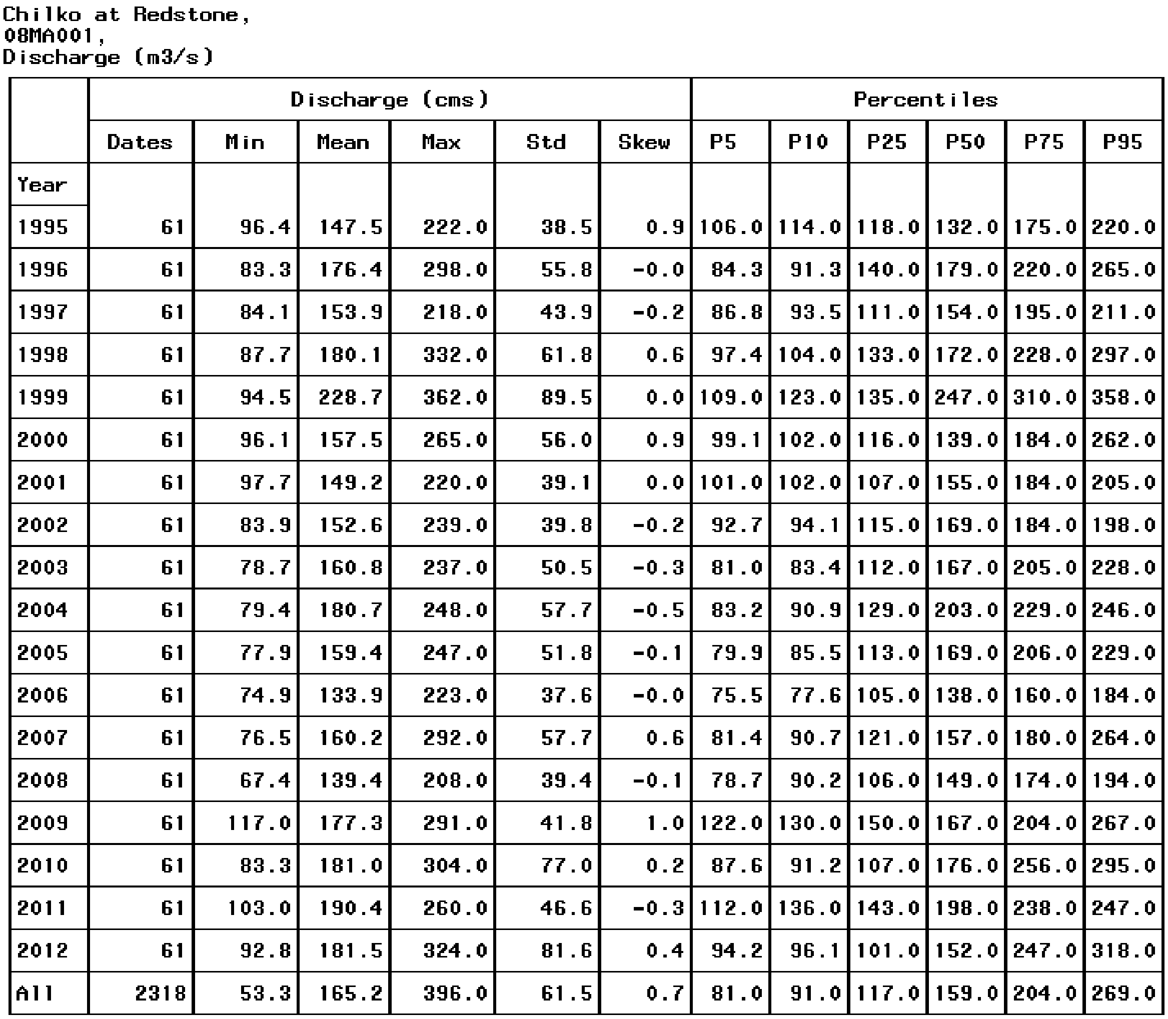
Table 4 (continued). Discharge statistics for observed WSC station data from the lower CHILCOTIN RIVER AT BIG CREEK, during the peak adult Sockeye migration period, August-September 1975-2012.

Chilko at Redstone,
08MA001,
Discharge (m3/s)

	Discharge (cms)						Percentiles					
	Dates	Min	Mean	Max	Std	Skew	P5	P10	P25	P50	P75	P95
Year												
1975	61	74.5	125.4	224.0	41.1	0.7	79.0	83.3	91.5	117.0	153.0	206.0
1976	61	104.0	206.2	396.0	94.2	0.7	105.0	108.0	133.0	168.0	294.0	385.0
1977	61	60.6	166.5	265.0	75.1	-0.0	65.7	74.2	93.7	159.0	247.0	261.0
1978	61	62.0	154.6	277.0	72.3	0.4	65.1	69.1	96.6	134.0	217.0	269.0
1979	61	105.0	163.0	201.0	31.1	-0.4	115.0	121.0	128.0	168.0	192.0	199.0
1980	61	81.0	136.9	199.0	42.6	0.2	84.0	87.0	102.0	119.0	180.0	196.0
1981	61	80.7	181.4	279.0	61.5	0.1	88.9	107.0	132.0	157.0	243.0	266.0
1982	61	103.0	165.9	280.0	44.2	1.0	115.0	118.0	128.0	155.0	183.0	262.0
1983	61	57.4	139.4	217.0	51.8	-0.2	63.7	67.2	83.4	149.0	182.0	211.0
1984	61	70.2	143.4	229.0	55.8	0.3	72.7	75.6	92.6	137.0	190.0	226.0
1985	61	53.3	135.9	246.0	58.2	0.2	55.1	59.8	83.0	140.0	179.0	236.0
1986	61	60.5	157.8	223.0	52.6	-0.7	65.3	73.3	108.0	178.0	196.0	220.0
1987	61	81.0	146.1	225.0	40.6	0.3	92.0	94.0	128.0	135.0	191.0	209.0
1988	61	68.6	158.9	227.0	46.8	-0.5	73.5	79.6	128.0	168.0	193.0	219.0
1989	61	87.9	164.0	225.0	45.9	-0.3	88.8	91.0	131.0	175.0	203.0	224.0
1990	61	102.0	175.2	265.0	59.1	0.3	108.0	110.0	125.0	145.0	240.0	260.0
1991	61	125.0	250.9	388.0	83.5	0.0	126.0	134.0	168.0	262.0	316.0	378.0
1992	61	82.3	163.7	268.0	60.7	0.2	83.7	87.3	100.0	162.0	221.0	259.0
1993	61	70.2	159.7	222.0	45.9	-0.6	71.9	85.1	133.0	167.0	196.0	219.0
1994	61	109.0	173.6	258.0	52.9	0.3	112.0	116.0	122.0	158.0	228.0	252.0

(Continued)

Table 5. Discharge statistics for observed WSC station data from the lower CHILKO RIVER AT REDSTONE, during the peak adult Sockeye migration period, August-September 1975-2012.



Chilko at Redstone,
08MA001,
Discharge (m3/s)

	Discharge (cms)						Percentiles					
	Dates	Min	Mean	Max	Std	Skew	P5	P10	P25	P50	P75	P95
Year												
1995	61	96.4	147.5	222.0	38.5	0.9	106.0	114.0	118.0	132.0	175.0	220.0
1996	61	83.3	176.4	298.0	55.8	-0.0	84.3	91.3	140.0	179.0	220.0	265.0
1997	61	84.1	153.9	218.0	43.9	-0.2	86.8	93.5	111.0	154.0	195.0	211.0
1998	61	87.7	180.1	332.0	61.8	0.6	97.4	104.0	133.0	172.0	228.0	297.0
1999	61	94.5	228.7	362.0	89.5	0.0	109.0	123.0	135.0	247.0	310.0	358.0
2000	61	96.1	157.5	265.0	56.0	0.9	99.1	102.0	116.0	139.0	184.0	262.0
2001	61	97.7	149.2	220.0	39.1	0.0	101.0	102.0	107.0	155.0	184.0	205.0
2002	61	83.9	152.6	239.0	39.8	-0.2	92.7	94.1	115.0	169.0	184.0	198.0
2003	61	78.7	160.8	237.0	50.5	-0.3	81.0	83.4	112.0	167.0	205.0	228.0
2004	61	79.4	180.7	248.0	57.7	-0.5	83.2	90.9	129.0	203.0	229.0	246.0
2005	61	77.9	159.4	247.0	51.8	-0.1	79.9	85.5	113.0	169.0	206.0	229.0
2006	61	74.9	133.9	223.0	37.6	-0.0	75.5	77.6	105.0	138.0	160.0	184.0
2007	61	76.5	160.2	292.0	57.7	0.6	81.4	90.7	121.0	157.0	180.0	264.0
2008	61	67.4	139.4	208.0	39.4	-0.1	78.7	90.2	106.0	149.0	174.0	194.0
2009	61	117.0	177.3	291.0	41.8	1.0	122.0	130.0	150.0	167.0	204.0	267.0
2010	61	83.3	181.0	304.0	77.0	0.2	87.6	91.2	107.0	176.0	256.0	295.0
2011	61	103.0	190.4	260.0	46.6	-0.3	112.0	136.0	143.0	198.0	238.0	247.0
2012	61	92.8	181.5	324.0	81.6	0.4	94.2	96.1	101.0	152.0	247.0	318.0
All	2318	53.3	165.2	396.0	61.5	0.7	81.0	91.0	117.0	159.0	204.0	269.0

Table 5 (continued). Discharge statistics for observed WSC station data from the lower CHILKO RIVER AT REDSTONE, during the peak adult Sockeye migration period, August-September 1975-2012.

Chilko at Chilko Lake,
08MA002,
Discharge (m3/s)

	Discharge (cms)						Percentiles					
	Dates	Min	Mean	Max	Std	Skew	P5	P10	P25	P50	P75	P95
Year												
1975	61	37.9	68.3	118.0	23.7	0.5	39.9	42.2	48.1	64.6	83.8	113.0
1976	61	67.1	112.3	180.0	39.4	0.4	67.7	68.8	73.3	96.0	150.0	176.0
1977	61	38.2	85.9	128.0	30.3	-0.2	39.9	44.5	55.8	91.2	115.0	123.0
1978	61	39.4	81.8	134.0	31.6	0.2	40.8	42.8	55.8	75.3	110.0	129.0
1979	61	59.5	82.0	95.0	10.9	-0.6	63.9	65.1	72.7	85.8	91.5	93.5
1980	61	47.3	75.1	102.0	18.9	0.1	48.7	52.2	58.1	72.2	94.7	99.7
1981	61	50.2	92.4	126.0	26.7	-0.1	53.4	57.6	67.5	90.9	122.0	125.0
1982	61	58.4	83.7	131.0	19.2	1.0	63.1	64.8	69.6	77.8	92.3	124.0
1983	61	34.8	68.7	93.7	19.4	-0.3	37.4	42.0	50.5	71.9	88.1	92.1
1984	61	43.7	75.7	108.0	23.2	0.1	45.7	48.2	52.4	74.8	101.0	106.0
1985	61	33.5	66.0	108.0	22.1	0.3	35.0	37.0	48.5	62.0	84.4	105.0
1986	61	38.9	81.6	107.0	21.2	-0.7	42.7	48.2	64.1	87.7	101.0	106.0
1987	61	46.4	77.0	117.0	20.0	0.3	48.5	51.2	66.1	72.7	96.9	108.0
1988	61	44.6	81.4	110.0	18.8	-0.4	48.5	50.1	68.3	83.3	97.2	107.0
1989	61	45.9	79.5	102.0	17.3	-0.6	48.6	51.7	66.9	88.1	93.8	98.1
1990	61	50.0	85.1	121.0	25.2	0.1	53.1	55.3	62.7	83.1	110.0	121.0
1991	61	67.4	126.6	170.0	34.1	-0.5	69.7	75.4	90.4	141.0	154.0	169.0
1992	61	41.8	82.1	129.0	28.7	0.1	44.9	46.0	51.7	81.8	109.0	126.0
1993	61	44.5	77.2	101.0	15.2	-0.8	46.4	53.3	68.7	80.7	88.8	94.4

(Continued)

Table 6. Discharge statistics for observed WSC station data from the upper CHILKO RIVER AT CHILKO LAKE, during the peak adult Sockeye migration period, August-September 1975-2012.

Chilko at Chilko Lake,
08MA002,
Discharge (m3/s)

	Discharge (cms)						Percentiles					
	Dates	Min	Mean	Max	Std	Skew	P5	P10	P25	P50	P75	P95
Year												
1994	61	59.4	90.3	131.0	25.2	0.2	60.2	60.8	65.2	86.0	116.0	128.0
1995	61	49.9	78.3	121.0	23.3	0.7	53.9	56.6	60.8	65.0	97.5	119.0
1996	61	47.7	96.2	143.0	25.3	-0.4	52.5	55.8	78.7	99.2	117.0	131.0
1997	61	51.4	82.9	109.0	19.8	-0.3	53.8	55.1	64.2	84.3	102.0	106.0
1998	61	52.0	98.5	154.0	30.3	0.3	56.0	59.2	71.9	92.6	127.0	150.0
1999	61	56.7	129.1	188.0	43.0	-0.2	65.9	72.1	85.0	143.0	164.0	184.0
2000	61	51.2	85.0	134.0	28.5	0.6	52.7	54.8	59.0	77.8	110.0	133.0
2001	61	50.4	79.5	113.0	19.4	-0.0	54.5	54.9	58.4	83.3	96.1	110.0
2002	61	46.9	82.2	122.0	19.4	-0.1	51.6	53.6	66.5	87.7	95.0	113.0
2003	61	47.1	87.3	119.0	22.1	-0.5	48.1	52.5	68.4	90.3	106.0	115.0
2004	61	49.4	94.8	122.0	21.4	-0.9	53.0	59.0	78.5	105.0	110.0	119.0
2005	61	44.9	83.0	119.0	24.0	-0.2	46.2	48.2	60.3	90.0	104.0	117.0
2006	61	42.1	71.3	118.0	20.1	0.4	42.2	45.7	53.5	68.1	85.6	104.0
2007	61	44.7	92.1	163.0	33.4	0.5	48.0	52.6	66.7	88.4	113.0	151.0
2008	61	39.5	72.8	96.1	18.3	-0.3	43.6	48.1	55.6	77.9	89.0	95.4
2009	61	63.6	91.7	128.0	20.1	0.5	68.4	69.1	75.5	84.1	107.0	125.0
2010	61	48.8	92.3	143.0	33.2	0.2	50.5	51.2	61.6	87.0	126.0	141.0
2011	61	67.8	105.4	139.0	21.1	-0.1	72.3	78.1	87.0	106.0	122.0	135.0
2012	61	50.9	95.9	161.0	36.9	0.3	51.8	52.8	58.9	88.2	128.0	150.0
All	2318	33.5	86.6	188.0	28.8	0.7	47.2	51.8	64.0	85.0	104.0	140.0

Table 6 (continued). Discharge statistics for observed WSC station data from the upper CHILKO RIVER AT CHILKO LAKE, during the peak adult Sockeye migration period, August-September 1975-2012.

Chilko at Redstone,
08MA001,
Discharge (m3/s)

	Discharge (cms)						Percentiles					
	Dates	Min	Mean	Max	Std	Skew	P5	P10	P25	P50	P75	P95
Year												
1975	61	74.5	125.4	224.0	41.1	0.7	79.0	83.3	91.5	117.0	153.0	206.0
1976	61	104.0	206.2	396.0	94.2	0.7	105.0	108.0	133.0	168.0	294.0	385.0
1977	61	60.6	166.5	265.0	75.1	-0.0	65.7	74.2	93.7	159.0	247.0	261.0
1978	61	62.0	154.6	277.0	72.3	0.4	65.1	69.1	96.6	134.0	217.0	269.0
1979	61	105.0	163.0	201.0	31.1	-0.4	115.0	121.0	128.0	168.0	192.0	199.0
1980	61	81.0	136.9	199.0	42.6	0.2	84.0	87.0	102.0	119.0	180.0	196.0
1981	61	80.7	181.4	279.0	61.5	0.1	88.9	107.0	132.0	157.0	243.0	266.0
1982	61	103.0	165.9	280.0	44.2	1.0	115.0	118.0	128.0	155.0	183.0	262.0
1983	61	57.4	139.4	217.0	51.8	-0.2	63.7	67.2	83.4	149.0	182.0	211.0
1984	61	70.2	143.4	229.0	55.8	0.3	72.7	75.6	92.6	137.0	190.0	226.0
1985	61	53.3	135.9	246.0	58.2	0.2	55.1	59.8	83.0	140.0	179.0	236.0
1986	61	60.5	157.8	223.0	52.6	-0.7	65.3	73.3	108.0	178.0	196.0	220.0
1987	61	81.0	146.1	225.0	40.6	0.3	92.0	94.0	128.0	135.0	191.0	209.0
1988	61	68.6	158.9	227.0	46.8	-0.5	73.5	79.6	128.0	168.0	193.0	219.0
1989	61	87.9	164.0	225.0	45.9	-0.3	88.8	91.0	131.0	175.0	203.0	224.0
1990	61	102.0	175.2	265.0	59.1	0.3	108.0	110.0	125.0	145.0	240.0	260.0
1991	61	125.0	250.9	388.0	83.5	0.0	126.0	134.0	168.0	262.0	316.0	378.0
1992	61	82.3	163.7	268.0	60.7	0.2	83.7	87.3	100.0	162.0	221.0	259.0
1993	61	70.2	159.7	222.0	45.9	-0.6	71.9	85.1	133.0	167.0	196.0	219.0

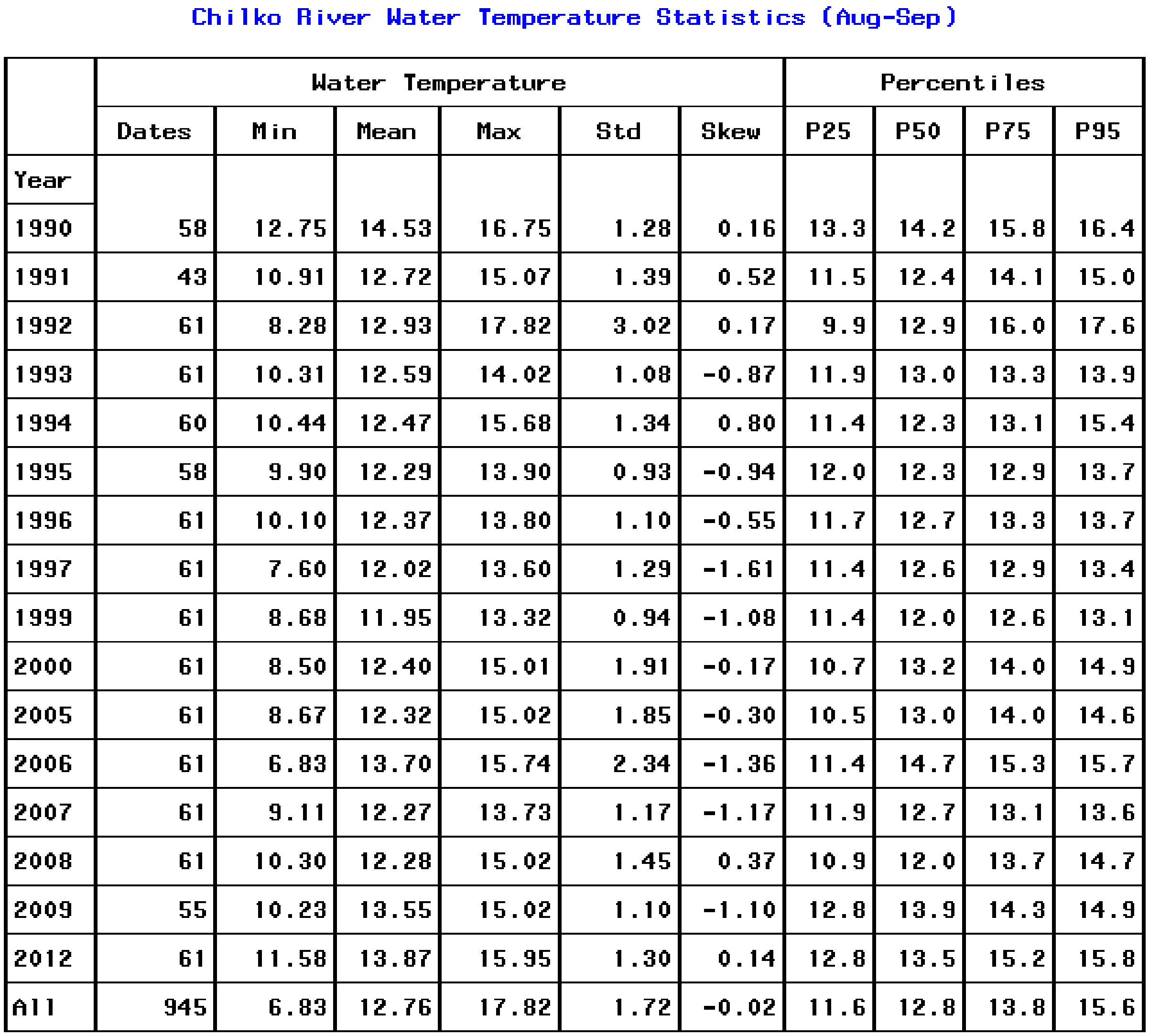
(Continued)

Table 7. Discharge statistics for observed WSC station data from the lower Chilko River at Redstone (confluence with the Chilcotin River), during the peak adult Sockeye migration period, August-September 1975-2012.

Chilko at Redstone,
08MA001,
Discharge (m3/s)

	Discharge (cms)						Percentiles					
	Dates	Min	Mean	Max	Std	Skew	P5	P10	P25	P50	P75	P95
Year												
1994	61	109.0	173.6	258.0	52.9	0.3	112.0	116.0	122.0	158.0	228.0	252.0
1995	61	96.4	147.5	222.0	38.5	0.9	106.0	114.0	118.0	132.0	175.0	220.0
1996	61	83.3	176.4	298.0	55.8	-0.0	84.3	91.3	140.0	179.0	220.0	265.0
1997	61	84.1	153.9	218.0	43.9	-0.2	86.8	93.5	111.0	154.0	195.0	211.0
1998	61	87.7	180.1	332.0	61.8	0.6	97.4	104.0	133.0	172.0	228.0	297.0
1999	61	94.5	228.7	362.0	89.5	0.0	109.0	123.0	135.0	247.0	310.0	358.0
2000	61	96.1	157.5	265.0	56.0	0.9	99.1	102.0	116.0	139.0	184.0	262.0
2001	61	97.7	149.2	220.0	39.1	0.0	101.0	102.0	107.0	155.0	184.0	205.0
2002	61	83.9	152.6	239.0	39.8	-0.2	92.7	94.1	115.0	169.0	184.0	198.0
2003	61	78.7	160.8	237.0	50.5	-0.3	81.0	83.4	112.0	167.0	205.0	228.0
2004	61	79.4	180.7	248.0	57.7	-0.5	83.2	90.9	129.0	203.0	229.0	246.0
2005	61	77.9	159.4	247.0	51.8	-0.1	79.9	85.5	113.0	169.0	206.0	229.0
2006	61	74.9	133.9	223.0	37.6	-0.0	75.5	77.6	105.0	138.0	160.0	184.0
2007	61	76.5	160.2	292.0	57.7	0.6	81.4	90.7	121.0	157.0	180.0	264.0
2008	61	67.4	139.4	208.0	39.4	-0.1	78.7	90.2	106.0	149.0	174.0	194.0
2009	61	117.0	177.3	291.0	41.8	1.0	122.0	130.0	150.0	167.0	204.0	267.0
2010	61	83.3	181.0	304.0	77.0	0.2	87.6	91.2	107.0	176.0	256.0	295.0
2011	61	103.0	190.4	260.0	46.6	-0.3	112.0	136.0	143.0	198.0	238.0	247.0
2012	61	92.8	181.5	324.0	81.6	0.4	94.2	96.1	101.0	152.0	247.0	318.0
All	2318	53.3	165.2	396.0	61.5	0.7	81.0	91.0	117.0	159.0	204.0	269.0

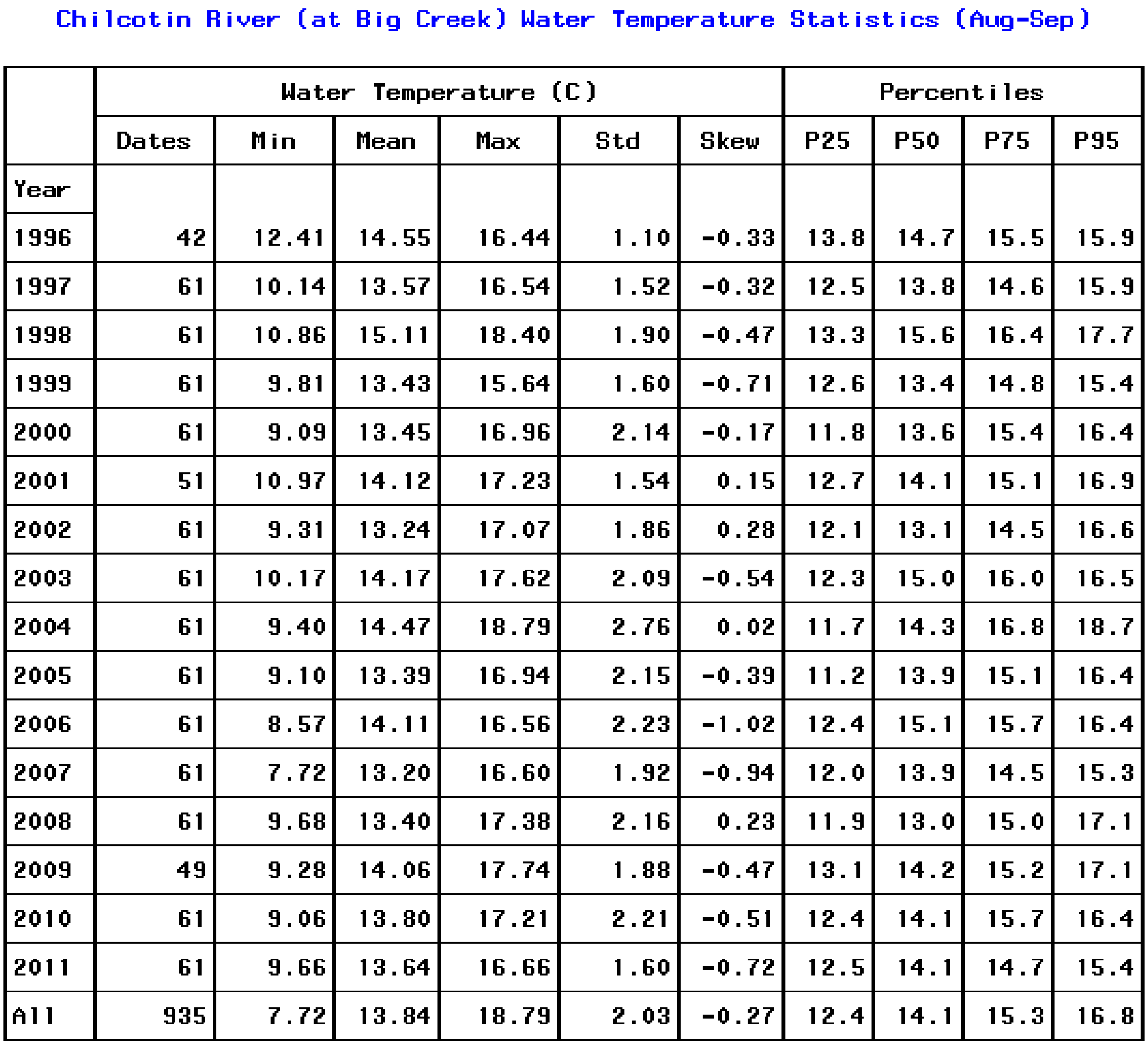
Table 7(continued). Discharge statistics for observed WSC station data from the lower Chilko River at Redstone (confluence with the Chilcotin River), during the peak adult Sockeye migration period, August-September 1975-2012.



Chilko River Water Temperature Statistics (Aug-Sep)

	Water Temperature						Percentiles			
	Dates	Min	Mean	Max	Std	Skew	P25	P50	P75	P95
Year										
1990	58	12.75	14.53	16.75	1.28	0.16	13.3	14.2	15.8	16.4
1991	43	10.91	12.72	15.07	1.39	0.52	11.5	12.4	14.1	15.0
1992	61	8.28	12.93	17.82	3.02	0.17	9.9	12.9	16.0	17.6
1993	61	10.31	12.59	14.02	1.08	-0.87	11.9	13.0	13.3	13.9
1994	60	10.44	12.47	15.68	1.34	0.80	11.4	12.3	13.1	15.4
1995	58	9.90	12.29	13.90	0.93	-0.94	12.0	12.3	12.9	13.7
1996	61	10.10	12.37	13.80	1.10	-0.55	11.7	12.7	13.3	13.7
1997	61	7.60	12.02	13.60	1.29	-1.61	11.4	12.6	12.9	13.4
1999	61	8.68	11.95	13.32	0.94	-1.08	11.4	12.0	12.6	13.1
2000	61	8.50	12.40	15.01	1.91	-0.17	10.7	13.2	14.0	14.9
2005	61	8.67	12.32	15.02	1.85	-0.30	10.5	13.0	14.0	14.6
2006	61	6.83	13.70	15.74	2.34	-1.36	11.4	14.7	15.3	15.7
2007	61	9.11	12.27	13.73	1.17	-1.17	11.9	12.7	13.1	13.6
2008	61	10.30	12.28	15.02	1.45	0.37	10.9	12.0	13.7	14.7
2009	55	10.23	13.55	15.02	1.10	-1.10	12.8	13.9	14.3	14.9
2012	61	11.58	13.87	15.95	1.30	0.14	12.8	13.5	15.2	15.8
All	945	6.83	12.76	17.82	1.72	-0.02	11.6	12.8	13.8	15.6

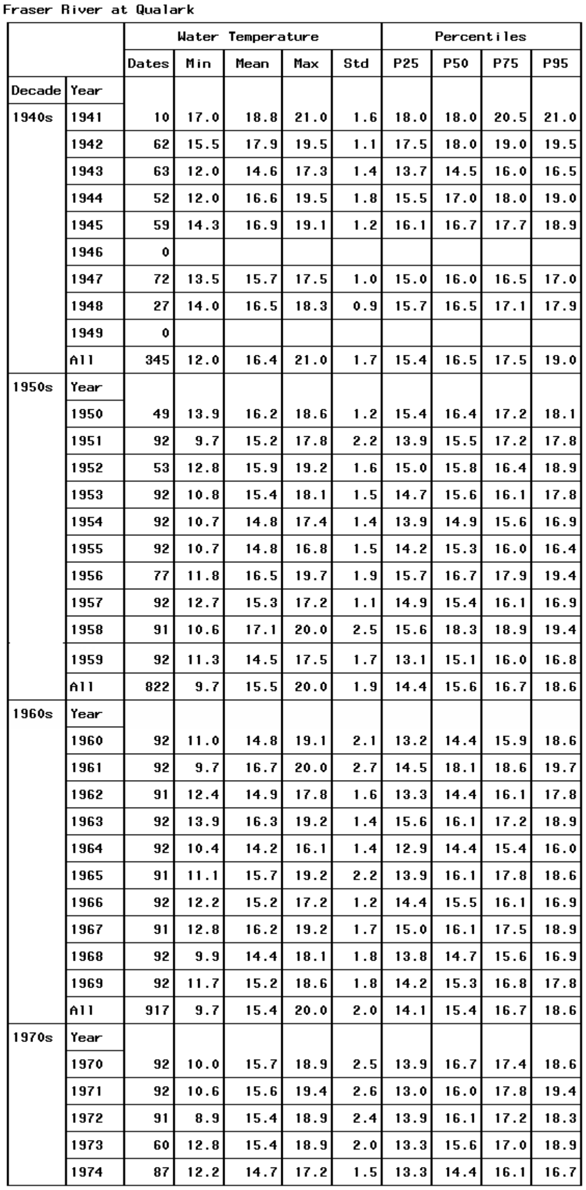
Table 8. Statistical summary of observed and estimated daily water temperature data for CHILKO RIVER (DFO CAMP) during Sockeye migration (August-September) (Source: DFO ENVIRONMENTAL WATCH PROGRAM). All statistics are derived from daily mean temperatures from *N* annual dates. For example, *MIN* and *MAX* are the minimum and maximum of the daily mean temperature estimates, and therefore are not the observed extremes.



Chilcotin River (at Big Creek) Water Temperature Statistics (Aug-Sep)

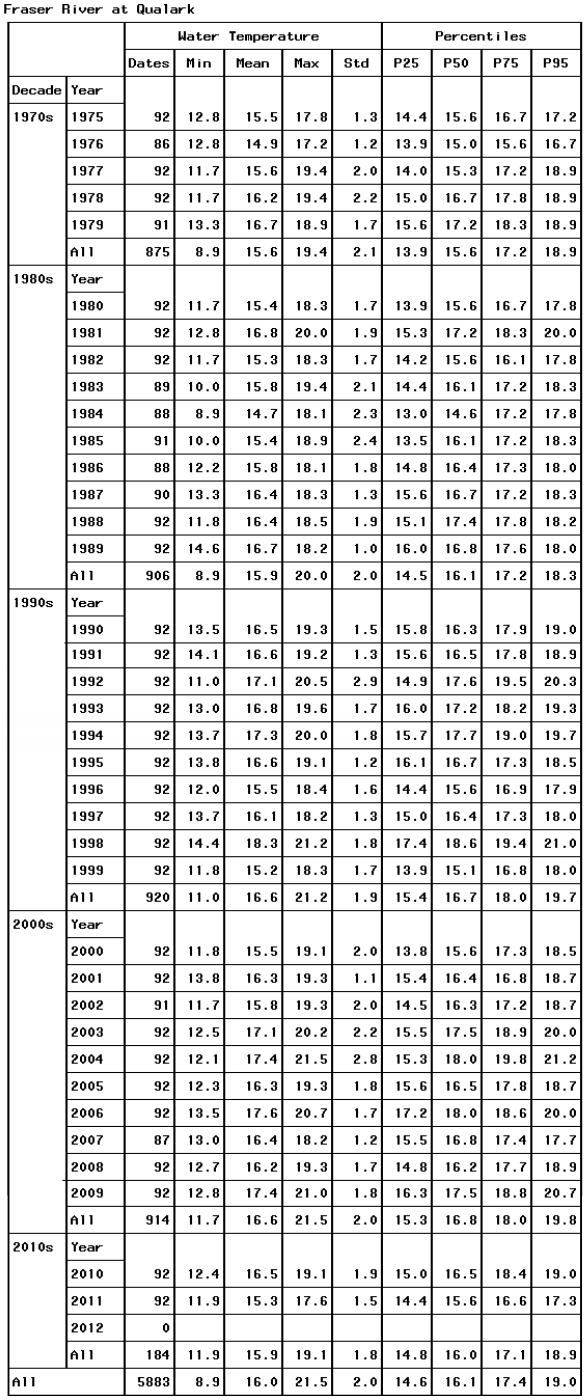
	Water Temperature (C)						Percentiles			
	Dates	Min	Mean	Max	Std	Skew	P25	P50	P75	P95
Year										
1996	42	12.41	14.55	16.44	1.10	-0.33	13.8	14.7	15.5	15.9
1997	61	10.14	13.57	16.54	1.52	-0.32	12.5	13.8	14.6	15.9
1998	61	10.86	15.11	18.40	1.90	-0.47	13.3	15.6	16.4	17.7
1999	61	9.81	13.43	15.64	1.60	-0.71	12.6	13.4	14.8	15.4
2000	61	9.09	13.45	16.96	2.14	-0.17	11.8	13.6	15.4	16.4
2001	51	10.97	14.12	17.23	1.54	0.15	12.7	14.1	15.1	16.9
2002	61	9.31	13.24	17.07	1.86	0.28	12.1	13.1	14.5	16.6
2003	61	10.17	14.17	17.62	2.09	-0.54	12.3	15.0	16.0	16.5
2004	61	9.40	14.47	18.79	2.76	0.02	11.7	14.3	16.8	18.7
2005	61	9.10	13.39	16.94	2.15	-0.39	11.2	13.9	15.1	16.4
2006	61	8.57	14.11	16.56	2.23	-1.02	12.4	15.1	15.7	16.4
2007	61	7.72	13.20	16.60	1.92	-0.94	12.0	13.9	14.5	15.3
2008	61	9.68	13.40	17.38	2.16	0.23	11.9	13.0	15.0	17.1
2009	49	9.28	14.06	17.74	1.88	-0.47	13.1	14.2	15.2	17.1
2010	61	9.06	13.80	17.21	2.21	-0.51	12.4	14.1	15.7	16.4
2011	61	9.66	13.64	16.66	1.60	-0.72	12.5	14.1	14.7	15.4
All	935	7.72	13.84	18.79	2.03	-0.27	12.4	14.1	15.3	16.8

Table 9. Statistical summary of observed and estimated daily water temperature data for CHILCOTIN RIVER AT BIG CREEK during Sockeye migration (August-September) (Source: DFO ENVIRONMENTAL WATCH PROGRAM). All statistics are derived from daily mean temperatures from *N* annual dates. For example, *MIN* and *MAX* are the minimum and maximum of the daily mean temperature estimates, and therefore are not the observed extremes.



Fraser River at Qualark

		Water Temperature					Percentiles			
		Dates	Min	Mean	Max	Std	P25	P50	P75	P95
Decade	Year									
1940s	1941	10	17.0	18.8	21.0	1.6	18.0	18.0	20.5	21.0
	1942	62	15.5	17.9	19.5	1.1	17.5	18.0	19.0	19.5
	1943	63	12.0	14.6	17.3	1.4	13.7	14.5	16.0	16.5
	1944	52	12.0	16.6	19.5	1.8	15.5	17.0	18.0	19.0
	1945	59	14.3	16.9	19.1	1.2	16.1	16.7	17.7	18.9
	1946	0								
	1947	72	13.5	15.7	17.5	1.0	15.0	16.0	16.5	17.0
	1948	27	14.0	16.5	18.3	0.9	15.7	16.5	17.1	17.9
	1949	0								
	All	345	12.0	16.4	21.0	1.7	15.4	16.5	17.5	19.0
1950s	Year									
	1950	49	13.9	16.2	18.6	1.2	15.4	16.4	17.2	18.1
	1951	92	9.7	15.2	17.8	2.2	13.9	15.5	17.2	17.8
	1952	53	12.8	15.9	19.2	1.6	15.0	15.8	16.4	18.9
	1953	92	10.8	15.4	18.1	1.5	14.7	15.6	16.1	17.8
	1954	92	10.7	14.8	17.4	1.4	13.9	14.9	15.6	16.9
	1955	92	10.7	14.8	16.8	1.5	14.2	15.3	16.0	16.4
	1956	77	11.8	16.5	19.7	1.9	15.7	16.7	17.9	19.4
	1957	92	12.7	15.3	17.2	1.1	14.9	15.4	16.1	16.9
	1958	91	10.6	17.1	20.0	2.5	15.6	18.3	18.9	19.4
	1959	92	11.3	14.5	17.5	1.7	13.1	15.1	16.0	16.8
	All	822	9.7	15.5	20.0	1.9	14.4	15.6	16.7	18.6
1960s	Year									
	1960	92	11.0	14.8	19.1	2.1	13.2	14.4	15.9	18.6
	1961	92	9.7	16.7	20.0	2.7	14.5	18.1	18.6	19.7
	1962	91	12.4	14.9	17.8	1.6	13.3	14.4	16.1	17.8
	1963	92	13.9	16.3	19.2	1.4	15.6	16.1	17.2	18.9
	1964	92	10.4	14.2	16.1	1.4	12.9	14.4	15.4	16.0
	1965	91	11.1	15.7	19.2	2.2	13.9	16.1	17.8	18.6
	1966	92	12.2	15.2	17.2	1.2	14.4	15.5	16.1	16.9
	1967	91	12.8	16.2	19.2	1.7	15.0	16.1	17.5	18.9
	1968	92	9.9	14.4	18.1	1.8	13.8	14.7	15.6	16.9
	1969	92	11.7	15.2	18.6	1.8	14.2	15.3	16.8	17.8
	All	917	9.7	15.4	20.0	2.0	14.1	15.4	16.7	18.6
1970s	Year									
	1970	92	10.0	15.7	18.9	2.5	13.9	16.7	17.4	18.6
	1971	92	10.6	15.6	19.4	2.6	13.0	16.0	17.8	19.4
	1972	91	8.9	15.4	18.9	2.4	13.9	16.1	17.2	18.3
	1973	60	12.8	15.4	18.9	2.0	13.3	15.6	17.0	18.9
	1974	87	12.2	14.7	17.2	1.5	13.3	14.4	16.1	16.7



Fraser River at Qualark

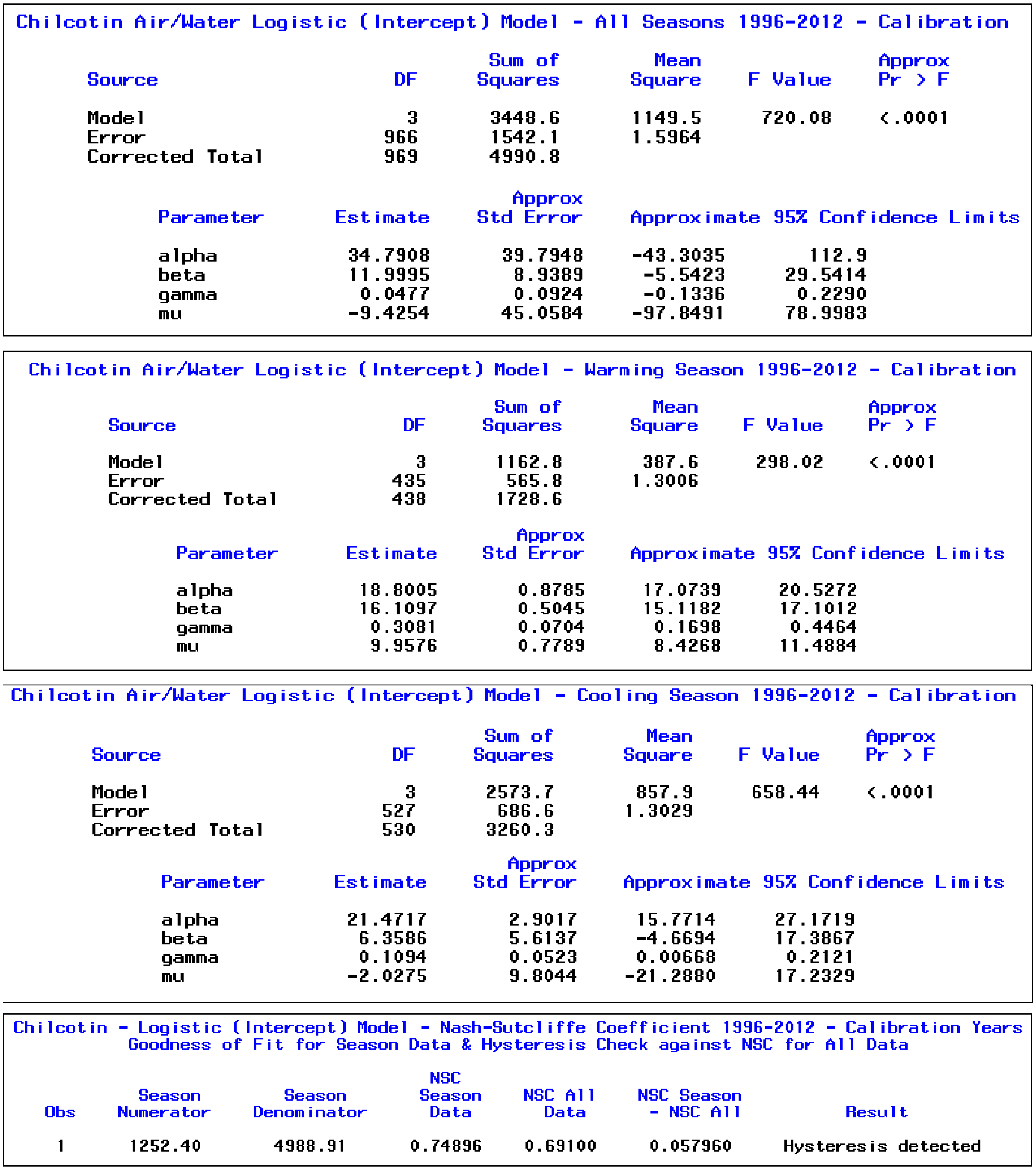
		Water Temperature					Percentiles			
		Dates	Min	Mean	Max	Std	P25	P50	P75	P95
Decade	Year									
1970s	1975	92	12.8	15.5	17.8	1.3	14.4	15.6	16.7	17.2
	1976	86	12.8	14.9	17.2	1.2	13.9	15.0	15.6	16.7
	1977	92	11.7	15.6	19.4	2.0	14.0	15.3	17.2	18.9
	1978	92	11.7	16.2	19.4	2.2	15.0	16.7	17.8	18.9
	1979	91	13.3	16.7	18.9	1.7	15.6	17.2	18.3	18.9
	All	875	8.9	15.6	19.4	2.1	13.9	15.6	17.2	18.9
1980s	Year									
	1980	92	11.7	15.4	18.3	1.7	13.9	15.6	16.7	17.8
	1981	92	12.8	16.8	20.0	1.9	15.3	17.2	18.3	20.0
	1982	92	11.7	15.3	18.3	1.7	14.2	15.6	16.1	17.8
	1983	89	10.0	15.8	19.4	2.1	14.4	16.1	17.2	18.3
	1984	88	8.9	14.7	18.1	2.3	13.0	14.6	17.2	17.8
	1985	91	10.0	15.4	18.9	2.4	13.5	16.1	17.2	18.3
	1986	88	12.2	15.8	18.1	1.8	14.8	16.4	17.3	18.0
	1987	90	13.3	16.4	18.3	1.3	15.6	16.7	17.2	18.3
	1988	92	11.8	16.4	18.5	1.9	15.1	17.4	17.8	18.2
	1989	92	14.6	16.7	18.2	1.0	16.0	16.8	17.6	18.0
	All	906	8.9	15.9	20.0	2.0	14.5	16.1	17.2	18.3
1990s	Year									
	1990	92	13.5	16.5	19.3	1.5	15.8	16.3	17.9	19.0
	1991	92	14.1	16.6	19.2	1.3	15.6	16.5	17.8	18.9
	1992	92	11.0	17.1	20.5	2.9	14.9	17.6	19.5	20.3
	1993	92	13.0	16.8	19.6	1.7	16.0	17.2	18.2	19.3
	1994	92	13.7	17.3	20.0	1.8	15.7	17.7	19.0	19.7
	1995	92	13.8	16.6	19.1	1.2	16.1	16.7	17.3	18.5
	1996	92	12.0	15.5	18.4	1.6	14.4	15.6	16.9	17.9
	1997	92	13.7	16.1	18.2	1.3	15.0	16.4	17.3	18.0
	1998	92	14.4	18.3	21.2	1.8	17.4	18.6	19.4	21.0
	1999	92	11.8	15.2	18.3	1.7	13.9	15.1	16.8	18.0
	All	920	11.0	16.6	21.2	1.9	15.4	16.7	18.0	19.7
2000s	Year									
	2000	92	11.8	15.5	19.1	2.0	13.8	15.6	17.3	18.5
	2001	92	13.8	16.3	19.3	1.1	15.4	16.4	16.8	18.7
	2002	91	11.7	15.8	19.3	2.0	14.5	16.3	17.2	18.7
	2003	92	12.5	17.1	20.2	2.2	15.5	17.5	18.9	20.0
	2004	92	12.1	17.4	21.5	2.8	15.3	18.0	19.8	21.2
	2005	92	12.3	16.3	19.3	1.8	15.6	16.5	17.8	18.7
	2006	92	13.5	17.6	20.7	1.7	17.2	18.0	18.6	20.0
	2007	87	13.0	16.4	18.2	1.2	15.5	16.8	17.4	17.7
	2008	92	12.7	16.2	19.3	1.7	14.8	16.2	17.7	18.9
	2009	92	12.8	17.4	21.0	1.8	16.3	17.5	18.8	20.7
	All	914	11.7	16.6	21.5	2.0	15.3	16.8	18.0	19.8
2010s	Year									
	2010	92	12.4	16.5	19.1	1.9	15.0	16.5	18.4	19.0
	2011	92	11.9	15.3	17.6	1.5	14.4	15.6	16.6	17.3
	2012	0								
	All	184	11.9	15.9	19.1	1.8	14.8	16.0	17.1	18.9
All		5883	8.9	16.0	21.5	2.0	14.6	16.1	17.4	19.0

Table 10. Statistical summary of observed and estimated daily water temperature data for FRASER RIVER AT QUALARK during Sockeye migration (July-September) (Source: DFO ENVIRONMENTAL WATCH PROGRAM). All statistics are derived from daily mean temperatures from *N* annual dates. For example, *MIN* and *MAX* are the minimum and maximum of the daily mean temperature estimates, and therefore are not the observed extremes.

------------------------- Site=Chilcotin -------------------------

	Calibration		Validation	
	Warming	Cooling	Warming	Cooling
	Observations	Observations	Observations	Observations
Year				
1996			45	45
1997	59	70		
1998	59	70		
1999			59	68
2000	58	70		
2001	59	53		
2002	59	70		
2003			59	70
2004	27	70		
2005			59	70
2006	59	70		
2007			59	63
2008			58	70
2009	59	58		
2010			6	70
2011			59	70
2012			30	0

Table 11. Number of annual water temperature observations available for WILLIAMS LAKE / CHILCOTIN RIVER air/water temperature analyses, partitioned into warming and cooling seasons at August 2nd 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.



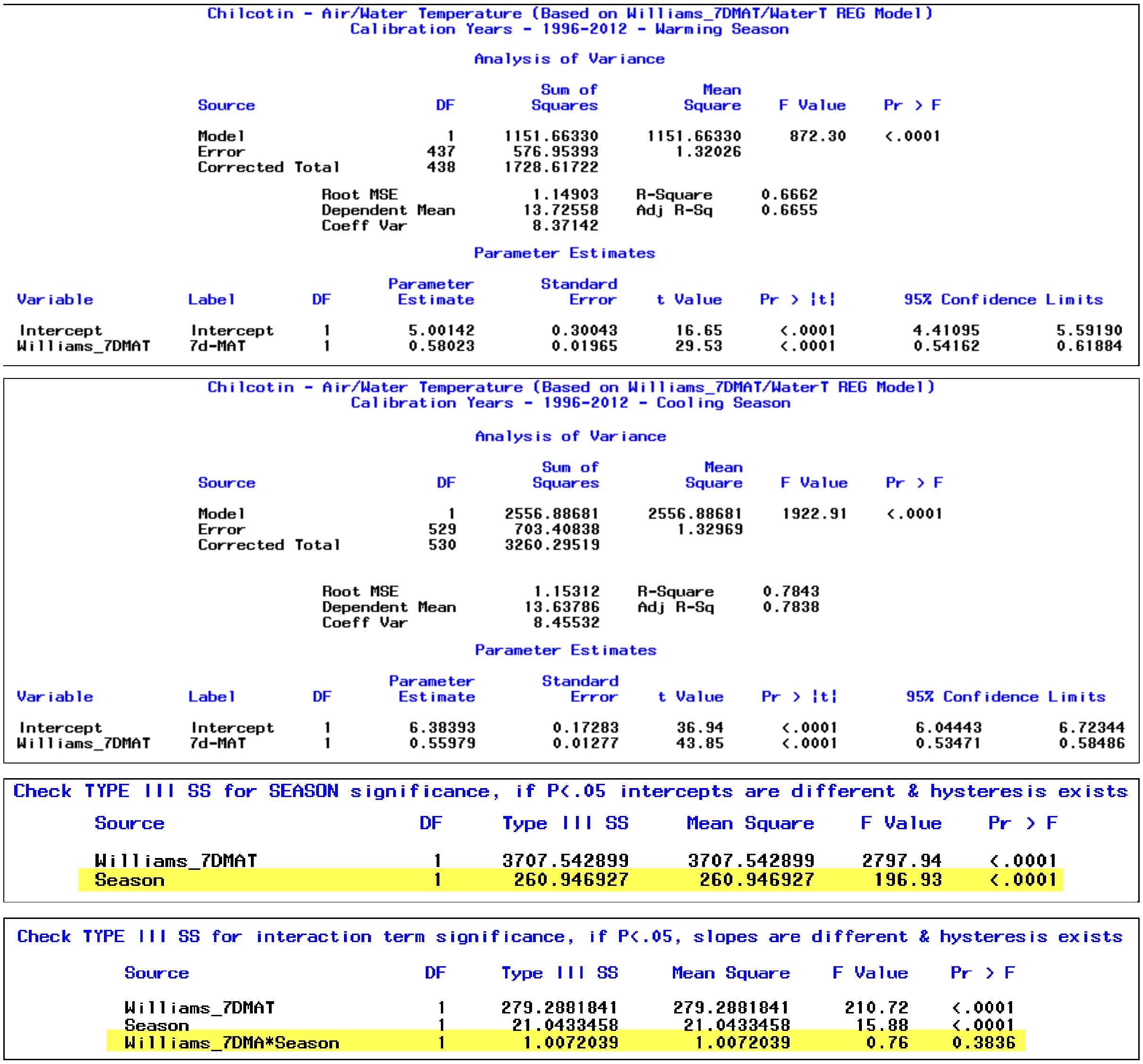
```
Chilcotin Air/Water Logistic (Intercept) Model - All Seasons 1996-2012 - Calibration

                                          Sum of        Mean                 Approx
     Source                   DF         Squares       Square     F Value    Pr > F

     Model                     3          3448.6       1149.5      720.08    <.0001
     Error                   966          1542.1       1.5964
     Corrected Total         969          4990.8

                                              Approx
          Parameter       Estimate         Std Error     Approximate 95% Confidence Limits

          alpha            34.7908           39.7948      -43.3035        112.9
          beta             11.9995            8.9389       -5.5423      29.5414
          gamma             0.0477            0.0924       -0.1336       0.2290
          mu               -9.4254           45.0584      -97.8491      78.9983
```

```
Chilcotin Air/Water Logistic (Intercept) Model - Warming Season 1996-2012 - Calibration

                                          Sum of        Mean                 Approx
     Source                   DF         Squares       Square     F Value    Pr > F

     Model                     3          1162.8        387.6      298.02    <.0001
     Error                   435           565.8       1.3006
     Corrected Total         438          1728.6

                                              Approx
          Parameter       Estimate         Std Error     Approximate 95% Confidence Limits

          alpha            18.8005            0.8785       17.0739      20.5272
          beta             16.1097            0.5045       15.1182      17.1012
          gamma             0.3081            0.0704        0.1698       0.4464
          mu                9.9576            0.7789        8.4268      11.4884
```

```
Chilcotin Air/Water Logistic (Intercept) Model - Cooling Season 1996-2012 - Calibration

                                          Sum of        Mean                 Approx
     Source                   DF         Squares       Square     F Value    Pr > F

     Model                     3          2573.7        857.9      658.44    <.0001
     Error                   527           686.6       1.3029
     Corrected Total         530          3260.3

                                              Approx
          Parameter       Estimate         Std Error     Approximate 95% Confidence Limits

          alpha            21.4717            2.9017       15.7714      27.1719
          beta              6.3586            5.6137       -4.6694      17.3867
          gamma             0.1094            0.0523       0.00668       0.2121
          mu               -2.0275            9.8044      -21.2880      17.2329
```

```
Chilcotin - Logistic (Intercept) Model - Nash-Sutcliffe Coefficient 1996-2012 - Calibration Years
        Goodness of Fit for Season Data & Hysteresis Check against NSC for All Data

                                             NSC
             Season         Season          Season    NSC All    NSC Season
   Obs     Numerator      Denominator        Data       Data     - NSC All          Result

    1       1252.40         4988.91        0.74896    0.69100     0.057960     Hysteresis detected
```

Table 12. Logistic regression output for air/water temperature relationship between the WILLIAMS LAKE 7d-CMAT (air temperature index) and calibration data for lower CHILCOTIN RIVER (BIG CREEK) daily mean water temperatures: seasons combined (top); warming season (middle); cooling season (bottom). Hysteresis was detected ($NSC_{seasonal} – NSC_{all}$ = 0.06).



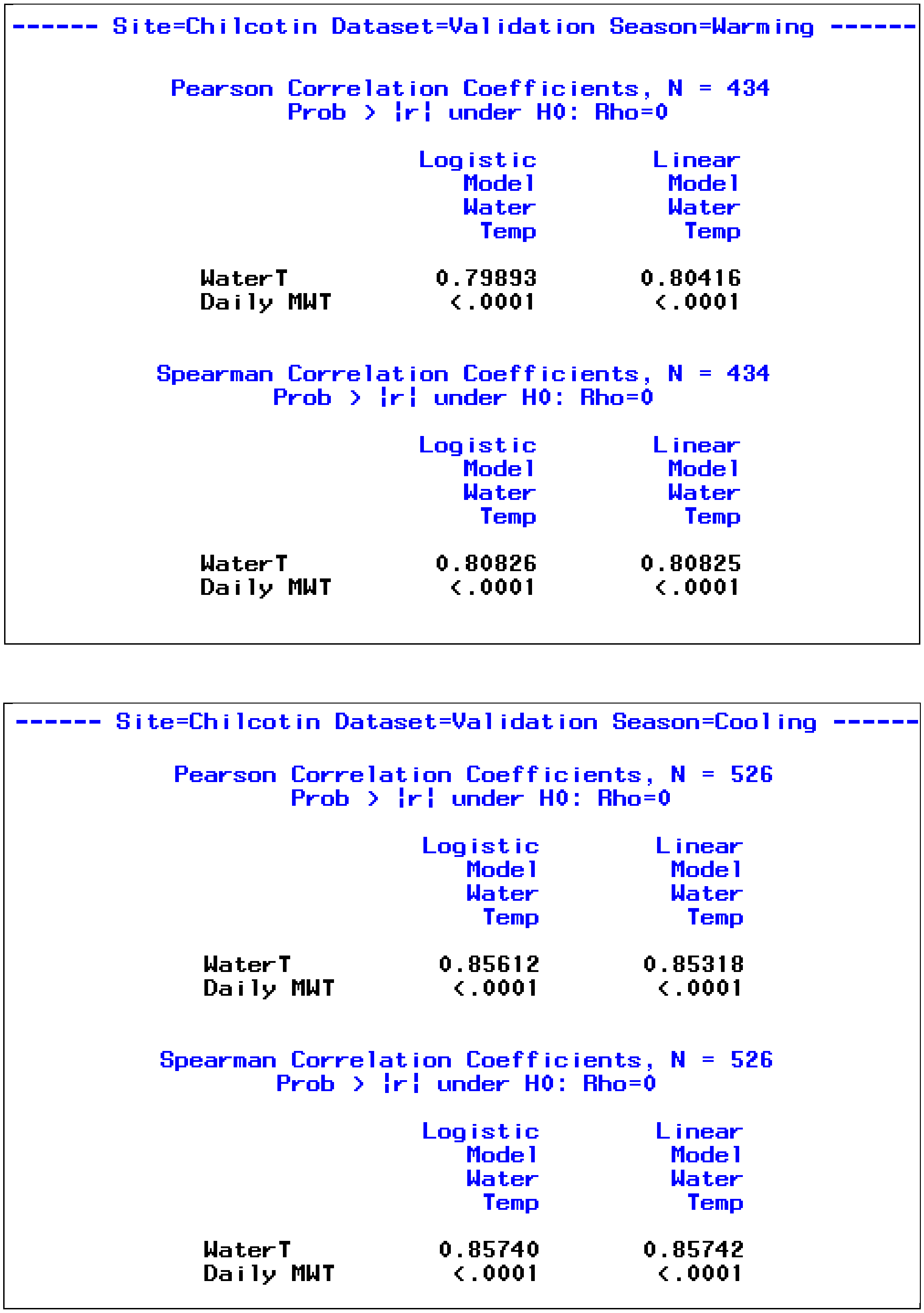
```
       Chilcotin - Air/Water Temperature (Based on Williams_7DMAT/WaterT REG Model)
                   Calibration Years - 1996-2012 - Warming Season

                               Analysis of Variance

                                          Sum of           Mean
              Source              DF     Squares         Square    F Value    Pr > F

              Model                1  1151.66330     1151.66330     872.30    <.0001
              Error              437   576.95393        1.32026
              Corrected Total    438  1728.61722

                       Root MSE              1.14903    R-Square     0.6662
                       Dependent Mean       13.72558    Adj R-Sq     0.6655
                       Coeff Var             8.37142

                               Parameter Estimates

                                 Parameter       Standard
Variable        Label       DF    Estimate          Error    t Value    Pr > |t|      95% Confidence Limits

Intercept       Intercept    1     5.00142        0.30043      16.65      <.0001      4.41095        5.59190
Williams_7DMAT  7d-MAT       1     0.58023        0.01965      29.53      <.0001      0.54162        0.61884
```

```
       Chilcotin - Air/Water Temperature (Based on Williams_7DMAT/WaterT REG Model)
                   Calibration Years - 1996-2012 - Cooling Season

                               Analysis of Variance

                                          Sum of           Mean
              Source              DF     Squares         Square    F Value    Pr > F

              Model                1  2556.88681     2556.88681    1922.91    <.0001
              Error              529   703.40838        1.32969
              Corrected Total    530  3260.29519


                       Root MSE              1.15312    R-Square     0.7843
                       Dependent Mean       13.63786    Adj R-Sq     0.7838
                       Coeff Var             8.45532

                               Parameter Estimates

                                 Parameter       Standard
Variable        Label       DF    Estimate          Error    t Value    Pr > |t|      95% Confidence Limits

Intercept       Intercept    1     6.38393        0.17283      36.94      <.0001      6.04443        6.72344
Williams_7DMAT  7d-MAT       1     0.55979        0.01277      43.85      <.0001      0.53471        0.58486
```

```
Check TYPE III SS for SEASON significance, if P<.05 intercepts are different & hysteresis exists
       Source                  DF    Type III SS    Mean Square    F Value    Pr > F

       Williams_7DMAT           1    3707.542899    3707.542899    2797.94    <.0001
       Season                   1     260.946927     260.946927     196.93    <.0001
```

```
Check TYPE III SS for interaction term significance, if P<.05, slopes are different & hysteresis exists

         Source                  DF   Type III SS    Mean Square    F Value    Pr > F

         Williams_7DMAT           1   279.2881841    279.2881841     210.72    <.0001
         Season                   1    21.0433458     21.0433458      15.88    <.0001
         Williams_7DMA*Season     1     1.0072039      1.0072039       0.76    0.3836
```

Table 13. Linear regression output for air/water temperature relationship between the Williams Lake 7d-CMAT (air temperature index) and calibration data for Chilcotin River (at Big Creek) daily mean water temperatures: warming season (top); cooling season (middle). Type III sum of squares for season interaction effect (test for equal slopes) was not significant (P = 0.38), but season effect (test for equal intercepts) and was highly significant, indicating hysteresis.



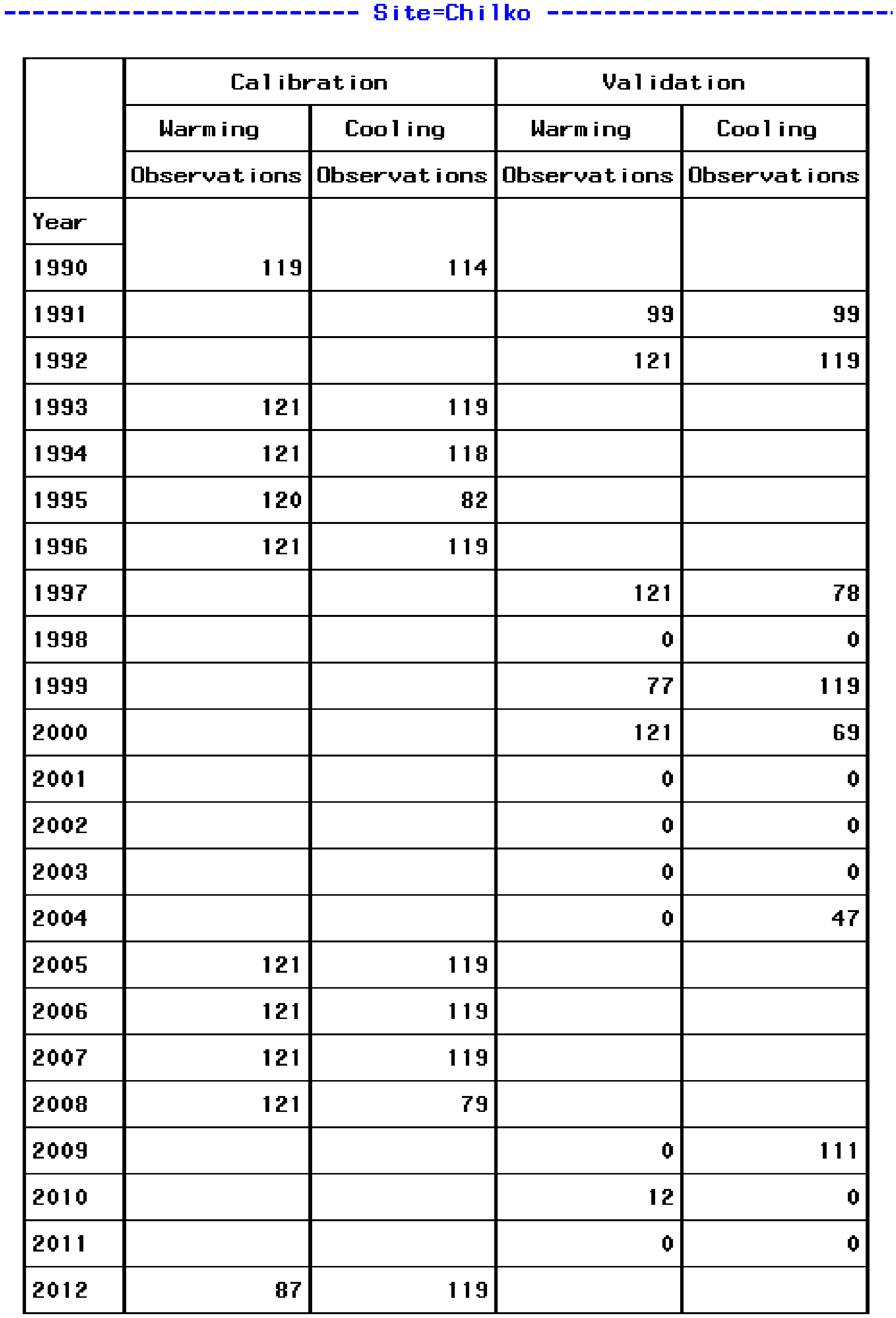
```
------ Site=Chilcotin Dataset=Validation Season=Warming ------

          Pearson Correlation Coefficients, N = 434
                  Prob > |r| under H0: Rho=0

                            Logistic          Linear
                               Model           Model
                               Water           Water
                                Temp            Temp

             WaterT          0.79893         0.80416
             Daily MWT        <.0001          <.0001

          Spearman Correlation Coefficients, N = 434
                  Prob > |r| under H0: Rho=0

                            Logistic          Linear
                               Model           Model
                               Water           Water
                                Temp            Temp

             WaterT          0.80826         0.80825
             Daily MWT        <.0001          <.0001
```

```
------ Site=Chilcotin Dataset=Validation Season=Cooling ------

          Pearson Correlation Coefficients, N = 526
                  Prob > |r| under H0: Rho=0

                            Logistic          Linear
                               Model           Model
                               Water           Water
                                Temp            Temp

             WaterT          0.85612         0.85318
             Daily MWT        <.0001          <.0001

          Spearman Correlation Coefficients, N = 526
                  Prob > |r| under H0: Rho=0

                            Logistic          Linear
                               Model           Model
                               Water           Water
                                Temp            Temp

             WaterT          0.85740         0.85742
             Daily MWT        <.0001          <.0001
```

Table 14. Comparison of Pearson (least squares) and Spearman (rank) correlation coefficients for observed (WaterT) versus estimated (from logistic and linear models) CHILCOTIN RIVER daily mean water temperature for validation data years: warming season (top); cooling season (bottom).

		Air Temp						Water Temp (Modeled)					Water Temp (Obs'd + Est'd)					
		N	Min	P10	Med	P95	Max	Min	P10	Med	P95	Max	N	Min	P10	Med	P95	Max
Decade	Month																	
1940s	8	278	7.9	11.7	14.9	18.4	20.9	12.0	13.6	14.8	16.1	16.7	0					
	9	270	1.5	5.7	11.0	15.1	18.1	8.7	10.2	12.5	14.6	15.9	0					
	All	548	1.5	7.9	13.2	17.6	20.9	8.7	11.3	13.9	15.7	16.7	0					
1950s	Month																	
	8	310	7.5	10.9	14.1	18.0	20.3	11.7	13.0	14.4	15.7	16.6	0					
	9	300	-2.4	5.4	11.0	15.2	20.7	6.9	9.8	12.7	14.3	15.2	0					
	All	610	-2.4	7.0	12.7	17.0	20.7	6.9	10.7	13.7	15.4	16.6	0					
1960s	Month																	
	8	310	5.0	10.6	14.8	20.0	23.1	11.3	13.1	14.6	16.7	17.5	0					
	9	300	-3.3	5.9	10.3	15.4	21.2	6.8	10.4	12.4	14.3	16.5	0					
	All	610	-3.3	7.3	12.8	18.8	23.1	6.8	10.9	13.6	16.3	17.5	0					
1970s	Month																	
	8	310	5.0	10.6	15.0	19.8	23.9	11.4	12.9	15.0	16.6	17.5	0					
	9	300	-2.5	5.4	10.2	15.0	20.2	5.9	9.8	12.3	14.2	15.7	0					
	All	610	-2.5	7.2	12.8	18.6	23.9	5.9	10.6	13.6	16.2	17.5	0					
1980s	8	310	7.0	11.2	14.7	19.6	23.6	11.8	13.3	14.8	16.4	17.7	0					
	9	300	0.9	5.1	10.2	15.3	24.8	7.5	9.6	12.4	14.7	16.5	0					
	All	610	0.9	6.7	13.0	18.7	24.8	7.5	10.4	14.0	16.1	17.7	0					
1990s	Month																	
	8	310	7.2	10.7	15.5	20.0	23.7	12.3	13.1	15.1	16.6	17.7	124	11.9	13.8	15.2	16.6	18.4
	9	300	1.1	6.4	11.9	15.9	20.5	8.2	10.6	12.9	14.6	15.8	101	9.8	10.8	13.0	14.4	16.6
	All	610	1.1	7.8	13.4	18.7	23.7	8.2	11.6	14.0	16.1	17.7	225	9.8	12.0	14.2	16.2	18.4
2000s	Month																	
	8	403	6.3	10.7	15.4	19.8	23.6	10.7	13.6	15.0	16.6	17.6	360	10.5	13.8	15.2	16.8	18.8
	9	390	1.0	6.1	10.5	16.1	23.6	9.1	10.5	12.4	14.7	16.7	350	7.7	10.1	12.2	14.3	16.1
	All	793	1.0	7.8	13.0	18.6	23.6	9.1	11.0	14.0	16.1	17.6	710	7.7	10.8	14.1	16.4	18.8
Total		4391	-3.3	7.3	13.0	18.3	24.8	5.9	10.9	13.8	16.0	17.7	935	7.7	10.9	14.1	16.4	18.8

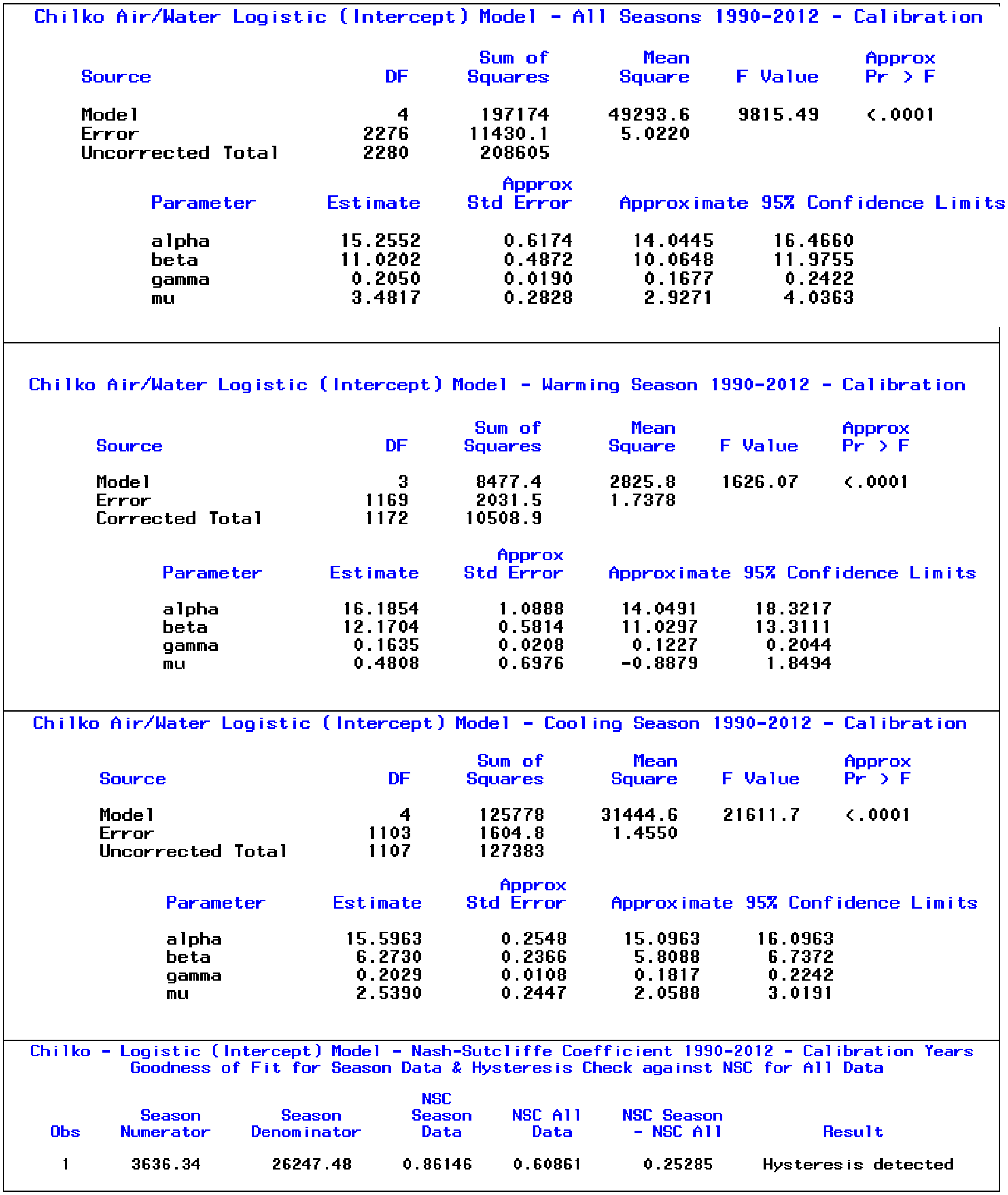
Table 15. Statistics for August-September regional mean air temperature (Williams Lake), Chilcotin River (Big Creek) modeled water temperature (1940-2012), and Chilcotin River (Big Creek) observed (or linearly estimated from Chilcotin (Redstone)), 1996-2012.



------------------------- Site=Chilko -------------------------

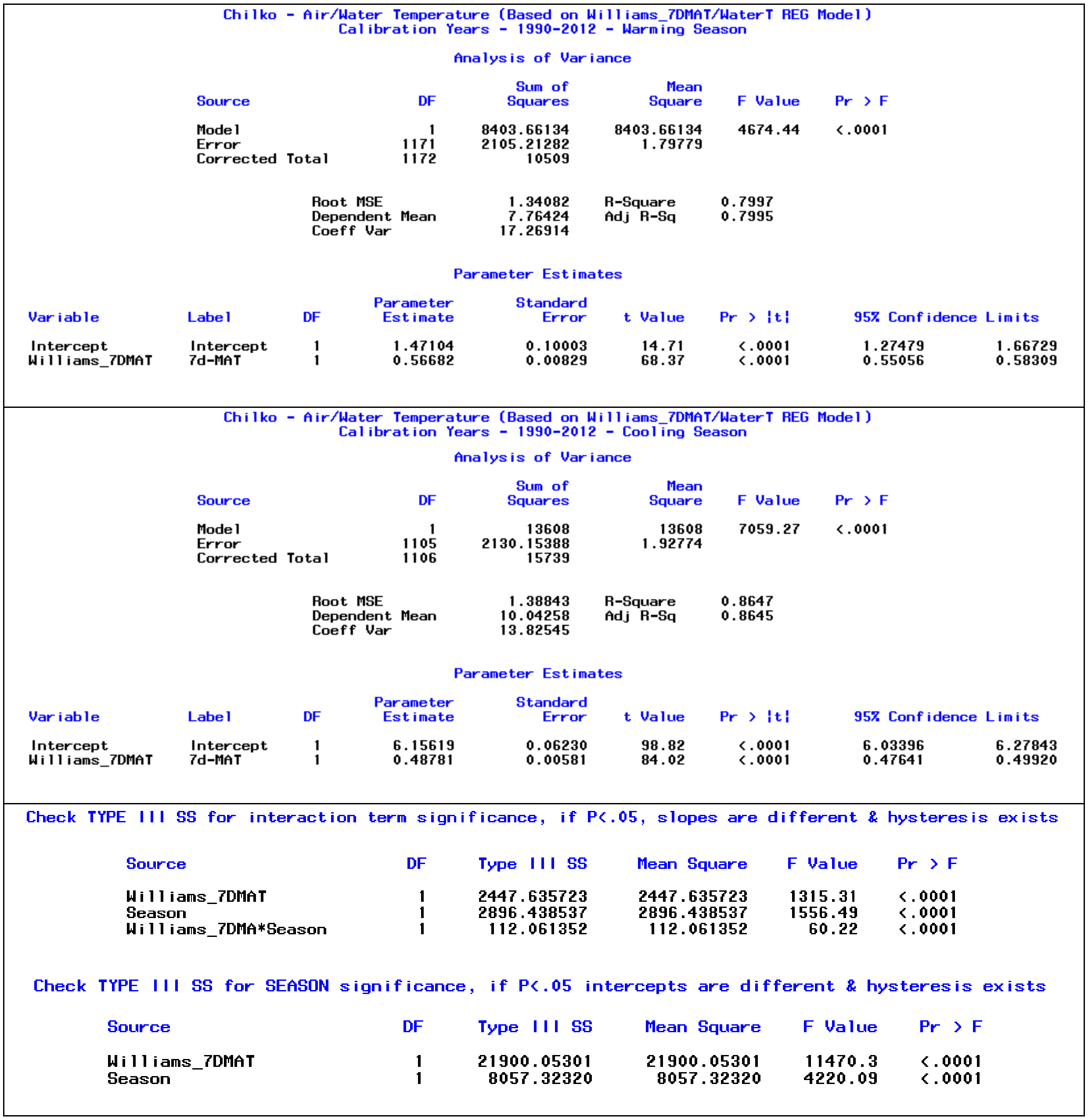
	Calibration		Validation	
	Warming	Cooling	Warming	Cooling
	Observations	Observations	Observations	Observations
Year				
1990	119	114		
1991			99	99
1992			121	119
1993	121	119		
1994	121	118		
1995	120	82		
1996	121	119		
1997			121	78
1998			0	0
1999			77	119
2000			121	69
2001			0	0
2002			0	0
2003			0	0
2004			0	47
2005	121	119		
2006	121	119		
2007	121	119		
2008	121	79		
2009			0	111
2010			12	0
2011			0	0
2012	87	119		

Table 16. Number of annual water temperature observations available for WILLIAMS LAKE / CHILKO RIVER air/water temperature analyses, partitioned into warming and cooling seasons at August 2nd for seasonal relationships.



```
 Chilko Air/Water Logistic (Intercept) Model - All Seasons 1990-2012 - Calibration

                                      Sum of        Mean                 Approx
    Source                  DF       Squares      Square     F Value     Pr > F

    Model                    4        197174     49293.6     9815.49     <.0001
    Error                 2276       11430.1      5.0220
    Uncorrected Total     2280        208605

                                          Approx
          Parameter      Estimate      Std Error    Approximate 95% Confidence Limits

          alpha           15.2552         0.6174       14.0445      16.4660
          beta            11.0202         0.4872       10.0648      11.9755
          gamma            0.2050         0.0190        0.1677       0.2422
          mu               3.4817         0.2828        2.9271       4.0363


 Chilko Air/Water Logistic (Intercept) Model - Warming Season 1990-2012 - Calibration

                                      Sum of        Mean                 Approx
    Source                  DF       Squares      Square     F Value     Pr > F

    Model                    3        8477.4      2825.8     1626.07     <.0001
    Error                 1169        2031.5      1.7378
    Corrected Total       1172       10508.9

                                          Approx
          Parameter      Estimate      Std Error    Approximate 95% Confidence Limits

          alpha           16.1854         1.0888       14.0491      18.3217
          beta            12.1704         0.5814       11.0297      13.3111
          gamma            0.1635         0.0208        0.1227       0.2044
          mu               0.4808         0.6976       -0.8879       1.8494

 Chilko Air/Water Logistic (Intercept) Model - Cooling Season 1990-2012 - Calibration

                                      Sum of        Mean                 Approx
    Source                  DF       Squares      Square     F Value     Pr > F

    Model                    4        125778     31444.6     21611.7     <.0001
    Error                 1103        1604.8      1.4550
    Uncorrected Total     1107        127383

                                          Approx
          Parameter      Estimate      Std Error    Approximate 95% Confidence Limits

          alpha           15.5963         0.2548       15.0963      16.0963
          beta             6.2730         0.2366        5.8088       6.7372
          gamma            0.2029         0.0108        0.1817       0.2242
          mu               2.5390         0.2447        2.0588       3.0191

 Chilko - Logistic (Intercept) Model - Nash-Sutcliffe Coefficient 1990-2012 - Calibration Years
             Goodness of Fit for Season Data & Hysteresis Check against NSC for All Data

                                                NSC
             Season          Season           Season      NSC All    NSC Season
    Obs     Numerator      Denominator         Data        Data      - NSC All          Result

     1       3636.34         26247.48        0.86146      0.60861      0.25285     Hysteresis detected
```

Table 17. Logistic regression output for air/water temperature relationship between the WILLIAMS LAKE 7d-CMAT (air temperature index) and calibration data for CHILKO RIVER daily mean water temperatures: seasons combined (top); warming season (middle); cooling season (bottom). Hysteresis was detected ($NSC_{seasonal} – NSC_{all}$ = 0.25).

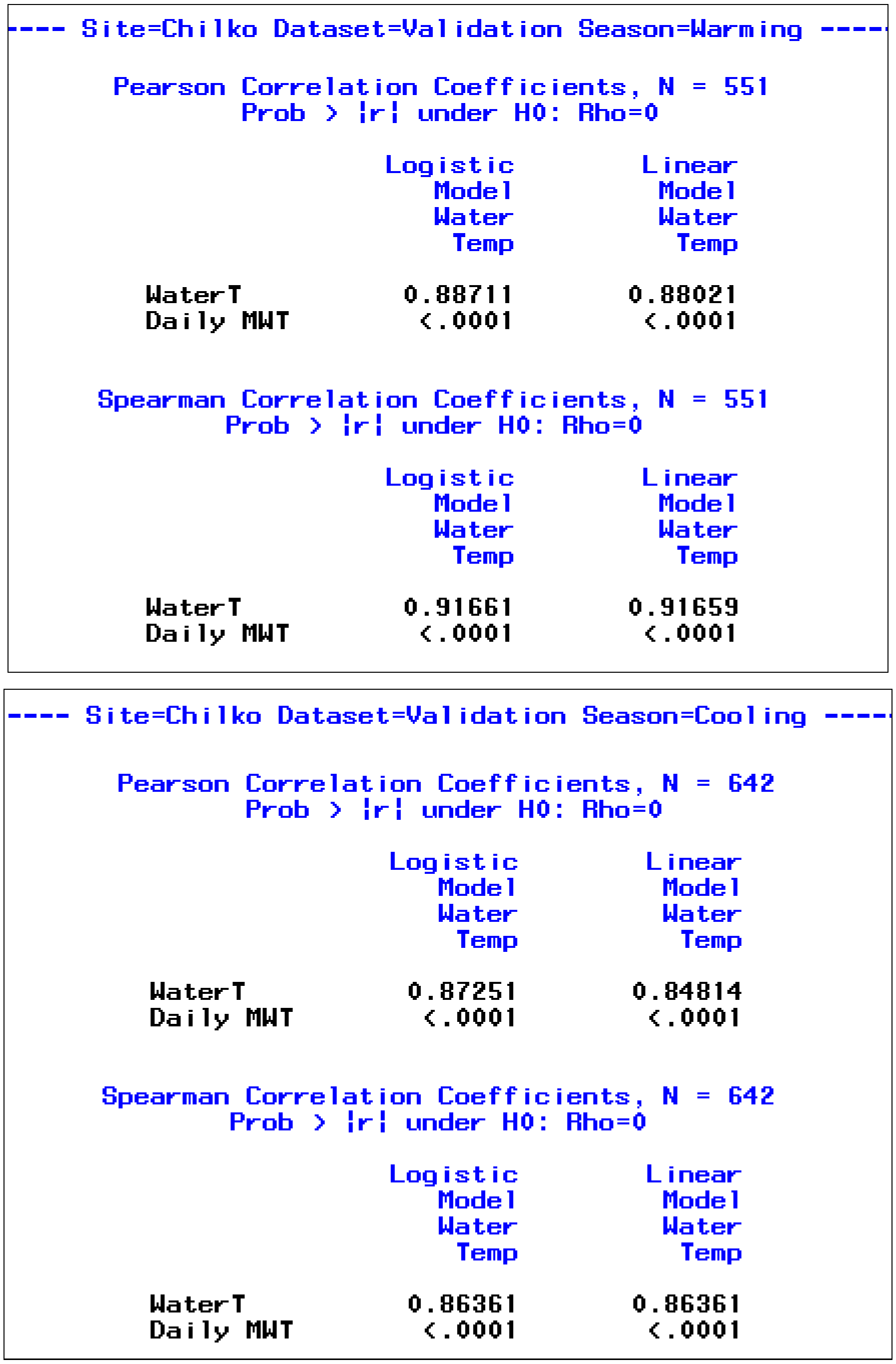


```
            Chilko - Air/Water Temperature (Based on Williams_7DMAT/WaterT REG Model)
                      Calibration Years - 1990-2012 - Warming Season

                                  Analysis of Variance

                                          Sum of           Mean
           Source                 DF     Squares         Square    F Value    Pr > F

           Model                   1  8403.66134     8403.66134    4674.44    <.0001
           Error                1171  2105.21282        1.79779
           Corrected Total      1172       10509

                        Root MSE              1.34082    R-Square     0.7997
                        Dependent Mean        7.76424    Adj R-Sq     0.7995
                        Coeff Var            17.26914

                                  Parameter Estimates

                                       Parameter       Standard
Variable         Label          DF      Estimate          Error    t Value    Pr > |t|       95% Confidence Limits

Intercept        Intercept       1       1.47104        0.10003      14.71      <.0001       1.27479         1.66729
Williams_7DMAT   7d-MAT          1       0.56682        0.00829      68.37      <.0001       0.55056         0.58309
```

```
            Chilko - Air/Water Temperature (Based on Williams_7DMAT/WaterT REG Model)
                      Calibration Years - 1990-2012 - Cooling Season

                                  Analysis of Variance

                                          Sum of           Mean
           Source                 DF     Squares         Square    F Value    Pr > F

           Model                   1       13608          13608    7059.27    <.0001
           Error                1105  2130.15388        1.92774
           Corrected Total      1106       15739

                        Root MSE              1.38843    R-Square     0.8647
                        Dependent Mean       10.04258    Adj R-Sq     0.8645
                        Coeff Var            13.82545

                                  Parameter Estimates

                                       Parameter       Standard
Variable         Label          DF      Estimate          Error    t Value    Pr > |t|       95% Confidence Limits

Intercept        Intercept       1       6.15619        0.06230      98.82      <.0001       6.03396         6.27843
Williams_7DMAT   7d-MAT          1       0.48781        0.00581      84.02      <.0001       0.47641         0.49920
```

```
Check TYPE III SS for interaction term significance, if P<.05, slopes are different & hysteresis exists

      Source                       DF      Type III SS     Mean Square     F Value     Pr > F

      Williams_7DMAT                1      2447.635723     2447.635723     1315.31     <.0001
      Season                        1      2896.438537     2896.438537     1556.49     <.0001
      Williams_7DMA*Season          1       112.061352      112.061352       60.22     <.0001


 Check TYPE III SS for SEASON significance, if P<.05 intercepts are different & hysteresis exists

     Source                       DF      Type III SS      Mean Square      F Value     Pr > F

     Williams_7DMAT                1      21900.05301      21900.05301      11470.3     <.0001
     Season                        1       8057.32320       8057.32320      4220.09     <.0001
```

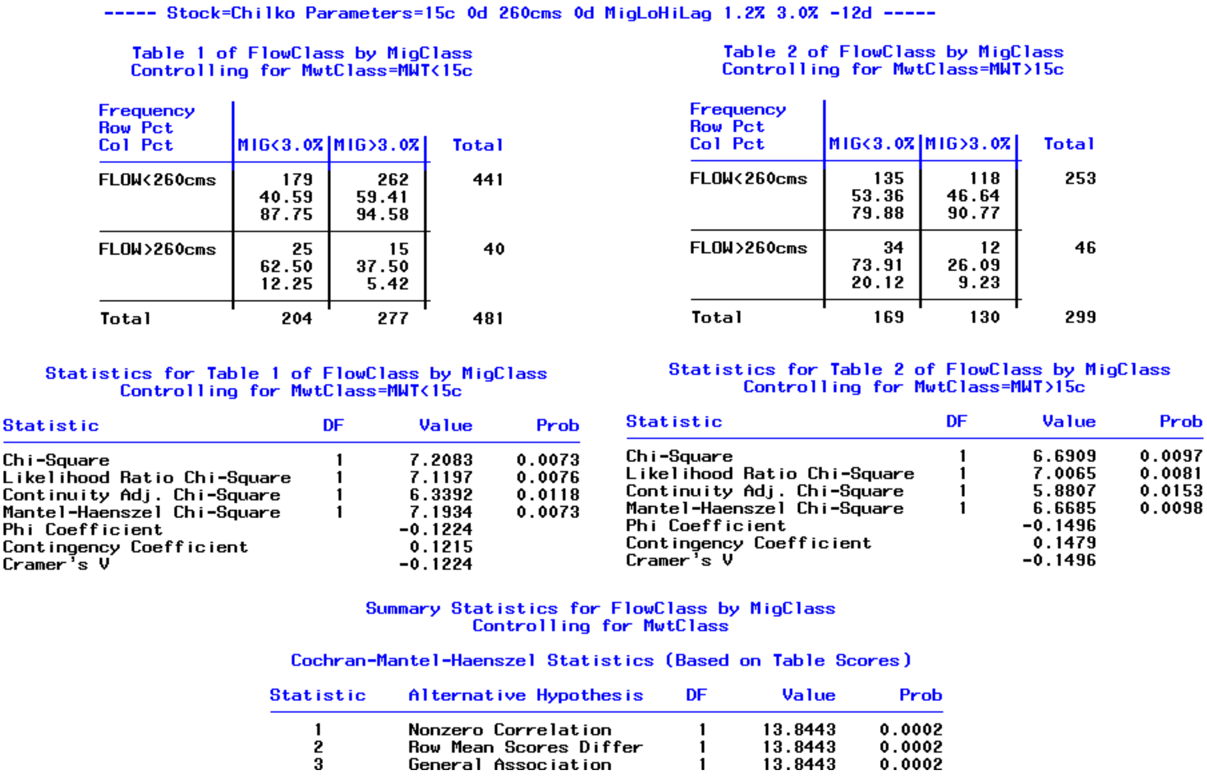
Table 18. Linear regression output for air/water temperature relationship between the Williams Lake 7d-CMAT (air temperature index) and calibration data for Chilko River daily mean water temperatures: warming season (top); cooling season (middle). Type III sum of squares for season interaction effect (test for equal slopes) and season effect (test for equal intercepts) was highly significant (bottom), indicating hysteresis.



```
---- Site=Chilko Dataset=Validation Season=Warming ----

     Pearson Correlation Coefficients, N = 551
             Prob > |r| under H0: Rho=0

                        Logistic        Linear
                           Model         Model
                           Water         Water
                            Temp          Temp

         WaterT          0.88711       0.88021
         Daily MWT        <.0001        <.0001


     Spearman Correlation Coefficients, N = 551
            Prob > |r| under H0: Rho=0

                        Logistic        Linear
                           Model         Model
                           Water         Water
                            Temp          Temp

         WaterT          0.91661       0.91659
         Daily MWT        <.0001        <.0001
```

```
---- Site=Chilko Dataset=Validation Season=Cooling ----

     Pearson Correlation Coefficients, N = 642
             Prob > |r| under H0: Rho=0

                        Logistic        Linear
                           Model         Model
                           Water         Water
                            Temp          Temp

         WaterT          0.87251       0.84814
         Daily MWT        <.0001        <.0001


     Spearman Correlation Coefficients, N = 642
            Prob > |r| under H0: Rho=0

                        Logistic        Linear
                           Model         Model
                           Water         Water
                            Temp          Temp

         WaterT          0.86361       0.86361
         Daily MWT        <.0001        <.0001
```

Table 19. Comparison of Pearson (least squares) and Spearman (rank) correlation coefficients for observed (WaterT) versus estimated (from logistic and linear models) CHILKO RIVER daily mean water temperature for validation data years: warming season (top); cooling season (bottom).

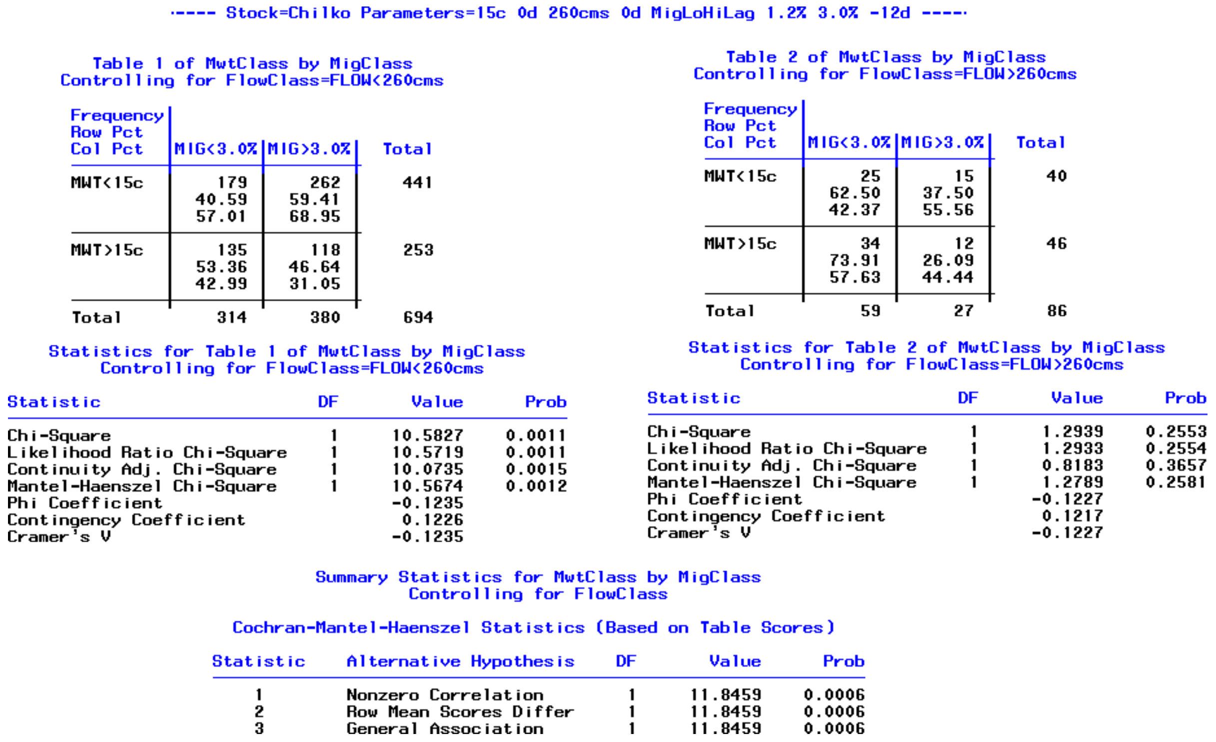


```
----- Stock=Chilko Parameters=15c 0d 260cms 0d MigLoHiLag 1.2% 3.0% -12d -----

     Table 1 of FlowClass by MigClass
     Controlling for MwtClass=MWT<15c

Frequency  |
Row Pct    |
Col Pct    |MIG<3.0%|MIG>3.0%|  Total
-----------+--------+--------+
FLOW<260cms|    179 |    262 |    441
           |  40.59 |  59.41 |
           |  87.75 |  94.58 |
-----------+--------+--------+
FLOW>260cms|     25 |     15 |     40
           |  62.50 |  37.50 |
           |  12.25 |   5.42 |
-----------+--------+--------+
Total           204      277      481

     Statistics for Table 1 of FlowClass by MigClass
          Controlling for MwtClass=MWT<15c

Statistic                     DF       Value      Prob
------------------------------------------------------
Chi-Square                     1      7.2083    0.0073
Likelihood Ratio Chi-Square    1      7.1197    0.0076
Continuity Adj. Chi-Square     1      6.3392    0.0118
Mantel-Haenszel Chi-Square     1      7.1934    0.0073
Phi Coefficient                      -0.1224
Contingency Coefficient               0.1215
Cramer's V                           -0.1224
```

```
     Table 2 of FlowClass by MigClass
     Controlling for MwtClass=MWT>15c

Frequency  |
Row Pct    |
Col Pct    |MIG<3.0%|MIG>3.0%|  Total
-----------+--------+--------+
FLOW<260cms|    135 |    118 |    253
           |  53.36 |  46.64 |
           |  79.88 |  90.77 |
-----------+--------+--------+
FLOW>260cms|     34 |     12 |     46
           |  73.91 |  26.09 |
           |  20.12 |   9.23 |
-----------+--------+--------+
Total           169      130      299

     Statistics for Table 2 of FlowClass by MigClass
          Controlling for MwtClass=MWT>15c

Statistic                     DF       Value      Prob
------------------------------------------------------
Chi-Square                     1      6.6909    0.0097
Likelihood Ratio Chi-Square    1      7.0065    0.0081
Continuity Adj. Chi-Square     1      5.8807    0.0153
Mantel-Haenszel Chi-Square     1      6.6685    0.0098
Phi Coefficient                      -0.1496
Contingency Coefficient               0.1479
Cramer's V                           -0.1496
```

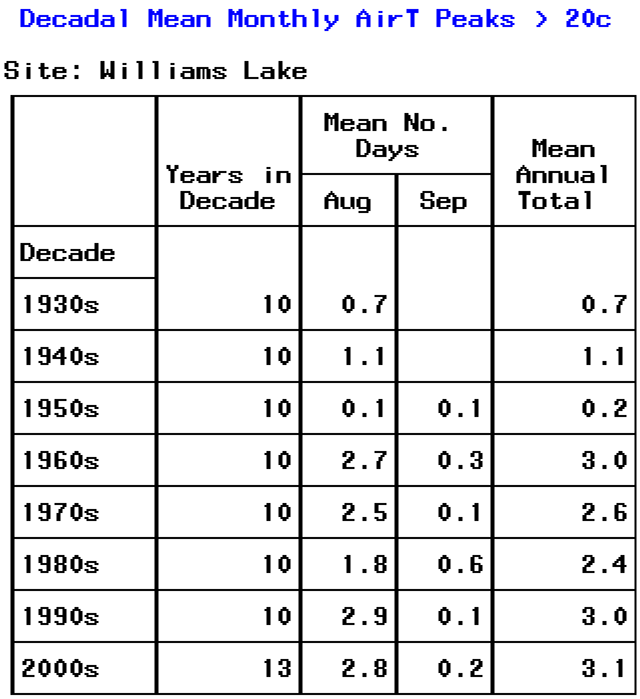
```
          Summary Statistics for FlowClass by MigClass
                   Controlling for MwtClass

   Cochran-Mantel-Haenszel Statistics (Based on Table Scores)

 Statistic    Alternative Hypothesis    DF       Value      Prob
 ---------------------------------------------------------------
     1        Nonzero Correlation        1     13.8443    0.0002
     2        Row Mean Scores Differ     1     13.8443    0.0002
     3        General Association        1     13.8443    0.0002
```

Table 20. Frequency analysis of categorical daily migration data (low/high based on P75% threshold of 3.0%, lagged 12 days) in relation to lower Chilcotin discharge categories (low/high based on 260 cms threshold), stratified by water temperature (low/high based on 15°C threshold). CMH-GA statistic (13.84, P = 0.0002) indicates significant association of migration classes with discharge class at both low and high water temperature class.



```
----- Stock=Chilko Parameters=15c 0d 260cms 0d MigLoHiLag 1.2% 3.0% -12d -----

          Table 1 of MwtClass by MigClass
     Controlling for FlowClass=FLOW<260cms

     Frequency|
     Row Pct  |
     Col Pct  |MIG<3.0%|MIG>3.0%|  Total
     ---------+--------+--------+
     MWT<15c  |    179 |    262 |    441
              |  40.59 |  59.41 |
              |  57.01 |  68.95 |
     ---------+--------+--------+
     MWT>15c  |    135 |    118 |    253
              |  53.36 |  46.64 |
              |  42.99 |  31.05 |
     ---------+--------+--------+
     Total         314      380      694

     Statistics for Table 1 of MwtClass by MigClass
         Controlling for FlowClass=FLOW<260cms

Statistic                     DF       Value      Prob
------------------------------------------------------
Chi-Square                     1     10.5827    0.0011
Likelihood Ratio Chi-Square    1     10.5719    0.0011
Continuity Adj. Chi-Square     1     10.0735    0.0015
Mantel-Haenszel Chi-Square     1     10.5674    0.0012
Phi Coefficient                      -0.1235
Contingency Coefficient               0.1226
Cramer's V                           -0.1235

          Table 2 of MwtClass by MigClass
     Controlling for FlowClass=FLOW>260cms

     Frequency|
     Row Pct  |
     Col Pct  |MIG<3.0%|MIG>3.0%|  Total
     ---------+--------+--------+
     MWT<15c  |     25 |     15 |     40
              |  62.50 |  37.50 |
              |  42.37 |  55.56 |
     ---------+--------+--------+
     MWT>15c  |     34 |     12 |     46
              |  73.91 |  26.09 |
              |  57.63 |  44.44 |
     ---------+--------+--------+
     Total          59       27       86

     Statistics for Table 2 of MwtClass by MigClass
         Controlling for FlowClass=FLOW>260cms

Statistic                     DF       Value      Prob
------------------------------------------------------
Chi-Square                     1      1.2939    0.2553
Likelihood Ratio Chi-Square    1      1.2933    0.2554
Continuity Adj. Chi-Square     1      0.8183    0.3657
Mantel-Haenszel Chi-Square     1      1.2789    0.2581
Phi Coefficient                      -0.1227
Contingency Coefficient               0.1217
Cramer's V                           -0.1227

          Summary Statistics for MwtClass by MigClass
                  Controlling for FlowClass

     Cochran-Mantel-Haenszel Statistics (Based on Table Scores)

Statistic    Alternative Hypothesis    DF       Value      Prob
---------------------------------------------------------------
    1        Nonzero Correlation        1     11.8459    0.0006
    2        Row Mean Scores Differ     1     11.8459    0.0006
    3        General Association        1     11.8459    0.0006
```

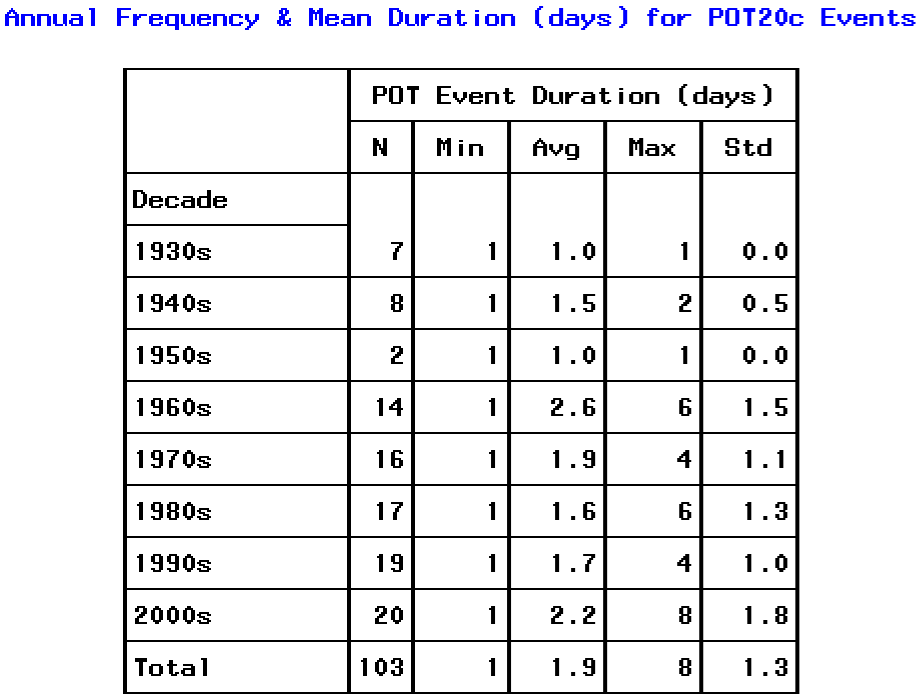
Table 21. Frequency analysis of categorical daily migration data (low/high based on P75% threshold of 3.0%, lagged 12 days) in relation to lower Chilcotin water temperature categories (low/high based on 15°C threshold), stratified by discharge level (low/high based on 260 cms threshold). CMH-GA statistic (11.85, P = 0.0006) indicates significant association of migration classes with temperature (MWT) class at both low and high water discharge classes, despite no significance association within the high flow class alone.



Decadal Mean Monthly AirT Peaks > 20c

Site: Williams Lake

		Mean No. Days		
Decade	Years in Decade	Aug	Sep	Mean Annual Total
1930s	10	0.7		0.7
1940s	10	1.1		1.1
1950s	10	0.1	0.1	0.2
1960s	10	2.7	0.3	3.0
1970s	10	2.5	0.1	2.6
1980s	10	1.8	0.6	2.4
1990s	10	2.9	0.1	3.0
2000s	13	2.8	0.2	3.1



Annual Frequency & Mean Duration (days) for POT20c Events

	POT Event Duration (days)				
Decade	N	Min	Avg	Max	Std
1930s	7	1	1.0	1	0.0
1940s	8	1	1.5	2	0.5
1950s	2	1	1.0	1	0.0
1960s	14	1	2.6	6	1.5
1970s	16	1	1.9	4	1.1
1980s	17	1	1.6	6	1.3
1990s	19	1	1.7	4	1.0
2000s	20	1	2.2	8	1.8
Total	103	1	1.9	8	1.3

Table 22. Frequency analysis of decadal mean number of dates per month (July-September) in which regional daily mean air temperature at WILLIAMS 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 (August-September), by decade (bottom).

Decadal Mean Monthly MWT Peaks > 16c

Site: Chilcotin River

	Years in Decade	Mean No. Days		Mean Annual Total
		Aug	Sep	
Decade				
1930s	10	3.7	0.4	4.1
1940s	10	5.3		5.3
1950s	10	1.5		1.5
1960s	10	7.0	0.9	7.9
1970s	10	8.3		8.3
1980s	10	6.3	0.4	6.7
1990s	10	7.6		7.6
2000s	13	6.2	0.5	6.6

Annual Frequency & Mean Duration (days) for POT16c Events

	POT Event Duration (days)				
	N	Min	Avg	Max	Std
Decade					
1930s	9	1	4.6	11	3.6
1940s	5	3	10.6	20	7.1
1950s	2	4	7.5	11	4.9
1960s	14	1	5.6	15	4.3
1970s	10	2	8.3	19	5.4
1980s	10	2	6.7	20	5.3
1990s	16	1	4.8	16	3.7
2000s	18	1	4.8	10	2.2
Total	84	1	6.0	20	4.4

Table 23. Frequency analysis of decadal mean number of dates per month (August-September) in which estimated mean water temperature in the lower Chilcotin River exceeded 16°C (top); min., mean and max. length (days) and total frequency of periods in which estimated mean water temperature continuously exceeded 16°C (August-September), by decade (bottom).

Monthly and Annual No. Peaks > 16c

		Freq POT16c Dates		Total Days
		Aug	Sep	
Decade	Year			
1930s	1930	11		11
	1931	1		1
	1932			
	1933	10		10
	1934	7	2	9
	1935	4	2	6
	1936			
	1937			
	1938			
	1939	4		4
1940s	1940	3		3
	1941	14		14
	1942	20		20
	1943			
	1944			
	1945	12		12
	1946	4		4
	1947			
	1948			

(Continued)

Monthly and Annual No. Peaks > 16c

		Freq POT16c Dates		Total Days
		Aug	Sep	
Decade	Year			
1940s	1949			
1950s	1950			
	1951			
	1952	11		11
	1953			
	1954			
	1955			
	1956			
	1957			
	1958	4		4
	1959			
1960s	1960	6		6
	1961	18		18
	1962	1		1
	1963	11	5	16
	1964			
	1965	12		12
	1966	1		1
	1967	19	4	23

(Continued)

Table 24. Frequency analysis of decadal mean number of dates per month (August-September) in which estimated mean water temperature in the lower Chilcotin River exceeded 16°C), by year (1930-2012).

Monthly and Annual No. Peaks > 16c

		Freq POT16c Dates		Total Days
		Aug	Sep	
Decade	Year			
1960s	1968	2		2
	1969			
1970s	1970	7		7
	1971	13		13
	1972	7		7
	1973	11		11
	1974	4		4
	1975			
	1976			
	1977	19		19
	1978	9		9
	1979	13		13
1980s	1980			
	1981	20		20
	1982			
	1983	7		7
	1984	6		6
	1985	2		2
	1986	15		15

(Continued)

Monthly and Annual No. Peaks > 16c

		Freq POT16c Dates		Total Days
		Aug	Sep	
Decade	Year			
1980s	1987			
	1988	4	4	8
	1989	9		9
1990s	1990	16		16
	1991	13		13
	1992	9		9
	1993	1		1
	1994	7		7
	1995			
	1996	4		4
	1997	7		7
	1998	12		12
	1999	7		7
2000s	2000	5		5
	2001	6		6
	2002	6		6
	2003	9		9
	2004	12		12
	2005			
2000s	2006		4	4
	2007			
	2008	6		6
	2009	13	2	15
	2010	9		9
	2011			
	2012	14		14

Table 24 (continued). Frequency analysis of decadal mean number of dates per month (August-September) in which estimated mean water temperature in the lower Chilcotin River exceeded 16°C), by year (1930-2012).

Annual Frequency & Mean Duration (days) for POT16c Events

		POT Event Duration (days)				
		N	Min	Avg	Max	Std
Decade	Year					
1930s	1930	1	11	11.0	11	
	1931	1	1	1.0	1	
	1933	2	2	5.0	8	4.2
	1934	2	2	4.5	7	3.5
	1935	1	6	6.0	6	
	1939	2	1	2.0	3	1.4
	Total	9	1	4.6	11	3.6
1940s	Year					
	1940	1	3	3.0	3	
	1941	1	14	14.0	14	
	1942	1	20	20.0	20	
	1945	1	12	12.0	12	
	1946	1	4	4.0	4	
	Total	5	3	10.6	20	7.1
1950s	Year					
	1952	1	11	11.0	11	
	1958	1	4	4.0	4	
	Total	2	4	7.5	11	4.9

(Continued)

		POT Event Duration (days)				
		N	Min	Avg	Max	Std
Decade	Year					
1960s	1960	2	3	3.0	3	0.0
	1961	2	6	9.0	12	4.2
	1962	1	1	1.0	1	
	1963	2	5	8.0	11	4.2
	1965	2	6	6.0	6	0.0
	1966	1	1	1.0	1	
	1967	3	2	7.7	15	6.7
	1968	1	2	2.0	2	
	Total	14	1	5.6	15	4.3
1970s	Year					
	1970	2	2	3.5	5	2.1
	1971	1	13	13.0	13	
	1972	1	7	7.0	7	
	1973	2	3	5.5	8	3.5
	1974	1	4	4.0	4	
	1977	1	19	19.0	19	
	1978	1	9	9.0	9	
	1979	1	13	13.0	13	
	Total	10	2	8.3	19	5.4

(Continued)

Table 25. Minimum, mean and maximum length (days) and total frequency of periods in which estimated mean water temperature continuously exceeded 16°C (August-September) in the lower Chilcotin River, by decade and year.

Annual Frequency & Mean Duration (days) for POT16c Events

		POT Event Duration (days)				
		N	Min	Avg	Max	Std
Decade	Year					
1980s	1981	1	20	20.0	20	
	1983	2	2	3.5	5	2.1
	1984	1	6	6.0	6	
	1985	1	2	2.0	2	
	1986	2	6	7.5	9	2.1
	1988	2	4	4.0	4	0.0
	1989	1	9	9.0	9	
	Total	10	2	6.7	20	5.3
1990s	Year					
	1990	1	16	16.0	16	
	1991	2	6	6.5	7	0.7
	1992	2	4	4.5	5	0.7
	1993	1	1	1.0	1	
	1994	2	3	3.5	4	0.7
	1996	1	4	4.0	4	
	1997	3	1	2.3	5	2.3
	1998	3	2	4.0	7	2.6
	1999	1	7	7.0	7	
	Total	16	1	4.8	16	3.7

		POT Event Duration (days)				
		N	Min	Avg	Max	Std
Decade	Year					
2000s	2000	2	1	2.5	4	2.1
	2001	1	6	6.0	6	
	2002	1	6	6.0	6	
	2003	2	4	4.5	5	0.7
	2004	2	2	6.0	10	5.7
	2006	1	4	4.0	4	
	2008	1	6	6.0	6	
	2009	4	1	3.8	5	1.9
	2010	2	4	4.5	5	0.7
	2012	2	6	7.0	8	1.4
	Total	18	1	4.8	10	2.2
Total		84	1	6.0	20	4.4

(Continued)

Table 25. Minimum, mean and maximum length (days) and total frequency of periods in which estimated mean water temperature continuously exceeded 16°C (August-September) in the lower Chilcotin River, by decade and year.

		POT Event Duration (days)				
		N	Min	Avg	Max	Std
Decade	year					
1930s	1933	1	1	1.0	1	
	1934	1	3	3.0	3	
	1935	1	8	8.0	8	
	Total	3	1	4.0	8	3.6
1940s	year					
	1941	1	8	8.0	8	
	1945	1	6	6.0	6	
	1946	1	9	9.0	9	
	1947	2	2	5.5	9	4.9
	1948	2	1	1.5	2	0.7
	1949	1	9	9.0	9	
	Total	8	1	5.8	9	3.5
1950s	year					
	1951	1	3	3.0	3	
	1952	1	8	8.0	8	
	1953	1	3	3.0	3	
	1958	1	5	5.0	5	
	1959	1	3	3.0	3	
	Total	5	3	4.4	8	2.2
1960s	year					
	1960	2	6	9.5	13	4.9
1960s	1961	1	4	4.0	4	
	1964	1	3	3.0	3	
	1965	2	2	4.0	6	2.8
	1968	1	6	6.0	6	
	1969	1	2	2.0	2	
	Total	8	2	5.3	13	3.6
1970s	year					
	1970	1	20	20.0	20	
	1971	1	11	11.0	11	
	1972	1	11	11.0	11	
	1973	2	3	7.0	11	5.7
	1975	2	3	7.5	12	6.4
	1977	1	13	13.0	13	
	1978	1	14	14.0	14	
	Total	9	3	10.9	20	5.3
1980s	year					
	1980	1	11	11.0	11	
	1981	1	4	4.0	4	
	1983	1	17	17.0	17	
	1984	2	6	7.5	9	2.1
	1985	1	19	19.0	19	

(Continued)

(Continued)

Table 26. Min., mean and max. length (days) and number of periods in which observed or estimated discharge at Chilko River at Redstone was less than 90 cms (10th percentile) August-September, by year (1930-2012).

		POT Event Duration (days)				
		N	Min	Avg	Max	Std
Decade	year					
1980s	1986	1	13	13.0	13	
	1987	1	3	3.0	3	
	1988	1	9	9.0	9	
	1989	1	5	5.0	5	
	Total	10	3	9.6	19	5.4
1990s	year					
	1992	2	1	4.0	7	4.2
	1993	1	8	8.0	8	
	1996	1	6	6.0	6	
	1997	1	6	6.0	6	
	1998	1	1	1.0	1	
	Total	6	1	4.8	8	3.1
2000s	year					
	2002	1	2	2.0	2	
	2003	1	11	11.0	11	
	2004	1	6	6.0	6	
	2005	1	8	8.0	8	
	2006	1	12	12.0	12	
	2007	1	6	6.0	6	
	2008	1	6	6.0	6	
	2010	1	6	6.0	6	

(Continued)

		POT Event Duration (days)				
		N	Min	Avg	Max	Std
Decade	Total					
2000s		8	2	7.1	12	3.2
Total		57	1	7.1	20	4.5

Table 26 (continued). Min., mean and max. length (days) and number of periods in which observed or estimated discharge at CHILKO RIVER AT REDSTONE was less than 90 cms (10th percentile) August-September, by year (1930-2012).

Decadal Mean Monthly Flow < 90 cms

Site: ChilkoRedstone River

	Years in Decade	Mean No. Days		Mean Annual Total
		Aug	Sep	
Decade				
1930s	10		1.2	1.2
1940s	10		4.6	4.6
1950s	10		2.1	2.1
1960s	10		4.1	4.1
1970s	10		9.7	9.7
1980s	10		9.6	9.6
1990s	10		2.9	2.9
2000s	13		4.4	4.4

Decadal Mean Monthly Flow > 240 cms

Site: ChilkoRedstone River

	Years in Decade	Mean No. Days		Mean Annual Total
		Aug	Sep	
Decade				
1930s	10	8.6	0.5	9.1
1940s	10	8.6		8.6
1950s	10	6.3		6.3
1960s	10	7.6	0.3	7.9
1970s	10	8.4		8.4
1980s	10	2.3		2.3
1990s	10	10.9	0.6	11.5
2000s	13	7.2		7.2

	POT Event Duration (days)				
	N	Min	Avg	Max	Std
Decade					
1930s	3	1	4.0	8	3.6
1940s	8	1	5.8	9	3.5
1950s	5	3	4.4	8	2.2
1960s	8	2	5.3	13	3.6
1970s	9	3	10.9	20	5.3
1980s	10	3	9.6	19	5.4
1990s	6	1	4.8	8	3.1
2000s	8	2	7.1	12	3.2
Total	57	1	7.1	20	4.5

	POT Event Duration (days)				
	N	Min	Avg	Max	Std
Decade					
1930s	13	1	7.2	17	5.9
1940s	9	2	9.6	27	7.9
1950s	9	2	6.9	13	3.3
1960s	12	1	6.8	14	4.0
1970s	7	2	12.1	20	7.4
1980s	4	2	6.0	12	4.2
1990s	10	2	11.9	32	10.4
2000s	11	2	8.5	22	6.8
Total	75	1	8.6	32	6.7

Table 27. (top) Decadal mean number of dates per month (August-September) in which observed or estimated discharge at CHILKO RIVER AT REDSTONE was less than 90 cms (left); or greater than 240 cms (right). Min., mean and max. duration (days) of POT periods, by decade (bottom).

		POT Event Duration (days)				
		N	Min	Avg	Max	Std
Decade	year					
1930s	1930	2	1	7.5	14	9.2
	1931	3	2	4.7	7	2.5
	1932	1	12	12.0	12	
	1933	1	16	16.0	16	
	1935	2	2	5.5	9	4.9
	1936	1	1	1.0	1	
	1937	1	6	6.0	6	
	1938	1	1	1.0	1	
	1939	1	17	17.0	17	
	Total	13	1	7.2	17	5.9
1940s	year					
	1941	2	2	6.5	11	6.4
	1942	1	27	27.0	27	
	1943	1	6	6.0	6	
	1944	1	17	17.0	17	
	1945	2	3	4.0	5	1.4
	1948	2	7	7.5	8	0.7
	Total	9	2	9.6	27	7.9
1950s	year					
	1950	1	5	5.0	5	
	1951	1	8	8.0	8	

(Continued)

		POT Event Duration (days)				
		N	Min	Avg	Max	Std
Decade	year					
1950s	1952	1	13	13.0	13	
	1954	2	7	8.0	9	1.4
	1955	1	2	2.0	2	
	1958	2	5	7.0	9	2.8
	1959	1	4	4.0	4	
	Total	9	2	6.9	13	3.3
1960s	year					
	1960	1	14	14.0	14	
	1961	2	3	3.5	4	0.7
	1962	1	10	10.0	10	
	1963	1	7	7.0	7	
	1965	2	6	7.5	9	2.1
	1966	1	12	12.0	12	
	1967	3	1	2.7	4	1.5
	1968	1	8	8.0	8	
	Total	12	1	6.8	14	4.0
1970s	year					
	1971	2	3	9.5	16	9.2
	1972	1	2	2.0	2	
	1974	1	11	11.0	11	
	1976	1	20	20.0	20	

(Continued)

Table 28. Min., mean and max. length (days) and number of periods in which observed or estimated discharge at CHILKO RIVER AT REDSTONE was greater than 240 cms (>90th percentile) August-September, by year (1930-2012).

		POT Event Duration (days)				
		N	Min	Avg	Max	Std
Decade	year					
1970s	1977	1	20	20.0	20	
	1978	1	13	13.0	13	
	Total	7	2	12.1	20	7.4
1980s	year					
	1981	2	5	8.5	12	4.9
	1982	1	5	5.0	5	
	1985	1	2	2.0	2	
	Total	4	2	6.0	12	4.2
1990s	year					
	1990	1	17	17.0	17	
	1991	2	7	17.5	28	14.8
	1992	1	9	9.0	9	
	1994	2	2	4.0	6	2.8
	1996	1	6	6.0	6	
	1998	2	3	6.0	9	4.2
	1999	1	32	32.0	32	
	Total	10	2	11.9	32	10.4
2000s	year					
	2000	1	11	11.0	11	
	2004	2	4	4.5	5	0.7
	2005	1	2	2.0	2	
	2007	1	10	10.0	10	
	2009	1	6	6.0	6	
	2010	1	20	20.0	20	
	2011	3	3	4.7	8	2.9
	2012	1	22	22.0	22	
	Total	11	2	8.5	22	6.8
Total		75	1	8.6	32	6.7

Table 28 (continued). Min., mean and max. length (days) and number of periods in which observed or estimated discharge at CHILKO RIVER AT REDSTONE was greater than 240 cms (>90th percentile) August-September, by year (1930-2012).

FIGURES

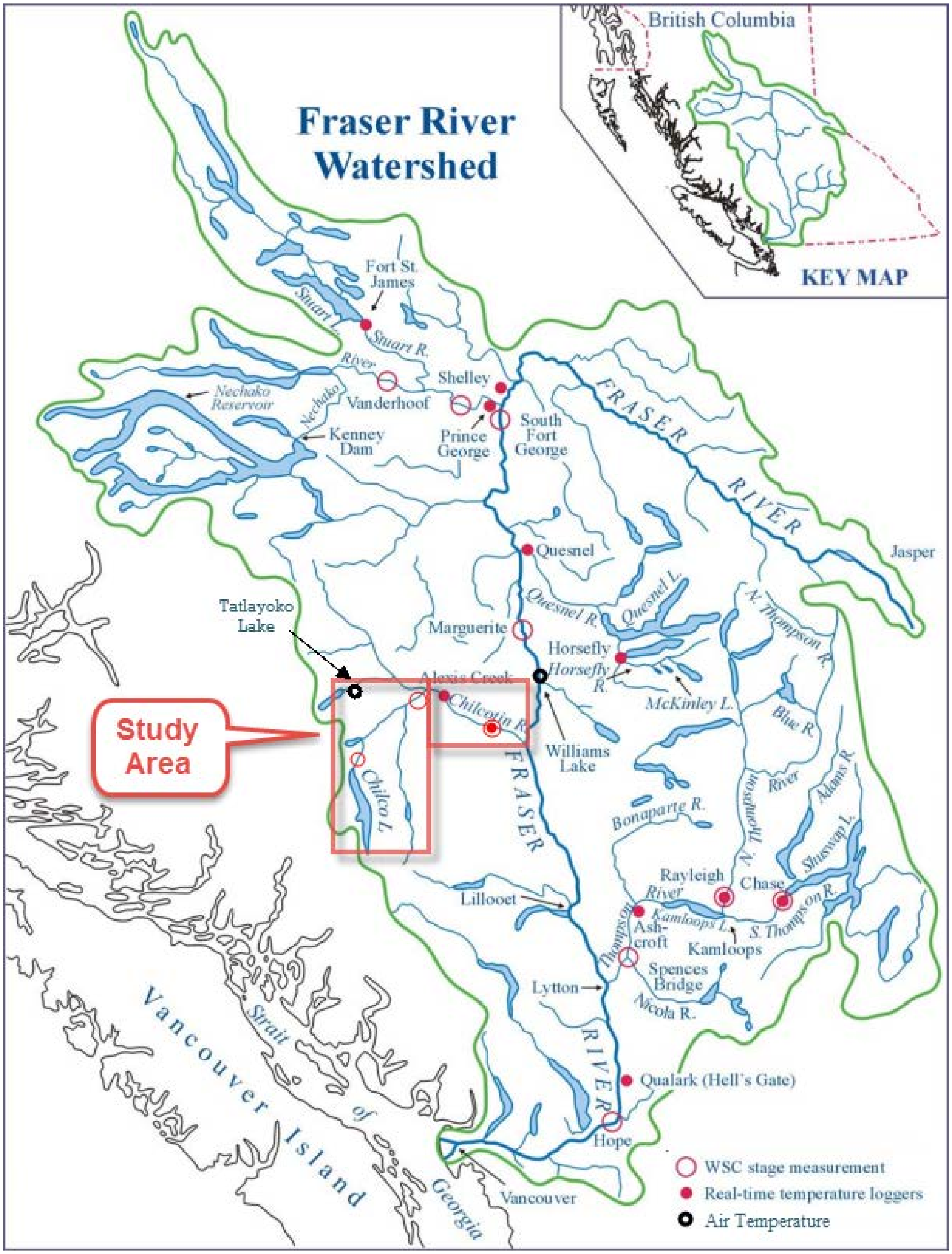


Figure 1. Chilcotin/Chilko study area with hydrometric (WSC), air temperature, and water temperature (DFO-EWP) monitoring locations (map courtesy of DFO ENVIRONMENTAL WATCH PROGRAM).

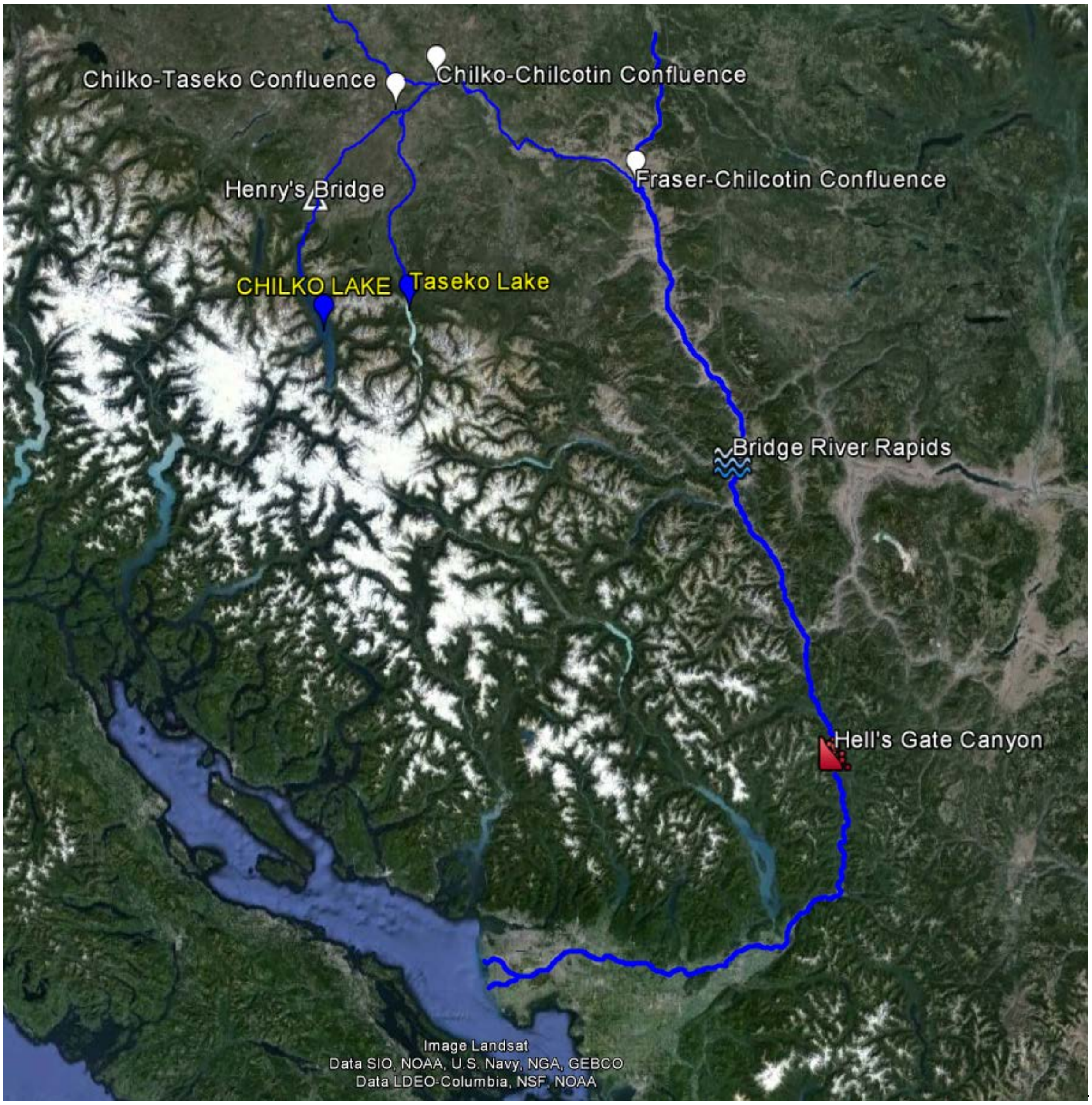


Figure 2. The Chilcotin/Chilko watershed originates in the eastern edge of the COAST MOUNTAIN range.

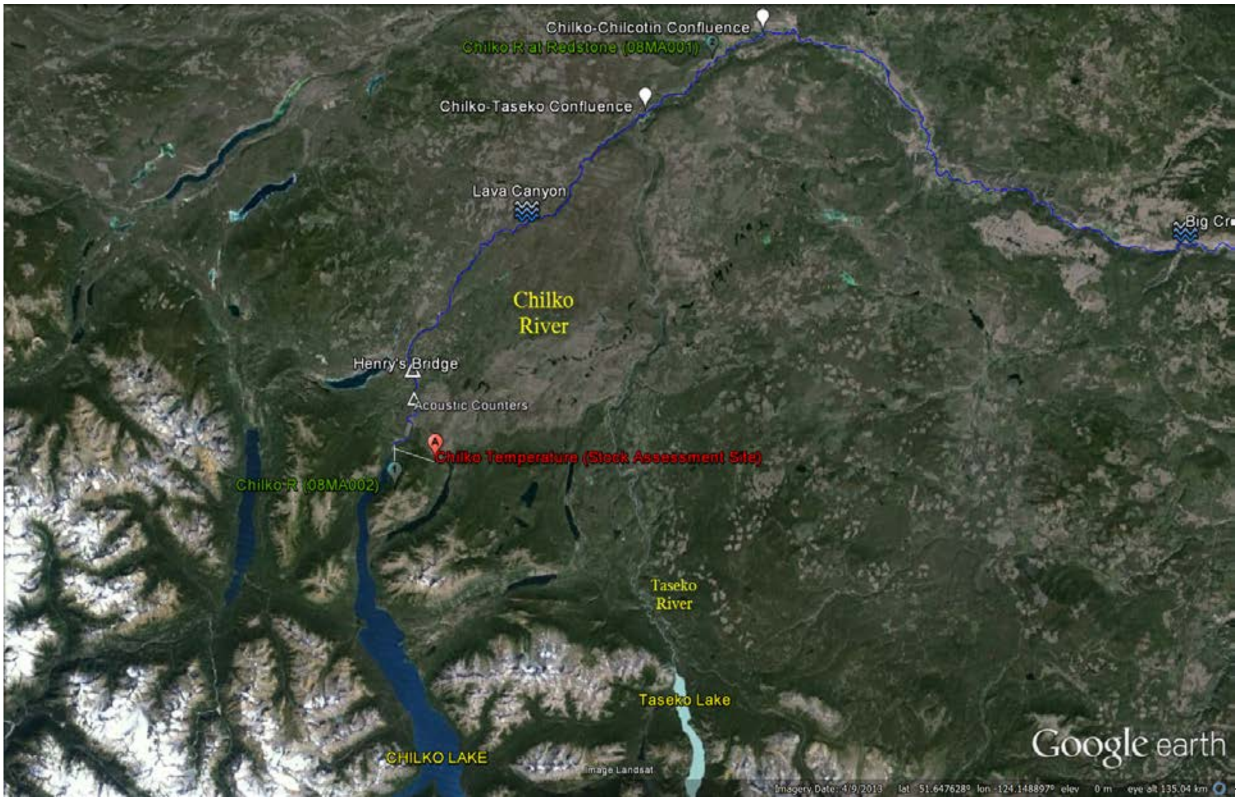


Figure 3. Chilko River to Chilcotin River confluence. DFO ENVIRONMENTAL WATCH PROGRAM water temperature station (red) and WSC hydrometric station (green) monitoring upper Chilko River environmental conditions. Minor rapids at Lava Canyon.

Figure 4. Chilko / Chilcotin confluence to Big Creek. DFO EWP water temperature station (red; discontinued). WSC hydrometric station (green) monitors lower Chilko River discharge. Minor rapids at Bull Canyon and Big Creek.

Figure 5. Chilcotin River from Big Creek to the Fraser confluence. DFO Environmental Watch Program water temperature station (red) and WSC hydrometric station (green) monitor lower Chilcotin River conditions.

Figure 6. Aerial view of site of major rapids at Farwell Canyon.

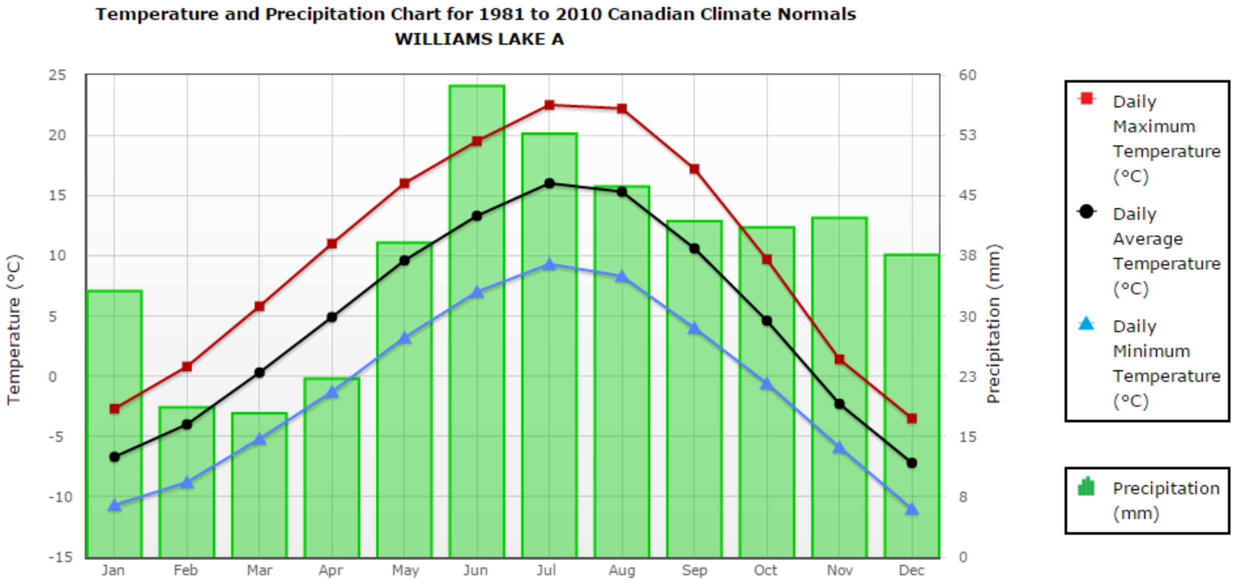


Figure 7. WILLIAMS LAKE Climate Normals (1981-2010). Source: Environment Canada (http://climate.weather.gc.ca/climate_normals/index_e.html).

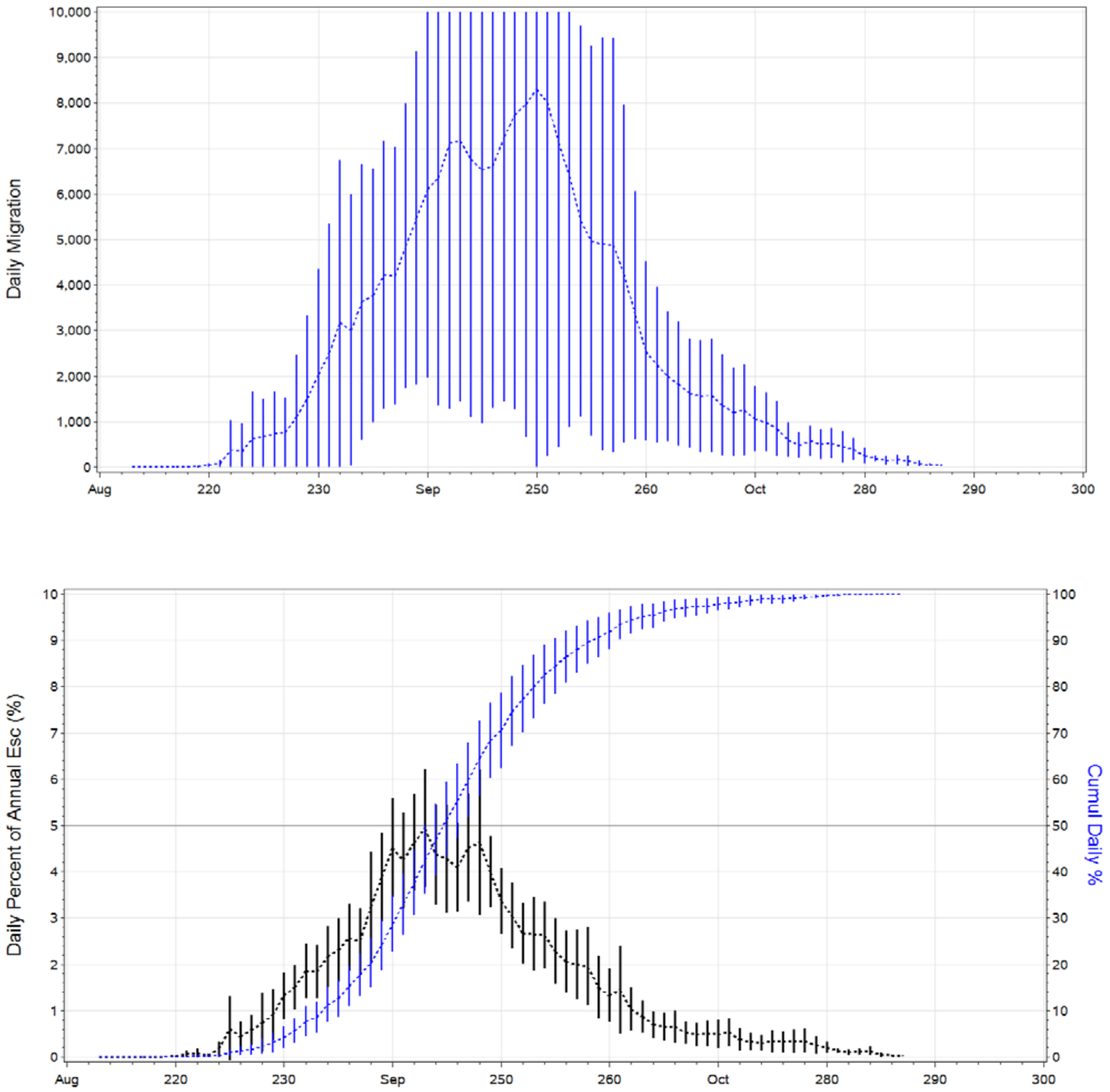


Figure 8. Historical mean daily Chilko Sockeye migration timing (1975-1976, 1978-2012). Mean and variance (95% CI) of daily migrants (top) and mean daily % and cumulative % of total annual escapement (bottom). Time-to-50% ~ day 245 ~ September 2nd (Source: DFO Stock Assessment, Fraser Division).

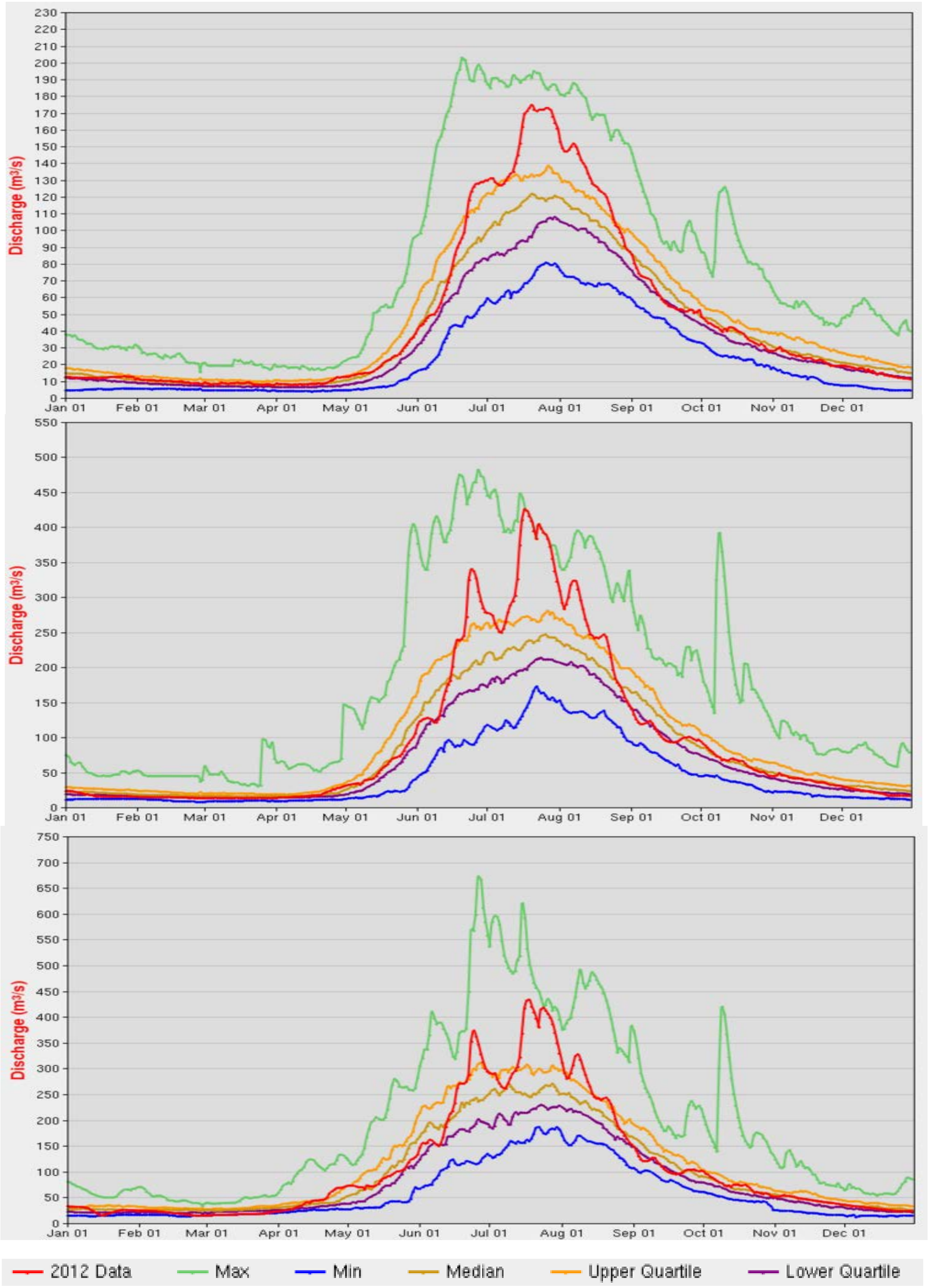


Figure 9. Watershed hydrology (source: Environment Canada)
- Chilko River at Chilko Lake Outlet (WSC 08MA002) 1928-2012 (top)
- Chilko River near Redstone (WSC 08MA001) 1927-2013 (middle)
- Chilcotin River at Big Creek (WSC 08MB005 1971-2013 (bottom).

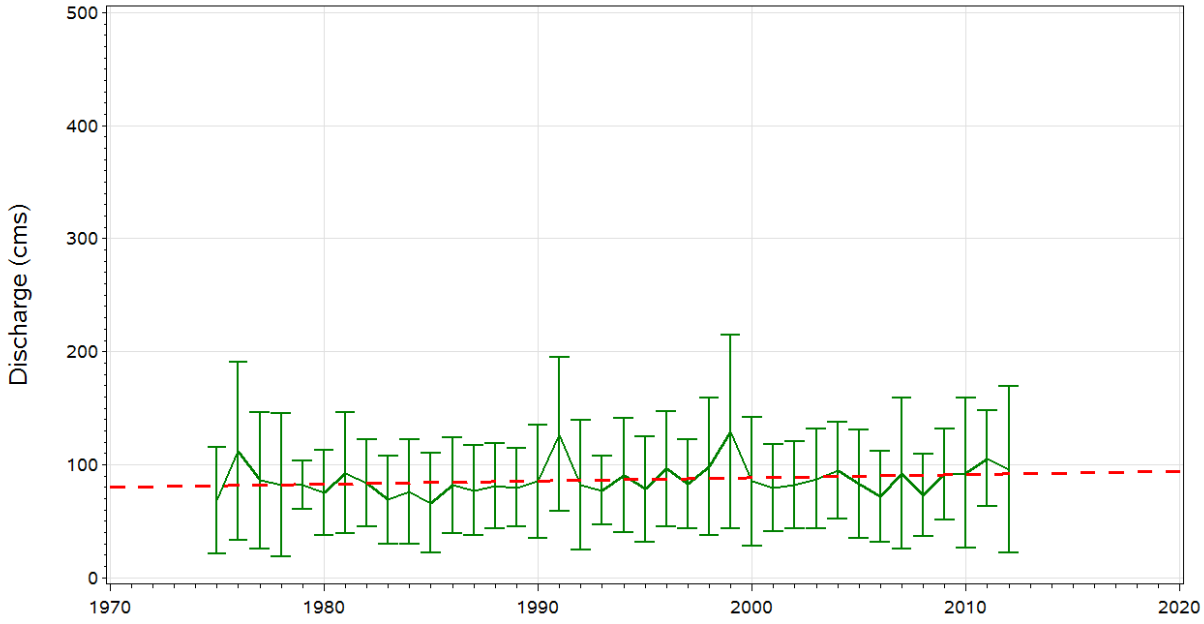


Figure 10. Upper Chilko River at Chilko Lake - mean discharge ± 2 std deviations, August-September 1975-2012. Trend in flow is +2.8 cms per decade (P<0.01).

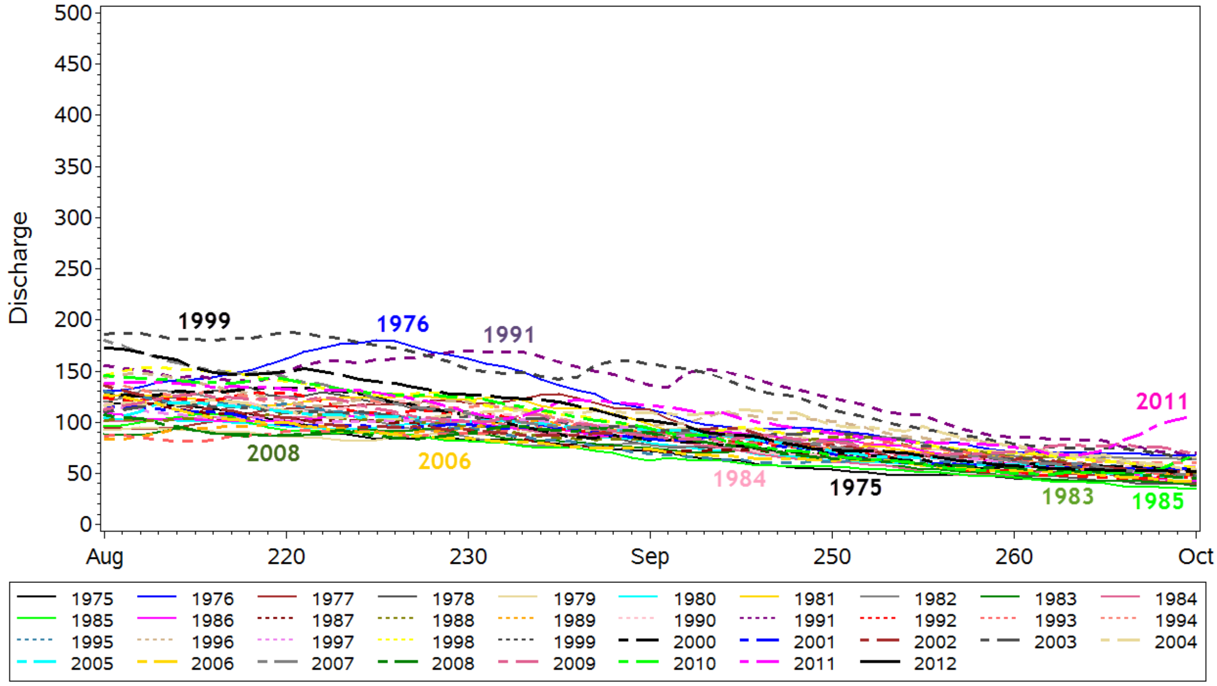


Figure 11. Lower Chilko River at Chilko Lake (outlet) mean daily discharge (cms) by year, August-September 1975-2012.

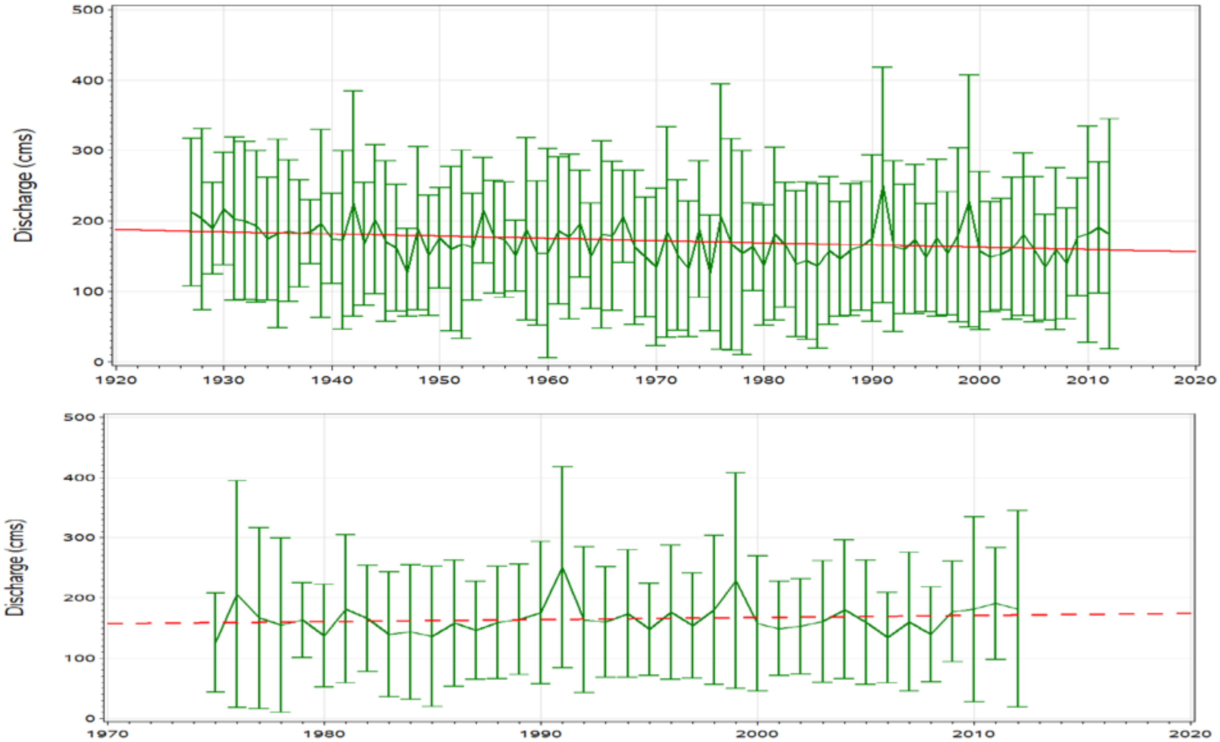


Figure 12. Lower Chilko River at Redstone (above the Chilcotin River confluence) mean discharge ± 2 std deviations, August-September, 1927-2012 (top), 1975-2012 (bottom). Long-term trend in flow is -3.1 cms per decade (P<0.001); recent trend is +3.3 cms per decade (P < 0.05).

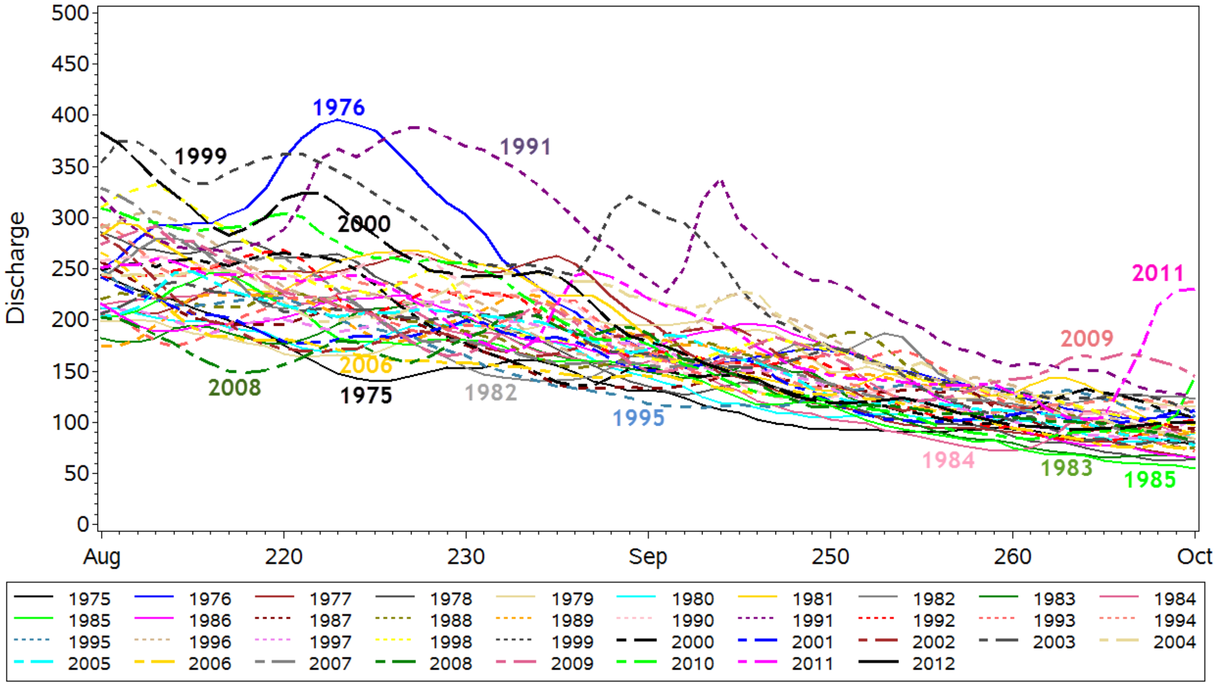


Figure 13. Lower Chilko River at Redstone (confluence with Chilcotin River) mean daily discharge (cms) by year, August-September 1975-2012.

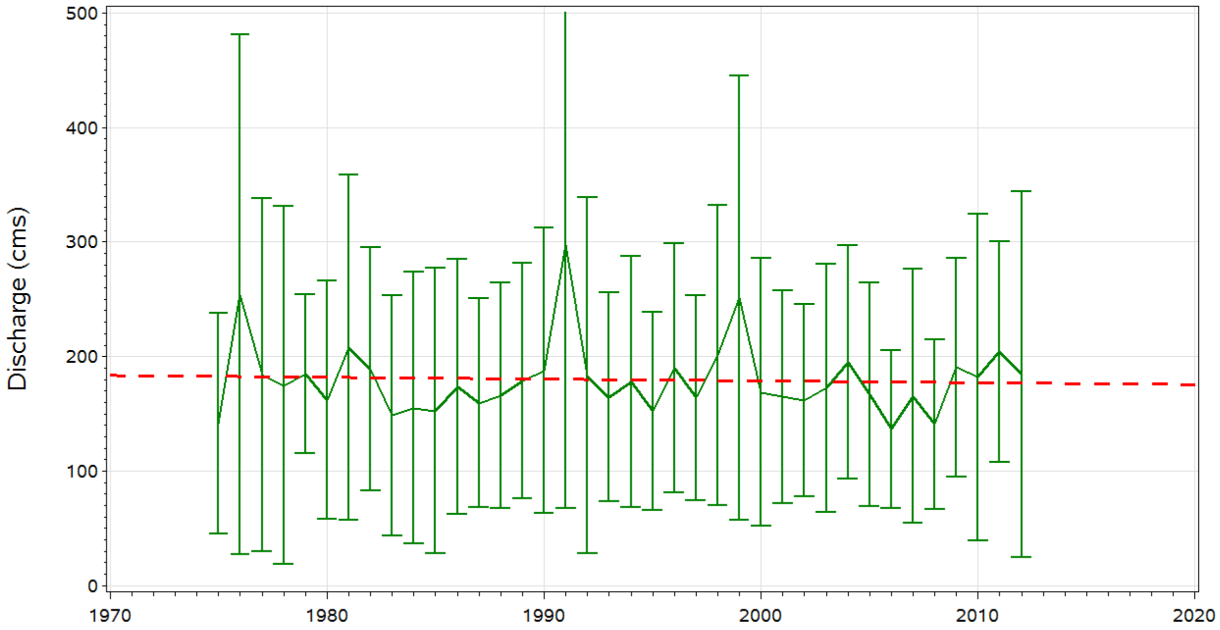


Figure 14. CHILCOTIN RIVER AT BIG CREEK - mean discharge ± 2 std deviations, August-September 1975-2012. No significant trend in time-series.

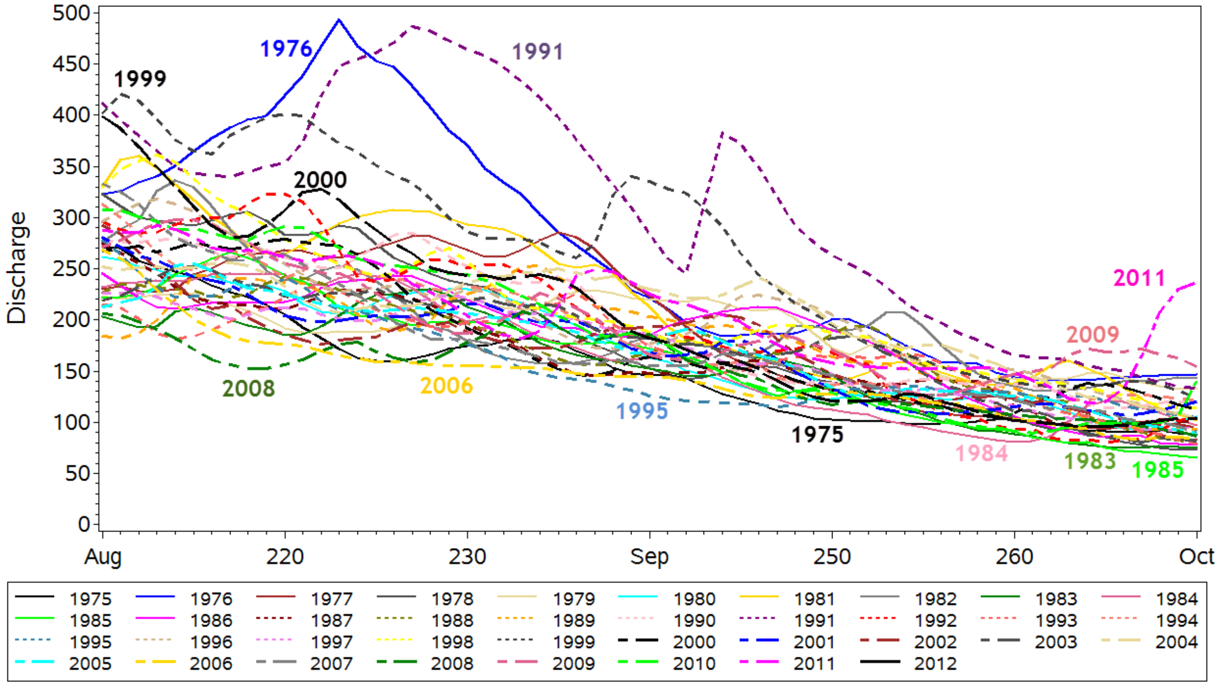


Figure 15. CHILCOTIN RIVER AT BIG CREEK mean daily discharge (cms) by year, August-September 1975-2012.

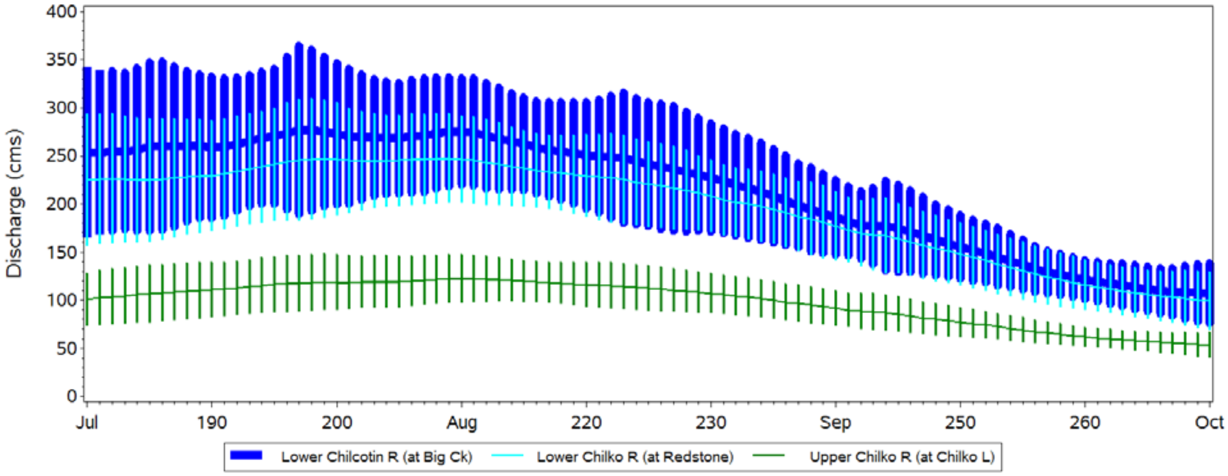
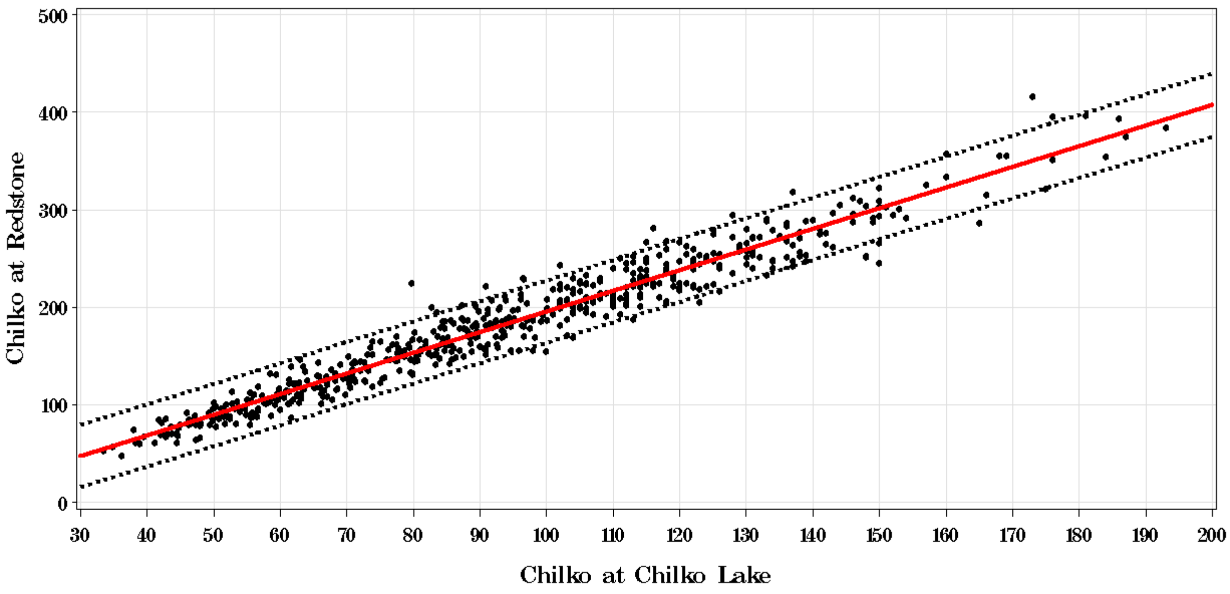
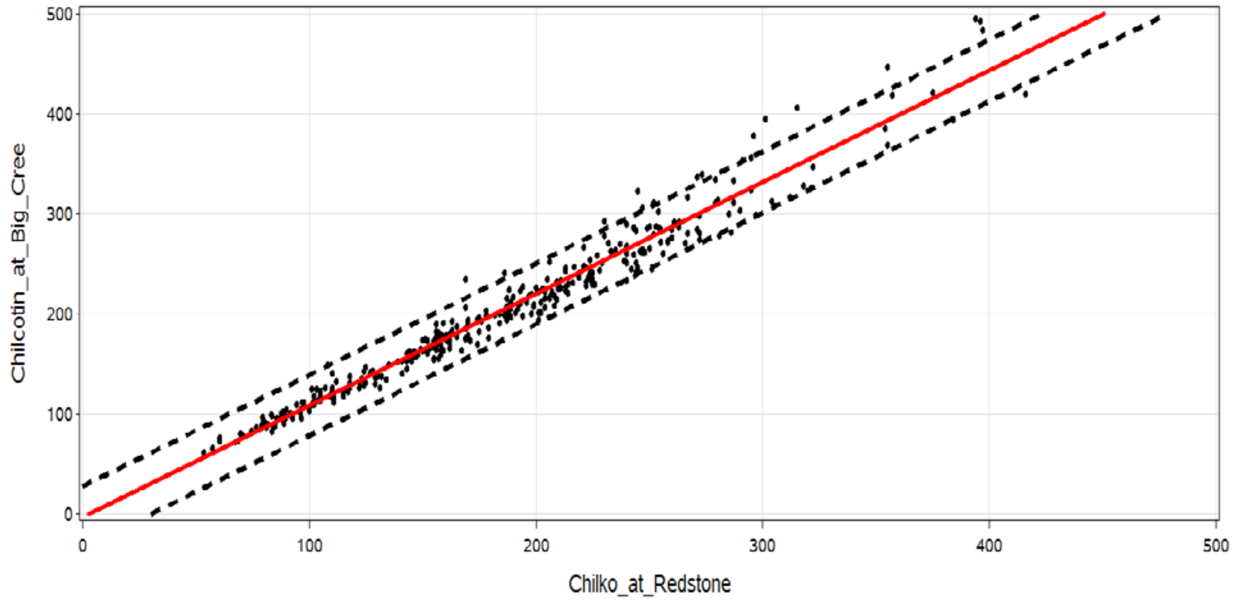


Figure 16. Observed daily mean discharge (cms) ± standard deviation during the Sockeye migration period for upper CHILKO RIVER AT CHILKO LAKE (08MA002; green), lower CHILKO RIVER AT REDSTONE (08MA001; cyan) and lower CHILCOTIN RIVER AT BIG CREEK (08MB005, blue).



```
                              Analysis of Variance

                                    Sum of           Mean
Source                    DF       Squares         Square    F Value    Pr > F

Model                      1       2549882        2549882    9643.03    <.0001
Error                    562        148608      264.42749
  Lack of Fit            299         71180      238.06094       0.81    0.9625
  Pure Error             263         77428      294.40315
Corrected Total          563       2698491


               Root MSE              16.26123    R-Square     0.9449
               Dependent Mean       184.04025    Adj R-Sq     0.9448
               Coeff Var              8.83569


                              Parameter Estimates

                                   Parameter       Standard
Variable                  DF        Estimate          Error    t Value    Pr > |t|

Intercept                  1       -16.13015        2.15035      -7.50      <.0001
Chilko_at_Chilko_Lake      1         2.11682        0.02156      98.20      <.0001
```

Figure 17. Mean daily discharge (cms) in the lower CHILKO RIVER AT REDSTONE (near Chilcotin River confluence) as a linear function of mean daily discharge in the upper CHILKO RIVER AT CHILKO LAKE during the adult Sockeye migration period (July-September, 1950-2012).



```
                              Analysis of Variance

                                       Sum of           Mean
Source                   DF           Squares         Square    F Value    Pr > F

Model                     1          59.37174       59.37174    15093.3    <.0001
Error                   340           1.33744        0.00393
  Lack of Fit           201           0.83722        0.00417       1.16    0.1784
  Pure Error            139           0.50023        0.00360
Corrected Total         341          60.70919


             Root MSE              0.06272    R-Square     0.9780
             Dependent Mean        5.21912    Adj R-Sq     0.9779
             Coeff Var             1.20171


                              Parameter Estimates

                                    Parameter       Standard
Variable                 DF          Estimate          Error    t Value    Pr > |t|

Intercept                 1           0.12805        0.04158       3.08      0.0022
Chilko_at_Redstone        1           0.99293        0.00808     122.85      <.0001
```

Figure 18. Mean daily discharge (cms) in the lower CHILCOTIN RIVER AT BIG CREEK as a linear function of mean daily discharge in the lower CHILKO RIVER AT REDSTONE (July-September, 1970-2012; top) indicated a significant lack-of-fit term in the model, which was eliminated via logarithmic transformation. Regression parameter estimates for the final $Y = aX^b$ model were $a = 1.137$ and $b = 0.99$ (based on ANOVA results, bottom).

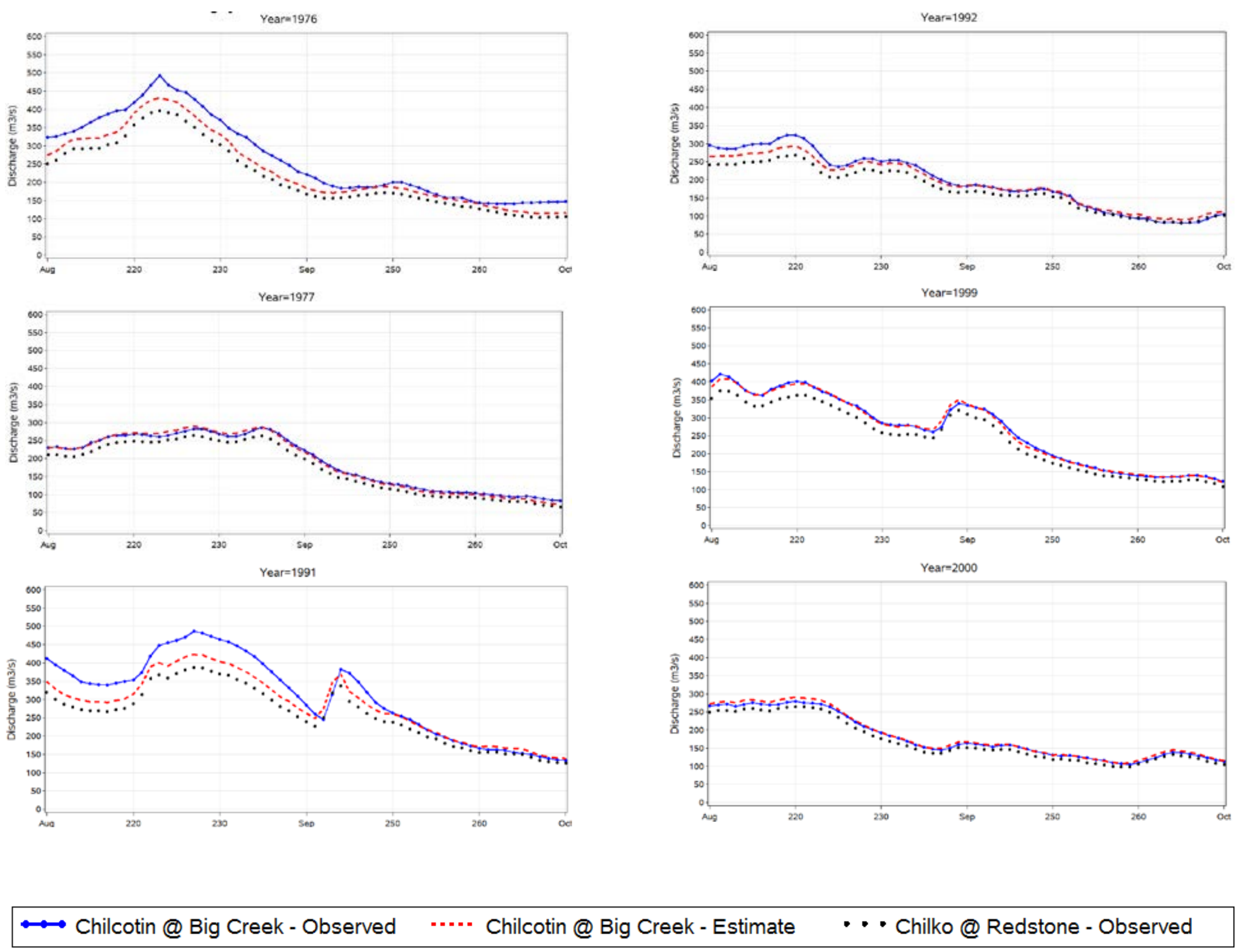


Figure 19. Observed (blue line) and estimated (red dashed line) daily discharge (cms) in the lower Chilcotin River at Big Creek based on predictive log-linear regression with Chilko River at Redstone daily discharge (black dotted line).

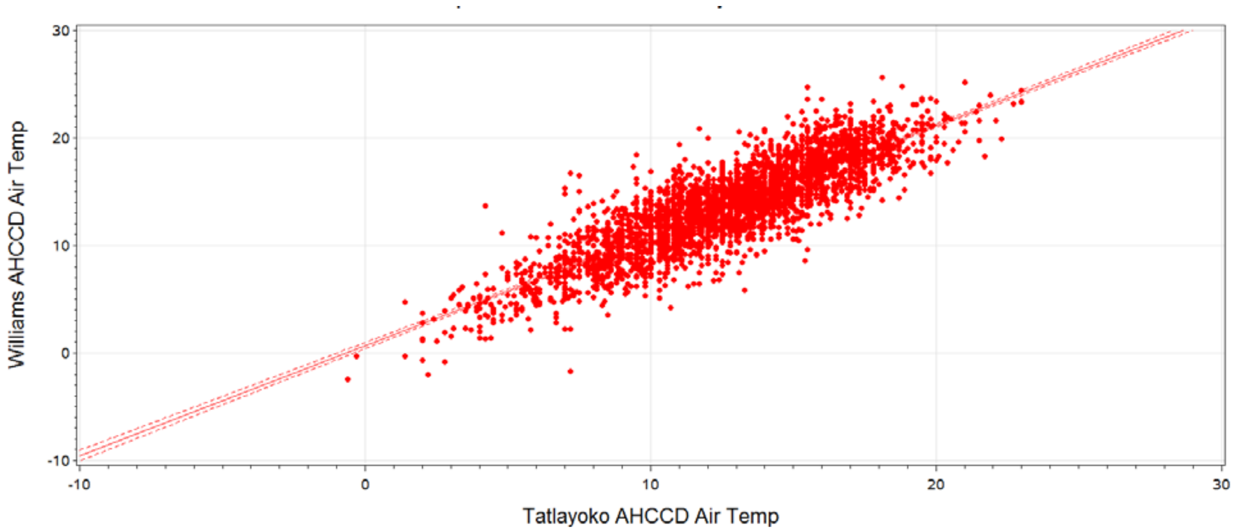


Figure 20. WILLIAMS LAKE daily air temperature as a function of regional AHCCD station air temperature at TATLAYOKO LAKE (r = 0.84; P = 0.001; n > 3,000).

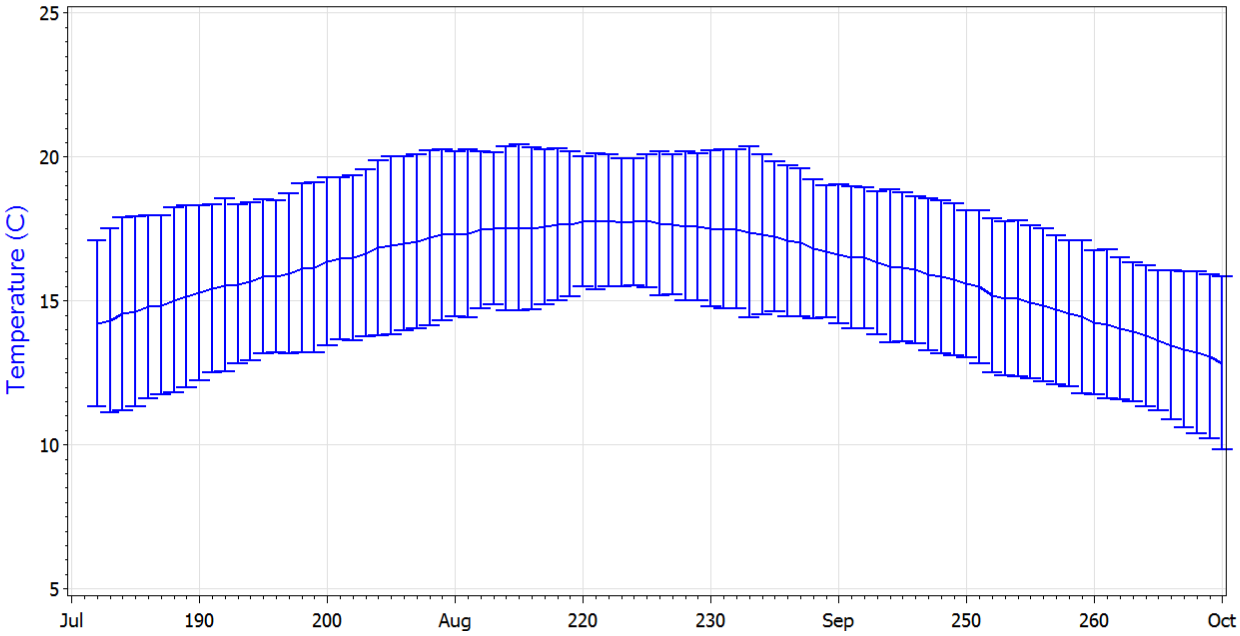
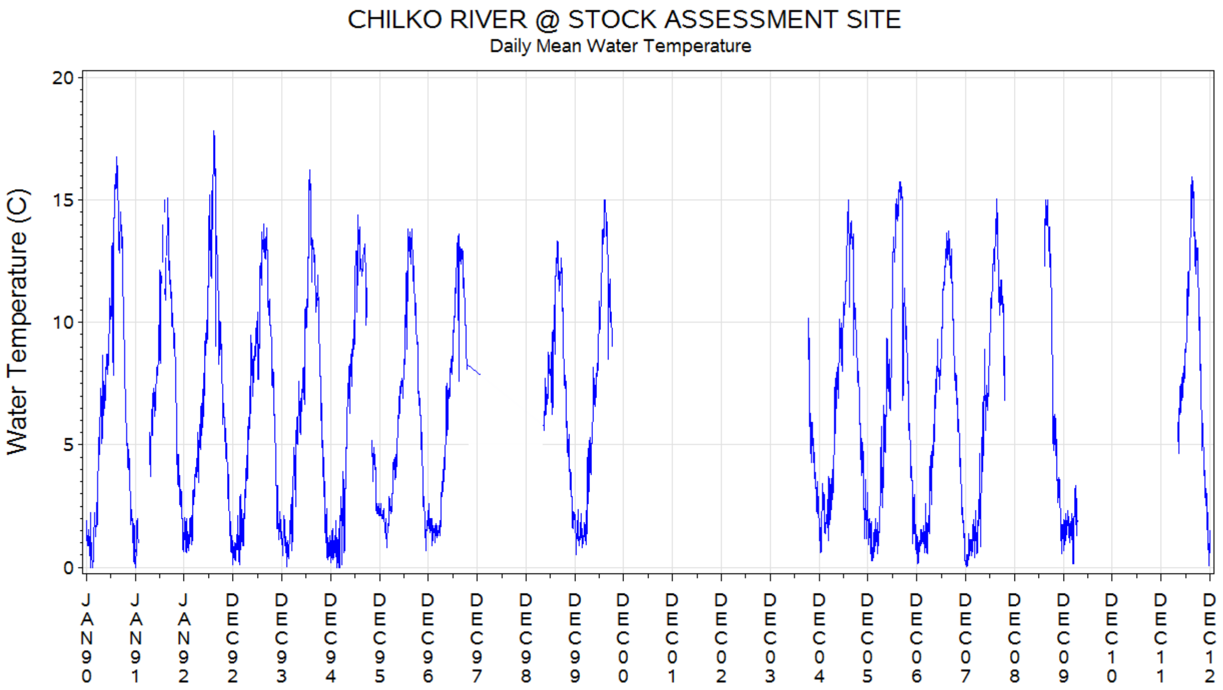


Figure 21. FRASER RIVER (AT QUALARK) daily mean water temperature observations as July-October, 1940-2012.



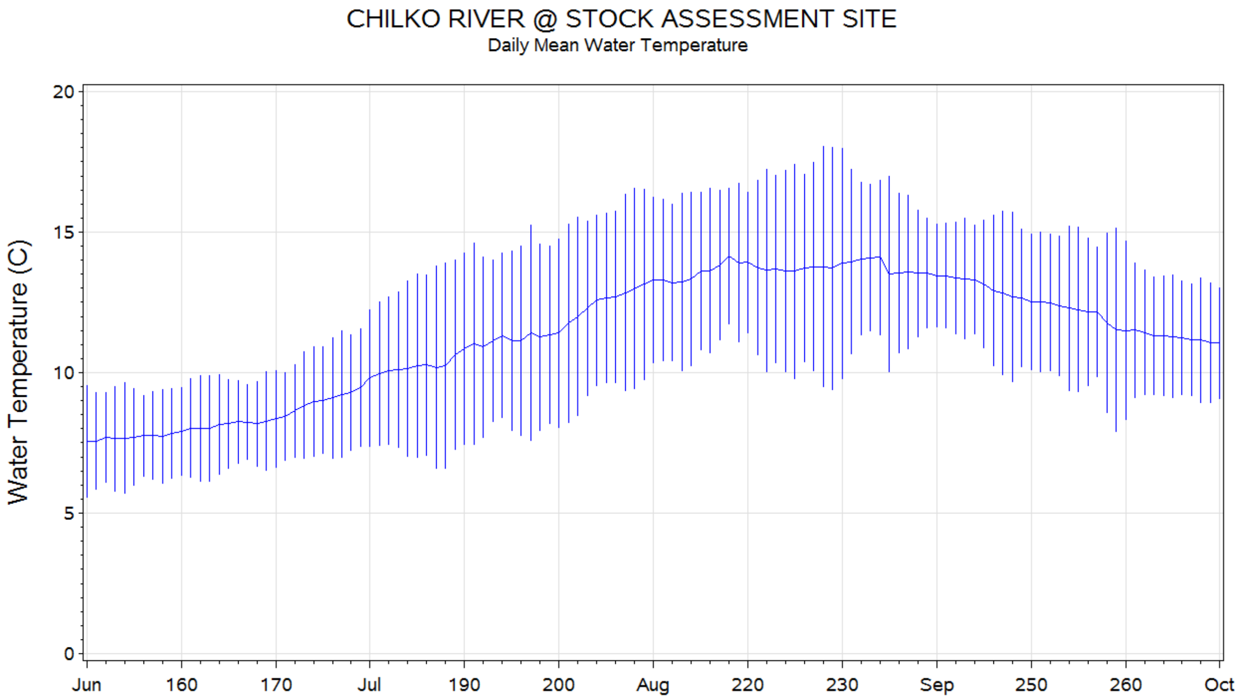


Figure 22. Chilko River daily water temperature observations at the stock assessment site (top) and annual thermograph of mean water temperature ± two standard deviations (bottom), 1990-1997, 1999-2000, 2004-2008, 2009, 2012. (Source: DFO Stock Assessment & Environmental Watch Program).

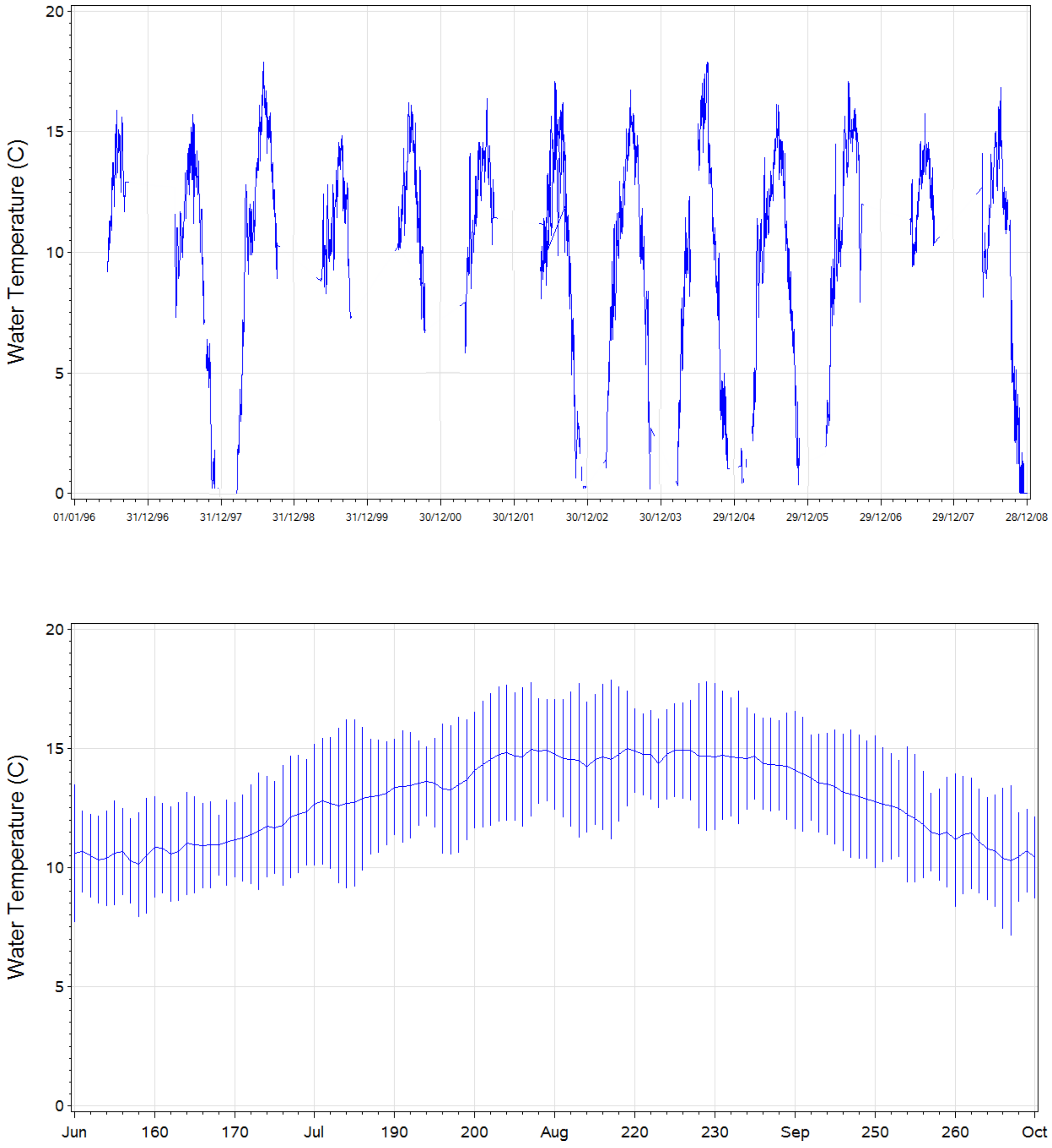
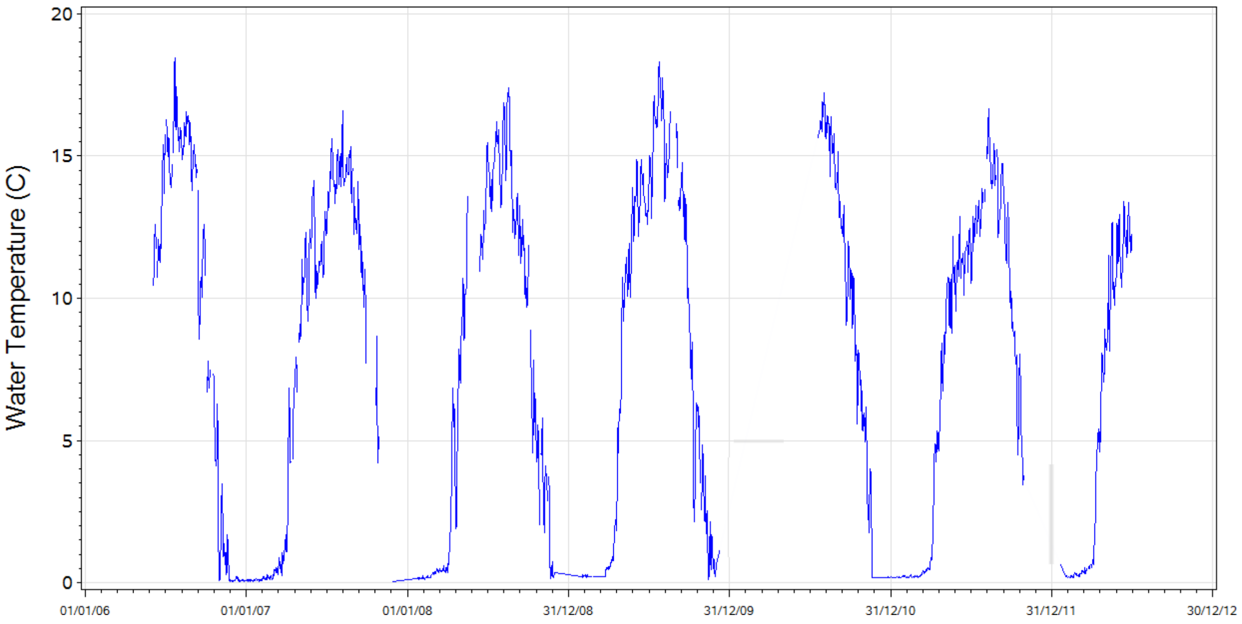


Figure 23. Chilcotin River (near Alexis Creek) daily water temperature observations (top) and annual thermograph of mean daily water temperature ± two standard deviations (bottom), 1996-2008. (Source: DFO Environmenal Watch Program).



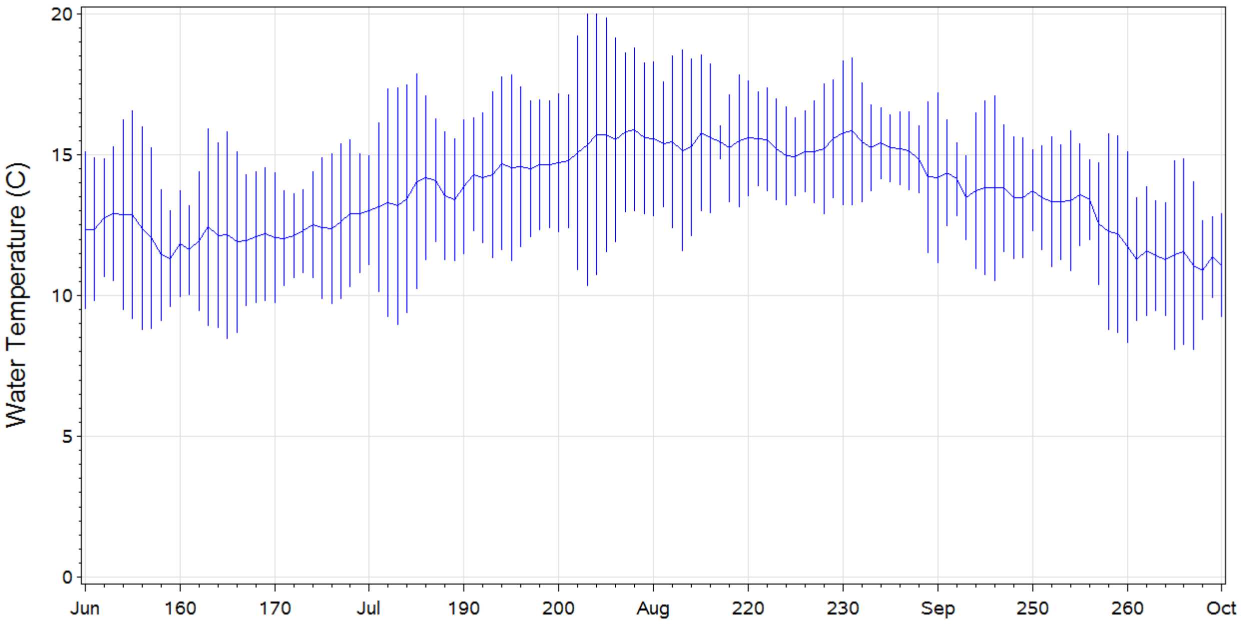


Figure 24. Chilcotin River (near Big Creek) daily water temperature observations (top) and annual thermograph of mean daily water temperature ± two standard deviations (bottom), 2006-2012. (Source: DFO ENVIRONMENAL WATCH PROGRAM).

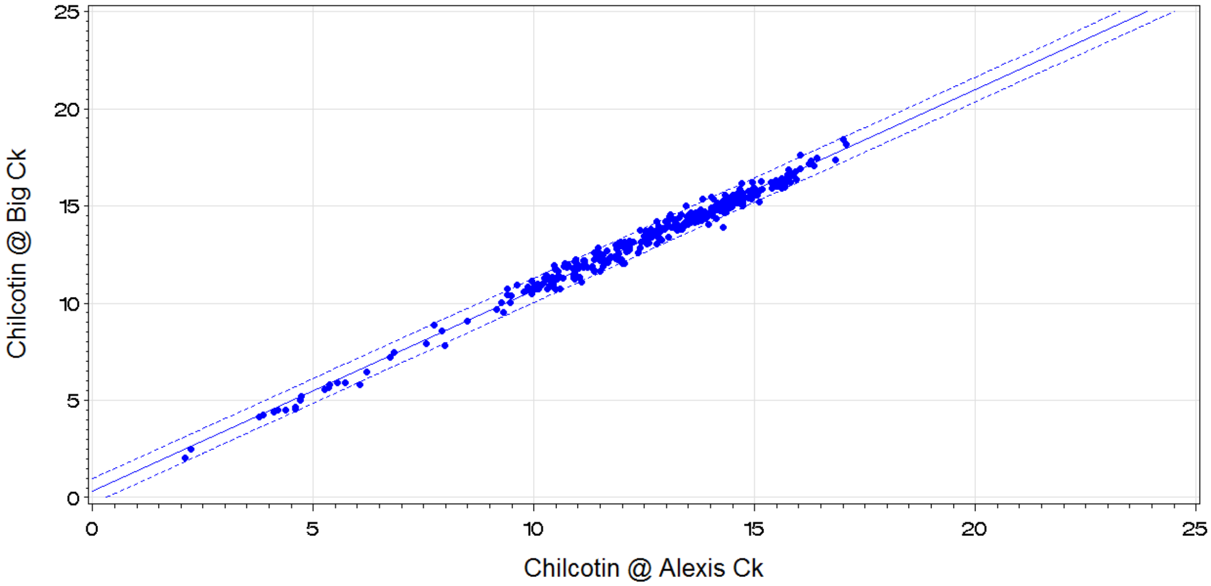


Figure 25. CHILCOTIN RIVER (NEAR BIG CREEK) daily mean water temperature observations as a function of CHILCOTIN RIVER (NEAR ALEXIS CREEK), June-October, 2006-2008 (r = 0.987; P < 0.001; n=340; a=0.324; b=1.033).

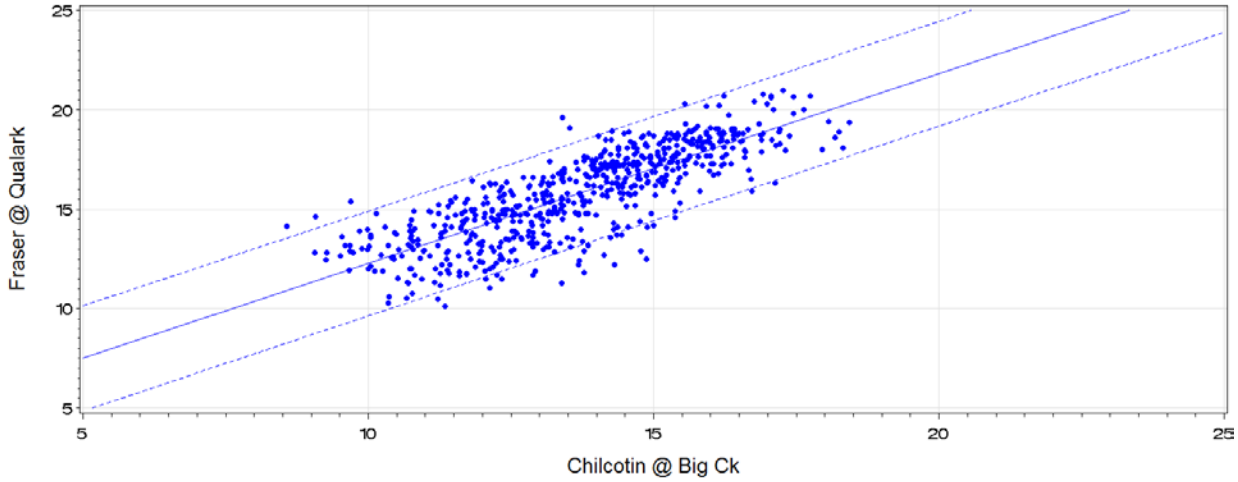


Figure 26. CHILCOTIN RIVER (NEAR BIG CREEK) daily mean water temperature observations as a function of FRASER RIVER (AT QUALARK), June-October, 2006-2008 (r = 0.83; P < 0.001; n=630; a=2.73; b=0.954).

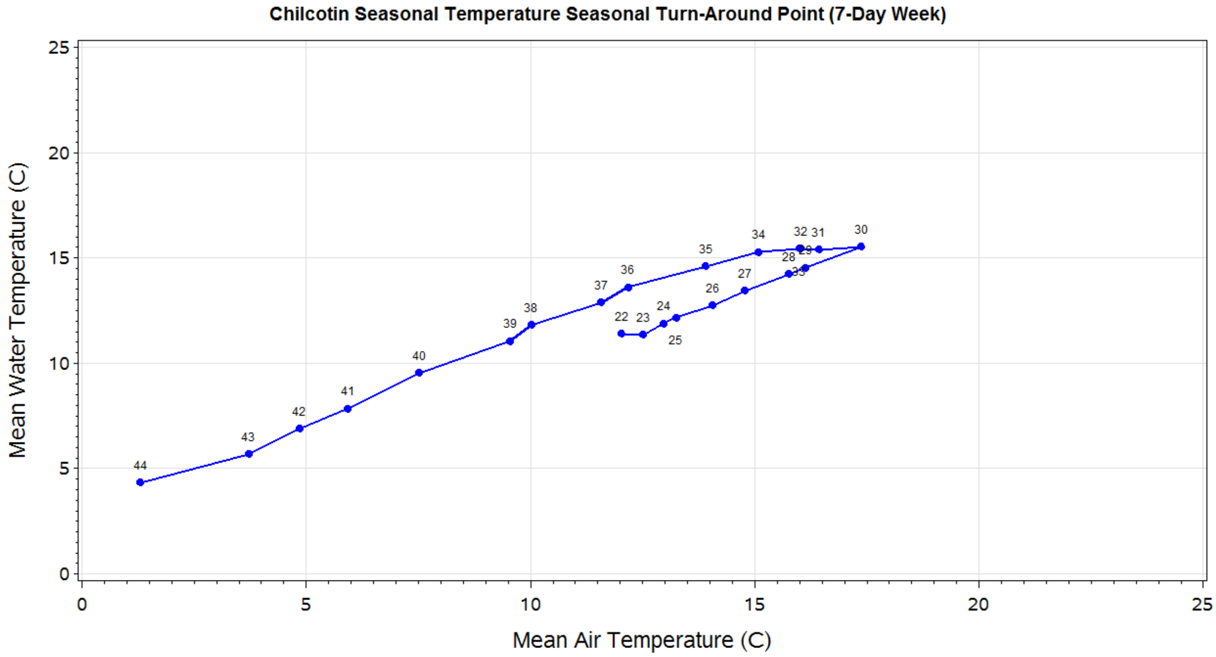


Figure 27. Derivation of seasonal turn-around point for Chilcotin River (at Big Creek), based on maximum weekly mean air and water temperature data. The seasonal turn-around point was week 30 (day 210), approximately August 2nd. The "warming season" therefore extends from April 1st to August 2nd, followed by the "cooling season" from day 211-329, i.e.August 3rd - November 25th.

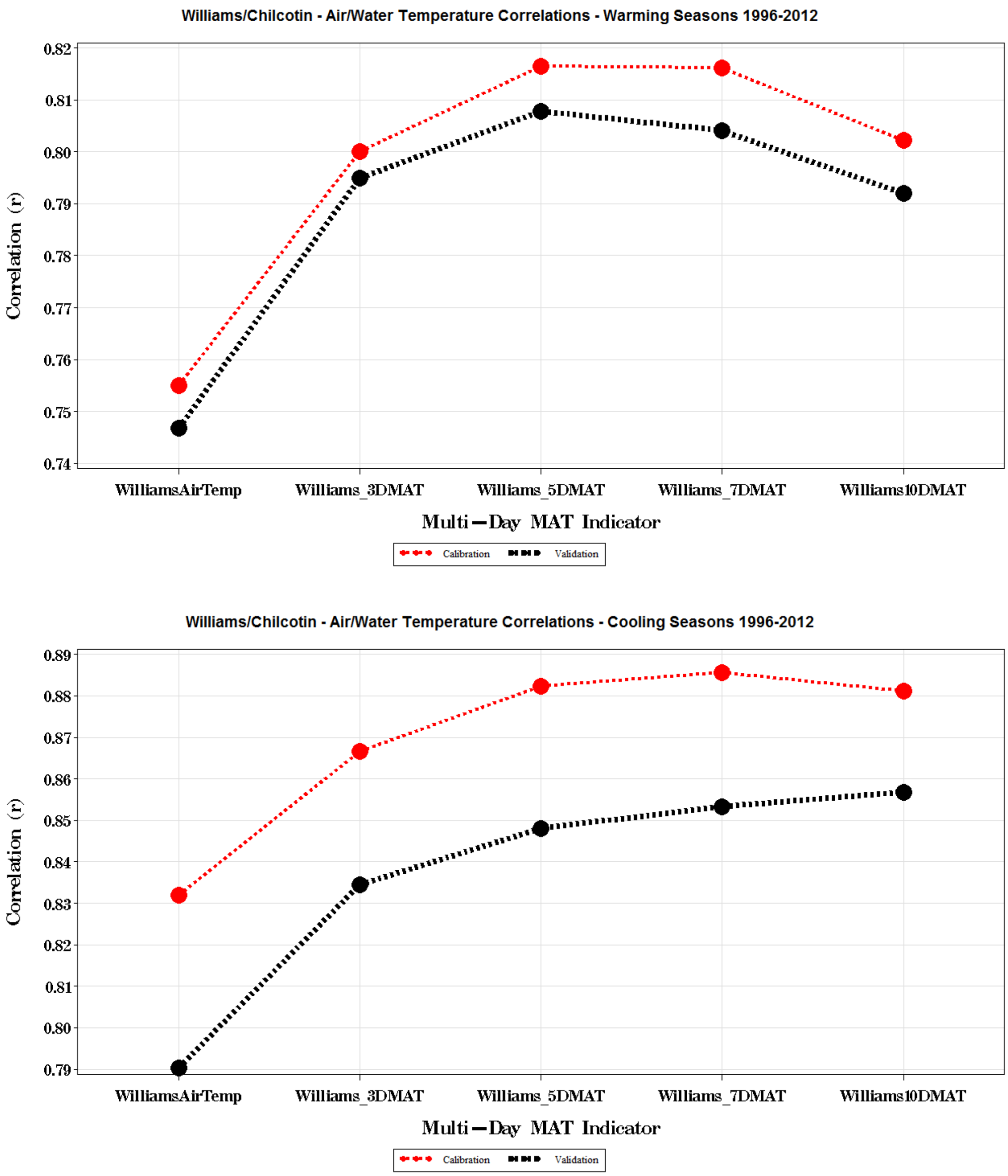


Figure 28. Derivation of optimum regional air temperature index for air/water temperature analyses, based on maximum all-year correlation between various Williams Lake multi-day mean air temperature indicators (MATs) with lower Chilcotin River daily mean water temperature (MWT) for calibration (red) and validation data; warming season (top), cooling season (bottom). Williams air temperature indicators include (l-r): Williams AirTemp (same day mean); Williams 3-day centered moving average air temperature (3d-MAT), 5d-MAT, 7d-MAT, and 10d-MAT.

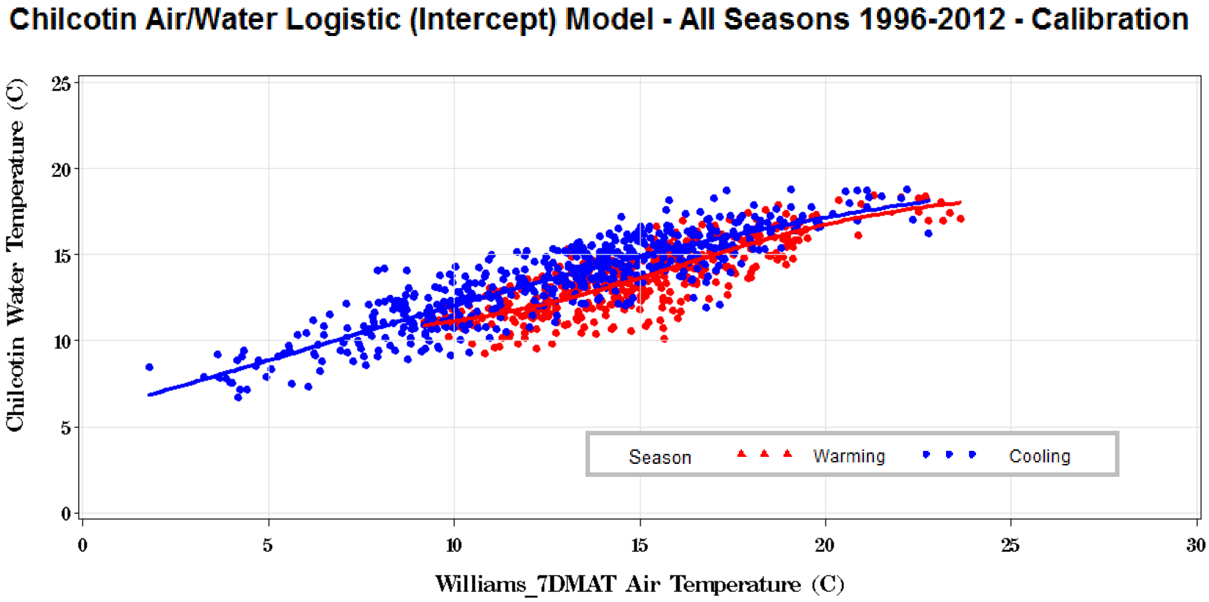


Figure 29. Logistic regression fits for air/water temperature relationship for lower CHILCOTIN RIVER (at Big Creek) daily mean water temperatures as a function of the WILLIAMS LAKE 7d-MAT (centered moving air temperature index) for calibration data years (see Table 11) by season (warming season: red; cooling season: blue).

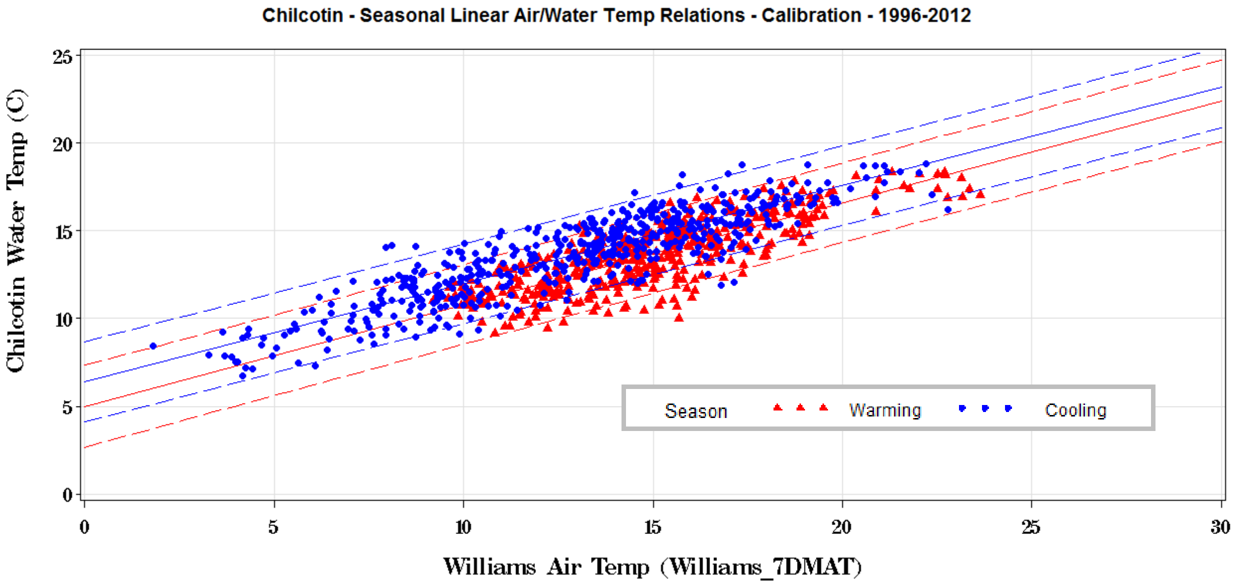


Figure 30. Linear regression fits for air/water temperature relationship for lower CHILCOTIN RIVER (at Big Creek) daily mean water temperatures as a function of the WILLIAMS LAKE 7d-MAT (centered moving air temperature index) for calibration data years (see Table 11), by season (warming season: red; cooling season: blue).

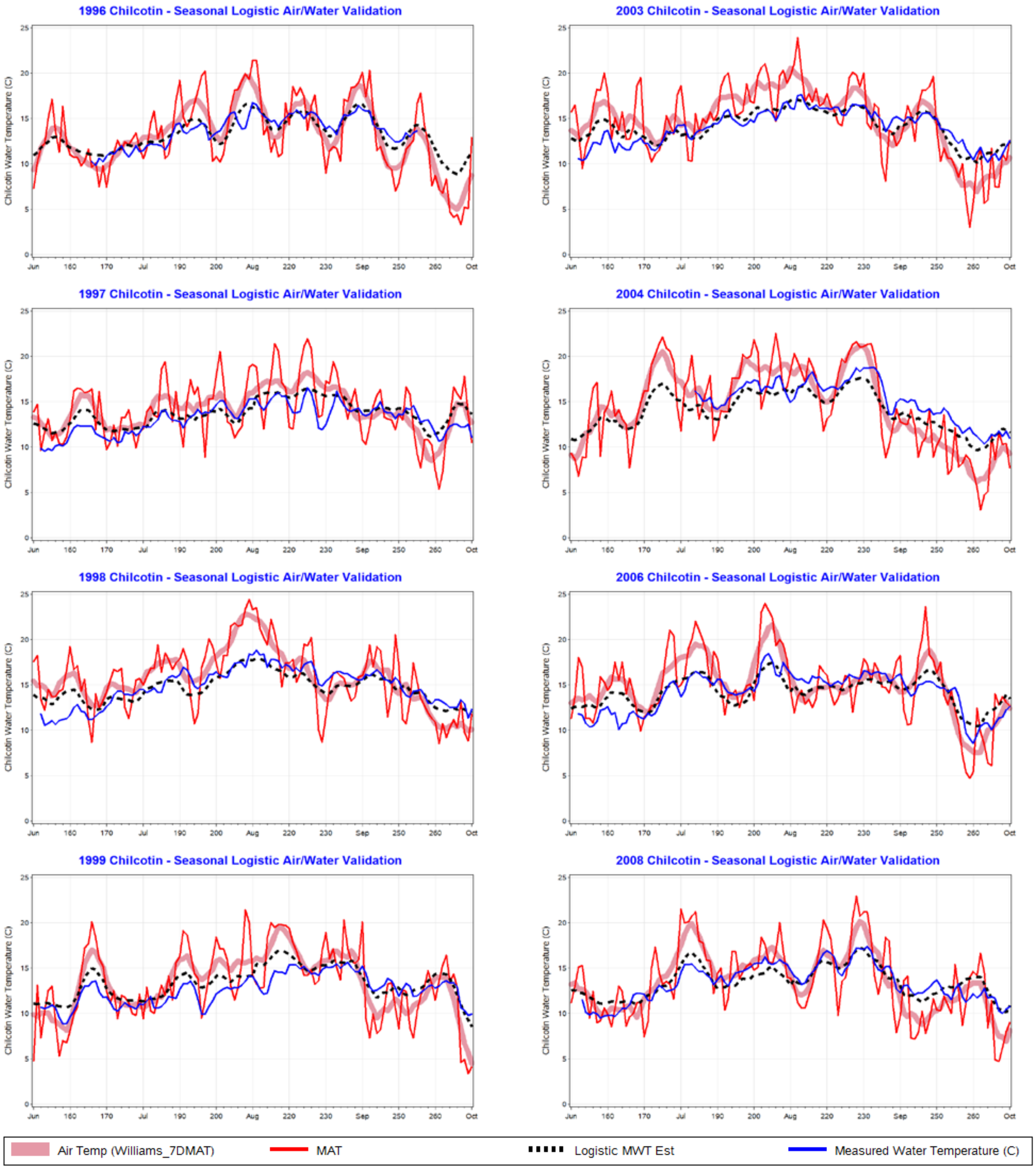


Figure 31. Sample plots of daily mean air temperature (red line), 7-day CMAT index (broad pink line), observed daily mean water temperature (blue solid line) and estimated daily MWT (black dashed line; based on seasonal logistic regression models) for lower Chilcotin River (at Big Creek), June-September 1996-1999, 2003, 2004, 2006, 2008.

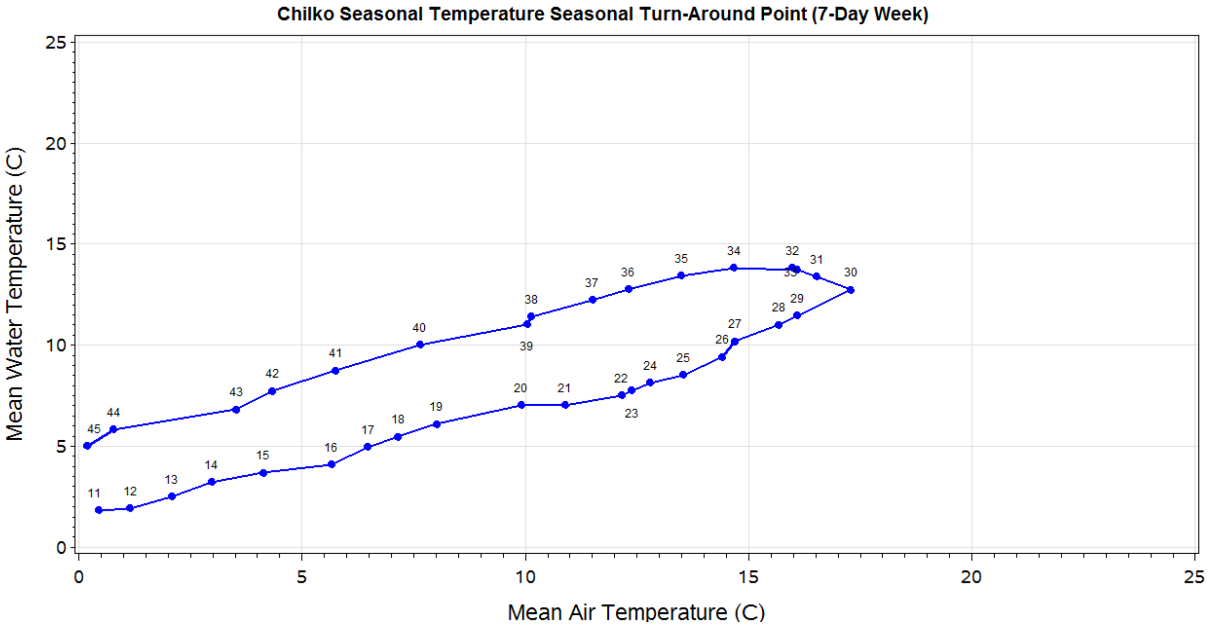


Figure 32. Derivation of seasonal turn-around point for Chilko River, based on maximum weekly mean air and water temperature data. The seasonal turn-around point was week 30 (day 210), approximately August 2nd. The “warming season” therefore extends from April 1st to August 2nd, followed by the “cooling season” from day 211-329, i.e.August 3rd - November 25th.

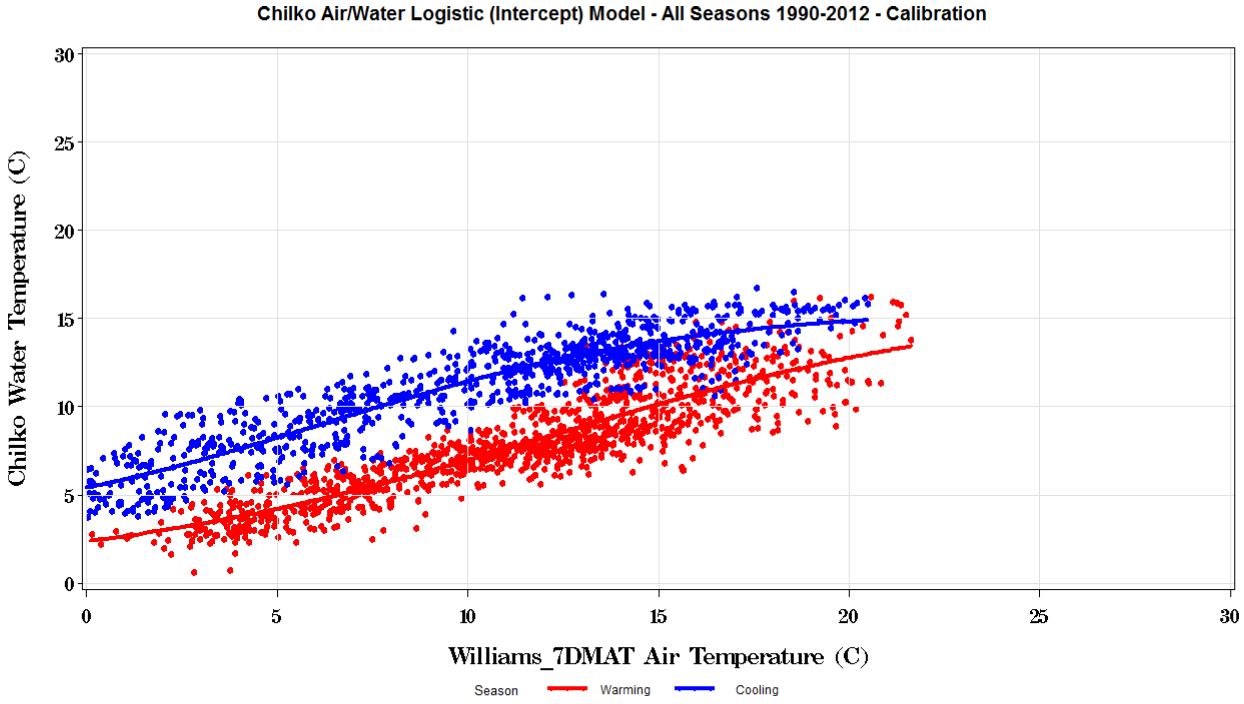

Chilko Air/Water Logistic (Intercept) Model - All Seasons 1990-2012 - Calibration

Figure 33. Logistic regression fits for air/water temperature relationship for CHILKO RIVER daily mean water temperatures as a function of the WILLIAMS LAKE 7d-CMAT (air temperature index) for calibration data years (see Table 16) by season (warming season: red; cooling season: blue).

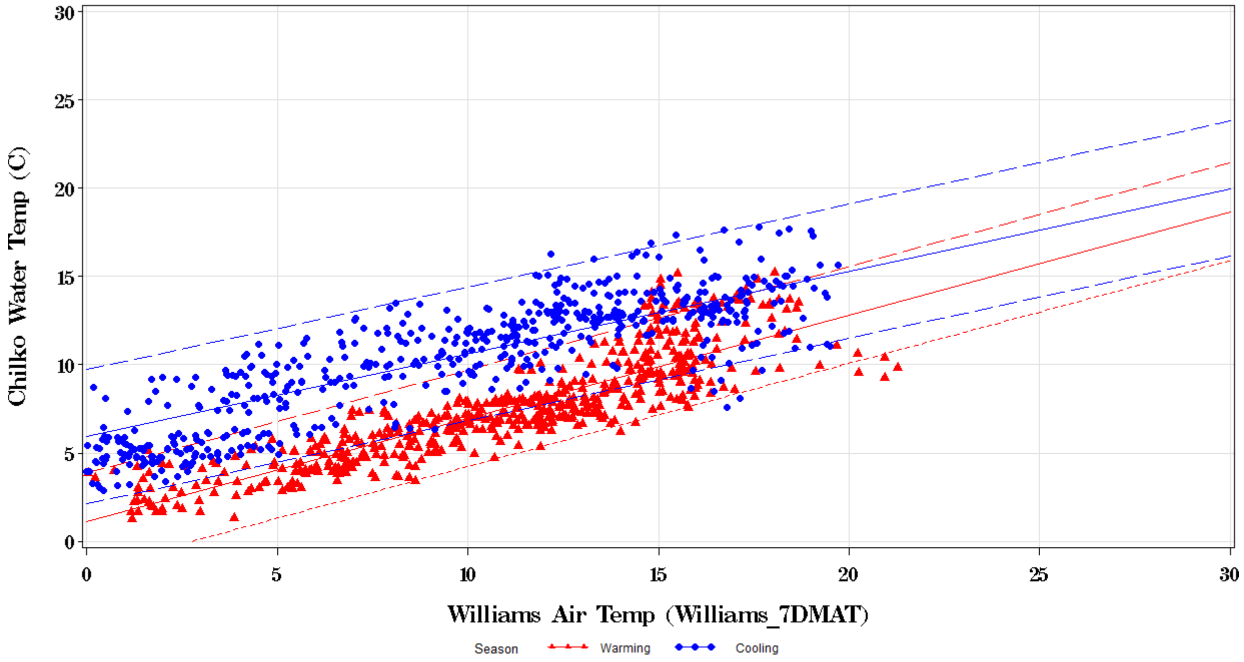


Figure 34. Linear regression fits for air/water temperature relationship for CHILKO RIVER daily mean water temperatures as a function of the WILLIAMS LAKE 7d-CMAT (air temperature index) for calibration data years (see Table 16), by season (warming season: red; cooling season: blue).

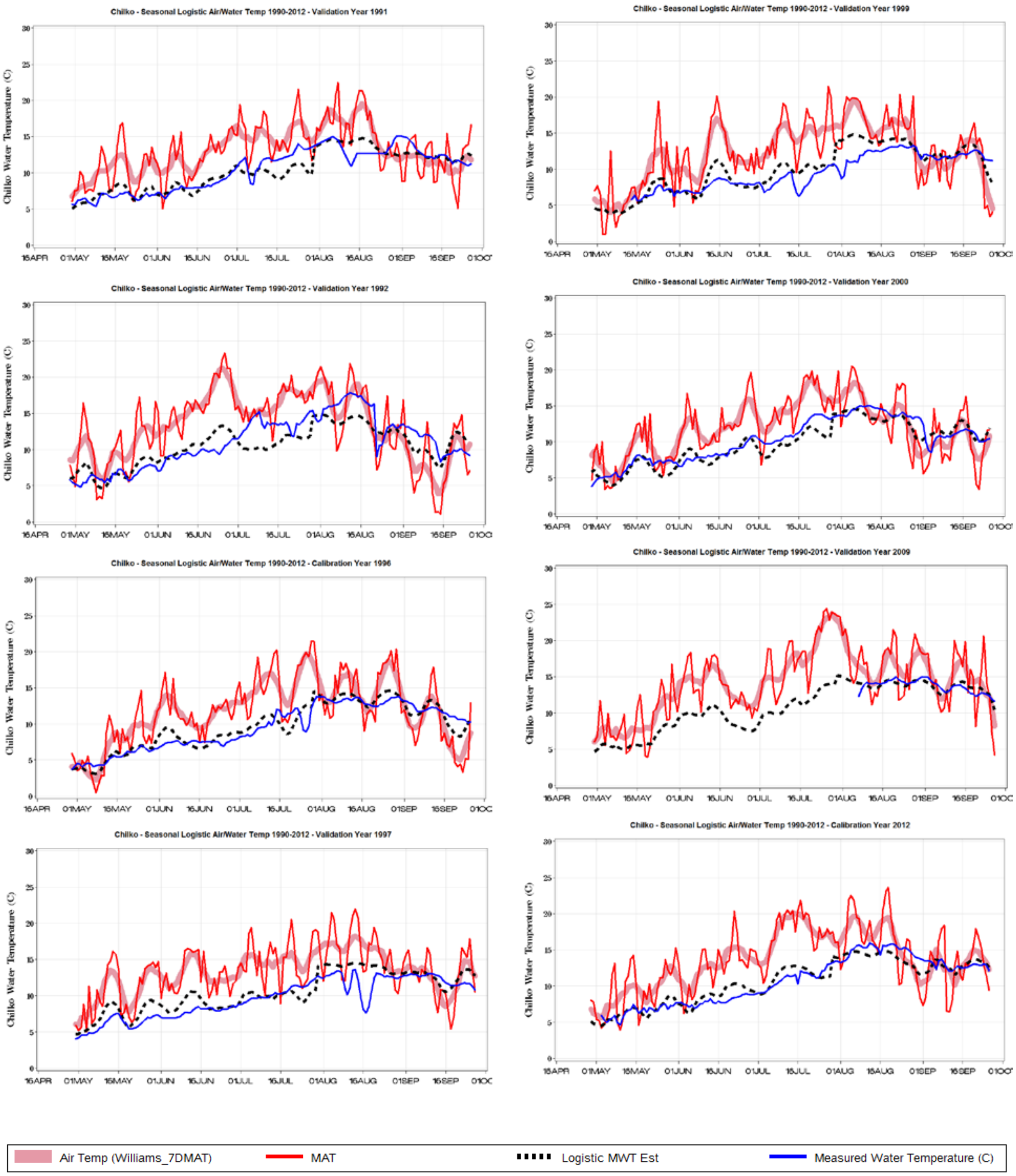


Figure 35. Sample plots of daily mean air temperature (red line), 7-day MAT index (broad pink line), observed daily mean water temperature (blue solid line) and estimated MWT (black dashed line; based on seasonal logistic regression models) for Chilko River, May-September.

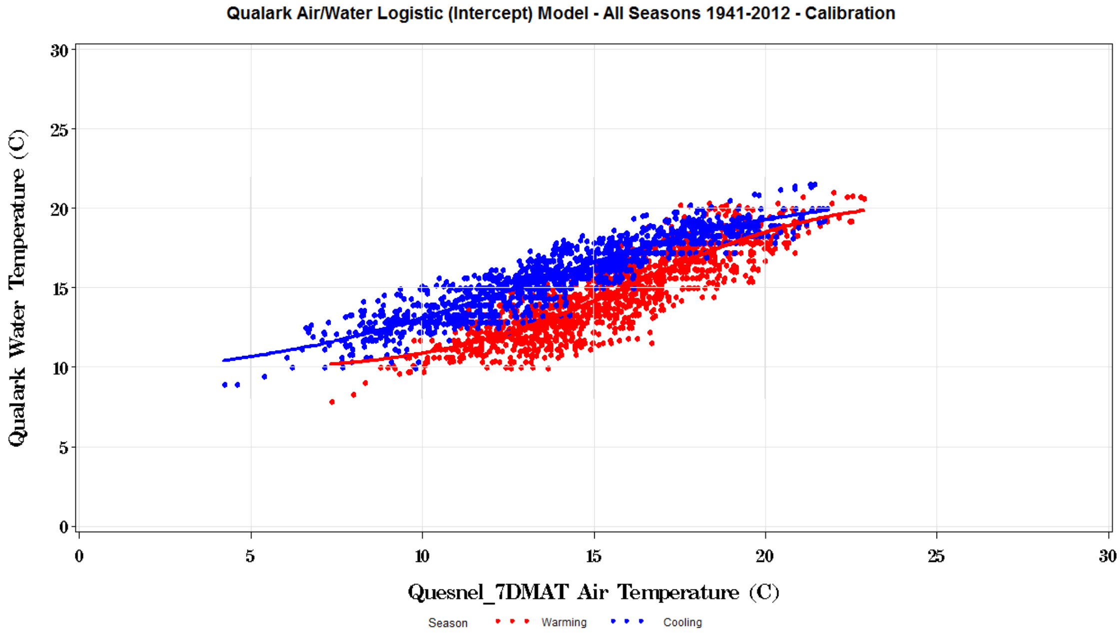


Figure 36. Logistic regression fits for air/water temperature relationship for the (lower) Fraser River at Qualark daily mean water temperatures as a function of the Quesnel 7d-CMAT (air temperature index) for calibration data years (see) by season (warming season: red; cooling season: blue).

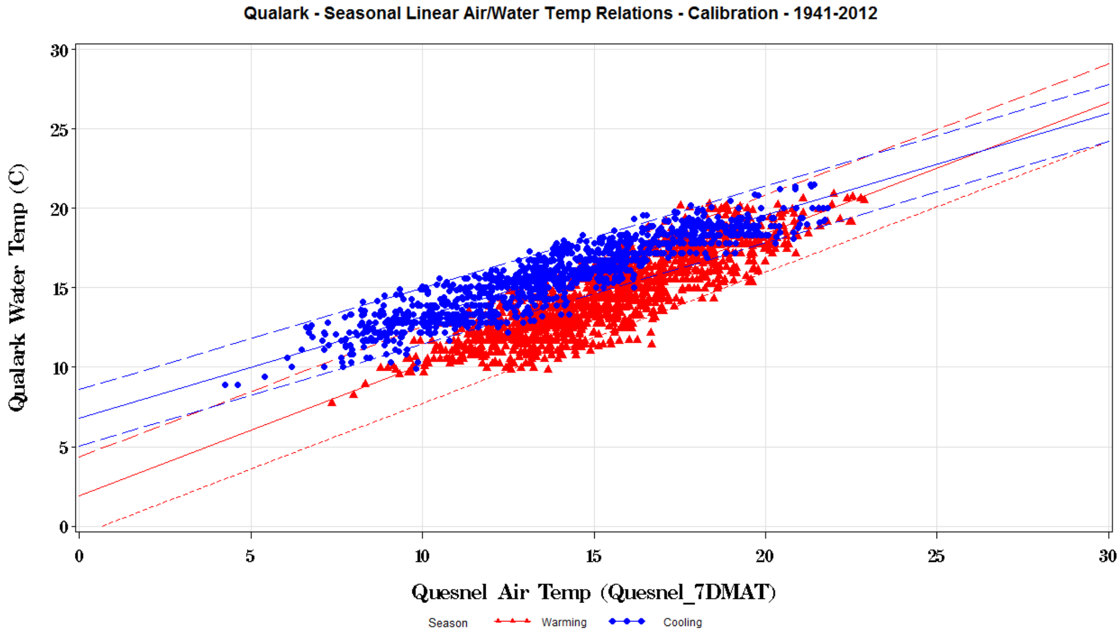


Figure 37. Linear regression fits for air/water temperature relationship for the (lower) Fraser River at Qualark daily mean water temperatures as a function of the Quesnel 7d-CMAT (air temperature index) for calibration data years (see), by season (warming season: red; cooling season: blue).

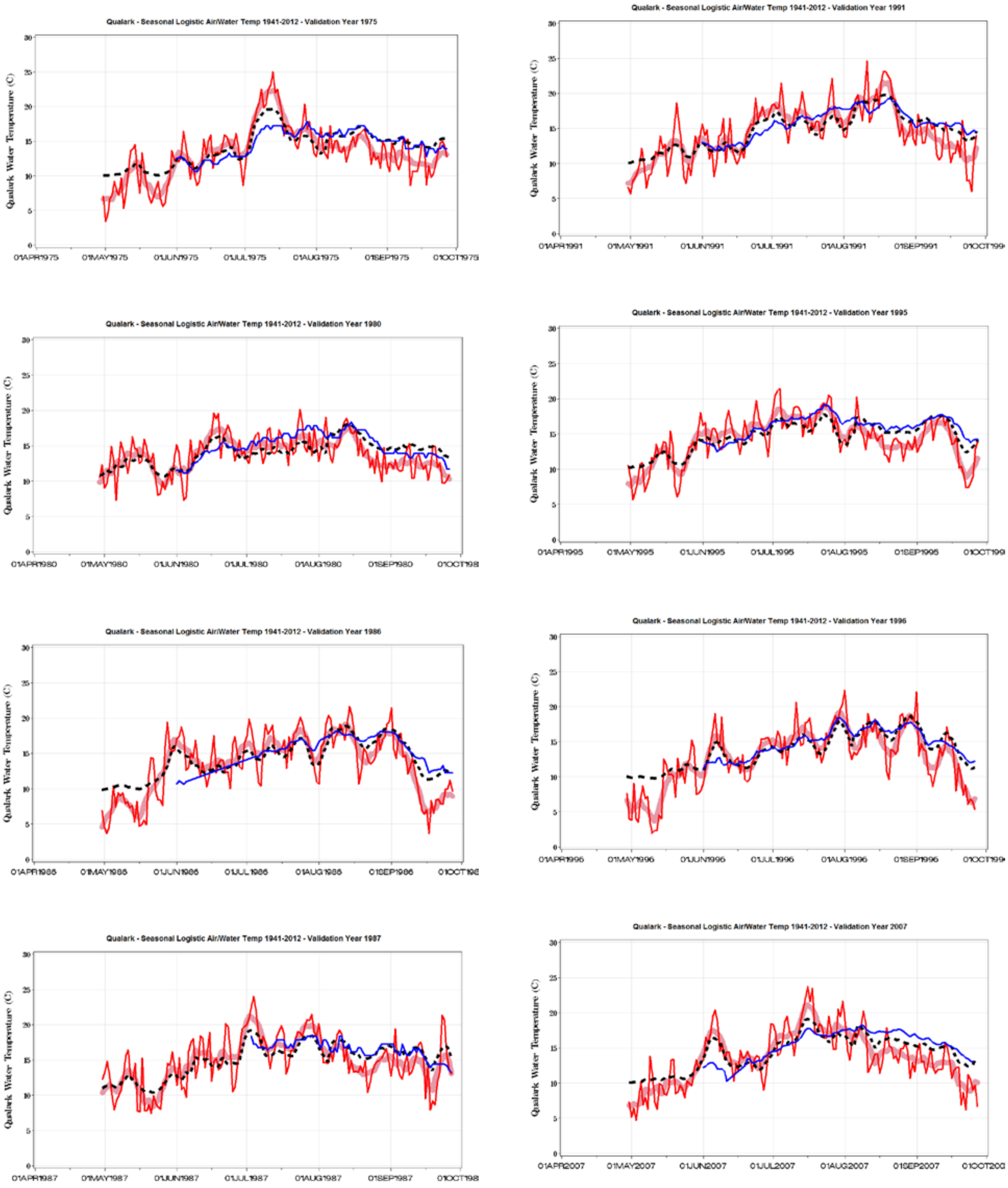


Figure 38. Validation plots of daily mean air temperature (red line), 7-day MAT index (broad pink line), observed daily mean water temperature (blue solid line) and estimated MWT (black dashed line; based on seasonal logistic regression models) for FRASER RIVER AT QUALARK, May-September.

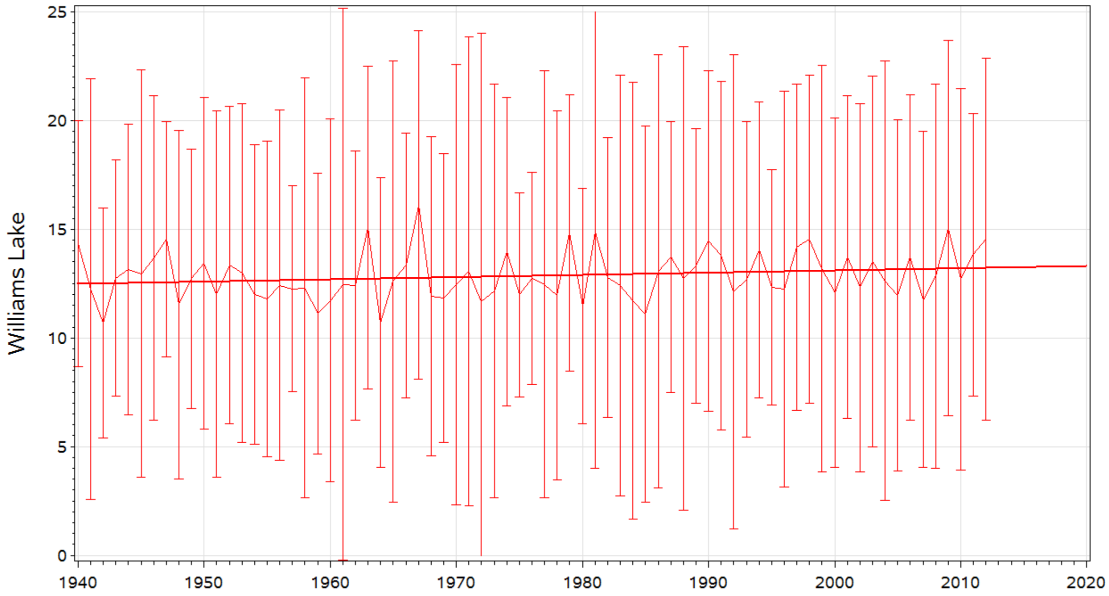


Figure 39. Observed and estimated WILLIAMS LAKE AHCCD station mean seasonal air temperature ± 2 std deviations, August-September 1940-2012. Weak long-term warming trend is evident (Y = -7.5 + 0.010 * Year; r = 0.05; P < .001).

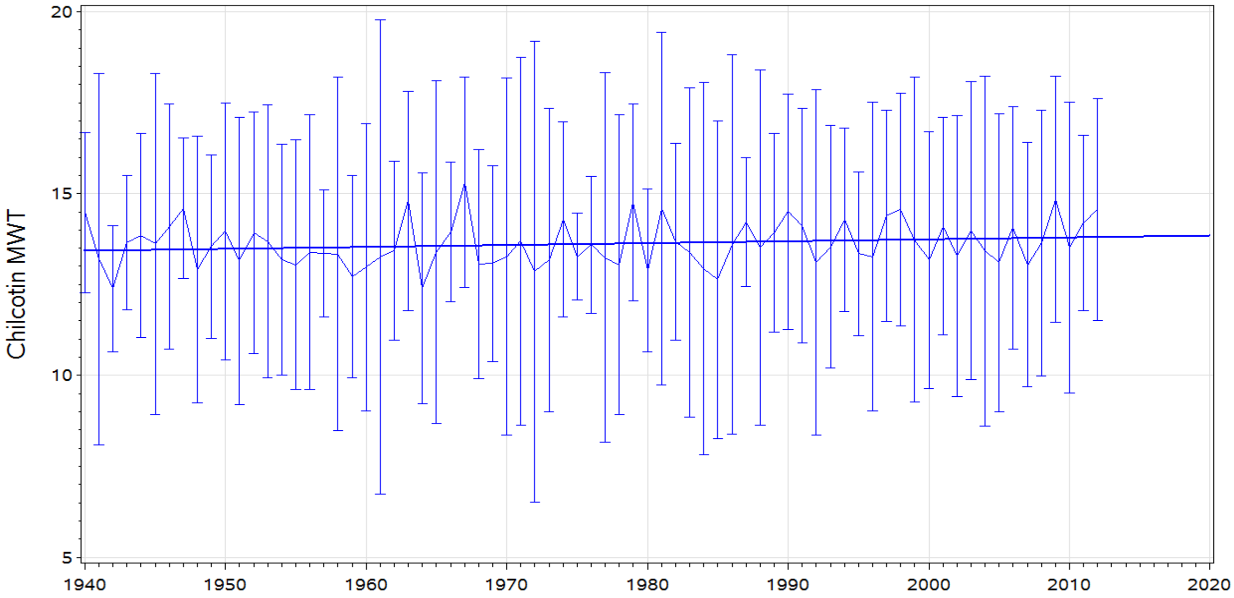


Figure 40. Estimated CHILCOTIN RIVER (at BIG CREEK) mean seasonal water temperature ± 2 std deviations, August-September 1940-2012, based on seasonal logistic air/water temperature regression models. Weak significant long-term trend is evident (Y = 2.76 + 0.005 * Year; r = 0.06; P < .001).

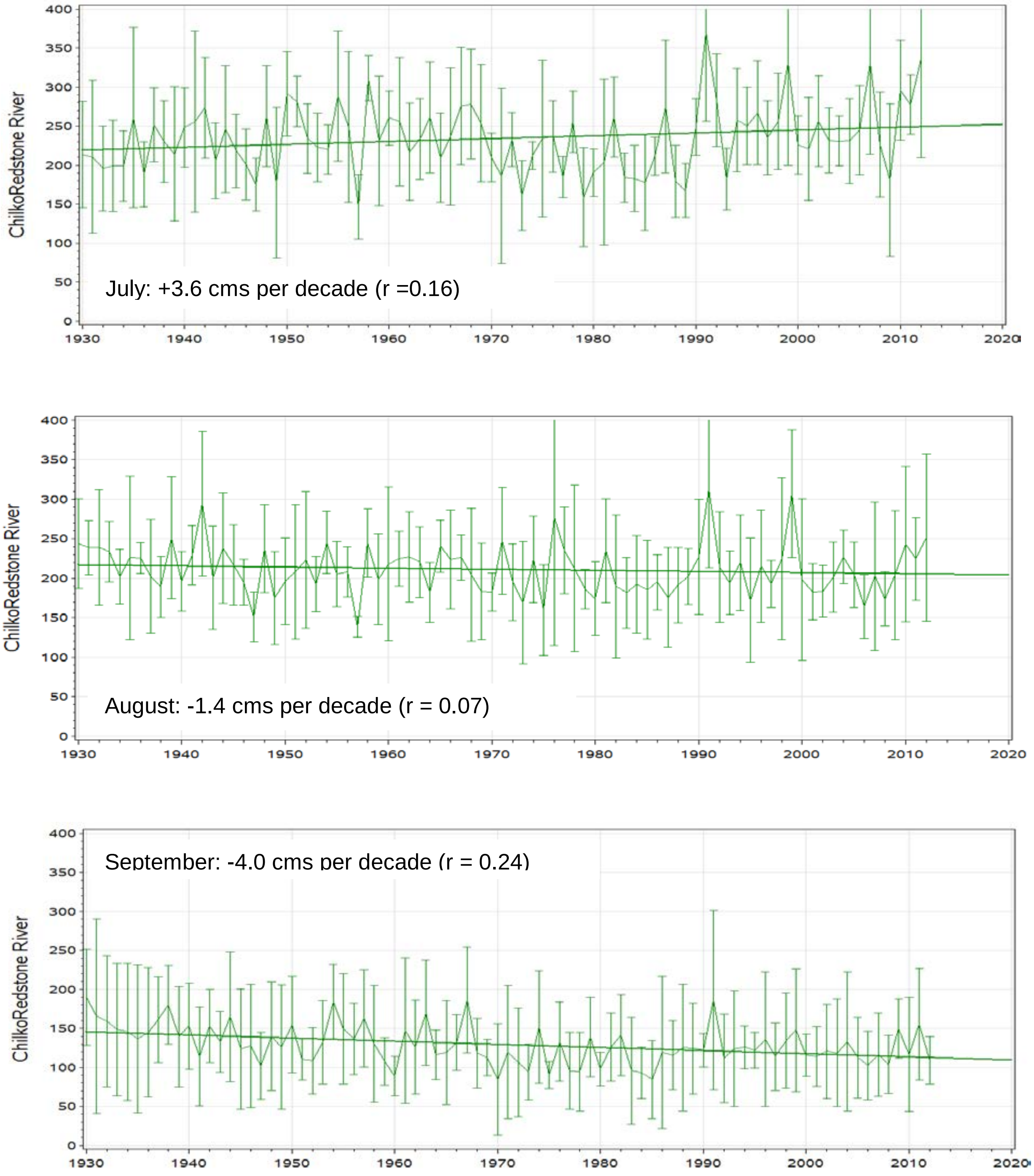


Figure 41. Observed LOWER CHILKO RIVER (AT REDSTONE) mean summer discharge ± 2 standard deviations, July-August-September, 1927-2012.

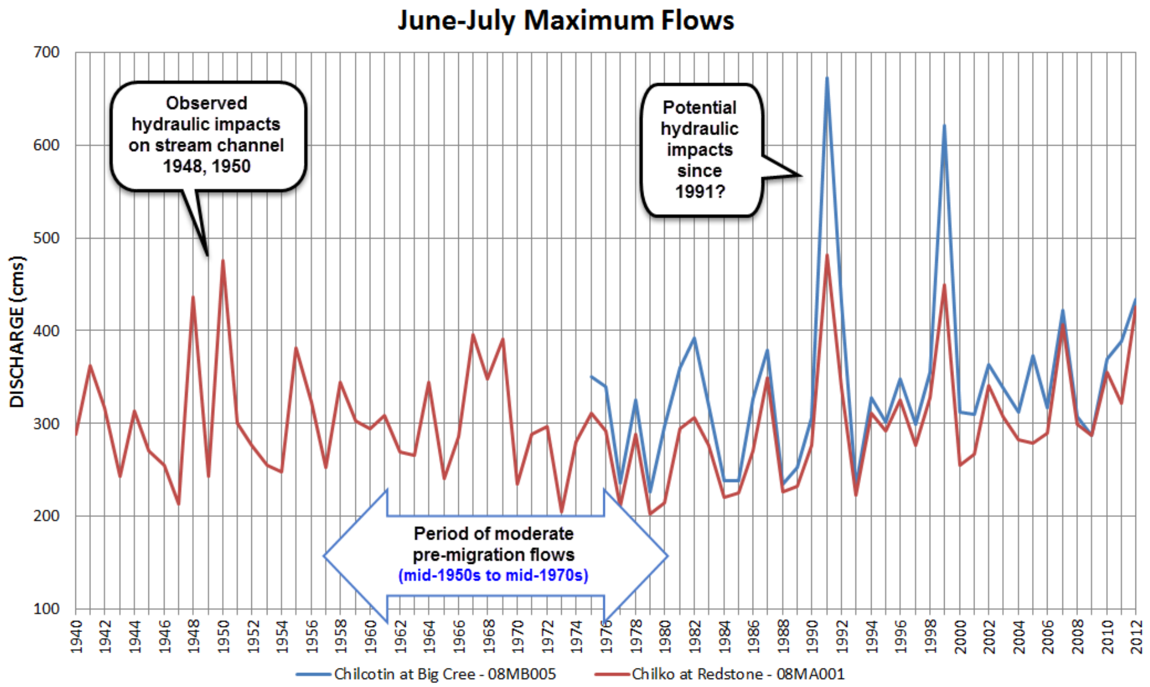


Figure 42. Observed maximum discharges in the LOWER CHILKO RIVER (AT REDSTONE) and LOWER CHILCOTIN RIVER (AT BIG CREEK) prior to adult migration, June-July, 1940-2012.

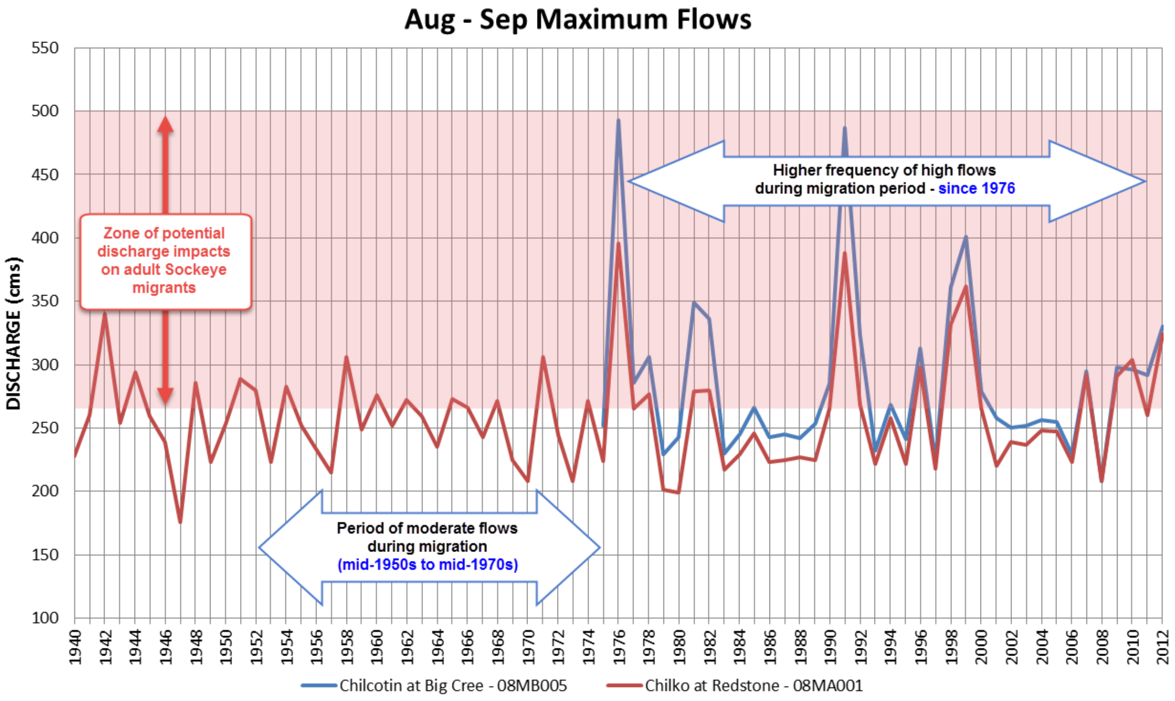


Figure 43. Observed maximum discharges in the LOWER CHILKO RIVER (AT REDSTONE) and LOWER CHILCOTIN RIVER (AT BIG CREEK) during adult migration, August-September, 1940-2012.

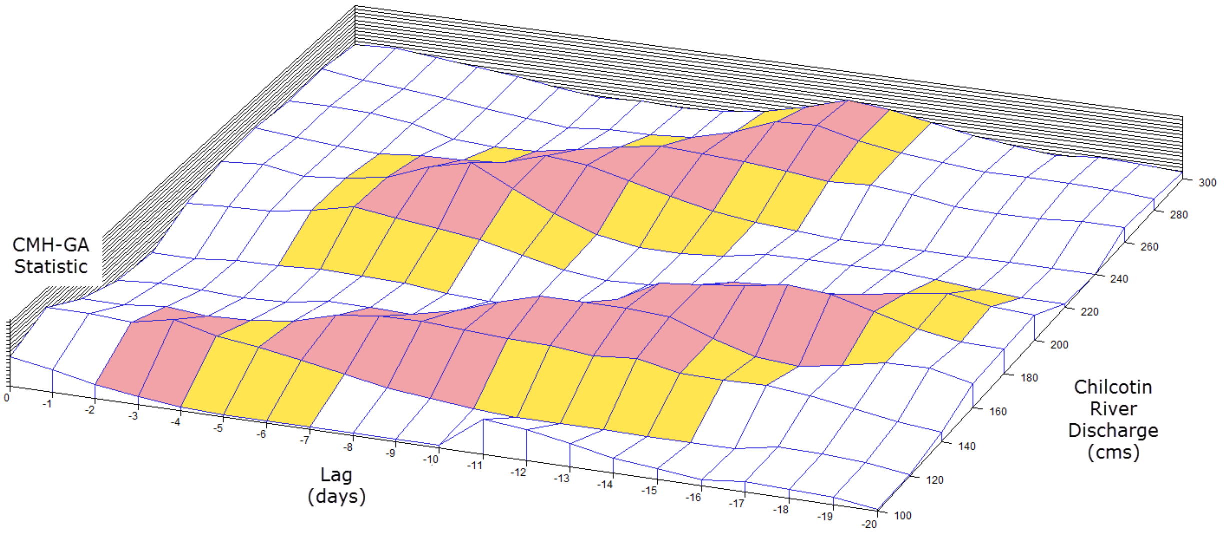


Figure 44. Distribution of the *CMH-GA chi-square* test statistic[64] for association of high/low daily migration categories in relation to lower Chilcotin discharge categories stratified by water temperature categories (Low ≤ 15°C; high >15°C). Large differences in Sockeye migration were most strongly associated with discharge levels ranging from 220 cms seven days prior to 280 cms twelve days prior to enumeration (purple areas; P < 0.0001). A distinct but similar pattern is apparent at lower discharge thresholds (140-180 cms) which extends from 7-16 days prior.

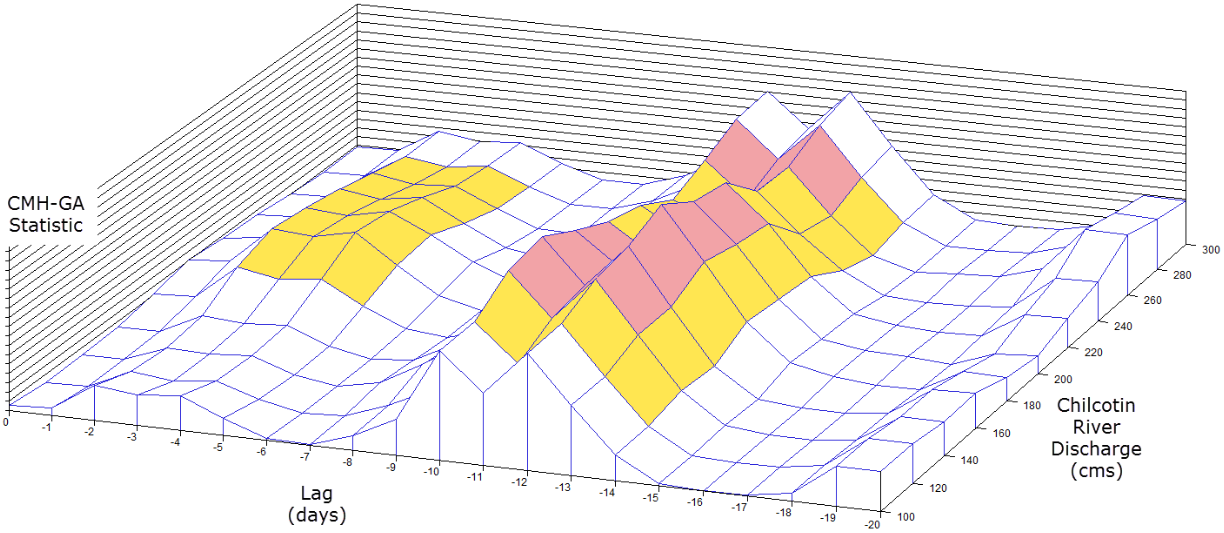


Figure 45. Distribution of the *CMH-GA chi-square* test statistic for association of high/low daily migration categories in relation to lower Chilcotin water temperature categories (Low ≤ 15°C; high >15°C) stratified by discharge categories (see footnote). Large differences in Sockeye migration were most strongly associated with discharge levels ranging from 150-260 cms occurring 10-12 days before reaching the counter site (purple areas; P < 0.0001). A lesser effect may be associated with high discharge levels of 190-240 cms 2-4 days prior to counting (P < 0.05).

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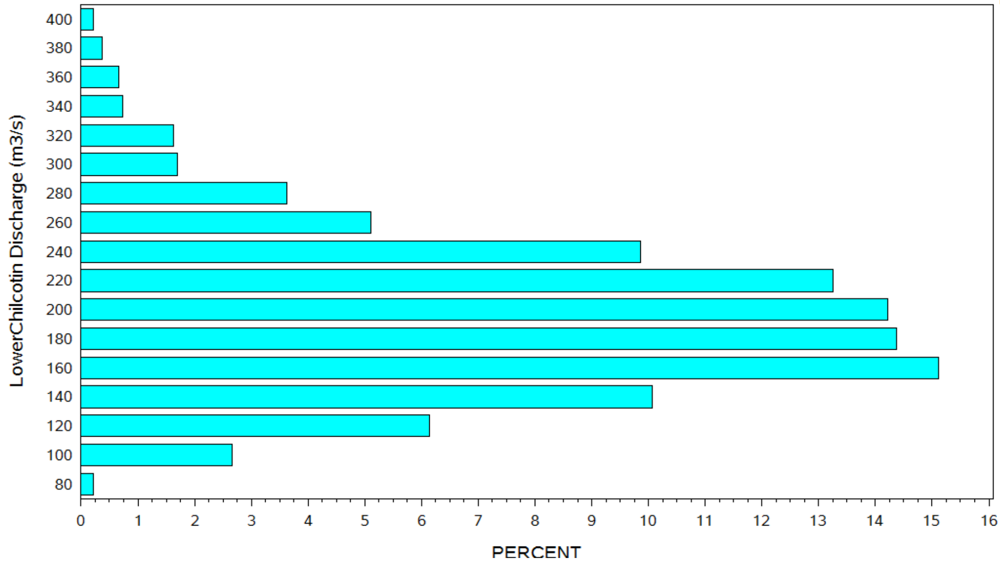
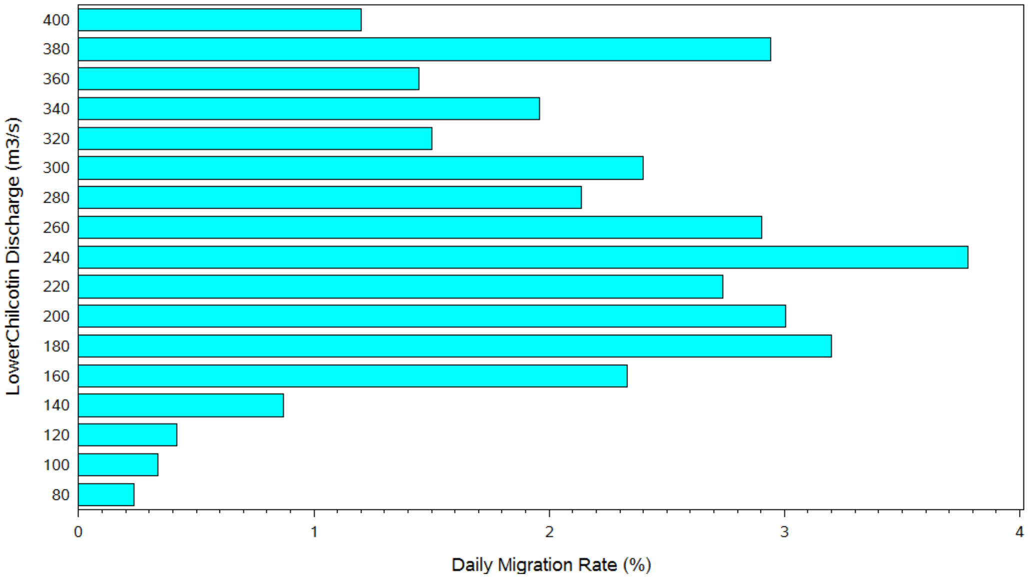
[64] Test-statistic was generated for a range of migration date time lags (0-20 days) for a range of discharge thresholds (100-300 cms) while holding the water temperature threshold constant (15°C).



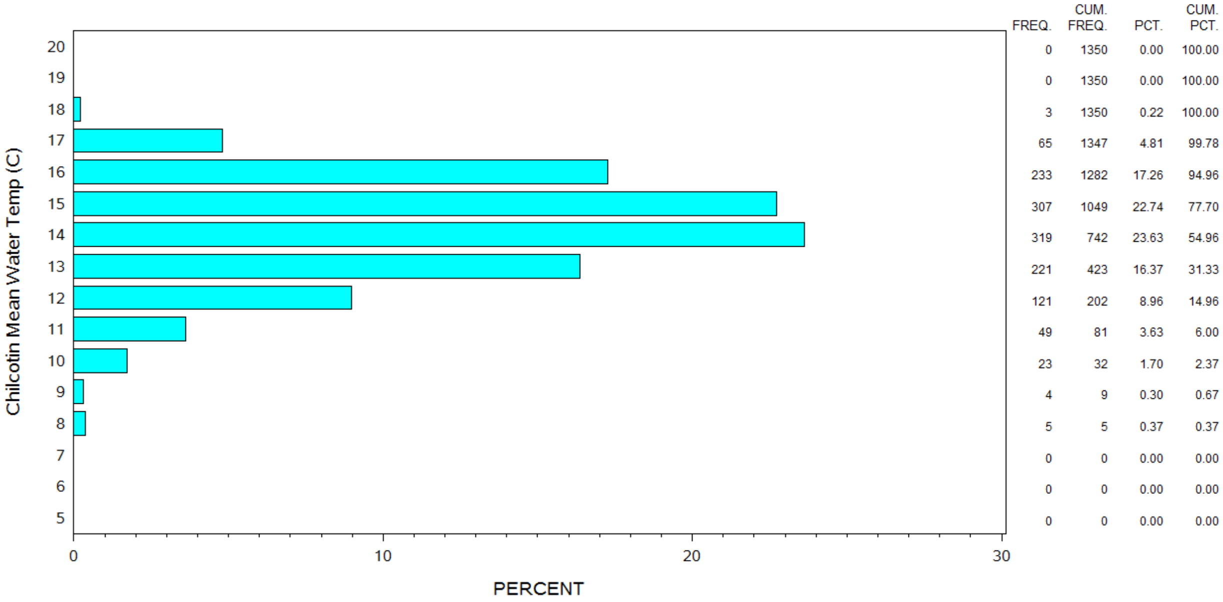
FREQ.	CUM. FREQ.	PCT.	CUM. PCT.
3	1350	0.22	100.00
5	1347	0.37	99.78
9	1342	0.67	99.41
10	1333	0.74	98.74
22	1323	1.63	98.00
23	1301	1.70	96.37
49	1278	3.63	94.67
69	1229	5.11	91.04
133	1160	9.85	85.93
179	1027	13.26	76.07
192	848	14.22	62.81
194	656	14.37	48.59
204	462	15.11	34.22
136	258	10.07	19.11
83	122	6.15	9.04
36	39	2.67	2.89
3	3	0.22	0.22

Figure 46. Frequency plot of historical Chilko Sockeye non-zero migration (un-weighted tally of non-zero migration dates), at varying levels of lower Chilcotin River discharge 12 days earlier. Most dates (75%) of migration occurred when flows in the Chilcotin 12 days earlier were ~140-240 cms.



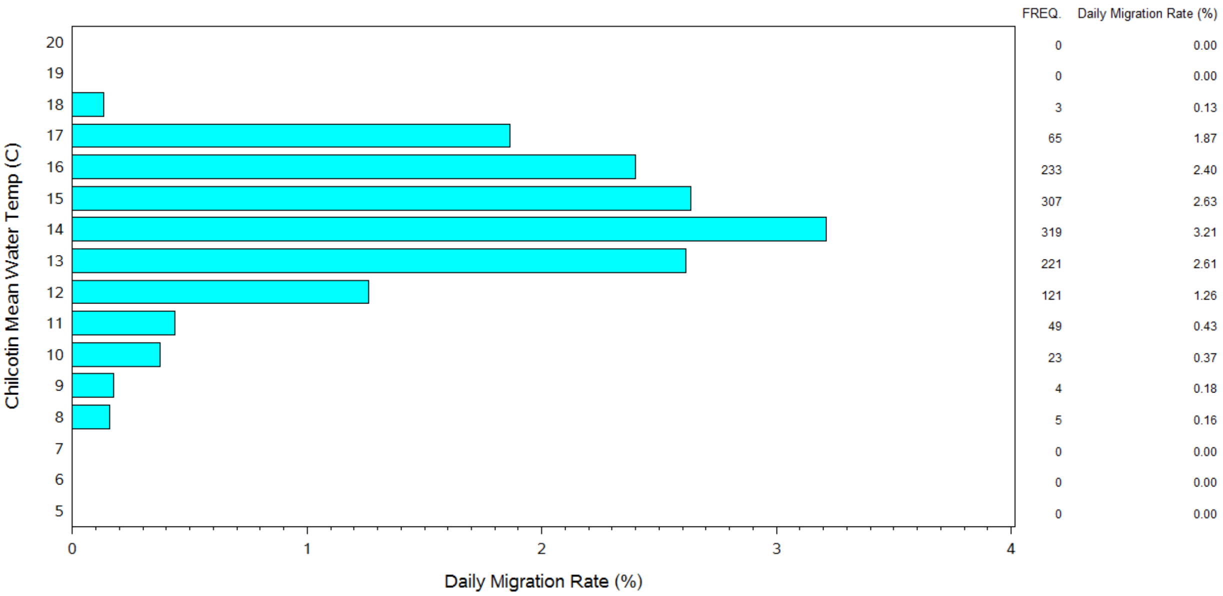
FREQ.	Daily Migration Rate (%)
3	1.20
5	2.94
9	1.44
10	1.96
22	1.50
23	2.40
49	2.14
69	2.90
133	3.78
179	2.74
192	3.00
194	3.20
204	2.33
136	0.87
83	0.42
36	0.34
3	0.23

Figure 47. Frequency plot of historical Chilko Sockeye non-zero migration dates, weighted by daily migration rate, at varying levels of lower Chilcotin River discharge 12 days earlier. Moderate daily migration rates (3-7%) occurred at a wide range of discharge levels (180-260 cms).



Chilcotin Mean Water Temp (C)	FREQ.	CUM. FREQ.	PCT.	CUM. PCT.
20	0	1350	0.00	100.00
19	0	1350	0.00	100.00
18	3	1350	0.22	100.00
17	65	1347	4.81	99.78
16	233	1282	17.26	94.96
15	307	1049	22.74	77.70
14	319	742	23.63	54.96
13	221	423	16.37	31.33
12	121	202	8.96	14.96
11	49	81	3.63	6.00
10	23	32	1.70	2.37
9	4	9	0.30	0.67
8	5	5	0.37	0.37
7	0	0	0.00	0.00
6	0	0	0.00	0.00
5	0	0	0.00	0.00

Figure 48. Frequency plot of historical Chilko Sockeye non-zero migration (un-weighted tally of non-zero migration dates), at varying levels of lower Chilcotin River water temperature 12 days earlier. ~80% of migration activity occurred at estimated temperatures of 13-16°C.



Chilcotin Mean Water Temp (C)	FREQ.	Daily Migration Rate (%)
20	0	0.00
19	0	0.00
18	3	0.13
17	65	1.87
16	233	2.40
15	307	2.63
14	319	3.21
13	221	2.61
12	121	1.26
11	49	0.43
10	23	0.37
9	4	0.18
8	5	0.16
7	0	0.00
6	0	0.00
5	0	0.00

Figure 49. Frequency plot of historical Chilko Sockeye non-zero migration dates, weighted by daily migration rate, at varying levels of lower Chilcotin River water temperature, 12 days earlier. Highest mean daily migration rates (i.e.> 75th percentile, ~3% per day) were associated with estimated water temperatures of 13-15°C.

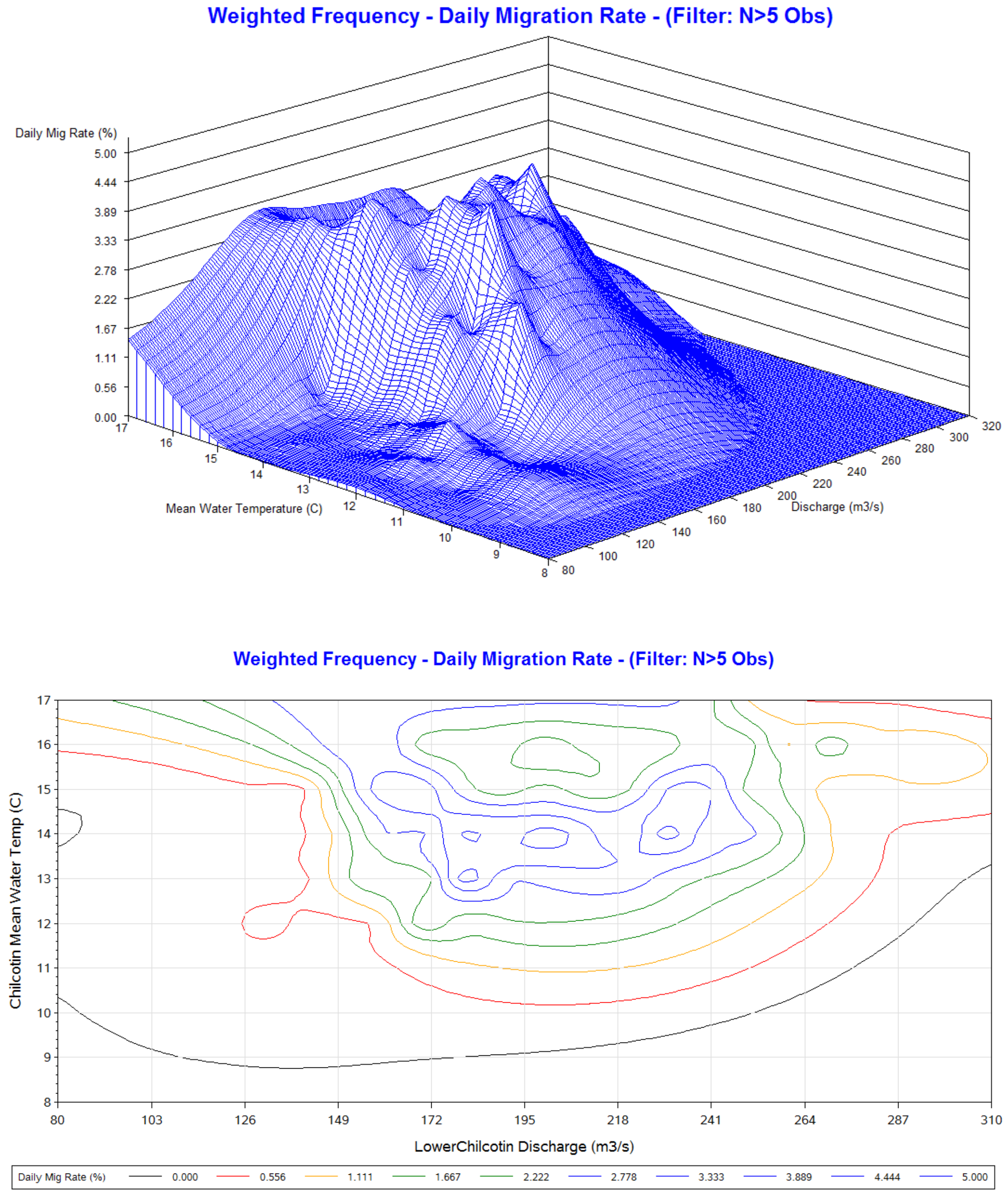


Figure 50. Weighted frequency distribution (top) and smoothed contour (bottom) of historical Chilko Sockeye migration rates (daily %), at varying levels of lower Chilcotin River water temperature and discharge 12 days earlier (filtered for a minimum of 5 observations at each temperature x flow point). Moderate-to-high migration rates were found at a wide range of discharge and temperature levels, with maxima at 13-15°C and 170-240 cms.

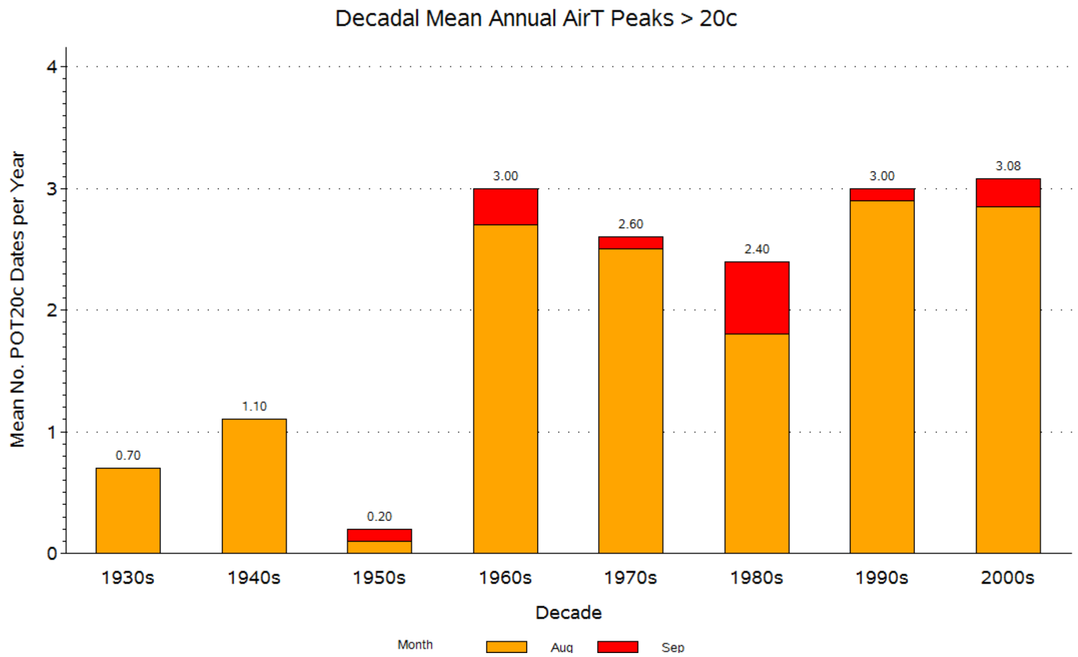


Figure 51. Frequency analysis of decadal mean number of dates per month in which regional daily mean air temperature (at Env Canada AHCCD station Williams Lake) exceeded 20°C (Aug-Sep).

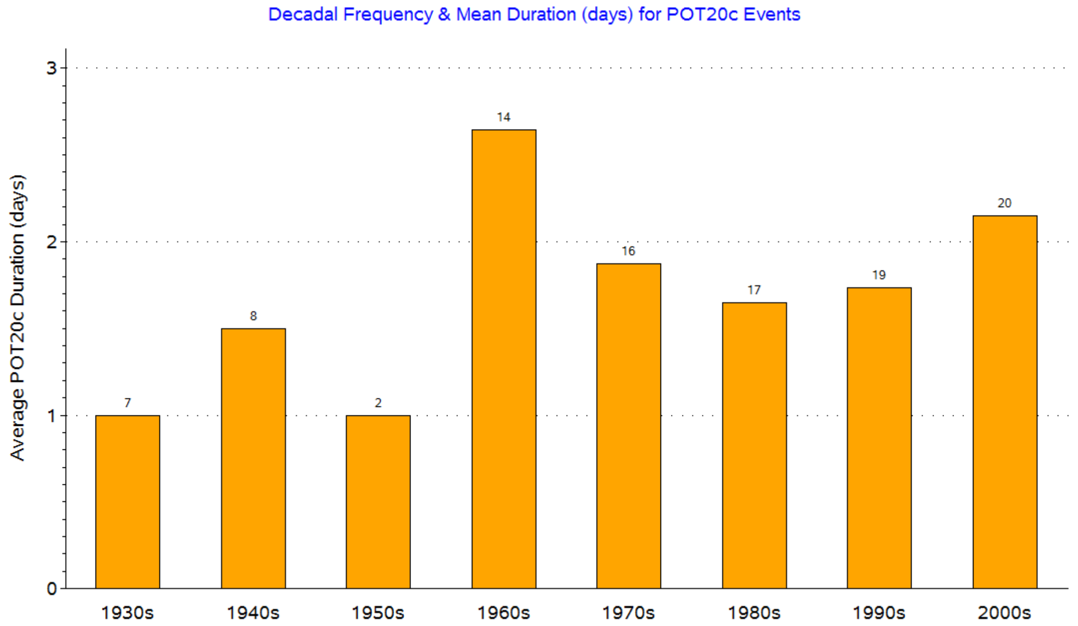


Figure 52. Mean length (days) and total decadal frequency of periods in which regional daily mean air temperature (at Env Canada AHCCD station Williams Lake) exceeded 20°C during Aug-Sep.

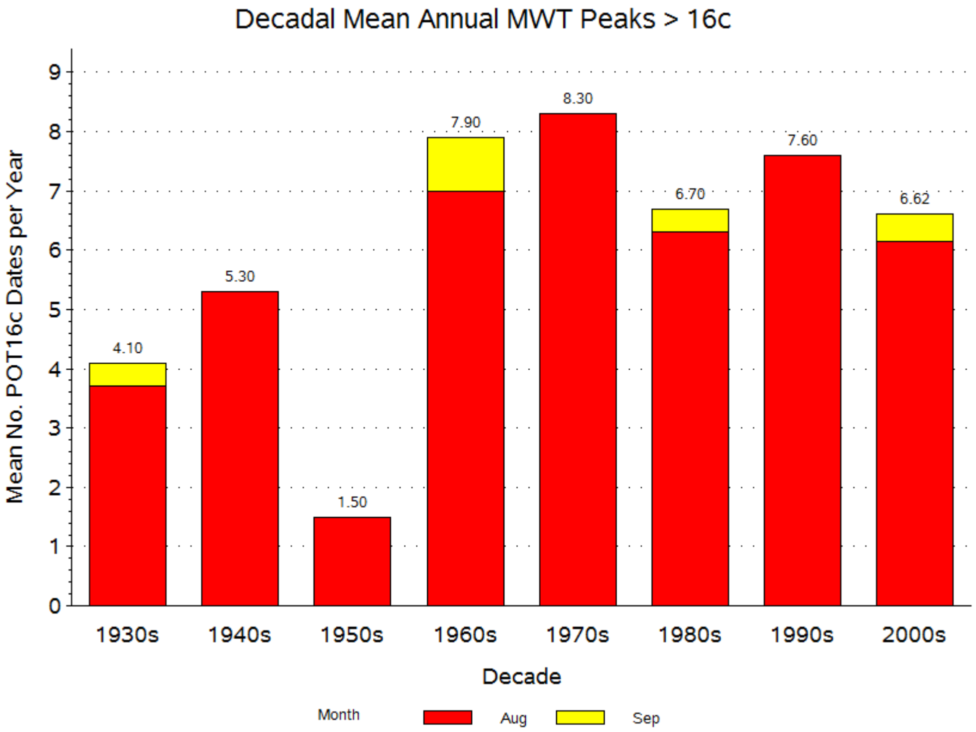


Figure 53. Frequency analysis of decadal mean number of dates per month (Aug-Sep) in which estimated mean water temperature in the lower Chilcotin River exceeded 16°C.

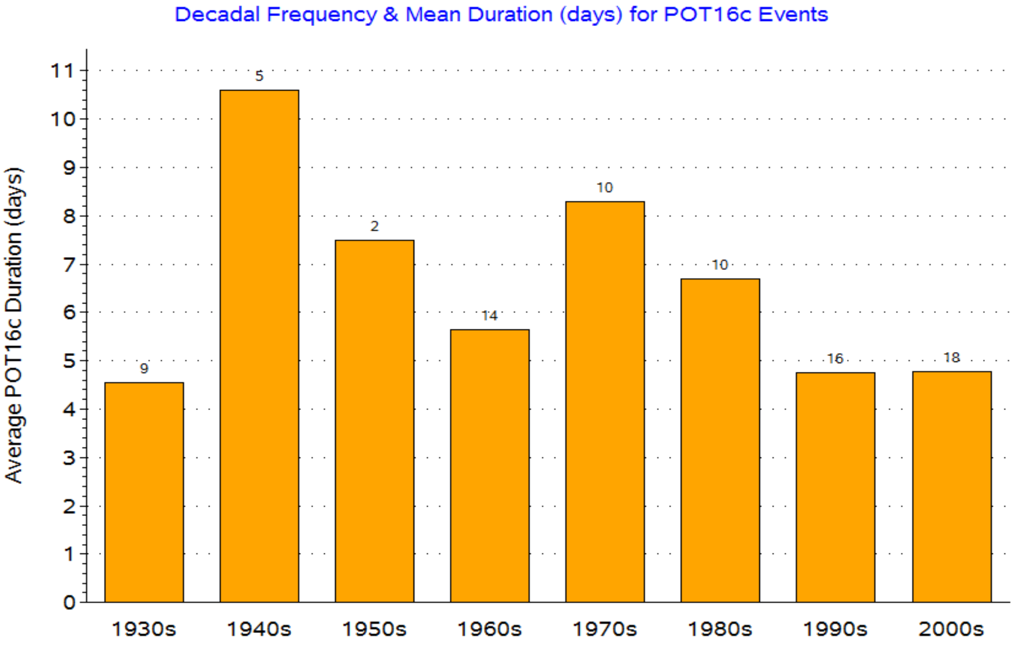


Figure 54. Mean length (days) and total decadal frequency of periods in which estimated daily mean water temperature (Aug-Sep) in the lower Chilcotin River continuously exceeded 16°C, by decade.

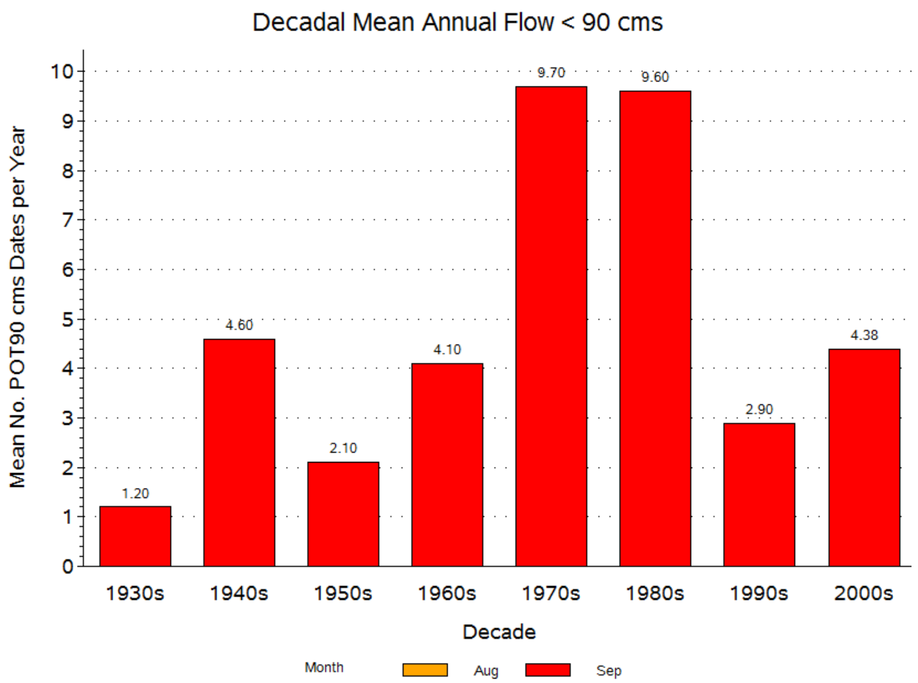


Figure 55. Frequency analysis of decadal mean number of “low flow” dates (< 90 cms, 10th percentile) per month at CHILKO AT REDSTONE. The 1970s and 1980s were significantly different from the multi-decadal mean (Note: 2000s represents 2000-2012).

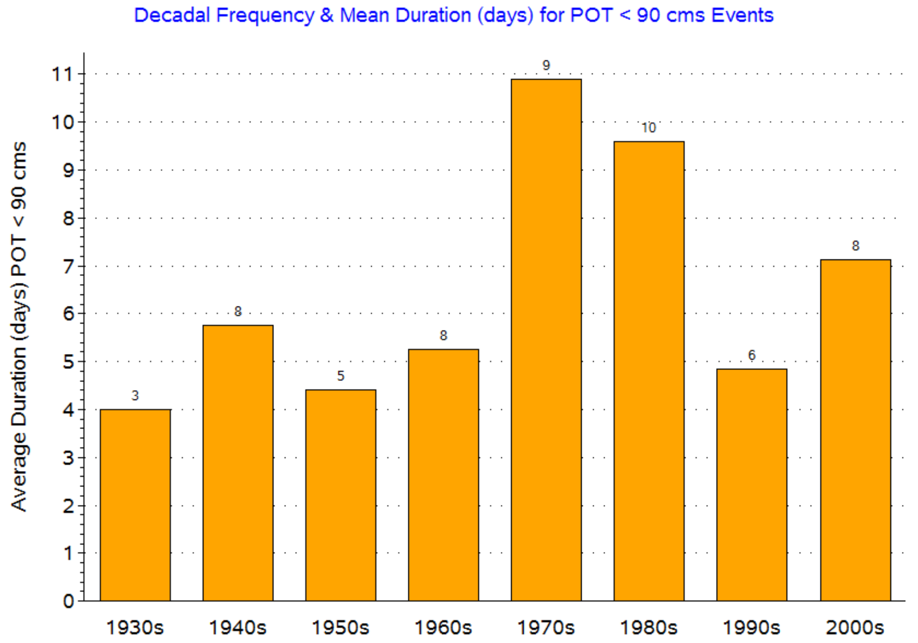


Figure 56. Mean length (days) and frequency of “low flow” periods in which CHILKO AT REDSTONE discharge continuously remained below the 10th percentile of August-September flows (~90 cms) (Note: 2000s represents 2000-2012).

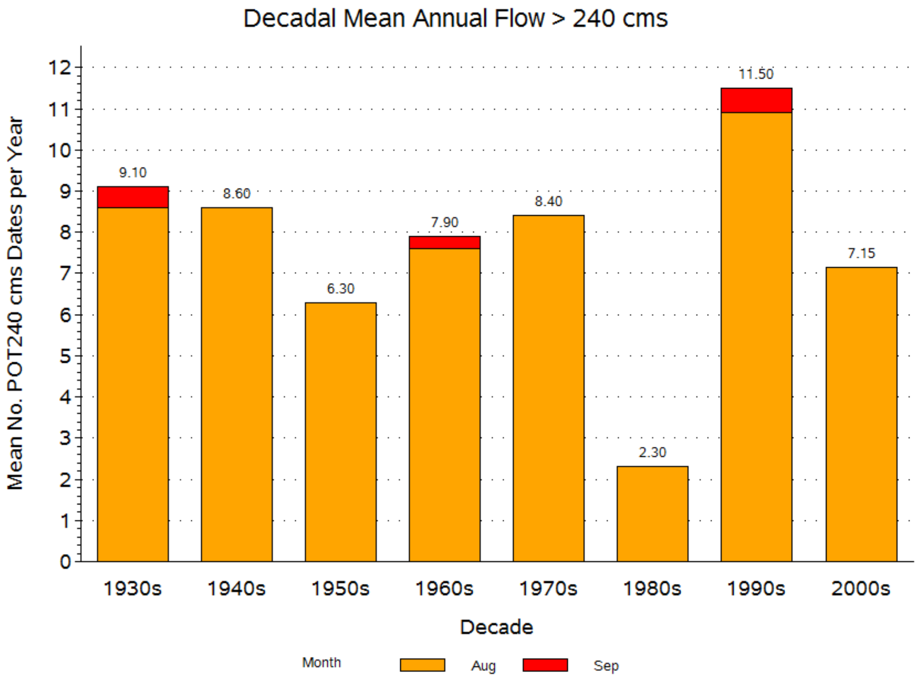


Figure 57. Frequency analysis of decadal mean number of “high flow” dates (i.e.>90th percentile of August-September flows: ~240 cms) per month at CHILKO AT REDSTONE (Note: 2000s represents 2001-2012).

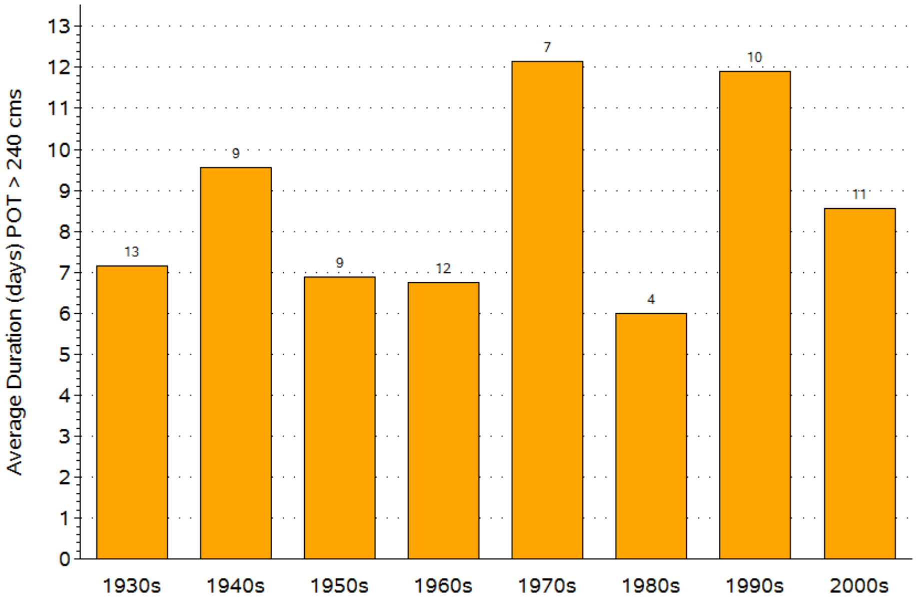
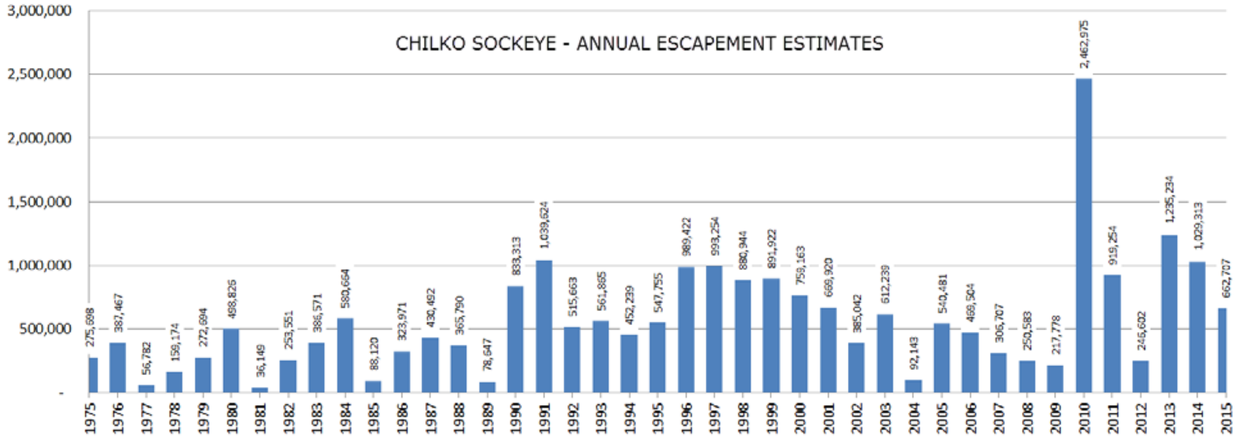


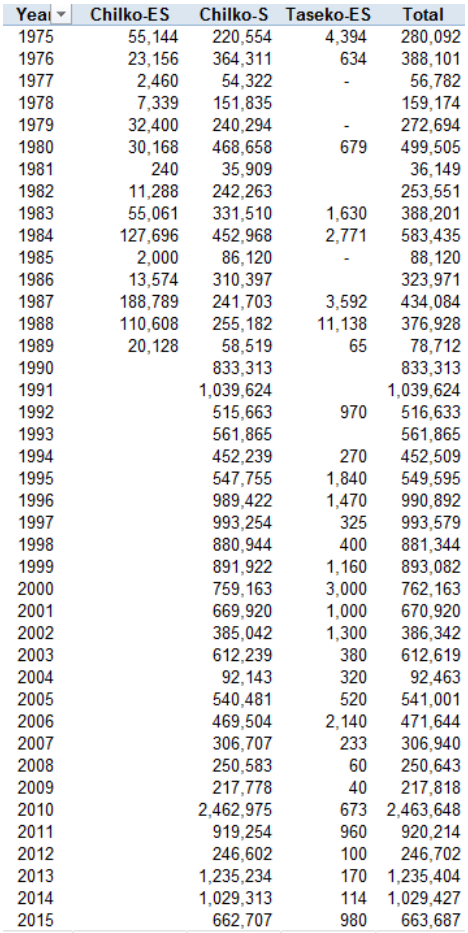
Figure 58. Mean length (days) and frequency of “high flow” periods in which CHILKO AT REDSTONE discharge continuously remained above the 90th percentile of August-September flows (~240 cms) (Note: 2000s represents 2001-2012).

APPENDICES

Appendix A. Total annual Chilko Sockeye escapement estimates, 1975-2008 (from mark-recapture methods) and 2009-2015 (from acoustic counters).



Appendix B. Total annual Sockeye escapement estimates, by conservation unit, 1975-2015 (Source: DFO Fraser Stock Assessment).



Yeai ▾	Chilko-ES	Chilko-S	Taseko-ES	Total
1975	55,144	220,554	4,394	280,092
1976	23,156	364,311	634	388,101
1977	2,460	54,322	-	56,782
1978	7,339	151,835		159,174
1979	32,400	240,294	-	272,694
1980	30,168	468,658	679	499,505
1981	240	35,909		36,149
1982	11,288	242,263		253,551
1983	55,061	331,510	1,630	388,201
1984	127,696	452,968	2,771	583,435
1985	2,000	86,120	-	88,120
1986	13,574	310,397		323,971
1987	188,789	241,703	3,592	434,084
1988	110,608	255,182	11,138	376,928
1989	20,128	58,519	65	78,712
1990		833,313		833,313
1991		1,039,624		1,039,624
1992		515,663	970	516,633
1993		561,865		561,865
1994		452,239	270	452,509
1995		547,755	1,840	549,595
1996		989,422	1,470	990,892
1997		993,254	325	993,579
1998		880,944	400	881,344
1999		891,922	1,160	893,082
2000		759,163	3,000	762,163
2001		669,920	1,000	670,920
2002		385,042	1,300	386,342
2003		612,239	380	612,619
2004		92,143	320	92,463
2005		540,481	520	541,001
2006		469,504	2,140	471,644
2007		306,707	233	306,940
2008		250,583	60	250,643
2009		217,778	40	217,818
2010		2,462,975	673	2,463,648
2011		919,254	960	920,214
2012		246,602	100	246,702
2013		1,235,234	170	1,235,404
2014		1,029,313	114	1,029,427
2015		662,707	980	663,687

Appendix C. Daily totals of Sockeye salmon and tallies of 15-minute counting efforts by year and date at Henry's Bridge, Chilko River, 1975-2008.

Date	1975		1976		1977		1978		1979		1980		1982		1983		1984		1986		1987		1988		1989	
01-Aug																	0	2								
02-Aug																										
03-Aug																	0	2								
04-Aug																										
05-Aug																	0	2								
06-Aug																	1	4	0	5			0	4		
07-Aug																	14	4					0	4		
08-Aug																	148	14	0	8			0	4		
09-Aug																	375	14			38	6	3	6		
10-Aug																	64	14	0	8			4	14		
11-Aug																	83	14					8	8		
12-Aug	10	9	1	15											718	14	162	14	16	8	12	14	3	8		
13-Aug	710	20	1	18											525	14	256	14			17	8	5	8		
14-Aug	222	18	0	18					48	7					537	14	1,836	14			111	14	4	8		
15-Aug	479	18	0	18					86	7					973	14	866	14	54	14	78	14	1	8		
16-Aug	241	18	4	18					376	15					461	14	639	14	18	8	51	14	833	14	0	4
17-Aug	107	18	1	16					180	7					692	14	553	14	192	14	136	14	224	14	0	4
18-Aug	298	18	0	18					661	15			0	14	504	14	491	14	1,294	14	1,324	14	167	13	0	4
19-Aug	845	18	0	18	104	8			185	8	53	6	0	14	782	14	1,458	14	1,445	14	581	14	272	14	0	4
20-Aug	1,710	18	2	15	105	11			637	14	559	12	0	14	1,036	14	4,702	14	579	14	492	14	246	14	0	7
21-Aug	1,171	18	0	16	162	14			497	8	126	13	1	7	653	14	3,427	14	1,546	14	459	14	163	14	0	5
22-Aug	1,068	18	4	16	133	4			470	12	237	14	5	7	386	14	4,344	14	3,176	14	1,089	14	46	14	0	6
23-Aug	973	18	1	18	112	6	4	8	99	8	1,207	14	15	14	1,037	14	1,626	14	3,817	14	2,923	14	374	14	1	7
24-Aug	1,088	18	297	18					408	8	971	14			1,451	14	2,532	14	2,409	14	5,673	14	746	14	82	14
25-Aug	2,657	18	610	18			14	13	576	16	1,415	14			1,055	14	6,541	14	1,989	14	3,260	14	1,795	14	49	14
26-Aug	6,369	18	1,516	18	43	4	5	5			2,371	14	569	14	822	14	3,334	14	1,533	14	2,079	14	3,590	14	21	14
27-Aug	3,228	18	680	18			9	2	1,401	16	6,155	14	1,276	14	915	14	6,039	14	1,796	14	1,780	14	2,725	14	66	14
28-Aug	3,515	18	582	18			269	16	1,851	16	9,158	14	2,362	14	1,093	14	5,072	14	1,841	14	2,360	14	2,115	14	51	14
29-Aug	2,919	18	1,280	18			127	6	1,370	16	5,523	14	2,497	14	1,755	14	5,055	14	3,134	14	1,688	14	3,963	14	455	14
30-Aug	1,601	18	704	18	131	15			565	16	3,080	14	1,357	14	5,810	14	2,353	14	3,105	14	2,122	14	997	14	151	14
31-Aug	599	18	2,350	18			805	17	589	16	4,166	14	2,516	14	5,466	14	1,116	14	3,707	14	3,455	14	1,902	14	706	14
01-Sep	782	18	2,743	18	33	6			491	16	3,838	14	1,500	14	3,007	14	1,653	14	3,300	14	5,561	14	5,245	14	625	13
02-Sep	390	18	5,880	18	25	6	612	16	974	16	5,351	14	1,693	14	2,077	14	812	14	1,163	14	2,404	14	2,958	14	1,162	14
03-Sep	92	18	7,740	18			296	16	2,198	14	5,280	14	333	14	2,630	14	2,081	14	626	14	1,997	14	1,930	14	659	14
04-Sep	224	18	8,484	18					1,807	16	4,821	14	878	14	3,144	14	1,612	14	1,127	14	1,230	14	1,428	14	1,068	14
05-Sep	383	18	3,252	13			1,519	16	625	14	5,819	14	597	14	2,223	14	1,213	14	1,863	14	1,636	14	832	14	2,452	14
06-Sep	968	18	4,268	18					377	15	4,356	14	764	14	730	14	715	14	2,782	14	1,402	14	513	14	637	14
07-Sep	247	18	2,155	18			951	16			2,479	14	1,364	14	618	14	890	14	2,203	14	1,437	14	371	14	598	12
08-Sep	107	18	1,309	18	23	5			409	16	1,090	14	813	14	1,158	14	1,231	14	1,574	14	1,613	14	146	14	246	14
09-Sep	58	18	2,683	18			1,239	16	457	8	1,414	14	450	14	1,724	14	1,307	14	1,170	14	2,285	14	187	14	91	14
10-Sep	44	18	3,140	18					1,016	16	1,030	14	462	14	1,053	14	1,511	14	1,021	14	1,098	14	133	14	83	13
11-Sep	227	18	1,045	15			1,217	8	374	8	770	14	503	14	738	14	913	14	662	14	1,316	14	117	14	106	14
12-Sep	120	18	2,571	18					217	8	368	14	826	14	577	14	758	14	294	14	1,665	14	94	14	0	0
13-Sep	21	14	1,828	18			518	16	127	8	467	14	1,123	14	278	14	722	14	176	14	1,004	14	109	14	0	0
14-Sep			1,201	18							318	14	851	14	126	14	723	14	75	14	717	14	76	8	75	14
15-Sep			953	18			21	16			569	14	1,117	14	155	14		14	96	14	746	14	19	8	0	0
16-Sep			576	18							733	14	213	14	58	14	596	14			288	14	11	8	0	0
17-Sep			507	18			117	8			515	14	135	14			529	14	193	14	112	14			0	0
18-Sep			403	18							293	14	34	14	82	14	476	14			82	14	1	8	46	14
19-Sep			293	18			174	8			228	14	7	14			585	14	38	14	21	8			0	0
20-Sep			134	18							124	14	2	11			209	8			18	8			10	7
21-Sep							86	8			94	7	14	5			253	14							0	0
22-Sep											174	7	25	6	169	14	244	14							36	14
23-Sep							50	8			92	7					162	10	55	4	55	4			0	0
24-Sep											22	7					97	14							20	14
25-Sep							93	8			31	7			154	7	318	14							0	0
26-Sep																	308	9							0	0
27-Sep							25	8									344	14	59	4	59	4			0	0
28-Sep																	106	7							0	0
29-Sep																	107	14							1	2
30-Sep																	222	14							0	0
01-Oct																	106	14	1	2	1	2			3	4
02-Oct																	127	14								
03-Oct																	140	14								
04-Oct																	114	14								
05-Oct																	117	14								
06-Oct																	136	14								
07-Oct																	112	14								
08-Oct																										
09-Oct																										
10-Oct																	141	14								

(cont'd.)

Appendix C (cont’d). Daily totals of Sockeye salmon and tallies of 15-minute counting efforts by year and date at Henry’s Bridge, Chilko River, 1975-2008.

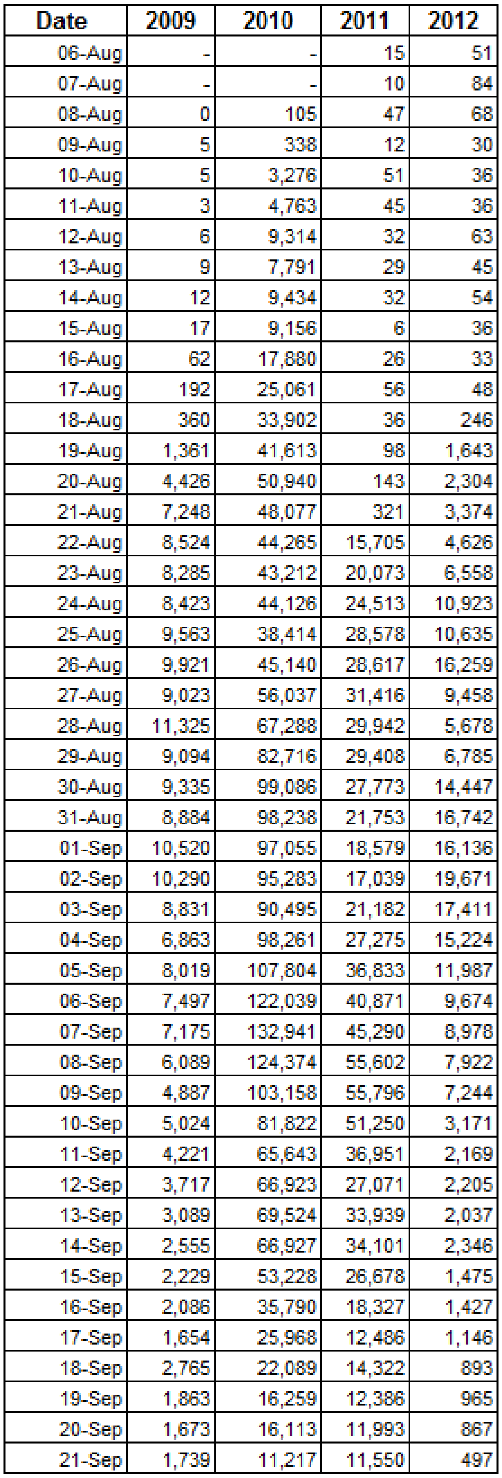
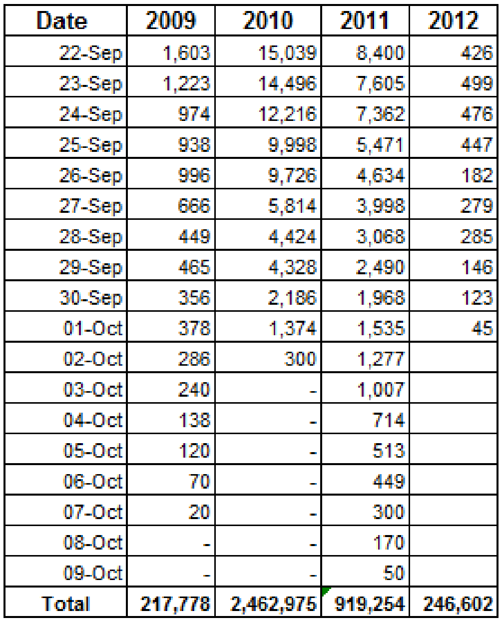
Date	1990		1991		1992		1993		1994		1995		1996		1997		1998		1999		2000		2001	
01-Aug											0	5			0	9	4	8					0	7
02-Aug																	0	8					-	-
03-Aug											0	5	0	7	0	9	0	8			0	7	0	7
04-Aug											0	5					0	8					-	-
05-Aug									0	9			0	7	0	9	4	8	0	4	0	7	0	7
06-Aug											1	7					1	9	0	4			-	-
07-Aug									1	8	0	7	0	7	0	9	0	9			0	7	0	7
08-Aug											3	6					6	14	0	8	1	7	0	7
09-Aug									0	9	119	14	0	7	0	9	6	14	0	8	2	7	0	7
10-Aug	0	3									48	14	14	14			10	14	0	8	1	7	0	7
11-Aug	1	3	0	5			0	1	0	9	4	9	222	14	2	18	144	14	0	8	269	7	0	7
12-Aug			0	5							22	14	315	14	1	18	75	14	0	8	571	14	0	7
13-Aug			0	6			0	1	6	9	152	14	1009	14	1	18	181	14	0	8	672	14	0	7
14-Aug	146	4	0	13					14	9	134	14	1602	14	0	18	127	14	0	8	313	14	184	14
15-Aug	50	12	22	14					24	9	510	14	1896	14	2	18	88	14	0	8	1,277	14	664	14
16-Aug	86	14	5	14	231	12	1	1	6	9	311	14	2299	14	36	18	144	14	0	8	1,154	14	532	14
17-Aug	46	7	38	14	384	12			188	9	175	14	4078	14	246	18	400	14	0	8	1,274	14	2,070	14
18-Aug	327	7	11	14	206	12			193	14	333	14	3821	14	59	14	1336	14	1	14	1,862	14	2,310	14
19-Aug	1,037	14	3	14	410	12			898	14	651	14	4422	14	111	14	2315	14	2	14	2,835	14	2,906	14
20-Aug			14	14	115	14			1124	14	765	14	3222	14	231	14	2121	14	0	14	3,772	14	3,581	14
21-Aug			19	14	117	13	262	14	2065	14	739	14	4460	14	529	14	3334	14	21	14	4,492	14	5,325	14
22-Aug			0	14	301	14	473	14	1345	14	549	14	4333	14	426	14	855	14	317	14	2,445	14	2,783	14
23-Aug			3	14	1717	14	169	14	1347	14	1251	14	2969	14	172	14	4420	14	4478	14	5,238	14	3,627	14
24-Aug	590	14	8	14	1768	14	237	14	310	14	1357	14	3524	14	312	14	3452	14	6333	14	7,764	14	4,740	14
25-Aug	215	15	21	14	2133	14	116	14	630	14	887	14	3425	14	359	14	1915	14	4625	14	10,109	14	2,645	14
26-Aug	706	14	1157	14	2250	14	380	14	745	14	1659	14	6266	14	337	14	3483	14	3789	14	9,896	14	2,586	14
27-Aug	1,742	14	2662	14	1179	14	103	14	1846	14	1026	14	6467	14	679	14	4289	14	3665	14	12,052	14	2,388	14
28-Aug	2,571	14	4542	14	800	14	987	14	2317	14	4065	14	7324	14	430	14	6702	14	4447	14	15,464	14	3,831	14
29-Aug	4,547	14	3827	14	2540	14	936	14	1517	14	2211	14	7778	14	842	14	4021	14	2713	14	13,323	14	3,576	14
30-Aug	6,133	14	4148	14	3596	14	1092	14	3796	14	4509	14	8530	14	1059	14	2740	14	3346	14	10,606	14	4,719	14
31-Aug	6,988	14	3552	14	3379	14	524	14	8510	14	4828	14	5582	14	1569	14	2976	14	2251	14	10,242	14	5,253	14
01-Sep	1,787	14	1837	14	3763	14	301	14	4393	14	6942	14	4503	14	2967	14	2340	14	3936	14	9,748	14	4,484	14
02-Sep	997	14	3205	14	3628	14	369	14	3046	14	5192	14	4056	14	2470	14	3957	14	2405	14	7,223	14	9,650	14
03-Sep	4,283	14	3620	14	4179	14	312	14	1841	14	1156	14	6859	14	3163	14	3083	14	5198	14	4,343	14	8,603	14
04-Sep	11,073	14	4146	14	5964	14	369	14	592	14	1024	14	8014	14	3058	14	4326	14	6163	14	3,278	14	10,252	14
05-Sep	4,075	13	5009	14	5059	14	792	14	982	14	588	14	9414	14	4732	14	3709	14	5284	14	2,824	14	13,695	14
06-Sep	2,513	13	5573	14	6203	14	1256	14	1730	14	1272	14	6425	14	6174	14	2386	14	6694	14	1,588	14	7,852	14
07-Sep	1,847	14	3723	14	7453	14	4923	14	700	14	0	0	7741	14	5013	14	3286	14	2426	14	580	14	5,281	14
08-Sep	522	14	4897	14	4543	14	3617	14	323	14	408	14	4873	14	11242	14	4139	14	3431	14	640	14	5,266	14
09-Sep	873	14	6072	14	3347	14	3009	14	658	14	276	14	2705	14	11378	14	5933	14	3539	14	349	14	5,204	14
10-Sep	2,865	14	7335	14	2846	14	1388	14	717	14	183	14	1103	14	15543	14	5781	14	3673	14	251	14	2,804	14
11-Sep	4,156	14	11933	14	3134	14	4667	14	833	14	190	14	672	14	10072	14	7002	14	3456	14	78	14	1,950	14
12-Sep	2,405	14	14522	14	2270	14	3899	14	923	14	276	14	418	14	9153	14	2756	14	2389	14	171	14	1,528	14
13-Sep	2,000	14	9005	14	2447	14	5948	14	1425	14	247	14	339	14	5088	14	2235	14	3856	14	230	14	1,110	14
14-Sep	3,016	14	2686	14	1750	14	5210	14	625	14	110	11	289	14	2962	14	1591	14	7999	14	401	14	966	14
15-Sep	2,440	14	2191	14	972	14	8318	14	291	14	329	14	249	14	2589	14	1068	14	8317	14	178	14	971	14
16-Sep	2,108	14	3899	14	1342	14	4152	14	246	14	431	14	307	14	1760	14	904	14	10148	14	92	14	536	14
17-Sep			5717	14	549	14	4156	14	191	14	309	14	568	14	1344	14	637	14	7299	14	79	14	568	14
18-Sep	507	7	5659	14	957	14	2836	14	176	14	268	14	294	14	1096	14	554	14	4161	14	102	14	443	14
19-Sep			4759	14	959	14	2977	14	252	14	288	14	192	14	968	14	326	14	6980	14	72	14	264	14
20-Sep	517	7	4367	14	662	14	2194	14	174	14	113	14	173	14	1306	14	410	14	5026	14	38	14	254	14
21-Sep	700	14	3570	14	394	14	1294	14	110	14	0	0	171	14	1284	14	249	14	3691	14	68	14	189	14
22-Sep	1,238	14	5323	14	340	14	784	14	108	14	84	14	100	14	1514	14	260	14	4110	14	48	14	207	14
23-Sep	894	12	6695	14	362	14	619	14	103	14	31	14			2041	14	270	14	3120	14	32	14	148	14
24-Sep	363	7	3248	14			472	14	68	14	88	14			1901	14	165	14	3011	14	40	14	88	14
25-Sep	198	6	2672	14	223	14	122	14	125	14					2172	14	124	14	1790	14	36	14	85	14
26-Sep	143	7	2434	14			318	14							2197	14	73	14	1504	14	23	14		
27-Sep	115	7	3743	14	104	14	259	14							1459	14	157	14	2062	14	26	14		
28-Sep			2703	12			311	14							1277	14	112	14	869	14	30	14		
29-Sep			2605	14	54	14	112	14							1587	14	46	14	552	14	17	14		
30-Sep			1973	14			255	14							1201	14	31	14	729	14				
01-Oct			1123	14			228	14							1595	14	93	14	472	14				
02-Oct			1201	14			131	14							1738	14	45	14	653	14				
03-Oct			535	14			132	14							1588	14	28	14	597	14				
04-Oct			481	14			60	14							1519	14			480	14				
05-Oct			410	14											1591	14			481	14				
06-Oct			445	14											1040	14			381	14				
07-Oct			282	14											796	14			295	14				
08-Oct			261	14											258	14			214	14				
09-Oct			204	14											321	14			138	14				
10-Oct			189	12											286	14			120	14				
11-Oct															295	14			56	14				
12-Oct															130	14			85	14				
13-Oct															74	14			42	14				
14-Oct															47	14			56	14				

(cont’d.)

Appendix C (cont'd). Daily totals of Sockeye salmon and tallies of 15-minute counting efforts by year and date at Henry's Bridge, Chilko River, 1975-2008.

Date	2002		2003		2004		2005		2006		2007		2008	
01-Aug	0	7							0	7			0	7
02-Aug	0	7					8	0	0	14			0	7
03-Aug	-	-			0	12	8	0	0	14			0	7
04-Aug	-	-			0	8			0	5			0	7
05-Aug	-	-			0	14	8	0	0	6			0	7
06-Aug	0	14			0	8	8	0	0	5			0	7
07-Aug	0	14			0	8	8	0	0	10	0	7	0	7
08-Aug	0	14	0	7	0	8			0	7	0	14	0	7
09-Aug	0	14	0	7	0	8	8	0	0	7			1	14
10-Aug	-	-	0	7	0	8	8	0	0	14	0	14	3	14
11-Aug	-	-	16	14	0	8	8	0	2	14	0	14	41	14
12-Aug	0	14	400	14	0	8	8	0	1	14		-	1,848	14
13-Aug	0	14	430	14	0	8	8	0	2	14	0	14	943	14
14-Aug	0	14	603	14	0	8	8	0	0	14	0	14	713	14
15-Aug	0	14	1,680	14	2	8	8	0	20	14	2	14	2,335	14
16-Aug	3	14	1,302	14	13	14	14	0	724	15	0	14	2,132	14
17-Aug	654	14	1,731	14	233	14	14	0	1,218	14	0	14	1,448	14
18-Aug	1,967	14	4,295	14	217	14	14	1	1,520	14	0	14	1,351	14
19-Aug	2,617	14	4,727	14	151	14	14	148	2,020	14	2	14	1,929	14
20-Aug	2,117	14	3,453	14	155	14	14	33	2,193	14	124	14	1,224	14
21-Aug	1,906	14	3,532	14	448	14	14	398	1,950	14	99	14	1,212	14
22-Aug	1,762	14	4,390	14	223	14	14	124	2,040	14	1,145	14	1,116	14
23-Aug	2,229	14	4,751	14	86	14	14	292	1,334	14	2,395	14	636	14
24-Aug	4,458	14	3,651	14	35	14	14	216	2,486	14	2,667	14	617	14
25-Aug	5,439	14	3,110	14	87	14	14	149	1,758	14	1,495	14	459	14
26-Aug	4,071	14	4,237	14	634	14	14	494	2,537	14	1,778	14	277	7
27-Aug	4,840	14	3,361	14	319	14	14	1,112	1,503	14	3,524	14	978	14
28-Aug	2,903	14	749	14	47	14	14	1,376	912	14	4,351	14	1,418	14
29-Aug	4,629	14	667	14	67	14	14	688	1,639	14	1,517	14	1,835	14
30-Aug	2,430	14	2,024	14	81	14	14	894	3,956	14	1,917	14	1,102	14
31-Aug	4,781	14	2,395	14	16	14	14	1,392	4,733	14	2,292	14	603	14
01-Sep	2,186	14	1,811	14	28	14	14	640	5,796	14	2,973	14	389	14
02-Sep	1,280	14	3,707	14	125	14	14	435	2,114	14	2,618	14	226	14
03-Sep	4,063	14	2,967	14	173	14	14	898	4,405	14	2,649	14	427	14
04-Sep	2,549	14	3,448	14	347	14	14	1,068	4,934	14	1,566	14	288	14
05-Sep	2,246	14	4,898	14	803	14	14	842	3,624	14	912	14	479	14
06-Sep	2,210	14	6,579	14	182	14	14	1,364	4,916	14	821	14	334	14
07-Sep	1,138	14	7,068	14	96	14	14	1,479	2,289	14	491	14	339	14
08-Sep	1,314	14	8,657	14	42	14	14	2,652	2,063	14	700	14	291	14
09-Sep	1,359	14	7,678	14	19	14	14	1,978	1,223	14	549	14	153	14
10-Sep	1,076	14	10,204	14	20	14	14	1,819	1,009	14	523	14	134	14
11-Sep	1,153	14	6,632	14	8	14	14	4,341	2,036	14	1,075	14	163	14
12-Sep	727	14	4,505	14	5	14	14	6,214	2,872	14	1,238	14	175	14
13-Sep	659	14	4,299	14	3	14	14	5,218	1,522	14	687	14	71	14
14-Sep	290	14	3,881	14	2	14	14	9,220	3,258	14	586	14	60	14
15-Sep	741	14	3,025	14	35	14	14	6,308	2,879	14	711	14	180	14
16-Sep	332	14	1,942	14	245	14	14	7,472	741	14	450	14	257	14
17-Sep	375	14	1,018	14	904	14	14	5,088	767	14	203	14	221	14
18-Sep	416	14	448	14	154	14	14	5,077	1,050	14	130	14	127	14
19-Sep	383	14	365	14	97	14	14	4,330	1,199	14	263	14	95	14
20-Sep	198	14	561	14	39	14	14	3,070	1,366	14	169	14	44	14
21-Sep	174	14	406	14	23	14	14	2,690	715	14	140	14	15	14
22-Sep	66	14	538	14	25	14	14	2,288	172	14	122	14	13	14
23-Sep	45	14	799	14	22	14	14	2,645	291	14	69	14	5	14
24-Sep	32	14	388	14	39	14	14	2,058	299	14	78	14	7	14
25-Sep	19	14	402	14	28	14	14	2,505	277	14	42	14	3	14
26-Sep	29	14	358	14	14	14	14	2,719	113	14	16	14	3	14
27-Sep	12	14	475	14	83	14	14	2,577	177	14	6	14		
28-Sep	11	14	318	14	45	14	14	2,373	57	14				
29-Sep	12	14	126	14	59	14	14	1,433	32	14				
30-Sep	8	14	81	14	45	14	14	1,030	9	14				
01-Oct			63	14			14	958	12	14				
02-Oct			77	14	4	14	14	994						
03-Oct							14	747						
04-Oct					34	14	14	623						
05-Oct							14	312						
06-Oct					18	14	14	251						
07-Oct							14	169						
08-Oct					3	14	14	106						
09-Oct							14	102						
10-Oct							14	58						
11-Oct							14	53						
12-Oct							14	15						
13-Oct							14	35						
14-Oct							14	22						

Appendix D. Daily totals of Sockeye salmon from DIDSON and ARIS acoustic imaging systems in Chilko River, 2009-2012.

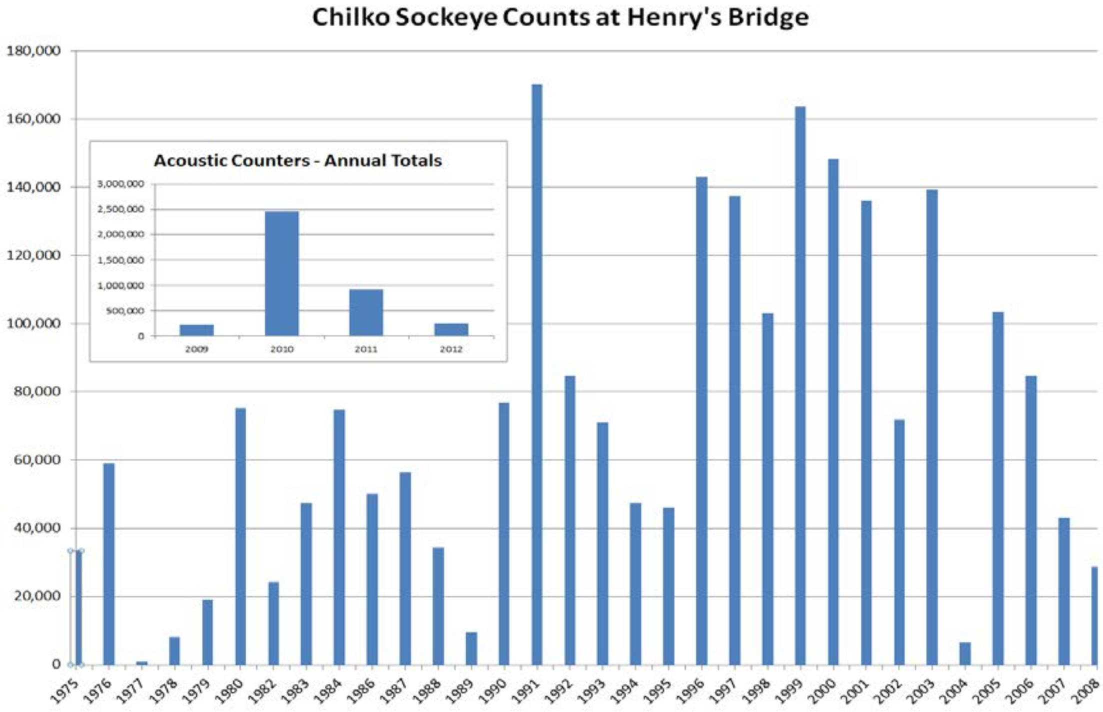
Date	2009	2010	2011	2012
06-Aug	-	-	15	51
07-Aug	-	-	10	84
08-Aug	0	105	47	68
09-Aug	5	338	12	30
10-Aug	5	3,276	51	36
11-Aug	3	4,763	45	36
12-Aug	6	9,314	32	63
13-Aug	9	7,791	29	45
14-Aug	12	9,434	32	54
15-Aug	17	9,156	6	36
16-Aug	62	17,880	26	33
17-Aug	192	25,061	56	48
18-Aug	360	33,902	36	246
19-Aug	1,361	41,613	98	1,643
20-Aug	4,426	50,940	143	2,304
21-Aug	7,248	48,077	321	3,374
22-Aug	8,524	44,265	15,705	4,626
23-Aug	8,285	43,212	20,073	6,558
24-Aug	8,423	44,126	24,513	10,923
25-Aug	9,563	38,414	28,578	10,635
26-Aug	9,921	45,140	28,617	16,259
27-Aug	9,023	56,037	31,416	9,458
28-Aug	11,325	67,288	29,942	5,678
29-Aug	9,094	82,716	29,408	6,785
30-Aug	9,335	99,086	27,773	14,447
31-Aug	8,884	98,238	21,753	16,742
01-Sep	10,520	97,055	18,579	16,136
02-Sep	10,290	95,283	17,039	19,671
03-Sep	8,831	90,495	21,182	17,411
04-Sep	6,863	98,261	27,275	15,224
05-Sep	8,019	107,804	36,833	11,987
06-Sep	7,497	122,039	40,871	9,674
07-Sep	7,175	132,941	45,290	8,978
08-Sep	6,089	124,374	55,602	7,922
09-Sep	4,887	103,158	55,796	7,244
10-Sep	5,024	81,822	51,250	3,171
11-Sep	4,221	65,643	36,951	2,169
12-Sep	3,717	66,923	27,071	2,205
13-Sep	3,089	69,524	33,939	2,037
14-Sep	2,555	66,927	34,101	2,346
15-Sep	2,229	53,228	26,678	1,475
16-Sep	2,086	35,790	18,327	1,427
17-Sep	1,654	25,968	12,486	1,146
18-Sep	2,765	22,089	14,322	893
19-Sep	1,863	16,259	12,386	965
20-Sep	1,673	16,113	11,993	867
21-Sep	1,739	11,217	11,550	497
22-Sep	1,603	15,039	8,400	426
23-Sep	1,223	14,496	7,605	499
24-Sep	974	12,216	7,362	476
25-Sep	938	9,998	5,471	447
26-Sep	996	9,726	4,634	182
27-Sep	666	5,814	3,998	279
28-Sep	449	4,424	3,068	285
29-Sep	465	4,328	2,490	146
30-Sep	356	2,186	1,968	123
01-Oct	378	1,374	1,535	45
02-Oct	286	300	1,277	
03-Oct	240	-	1,007	
04-Oct	138	-	714	
05-Oct	120	-	513	
06-Oct	70	-	449	
07-Oct	20	-	300	
08-Oct	-	-	170	
09-Oct	-	-	50	
Total	**217,778**	**2,462,975**	**919,254**	**246,602**

Appendix E. Annual Time-To-50% for Chilko Sockeye, 1975-2012.

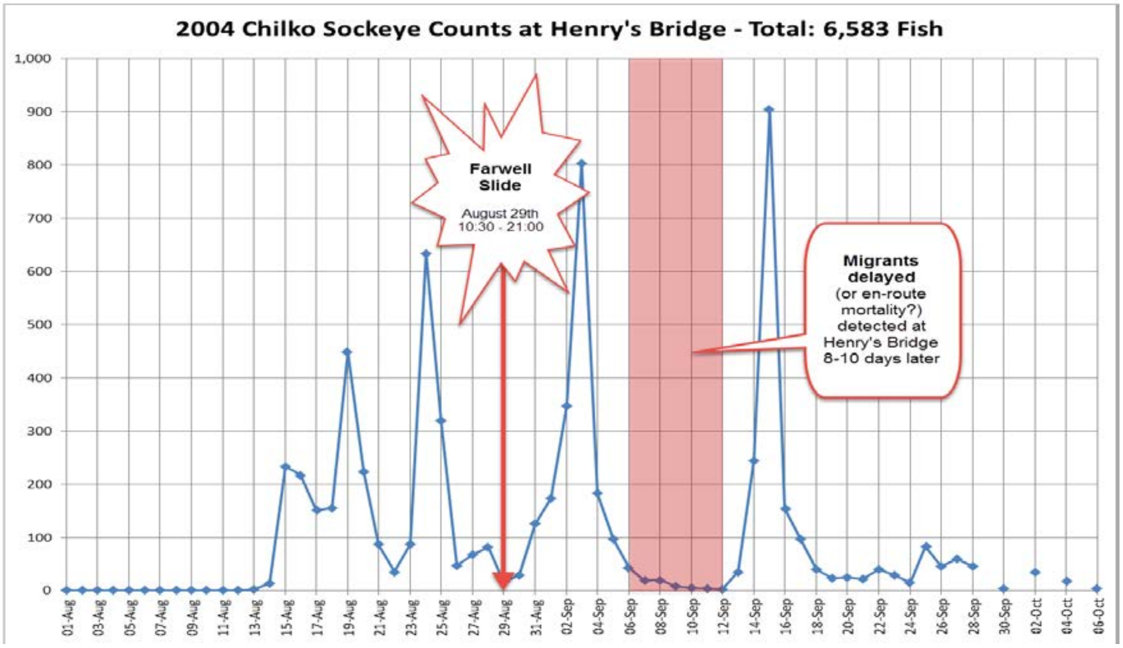
TT50% by Year

Year	Date	Cumul Pct
1975	26AUG75	53.6193
1976	04SEP76	55.5424
1979	31AUG79	52.4304
1980	01SEP80	51.6076
1982	02SEP82	56.7484
1983	31AUG83	56.3012
1984	27AUG84	52.8117
1986	30AUG86	55.7442
1987	31AUG87	52.6392
1988	29AUG88	50.3173
1989	04SEP89	53.6421
1990	04SEP90	56.3981
1991	12SEP91	53.9710
1992	05SEP92	51.6590
1993	13SEP93	50.8372
1994	31AUG94	56.5770
1995	31AUG95	57.0521
1996	30AUG96	54.5199
1997	10SEP97	53.2367
1998	03SEP98	52.8254
1999	11SEP99	50.1556
2000	28AUG00	54.9612
2001	03SEP01	56.1696
2002	29AUG02	55.0626
2003	06SEP03	53.8067
2004	04SEP04	52.9698
2005	16SEP05	57.2095
2006	03SEP06	52.9263
2007	31AUG07	54.0852
2008	21AUG08	52.8552
2009	01SEP09	53.5392
2010	04SEP10	51.2088
2011	07SEP11	50.6712
2012	01SEP12	51.2538

Appendix F. Annual totals of Chilko Sockeye salmon from partial daily counts at Henry's Bridge (1975-2008) and 24-hour DIDSON and ARIS acoustic imaging systems (2009-2012).



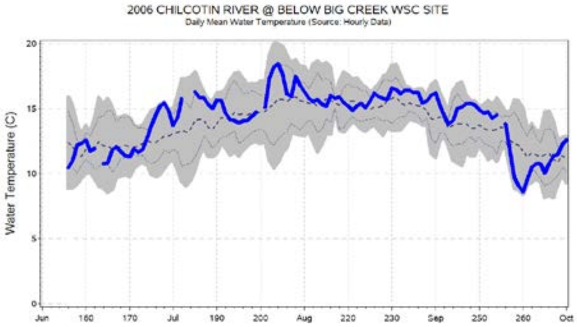
Appendix G. Early September migration gap in daily totals of Chilko Sockeye salmon impacted by debris dam caused by land-slide in Farwell Canyon, August 29th, 2004.

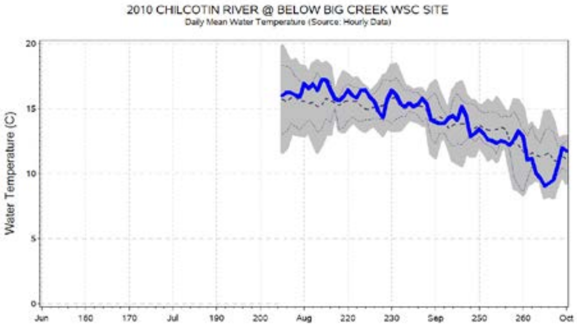

2004 Chilko Sockeye Counts at Henry's Bridge - Total: 6,583 Fish

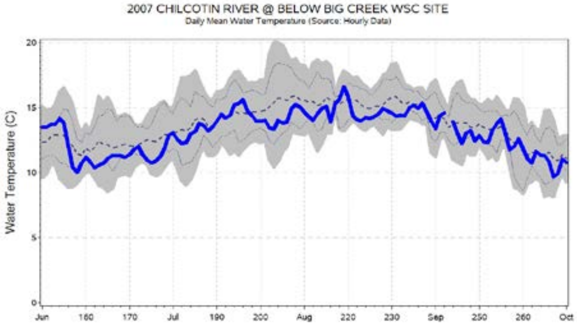
Farwell Slide
August 29th
10:30 - 21:00

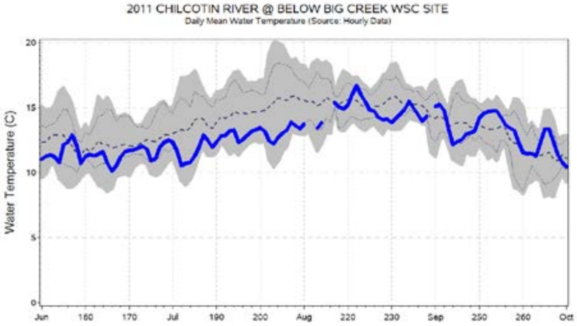
Migrants delayed
(or en-route mortality?)
detected at Henry's Bridge
8-10 days later

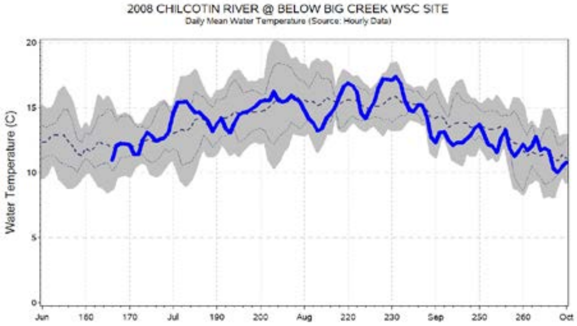
Appendix H. Chilcotin River at Big Creek water temperature from hourly observations, by year, 2006-2012 (source: DFO Environmental Watch Program). Daily mean water temperature (solid blue line), multi-year minimum, mean, and maximum values (dashed lines), and 95% confidence intervals (gray area).

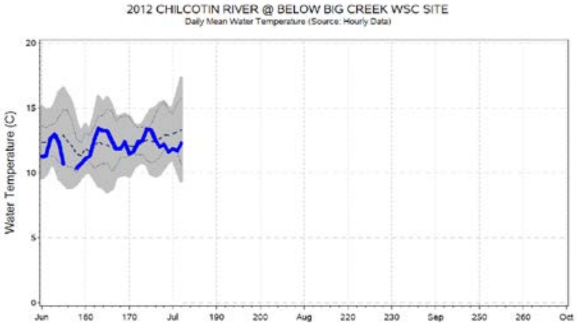


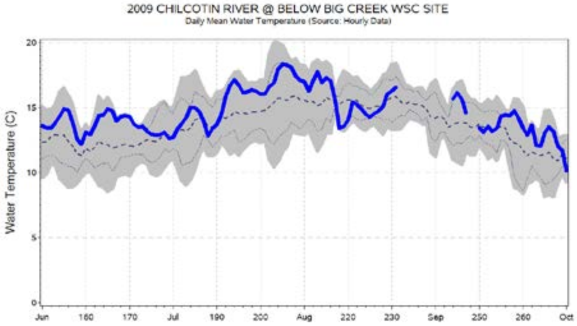




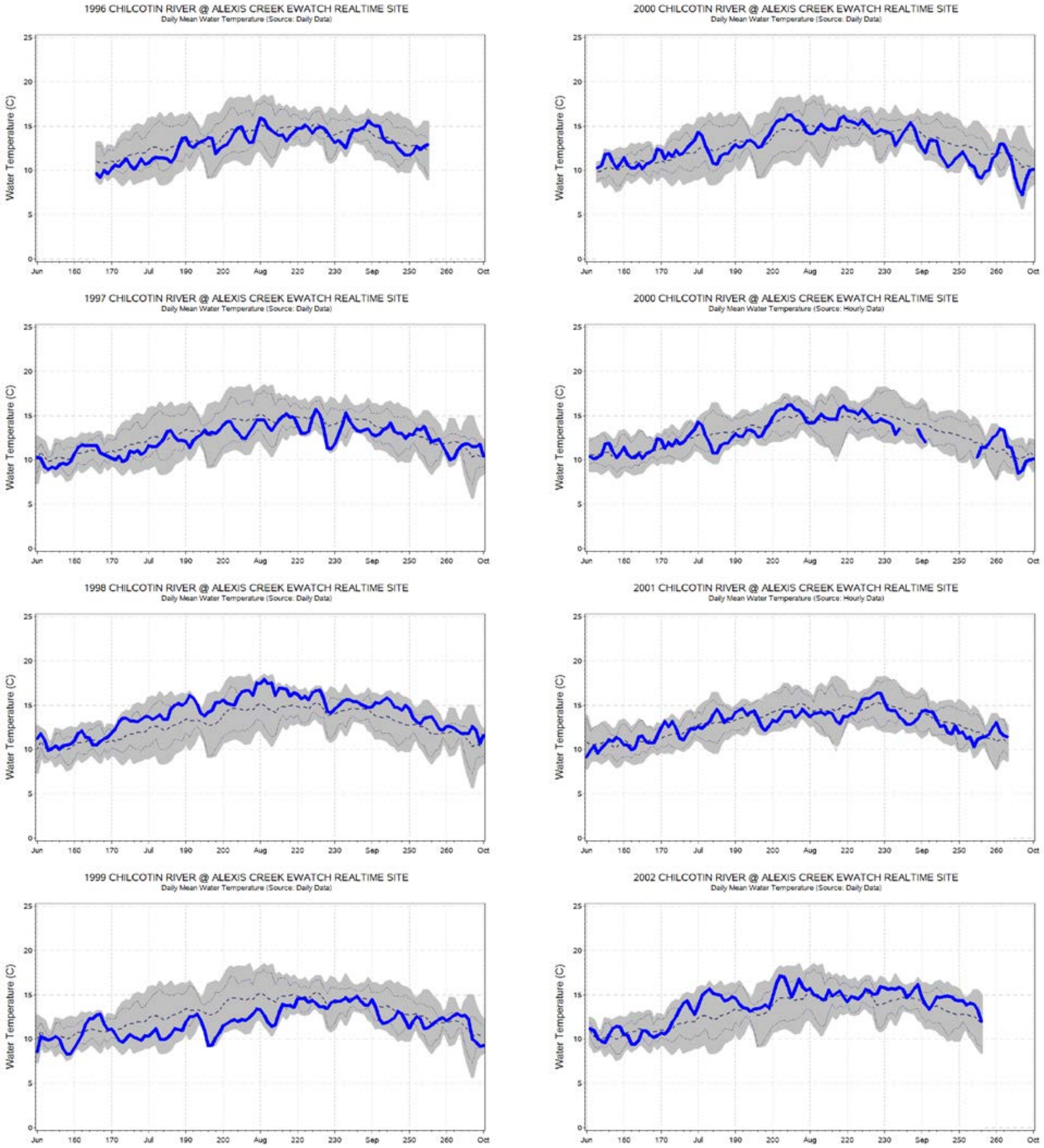


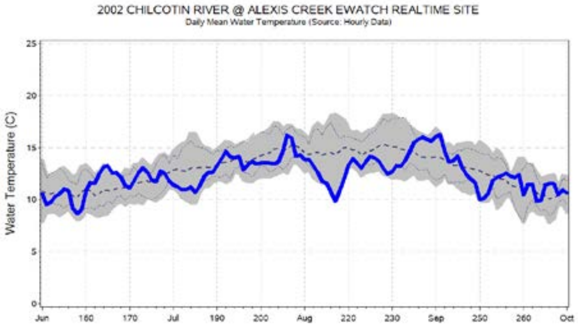


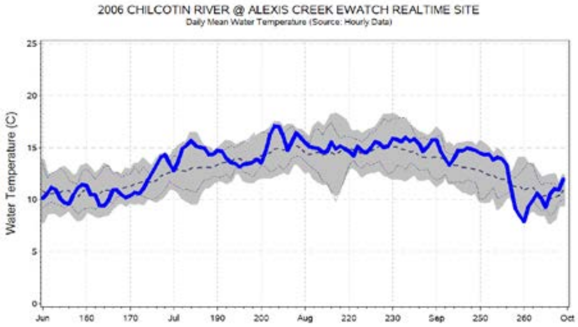


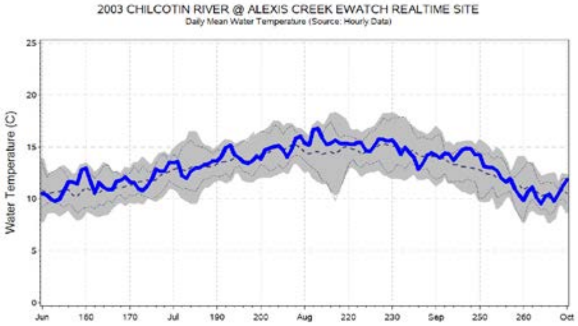


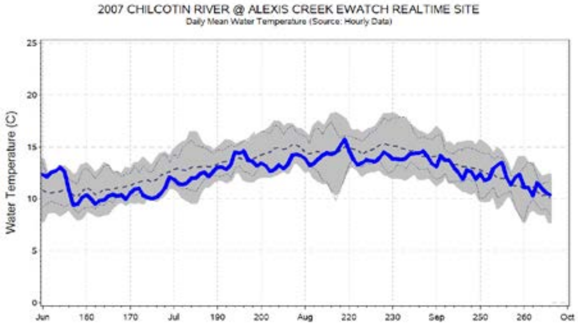
Appendix I. CHILCOTIN RIVER AT ALEXIS CREEK water temperature from daily or hourly observations, by year and data type, 1996-2008 (source: ENVIRONMENTAL WATCH PROGRAM). Daily mean water temperature (solid blue line), multi-year minimum, mean, and maximum values (dashed lines), and 95% confidence intervals (gray area).

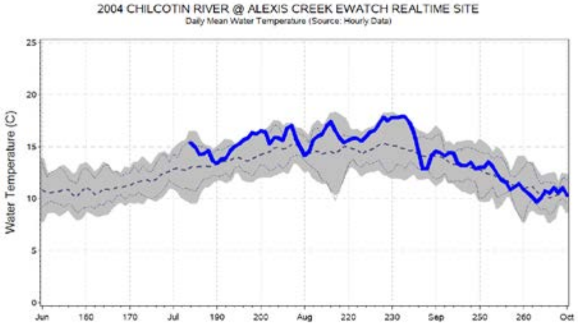


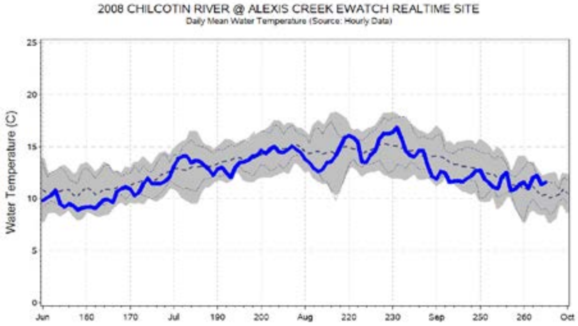

2002 CHILCOTIN RIVER @ ALEXIS CREEK EWATCH REALTIME SITE
Daily Mean Water Temperature (Source: Hourly Data)

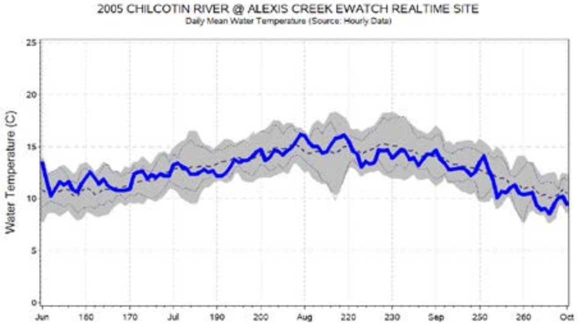

2006 CHILCOTIN RIVER @ ALEXIS CREEK EWATCH REALTIME SITE
Daily Mean Water Temperature (Source: Hourly Data)


2003 CHILCOTIN RIVER @ ALEXIS CREEK EWATCH REALTIME SITE
Daily Mean Water Temperature (Source: Hourly Data)


2007 CHILCOTIN RIVER @ ALEXIS CREEK EWATCH REALTIME SITE
Daily Mean Water Temperature (Source: Hourly Data)

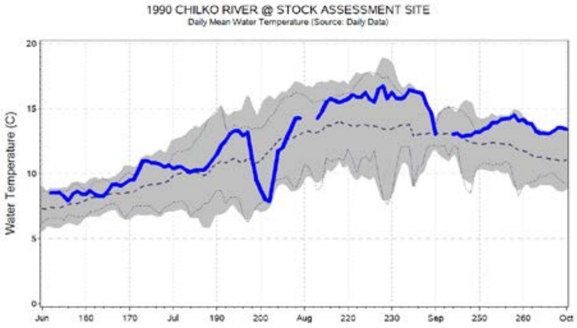

2004 CHILCOTIN RIVER @ ALEXIS CREEK EWATCH REALTIME SITE
Daily Mean Water Temperature (Source: Hourly Data)

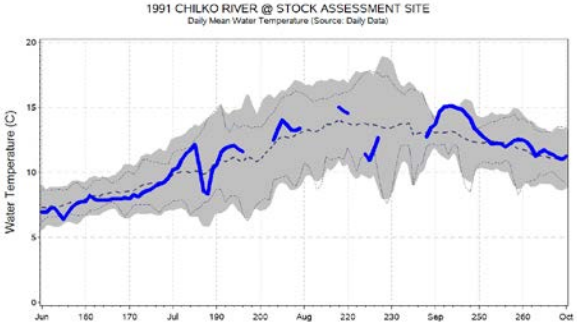

2008 CHILCOTIN RIVER @ ALEXIS CREEK EWATCH REALTIME SITE
Daily Mean Water Temperature (Source: Hourly Data)

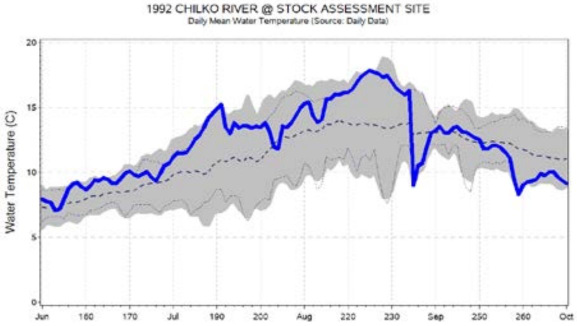

2005 CHILCOTIN RIVER @ ALEXIS CREEK EWATCH REALTIME SITE
Daily Mean Water Temperature (Source: Hourly Data)

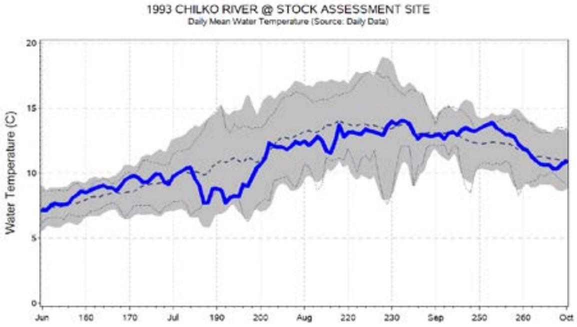
Appendix J. Chilko River (stock assessment site) water temperature observations, by year and data type, 1990-2012 (source: DFO StAD; Environmental Watch Program). Daily mean water temperature (solid blue line), multi-year minimum, mean, and maximum values (dashed lines), and 95% confidence intervals (gray area)

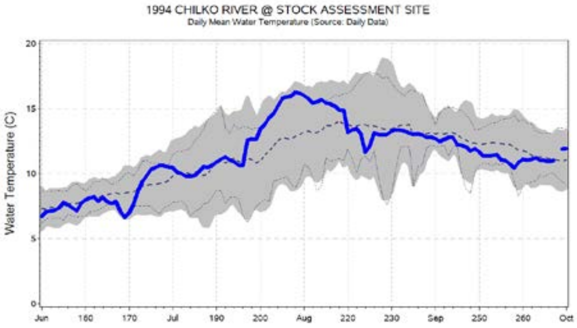
.

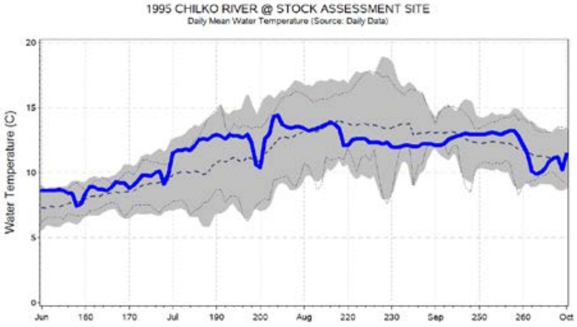


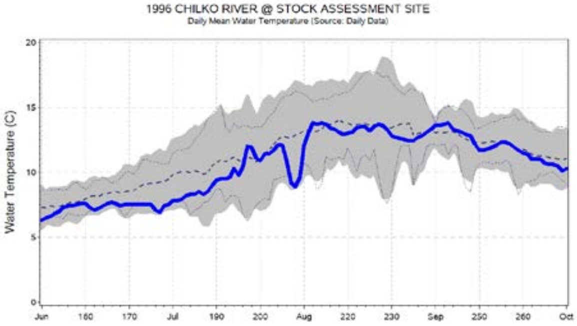


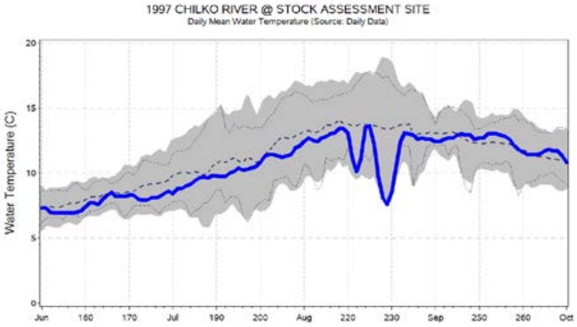




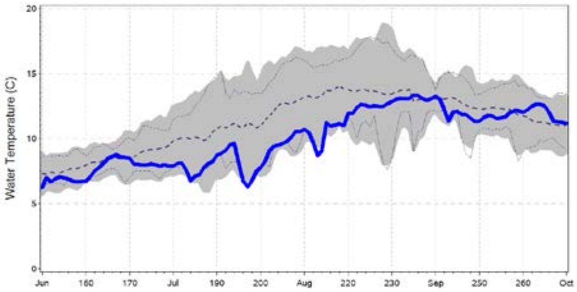




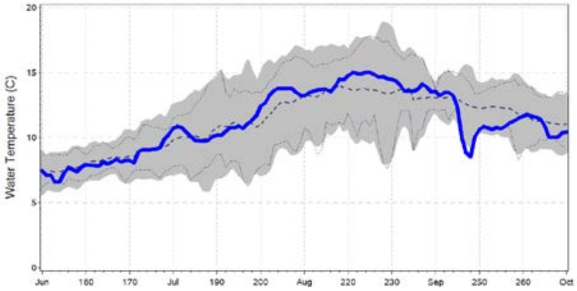




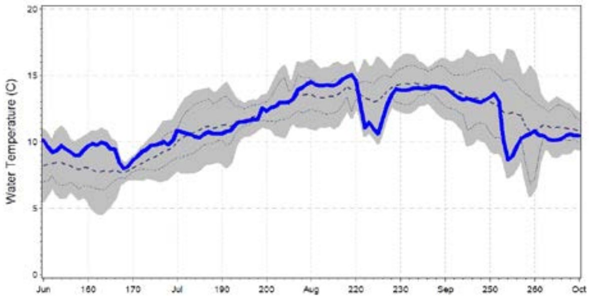
1999 CHILKO RIVER @ STOCK ASSESSMENT SITE
Daily Mean Water Temperature (Source: Daily Data)



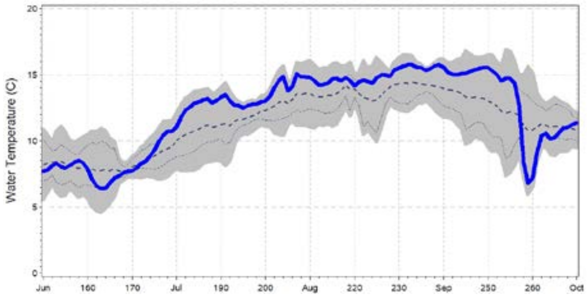
2000 CHILKO RIVER @ STOCK ASSESSMENT SITE
Daily Mean Water Temperature (Source: Daily Data)



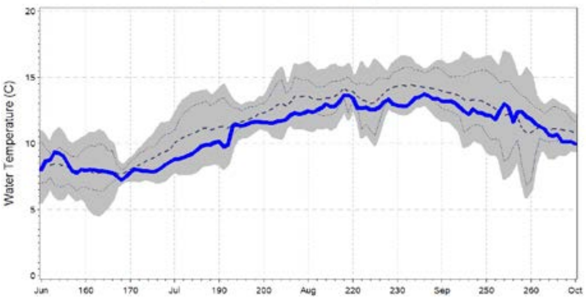
2005 CHILKO RIVER @ STOCK ASSESSMENT SITE
Daily Mean Water Temperature (Source: Hourly Data)



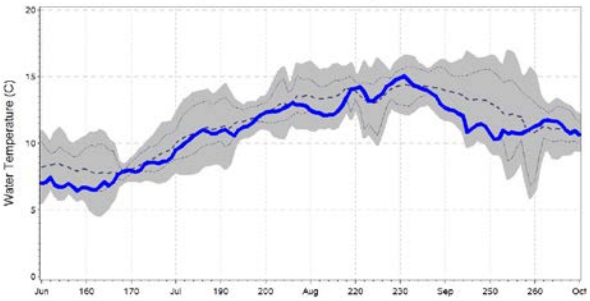
2006 CHILKO RIVER @ STOCK ASSESSMENT SITE
Daily Mean Water Temperature (Source: Hourly Data)



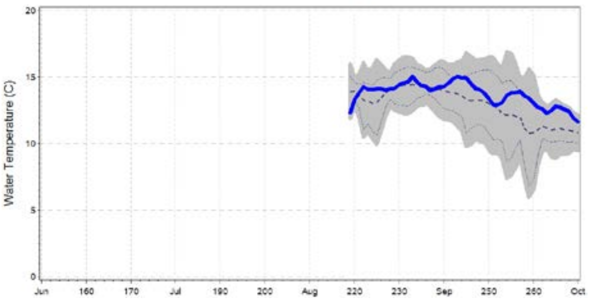
2007 CHILKO RIVER @ STOCK ASSESSMENT SITE
Daily Mean Water Temperature (Source: Hourly Data)



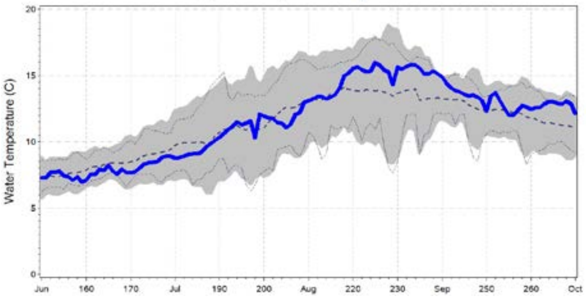
2008 CHILKO RIVER @ STOCK ASSESSMENT SITE
Daily Mean Water Temperature (Source: Hourly Data)



2009 CHILKO RIVER @ STOCK ASSESSMENT SITE
Daily Mean Water Temperature (Source: Hourly Data)

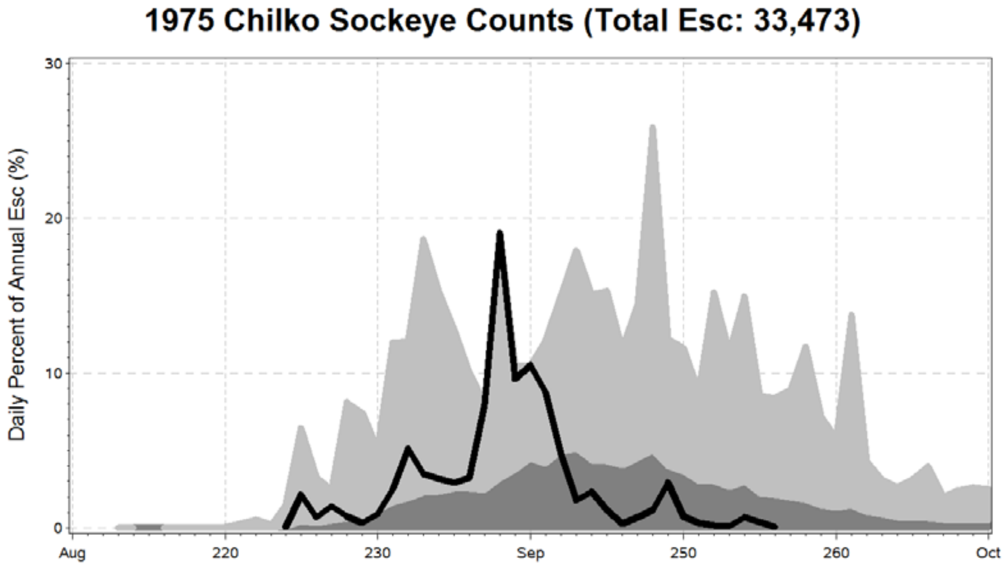


2012 CHILKO RIVER @ STOCK ASSESSMENT SITE
Daily Mean Water Temperature (Source: Daily Data)

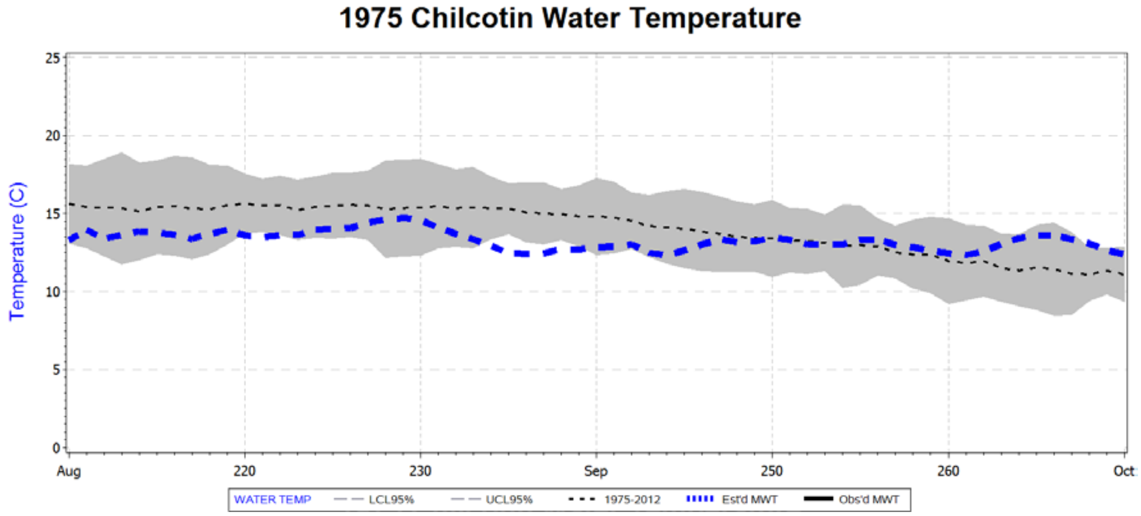


Appendix K. Multi-panel plots of daily Chilko Sockeye migration in relation to environmental variables, by year, 1975-2012.

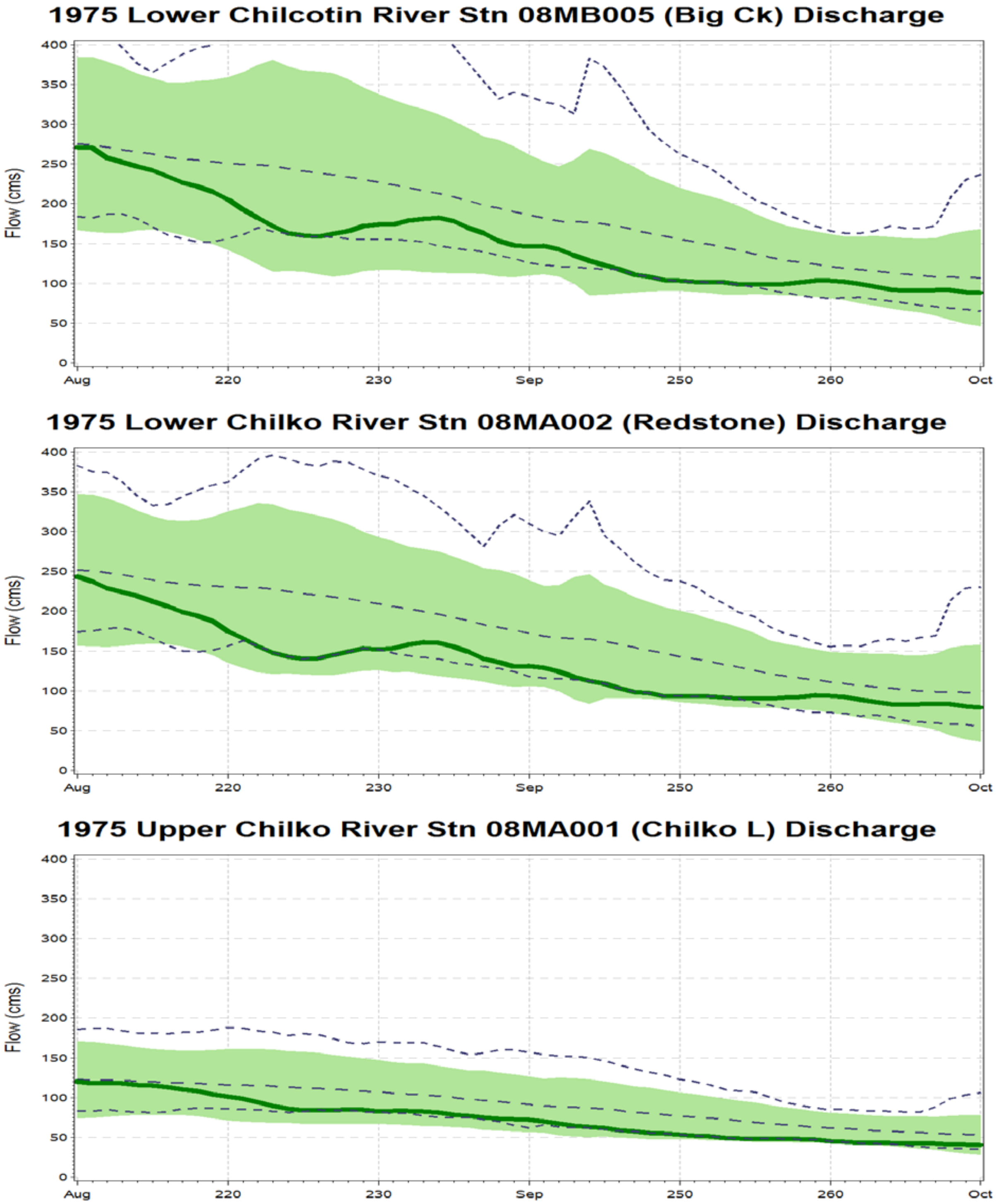
Sample plots for the year 1975 (below) display legend with vertical axis variates and horizontal axis with day of year (month label is *approximate* start of each month). Annual plots (following pages) are organized in a multi-panel format for cross-comparison of the following co-variates:



1. Daily migration rates (black line) as a percent (%) of annual counts from daily Sockeye (adult + jack) migrants counted at Henry's Bridge, Chilko River. Historical mean daily migration rate (dark gray area) and maximum daily migration rate (light gray area) for years 1975-2012.



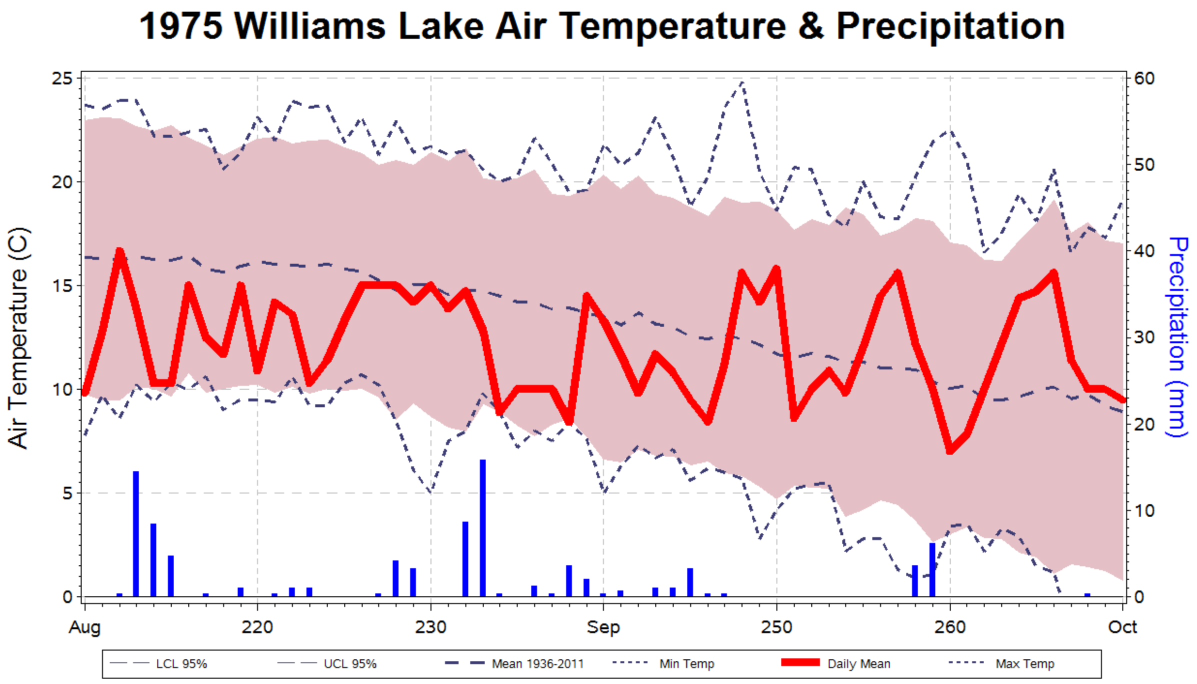
2. Observed (solid black line) and estimated (dashed blue line) daily mean water temperature in the lower Chilcotin River near Big Creek, with 1975-2012 daily mean MWT and variance (dashed line and gray area).


1975 Lower Chilcotin River Stn 08MB005 (Big Ck) Discharge

1975 Lower Chilko River Stn 08MA002 (Redstone) Discharge

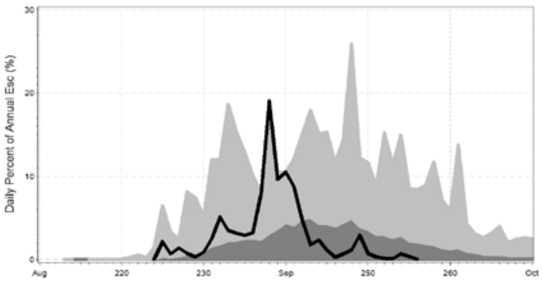
1975 Upper Chilko River Stn 08MA001 (Chilko L) Discharge

3. Daily mean discharge (cms; solid green line) at WSC stations in the lower Chilcotin River at Big Creek (top), lower Chilko River at Redstone (middle) and upper Chilko River at Chilko Lake (bottom), with historical daily mean and variance (dashed line and green area), 1975-2012.

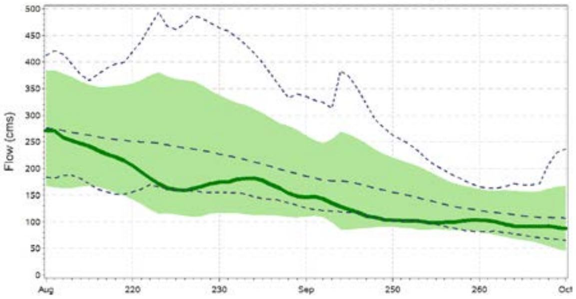


4. Observed precipitation (mm, blue bars), and regional daily mean air temperature (°C, red line) based on EC meteorological station Williams Lake (station 1098940) with historical daily mean and variance (dashed line and red area), 1936-2012.

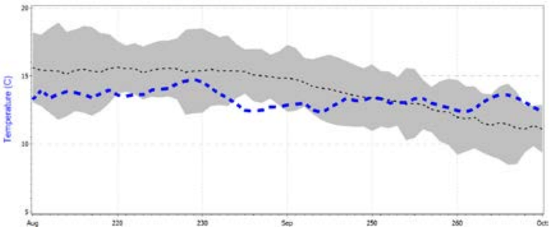
1975 Chilko Sockeye Counts (Total Esc: 33,473)



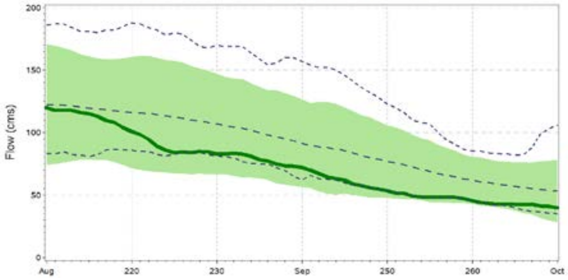
1975 Chilcotin Stn 08MA005 Discharge



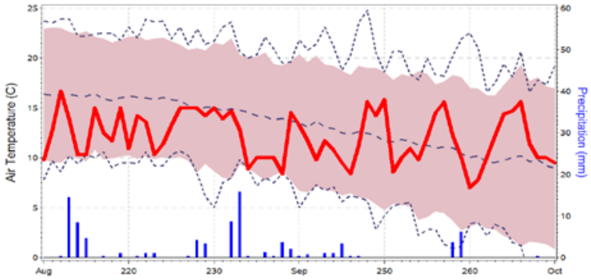
1975 Chilcotin Water Temperature



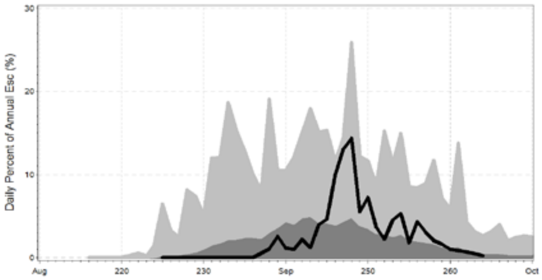
1975 Upper Chilko River Discharge



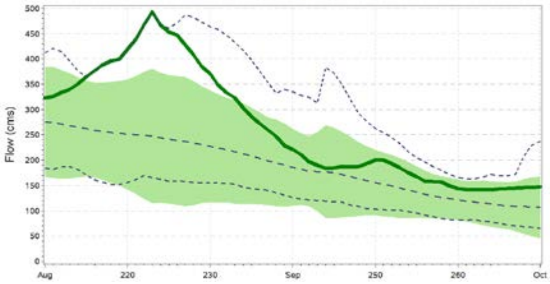
1975 Williams Lake Air Temperature & Precipitation



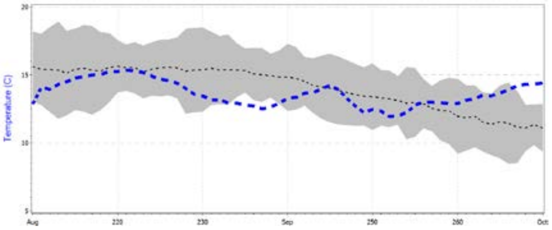
1976 Chilko Sockeye Counts (Total Esc: 59,198)



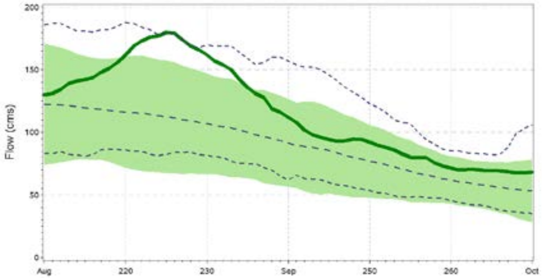
1976 Chilcotin Stn 08MA005 Discharge



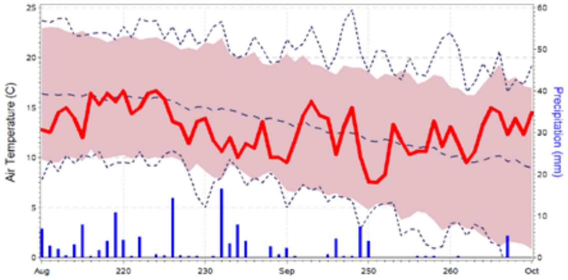
1976 Chilcotin Water Temperature



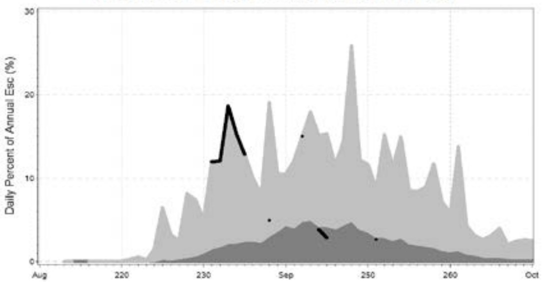
1976 Upper Chilko River Discharge



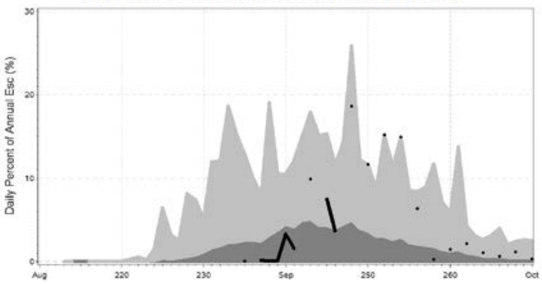
1976 Williams Lake Air Temperature & Precipitation



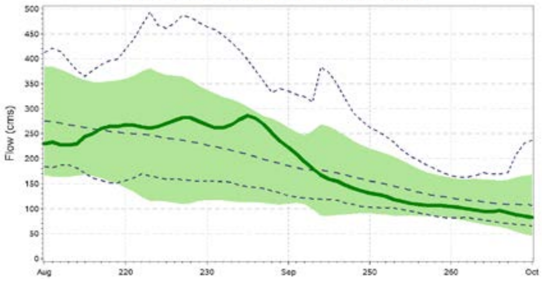
1977 Chilko Sockeye Counts (Total Esc: 871)



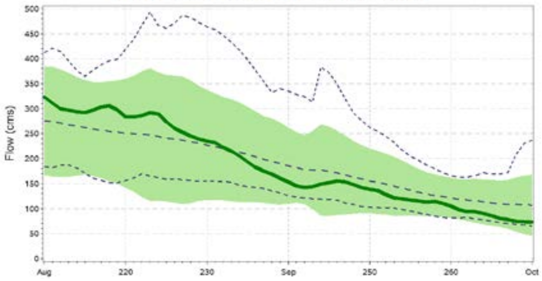
1978 Chilko Sockeye Counts (Total Esc: 8,151)



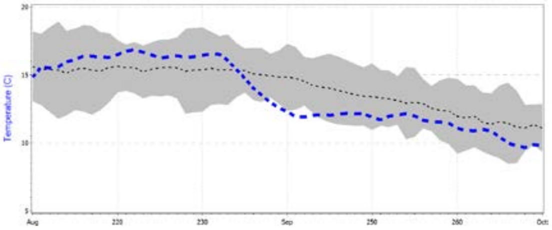
1977 Chilcotin Stn 08MA005 Discharge



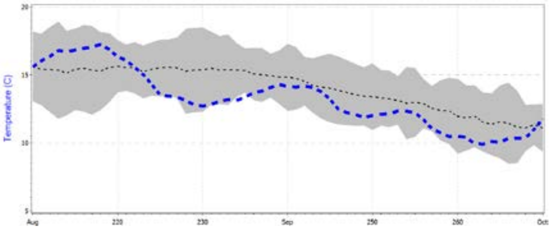
1978 Chilcotin Stn 08MA005 Discharge



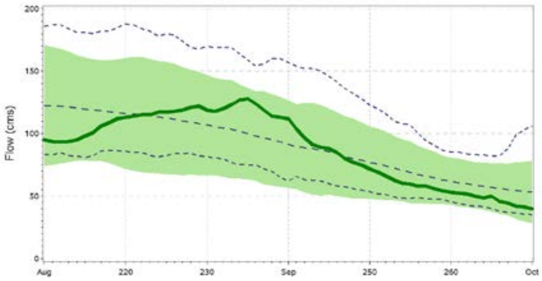
1977 Chilcotin Water Temperature



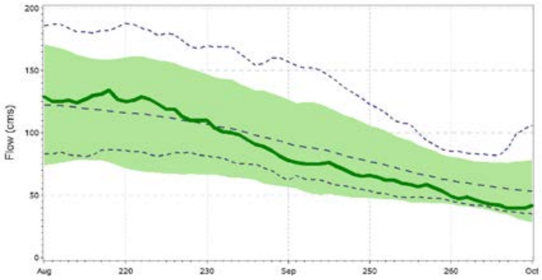
1978 Chilcotin Water Temperature



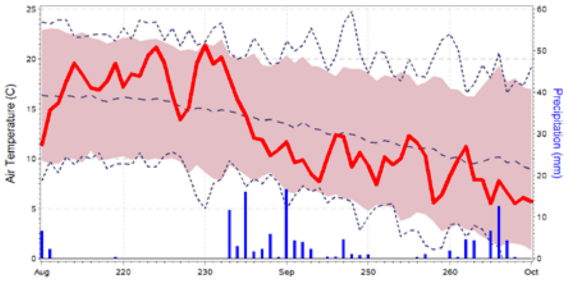
1977 Upper Chilko River Discharge



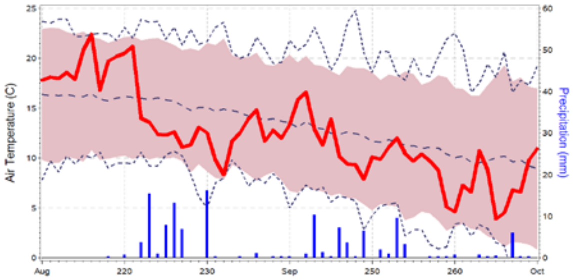
1978 Upper Chilko River Discharge

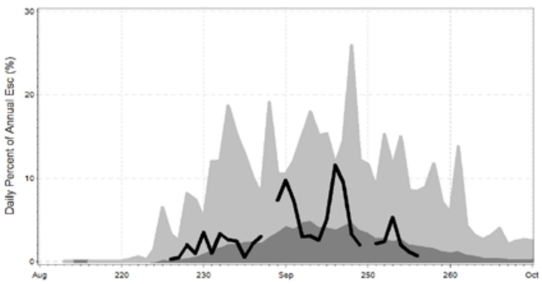


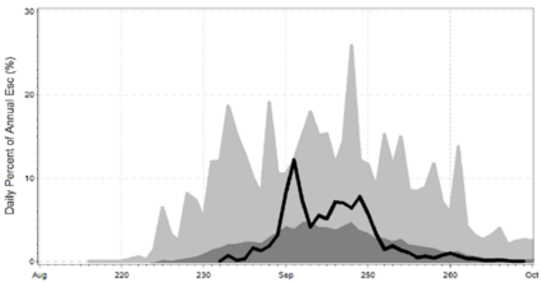
1977 Williams Lake Air Temperature & Precipitation

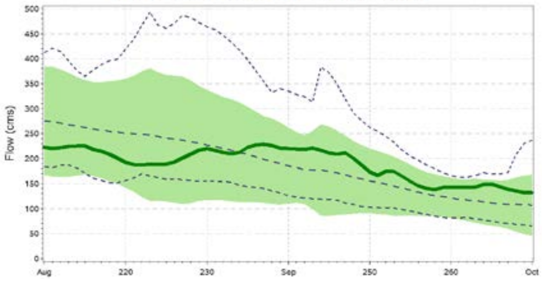


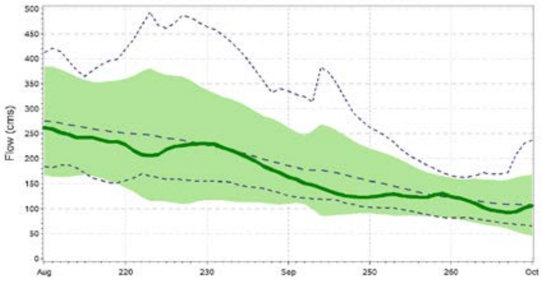
1978 Williams Lake Air Temperature & Precipitation

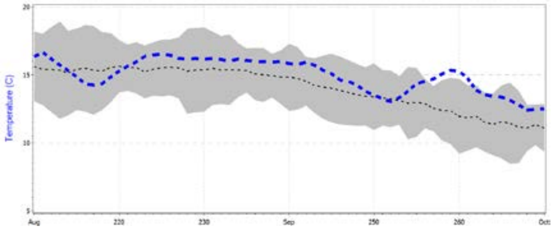


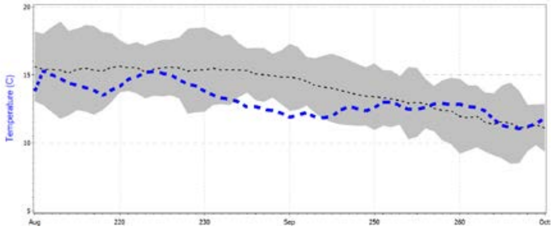

1979 Chilko Sockeye Counts (Total Esc: 19,071)

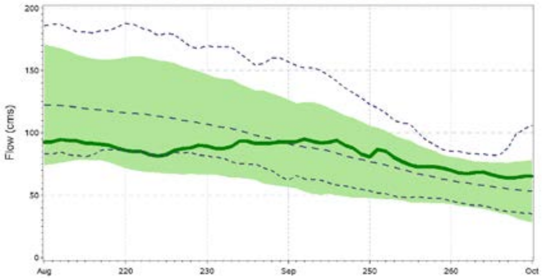

1980 Chilko Sockeye Counts (Total Esc: 75,297)

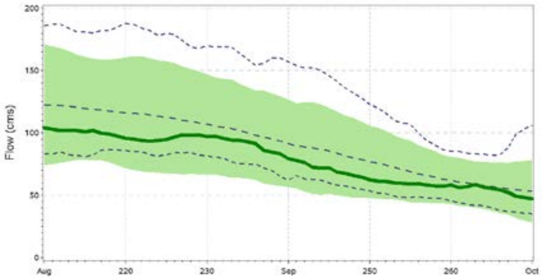

1979 Chilcotin Stn 08MA005 Discharge

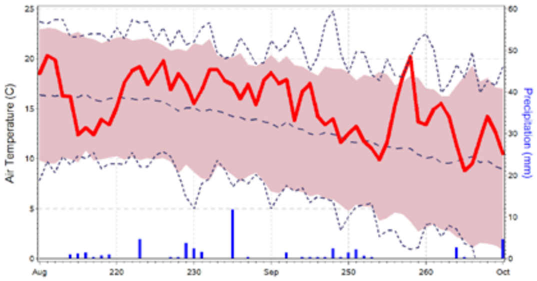

1980 Chilcotin Stn 08MA005 Discharge

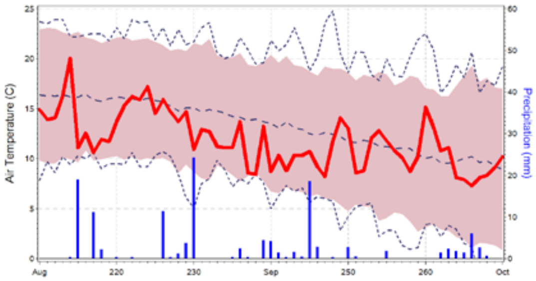

1979 Chilcotin Water Temperature

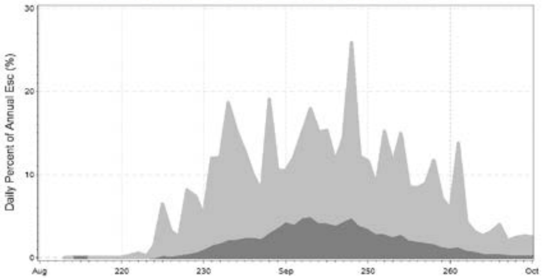

1980 Chilcotin Water Temperature


1979 Upper Chilko River Discharge

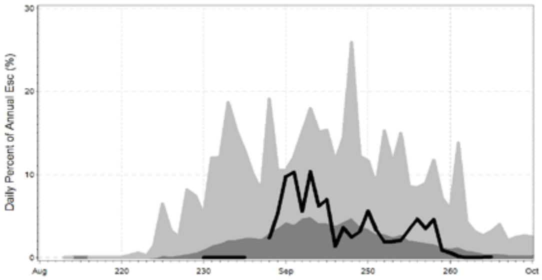

1980 Upper Chilko River Discharge


1979 Williams Lake Air Temperature & Precipitation

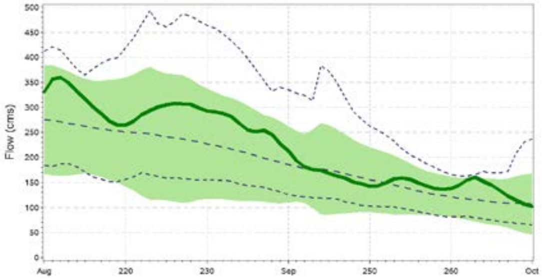

1980 Williams Lake Air Temperature & Precipitation



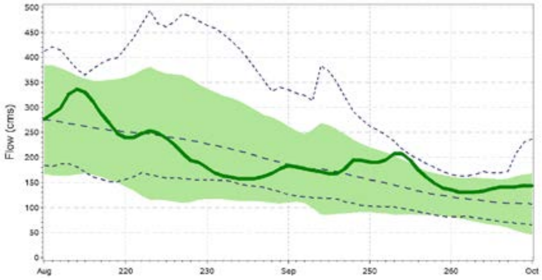
1981 Chilko Sockeye Counts (Total Esc: .)



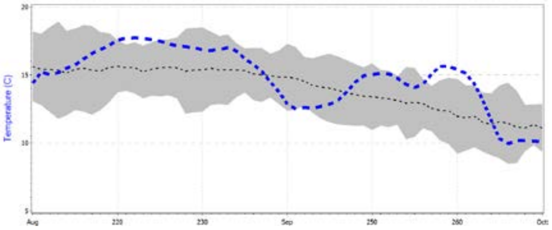
1982 Chilko Sockeye Counts (Total Esc: 24,302)



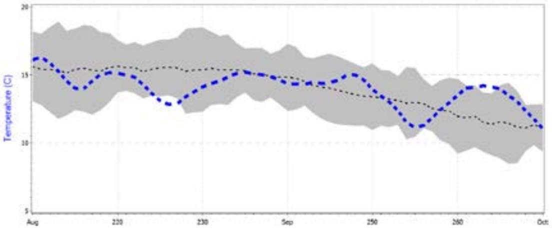
1981 Chilcotin Stn 08MA005 Discharge



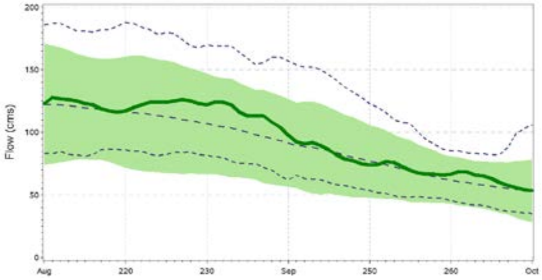
1982 Chilcotin Stn 08MA005 Discharge



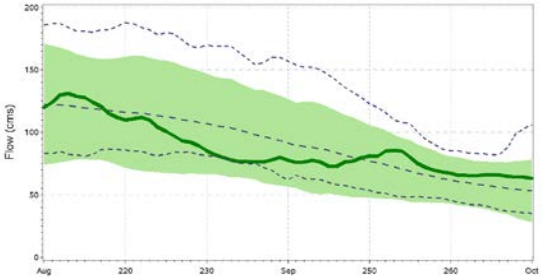
1981 Chilcotin Water Temperature



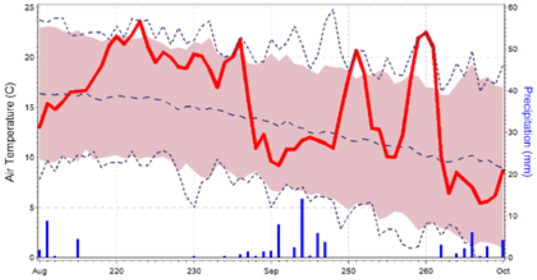
1982 Chilcotin Water Temperature



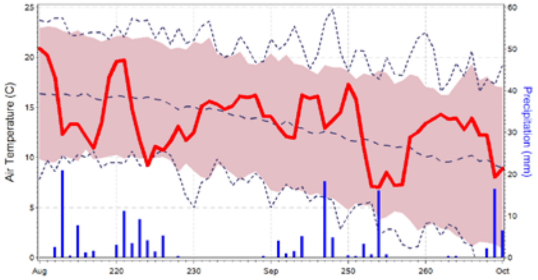
1981 Upper Chilko River Discharge



1982 Upper Chilko River Discharge

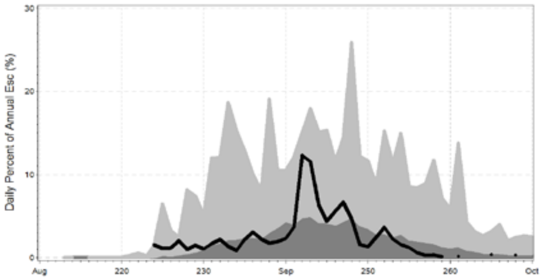


1981 Williams Lake Air Temperature & Precipitation

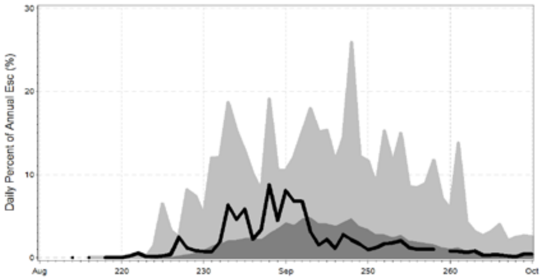


1982 Williams Lake Air Temperature & Precipitation

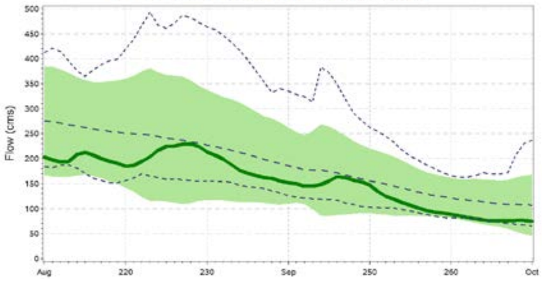
1983 Chilko Sockeye Counts (Total Esc: 47,372)



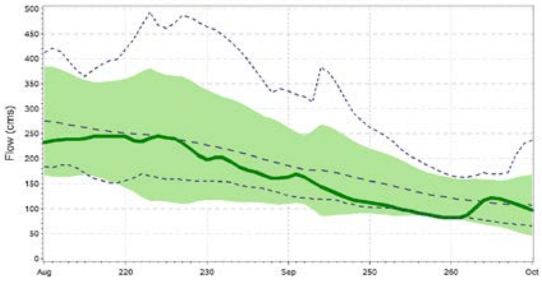
1984 Chilko Sockeye Counts (Total Esc: 74,777)



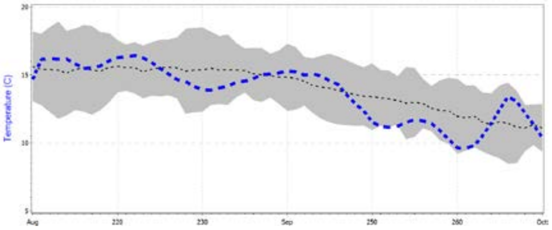
1983 Chilcotin Stn 08MA005 Discharge



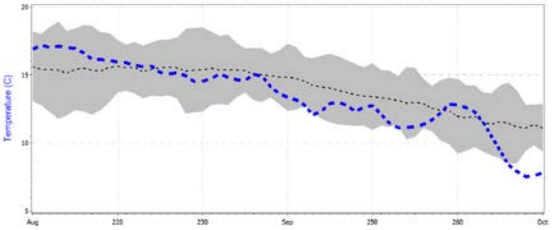
1984 Chilcotin Stn 08MA005 Discharge



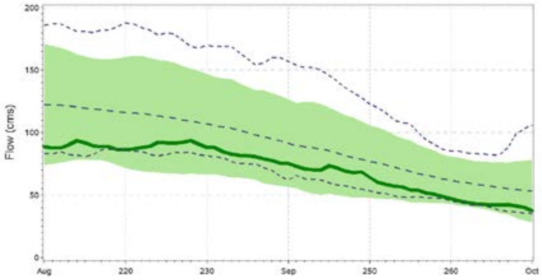
1983 Chilcotin Water Temperature



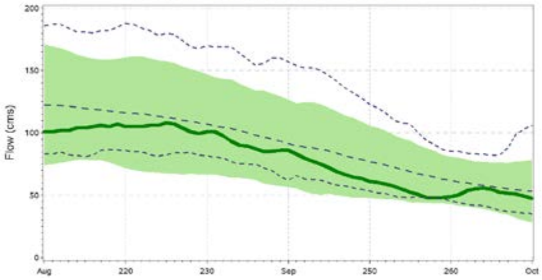
1984 Chilcotin Water Temperature



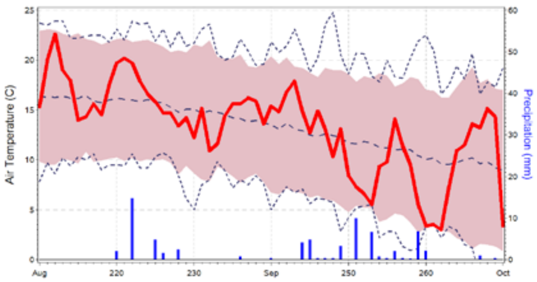
1983 Upper Chilko River Discharge



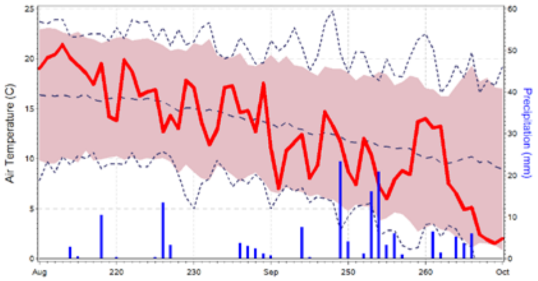
1984 Upper Chilko River Discharge



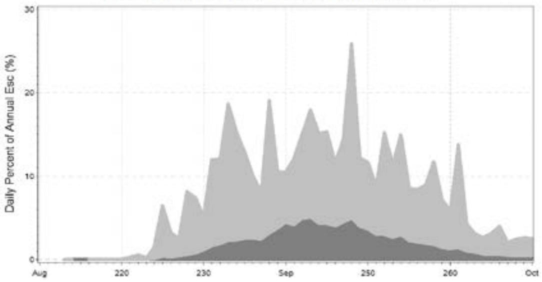
1983 Williams Lake Air Temperature & Precipitation



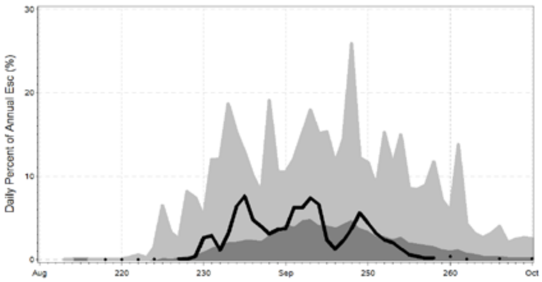
1984 Williams Lake Air Temperature & Precipitation



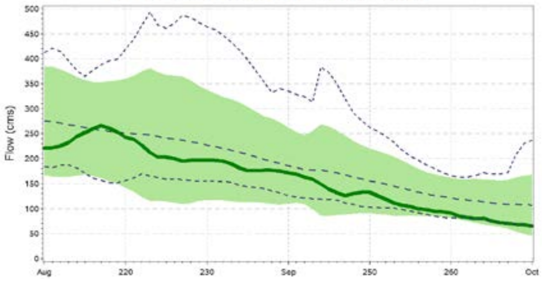
1985 Chilko Sockeye Counts (Total Esc: .)



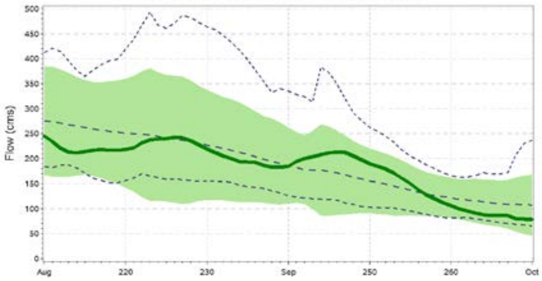
1986 Chilko Sockeye Counts (Total Esc: 50,129)



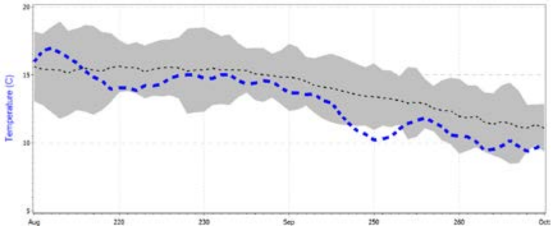
1985 Chilcotin Stn 08MA005 Discharge



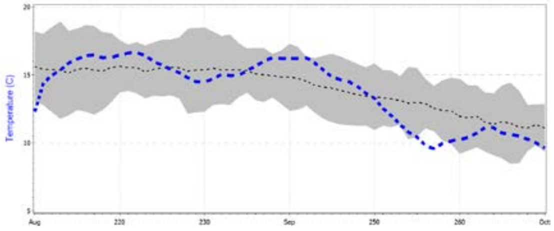
1986 Chilcotin Stn 08MA005 Discharge



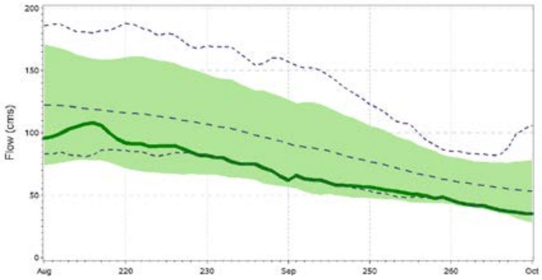
1985 Chilcotin Water Temperature



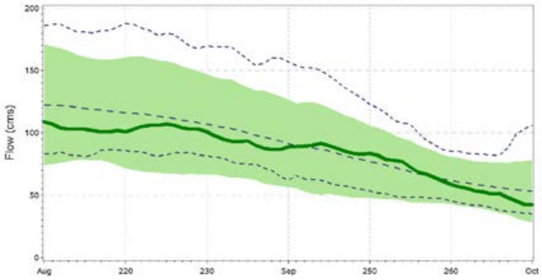
1986 Chilcotin Water Temperature



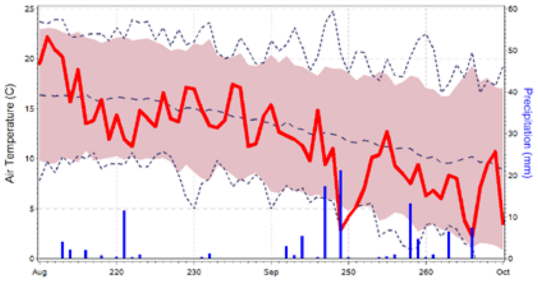
1985 Upper Chilko River Discharge



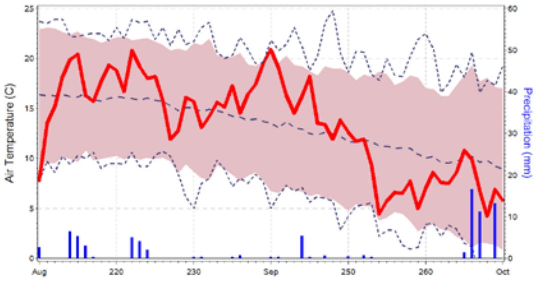
1986 Upper Chilko River Discharge



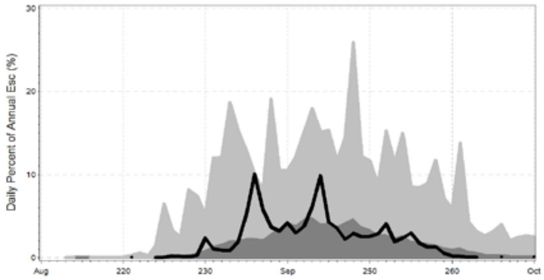
1985 Williams Lake Air Temperature & Precipitation



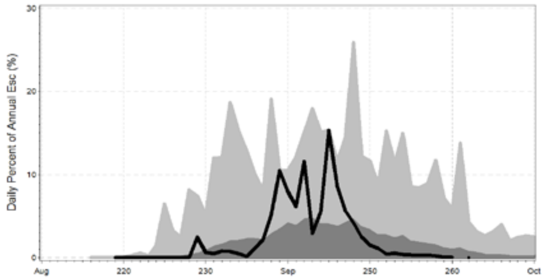
1986 Williams Lake Air Temperature & Precipitation



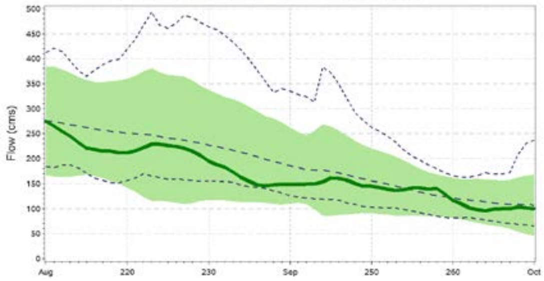
1987 Chilko Sockeye Counts (Total Esc: 56,475)



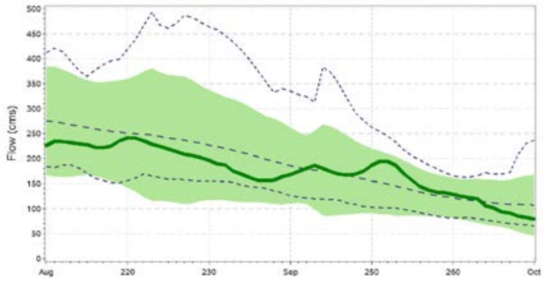
1988 Chilko Sockeye Counts (Total Esc: 34,356)



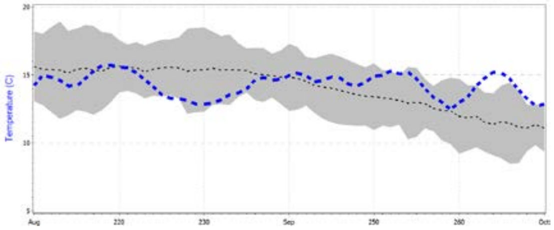
1987 Chilcotin Stn 08MA005 Discharge



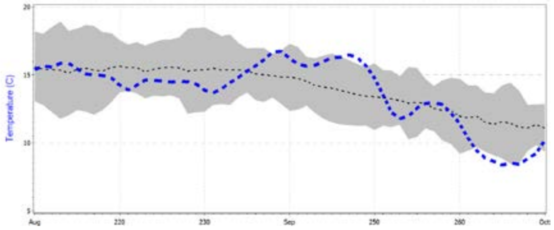
1988 Chilcotin Stn 08MA005 Discharge



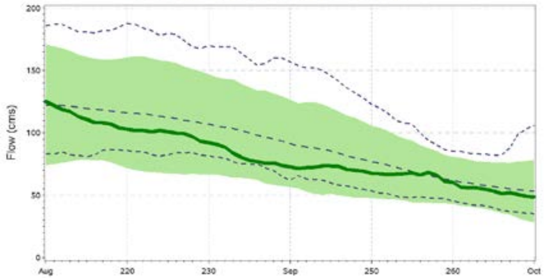
1987 Chilcotin Water Temperature



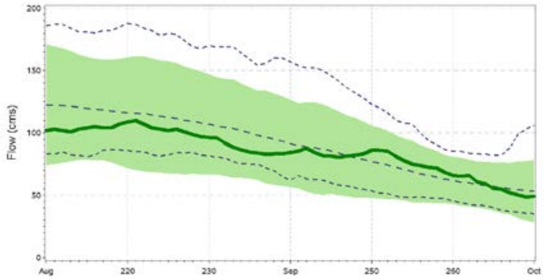
1988 Chilcotin Water Temperature



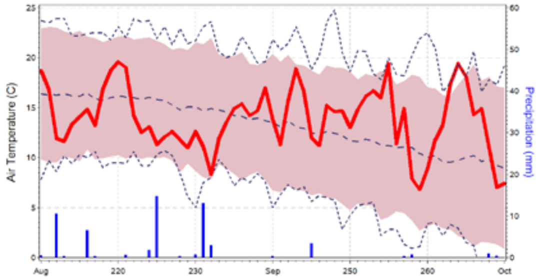
1987 Upper Chilko River Discharge



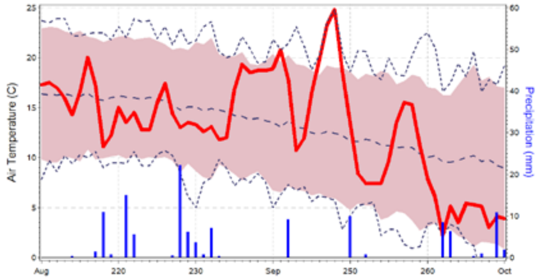
1988 Upper Chilko River Discharge

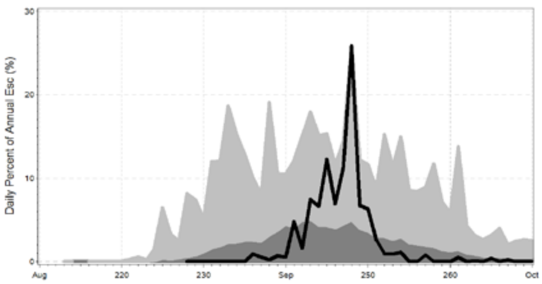


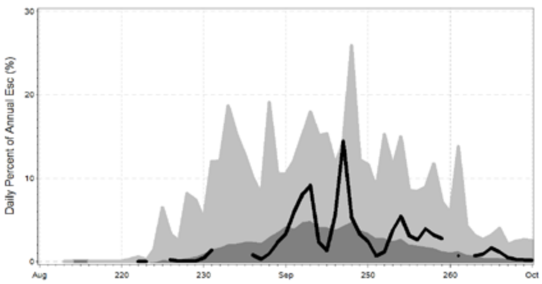
1987 Williams Lake Air Temperature & Precipitation

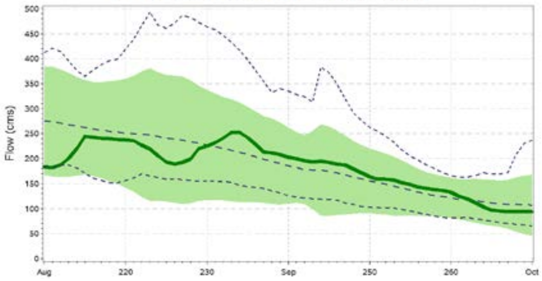


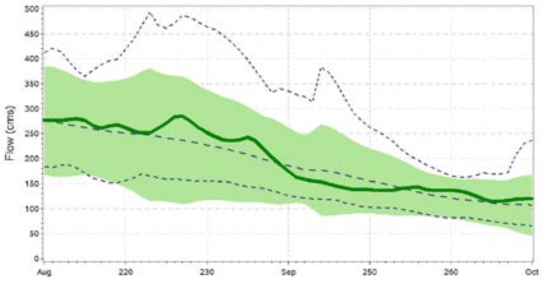
1988 Williams Lake Air Temperature & Precipitation

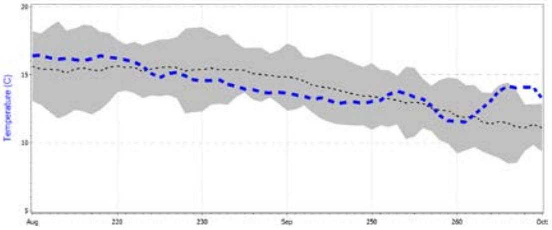


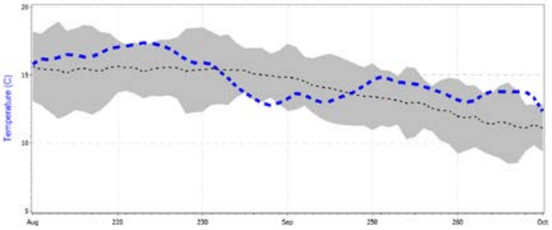

1989 Chilko Sockeye Counts (Total Esc: 9,500)

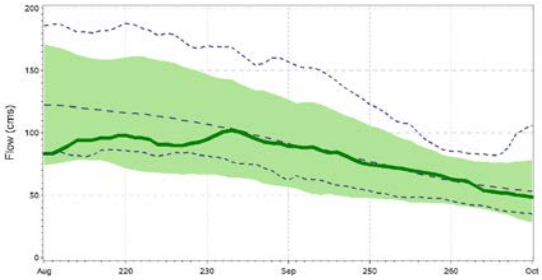

1990 Chilko Sockeye Counts (Total Esc: 76,820)

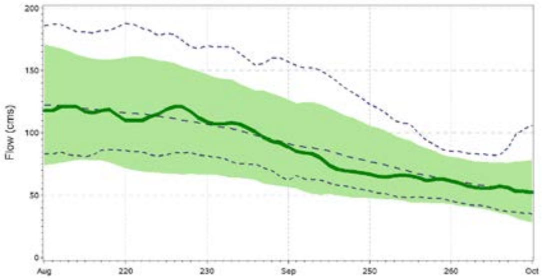

1989 Chilcotin Stn 08MA005 Discharge

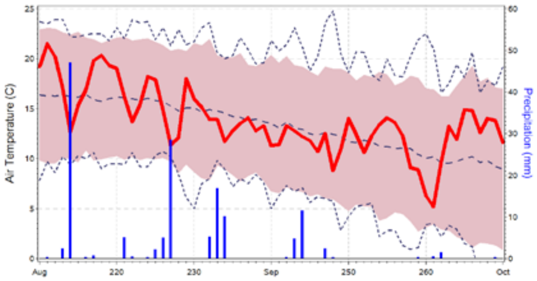

1990 Chilcotin Stn 08MA005 Discharge

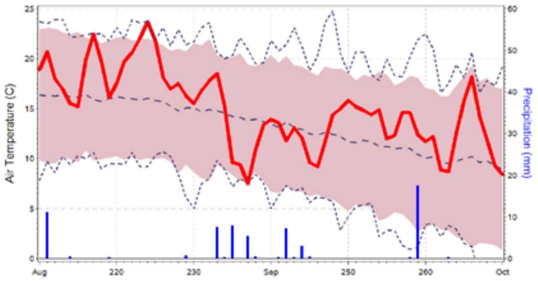

1989 Chilcotin Water Temperature


1990 Chilcotin Water Temperature

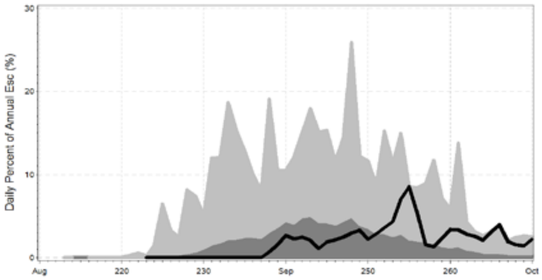

1989 Upper Chilko River Discharge


1990 Upper Chilko River Discharge

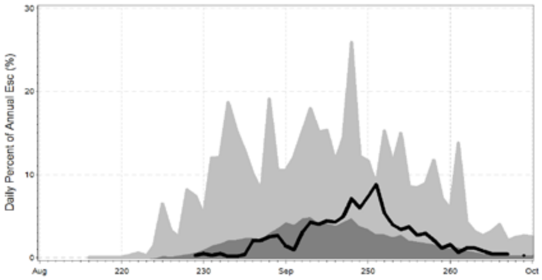

1989 Williams Lake Air Temperature & Precipitation


1990 Williams Lake Air Temperature & Precipitation

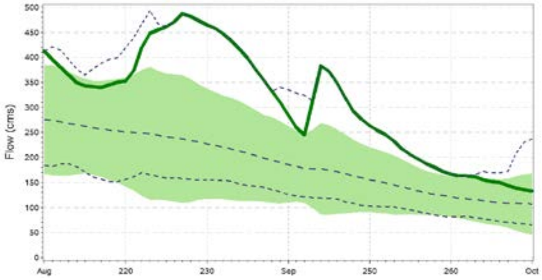
1991 Chilko Sockeye Counts (Total Esc: 170,284)



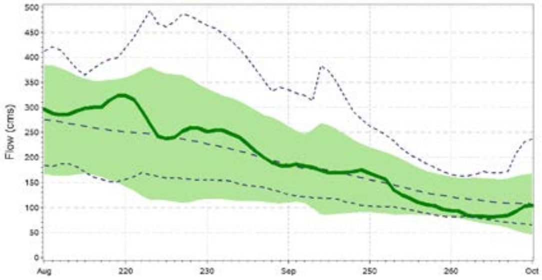
1992 Chilko Sockeye Counts (Total Esc: 84,630)



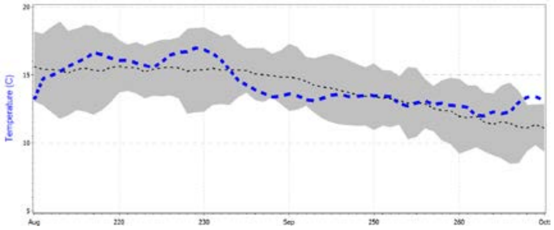
1991 Chilcotin Stn 08MA005 Discharge



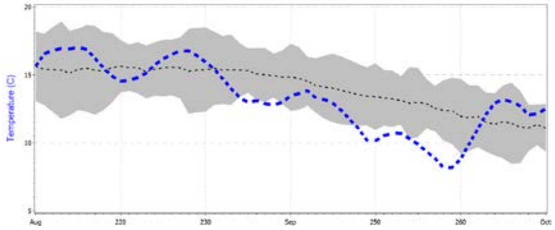
1992 Chilcotin Stn 08MA005 Discharge



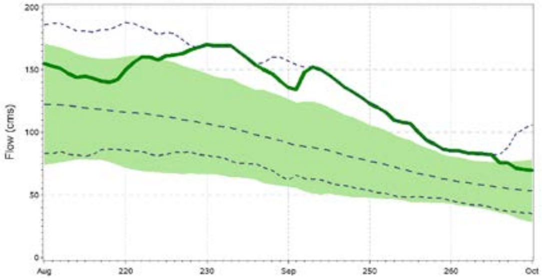
1991 Chilcotin Water Temperature



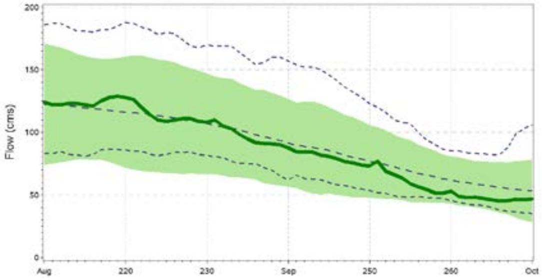
1992 Chilcotin Water Temperature



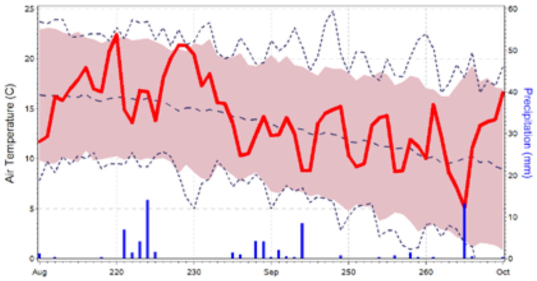
1991 Upper Chilko River Discharge



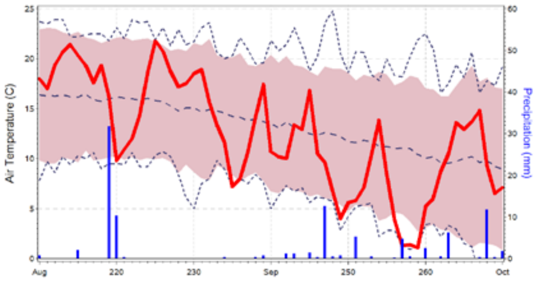
1992 Upper Chilko River Discharge



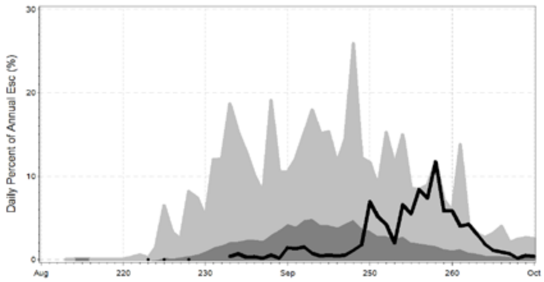
1991 Williams Lake Air Temperature & Precipitation



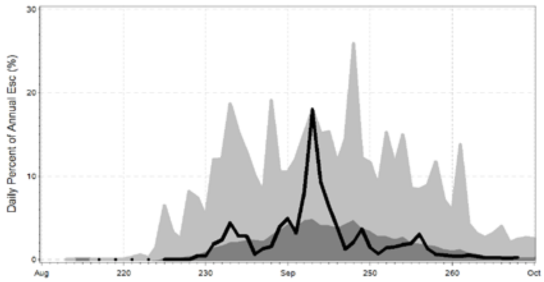
1992 Williams Lake Air Temperature & Precipitation



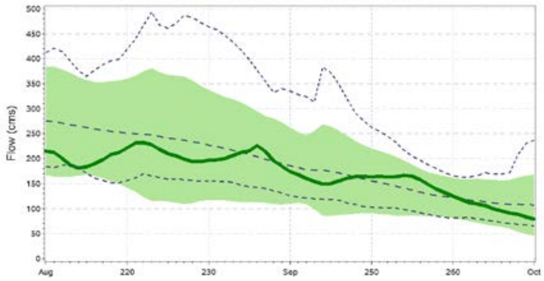
1993 Chilko Sockeye Counts (Total Esc: 71,070)



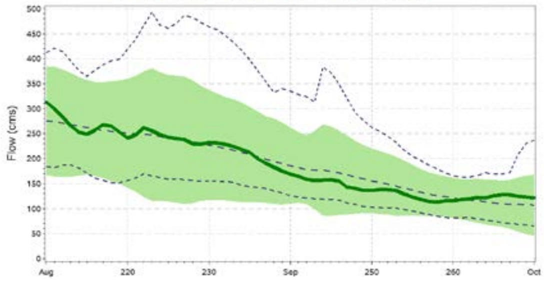
1994 Chilko Sockeye Counts (Total Esc: 47,514)



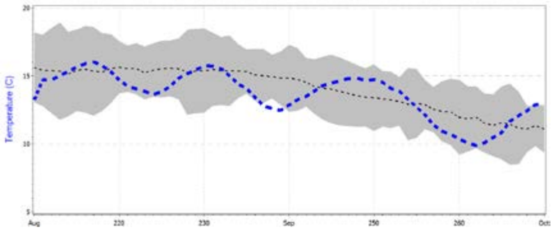
1993 Chilcotin Stn 08MA005 Discharge



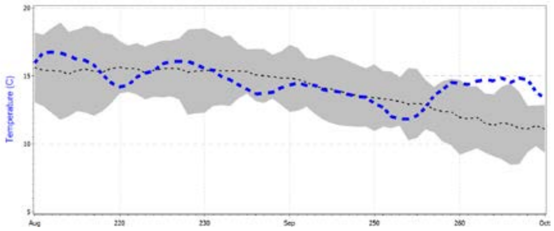
1994 Chilcotin Stn 08MA005 Discharge



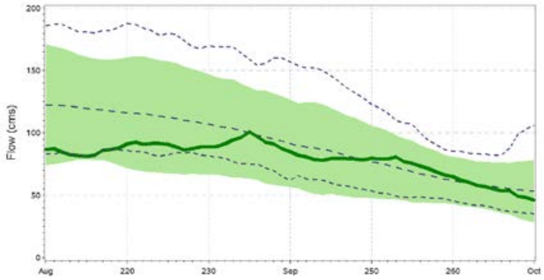
1993 Chilcotin Water Temperature



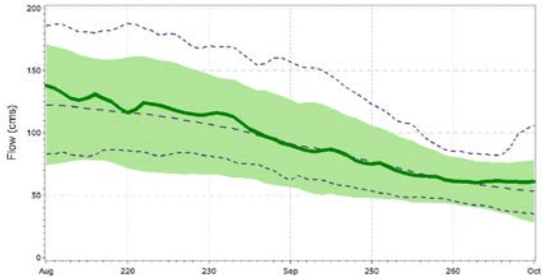
1994 Chilcotin Water Temperature



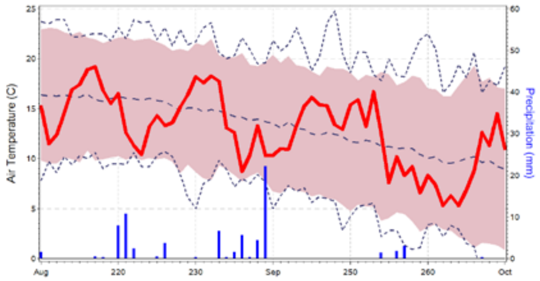
1993 Upper Chilko River Discharge



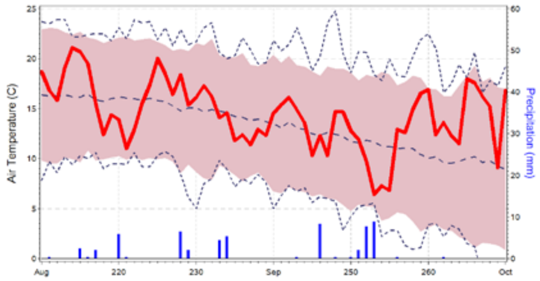
1994 Upper Chilko River Discharge



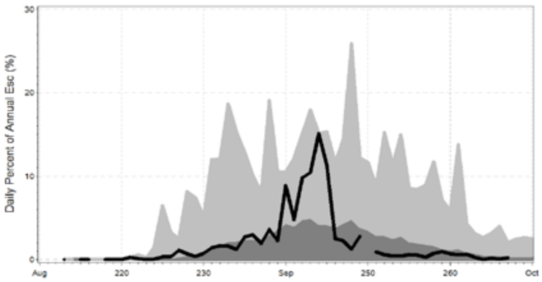
1993 Williams Lake Air Temperature & Precipitation



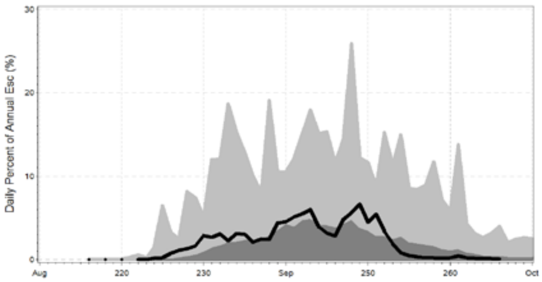
1994 Williams Lake Air Temperature & Precipitation



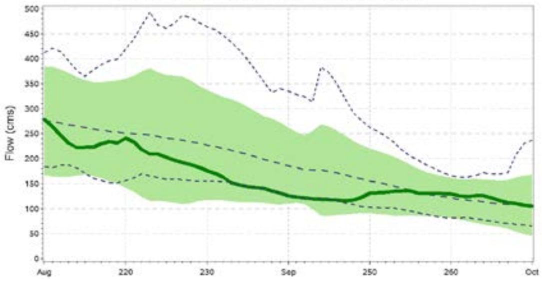
1995 Chilko Sockeye Counts (Total Esc: 46,114)



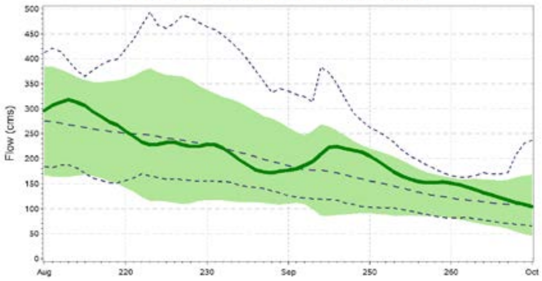
1996 Chilko Sockeye Counts (Total Esc: 143,023)



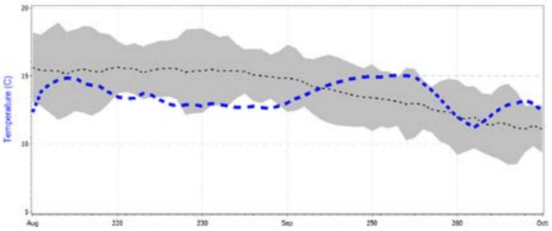
1995 Chilcotin Stn 08MA005 Discharge



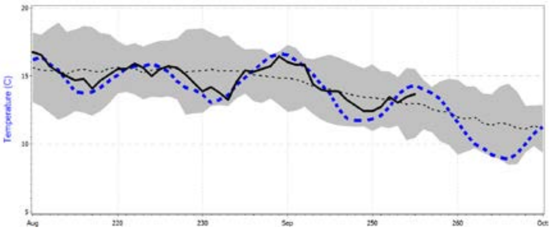
1996 Chilcotin Stn 08MA005 Discharge



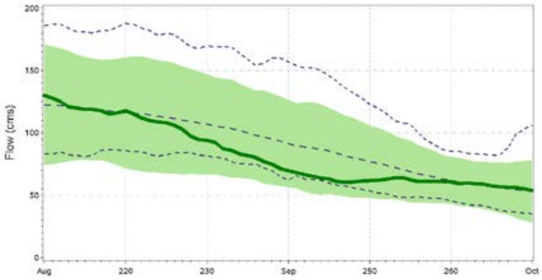
1995 Chilcotin Water Temperature



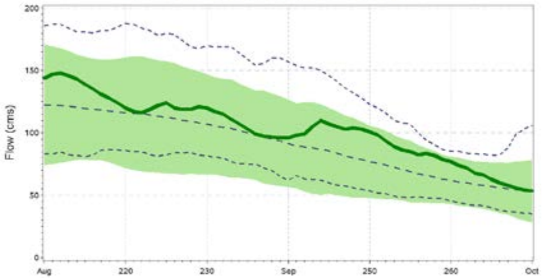
1996 Chilcotin Water Temperature



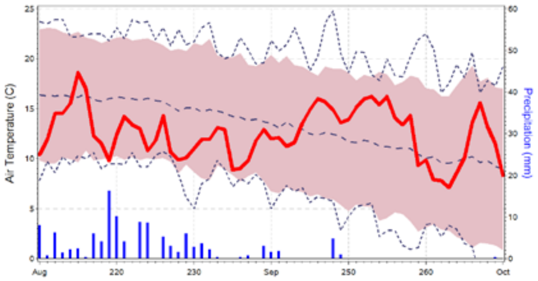
1995 Upper Chilko River Discharge



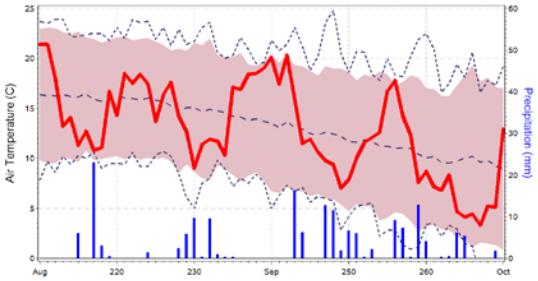
1996 Upper Chilko River Discharge

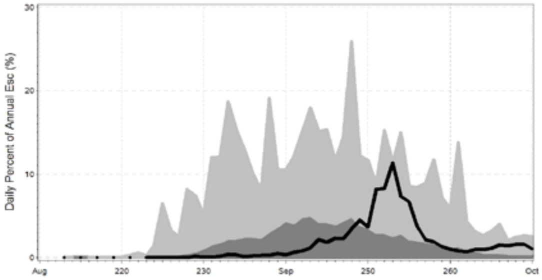


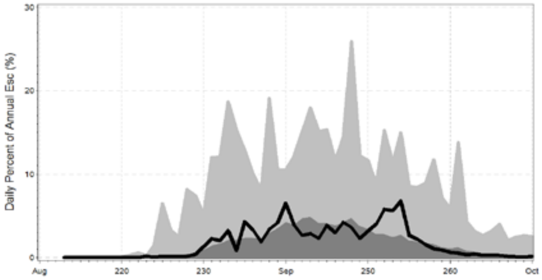
1995 Williams Lake Air Temperature & Precipitation

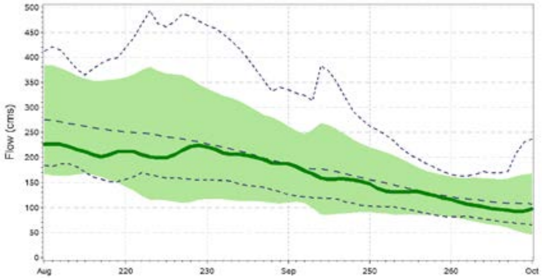


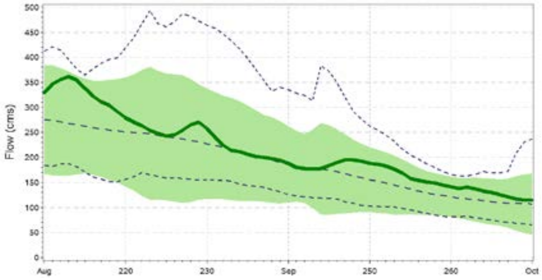
1996 Williams Lake Air Temperature & Precipitation

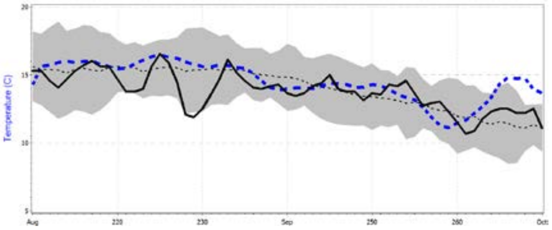


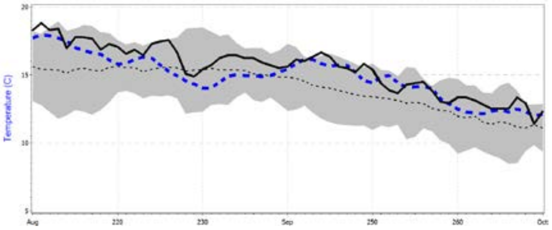

1997 Chilko Sockeye Counts (Total Esc: 137,392)

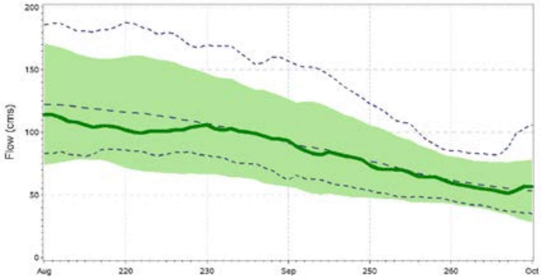

1998 Chilko Sockeye Counts (Total Esc: 103,225)

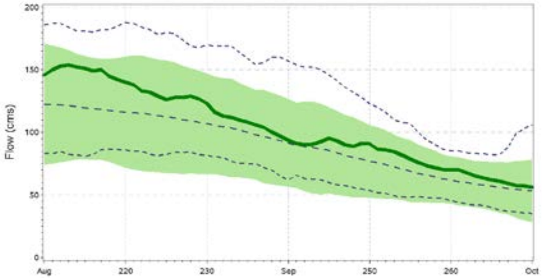

1997 Chilcotin Stn 08MA005 Discharge

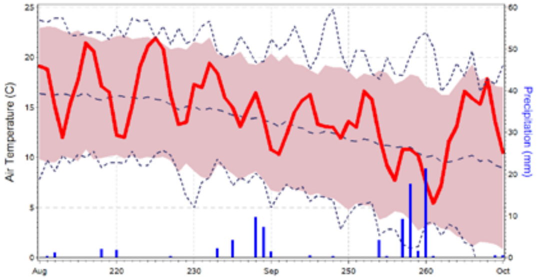

1998 Chilcotin Stn 08MA005 Discharge

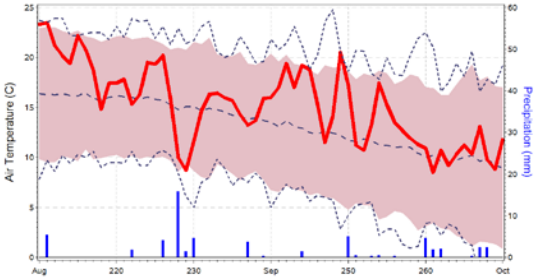

1997 Chilcotin Water Temperature


1998 Chilcotin Water Temperature

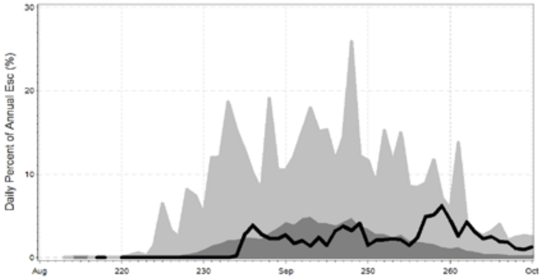

1997 Upper Chilko River Discharge


1998 Upper Chilko River Discharge

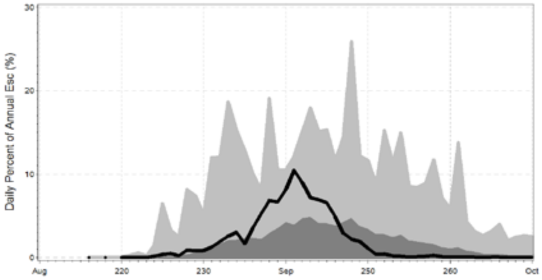

1997 Williams Lake Air Temperature & Precipitation


1998 Williams Lake Air Temperature & Precipitation

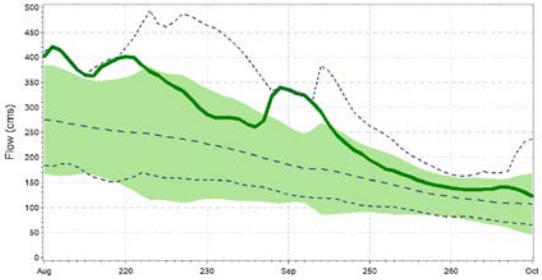
1999 Chilko Sockeye Counts (Total Esc: 163,876)



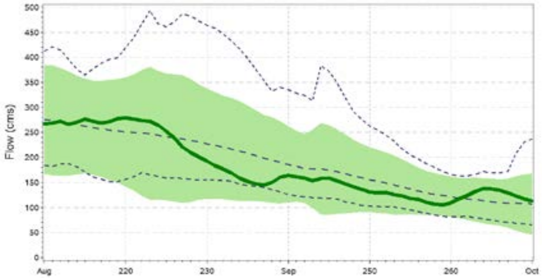
2000 Chilko Sockeye Counts (Total Esc: 148,219)



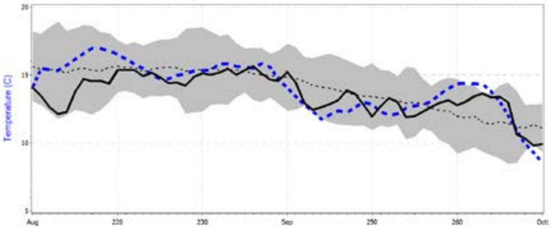
1999 Chilcotin Stn 08MA005 Discharge



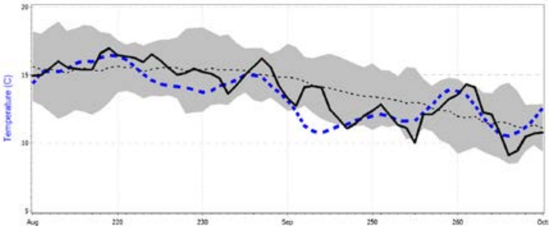
2000 Chilcotin Stn 08MA005 Discharge



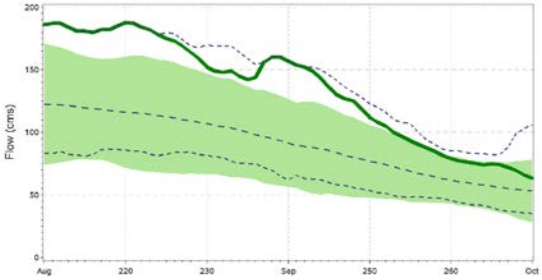
1999 Chilcotin Water Temperature



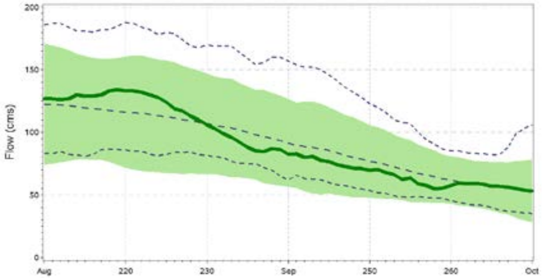
2000 Chilcotin Water Temperature



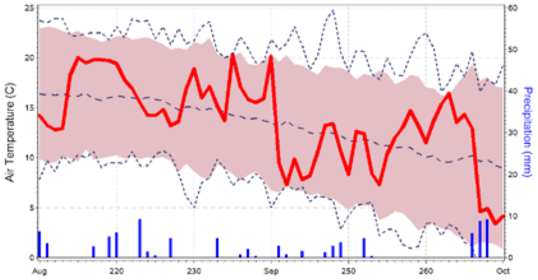
1999 Upper Chilko River Discharge



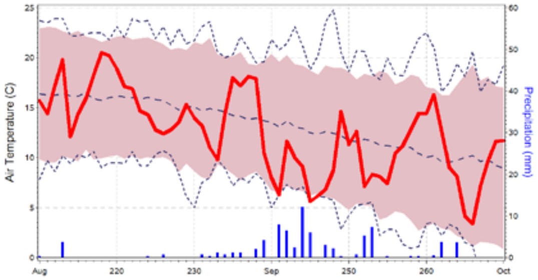
2000 Upper Chilko River Discharge

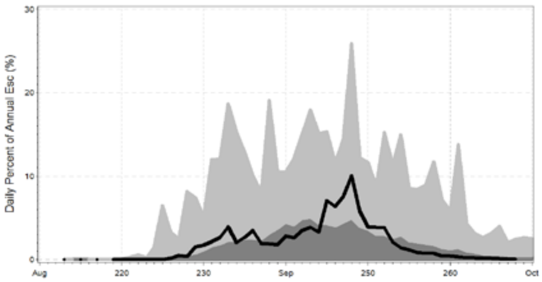


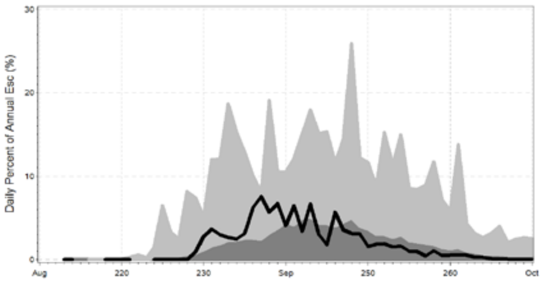
1999 Williams Lake Air Temperature & Precipitation

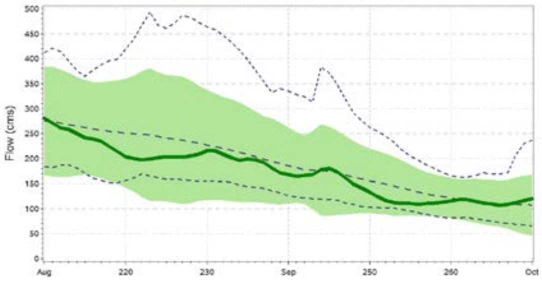


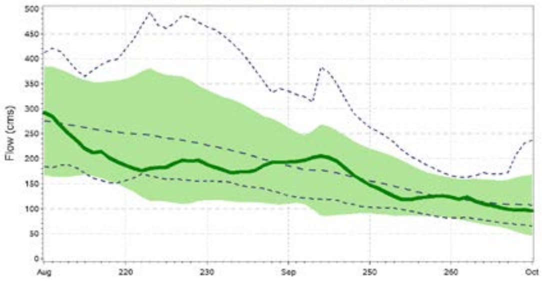
2000 Williams Lake Air Temperature & Precipitation

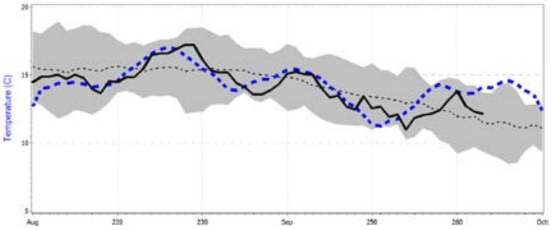


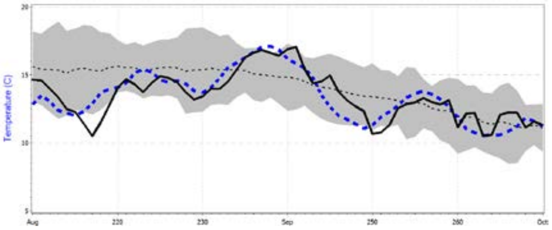

2001 Chilko Sockeye Counts (Total Esc: 136,118)

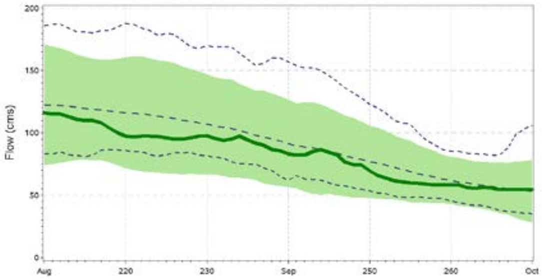

2002 Chilko Sockeye Counts (Total Esc: 71,909)

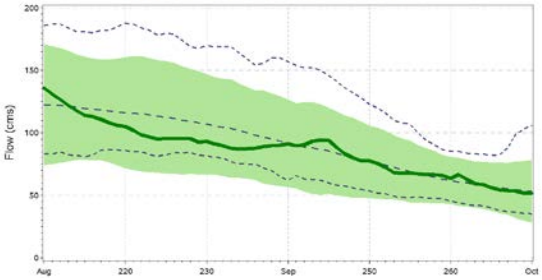

2001 Chilcotin Stn 08MA005 Discharge

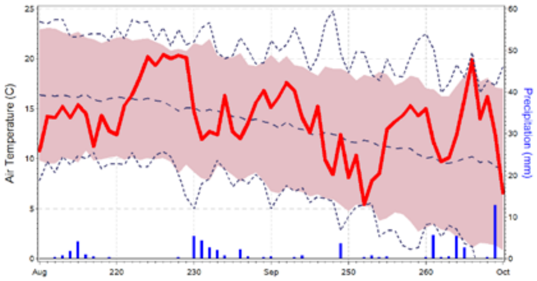

2002 Chilcotin Stn 08MA005 Discharge

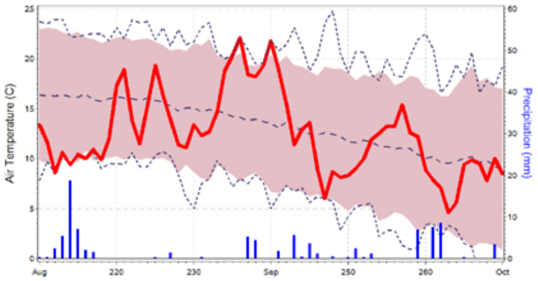

2001 Chilcotin Water Temperature


2002 Chilcotin Water Temperature

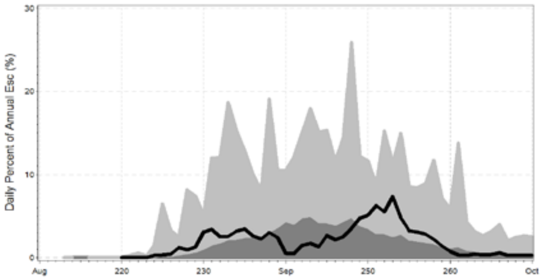

2001 Upper Chilko River Discharge


2002 Upper Chilko River Discharge

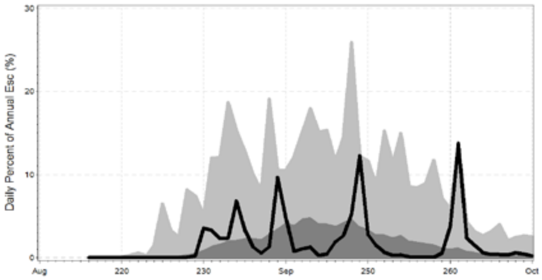

2001 Williams Lake Air Temperature & Precipitation


2002 Williams Lake Air Temperature & Precipitation

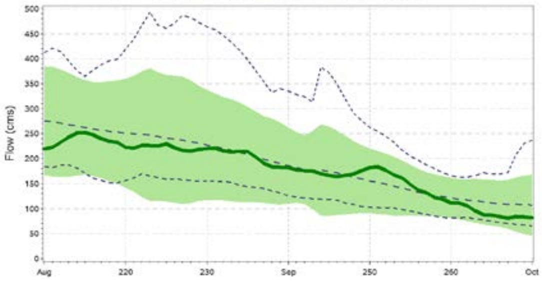
2003 Chilko Sockeye Counts (Total Esc: 139,228)



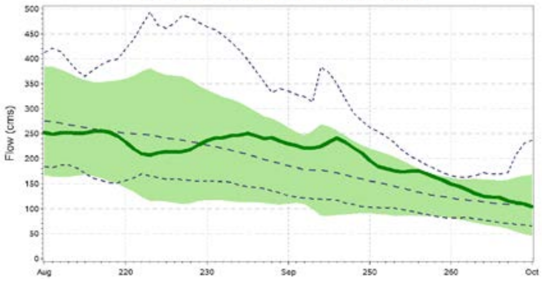
2004 Chilko Sockeye Counts (Total Esc: 6,583)



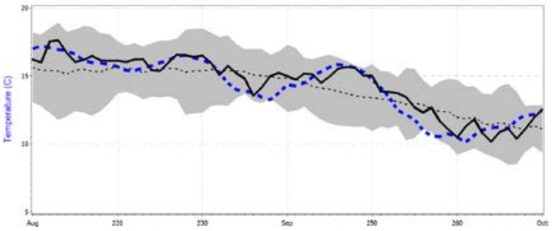
2003 Chilcotin Stn 08MA005 Discharge



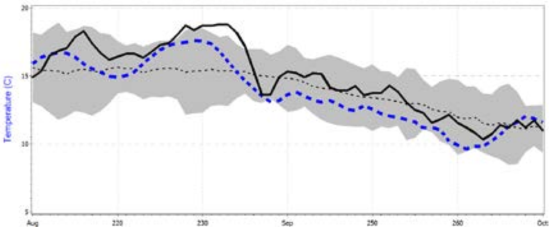
2004 Chilcotin Stn 08MA005 Discharge



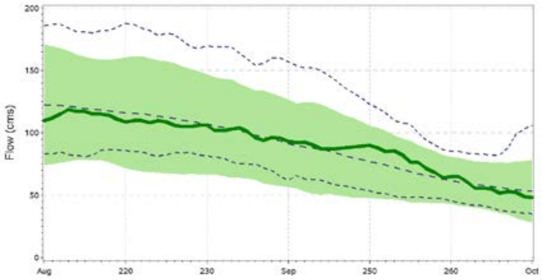
2003 Chilcotin Water Temperature



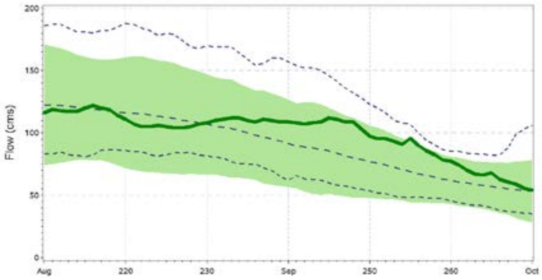
2004 Chilcotin Water Temperature



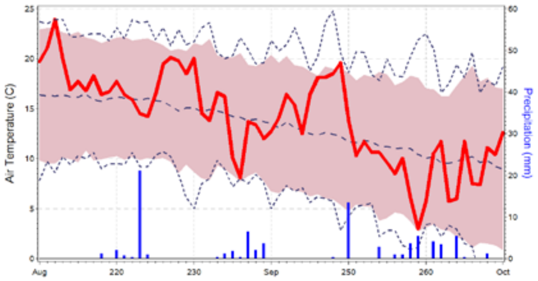
2003 Upper Chilko River Discharge



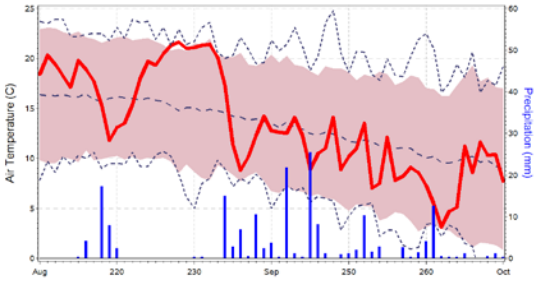
2004 Upper Chilko River Discharge

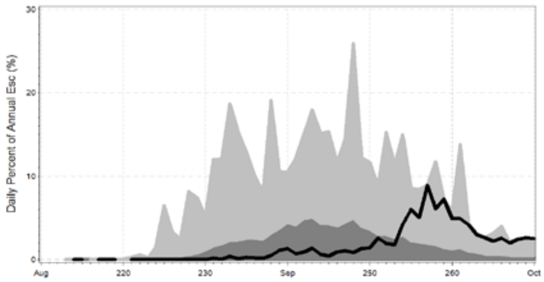


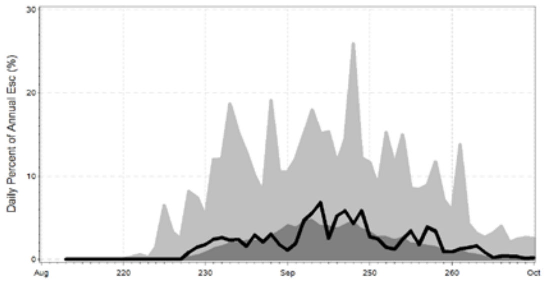
2003 Williams Lake Air Temperature & Precipitation

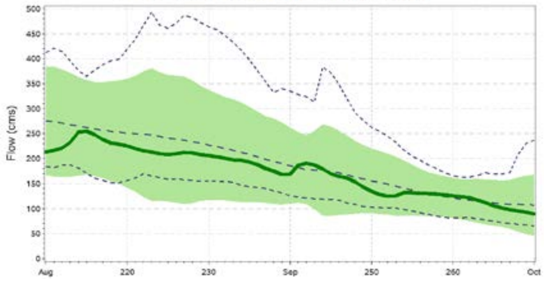


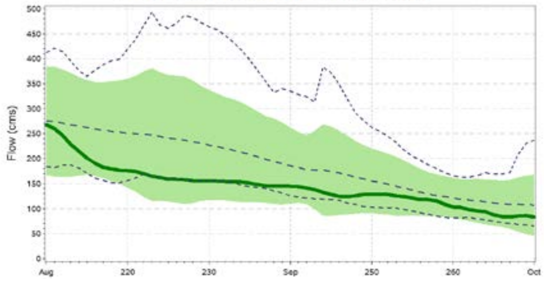
2004 Williams Lake Air Temperature & Precipitation

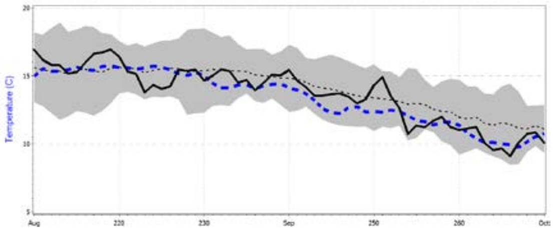


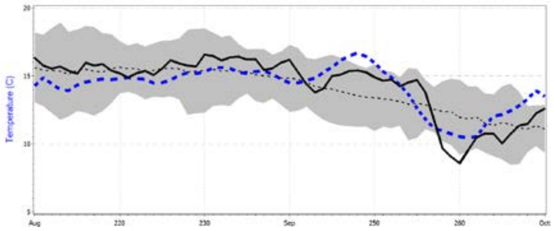

2005 Chilko Sockeye Counts (Total Esc: 103,593)

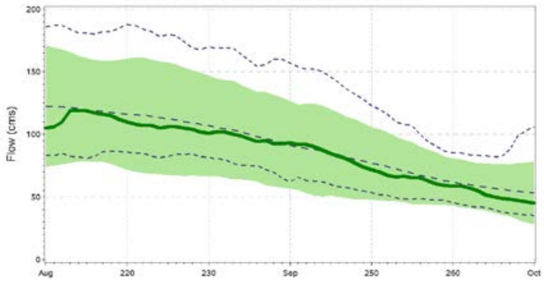

2006 Chilko Sockeye Counts (Total Esc: 84,765)

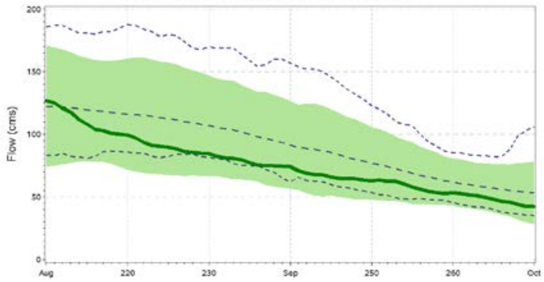

2005 Chilcotin Stn 08MA005 Discharge

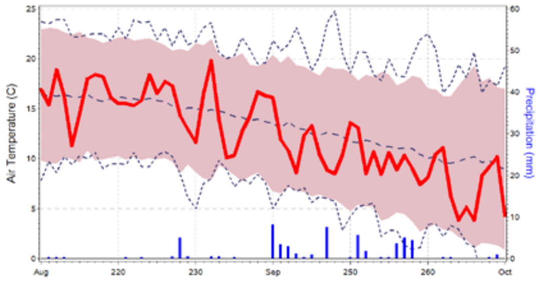

2006 Chilcotin Stn 08MA005 Discharge

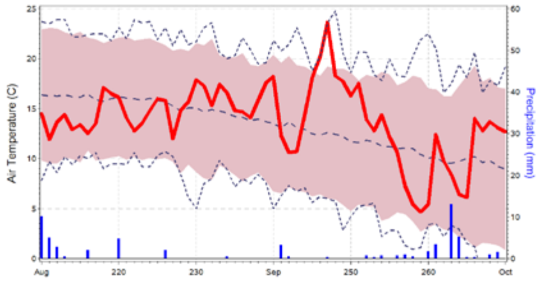

2005 Chilcotin Water Temperature


2006 Chilcotin Water Temperature

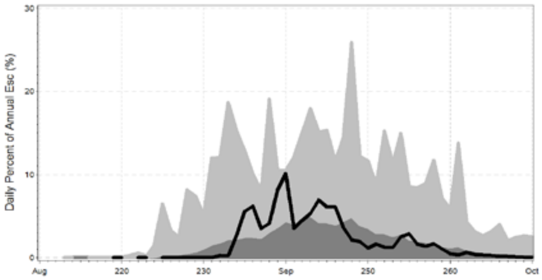

2005 Upper Chilko River Discharge


2006 Upper Chilko River Discharge

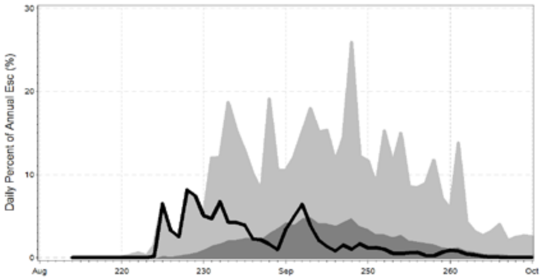

2005 Williams Lake Air Temperature & Precipitation


2006 Williams Lake Air Temperature & Precipitation

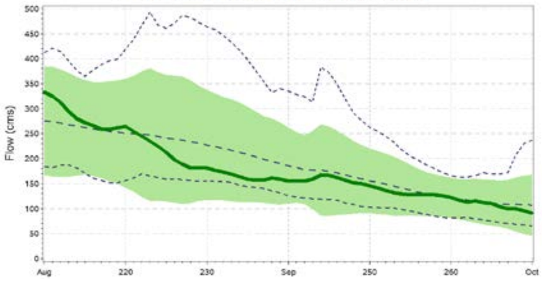
2007 Chilko Sockeye Counts (Total Esc: 43,095)



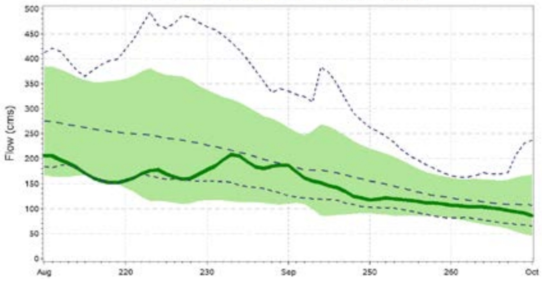
2008 Chilko Sockeye Counts (Total Esc: 28,720)



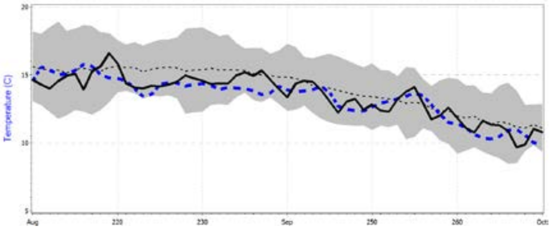
2007 Chilcotin Stn 08MA005 Discharge



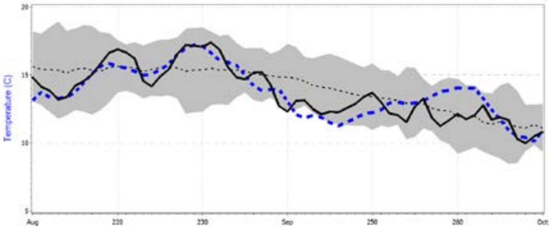
2008 Chilcotin Stn 08MA005 Discharge



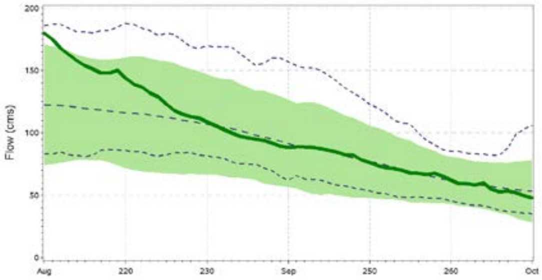
2007 Chilcotin Water Temperature



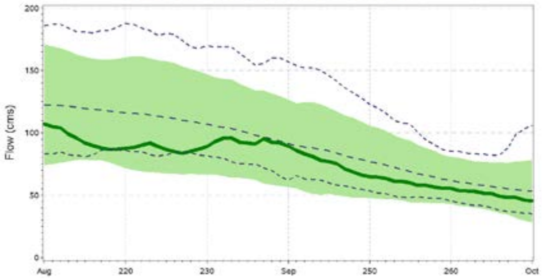
2008 Chilcotin Water Temperature



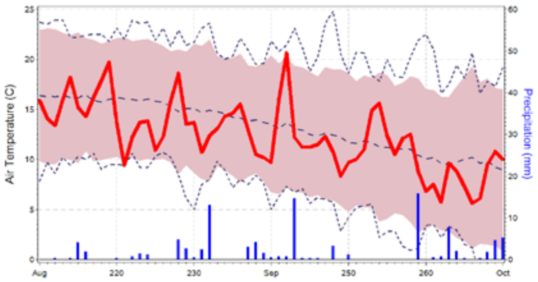
2007 Upper Chilko River Discharge



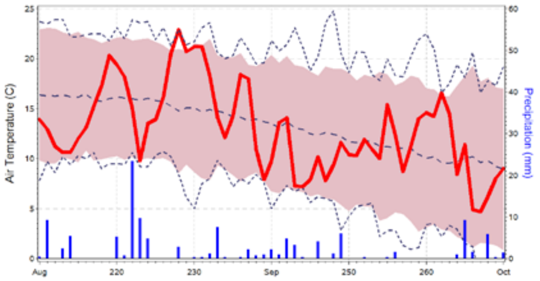
2008 Upper Chilko River Discharge

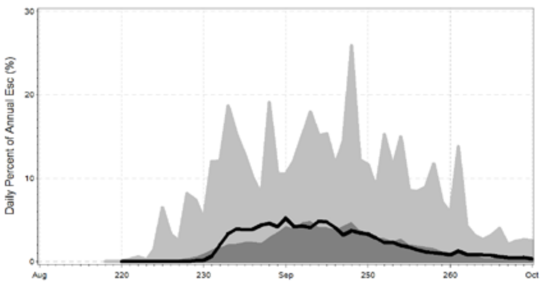


2007 Williams Lake Air Temperature & Precipitation

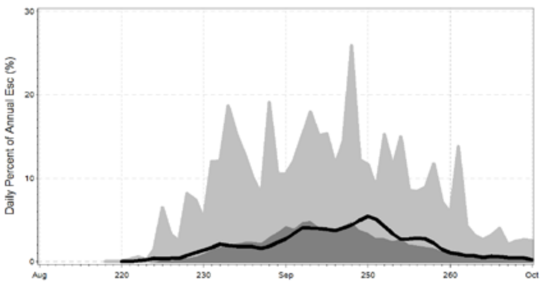


2008 Williams Lake Air Temperature & Precipitation

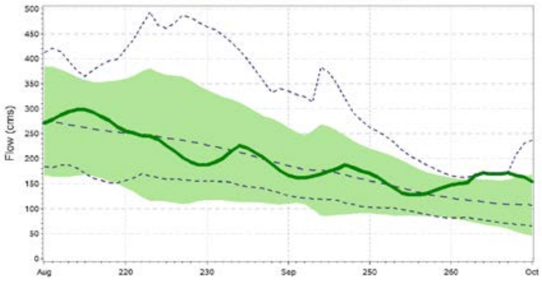




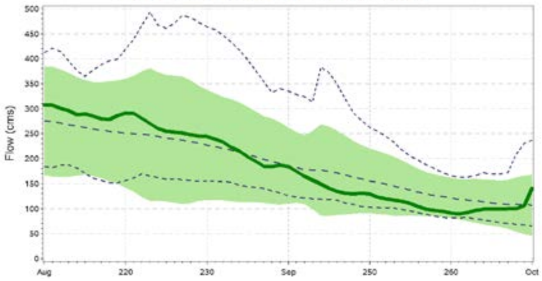
2009 Chilko Sockeye Counts (Total Esc: 217,778)



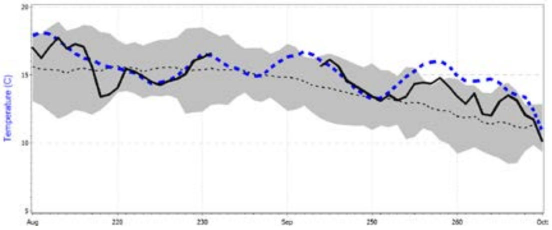
2010 Chilko Sockeye Counts (Total Esc: 2462975)



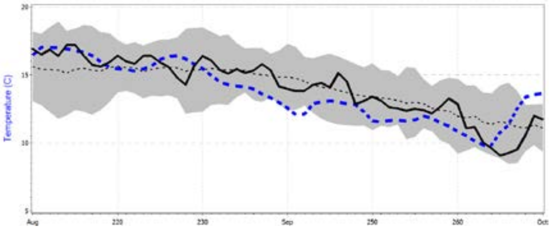
2009 Chilcotin Stn 08MA005 Discharge



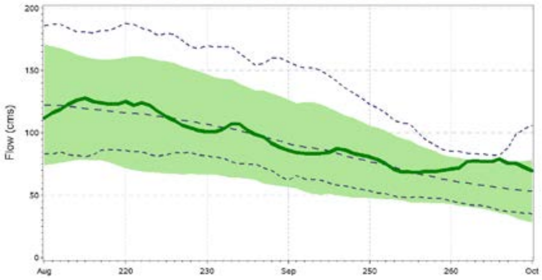
2010 Chilcotin Stn 08MA005 Discharge



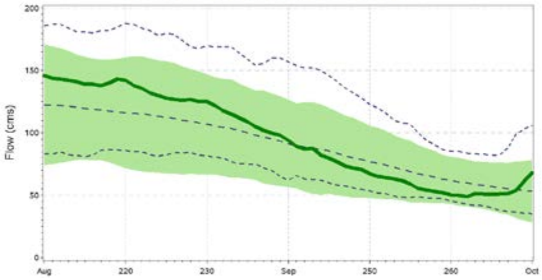
2009 Chilcotin Water Temperature



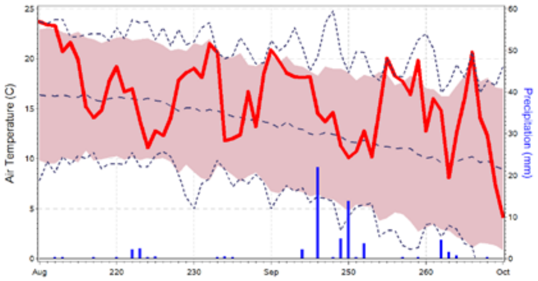
2010 Chilcotin Water Temperature



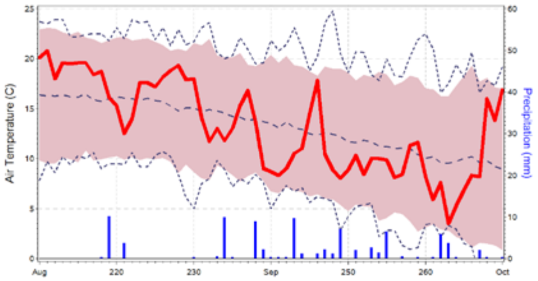
2009 Upper Chilko River Discharge



2010 Upper Chilko River Discharge

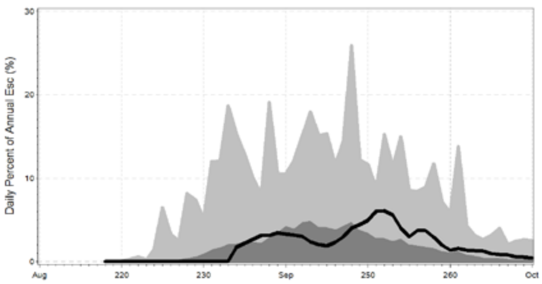


2009 Williams Lake Air Temperature & Precipitation

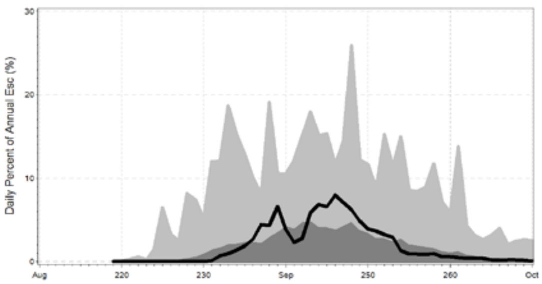


2010 Williams Lake Air Temperature & Precipitation

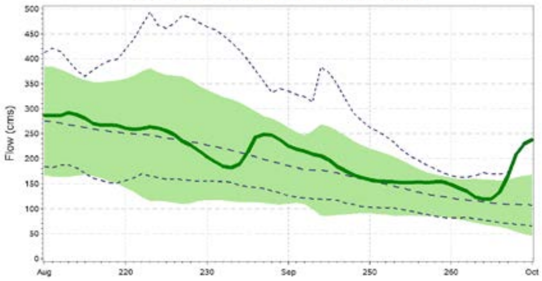
2011 Chilko Sockeye Counts (Total Esc: 919,254)



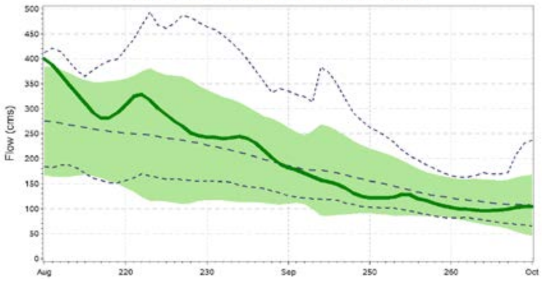
2012 Chilko Sockeye Counts (Total Esc: 246,602)



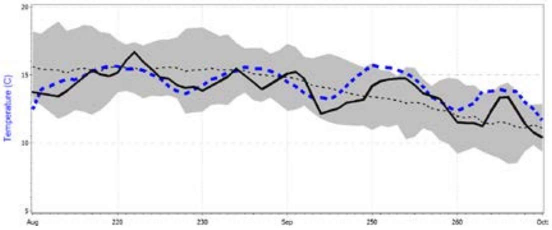
2011 Chilcotin Stn 08MA005 Discharge



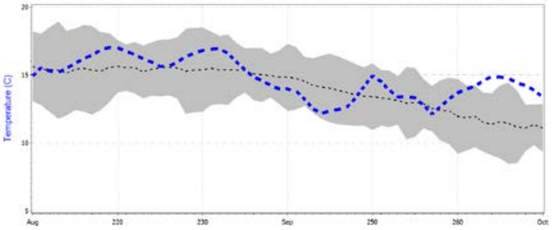
2012 Chilcotin Stn 08MA005 Discharge



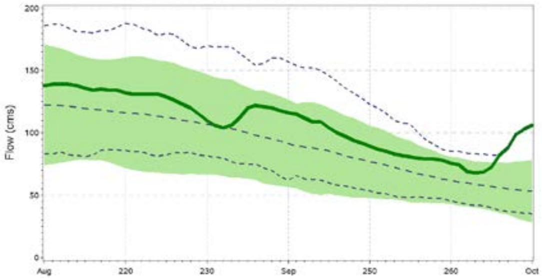
2011 Chilcotin Water Temperature



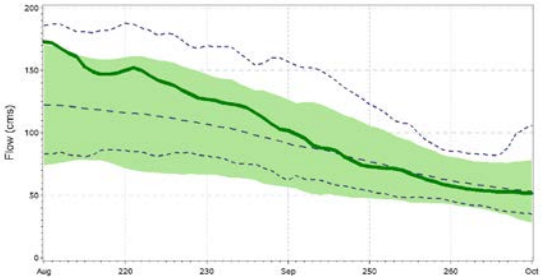
2012 Chilcotin Water Temperature



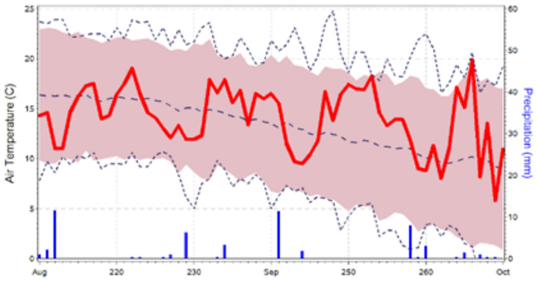
2011 Upper Chilko River Discharge



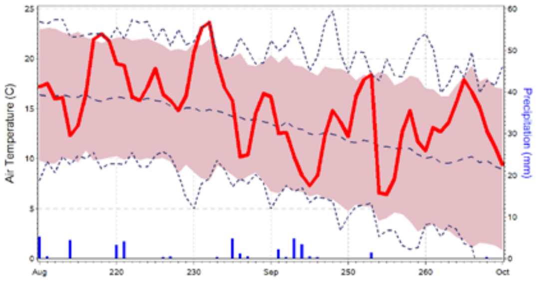
2012 Upper Chilko River Discharge



2011 Williams Lake Air Temperature & Precipitation



2012 Williams Lake Air Temperature & Precipitation



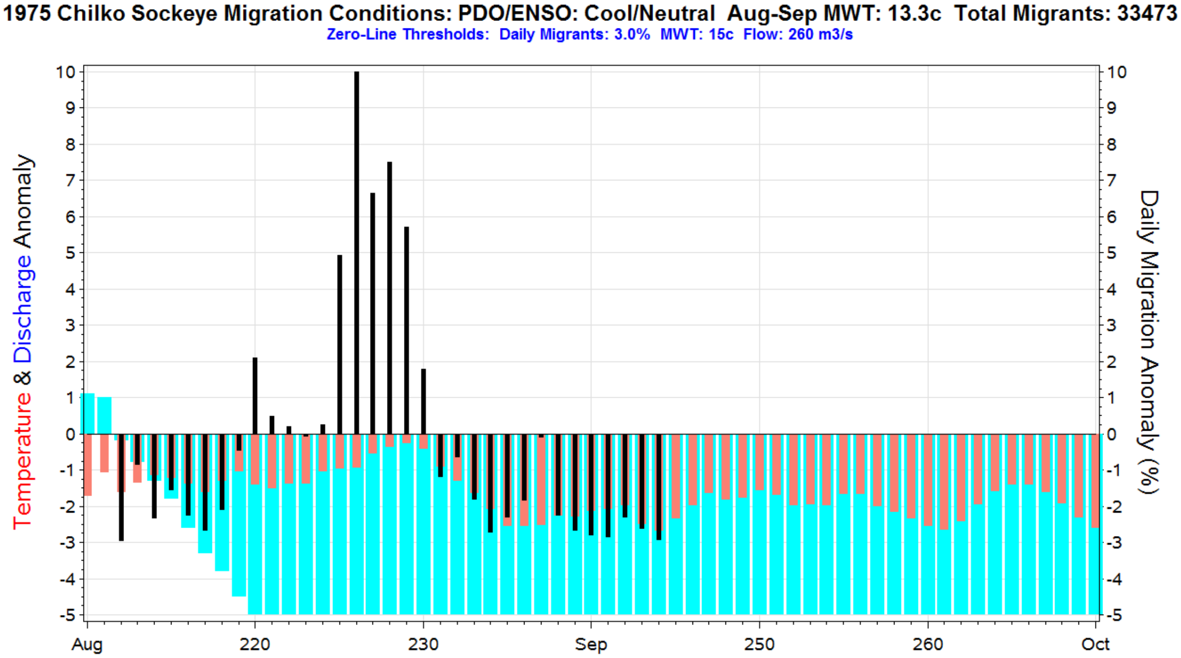
Appendix L. Annual anomaly plots for Chilko Sockeye daily migration lagged 12 days to align with water temperature (estimated), and discharge (observed & estimated) 12 days earlier in the lower Chilcotin River.

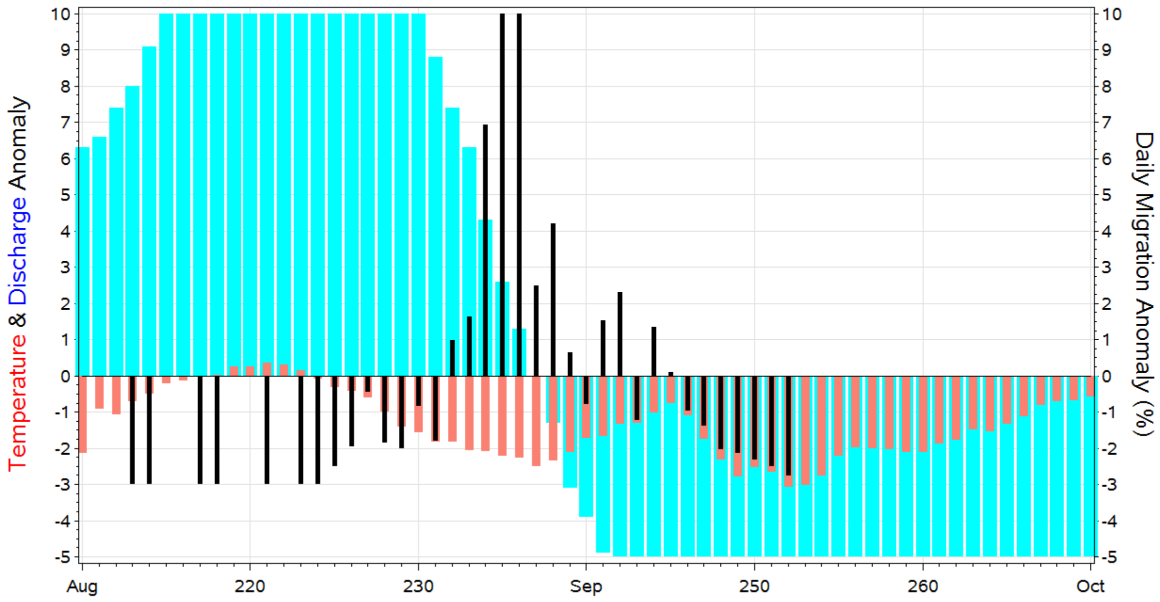
Zero-line thresholds:

- Daily migration rate = 3.0% (75th percentile of non-zero daily migration rates (1975-2012);
- Water temperature = 15°C (~75th percentile);
- Discharge = 260 cms (~90th percentile).

To read the plot: environmental variate anomalies are read from the primary y-axis; migration anomalies are read from the secondary y-axis.

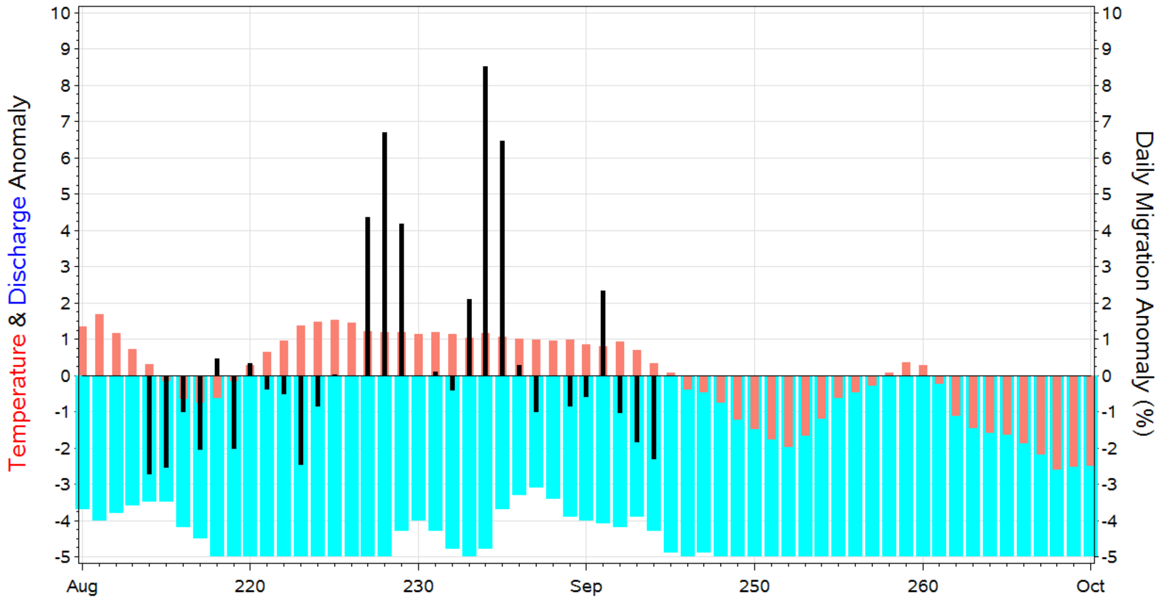
1. Black bars are the daily migration rate (%) minus the 3% threshold (e.g. 5% is represented as 2% on the secondary y-axis (5-3 = 2)).
2. Red bars are the estimated daily mean water temperature minus the 15°C threshold (e.g. 14°C → -1 since 14-15 = -1).
3. Blue bars are the observed daily discharge minus the 260 cms threshold, and divided by 10 to fit the axis (e.g. 270 cms → (270-240)/10 = +3).





1976 Chilko Sockeye Migration Conditions: PDO/ENSO: Cool/Cool Aug-Sep MWT: 13.6c Total Migrants: 59198

Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 15c Flow: 260 m3/s

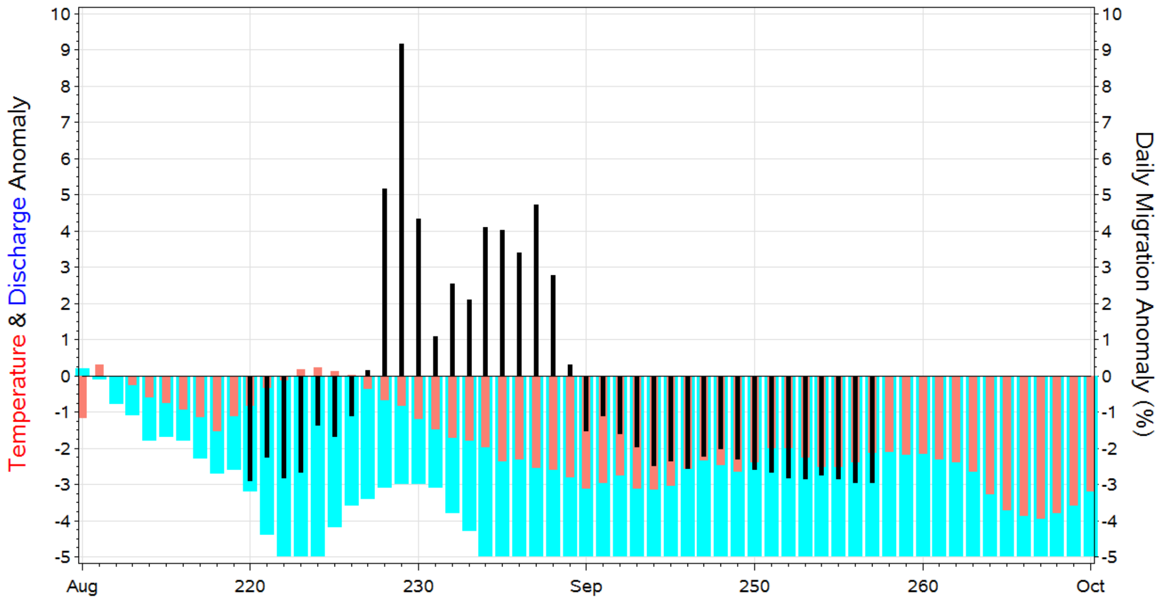


1979 Chilko Sockeye Migration Conditions: PDO/ENSO: Cool/Neutral Aug-Sep MWT: 15.0c Total Migrants: 19071

Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 15c Flow: 260 m3/s

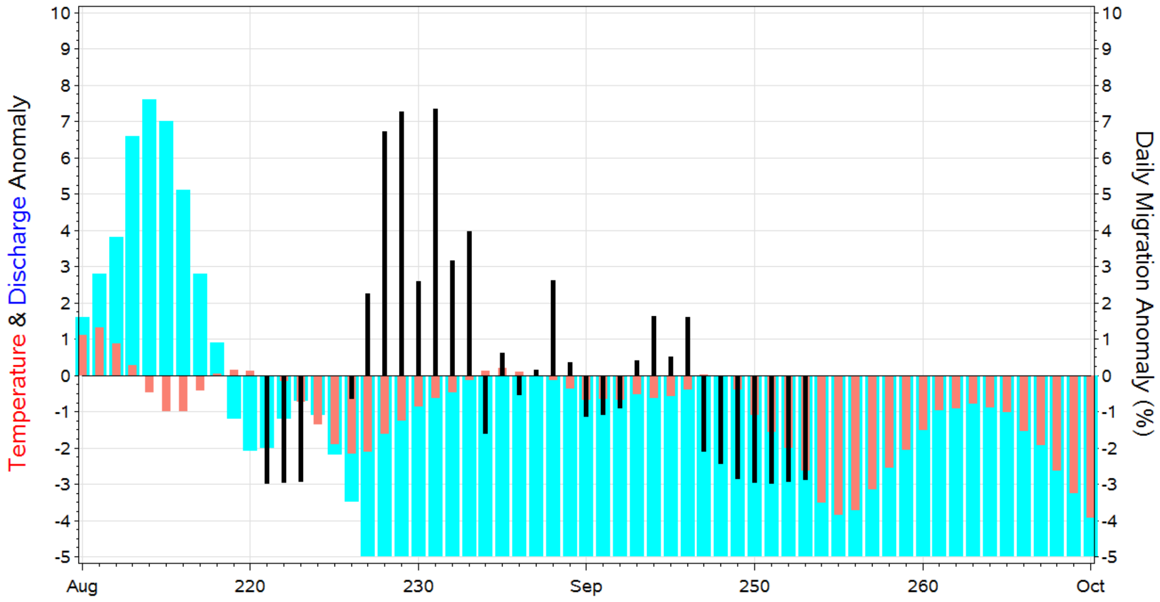
1980 Chilko Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Aug-Sep MWT: 13.1c Total Migrants: 75297

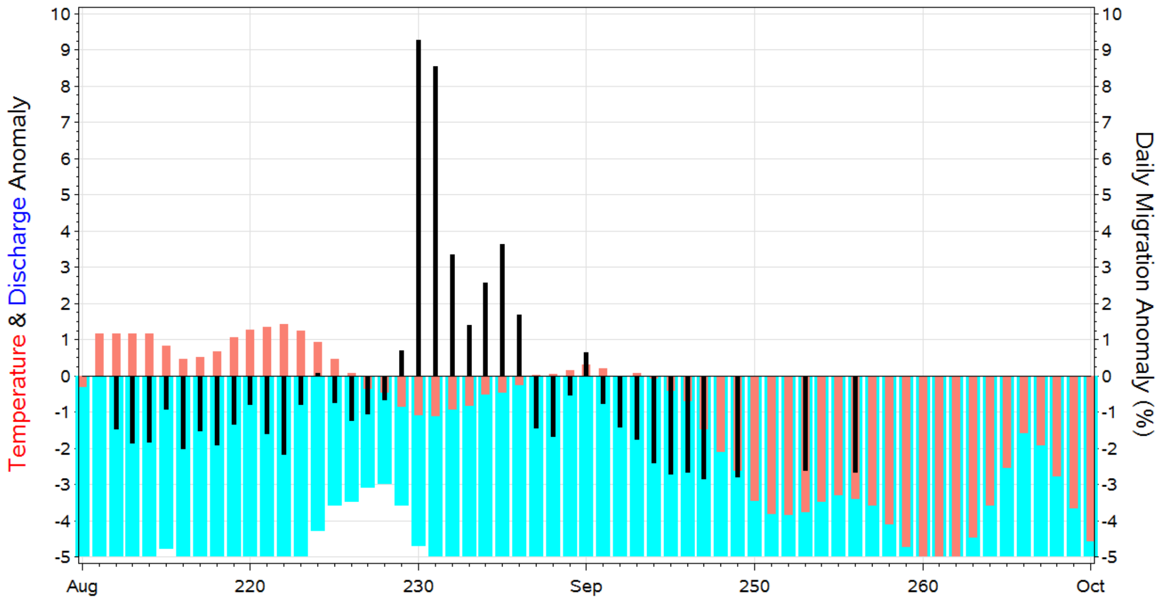
Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 15c Flow: 260 m3/s



1982 Chilko Sockeye Migration Conditions: PDO/ENSO: Warm/Neutral Aug-Sep MWT: 14.0c Total Migrants: 24302

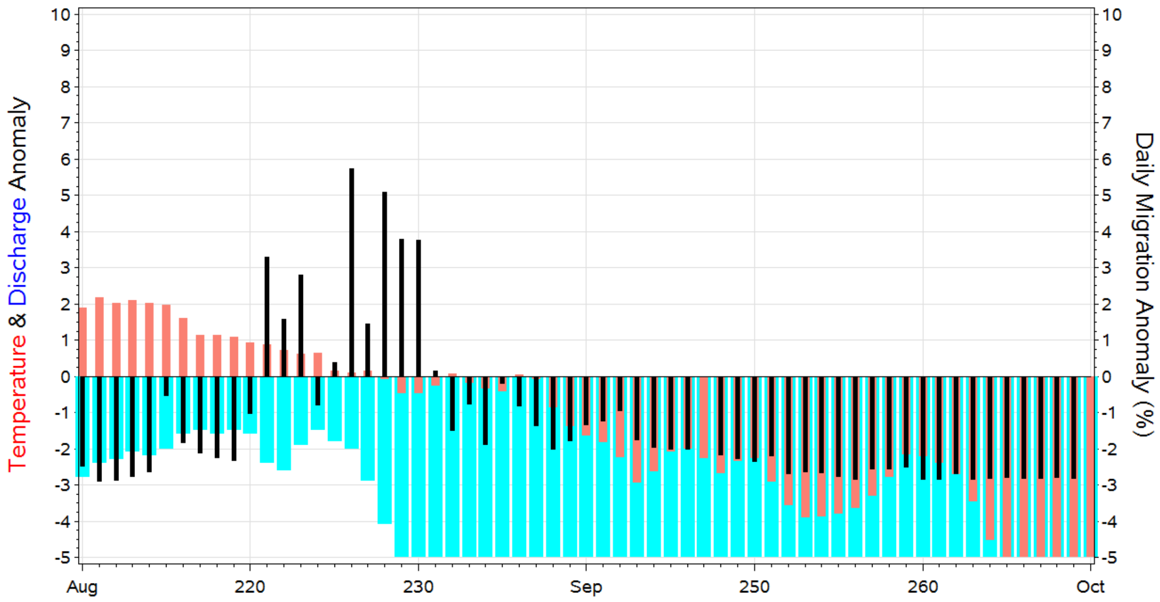
Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 15c Flow: 260 m3/s





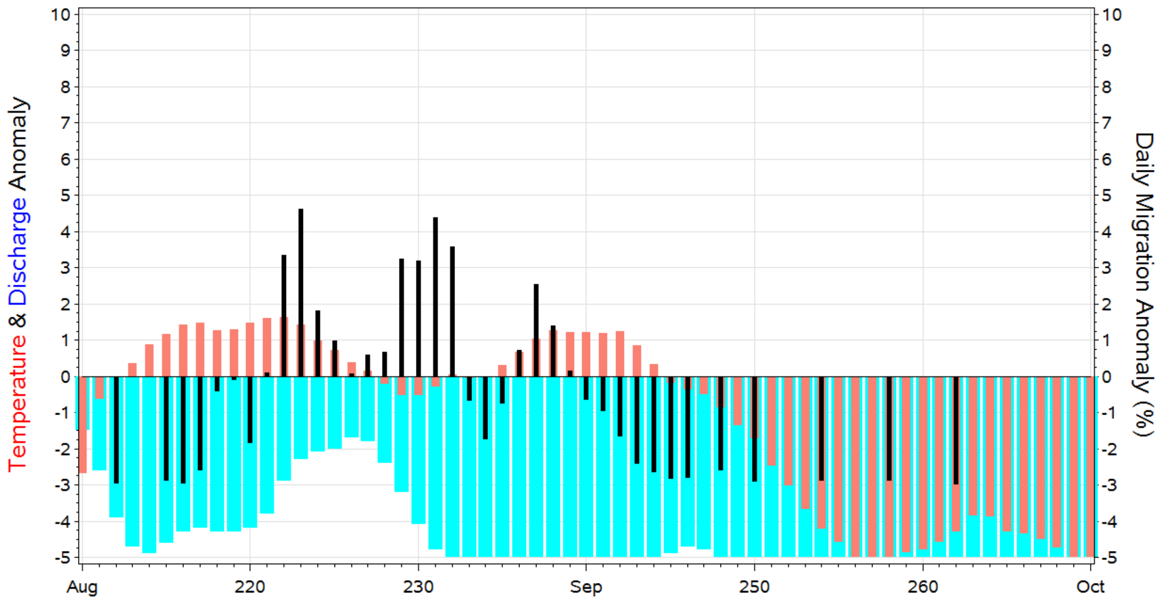
1983 Chilko Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Aug-Sep MWT: 13.7c Total Migrants: 47372

Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 15c Flow: 260 m3/s



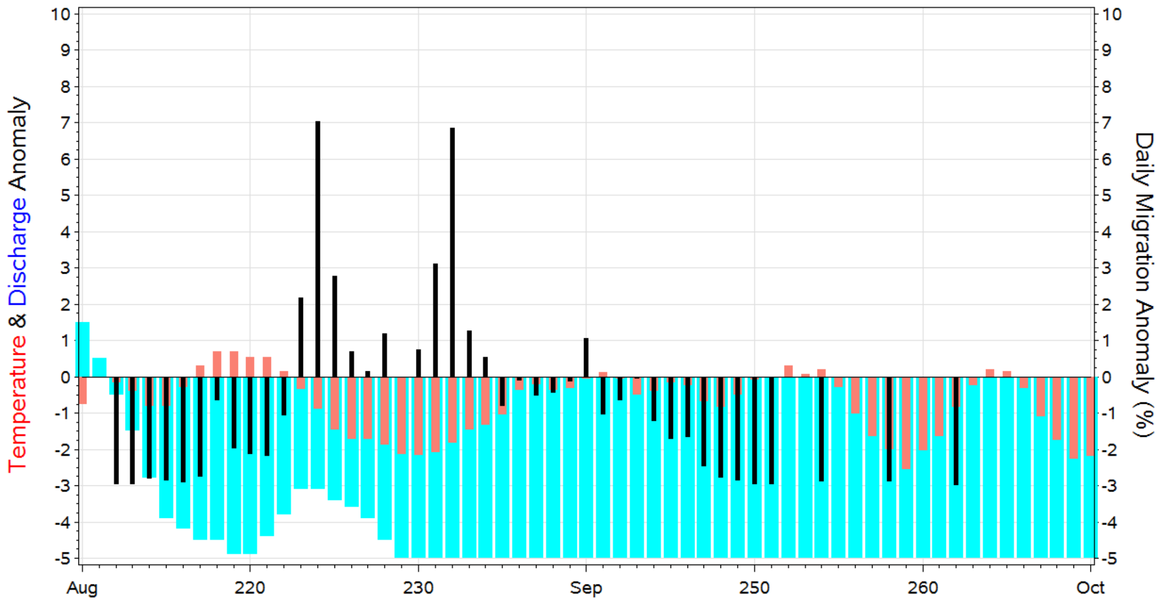
1984 Chilko Sockeye Migration Conditions: PDO/ENSO: Warm/Cool Aug-Sep MWT: 13.4c Total Migrants: 74777

Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 15c Flow: 260 m3/s



1986 Chilko Sockeye Migration Conditions: PDO/ENSO: Warm/Neutral Aug-Sep MWT: 13.8c Total Migrants: 50129

Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 15c Flow: 260 m3/s

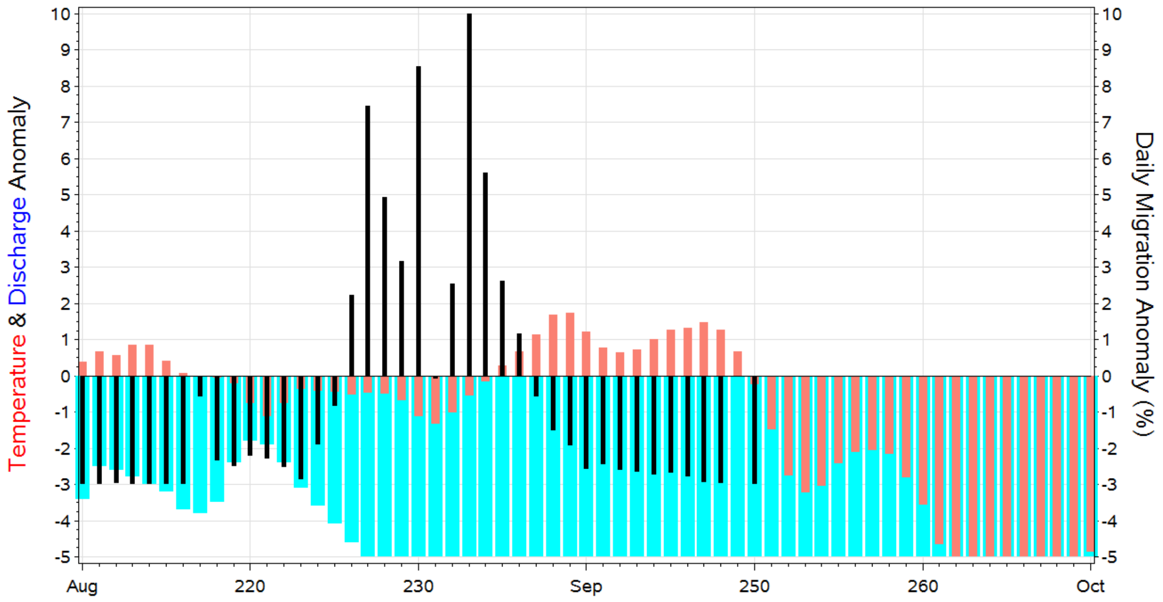


1987 Chilko Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Aug-Sep MWT: 14.3c Total Migrants: 56475

Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 15c Flow: 260 m3/s

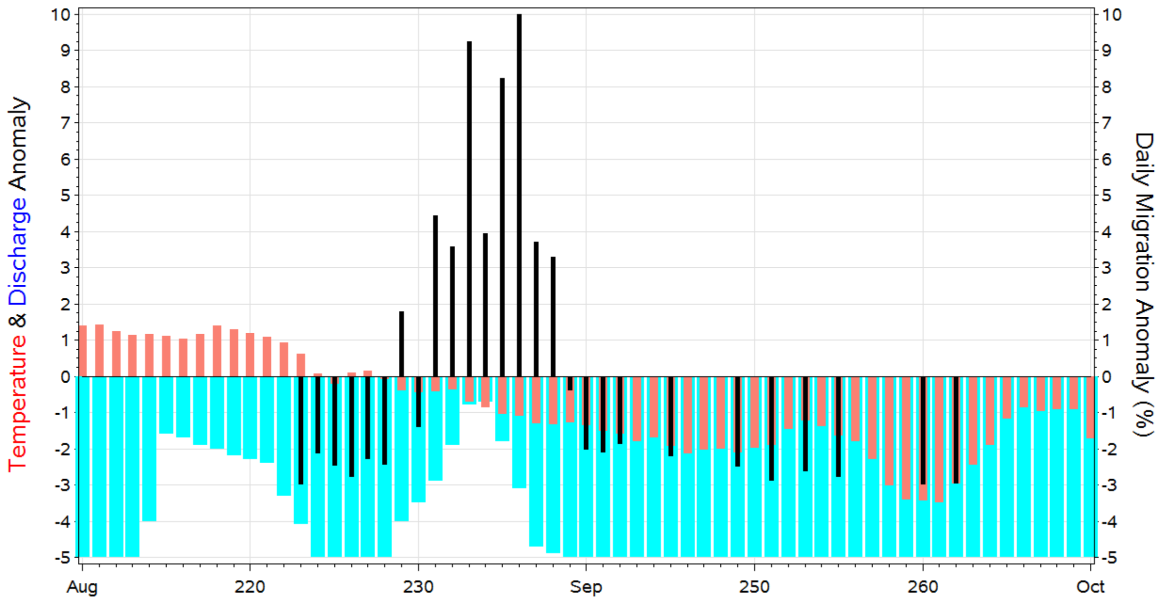
1988 Chilko Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Aug-Sep MWT: 13.8c Total Migrants: 34356

Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 15c Flow: 260 m3/s



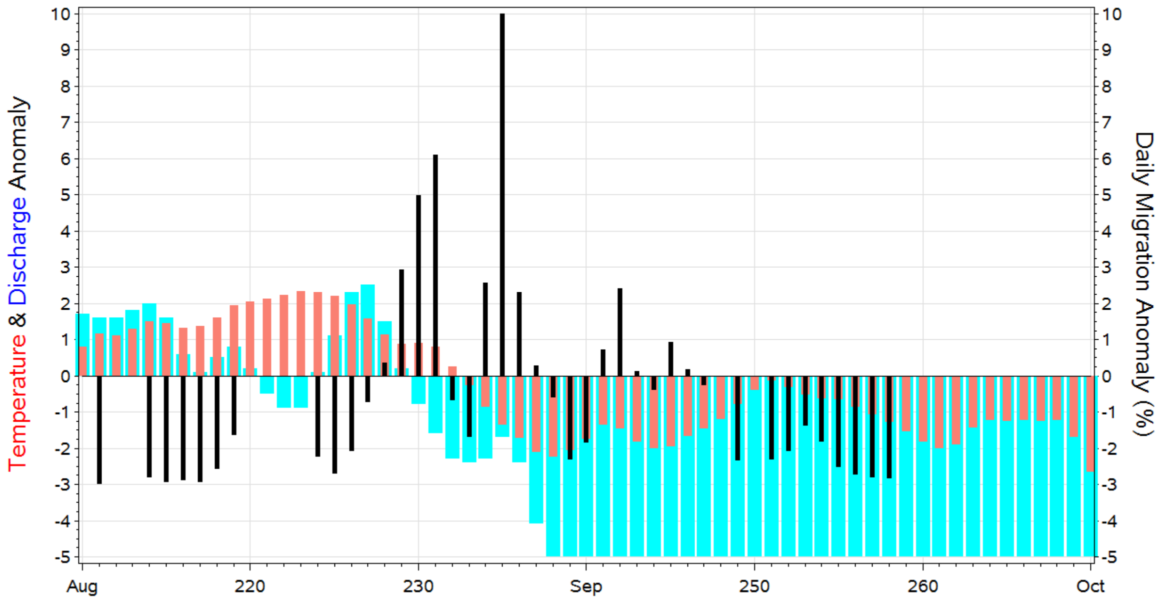
1989 Chilko Sockeye Migration Conditions: PDO/ENSO: Cool/Cool Aug-Sep MWT: 14.1c Total Migrants: 9500

Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 15c Flow: 260 m3/s



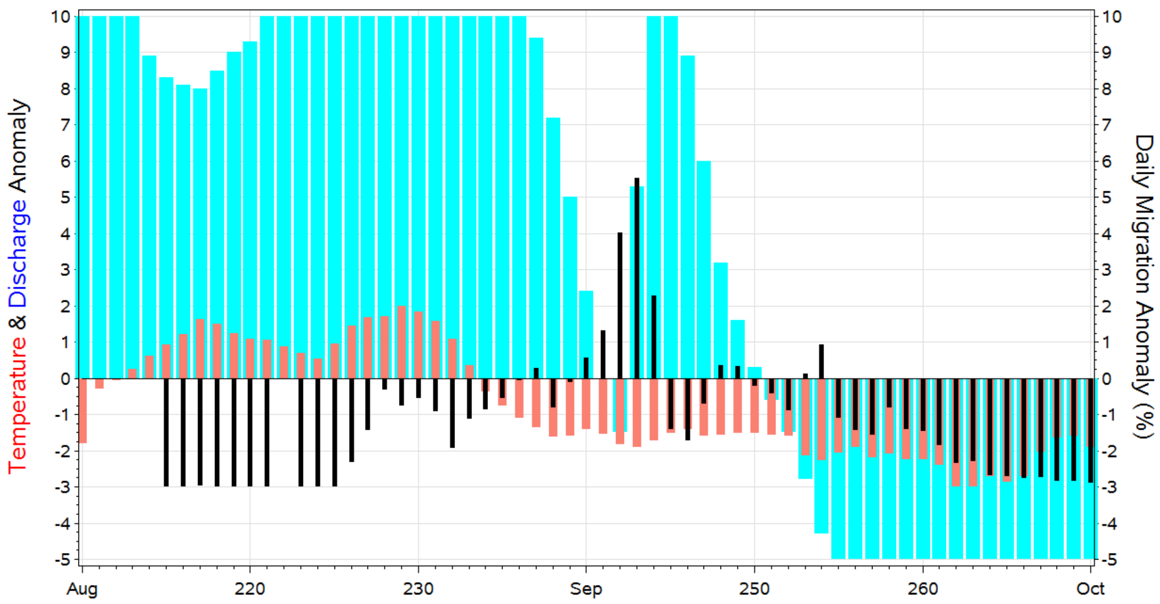
1990 Chilko Sockeye Migration Conditions: PDO/ENSO: Cool/Neutral Aug-Sep MWT: 14.7c Total Migrants: 76820

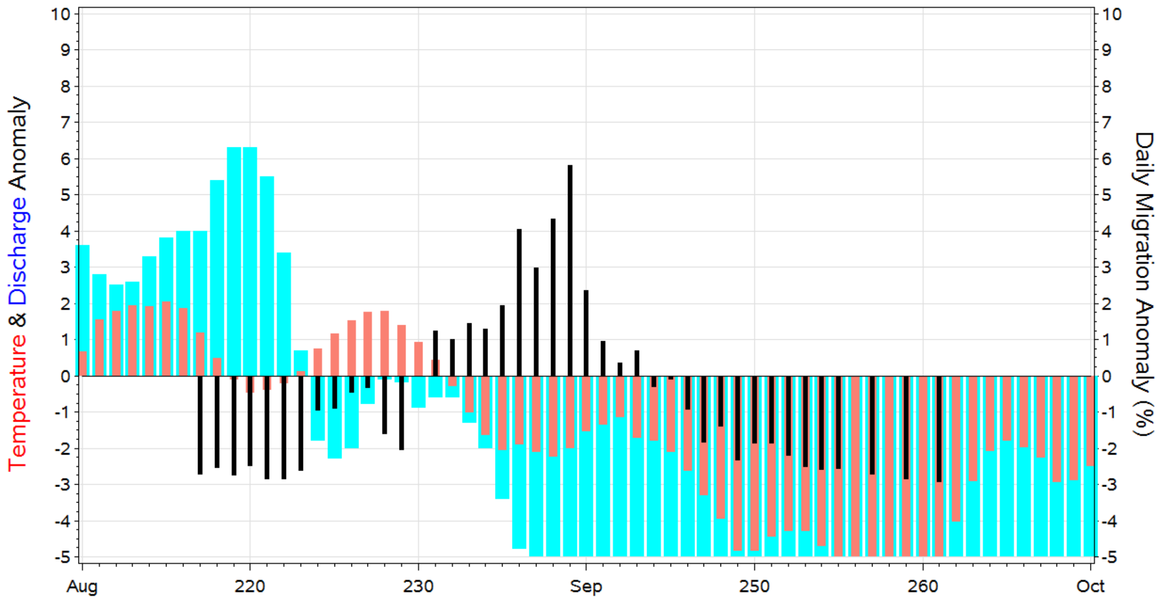
Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 15c Flow: 260 m3/s



1991 Chilko Sockeye Migration Conditions: PDO/ENSO: Cool/Warm Aug-Sep MWT: 14.2c Total Migrants: 170284

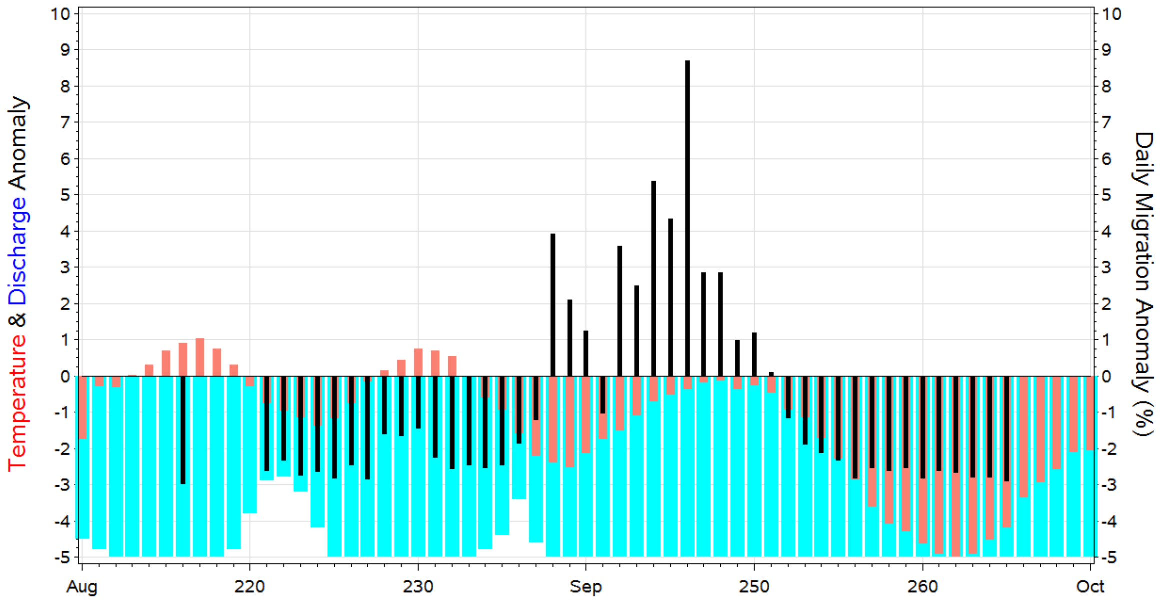
Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 15c Flow: 260 m3/s





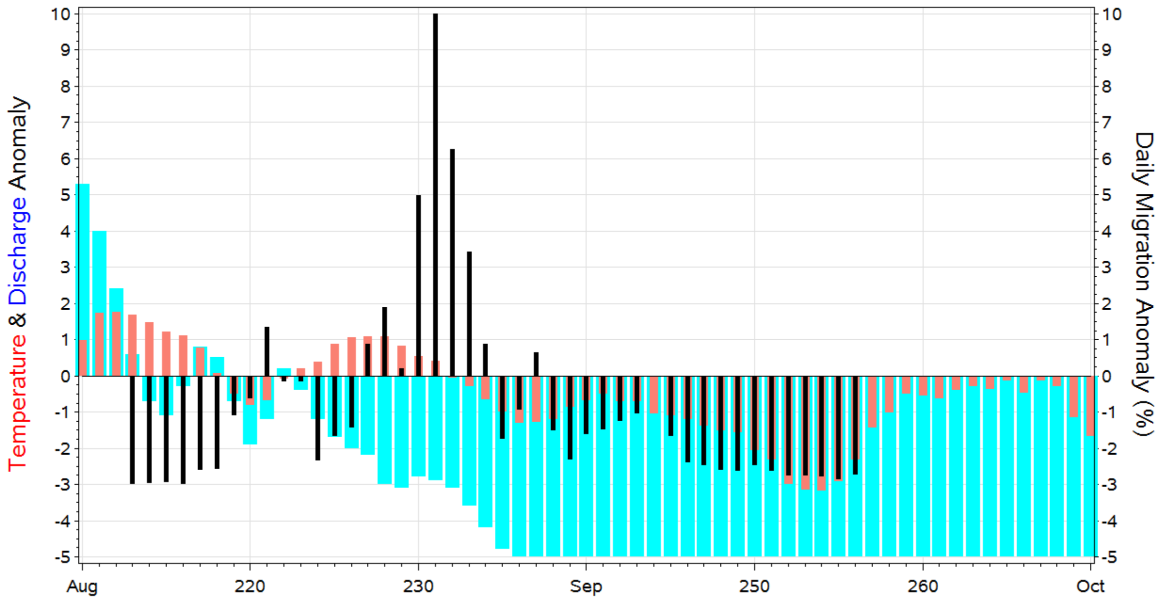
1992 Chilko Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Aug-Sep MWT: 13.3c Total Migrants: 84630

Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 15c Flow: 260 m3/s



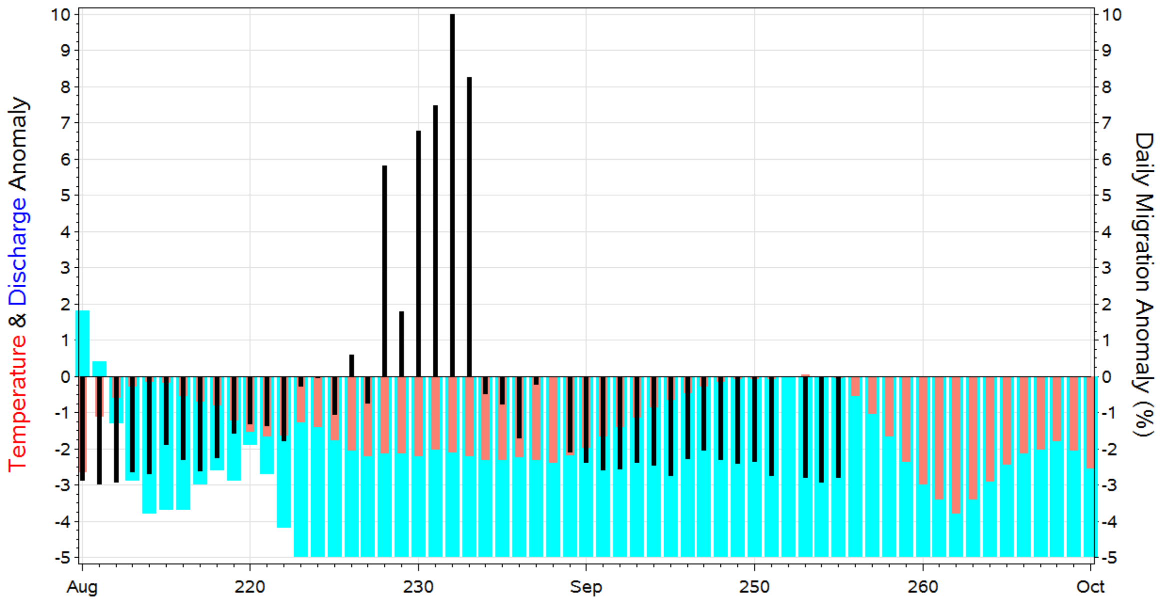
1993 Chilko Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Aug-Sep MWT: 13.6c Total Migrants: 71070

Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 15c Flow: 260 m3/s



1994 Chilko Sockeye Migration Conditions: PDO/ENSO: Warm/Neutral Aug-Sep MWT: 14.5c Total Migrants: 47514

Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 15c Flow: 260 m3/s

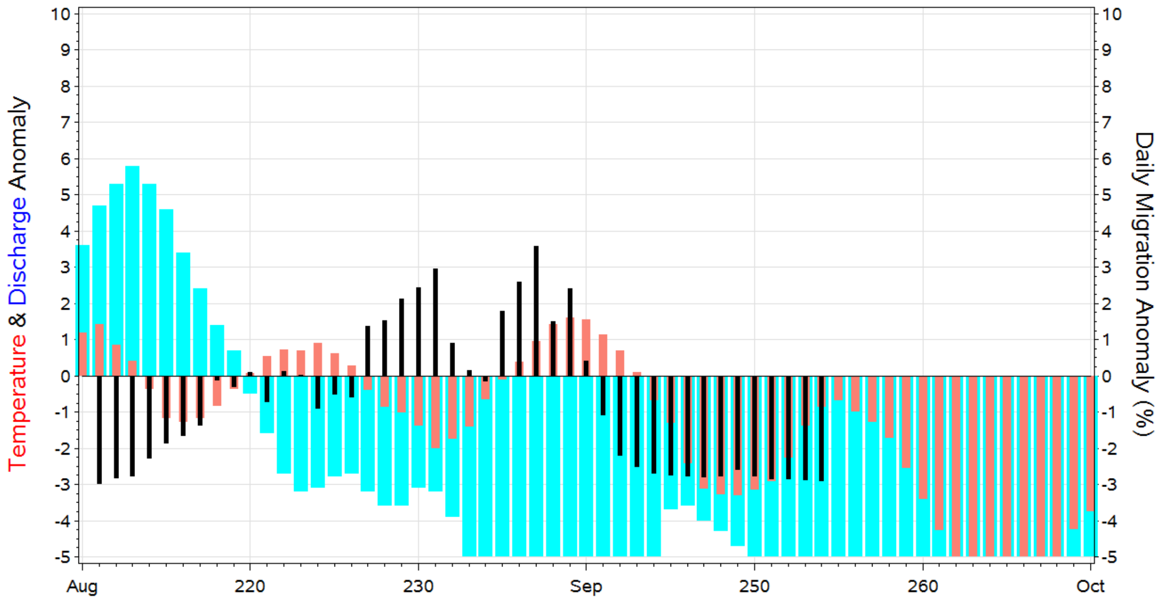


1995 Chilko Sockeye Migration Conditions: PDO/ENSO: Cool/Warm Aug-Sep MWT: 13.5c Total Migrants: 46114

Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 15c Flow: 260 m3/s

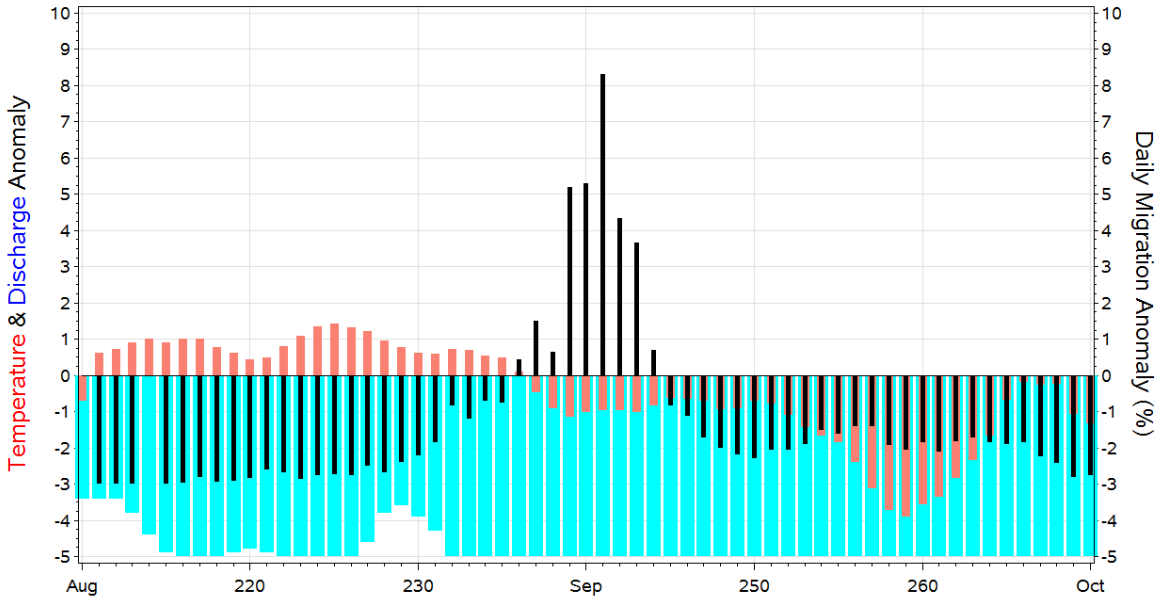
1996 Chilko Sockeye Migration Conditions: PDO/ENSO: Warm/Neutral Aug-Sep MWT: 13.6c Total Migrants: 143023

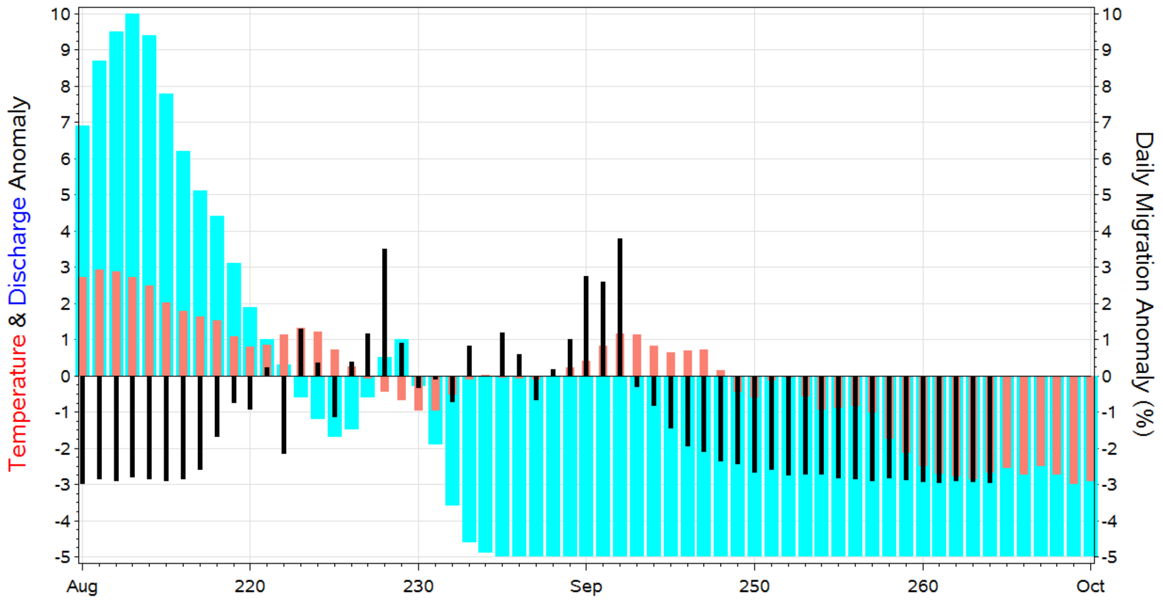
Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 15c Flow: 260 m3/s



1997 Chilko Sockeye Migration Conditions: PDO/ENSO: Warm/Neutral Aug-Sep MWT: 14.5c Total Migrants: 137392

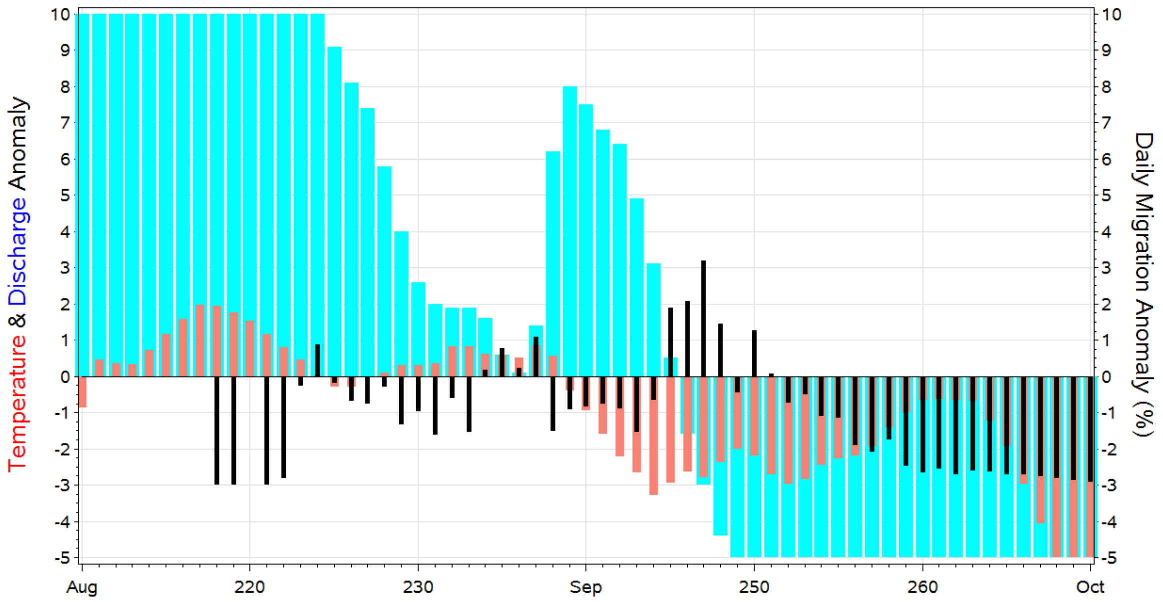
Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 15c Flow: 260 m3/s





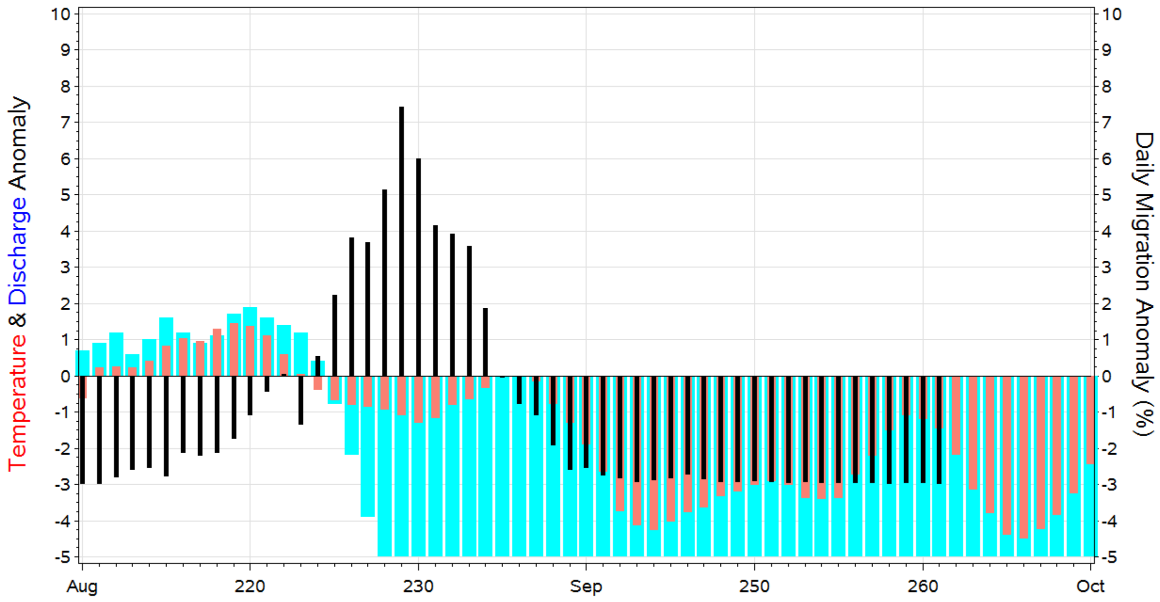
1998 Chilko Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Aug-Sep MWT: 14.9c Total Migrants: 103225

Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 15c Flow: 260 m3/s

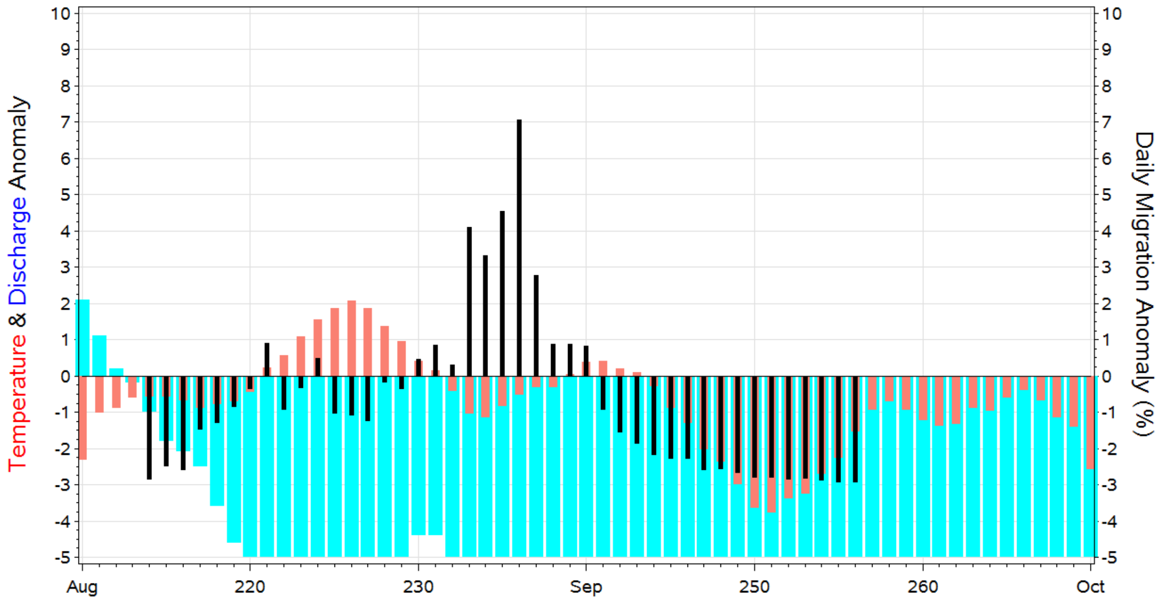


1999 Chilko Sockeye Migration Conditions: PDO/ENSO: Cool/Cool Aug-Sep MWT: 14.1c Total Migrants: 163876

Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 15c Flow: 260 m3/s


2000 Chilko Sockeye Migration Conditions: PDO/ENSO: Cool/Cool Aug-Sep MWT: 13.4c Total Migrants: 148219

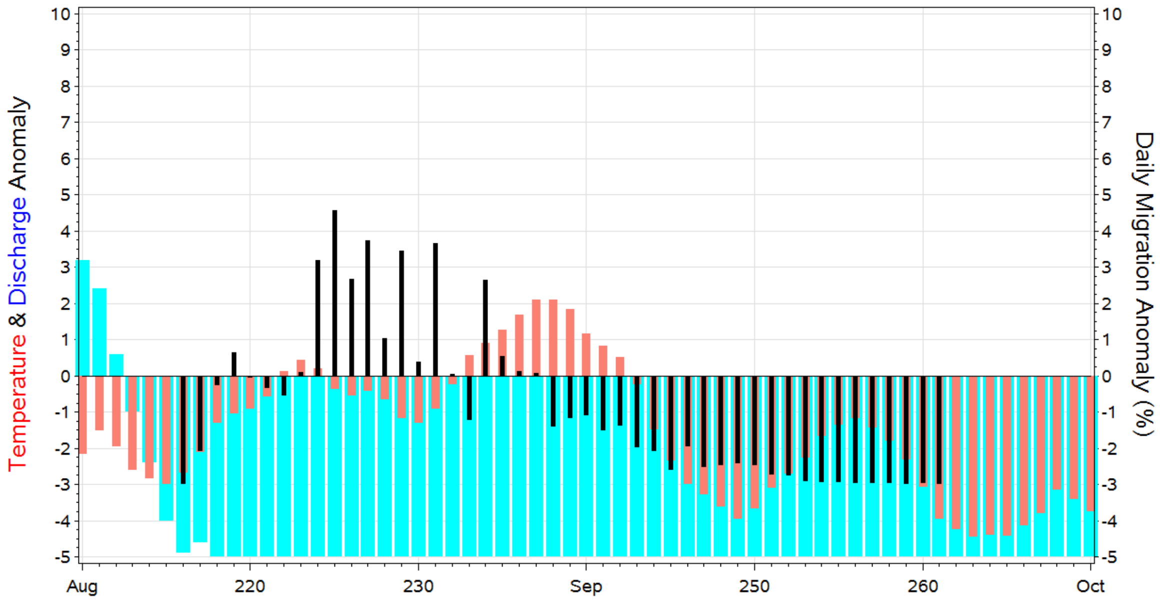
Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 15c Flow: 260 m3/s


2001 Chilko Sockeye Migration Conditions: PDO/ENSO: Cool/Neutral Aug-Sep MWT: 14.2c Total Migrants: 136118

Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 15c Flow: 260 m3/s

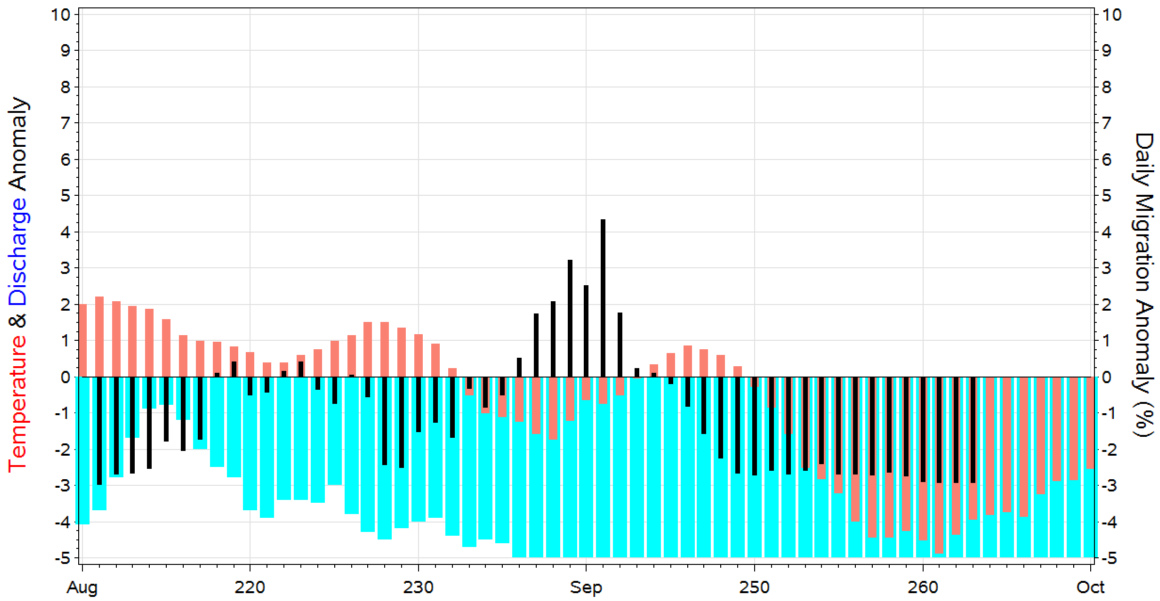
2002 Chilko Sockeye Migration Conditions: PDO/ENSO: Cool/Neutral Aug-Sep MWT: 13.4c Total Migrants: 71909

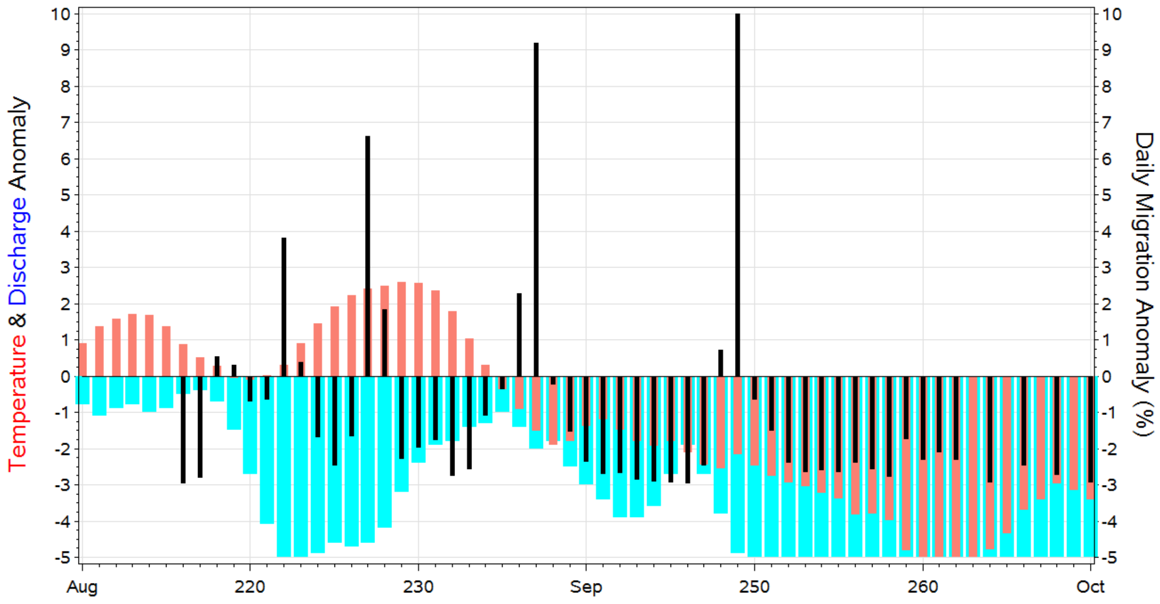
Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 15c Flow: 260 m3/s



2003 Chilko Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Aug-Sep MWT: 14.2c Total Migrants: 139228

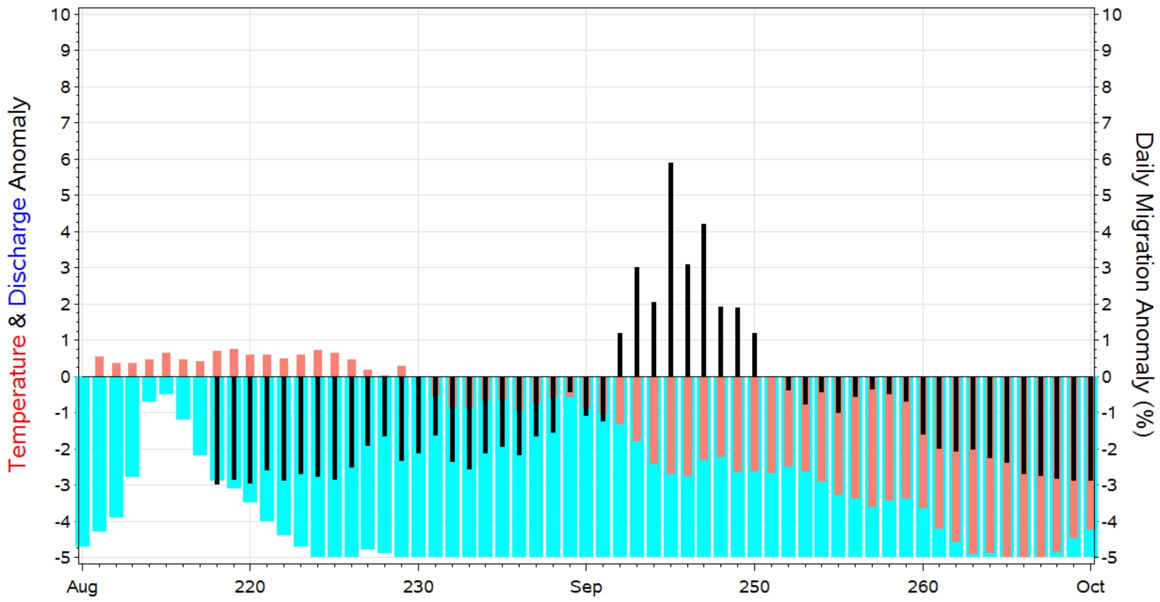
Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 15c Flow: 260 m3/s





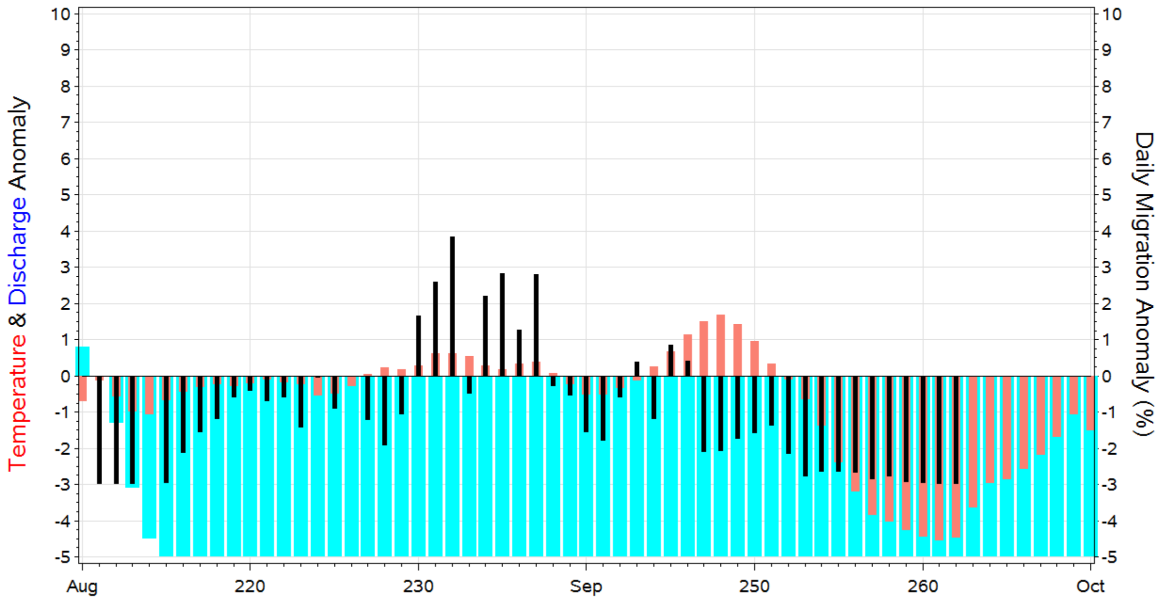
2004 Chilko Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Aug-Sep MWT: 13.8c Total Migrants: 6583

Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 15c Flow: 260 m3/s



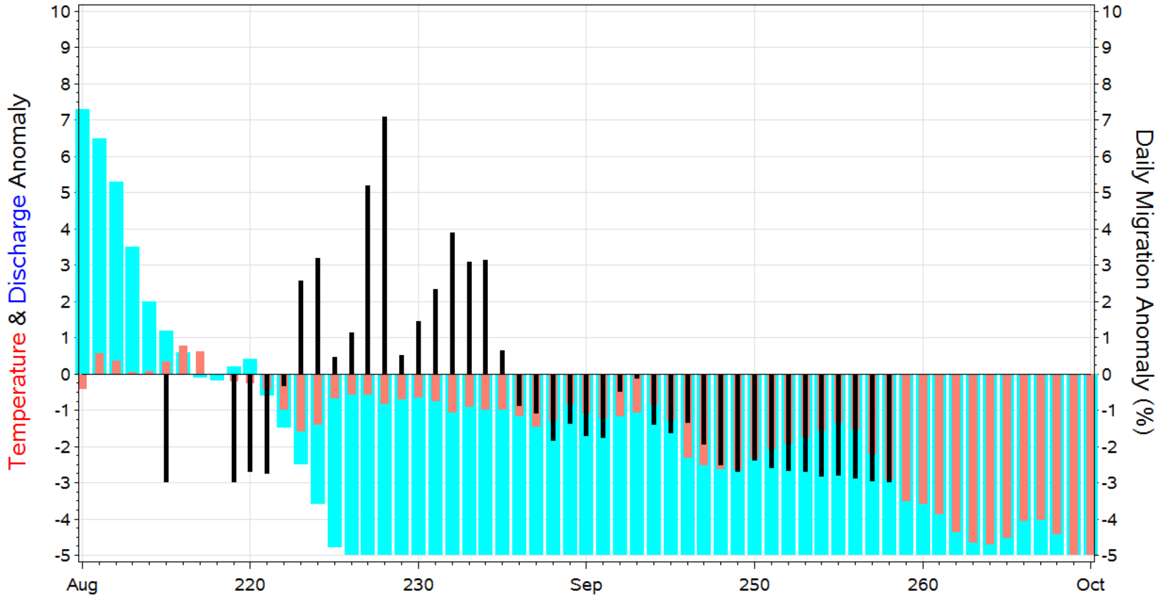
2005 Chilko Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Aug-Sep MWT: 13.4c Total Migrants: 103593

Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 15c Flow: 260 m3/s



2006 Chilko Sockeye Migration Conditions: PDO/ENSO: Cool/Neutral Aug-Sep MWT: 14.2c Total Migrants: 84765

Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 15c Flow: 260 m3/s

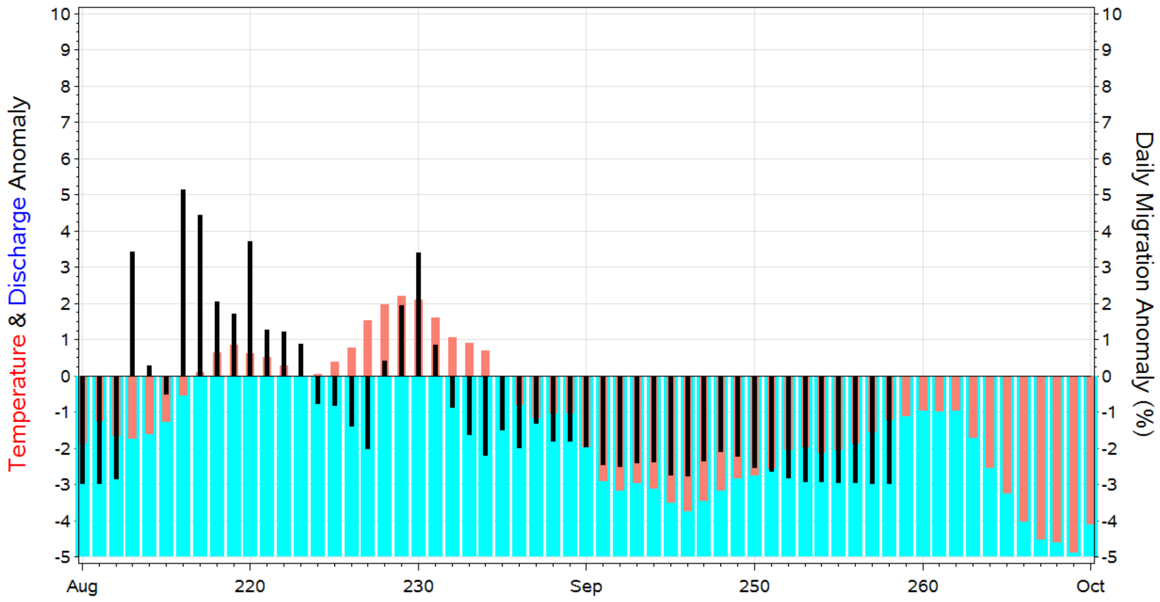


2007 Chilko Sockeye Migration Conditions: PDO/ENSO: Cool/Warm Aug-Sep MWT: 13.3c Total Migrants: 43095

Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 15c Flow: 260 m3/s

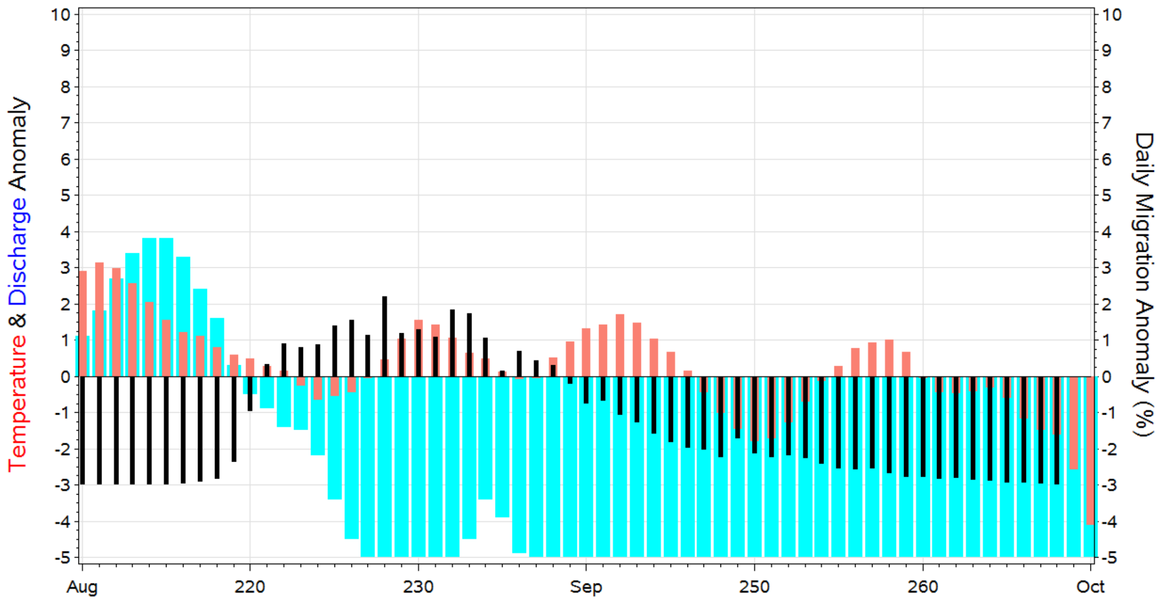
2008 Chilko Sockeye Migration Conditions: PDO/ENSO: Cool/Cool Aug-Sep MWT: 13.7c Total Migrants: 28720

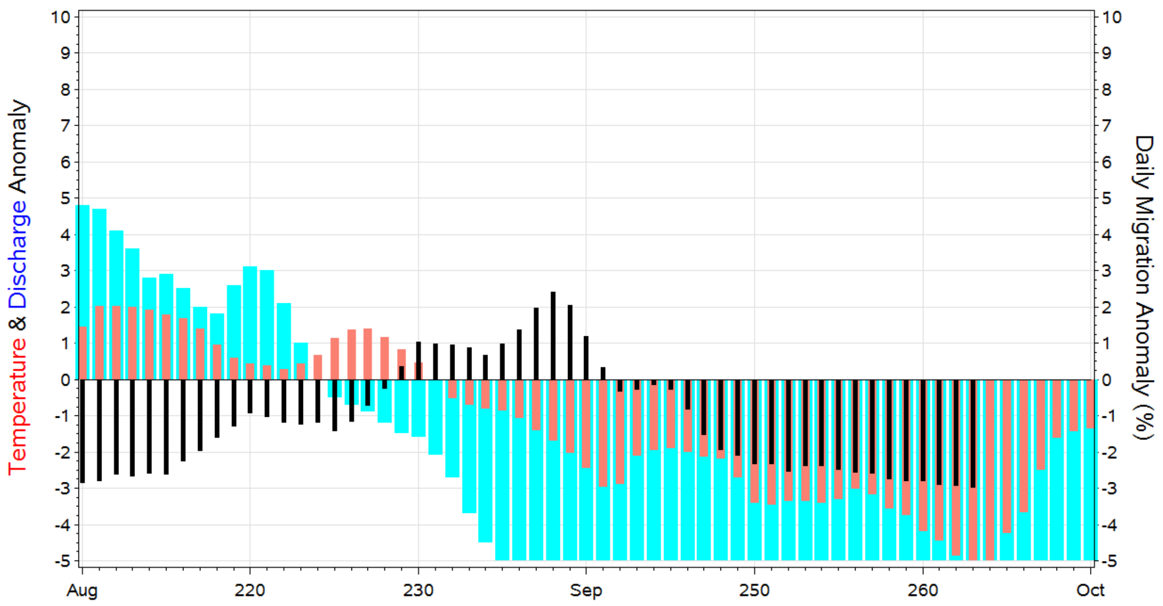
Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 15c Flow: 260 m3/s



2009 Chilko Sockeye Migration Conditions: PDO/ENSO: Cool/Neutral Aug-Sep MWT: 15.3c Total Migrants: 217778.22896

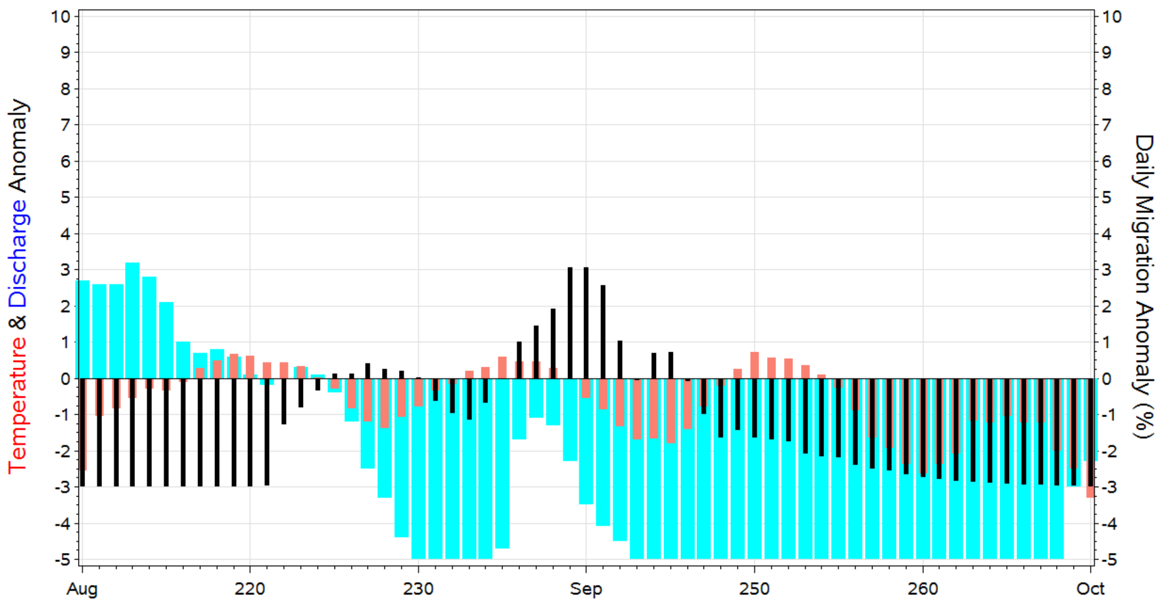
Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 15c Flow: 260 m3/s





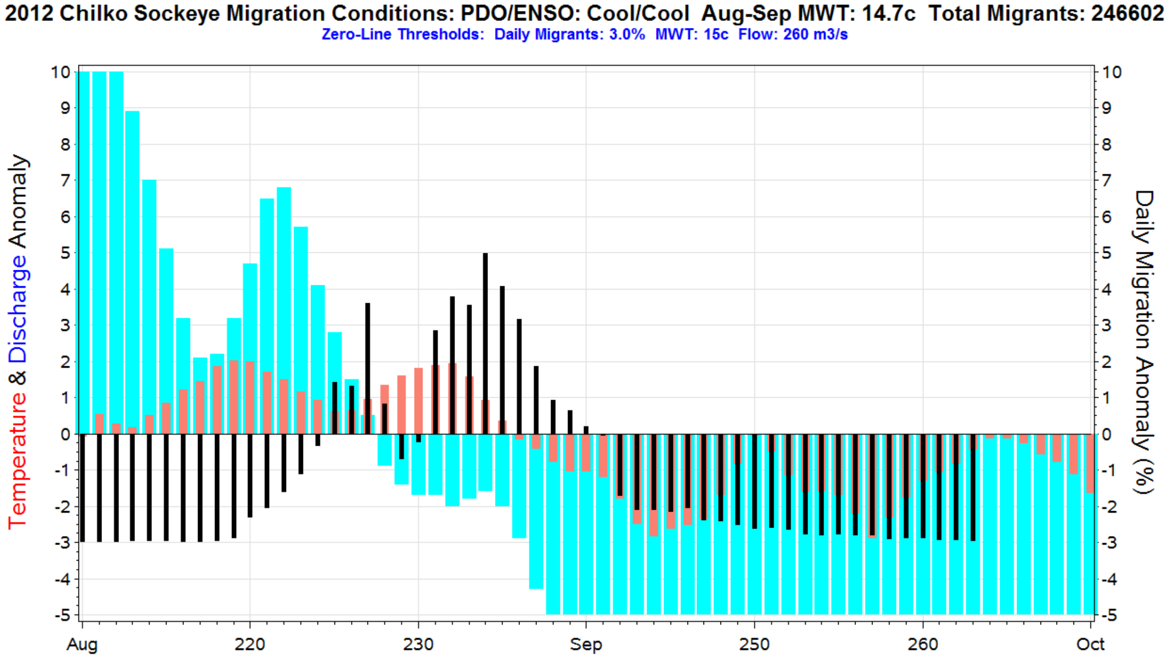
2010 Chilko Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Aug-Sep MWT: 13.7c Total Migrants: 2462974.5455

Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 15c Flow: 260 m3/s



2011 Chilko Sockeye Migration Conditions: PDO/ENSO: Cool/Cool Aug-Sep MWT: 14.3c Total Migrants: 919253.75

Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 15c Flow: 260 m3/s



2012 Chilko Sockeye Migration Conditions: PDO/ENSO: Cool/Cool Aug-Sep MWT: 14.7c Total Migrants: 246602

Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 15c Flow: 260 m3/s