Historic Water Temperature (1924-2018), River Discharge (1929-2018), and Adult Sockeye Salmon Migration (1937-2018) Observations in the Columbia, Okanogan, and Okanagan Rivers

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HISTORIC WATER TEMPERATURE (1924-2018),
RIVER DISCHARGE (1929-2018), AND
ADULT SOCKEYE SALMON MIGRATION OBSERVATIONS (1937-2018)
IN THE COLUMBIA, OKANOGAN, AND OKANAGAN RIVERS

by

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ABSTRACT

Hyatt, K. D. , Stiff, H. W. and Stockwell, M. M. 2020. Historic water temperature (1924-2018), river discharge (1929-2018), and adult Sockeye Salmon migration (1937-2018) observations in the Columbia, Okanogan, and Okanagan rivers. Can. Manuscr. Rep. Fish. Aquat. Sci. 3206: xv + 203 p.

Historical meteorological and hydrological data were assembled to review the influence of environmental factors on patterns of adult Sockeye Salmon migration, as enumerated at Zosel Dam in the Okanogan River, WA, en route to spawning grounds in the Okanagan River, BC. We identify three locations of vulnerability for Okanagan Sockeye Salmon along the migration corridor as likely ‘control points’ exerting a disproportionate impact on upstream migration success: (1) the warmest segments of the lower Columbia River, associated with Bonneville and John Day dams; (2) Pateros Lake, above Wells dam in the mid-Columbia where salmon may hold before entering the Okanogan watershed; and (3) the 185-km Okanogan River, where summer water temperatures are typically 3-5°C warmer than Pateros Lake.

In the highly regulated flow environment of the Columbia and Okanagan watersheds, water temperature appears to be more influential than discharge on the migratory behaviour, timing, and survival of adult Sockeye Salmon. Okanogan River water temperatures have been trending upwards since the 1970s-1990s. Approximately 80% of dates during peak migration (July-August) in recent decades exceeded 20°C, up from 50% between the 1950s and 1990s. The impacts of prolonged exposure to super-optimal temperatures on adult migration success are evident from annual variations in travel time and abundance between Wells Dam and the Okanagan River spawning grounds. In cool, wet years when Okanogan water temperatures averaged <22°C during Sockeye Salmon passage (e.g. 2010 and 2011), the Wells-to-Okanagan “conversion rate” (CR) was 79-87%. In recent warm years (e.g. 2016-2018) when Okanogan temperatures were 22-23°C during adult migration, the CR fell to 43% (range 34-65%). In 2015, when Okanogan mean temperatures reached ~24°C, the CR was 8.5%. Median TT between Wells and Zosel dams averaged ~5 days (range 3-7) in 2016 and 2017, but averaged 28 days (range 13-35) due to temperature-induced migration delays during the hot spell in 2015.

RÉSUMÉ

Hyatt, K. D. , Stiff, H. W. and Stockwell, M. M. 2020. Historic water temperature (1924-2018), river discharge (1929-2018), and adult Sockeye Salmon migration (1937-2018) observations in the Columbia, Okanogan, and Okanagan rivers. Can. Manuscr. Rep. Fish. Aquat. Sci. 3206: xv + 203 p.

Nous avons rassemblé des données météorologiques et hydrologiques historiques afin d’examiner l’influence des changements touchant les facteurs environnementaux sur les profils saisonniers à annuels de la migration des saumons rouges adultes, tels qu’ils sont dénombrés au barrage de Zosel sur la rivière Okanogan, dans l’État de Washington, en direction des frayères dans la rivière Okanagan en Colombie-Britannique. L’analyse de notre étude détermine trois endroits clés de vulnérabilité potentielle pour le saumon rouge de l’Okanagan le long du couloir de migration, qui constituent des impacts disproportionné sur le succès de la migration de la population: 1) les tronçons les plus chauds du cours principal du Columbia, qui sont associés aux barrages de Bonneville et de John Day; 2) le lac Pateros, le réservoir dans le cours principal du Columbia, où les saumons rouges adultes peuvent rester avant d’entrer dans le bassin hydrographique de l’Okanogan; et 3) le segment de 185 km de l’Okanogan en aval du lac Osoyoos, où les températures estivales de l’eau sont généralement de 3 à 5 °C plus élevées que celles du lac Pateros dans le cours principal du Columbia.

Dans l’environnement à débit fortement régulé des bassins hydrographiques du Columbia et de l’Okanagan, la température de l’eau semble avoir plus d’influence que le débit sur le comportement migratoire, le moment de la migration et la survie des saumons rouges adultes. La température de l’eau de la rivière Okanogan a augmenté depuis les années 1970-1990. Près de 80 % des dates dépassaient 20 °C au cours des dernières décennies pendant juillet-août, comparativement à 50 % entre les années 1950-1990. Les impacts d’une exposition prolongée à des températures super-optimales sur le succès de la migration des saumons rouges adultes sont évidents d’après les analyses visant à déterminer les variations annuelles du temps de trajet et des « taux de conversion » à partir des dénombrements en aval au barrage de Wells par rapport aux estimations visuelles de l’abondance des saumons rouges adultes dans les frayères de la rivière Okanagan. Lors des années fraîches et humides où la température de l’eau de l’Okanogan était en moyenne inférieure à 22 °C durant le passage du saumon rouge (p. ex. en 2010 et 2011), le taux de mortalité était de 79 à 87 %. Au cours des dernières années chaudes (p. ex. 2013, 2014, 2016-2018), lorsque les températures moyennes de l’Okanogan étaient comprises entre 22 et 23 °C, le taux de conversion de Wells à Okanagan était réduit en moyenne à 43 % (fourchette de 34 à 65 %). En 2015, lorsque les températures moyennes de l’Okanogan ont atteint ~24 °C, la valeur du taux de conversion est tombée à 8,5 %. Le temps de trajet médian entre les barrages de Wells et de Zosel a été en moyenne de 5 jours (gamme 3-7) en 2016 et 2017, mais en moyenne 28 jours (gamme 13-35) en raison de retards de migration induits par la température pendant la période de chaleur en 2015.

EXECUTIVE SUMMARY

Historical meteorological and hydrological data were assembled to review the influence of changes in environmental factors on seasonal to annual patterns of adult Sockeye Salmon migration, as enumerated at Zosel Dam in the Okanogan River, Washington State, en route to spawning grounds in the Okanagan River, British Columbia. Frequency distributions and non-parametric tests of association between temperature, discharge, and historical migration data were used to discern possible environmental thresholds delineating high versus low migration levels. Decadal-scale peak-over-threshold (POT) analyses were then applied to the reconstructed environmental time-series[1] to ascertain potential impacts of water temperature and flow extremes when adult Sockeye were present. Similar exceedance analyses were applied to observed temperature data at the Bonneville Dam in the lower Columbia River, and Wells Dam in the mid-Columbia during adult migration.

In the highly regulated flow environment of the Columbia and Okanagan watersheds, water temperature appears to be more influential than discharge in affecting the migratory behaviour, timing, and survival of adult Sockeye Salmon. Analyses here identify three key locations of potential vulnerability for Okanagan Sockeye Salmon along their migration corridor as likely ‘control points’ exerting a disproportionate impact on the population’s migration success. These include: (1) the warmest reaches of the Columbia mainstem, which are associated with Bonneville and John Day dams in the lower Columbia River; (2) Pateros Lake, the forebay above Wells dam in the mid-Columbia mainstem where adult Sockeye Salmon may hold before entering the Okanogan watershed; and (3) the 185-km Okanogan River below Osoyoos Lake, where summer water temperatures are typically 3-5°C warmer than in Pateros Lake.

Estimated summer water temperatures in the Okanogan River have been trending upwards since the 1970s-1990s. POT analyses indicated nearly 80% of dates exceeded 20°C in recent decades during peak migration (July-August), up from 50% between the 1950s and 1990s. The average annual duration of continuous “warm spell” events since 2010 was 25 days, up 60% from previous decades. A prolonged meltwater discharge may occasionally inhibit early upstream migration (e.g. 2010), but in most years, migration activity is most frequently delayed by water temperatures exceeding 20-22°C. Highest daily migration rates (>75th percentile) occurred when discharge was 90-160 cms and water temperature was < 19°C.

The impacts on adult Sockeye Salmon migration success of prolonged exposure to above-optimal temperatures are evident from analyses of annual variations in travel time (TT) and “conversion rates” (CR) based on downstream counts at Wells Dam versus visual estimates of adult Sockeye Salmon abundance on the Okanagan River

[1] Daily air temperature data at Malott, WA (2008-2018) were statistically extended back to 1924 based on linear relations with Oliver, BC air temperature. The resulting mean air temperature index was correlated with Okanogan River water temperature at Malott, WA to hind-cast daily water temperature in the lower Okanogan River from 1924-2018. Discharge data for the Okanogan River at Tonasket, WA were used to extend the daily discharge time-series for the Okanogan River at Malott back to 1929.

spawning grounds (adjusted for exploitation above Wells Dam). In cool, wet years when Okanogan water temperatures averaged less than 22°C during Sockeye Salmon passage (e.g. 2010 and 2011), the Wells-to-Okanagan CR was 79-87%. In recent warm years (e.g. 2013, 2014, 2016-2018) when Okanogan mean temperatures ranged from 22-23°C during adult migration, the Wells-to-Okanagan CR averaged 43% (range 34-65%). In 2015, when Okanogan mean temperatures during peak migration reached ~24°C, the CR value fell to 8.5%, indicating a 91.5% natural en route mortality rate for the passage between Wells Dam and the spawning grounds alone. Median TT between Wells and Zosel dams averaged ~5 days (range 3-7) in 2016 and 2017, but averaged 28 days (range 13-35) due to temperature-induced migration delays during the hot spell in 2015 (Fryer et al. 2018).

INTRODUCTION

Maintaining healthy and diverse populations of salmon that will support sustainable fisheries for present and future generations is the key goal of the Department of Fisheries and Oceans' *Wild Salmon Policy* (DFO 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 (Crozier et al. 2019; 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. Furthermore, 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 human-induced 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 et al. 2011; Littell et al. 2011).

Recent investigations in the Pacific Northwest and British Columbia have demonstrated regional temperature shifts of about 0.8°C over the past century, with projected temperature increases of 1.5-3.2°C in near-future decades (Mote et al. 2003; Mote and Salathé 2009). 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; Cohen and Kulkarni 2001). These analyses also indicate that the magnitude, and, in some cases the direction, of historical and projected climate variability fluctuate regionally within the province due to the large and topographically complex areas involved (Walker and Sydneysmith 2008).

For salmon (*Oncorhynchus sp.*), the two freshwater life stages most sensitive to climate change are upstream migration of returning spawners, and post-spawn egg-to-fry incubation (McDaniels et al. 2010; Healey 2011). Temperature impacts on migrating adult salmon have been well documented in many river systems in the Pacific Northwest (Goniea et al. 2006; Nelitz et al. 2007; Salinger and Anderson 2006). Lethal temperatures are reported in the range 21-24°C, and water temperatures in excess of 18°C may affect migration speed, cause timing delays, and alter spatial distribution of salmon (Jensen et al. 2004; Keefer et al. 2008; Martins et al. 2010). Elevated water temperatures (>18°C) may also result in secondary effects such as increased disease, resulting in pre-spawn mortality (Cooke et al. 2004; Hinch and Martins 2011; Miller et al. 2014). Thermal stress has also been found to reduce salmon gamete viability, fertilization rates and decrease egg to fry survival rates (Jensen et al. 2004). Since salmon populations may also differ in their thermal tolerances, reflecting local adaptation to conditions over their historic evolution (Farrell 2009; Martins et al. 2012), species- and 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 (natural rapids, falls, and canyons, etc., but also installed fishways and weirs) which influence water velocity in key locations along the migratory route. In some cases, low flows may result in physical limits to fish passage; in other cases, high flows may generate velocity barriers that reduce or prohibit upstream migration.

This report is one of a series[2] intended to consolidate and document historic observations on key life history events and associated environmental variables for relatively data-rich salmon populations distributed throughout their range in Canada's Pacific region. The purpose is to develop lifestage-specific statistical or process 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.

BACKGROUND

At the turn of the century, more than a dozen anadromous populations of Sockeye Salmon (*Oncorhynchus nerka*) inhabited at least eight distinct river basins in the Columbia River system (Fryer 1995; Allen and Meekin 1980). Similarly, Chinook (*O. tschawytscha*) and Steelhead salmon (*Salmo gairdneri*) populations occupied extensive areas of Columbia basin watersheds extending to its headwaters in Canada (CBTFN 2015). Over the past century, dams, overfishing, and habitat degradation have reduced the distribution and abundance of anadromous salmon populations originating in the Columbia basin to less than 5% of their historic numbers (Lackey 2000). The construction of Grand Coulee Dam (completed: 1942) prevented passage

[2] Hyatt et al. 2015b; Stiff et al. 2013; 2015a; 2015b; 2015c; 2016; 2018.

of adult fish, eliminating access to ~1,800 km of salmonid habitat in the upper Columbia River Basin, and eradicating the annual harvest and consumption of up to 4 million salmon by the peoples of northeast Washington State and southeast British Columbia (CBTFN 2015). Currently, salmonids returning to the Okanagan sub-basin of the mid-Columbia River (i.e. salmon of Canadian origin or SOCO) are reduced to single Conservation Units[3] (CUs) of Sockeye, Chinook and Steelhead salmon. These populations have exhibited declines similar to those observed generally for salmon throughout the Columbia basin. Although efforts to restore Okanagan Sockeye Salmon appear to have been remarkably successful – with total returns frequently exceeding 200,000 adults in recent years (Hyatt and Stockwell 2019) – only a few hundred Steelhead Salmon (Howie Wright, Okanagan Nation Alliance, pers. comm.) and far fewer than 100 Chinook Salmon (DFO 2019) now return annually to the Okanagan and its tributaries in Canada.

Total returns of adult Okanagan Sockeye Salmon have fluctuated greatly over the period of record, from a low of <2,000 fish in 1994, to a high of >500,000 fish in 2015 (Hyatt and Stockwell 2019). Factors contributing to this wide range of adult Sockeye returns include harvest rates, habitat loss, hydroelectric development of the Columbia River, and two decades of recent collaborative, stock restoration work (Hyatt and Rankin 1999; Hyatt and Alexander 2005; Hyatt et al. 2003; 2009; 2015a; Hyatt and Stockwell 2019). Collaborations involved numerous initiatives undertaken through the efforts of First Nation and Tribal entities (i.e. Okanagan Nation Alliance, Colville Confederated Tribes), industry (Douglas, Grant and Chelan Public Utilities in Washington State), non-governmental organizations (BC Habitat Conservation Trust) and government agencies (Fisheries and Oceans Canada, BC Forests Lands and Natural Resource Operations, Washington Department of Fish and Wildlife) that appear to have facilitated the restoration of wild-origin Okanagan Sockeye Salmon to record levels of abundance.

The successful restoration of Okanagan Sockeye has provided added encouragement to First Nations and Tribes in Canada and the US to pursue a long-held vision of restoring anadromous salmon (Sockeye, Chinook and Steelhead) to reaches of the Upper Columbia basin from which they were excluded (UCUT 2019) following the construction of the Grand Coulee Dam. Formal negotiations to renew the 60 year-old Columbia River Treaty, and operation of the many dams built under its terms in the 1960s, were initiated between Canada and the US in 2018. The original treaty focused on hydroelectric power generation and flood control benefits but failed to include provisions to maintain benefits from ecosystem services such as sustainable production of salmon. Consequently, restoration of anadromous salmon to barriered reaches of the upper Columbia River in the US (UCUT 2019; ISAB 2019) and Canada (CBTFN 2015; CRSRI 2020) is an active area of discussion among the parties.

Despite the recent success in rebuilding Okanagan Sockeye Salmon numbers, major threats to the future sustainability of this, as well as other salmon populations in the Columbia and Okanagan basins, remain. Transboundary water and harvest regulations under existing treaties (i.e. Columbia River Treaty, Pacific Salmon Treaty)

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[3] CUs are the Canadian counterpart of the Evolutionary Significant Units (ESU) in the US.

do not effectively address sustainable production issues for Columbia River SOCO (CBTFN 2015), and the threats posed by current and future climate change to sustainable production of anadromous salmon throughout the basin[4] are a major concern (Mote et al. 2003; Mote and Salathé 2009).

The current report reviews variations in adult Sockeye Salmon behaviour associated with climate-related factors (water temperature and discharge) that generally affect migration and spawning success of SOCO returning through the Columbia River and Okanagan rivers to their terminal spawning grounds in southern BC. As such, the report will serve as a source of background information to be used in further analysis and modelling work to examine (a) the potential impact of interactions among fisheries, hydro-system operation and future climate change on the sustainability of existing SOCO, and (b) the feasibility of re-establishing anadromous salmon in Canadian portions of the Columbia River upstream of Chief Joseph and Grand Coulee dams.

STUDY AREA

The Columbia River is the largest river in the Pacific Northwest region of North America with respect to river length (2,000 km), basin area (668,000 km^2), and mean annual discharge (7,500 cms or $m^3 \cdot s^{-1}$). The river originates in the Columbia Mountain Range of southeastern BC (Columbia Lake elevation: 820 m), flows northwest and then south into the US state of Washington, then turns west to form most of the border between Washington and the state of Oregon before emptying into the Pacific Ocean (Figure 1).

The diverse climatology of the Columbia River Basin (CRB) reflects its large geographic area, primarily delineated by the Cascade Mountain Range, which extends from southern BC to Northern California. The climate west of the Cascade Mountains is primarily influenced by the proximity of the Pacific Ocean. Winters are mild, and rainfall is frequent and at times voluminous. Snowfall is rare except at the higher elevations in the Cascades and Coast Ranges. In low-lying areas of the Columbia and Willamette river valleys, snowfall may be limited to a few weeks in January and February.

The climate east of the Cascades is continental, with cold, snowy winters and warm, dry summers. Continental climate extends into British Columbia, where summers are generally also warm and dry, but where successive mountain ranges intercept winter storms, and snowfall may be frequent and heavy. Thus the Canadian portion of the Columbia River, which represents ~15% of the CRB area, typically provides ~75% of summer flows for the Columbia River, as measured at the Dalles Dam.[5]

Annual precipitation across the CRB ranges from 115 cm in the coastal area, to >254 cm in the heart of the Columbia River Gorge, to <20 cm in the rain-shadow east of the Cascades. The interior of the CRB receives 30-75 cm of annual precipitation, except

[4] For example, in 2015, given highly elevated temperatures in the Columbia main-stem and its tributaries during the peak weeks of migration, fewer than < 5% of the adult Sockeye Salmon counted at Bonneville Dam in the lower Columbia River survived to reach their spawning grounds at several locations in either the US or Canada (NOAA 2016).

[5] Range: 60% (in wet years, such as 2011) to 84% (in dry years, such as 2015). Source: USGS National Water Information System (NWIS) Surface Water, Jul-Aug-Sep months, 2008-2018.

for the drier Snake River Plain in southern Idaho. The Cascade, Columbia, and Rocky mountain ranges typically accumulate 200-500 cm of snow annually.

Okanogan (US) / Okanagan (Canada) Watershed

In the mid-Columbia region, two tributaries, the Okanagan River in British Columbia and Wenatchee River in Washington State, support the only two self-sustaining Sockeye Salmon populations remaining out of more than a dozen that historically returned to the Columbia River.[6] The population of interest in this paper, Okanagan Sockeye Salmon, originates in the Okanagan Highlands Ecoregion, a hilly plateau-like area in south-central British Columbia. The Okanagan Lake and River System (OLRS) is characterized by a chain of six lakes joined by rivers in a north-to-south configuration along the valley bottom (Stockwell et al. 2020). At its southern end, Osoyoos Lake straddles the international border with the United States, and drains into the Okanogan River (note U.S. spelling) in Washington State, which flows 185 km south to join the Columbia River.

Climate normals (1971-2000) for the semi-arid Okanagan River basin, north of Osoyoos Lake, indicate annual average temperatures of 9-10°C, while average summer temperatures range from 21-22°C, with maximum daily temperatures of 28-30°C (Table 1). Annual total precipitation in the region varies from <30 cm in the Okanagan valley to 127–229 cm in the Cascade Mountains. Total annual precipitation at Oliver, B.C. is ~33 cm; the driest months (Sep-Oct) contribute, on average, <2 cm per month (Table 1).

The OLRS is a snowmelt-dominated system, with a spring freshet that occurs from April through June, accounting for as much as 90% of mean annual discharge (MAD). By July, flows decline, and inflows to the system generally remain very low for the summer, fall, and following winter. Wide fluctuations between spring and summer flows are moderated by water regulation at a series of dams in the basin (Hyatt et al. 2015a). Penticton Dam at the outlet of Okanagan Lake is the main water regulation point in the valley for flood control and storage of water for irrigation purposes while Zosel Dam (Oroville, WA), at the outlet of Osoyoos Lake (Stockwell et al. 2020), is operated by a Board of Control to maintain water levels on the international lake under orders of the Canada-US International Joint Commission.

South of Zosel Dam, the 197 km Similkameen River joins the Okanogan River, supplying additional cool water from the Cascade Mountains during the freshet, usually between May and early July, depending on snow-pack depth and melt rate (Johnston et al. 2009). The annual freshet historically transported juvenile salmonids seaward, and reduced Okanogan water temperatures during upstream migration of adults. Regional climate change (warmer, wetter winters: Mantua et al. 2010; Littell et al. 2011) may be altering the hydrological cycle, however, resulting in reduced cold water inputs from the Similkameen in early summer (e.g. 2015, when freshet

[6] A third remnant stock, returning to the Snake River and comprising less than 0.1% of current Columbia Sockeye abundance, is listed under the US Endangered Species Act, and is maintained through hatchery production. Fryer (1995) and Hyatt and Rankin (1999) provide further details regarding historic abundance, biological traits, and factors leading to the general decline of Columbia and Okanagan Sockeye.

temperatures exceeded 20°C in June). Daily mean water temperatures in July/August in the lower Okanogan River often exceed 22°C, with maximum temperatures exceeding 24-25°C (Stockwell et al. 2001, Hyatt et al. 2003), making this leg of the migratory journey particularly challenging for salmonids.

In addition to climate change, the proliferation of >60 dams for irrigation, flood control, and hydroelectric power generation in the Columbia watershed over the past century (Figure 2) has altered the overall flow regime by retaining water in reservoirs, reducing the volume and velocity of the spring flow. The widespread management of the river for human uses has led to reduced discharge levels and flow speeds and increased warming of the lower river in late spring and early summer over recent decades (Quinn and Adams 1996)[7]. These changes have been correlated with progressively earlier arrivals of adult Sockeye Salmon at Bonneville Dam (Quinn et al. 1997), and high en route mortality in the Columbia mainstem and tributaries (e.g. 95% mortality of Sockeye Salmon in 2015; NOAA 2016).

Okanagan-bound Sockeye Salmon must migrate past nine dams on the Columbia River mainstem (Figure 2). Though all are equipped with fishway structures to facilitate upstream migration, the dams and their associated impoundment reservoirs present challenges affecting fish survival (NWPPC 1986) and migration behaviour, including energy depletion, reduced migration rate and delays in migration timing (Beechie et al. 2006; Keefer et al. 2018), any and all of which are exacerbated by elevated water temperatures, resulting in reduced reproductive success (McCullough et al. 2001; Crozier et al. 2019).

Therefore, in addition to the thermally-challenging Okanogan River, other critical points along the migration route affecting the sustainability of SOCO must include:

(1) the fishways and reservoirs associated with lower river dams, where Columbia mainstem water temperatures are at their maximum (exceeding 20°C in June/July) (Figure 2);

(2) the slightly cooler reservoir associated with Wells Dam (Lake Pateros) in the mid-Columbia, where Okanagan-bound fish may hold before ascending the Okanogan River (Figure 3).

Mainstem River Dams and Reservoirs

Mainstem Columbia River dams in the U.S. are considered run-of-river (RoR) control structures, for which the daily through-put of water in the associated reservoir represents a significant fraction of the reservoir’s storage capacity. The short residence time of water (<40 days) in these reservoirs generally restricts the degree of vertical or horizontal stratification that can occur in the waterbody, resulting in near-isometric temperature and chemical composition at all depths and locations (USBR 2018). Water temperatures are less than 1-2°C warmer in surface waters at the dam than at depth or upstream (ibid). Though small, these temperature differences may of course be important to migrant salmonids. Adult migrants can theoretically avoid the warmest

[7] For example, the first date of lower Columbia water temperature exceeding 15.5°C water occurred 30 days earlier in 1993 than in 1938; the annual maximum temperatures increased by 1.8°C from 1949 to 1993; and fall cooling of the river occurred later in the season (Quinn and Adams 1996).

surface waters in reservoirs by moving deeper in the water column. But to pass dams, the fish must swim near the surface to navigate the relatively shallow (2-3 m depth) fishways.

The RoR classification applies to all major dams in the lower Columbia, including Bonneville, Dalles, John Day, and McNary; Wells Dam, and the four smaller Public Utility District dams between McNary and Wells, in the mid-Columbia below the Okanogan confluence; and Chief Joseph Dam upstream of the Okanogan confluence (USACE 1974, 1976; USBR 2018). The one exception might be the largest dam in the system, Grand Coulee (upstream of Chief Joseph Dam) where extended warm weather in late summer and fall may result in "shallow and weak stratification" associated with up to 3°C difference between epi- and hypolimnion temperatures in the forebay of Lake Roosevelt (NWPPC 1986; USBR 2018)[8].

Bonneville Dam and Lake Bonneville Reservoir

The Bonneville Lock and Dam consists of several RoR dam structures spanning the Columbia River Gorge, 245 km upriver from the mouth of the Columbia near Astoria, Oregon (Figure 2). The primary functions of Bonneville Lock and Dam are electrical power generation and river navigation. Lake Bonneville extends 77 km upstream; water level is approximately 18 meters above the level of the Columbia River on the downstream side of the dam at the spillway (Wikipedia, retrieved June 2020; USACE).

The Dalles Dam and Lake Celilo Reservoir

The Dalles Dam is a concrete-gravity RoR dam spanning the Columbia River at river kilometer (rkm) 309. The Lake Celilo reservoir behind the dam is ~48 m above the Columbia below the dam, and extends 39 km to the foot of John Day Dam (ibid).

John Day Dam and Lake Umatilla Reservoir

The 56 m high John Day Dam is a concrete-gravity RoR dam located at rkm 348. Lake Umatilla Reservoir is the longest reservoir in the lower Columbia River, and extends 123 km to the McNary dam (ibid).[9]

McNary Dam and Lake Wallula Reservoir

McNary Dam is a 56 m high concrete-gravity RoR hydropower dam spanning the Columbia River at rkm 470 (ibid). The dam flooded the Umatilla Rapids, forming a reservoir called Lake Wallula, the second-largest reservoir in the lower Columbia. The reservoir extends 103 km up the Columbia to the US Department of Energy Hanford Site. It also extends up the Snake River tributary to the Ice Harbor Dam.

Wells Dam and Lake Pateros Reservoir

Four smaller RoR dams operate on the Columbia mainstem above McNary Dam,

[8] The heat gain in a reservoir is related to the advective flow of water and energy (temperature) from upstream, plus the net gain of energy from reservoir surface solar radiation. Residence time controls the contribution of advective heat: shorter residence time means less advective warming, and less stratification (USBR 2018). Monthly average residence time of water in Grand Coulee's 243 km long Lake Roosevelt ranges from 36 days in June, to 76 days in September (ibid).

[9] In addition to providing a rearing and/or migration corridor for various salmonid species' life stages, prior to impoundment, this stretch of the Columbia supported spawning fall Chinook (*O. tschawytscha*): estimated 34,000 adults (Fulton 1970; Sheer 1999).

ranging from 40 – 56 m in height (ibid), followed by Wells Dam at rkm 830 (Figure 2). Wells Dam is the last major dam that Okanagan Sockeye Salmon must pass to reach the Okanogan River, and is situated approximately 30 km downstream of the confluence of the Columbia and Okanogan rivers (Figure 3). The isothermal reservoir, Lake Pateros, extends 47 km to the base of Chief Joseph dam at rkm 877 and directly influences the lower 24 km of Okanogan River (USBR 2018; WEST 2008).

Zosel Dam and Osoyoos Lake

Zosel Dam, located 185 km up the Okanogan River in Washington State, is a water control structure operated by the WASHINGTON DEPARTMENT OF ECOLOGY to maintain Osoyoos Lake water levels, provide flood control, and supply irrigation water, as mandated by the INTERNATIONAL JOINT COMMISSION (Hyatt et al. 2015a). Zosel Dam is equipped with four spillway gates and two pool-and-weir adult fish ladders (Johnston et al. 2007). Mean annual discharge at Zosel is 18.2 cms.

OKANAGAN SOCKEYE SALMON MIGRATION CORRIDOR

Okanagan Sockeye Salmon return to the mouth of the Columbia River in early June to commence the 986 km journey up-river to their spawning grounds. Peak migration past Bonneville Dam occurs by late June/early July (CBR-DART[9]). Travelling at 27-60 km/day in the lower river, and ~30-50 km/day in the mid-Columbia (Quinn et al. 1997; Fryer et al. 2018), Sockeye Salmon typically take two to three weeks to arrive at Wells Dam, beginning in the last week of June or the first week of July (Hyatt et al. 2003). Migration past Wells Dam generally peaks in mid-July, and continues into August. Fish may hold in the reservoir upstream of the Wells Dam (Lake Pateros, or “Wells Pool”) before migrating into the Okanogan River (Figure 3), particularly if temperatures in the Okanogan River exceed 20-21°C (Hyatt et al. 2003). Sockeye Salmon take 5-7 days to migrate up the Okanogan River from Wells Dam to Zosel Dam in Oroville, but migration may be delayed by as much as three weeks in some years by elevated water temperatures (>20°C) in the Okanogan River (ibid; Fryer et al. 2018). Flow levels may be an interacting factor. “Flashiness” and turbidity are both characteristic of the lower Okanogan River during the annual freshet due to inputs from the snowmelt-driven Similkameen River (Johnston et al. 2009).

Once past Zosel Dam, Sockeye Salmon hold in Osoyoos Lake for three weeks to three months (Hyatt et al. 2003). The primary spawning areas for Sockeye Salmon are approximately 42 km upstream of Zosel Dam, above Osoyoos Lake in the Okanagan River near the BC town of Oliver (Figure 3). Spawning occurs from late September through October. Fry emergence timing and juvenile rearing in Osoyoos Lake are detailed elsewhere (Stockwell and Hyatt 2003; Stockwell et al. 2020).

METHODS

SOCKEYE MIGRATION DATA

Fish enumeration programs in the Columbia River historically depended on visual observations at fish ladders associated with the dams. Since the 1990s, fish enumeration programs in the Columbia basin have shifted to video monitoring (Johnston et al. 2009). Estimates of the daily number of adult Sockeye Salmon migrants passing the Bonneville Dam in the lower Columbia, the Wells Dam in the mid-Columbia, and Zosel Dam in the Okanogan River, were obtained from the COLUMBIA BASIN RESEARCH DATA ACCESS IN REAL-TIME (DART) website for all available years.[10]

Estimates of daily migrants at Zosel Dam were used as the indicator of daily run-timing specific to the Okanagan Sockeye Salmon stock. Visual observer counting methods were employed for intermittent years between 1937 and 1963. Efforts to enumerate salmon at Zosel Dam with video technology began in 1991, but terminated in 1993 (Johnston et al. 2009). Video enumeration was revived in October 2005, providing daily count data for Sockeye Salmon migrants from 2006-2017. However, high water levels and/or equipment failures in 2011, 2012, 2013, and 2017 precluded date-based observations during peak migration periods. Years of comprehensive data availability for the Zosel Dam counts were limited to: 1937, 1944, 1952-1954, 1962-1963, 1992-1993, 2006-2010, 2014-2016. Data issues identified in the DART adult passage inventory are listed in Appendix F and Appendix G.

Daily Wells Dam Sockeye Salmon counts (1967-2019) were obtained as a reference for annual Sockeye Salmon migration timing up to the confluence of the Columbia and Okanogan rivers, and for comparison to Zosel Dam migrant numbers and timing.

Weekly estimates of Okanagan Sockeye Salmon migration onto the spawning grounds in the Okanagan River north of Osoyoos Lake were obtained for the years 2000-2018. Historical spawning ground survey methods are described in Stockwell and Hyatt (2003) and Stockwell et al. (2020)[11].

To standardize the annual adult migration time-series for inter-year and inter-stock comparisons (e.g. those completed for salmon returning to the Okanagan and other river systems in BC; Hyatt et al. 2015b; Stiff et al. 2013; 2015abc; 2016; 2018), daily percentages of Okanagan Sockeye Salmon migrants enumerated at Zosel Dam were calculated relative to the annual total Zosel count. Time-to-50% (TT50%) statistics were calculated as the day-of-year when the cumulative sum of daily percentages exceeded 50 percent of the annual total. Annual plots of daily migration rate (% relative to the annual total) were overlaid with historical mean and maximum daily migration rate, by Julian day-of-year, for inter-annual migration pattern comparisons.

Univariate statistical analyses were used to characterize the historical stock migration data for number of observations, location (mean, median, mode), 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 low (0-75th percentile), medium (75-90th percentile) and high (90-100th percentile) categories for daily migration rate classification. Quartiles of the Julian dates of migration in the historical data were used to categorize daily migrant data into

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[10] Columbia Basin Research DART: http://www.cbr.washington.edu/dart. Data Courtesy of U.S. Army Corps of Engineers, NWD and Chelan, Douglas, and Grant County PUDs, Yakima Klickitat Fisheries Project, Colville Tribes Fish & Wildlife (OBMEP), Oregon Department of Fish & Wildlife, Washington Department of Fish & Wildlife.

[11] The majority of spawner estimates prior to 1997 are based on an all-year calibration relationship developed to convert a limited number of visual survey area-under-the-curve (AUC) estimates of peak live plus dead adults on the spawning grounds into AUC-equivalent estimates. After 1997, all years have sufficient survey dates to calculate year-specific AUC estimates directly.

early (<25th percentile), middle (25-75th percentile), and late (>75th percentile) classes.

For key years of this time-series, annual inter-site Conversion Rates (CR, i.e. estimates of survival between sites) from recent PIT-tag[12] studies (Fryer et al. 2011; 2017; 2018) were compiled to develop further insights into seasonal Okanagan Sockeye Salmon migration success.

ENVIRONMENTAL DATA

Meteorological, hydrological, 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., U.S. GEOLOGICAL SURVEY (USGS), U.S. AGRICULTURAL WEATHER NETWORK (AWN), Columbia Basin Research (CBR-DART), ENVIRONMENT CANADA AND CLIMATE CHANGE (ECCC), WATER SURVEY OF CANADA (WSC), and 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 9.4) was used to assemble data from online source and MICROSOFT EXCEL® spreadsheets and to analyze the data. The resulting datasets were stored in a relational MICROSOFT ACCESS® FRESHWATER ENVIRONMENTAL VARIABLES DATABASE and may be available from DFO upon request.[13]

WATER TEMPERATURE

Lower Columbia River

Mean daily water temperatures were obtained from the CBR DART website[14] as recorded by dataloggers at Water Quality Monitoring (WQM) stations in the forebay of mainstem dams for available dates (generally restricted to the adult salmon migration season). DART provided daily averages calculated from hourly values between 0 and 35°C. Quality-assured (QA) data were retrieved for 1986-2019 at Bonneville, John Day (2004-2019) and McNary (1996-2019) forebays.

To identify the principal location of thermal stress in the lower Columbia River, nonparametric means tests were used to analyze for differences in mean temperature between sites during peak salmon migration months. Regression models were established to evaluate the relationship between the longer-running time-series of temperature data at Bonneville versus upstream dam sites.

Mid-Columbia River at Wells

Wells Dam forebay water temperatures were obtained from the CBR DART website. Daily mean surface water temperatures, from continuous datalogger recordings, were

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[12] Passive Integrated Transponder network implemented and maintained in association with decadal-scale studies by the Columbia River Inter-Tribal Fish Commission (CRITFC) and others.
[13] Contact Howard.Stiff@dfo-mpo.gc.ca or Kim.Hyatt@dfo-mpo.gc.ca.
[14] Columbia Basin Research DART: http://www.cbr.washington.edu/dart/.

available from 1998-2019.[15,16] DART data were supplemented with daily mean water temperatures recorded in the forebay at dam center between 1993 and 1997, supplied by the Douglas County Public Utility District (Stockwell et al. 2001). Periods of missing temperature data 3 days or less in length were estimated via linear interpolation. Tail-race measurements, which averaged <0.2°C warmer than forebay temperatures at Wells Dam, were applied where periods of missing data were 4-10 days in length, representing <5% of daily mean between 1998-2019, mostly in 2011 (25 days).

Okanogan River at Malott

Continuous water temperature data were obtained for the lower Okanogan River at Malott, WA, from the WASHINGTON STATE DEPARTMENT OF ECOLOGY[17] (July-September, 2005-2006, recording at 30-minute intervals) and the USGS NATIONAL WATER INFORMATION SYSTEM[18] (2008-2018, deployed all year, recording at 15-minute intervals). Daily mean water temperatures were summarized from the sub-hourly readings and concatenated into a single water temperature dataset.

Okanagan River at Oliver

Continuous water temperature data for the OKANAGAN RIVER AT OLIVER[19] were available for January 2004 - June 2007 and April 2008 – December 2018, but calibration problems rendered data prior to 2008 unsuitable for this analysis and were omitted (Stockwell et al. 2001).

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

Water temperature data cleanup consisted of examining descriptive statistics and graphical output to identify anomalous data and outliers, in conjunction with a review of field notes regarding datalogger installation and removal dates and times. Anomalous data, if any, were corrected, or retained in the database but flagged for omission (i.e., OMIT field = YES) from data analyses.

WATER TEMPERATURE TIME-SERIES RECONSTRUCTION

Reconstruction of a long-term freshwater temperature dataset suitable for climate analyses is contingent on a set of daily mean air temperature records spanning 2-3 decades, or more for historic trend analyses. The relatively brief year-span and

[15] Of the high resolution Wells forebay data, only the years 2013-2019 were recorded in all seasons. For 1998-2012, records were only available from April to early September, limiting the ability to model the cooling season effectively.

[16] Low resolution "scroll case" data have been removed from the DART website due to data discrepancies, and this report has been limited to official quality-assured (QA) DART data from 1998 to present, supplemented with daily mean Wells forebay temperature data for 1993-1997 (pers. comm., R. Klinge, District Fisheries Biologist, Douglas County Public Utility District No. 1).

[17] Washington State Department of Ecology River & Stream Water Quality Monitoring: http://www.ecy.wa.gov/apps/watersheds/riv/station.asp?theyear=&tab=temperature&scrolly=0&showhistoric=true&wria=49&sta=49A070#tempdatadownload. Water quality monitoring protocols are available at: https://fortress.wa.gov/ecy/publications/publications/0303052.pdf.

[18] USGS Station 12447200 Okanogan River At Malott.

[19] Environment Canada WSC Station 08NM085.

seasonally-limited coverage from QA water temperature time-series for Columbia mainstem and/or Okanogan/Okanagan locations render them inadequate in themselves for establishing baseline climatological conditions. Other studies have demonstrated, however, that variations in regional air temperature are generally sufficient to explain as much as 80% of the variation in local daily mean water temperature, at least for mid-sized streams and rivers[20] (Mohseni and Stefan 1999; Hyatt and Stockwell 2003; Pilgrim et al.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 Salmon migration periods (i.e. 10-20°C), while water temperature "extremes" (<5°C or >20°C) are more appropriately modeled nonlinearly (Mohseni et al. 1998). As extremes in temperature are of interest in this study, the nonlinear "Mohseni logistic" modelling approach was used. The resulting estimated MWT time-series spanning the period of record of meteorological observations was employed as a consistent index of site-specific water temperature conditions at the daily time-scale in lieu of the original (observed) data, and summarized to examine trends and shifts in water temperature regimes at longer time-scales (e.g., decadal).

Air Temperature

ENVIRONMENT CANADA'S METEOROLOGICAL SERVICES group maintains an archive of climate data collected at both active and inactive stations in the Okanagan watershed.[21] At Canadian climate stations, air temperature measurements are taken from self-registering, maximum and minimum thermometers that record the extremes of each parameter within a 24-hour period. Daily mean temperature, where provided, is defined as the average of the maximum and the minimum temperatures attained during the 24-hour period. These datasets undergo detailed quality-control analysis before posting to the web site.

The ENVIRONMENT AND CLIMATE CHANGE CANADA (ECCC) web site was accessed to identify potential sites of air temperature data within the area of interest for statistical relationships with water temperature data. ECCC climate stations near Oliver, BC were selected for climate data retrieval on the basis of: (i) the quantity and quality of data available; (ii) proximity to the Okanagan Sockeye Salmon spawning grounds (< 10 km) (Figure 4); and (iii) the potential to routinely update data in future from an "active" climate station. In addition, ENVIRONMENT CANADA has refined the air temperature and precipitation time-series for this station, as part of the ADJUSTED AND HOMOGENIZED CANADIAN CLIMATE DATA (AHCCD)[22] group of climatological stations across Canada. These data incorporate a number of adjustments applied to the original station data to

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[20] Parameters for site-specific nonlinear air-to-water statistical models (Mohseni et al. 1998) in the Columbia River Basin, including the mainstem are tabled in Appendix A of Mantua et al. (2010). Note that, at sites where aquatic thermal hysteresis was detected, Mantua et al. (2010) combined separate seasonal regressions into a single all-season model, utilizing the larger α, the smaller μ, and the mean of each of the two γ and two β parameters.

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

[22] ADJUSTED AND HOMOGENIZED CANADIAN CLIMATE DATA (AHCCD) – Daily AHCCD surface air temperature data are not currently freely distributable or available online but may be obtained by request to AHCCD@ec.gc.ca. See http://www.ec.gc.ca/dccha-ahccd/default.asp?lang=En&n=B1F8423A-1 for monthly AHCCD data.

address non-climatological shifts related to changes in instruments and observation conditions or procedures, thus optimizing their use for climate research (Mekis and Vincent 2011; Vincent 1998; Vincent et al. 2002; 2012).[23]

AHCCD data at Oliver only cover 1955-2018, however. Prior to that, daily temperatures were available from highly correlated ECCC stations OLIVER[24] (1938-2012) and OLIVER STP[25] (1924-1941, 1955-2012). Data gaps in the OLIVER STP time-series were in-filled based on linear statistical relations with OLIVER data to generate a continuous air temperature time-series for the region from 1924-2018.

South of the border, meteorological data associated with the lower Okanogan River were retrieved from the AWN[26] station at Malott, WA, near the confluence of the Okanogan and Columbia rivers. Air temperature data at MALOTT commenced in 1994, but QA data were only available from 2008. These data were highly correlated with OLIVER AHCCD air temperatures ($r = 0.98$; $P < .0001$; $n = 4{,}003$), from which MALOTT daily mean air temperatures were extended back to 1924 via linear statistical relations.

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 mean air temperature time-series. Hyatt et al. (2015b) found that a seven-day centered moving average air temperature (7d-CMAT) index[27] provided the best trade-off between maximizing air/water time-series correlations and minimizing the effects of multi-day averaging on predictive power at longer period lengths. Thus, 7d-CMAT indices were derived for locations in the Okanogan (based on the MALOTT 7d-CMAT) and the Okanagan (based on the OLIVER 7d-CMAT), and used for subsequent air/water temperature analyses.

Air/Water Temperature Relationships

Hyatt et al. (2015b) describe the basic methodology used to estimate missing or historical daily MWTs based on statistical relations with a regional 7-day CMAT index. 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 index. A minimum of 5 years of representative data, including sufficient observations at the upper end of the temperature range for both warming and cooling seasons, were found to be sufficient to calibrate the models. The

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

[24] Meteorological station 1125760 (49°09'57"N x 119°33'51°W; 315 m elevation).

[25] Meteorological station 1125766 (49°10'44"N x 119°32'40°W; 297 m elevation).

[26] Agricultural Weather Network (AWN), University of Washington

[27] Like other multi-day moving average temperature indices, this 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.

remaining water temperature data were used as a validation dataset to test the goodness of fit for the following air-to-water temperature relations:

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

T_w is the *estimated mean water temperature in the waterbody*;

T_a is the *7-day mean air temperature index*; and

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

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

T_w is the estimated mean water temperature in the waterbody;

T_a is the 7-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; and

β represents the air temperature at the inflection point.

The existence of hysteresis[28] in a water body, and the resulting need to use separate warming and cooling season regression models to describe air/water temperature relations at a particular site, was evaluated for both linear and logistic models. In the linear model, an additional categorical "season" effect was tested for significance (signifying different seasonal model intercepts), and as an interaction effect with air temperature, signifying potential differences in seasonal model slopes (i.e., $P < 0.05$ for the Type III model sum of squares; SAS 1987), which would suggest a hysteresis effect. 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.

Model Calibration

Logistic regression relations described above were developed using site-specific daily mean water temperatures (MWTs) for the Okanogan River (migration route) as a function of the local air temperature index (7-day centered MALOTT MAT variate), and for the Okanagan River (spawning grounds) based on the OLIVER 7d-CMAT.

Calibration data were selected based on subjective and statistical examination of annual air and water temperature time-series and correlation plots. Years with consistent and apparently unbiased datalogger readings associated with a maximum

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[28] Hysteresis is a measure of the seasonal effect of differential rates of heat exchange between air and water due to evaporative cooling during spring-to-summer warming and fall-to-winter cooling (Wetzel 1975).

range of temperature values for both warming and cooling periods[29] were preferred for characterizing the all-year air/water temperature relationship. The remaining data (if any) were used for validation of statistical relations. Source MWT datasets were partitioned as follows:

Waterbody	Calibration Years	Validation Years
Okanogan River	2010, 2013-2015, 2017-2018	2005-2009, 2011, 2012, 2016
Okanagan River	2009, 2010, 2012, 2014, 2015, 2017	2008, 2011, 2013, 2016, 2018

To determine whether seasonally-distinct regression relations were required, the air/water temperature data for each water body were checked for hysteresis. To detect hysteresis, separate functions were fitted to the air and water temperature data in each of the warming and cooling seasons and checked for statistical significance.

The warming and cooling seasons were first distinguished from each other by determining the seasonal temperature “turn-around point”.[30] The seasonal transition date was 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 plotted 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 the calibration data. If hysteresis was detected, then regression coefficients obtained from logistic models fitted to the multi-year data for each of the warming and cooling seasons separately were retained for water temperature estimation. To minimize any abrupt inter-seasonal step-effect in the predicted time-series, daily water temperature estimates for five days on each side of the turn-around-point were generated using an intermediate model parameterized with the means of the coefficients for the warming and cooling seasons.

Model Validation

Site-specific linear and nonlinear air/water regression parameter estimates were tested for statistical significance, and applied to the OLIVER and MALOTT 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 compared between model types to determine whether linear or logistic outputs best simulated observed MWTs in the waterbody. Mean absolute error (MAE)

[29] Derivation of the seasonal flux point between warming and cooling “seasons” is described below.
[30] 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, including freezing temperatures. These data were omitted from this analysis.

statistics were compared for observed vs estimated annual temperature threshold exceedance frequencies between model types to assist in determining whether linear or logistic outputs best simulated observed MWTs.

HYDROLOGY

Hydrometric data analyses were restricted to the Okanogan/Okanagan watershed.

Okanogan River

Mean daily discharge data (cfs) were obtained from the USGS National Water Information System[31] for the Okanogan River Near Malott (1966-2019)[32]. Discharge data for the Okanogan River Near Tonasket (1929-2019)[33] were retrieved in order to extend the Malott discharge dataset via statistical analysis. Discharge values were factored by 35.3 to convert data from cubic feet per second (cfs) to cubic meters per second (cms or m^3/s).

Simple least-squares regression models (linear: $Y = a + bX$; logarithmic: $Y = aX^b$; quadratic: $Y = a + bX + cX^2$; and cubic: $Y = a + bX + cX^2 + dX^3$) were derived[34] for estimating missing daily Okanogan River Near Malott discharge levels as a function of the more extensive discharge time-series for Okanogan River Near Tonasket back to 1929. Additional explanatory factors were created from the Tonasket discharge time-series lagged one and two days to account for spatial separation between sites. Model selection was based on: lowest Akaike Information Criterion (AIC), maximum adjusted correlation (r^2), the significance of the lack-of-fit component of the regression error term, and lowest root mean square error (RMSE) (SAS 1987).

Okanagan River

Mean daily discharge data (m^3/s or cms) were obtained from the web archives of the Water Survey of Canada (WSC)[35] for the active hydrological station Okanagan River at Oliver[36]. Archived discharge data were downloaded for the years 1944-2017, and supplemented with real-time discharge data at the same station for 2018. With the exception of the real-time data (preliminary), these datasets undergo detailed quality-control analysis before posting to the WSC web site.

Univariate statistical analyses were used to characterize the WSC and USGS station data including: number of observations, location (mean, median, mode), scale (range, variance, extreme values and outliers), and shape (skewness, kurtosis). Plots of the historic mean and variance of daily water level were used to characterize the flow patterns during the adult migration period (July-August). Deciles and quartiles were derived for the peak Sockeye Salmon migration months to identify low (<10th percentile), moderate (10-90th percentile) and high (90-100th percentile) flow categories. Plots of the historic mean and variance of daily discharge were used to characterize the flow patterns during the adult migration period.

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[31] USGS National Water Information System: http://waterdata.usgs.gov/WA/nwis/current/?type=flow.
[32] USGS Station 12447200 (48°16'53" x 119°42'12"); median discharge: 1,110 cfs; drainage: YY km^2.
[33] USGS Station 12445000 (48°37'57" x 119°27'38"); median discharge: 1,080 cfs; drainage: YY km^2.
[34] Omitting partial days.
[35] Water Survey of Canada: https://wateroffice.ec.gc.ca.
[36] WSC Station 08NM085 (49°6'52" N x 119°33'59" W); elevation: 281 m; drainage: 7,540 km^2.

Precipitation

Precipitation data may be 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 data from the Oliver AHCCD station 1125766 were obtained from Environment Canada.[37] The AHCCD precipitation data (1955-2017) were supplemented with unadjusted daily total precipitation data from Oliver ECCC stations 1125766 (1942-1954) and 1125760 (1924-1941, 2018). Due to the highly localized and non-normal distribution of precipitation data, missing values were not interpolated.

TREND AND EXCEEDANCE ANALYSES

Air Temperature

Monthly mean air temperatures of 20°C are considered an upper threshold for viable salmonid populations (Mote et al. 2003). For the purpose of this report, summary analyses of air temperature trends were restricted to the Okanogan/Okanagan region to review conditions associated with the final leg of adult Okanagan Sockeye Salmon migration and spawning life history stages.

Meteorological data at MALOTT were summarized by year to obtain the mean air temperature for the combined months of July-August (1924-2018) to review trends in regional air temperature during upstream migration. Temperature data were analyzed for the frequency of dates in each year and migratory month (July-August) for which mean daily air temperature exceeded the 20°C threshold value, and summarized by decade as a trend indicator. In addition, the frequency of annual periods in which water temperature continuously exceeded this value, and the mean duration (days) of these periods, were derived for each year, and summarized by decade to review trends in the frequency and duration of continuous periods of potentially stressful temperature conditions.

Historic air temperature data at OLIVER were also summarized by year (1924-2018) across fall months (Oct-Nov) to review trends in regional air temperature during the spawning period.

Mainstem Water Temperature

Observed daily mean temperature data at Bonneville Dam were summarized by year to determine mean values during peak adult Sockeye Salmon migration (June-July), and plotted to review the 30-year time trend in mainstem temperature conditions in the lower Columbia. A threshold exceedance analysis, tallying the decadal mean monthly frequency of dates for which observed daily temperatures exceeded 20°C ($POT_{20°C}$; i.e., peak-over-threshold > 20°C), was used to examine site-specific trends in water temperature conditions during peak adult migration (June) in the lower Columbia (at B).

A similar analysis was utilized to examine trends upstream, in the generally cooler

[37] ADJUSTED AND HOMOGENIZED CANADIAN CLIMATE DATA (AHCCD) – Daily AHCCD precipitation data are not currently freely distributable or available online but may be obtained by request to AHCCD@ec.gc.ca. See the ENVIRONMENT CANADA website for monthly AHCCD values.

Wells Dam forebay (Lake Pateros), where Sockeye Salmon hold if necessary, before migrating up the Okanogan River (Hyatt et al. 2003). This was based on a lower peak-over-threshold of 18°C, to reduce zero-frequency

Okanogan River Water Temperature

Reconstructed daily mean water temperature data for MALOTT, WA, were summarized by year (1924-2018) to determine mean values during peak migration through the Okanogan River (July-August). A threshold exceedance analysis, tallying the decadal mean monthly frequency of dates for which the reconstructed MWT temperature index exceeded 20°C, was used to examine trends in stressful water temperature conditions during peak adult migration.

The frequency of annual periods in which (estimated) daily mean water temperature continuously exceeded the threshold, 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, by site.

A paired t-test was used to compare the annual frequency of $POT_{20°C}$ dates derived from observed versus estimated mean daily water temperature to assess bias in the POT indicator. The t-test was applied separately for calibration years and validation years.

Okanagan River Water Temperature

A similar trend and exceedance analysis, based on a threshold of 12°C, was utilized to examine changing conditions in the Okanagan River when Sockeye Salmon move onto the spawning grounds in the autumn (October-November).

River Level / Discharge

For discharge, exceedance analyses for 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 estimated discharge in the lower Okanogan (at MALOTT) was either less than the lower 10^{th} percentile, or greater than the upper 90^{th} percentile of summer readings, was calculated by year and month (for July-August), and summarized by decade. A similar analysis was performed for the Okanagan River (September – November) to examine trends in extreme flows on the spawning grounds. From these data, the frequency of annual periods in which flow levels continuously remained below/above the lower/upper thresholds, and the mean duration (days) of these periods, was derived for each year, and summarized by decade to review trends in the frequency and duration of continuous periods of potential flow barriers to upstream migration.

MIGRATION, TEMPERATURE AND DISCHARGE

Reconstructed daily mean Okanogan River water temperature and discharge estimates at Malott were combined with daily Sockeye Salmon migration rate data at Zosel to test the null hypothesis that daily migration rates were not influenced by changes in river temperature and discharge. For categorical analyses, the continuous variates were categorized according to thresholds based on percentiles (i.e., for migration and discharge) or assumed upper limits (e.g. 21°C) known to be stressful to

Sockeye Salmon (Nelitz et al. 2007; Salinger and Anderson 2006).

The 50th percentile (median) migration rate was used as the threshold to define whether a daily migration rate was "negligible" (i.e., negative anomaly) or "significant" (i.e. positive anomaly), and the 75th percentile of migration rates was used to define whether a positive migration rate was "moderate" (between 50th - 75th percentile) or "high" (>= 75th percentile).

Okanagan Sockeye Salmon travel approximately 40-50 km/day in the Columbia mainstem between Bonneville and Wells dams, but travel times are quite variable for the 185-km Okanogan leg of the journey due to migration delays (Hyatt et al. 2003; Fryer et al. 2018). Minimum travel times from Wells to Zosel were determined via PIT-tag analysis to be as low as 2 days (2016) to 3.6 days (2017) (median 5 days; Table 16 in Fryer et al. 2018), but 6.5 days in 2015 (median 28 days) when temperatures were elevated to record levels (Table 13 in Fryer et al. 2017). Assuming that a "decision point" for upstream migration likely exists for Sockeye Salmon at the confluence of the Okanogan and the Columbia (contributing to the run timing pattern at Zosel), daily counts at Zosel were incrementally lagged backwards 3-7 days to simulate migration timing at the confluence 185 km downstream (Hyatt et al. 2003). To align lagged migration rate data with environmental conditions measured at Malott (31 km upstream of the confluence), water temperature and discharge were lagged forward one day to account for downstream flow time.

The date-lagged environmental variates and categorical classifications were merged with the migration data to test the null hypothesis that downstream conditions in the previous few days, at the Okanogan/Columbia confluence, were not associated with variations in adult migration patterns at Zosel Dam. Non-parametric test statistics of association derived from frequency analyses of the categorical contingency tables were used to indicate to what degree differences in daily migration rate (high versus low level) were associated with variable water temperature and discharge categories, based on the Cochran-Mantel-Haenszel test statistic of General Association (CMH-GA), which provides a stratified statistical analysis of the relationship between migration and temperature variables after controlling for the strata variable (discharge level) in a multi-way table (SAS 1987).[38]

The CMH-GA analysis was repeated at integer temperature thresholds (20 - 24°C) and flow increments (20, 40, 60…200 cms), for each migration time-lag (1 - 6 days) to identify – via maximum GA test statistic – the combination of migration date lags and threshold levels for each environmental variable that generated the most significant associations with categorical changes in migration rate contributing to historic Sockeye Salmon count variation at Zosel Dam.

To then characterize the temperature and discharge conditions during active migration, the frequency distributions of observed migration dates (i.e., lagged and filtered for non-zero migration rates) were generated for the varying levels of (rounded) temperature, discharge, and temperature x discharge combinations. A basic frequency distribution, tallying the number of dates of non-zero migratory activity, indicated the

[38] 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).

general distribution of temperature and flow conditions that occurred during the migratory period.

Similar frequency distributions of active migration dates, *weighted by the daily migration rate*, were generated to indicate *how much* migration occurred at a given temperature, discharge, or temperature x discharge combination. In contrast to the simple distribution of dates of non-zero migration, these latter plots indicated which water temperature and flow conditions were associated with the highest migration rates (i.e., presumably most favourable to salmon migration), and, by extension, the thermal and hydrological limits (if any) that differentiate high versus low rates of migration.

Some data were omitted from the frequency analyses. Years where total annual escapement was less than 1,000 fish (i.e., 1944, 1954) were omitted since calculations based on few fish resulted in estimates of daily percentages biased high. In addition, a minimum of two date observations at each water temperature x discharge combination were required for bi-variate frequency plots.

Environmental thresholds derived from the above analyses were used to define values for calculation of daily deviations in the modeled water temperature and discharge time-series. These were combined with deviations in daily Sockeye Salmon migration rate (from the median 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

SOCKEYE SALMON MIGRATION DATA

An annual average of ~70,000 Sockeye Salmon were counted at the Wells Dam over the past 54 years (1967-2019), ranging from a low of 1,600 in 1994 to a high of 490,000 in 2014 (Table 2, Figure 5). Daily migrant counts at Wells typically extended from June-September, with peak migration occurring in July and August (time-to-50% ~ July 20th) (Figure 6). Daily counts exceeding 10,000 fish per day accompanied large Sockeye Salmon returns in 2008-2010, 2012, 2014, 2015 and 2018.

Sockeye Salmon appearing on the terminal spawning areas of the Okanagan River accounted for an annual average of 67% of adjusted Wells Dam counts between 1961 and 2018 (Table 3)[39]. Since 1998, this value has averaged 58% (range: 34-96%), not including the extreme hot year of 2015, when the number of migrants reaching the

[39] These values account for US and CDN harvest above Wells Dam. Prior to 2008, total annual harvests in the Okanagan River and Osoyoos Lake were small (<1,000 fish), and could be ignored. Since 2008, total catch has averaged >40,000 fish. While the values for US catch above Wells are all based on routine annual assessments, Canadian harvest estimates above Wells for years prior to 2008 are assumed to be a rough constant (200-500 fish). A portion of catches above Wells have been added to AUC-based escapement estimates or subtracted from the Wells counts to maintain consistency in identifying adult Sockeye that successfully reached the terminal spawning area in Canada as a proportion of the numbers that would have migrated through the lower Okanogan River. Okanagan spawner estimates may exceed Wells counts in some years (e.g. 1971, 1994) due to ambiguities associated with a wide variety of enumeration and survey methods between years, as well as the AUC calibration methods applied to low-frequency spawner counts pre-1997 (Stockwell and Hyatt 2003).

terminal spawning areas was reduced to 8.5% of Wells counts. The five lowest survival rates in the time-series for this segment of the migration route all occurred since 2013. Excluding 2015, survival averaged 37% (range: 34 – 43%) during 2013, 2014, 2017 and 2018 (Table 3).

Though peak daily migration rates at Zosel Dam typically ranged from 10-25% of the run (and maximum daily counts surpassed 30,000 fish for several days in 2010, 2014, and 2016), median daily rates were generally low (<3% of annual counts) with an all-year median daily migration rate of 0.4% (Table 4), indicating a stock characterized by an extended and variable run-timing period. Previous work indicated that Okanagan Sockeye Salmon adult passage at Zosel Dam commonly exhibited temperature mediated migration start, stop and restart patterns (Hyatt et al. 2003). In the current report, excluding years for which peak migrant counts were not available (2011-2013, 2017)[40], and limiting observations to the peak migration period (last week of June to first week of September), non-zero migrant counts at Zosel Dam averaged approximately 1,400 fish per day for the 17 years of available daily run-timing data since 1937. The corresponding all-year mean daily migration rate was 2.1% of total annual migrants at Zosel Dam. The all-year median daily migration rate of 0.4% (50th percentile) was defined as the threshold for “negligible” versus “significant” migration, and the 75th percentile of 2.9% was defined as the threshold for “low” versus “high” migration.

Annual time-to-50% (TT50%) at Zosel ranged from mid-July to mid-August; late timing was often associated with low run sizes (e.g. 2015), while strong runs (e.g. 2010, 2014, 2016) contributed more counts in late June and early July. The all-year mean TT50%, unweighted by run size, was day 214 (August 2nd; Figure 7).

After holding in the north basin of Osoyoos Lake for 2-6 weeks, Sockeye Salmon movement onto the spawning grounds (Okanagan River; Figure 3) typically commenced in mid-to-late September, with peak migration occurring the third week of October (TT50% ~ October 14th) (Figure 8). Annual survey data (2000-2018), summarized weekly (Table 5), indicated relatively little deviation from the all-year average run-timing pattern (Appendix B), suggesting a comparatively uniform timing of fish movement out of Osoyoos Lake into the Okanagan River across years. Of the years of overlapping migrant data (2006-2010, 2014-2017), late timing at Zosel in 2007 and 2017 and early timing in 2008, 2014, and 2016 were not reflected in spawning ground migration timing, while late timing in 2009 and early timing in 2010 at Zosel may have influenced timing of spawning ground arrivals (*cf.* Appendix A – Zosel migrant counts and Appendix B – Okanagan River peak spawner counts). Annual differences in timing of recruitment to the spawning grounds are likely under some degree of environmental control as Stockwell et al. (2020) observed that peak abundance and adult spawning within the majority of years tended to occur in close association with the interval during which the Okanagan River reached 12°C. However, the lack of direct observations of daily abundance of adult Sockeye Salmon in terminal spawning areas precluded any useful covariation analysis with Okanagan River conditions in the current report.

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[40] Due to high discharge levels and/or equipment failure.

EXPLOITATION IMPACTS ON SOCKEYE SALMON MIGRATION DATA

In theory, exploitation by fisheries could potentially influence apparent run time distributions of adult Sockeye in portions of either the mainstem of the Columbia River or alternatively in the Okanagan River via selective removal of salmon run timing segments. However, in practice, harvest levels over most of the period of record dealt with here have been low to moderate. Hyatt and Rankin (1999) provided information on locations and magnitude of harvest for years prior to the early 1990s, and Hyatt and Stockwell (2019) provided similar information from that point to 2016.

In brief, an average of just 7.8% (range <1% to 49%) of all adult Sockeye Salmon returning to the Columbia River were taken as catch in various fisheries from 1961-2018. Furthermore, exploitation rates exceeded 20% in just 7 years between 1961 and 2018 (i.e. 1961, 1967, 1971, 1972, 1985, 1987 and 1988). The most notable observation regarding trends in Okanagan Sockeye Salmon catch is that, prior to 2009, the average annual catch of this stock was around 10,000 fish (range 206 - 61,000) but from 2009 to 2018 average annual catch increased to 69,000 fish (range 9,245 – 159,488). Increases in total returns of Okanagan Sockeye Salmon in the most recent decade have been accompanied by not only increases in average catch, but also in the number of local areas that are now focal points for subsistence, recreational and commercial fisheries. In particular, prior to 2009, on average only 3.1% (range 0%-17%) of Okanagan Sockeye Salmon counted at Wells Dam were subsequently harvested further upstream (i.e. in Lake Pateros, the Okanagan River and Osoyoos Lake).

By contrast, from 2009-2018, an average of 19.2% of Sockeye Salmon counted at Wells Dam were subsequently harvested in tribal, First Nations, recreational and commercial economic opportunity fisheries (Hyatt and Stockwell, DFO, Nanaimo, unpublished observations). Despite these changes, and given the low to moderate harvest rates, annual to seasonal variations in environmental conditions are more likely than harvest events to be the source of the majority of seasonal timing and abundance variations that are the subjects of the current report.

ENVIRONMENTAL FACTORS AFFECTING MIGRATION

WATER TEMPERATURE DATA

Lower Columbia River

Summer water temperatures in the Columbia mainstem are generally warmest in the lower river, in association with the reservoirs at Bonneville, John Day, and McNary dams (Figure 21). Kruskal-Wallis, non-parametric, chi-square analysis of mean water temperatures indicated no significant difference between dams for the combined months of peak Sockeye Salmon migration past these dams (June/July: $P = 0.31$; Table 9). However, analysis by month revealed that the relative temperatures between sites change over the season (Figure 22). In June, temperatures are warmest at Bonneville (16.3°C) and coolest at McNary (15.6°C) relative to the overall June mean of 16.0°C ($P = 0.04$), but warmest at John Day in July and subsequent months (significantly, as of August; $P = 0.01$) as lower Columbia River temperatures reach 19 - 21°C. This may indicate that a low level of horizontal and/or vertical stratification occurs in the reservoir associated with John Day Dam by virtue of its large size.

Coefficients from robust regression between Bonneville and the upstream dams indicated real differences (i.e., intercepts a ≠ 0 and slopes b ≠ 1), thus mean daily temperature conversion functions for June/July are included here:

John Day Dam Forebay = 1.0377 * Bonneville Forebay – 0.7432 (r^2 = 0.85)

McNary Dam Forebay = 1.0336 * Bonneville Forebay – 1.0354 (r^2 = 0.82)

As water temperature time-series between dam sites were highly correlated, the longer time-series at Bonneville (1986-2019; Figure 23) was utilized to characterize historic trends in the lower Columbia River. Observed daily mean water temperatures during adult Sockeye Salmon migration (June/July) averaged 18.1 ± 2.3°C (Table 10). In 1999, 2008, 2010-2012, temperatures during June and July were cooler than the multi-year average, whereas anomalously warm conditions during migration occurred in June/July 2015, when mean temperatures at Bonneville approached or exceeded 21°C (Figure 24). No linear trend was detected in mean June/July water temperatures at this site since 1986, but evident oscillations between above-average temperatures (early 1990s, mid-2000s, late 2010s) and below-average conditions (late 1990s, early 2010s) correlate with phase changes in the Pacific Decadal Oscillation (PDO).

Exceedance analyses (peak-over-threshold of 20°C; $POT_{20°C}$), based on the longer time-series at Bonneville, indicated that virtually none of June, but 50% of July and nearly 100% of August were characterized by mean temperatures >20°C since 2000 (Table 11)[41]. On average, $POT_{20°C}$ events have lasted 38-40 days since the year 2000 (Figure 25). In 2015, mean daily water temperatures exceeded 20°C continuously for 71 days, beginning in June (Table 12). Anomalously wet years (1999, 2011 and 2012), however, displayed no $POT_{20°C}$ dates in July.

Focusing on the period of peak Sockeye Salmon migration in the lower Columbia (June-July), the frequency and duration of $POT_{20°C}$ events are trending upwards, with increased variability in the annual frequency and duration statistics (Figure 26). Once water temperature in the lower Columbia surpasses 20°C, it generally remains there until fall. In recent decades (since 2000), the median $POT_{20°C}$ frequency and duration of 13-15 days indicates that, of the ~60 days of Sockeye Salmon migration through the lower Columbia in June and July, 25% of the time, mean temperatures exceed 20°C, most likely for the last 2 weeks of July. While few Sockeye Salmon are transiting the zone in August – when all dates generally exceed 20°C – other salmonid species (e.g. fall Chinook and Steelhead) may be impacted.

Wells Dam Forebay

The annual time-series of observed water temperature data obtained at Wells Dam indicates that maximum water temperatures historically[42] occurred in late August and early September (MWT > 19°C; Figure 27), after the majority of Okanagan Sockeye Salmon migrants have passed. Average water temperature, summarized for the

[41] Only four years of Bonneville temperature data were available in the 1990s; $POT_{20°C}$ frequencies for those years (1996-1999) represented about 33% of the month of July.

[42] Unlike mid-sized streams and rivers for which statistical relations with air temperature allow water temperature time-series to be estimated and extended, water temperature in major dam reservoirs are more difficult to model statistically, thus POT analyses for Columbia River dam forebays are based on observed water temperature data only (Wells Dam: 1993-2019; Bonneville Dam: 1996-2019).

months of peak migration (July-August), was 17.5 ± 1.5°C, with <5% of dates surpassing 19.6°C (Table 13). An apparent linear warming trend of <0.01°C per year since 1993 was not found to be statistically significant based on non-parametric (Mann-Kendall test statistic: MK = 1.5, P > 0.10; Spearman rho: z = 1.8, P > 0.05, n = 27 years), however a positive step-change may be evident after 2012 (Figure 28).[43,44] Warmest conditions during this period were found in 2015, followed by 1998, 2003, 2004, 2006, and 2013, each characterized by mean July-August water temperatures >18°C, and 50% of dates >19°C. Coolest years included 2011, 2001, 2012, 1996, 1997, and 1999, in order of coolest to warmest.

An exceedance analysis based on an 18°C threshold for Wells Dam forebay surface water temperatures during peak migration months reflected the weak positive trend over recent decades. Peak-over-threshold ($POT_{18°C}$) events (number of dates) have with marginal increases in the decadal average frequency and duration since the 1990s, notably in August and September (Table 27, Figure 29 (top)). The weighted mean duration of $POT_{18°C}$ periods rose from about 17 days per year in the 1990s to over 30 days per year in the 2010s, while the mean decadal frequency of such periods remained about the same, which suggests that the relatively low frequency (<2 per year) of warm spells are lasting longer (Table 28, Figure 29 (bottom)).

When limited to the months of peak Sockeye Salmon migration (July-August), the annual frequency of $POT_{18°C}$ events ranged from 3-45 dates per year, with a median of ~30 days over the last two decades (Figure 30, left), i.e. roughly 50% of the two-month period. Low frequency years occurred in 2001, 2011, and 2012 (3, 10 and 8 days, respectively). High frequency years, when warm spells persisted for more than 50% of the July-August period, occurred in 1998, 2003-2007 and 2013-2019 (Table 27), suggesting a warming trend. While no trend is evident in the observed duration of these events (Figure 30, right), this indicator is sensitive to the occurrence of single dates or short periods where estimated temperatures might briefly fall below the threshold.

US Portion of the Okanogan River

Eleven complete years of continuous data logger records were available for 2008-2018 for the lower Okanogan River (Figure 31). Water temperatures and flows (at MALOTT: MAD 86.1 cms) were influenced by annual freshets from the Similkameen River (MAD: 64.6 cms), which lacks a buffering headwater lake and is thus hydrologically controlled by the quantity and timing of annual snow-melt (Hatch 2009). Years of high snow-pack, and prolonged runoff causing above average discharge of the Similkameen in late spring / early summer can induce a marked delay in Okanogan River warming, typically until early July, or, in the case of 2011[45], early August (Figure 32). By contrast, years of low snowpack or early snow-melt can deprive the Okanogan of cold Similkameen inputs in June/July, most notably 2015 – 2018, and 2006 (Figure 33).

Peak water temperatures generally arrive by early-to-mid August, coincident with the

[43] Note that a statistically-significant warming trend is also evident at Bonneville when that time-series is limited to 1994-2019, but no overall trend is evident for the period 1986-2019 (Figure 24).
[44] Quinn et al. (1994) noted a warming trend in the lower, but not mid-Columbia, up to about 1994.
[45] No migration data were available at Zosel in 2011, 2012, 2013, or 2017 due to high water levels.

peak Sockeye Salmon migration period. The daily average of observed Okanogan water temperatures in July and August for complete years (2008-2018) was 22.0 ± 2.4°C. For 75% of July-August dates, the daily mean temperature exceeded 20°C; 50% of dates exceeded 22°C, and 5% exceeded 25°C (Table 16).

Canadian Portion of the Okanagan River

Observations in the Okanagan River (MAD: 18.2 cms) indicated that summer conditions were very similar, at least in terms of peak temperatures, to the lower Okanogan for the eleven years of available data-logger records (2008-2018; Figure 34). Mean July-August water temperatures were equivalent: 22 ± 1.5°C, with maximums near 25°C (95th percentile: 24.3°C; Table 17, top).

The thermograph of the Okanagan (Figure 35, Figure 36), however, contrasts distinctly from the lower Okanogan River (Figure 32, Figure 33) where early summer water temperatures are frequently buffered by the inflow of cool meltwaters from the Similkameen. As the Okanagan receives water from a series of large lakes, regulated by Penticton, Okanagan Falls, and McIntyre Dams upstream (Hyatt et al. 2009), the water temperature signature during extreme years (cool, wet: 2011 and 2012; warm: 2014 – 2016) is largely muted (Figure 36).

Fortunately for adult Sockeye Salmon, by the time the fish move into the Okanagan River to spawn (October-November), mean temperatures have dropped to near-optimum levels in the 9-10°C range, with 75% of dates below 12°C (Table 17, bottom).

Okanagan Temperature Time-Series Reconstruction

Air Temperature

Adjusted and homogenized climate data at Oliver, B.C. (ECCC Station 1125760, 1955-2012) served as the basis for a standard regional air temperature time-series for correlation with Okanagan River water temperature data. Linear relations between OLIVER 1125760 and OLIVER STP 1125766 data (Figure 16) were used to extend the "OLIVER STANDARD" time-series back to 1924. Summer air temperatures (July-August) averaged 22-23°C, and exhibited a linear trend of approximately +0.1°C per decade since the 1920s ($P < 0.001$; $n = 95$ years; Figure 17). Non-parametric trend analyses support a rising trend in summer air temperatures (MK = 1.8, $P < 0.1$; Spearman's rho = 2.0, P M 0.05), and a step-change in the 1990s. Autumn air temperatures (Oct-Nov), when Sockeye Salmon migrants utilize Okanagan River, are cooler, averaging 6-7°C, and similarly trending (Figure 18).

For the lower Okanogan River region, meteorological data assembled from the MALOTT AWN station (2008-2018) correlated with observed OLIVER air temperature data (Figure 19). The resulting linear relationship was used to extend the MALOTT time-series back to 1924, and reflected a similar positive trend over the decades ($P < 0.001$; Figure 20).

Seasonal Turn-Around Point

The mid-year, seasonal, turn-around point for both Okanogan and Okanagan reference sites was in week 30 – approximately day 210, or July 30th – based on maximum mean weekly air and water temperatures (Figure 37). The "warming season" therefore extended from April 1 to July 30th, followed by the "cooling season" from day 211-329, i.e., July 31st – November 25th.

Multi-Day Air Temperature Index

The multi-day MALOTT AWN and OLIVER STP air temperature indices that best correlated with Okanogan (Figure 38) and Okanagan River (Figure 39) daily mean water temperatures were identified as the 7-day centered moving average (7d-CMAT). The 7d-CMATs provided the best trade-off between maximizing correlation and minimizing the effects of multi-day averaging on predictive power at longer period lengths, relative to the 3d-, 5d-, 10d-, and simple daily MAT air temperature indices.

Model Calibration and Validation

Logistic and linear air/water temperature models were parameterized using a subset of the available data for calibration, and tested for goodness-of-fit against the remaining years for model validation. Calibration and validation data years, and the number of observations available for analyses by season, are identified for the Okanogan watershed reference site at MALOTT and Okanagan River site at OLIVER in Table 18.

The nonlinear parameter estimation procedure could not converge on a logistic model for the calibration years for all seasons combined at Malott. Convergence was obtained for warming and cooling season components, however, and hysteresis was detected at both sites for logistic relationships, indicating that the site-specific air/water temperature relationships were best modeled using separate seasonal models for the Okanogan (Figure 40) and Okanagan (Figure 41) locations. Seasonal model parameters, 95% confidence limits, and NSC goodness-of-fit coefficients are listed in Table 19 (Okanogan) and Table 21 (Okanagan).

Paired t-tests for annual frequencies of POT_{20} dates for observed (O) versus logistic model estimates (E) of daily mean water temperature in the lower Okanogan showed no overall significant differences for calibration years (O-E% = +3%; n = 7 years) or validation years (O-E% = +10%; n = 6 years). However, logistic model estimates tended to underestimate actual POT_{20} dates in 5 of 6 validation years at this site (Table 20). These results indicate that the estimated frequency and duration of events where temperatures exceed the 20°C threshold are generally conservative.

Linear regression model output for Okanagan (Figure 42) and Okanogan (Figure 43) seasonal air/water temperature relationships and calibration data are provided in Table 22 and Table 23. Type III sum of squares for a season effect and a season/air temperature interaction effect are highly significant, indicating again, an effect due to hysteresis and that seasonal models provide the best fit to the Okanogan data.

Predictive estimates of daily mean water temperature were generated for each model type and season for the extent of the air temperature record. Correlation analyses between observed and predicted daily MWT values for the validation years were used to compare the predictive skill of logistic versus linear models. Season-specific Pearson (least squares) and Spearman (rank) correlation coefficients for the validation data are contrasted in Table 24.

Paired t-tests for annual frequencies of POT_{20} dates for observed (O) versus linearly modelled estimates (E) of daily mean water temperature in the lower Okanogan showed a statistically-significant difference across six validation years (O-E% = +21%, $P < 0.04$; Table 25). These results suggest that the nonlinear model has a predictive advantage over the linear model at upper temperature levels. Thus, the seasonal logistic model parameters were selected as the best estimators of daily mean water temperature at each site, and were used to reconstruct historical daily water temperature estimates for the period of available air temperature data. A subset of the validation data years with observed and modeled MWT output, along with daily MAT and the 7-d MAT index, are plotted in Figure 44 (Okanogan) and Figure 45 (Okanagan).

DISCHARGE DATA

Okanogan River

Observed daily mean discharge data were summarized for the OKANOGAN RIVER AT MALOTT (Table 6) and TONASKET (Table 7) for peak adult migration months (July-August). The hydrographs for the MALOTT (Figure 9 - Figure 10) and TONASKET sites (Figure 11 - Figure 12) are highly similar. Though extremely variable in the spring and early summer, the annual time-series typically display a steady drop in mean daily discharge during peak Sockeye Salmon migration from a high of about 300 cms in June, to less than 100 cms by early August. Median flow rate for the July-August months in the lower Okanogan (MALOTT) was 53 cms, with extreme flow thresholds of ~20 cms (10th percentile) and ~170 cms (90th percentile) (Table 6). Extreme high flow years (>95th percentile) include: 1972, 1974, 1976, 1982, 1990, 1991, 1996, 1997, 1999, 2011, 2012, 2013.[46] Extreme low flow years (<5th percentile): 1970, 1973, 1977, 1979, 1985, 1987, 1988, 1992, 1994, 2001, 2003, 2006, 2015 (Appendix D).[47]

A simple linear regression based on unlagged Okanogan (TONASKET) discharge explained 99.5% of variation at Okanogan (MALOTT) flow levels (Figure 13), enabling an extension of the discharge time-series in the lower Okanogan back to 1929.

Okanagan River

Discharge levels in the Okanagan River above Osoyoos Lake, near Oliver, BC, typically ranged from 5-25 cms during the spawn migration period (September – November, 1944-2019) (Figure 14 - Figure 15; Table 8). Extreme high flow years include: 1948, 1976, 1982, 1990, 1993, 1997. Extreme low flow years include: 1944, 1963, 1967, 1970, 1973, 1977, 1987, 1988, 2001, 2003, 2009, 2015 (Appendix E).

TRENDS IN ENVIRONMENTAL VARIABLES

Since a long-term warming trend in the MALOTT/OLIVER air temperature index for the summer months (July-August) was apparent over the period of record (1924-2018) (Figure 20), a warming trend in estimated Okanogan/Okanagan River mean water temperature was unsurprising (Figure 46). Mean summer temperatures were generally higher than the trend line for much of the 1920s - 1940s, early 1960s, and most years since the mid-1990s, consistent with cyclic patterns of the Pacific Decadal Oscillation (Hyatt et al. 2003, Mantua et al. 2010).

These conditions were reflected in trends in Okanogan discharge, with warm periods

[46] Include 1933, 1943, 1950, 1953, 1959, and 1964 as extreme high flows, based on 95th percentile of Tonasket discharge observations.
[47] Include 1929, 1931, and 1944 as extreme low flows, based on 5th percentile of Tonasket discharge observations.

corresponding to lower mean summer flows, and cool periods (early 1950s, early 1970s, 1997, 1999, 2011, 2012) corresponding to high summer flows. The weak positive trend over the decades was not statistically significant (Figure 48).

Fall temperatures in the Okanagan River also indicated a slight warming trend since 1924, though mean October-November temperatures of ~10°C have remained within the optimum temperature levels for spawning activity (Figure 47). A general decline in fall flow levels was evident since the 1950s (MK = -2.4, $P < 0.05$, n=67 years; Figure 49).

TEMPERATURE EXCEEDANCE ANALYSES

Okanogan River

Peak-over-threshold analysis ($POT_{>20°C}$) of July-August air temperatures at MALOTT reflected the phased warming trend in regional summer temperatures (Figure 20) since the 1920s (Figure 56). Though the frequency of warm dates (>20°C) in several earlier decades (e.g., 1920s) rivalled the 1990s, the recent warming trend since the 1980s is unmatched in this century. On average, ~80% of the days in July and August exceeded 20°C in the most recent decade, and the average duration of continuous $POT_{>20°C}$ periods has nearly doubled for regional air temperatures, from a long-term average of ~5-7 days to the 1980s, to ~10 days in the 2010s (Figure 57, Table 29).

Water temperatures in the lower Okanogan have followed suit. Estimated water temperatures indicated that nearly 80% of July-August dates may have exceeded 20°C, on average, in the last two decades (46-50 of 62 days; Figure 58, Table 30). The average duration of $POT_{>20°C}$ events in the past decade was ~25 days (Figure 59)[48], 10 days longer than the long-term average of ~15 days. The median length of warm water events (~10 days) doubled in the 2010s relative to previous decades (Figure 60). Specific years in which estimated Okanogan water temperatures were >20°C for >80% of July and August included: 1940, 1970, 1998, 2003, 2004, 2006, 2007, 2009, 2013, 2014, 2015, and 2017 – occurring mainly in the last two decades. “Hot-spell” years in which estimated water temperatures exceeding 20°C persisted for six weeks or more without a break occurred in 1927, 1931, 1936, 1956, 1958, 1960, 1971, 1979, 1994, 1998, 2003, and 2017 (Table 30).

Okanagan River

Further north, in the Okanagan River watershed, average water temperatures on the spawning grounds (near Oliver, BC) at the time of adult Sockeye Salmon arrival in October and November were ~10°C. The long-term decadal average frequency of dates exceeding the optimum spawning temperature of 12°C was 12 dates, occurring almost exclusively in October (Figure 61, Table 31). The decadal average was slightly elevated to ~14 days in the past two decades, with some dates occurring in November in recent years (2012, 2014, 2016).

While the long-term average length of fall warm spells approximated one week (Figure 62), in some years warm spells persisted for 3 or 4 weeks (1936, 1937, 1940, 1944, 1963, 2014 and 2015) (Table 32), potentially impacting spawning behaviour or timing.

[48] This includes $POT_{>20°C}$ periods that began in August but extended into September.

DISCHARGE EXCEEDANCE ANALYSES

Okanogan River

Depending on the timing of spring melt, adult Sockeye Salmon migrants ascending the Okanogan River may be exposed to high discharge extremes in July, low discharge extremes during August, or (rarely) both.

As indicated in Figure 54, limited Sockeye Salmon migration above 160-170 cms might flag the upper discharge threshold for high Okanagan Sockeye Salmon migration rates in the lower Okanogan River. A $POT_{>160\ cms}$ analysis indicated high frequencies (11-12 dates per year) of flows above the 90th percentile in the 1950s, 1970s, and 1990s, almost exclusively in July (Figure 65, Table 33 (top)). During the 2000s, the frequency averaged <2 dates per year. For other decades, the frequency averaged ~4-5 dates per year.

Years in which the duration of high July flows in the Okanogan continuously exceeded 160 cms for more than two weeks include 1933, 1954, 1955, 1964, 1972, 1974, 1976, 1982, 1990, 1999, 2011 and 2012 (Table 35). This elevated the decadal mean duration of high flow events for the 1930s, 1950s, 1970s and 2010s decades (Figure 66).

The frequency of low flows (below the 10th percentile, i.e., $POT_{<20\ cms}$) during peak adult migration were at lowest levels in the 1950s (< 2 dates per year), from a prior annual average frequency of ~10 days per year, then peaked again in the 1970s and again in the 2000s at 12-14 days per year, principally in August (Figure 63, Table 33 (bottom)). While the average length of low-flow periods over the decades since 1930 was 13.5 days (Figure 64), extended low-flow periods, persisting for more than 30 days, occurred in 1931, 1940, 1970, 1973, 1977, 1985, 1988, 2003, and 2015 (Table 34).

Okanagan River

The annual frequency of observed “low flow” dates (<10th percentile, i.e., POT<6 cms) in the Okanagan River during the spawning period (September-November) was variable over the decades, ranging from zero dates in the 1930s and 1950s, to ~4 dates in the 2000s, to 14-16 dates in the 1960s and 1970s (Figure 67, Table 36). Since the 1990s, these low flow dates have fallen primarily in November and are due in part to improvements in adherence to a Canada-BC water regulation agreement to satisfy both agricultural and fish production objectives (Hyatt et al. 2015). In decades prior to the 1990s, low flow dates were more common in September and/or October. The average duration of low flow periods was ~13 days over the decades (Figure 68), but reached four weeks or more in 1944, 1966, 1967, 1970, 1973, 1988, 2003, and 2006 (Table 37).

In keeping with an apparent downward trend in autumn discharge levels (Figure 49), the average frequency and duration of autumn “high flow” dates (> 90th percentile of September-November flows, i.e., >23 cms) in the Okanagan River has been variable, but falling, with an overall average duration of ~17 days (Figure 69, Figure 70). Maximum durations occurred during heavy fall precipitation events in 1946 (65 days), 1948 (91 days), and 1997 (51 days), but extreme high flow events were almost non-existent in the drought years of the 1930s and low snow-pack years in the 1960s (Table 38, Table 39).

MIGRATION IN RELATION TO TEMPERATURE AND DISCHARGE

When daily migration rate data were aligned with conditions in the lower Okanogan River, tests of association indicated maximum categorical differences in daily migration rate lagged backwards 3-4 days in conjunction with 1-day forward lags for temperature and discharge based on temperature thresholds of 21°C across the full range of discharge levels (20 – 220 cms). Maximum CMH-GA statistic values (>15.0, P << 0.0001) corresponded to low (20 cms) and high (110-220 cms) discharge levels using a 4-day migration data lag (Appendix K). Moderate flow thresholds between 60-90 cms demonstrated less association with differences in migration rate (CMH-GA statistic <10.0, P < 0.01). Lags of 2 or 5 days also yielded lower CMH-GA statistics at various discharge levels (P < 0.05), indicating slightly weaker associations with environmental conditions, and lags of 1 or 6 days were generally not significantly related.

Correspondence analysis using the 21°C and 150 cms categorical thresholds indicated that low daily migration rates (< 0.4%) were most associated with high temperatures (> 21°C) and low flows (< 20 cms), while high migration rates were most associated with moderate temperatures (< 21°C) and moderate flow levels (Figure 55, top). At moderate to high flow levels (100-200 cms), low migration rates were still associated with high temperatures, but high migration rates appeared only weakly associated with temperature and flow thresholds (Figure 55, bottom). This suggests that water temperature in the lower Okanogan River is the larger influence on variation in daily migration, and, more specifically, 21°C presents a potentially critical threshold defining high versus low migration rates for Okanagan Sockeye Salmon four days later at Zosel Dam, most frequently at extremes in Okanogan discharge levels.

Based on the combined five-day lag (i.e. migration lagged backward four days and temperature/discharge lagged forward one day), an un-weighted tally of non-zero migration dates indicated that approximately 80% of the historic adult migration dates[49] occurred at Okanogan River discharge levels of ~20-80 cms (Figure 50). Weighting the frequency distribution by the daily migration rate indicated that the consistently highest daily migration rates (>75th percentile of 2.9% per day) occurred when discharge was ~90-160 cms (Figure 51). Although dates with discharge volumes exceeding 160 cms were rare (< 3% of all dates), substantial migration rates were evident as high as 200 cms, indicating some tolerance for elevated Okanogan flow levels. Migration activity at discharge levels below 20 cms were also infrequent (4%), but appear not to indicate a barrier to passage, as daily migration rates were moderate (1.7%) at discharges as low as ~10 cms.

While “significant” daily migration rates (i.e. >50th percentile rate of 0.4%) occurred across a wide range of available temperatures (12-25°C), highest average migration rates (>2.9%) were located at 19°C or lower (Figure 53). The median water temperature for active migration dates was 20°C, indicating that about half of the time, temperatures during the defined migration interval were > 20-21°C (Figure 52). In fact, ~60% of defined migration dates (but not migration rates) were characterized by water temperatures in the 20-23°C range.

A weighted two-way frequency distribution based on combined flow and temperature

[49] See Table 4 for years of available migration data for the Zosel Dam site.

ranges showed that high migration rates for Okanagan Lake Sockeye Salmon were multi-modal, with maximums at a wide range of discharge levels (90-180 cms) when temperatures were low (<19°C), but largely restricted to moderate discharge levels (80-120 cms) when temperatures exceeded 19-20°C (Figure 54).[50]

Anomaly plots of migration, water temperature and discharge deviations (Appendix C) were constructed based on the 50th percentile of migration rate observations (0.4%; Table 4), combined with apparent upper environmental thresholds for high migration rates (~21°C and ~150 cms discharge).

Most years indicated an inverse relationship between migration rate and water temperature (e.g., 1962, 1963, 1992, 1993, 2006-2009, 2014-2016), though the actual threshold above which migration dropped to negligible rates varied from 22°C (e.g., 1963, 1992, 2006, July 2009) to 24°C (e.g., 2007, August 2009, 2015). Some years exhibited high migration rates (>75th percentile) for periods where temperatures may have exceeded the 24°C lethal level for Sockeye Salmon (e.g., 1937, 1944, 2014). Migration often restarted as temperatures fell back below 22-23°C (e.g., 2006, 2009, 2010, 2014, 2015, 2017).

Observed discharge levels in the lower Okanogan appear to have minor impact on migration rates. "High" daily migration rates (>2.9%) occurred most frequently between 90-160 cms. While "moderate" daily migration rates (> 0.4%) were evident at a wider range of discharge levels, from 10-200 cms (Figure 51; e.g., Appendix C:1993), high spring flows may need to drop below ~150 cms before initial migration can commence in full (e.g., Appendix C: 1954, 1963, 2008, 2010, 2014). Several instances of rapidly declining discharge levels at the beginning of the active migration period, combined with rising water temperatures appear to have combined to delay Sockeye Salmon migration in some years (e.g., 1937, 1944, 1962, 2006, 2007, 2009 and 2014).

A minimum discharge threshold of 10-20 cms was associated with low migration – persistent low water levels approached this threshold in 1992, 2006, 2007 and 2009 during active migration events: despite relatively low water temperatures (<20°C) in 1992 and 2007, migration petered out (though perhaps naturally at the end of the run). There may also be an interaction between water temperature and discharge on migration, such that Sockeye Salmon are more likely to migrate in significant numbers at temperatures in the 20+ degree range if flows are 100 cms or more (e.g., 1993, 2014). Generally-speaking, the inverse relation between temperature and migration is most apparent at sub-average flows.

[50] Several exceptions to this pattern, in which high daily migration rates (~20%) were evident at high temperature (22-26°C) / low discharge (25-35 cms) combinations, were omitted from these analyses, as they were attributed to years of very low total escapement (<1,000 migrants in 1944 and 1962), resulting in a disproportionate weighting of the contribution of a small number of fish. In 1937 (total migrants: 2,249), the alignment of temperature and migration data indicated a high rate of fish passage at lethal temperatures of 26°C; these "outliers" were also excluded as a possible error associated with the original data.

DISCUSSION

As the most southerly location for populations of the cold-water species *Oncorhynchus nerka*, the Columbia system is commonly viewed as a key location of interest regarding impacts of changing climatic conditions on the fresh-water life history of Sockeye Salmon (Nelitz et al. 2007). The two freshwater life history stages in Pacific Salmon regarded as most sensitive to climate change include upstream migration of returning adults, and post-spawn egg-to-fry incubation (McDaniels et al. 2010; Healey 2011). As each life stage has optimal thermal and flow requirements, seasonal changes, inter-annual variability, and long-term trends in site-specific freshwater temperature and flow are key elements in assessing the impacts of climate change on a salmon population's reproductive success and sustainability.

In the highly regulated flow environment of the Columbia and Okanagan watersheds, water temperature appears to be the more influential of these two factors in terms of impacts on behaviour and timing of adult Sockeye Salmon migration, the focus of this analysis. Three key locations of potential vulnerability along the migration corridor of Okanagan Sockeye Salmon emerge out of this analysis and are likely to present 'control points' exerting disproportionate impact on the population's migration success. These include: (1) the warmest reaches of the Columbia mainstem, which are associated with Bonneville, John Day and McNary dams in the lower Columbia River; (2) Pateros Lake (Wells Pool), which forms the Wells Dam forebay, where adult Sockeye Salmon often pause to hold in the Columbia mainstem before entering the Okanogan watershed (Hyatt et al. 2003); and (3) the 185-km Okanogan River, where summer water temperatures are typically 3-5°C warmer than in Pateros Lake.[51]

LOWER COLUMBIA: MAINSTEM DAMS

Regional July-August air temperatures have exceeded 20°C since the beginning of the century, with a positive trend (Figure 20) and an evident 3-4°C oscillation around the trend line, depending on decade. Above-average temperatures characterized the 1920s and 1930s, the late 1990s, mid-2000s, and late 2010s, and below-average temperatures typified the late 1970s, and early 2010s. Various studies have associated this level of decadal climate variability with phase changes in the Pacific Decadal Oscillation (PDO) and/or Oceanic Niño Index (ONI) patterns (Cohen and Kulkarni 2001; Hyatt et al. 2003; EPA 2018a). An overall warming trend is evident in the Pacific Northwest region and BC of 0.1-0.2°C per decade for the first half of the century (GCRP 2017; in EPA 2018a), and 0.2-0.3°C per decade since 1986 (Isaak et al. 2011).

[51] Other locations of potential impact on spawning success (outside the scope of this report) include: (4) Osoyoos Lake, a shallow water body characterized by summer water temperature and dissolved oxygen fluxes that can be stressful to pre-spawn holding Sockeye (see Hyatt and Rankin 1999; Hyatt et al. 2003); and (5) the Okanagan River spawning grounds above Osoyoos Lake. While spawning ground temperatures appear to be hospitable to spawning Okanagan Sockeye for the near future, historic and projected thermal impacts on egg incubation, fry emergence timing, and fry survival and recruitment require further investigation (see Stockwell et al. 2020). Furthermore, changing climatic conditions in concert with human development demands may affect the hydrology of these sites, with potentially negative impacts on spawning and rearing habitat quality (Cohen and Kulkarni 2001; Nelitz et al. 2007).

Columbia River mainstem summer water temperatures are more strongly influenced by air temperature than flow variation, tributary inputs or shade factors, and have had a pronounced increase during summer months (EPA 2018a). Lower Columbia temperatures (at Bonneville Dam) in July have increased 2.6°C since 1949 (Crozier et al. 2011, in EPA 2018a). Studies indicate that an increase in the frequency of dates with elevated thermal conditions, of the magnitude identified here, will negatively affect migration speed, timing, spatial distribution and disease profiles of migrating Sockeye Salmon, leading to depleted energy reserves and reduced fitness for the final stages of upstream migration (Jensen et al. 2004; Goneia et al. 2006; Keefer et al. 2008; Martins et al. 2010; Miller et al. 2014). Such effects likely impacted adult Sockeye Salmon in the Columbia River in 2015, when Bonneville temperatures in June were 3.4°C above the 10-year average. Sockeye Salmon mortality between Bonneville and McNary dams in 2015 was ~2x the multi-year mean for 2006-2014 (Fryer et al. 2018), and mass die-offs of salmon as well as Sturgeon occurred at multiple locations in the basin (NOAA 2016).

A trend towards longer periods of thermal exposure and stress is marked by earlier occurrence of first date, and later occurrence of last date, of temperatures exceeding 20°C (EPA 2018a). Since the 1990s, the median frequency of dates per decade when mean water temperatures at Bonneville exceeded 20°C has risen from 13 to 19 days (Figure 26), principally in July, affecting the tail end of the run. These decadal averages were lowered by cool wet years, notably 1993, 1999, 2011, and 2012, when no dates exceeded that threshold, and inflated by warm years, notably 1992 and 2015, when all of July and the last week of June exceeded 20°C. For the recent warm phase PDO/ONI years (1987, 1992, 2004, 2006, 2007, 2014-2018), 33-60% of June/July dates exceeded 20°C temperatures.

The annual level of thermal exposure experienced by Sockeye Salmon migrants is variable, however, as is the annual return timing and sequential passage through the various dams of the lower Columbia River. Adult Sockeye passage in the lower Columbia is concentrated in June and July. In June, temperature conditions rarely exceed 18°C in the warmest forebay (Bonneville), but seasonal warming raises average temperatures to 20°C in July. The CBR-DART temperature exposure index – the mean daily water temperature during Sockeye Salmon passage, weighted by the daily number of Sockeye Salmon counted[52] – ranged from a low of 15.9°C in 2011, up to 20.8°C in 2015. While the percentage of Sockeye Salmon exposed to 20°C temperatures at Bonneville averaged 0.1% of the run in the cool wet years (1993, 1999, 2011, and 2012), the percentage was 4-9% in the most recent warm years (2013, 2014, 2016-2018), 10-20% in powerful El Niño years (1987, 1992, 1998), but 61% of the total run in 2015 (CBR-DART).

Of the mainstem dams in the lower Columbia, seasonal temperatures rise most significantly in the John Day Dam reservoir (Lake Umatilla), which is the longest reservoir in the lower Columbia. Though the short residence time of water in any of the lower Columbia mainstem dam forebays creates near-isothermal conditions at all

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[52] For more information about the exposure index, see CBR-DART http://www.cbr.washington.edu/perform/methods.php

depths (USBR 2018), the larger Lake Umatilla (behind John Day Dam) tends to reach warmer temperature levels than Bonneville Lake as the season progresses into July (Figure 22), corresponding to increased thermal exposure for Sockeye Salmon migrants. In 2015, 75% of Sockeye Salmon tallied at John Day Dam were exposed to temperatures >20°C, with a mean thermal exposure index of 21.1°C. Large numbers of these fish ceased migration to hold below McNary Dam which was one of several locations at which mass die-offs of adult Sockeye Salmon were directly observed (NOAA 2016).

CRITFC PIT-tag studies indicated a general increase in travel rate (km/day) for Sockeye Salmon in the Columbia mainstem as the season progressed in most years (coincident with falling seasonal discharge levels), but, overall, showed similar travel rates between years (Fryer et al. 2012; 2016; 2018)[53]. For example, in 2015, 2016, and 2017 (warm years), adult Sockeye Salmon took 4.7 - 5.0 days to traverse the lower Columbia between Bonneville and McNary dams at ~50 km/day, and took between 5.1 - 5.7 days in the cooler, high flow years of 2010 and 2011. Travel times from Bonneville to Wells Dam showed similar inter-year variations: over this distance, fish traveled at ~40 km/day, taking from 13-14 days in 2015, 14-16 days in 2016 and 2017, and 16-18 days in 2010 and 2011 (high flow years).

While travel time between dams in the Columbia mainstem may be partially affected by river discharge levels, “survival” rates (conversion factors) between dams appear strongly influenced by mainstem temperatures exceeding 18-19°C, as indicated by CBR-DART visual counts as well as CRITFC PIT-tag studies. In recent years, the CBR-DART temperature exposure index for Bonneville Dam, which is weighted by the daily number of Sockeye Salmon counted, ranged from ~16.0°C (2010 and 2011), to 17.6°C (2017) and 18.2°C (2016), but reached 20.8°C in 2015 (CBR-DART). Inter-dam “survival” for the associated years based on PIT-tag conversions between Bonneville and McNary Dams ranged from 76% (2011) to 89% (2016), bracketing the long-term mean (2006-2017: 84.4%), but fell to 54% in 2015 (Fryer et al. 2018). Similarly, PIT-based conversions between Bonneville and Wells dams averaged 60% between 2006-2017, but dropped to 29.4% in 2015 (ibid), indicating markedly reduced fitness in warmer years.

MID-COLUMBIA: WELLS DAM – PATEROS LAKE

Sockeye Salmon passage at Wells Dam is concentrated in July and August. Lake Pateros has generally provided a critical thermal refuge for Sockeye Salmon during periods in July and August when temperatures >21°C in the Okanogan River present a thermal barrier to continuous upstream migration that, in recent years (2005-2018), has lasted for an average of more than 6 weeks.

The thermal refuge of Pateros Lake is largely a consequence of the seasonal asymmetry that exists between the hydrological regimes of the Columbia and Okanogan rivers. On average, temperatures in the Okanogan River reach a peak near

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[53] A more striking inter-year difference, discussed below in relation to Okanogan River migration, was revealed by PIT-tag detections between Wells and Zosel Dams, demonstrating the impacts of high water temperatures on migration delays.

24°C by the first week of August followed by seasonal cooling that is well underway by the end of August (Figure 33). By contrast, the Columbia River at Lake Pateros reaches its peak temperatures of roughly 19°C during the first week of September (Figure 27), a full month later than the Okanogan River. By the first week of September, cooling of the Okanagan River to 19°C matches the temperatures in Lake Pateros and generally allows adult Sockeye Salmon to resume their migration up the Okanogan River before Lake Pateros reaches its maximum seasonal temperature.

The Columbia mainstem has been warming over the past 5 decades (EPA 2018a). Despite this warming trend, Pateros Lake still provides a thermally tolerable location (Table 13) for adult Sockeye Salmon to hold during migratory delays, with mean July-August water temperatures in Pateros Lake ranging from 17-18°C on average (but 18-19°C during the hottest years, e.g. 1998, 2015). While water temperature patterns in Pateros Lake mirror the regional trend towards warmer summers, with thermal highs during warm phase PDO/ENSO years (1998, 2003-2007, 2013-2018), temperatures during Sockeye Salmon passage since 1993 have averaged <18°C (17.5 ± 1.5°C; Figure 28). The CBR-DART temperature exposure index for the most stressful year on record, 2015, was only 17.4°C, and only 8.5% of the 16,075 survivors tallied at Wells were exposed to temperatures above 18°C. However, there is also a within-year temporal change in thermal exposure for migrants arriving in July, when data from the most recent 20 years indicate only 10% of dates exceeded 18°C, versus arriving in August, when 80% of the dates exceeded 18°C. Thus, later migrants in most years are vulnerable to higher thermal stress when required to hold in Lake Pateros. Like other mainstem reservoirs, peak temperatures achieved there in August tend to persist into September, providing little chance of relief to holding fish awaiting a falling temperature signal for a resumption of active migration into the Okanogan system. Also, due to the high ratio of hydrological inputs to storage capacity, the reservoir (Lake Pateros) is isothermal, and therefore may not continue to provide a cool-water refuge, especially during acute warm phase PDO/ENSO years to come.

OKANOGAN RIVER

Based on an alignment of daily Sockeye Salmon counts at Zosel Dam with Okanogan River temperature and discharge data, it appears that the decision by adult Sockeye Salmon to continue or pause upstream migration is primarily based on thermal conditions at the mouth of the Okanogan River, though there may be an interaction effect between temperature and Okanogan discharge levels.

A combined lag of five days for daily Sockeye Salmon counts and stream conditions was utilized to align the data, based on a statistical approach used in other reports (e.g. Stiff et al. 2015c; 2016; 2018) for systems that lack much information on Sockeye Salmon travel time between enumeration sites and potential 'control points' downstream, where thermal or flow conditions may present a barrier to migration. Though experimental in application, the statistical method tests the null hypothesis that significant changes in daily migration at the enumeration site are not related to variation in temperature or discharge temporally lagged for association with locations downstream. Maximum rejection of the null hypothesis occurred when daily migration data (from Zosel) were lagged backwards 3-4 days and temperature/discharge (from Malott) lagged forward one day, essentially coincident with conditions near the mouth of the Okanogan River, based on an approximate swim speed by adult Sockeye Salmon of 40 km/day. In the Okanogan system, CRITFC PIT-tag studies have provided similar estimates based on direct observations of how long Sockeye Salmon take to navigate upstream: mean travel time in 2016 and 2017 was 4 - 5 days (range 2.0 – 6.5), and minimum travel time in 2015, when migration delays resulted in median travel time of 28 days, was 6.5 days (Fryer et al. 2016; 2018).

Based on a five-day combined lag, anomaly plots matching daily migration rates with temperature and discharge levels near the mouth of the Okanogan show, in most years, that while a high freshet discharge (>180 cms) may inhibit migration (e.g. 1954, 2010), high migration rates are more frequently inhibited by high temperatures (e.g. 1962, 2006, 2015), in the 20-22°C range, at all discharge levels. Major and Mighell (1967; in Hyatt et al. 2003) noted that adult Sockeye Salmon migrations into the Okanogan River halt as rising water temperatures exceed 21°C, and then restart if temperatures fall again below this threshold. Based on this temperature threshold, Hyatt et al. (2003) found a predictable relationship between the *observed* and *expected* duration of historical migratory delays, and estimated a mean delay frequency of 29 days per year (range 0 - 55 days; 1924-1998). This is similar to this report's mean decadal estimates of 28 - 40 days per year (based on a 20°C threshold[54]) from the 1920s to the 1990s, which have subsequently risen to 46 - 50 days per year (range 32 - 62) in the 2000s and 2010s (Figure 58). These results suggest that, on average, 50 out of 60 days (~80%) during the months of peak Sockeye Salmon migration in the Okanogan are currently stressful to this population, with consequent impacts on migration patterns and survival.

As a result, Okanagan Sockeye Salmon counted at Zosel generally demonstrated one of two patterns of migration (Hodgson and Quinn 2002; Hyatt et al. 2003): either as a single clump, migrating as early as possible, when Okanogan River thermal conditions were hospitable (e.g. 1937, 1953, 1963, 2008, 2010, 2014, 2016), or intermittently, with evident delays due to the onset of high water temperatures (e.g. 1952, 1962, 1992, 1993, 2007, 2009, 2015, 2017).[55]

A frequency distribution of all migration dates available from the Zosel site indicated that 50-60% of migration dates were characterized by Okanogan water temperatures of 20-23°C, with "significant" daily migration rates (>50th percentile) at a wide range of temperatures (13-24°C). However, the highest migration rates still occurred at <22°C (Figure 52 vs Figure 53). Sockeye Salmon migrants enumerated at Zosel Dam in 2006-2008 were most likely exposed to water temperatures near critical lethal levels of 23-24°C during peak migratory activity (Johnston et al. 2007; 2008; 2009). The years 2009, and 2014-2017 provided similar thermal challenges.

The impacts of this level of temperature exposure on migration success are evident in both travel time and "conversion rate" (CR) between Wells Dam visual counts versus estimates of total fish on the Okanagan River spawning grounds. In cool, wet years

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[54] A 20°C threshold was applied for consistency with other publications in this report series (e.g. Hyatt et al. 2015b; Stiff et al. 2013; 2015a; 2015b; 2015c; 2016; 2018).

[55] For the years of available overlapping daily migration data, the timing at Wells was, coincidentally, always earlier than the historical average (see Appendix A) – indicating that any spread in the timing at Zosel must be largely a function of environmental conditions, rather than straggling migrants.

when Okanogan water temperatures averaged less than 22°C (e.g. 2010 and 2011), the Wells-to-Okanagan CR was 79-87%. In recent warm years (e.g. 2013-2014, 2016-2018) when Okanogan mean temperatures ranged from 22-23°C, the Wells-to-Okanagan CR was reduced on average to 43% (range 34-65%). In 2015, when Okanogan mean temperatures reached ~24°C, the CR value fell to 8.5%, indicating a 91.5% natural mortality rate from Wells to the spawning grounds (Table 3).

A striking inter-year difference in travel time was revealed by PIT-tag detections (Fryer et al. 2016, 2017, 2018) between Wells and Zosel Dams: median travel time was similar in 2016 (4.9 days, range 3.6 - 6.5) and 2017 (4.5 days, range 2.0 - 4.8), but jumped to 28 days (range 6.5 - 35.4) in 2015 due to temperature-induced migration delays. Minimum travel times in 2015 (6.5 - 7.8 days) were restricted to the earliest tag groups (stat week 22-23) which encountered slightly better thermal conditions for migration, after which tagged fish took 13.3 - 35.4 days to travel between Wells and Zosel dams (Fryer et al. 2016).

Poor detection rates for PIT-tags at high discharge levels prevented accurate counts at Zosel in 2010-2012, but not in 2015, when tag detection approached 100% (Fryer et al. 2016). In 2015, the PIT-based conversion from Wells to Zosel was only 7% (i.e. similar to the 8.5% CR value noted immediately above), compared to 37 – 39% in 2014 and 2016 (Fryer et al. 2018, Table 7).

An inter-year comparison of CR survival factors based on visual counts from dams in the lower Columbia mainstem versus those in terminal spawning areas in the Okanagan River tells a similar story. While CR between Bonneville and the terminal spawning area for Okanagan Sockeye Salmon ranged from 46% to 59% in the cool wet years of 2010-2011, it has averaged 27% (range: 15-40%) in six of seven years since 2012, and was reduced to 2% in 2015.

The effects of discharge alone on Okanogan migration patterns were less apparent or less easily distinguishable from temperature effects, and therefore less quantifiable. “Flashiness” and high turbidity are both characteristic of the lower Okanogan River during the annual spring freshet due to inputs from the snowmelt-driven Similkameen River (Johnston et al. 2009). The melting snow-pack and associated Similkameen freshet has historically delivered cool waters into the Okanogan from late April into July, as shown in the typical annual thermograph (Figure 32). High Similkameen River discharge from large, rapidly melting snow-packs during warm springs (e.g. 2010, 2011) may deter upstream migration, until discharge volumes fall to 200 cms or less. However, when the snow-pack is low, or the annual freshet ends early, as was the case in 2015, warm water from the lakes of the Okanagan valley bottom then dominate thermal conditions in the Okanogan River below the confluence of the Similkameen River (Figure 3) in June and July. Elevated thermal conditions then delay early Sockeye Salmon migrants from entering the Okanogan River, as in 2015. In the latter year, Sockeye Salmon migration was clumped and intermittent, and only reached Zosel Dam in significant numbers in late July and early September during intervals when water temperatures fell below 21°C.

An un-weighted tally of available migration dates indicated that approximately 70% of the historic non-zero migration activity at Zosel occurred at Okanogan River discharge levels of ~20-80 cms (Figure 50), while the consistently highest daily migration rates (>75th percentile of 2.5% per day) occurred when discharge was ~80-180 cms (Figure 51). However, infrequent but "significant" migration activity was evident at both low (10-20 cms) and high (240 cms) discharge, indicating a high tolerance for variable flows. Decadal trends in extreme flows (peak-over-threshold analyses) did not reveal strong trends.

A potential interaction effect between water temperature and discharge volume on migration rates was most apparent in the bi-variate weighted frequency distribution (Figure 54). High migration rates for Okanagan Lake Sockeye Salmon were multi-modal, with "preferred migration zones" at moderately high Okanogan River discharge levels (130-190 cms) when temperatures were low (<18°C) (i.e. early in the season), but also at lower discharge levels as temperatures exceeded 19-20°C. Perhaps this merely reflects the two patterns of migration that take shape as a response to hydrological conditions: (1) early migration of fish when temperatures are cool, at a variety of discharge levels characterizing the end of the freshet; or (2) delayed or multi-modal migration pulses when temperature conditions are not optimal, mainly irrespective of declining seasonal flow levels.

OUTLOOK

Warmer, wetter winters, and warmer, drier summers are projected to increasingly modify the hydrography of watersheds in the Columbia River Basin as the 21st century proceeds (EPA 2018a). While changes to precipitation levels are less certain, a regional increase in annual mean air temperature of 1.8° to 5.4°C by 2100 is anticipated to reduce winter snowpack levels and subsequent summer flows, coupling stream temperatures to rising air temperature more closely in both Columbia mainstem and tributaries. Projected summer water temperature increases in the Columbia River Basin range from 1.7° – 2.0°C over the next 80 years (Yearsley 2009 and Isaak et al. 2018; in EPA 2018a)[56].

A 2-degree increase in summer mainstem water temperatures will shift the average temperature during Sockeye Salmon migration in the lower Columbia River from the current all-year average of 18°C to 20°C (EPA 2018a), as in 2015, when 46% of Sockeye Salmon counted at Bonneville did not pass McNary dam, <30% reached Wells Dam, and <5% reached their terminal spawning areas. The implications for Okanagan Sockeye Salmon migrants holding in the Columbia River above the Wells Dam are two-fold: first, thermal conditions in the lower Okanogan River will increasingly deter or delay upstream passage; second, conditions in the isothermal Lake Pateros (i.e. Wells Pool), usually a thermal refuge, will become increasingly unfavourable for low-risk holding by adult Sockeye Salmon. A projected 1-2°C increase will elevate Pateros Lake temperatures to biologically stressful levels of 19-20°C, exceeding the values observed there in 2015.

Though hydrological shifts are basin-dependent, most climate models generally project

[56] It is anticipated that a full mathematical modelling of the thermal energy budgets of each unique mainstem reservoir, under varying climatic and operational conditions, will be necessary to accurately forecast impacts on all life stages of CBR salmonids (e.g. via thermal energy budget applications such as the EPA's one-dimensional mathematical process model, RBM-10 (EPA 2018b)).

earlier onset of spring snow-melt and reduced annual mean and spring stream flows in Okanagan watersheds as they shift toward an increasingly pluvial climatology (Merrit et al. 2006; Rodenhuis et al. 2009). The specific implications for Sockeye Salmon migrants in the Okanogan watershed will be reduced cold-water inputs from Similkameen freshets, which have generally served to keep Okanogan River water temperatures at hospitable levels (<18°C) into July. Freshet events may be lower in magnitude and/or occur earlier, and dry-season low flow periods will be more extensive, exacerbating thermal barriers to upstream migration. Higher Okanogan River temperatures will result in more frequent and longer delays for upstream migration. The combined impacts of the projected increases in mainstem and tributary temperatures suggest that, in a typical year between 2050 and 2100, annual Okanagan Sockeye Salmon survival may be reduced to 2015-equivalent levels, i.e. <10% of the fish tallied at Bonneville Dam survive to spawn in the Okanagan River.

Autumn conditions in terminal spawning areas of the Okanagan River appear to be hospitable to Sockeye Salmon for the near future, with current mean water temperatures of 10.0 ± 3.2°C, up slightly from a long term average of 9.6°C, but within the optimum range (<12°C) for spawners, with no clear trends. However, projected increases in the frequency and duration of low flow conditions due to climate change, in concert with increasing human pressures on upstream water supply (Anon. 2012), will likely present further challenges to Okanagan water and fisheries management.

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TABLES

OLIVER *
BRITISH COLUMBIA

Latitude:	49°09'57.000" N	Longitude:	119°33'51.000" W	Elevation:	315.20 m

1971 to 2000 Canadian Climate Normals station data

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Code
Temperature:														
Daily Average (°C)	-2.6	0.7	5.5	10.1	14.5	18.2	21.1	20.5	15.3	8.8	2.7	-1.7	9.4	A
Standard Deviation	2.9	2.6	1.6	1.4	1.4	1.3	1.6	1.4	1.7	1.1	2.3	2.7	1.7	A
Daily Maximum (°C)	0.4	4.6	11.4	17.3	21.8	25.5	29.2	28.5	23.1	15.2	6.2	1.1	15.4	A
Daily Minimum (°C)	-5.6	-3.3	-0.4	3	7.2	10.9	13	12.5	7.4	2.4	-0.9	-4.5	3.5	A
Extreme Maximum (°C)	15.5	17	24	30.6	36.5	38	**42.8**	39.4	36.1	29.4	20	15.6		
Date (yyyy/dd)	1989/ 30	1995/ 20	1994/ 31	1946/ 25	1986/ 31	1987/ 30	**1939/ 27**	1967/ 17	1940/ 11	1947/ 03	1975/ 03	1943/ 03		
Extreme Minimum (°C)	**-30.6**	-30.6	-22.2	-8.3	-7.8	-0.6	2.8	2.8	-4.4	-13.5	-21	-28.3		
Date (yyyy/dd)	**1950/ 18**	1950/ 03	1951/ 11	1968/ 13	1954/ 01	1976/ 03	1952/ 06	1959/ 29	1972/ 25	1984/ 31	1985/ 23	1968/ 31		
Precipitation:														
Rainfall (mm)	10.5	17.2	20.8	24.5	37.2	37.2	30.4	27.2	19.3	17.1	23.5	15.8	280.7	A
Snowfall (cm)	15.4	7.6	1.4	0	0	0	0	0	0	0.2	4.6	17.7	46.9	A
Precipitation (mm)	26	24.8	22.2	24.5	37.2	37.2	30.4	27.2	19.3	17.3	28	33.5	327.5	A
Extreme Daily Rainfall (mm)	21	27.6	15.2	40	50.8	33.6	50	**61**	29.2	16.3	19.6	19.6		
Date (yyyy/dd)	1983/ 26	1994/ 17	1984/ 20	1992/ 16	1977/ 02	1982/ 30	1989/ 14	**1989/ 09**	1997/ 17	1956/ 29	1958/ 03	1973/ 12		

Table 1. 1971-2000 climate normals for Oliver, BC (Okanagan River) (Source: Environment Canada).

	Wells Dam									
	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											
1967	97	03JUL	25OCT	1,167	7,871	113,233	0.10	0.93	5.66	1.03	6.95
1968	112	09JUN	30OCT	728	4,301	81,530	0.13	1.44	3.95	0.89	5.28
1969	100	25JUN	25OCT	174	1,115	17,352	0.21	1.41	5.04	1.00	6.43
1970	99	21JUN	09OCT	512	2,806	50,667	0.18	1.78	4.37	1.01	5.54
1971	95	03JUL	19OCT	507	3,484	48,172	0.09	0.96	5.69	1.05	7.23
1972	89	01JUL	02NOV	375	2,708	33,396	0.25	1.77	4.82	1.12	8.11
1973	100	19JUN	11OCT	372	2,060	37,174	0.26	1.73	4.16	1.00	5.54
1974	77	01JUL	10OCT	217	1,006	16,716	0.23	2.25	5.71	1.30	6.02
1975	89	19JUN	29SEP	250	1,803	22,286	0.17	0.93	6.83	1.12	8.09
1976	84	26JUN	20SEP	329	1,526	27,619	0.48	2.22	3.97	1.19	5.53
1977	123	25MAY	14NOV	179	1,305	21,973	0.24	1.25	3.27	0.81	5.94
1978	97	01MAY	08OCT	79	414	7,644	0.35	1.22	4.62	1.03	5.42
1979	89	03MAY	05OCT	299	19,762	26,655	0.02	0.38	1.95	1.12	74.14
1980	95	30JUN	31OCT	280	1,698	26,573	0.26	1.01	5.39	1.05	6.39
1981	108	14JUN	10NOV	261	1,926	28,234	0.08	0.71	5.53	0.93	6.82
1982	105	04JUN	30OCT	181	1,020	19,005	0.14	1.34	4.36	0.95	5.37
1983	86	20JUN	23SEP	325	1,165	27,925	0.48	2.38	3.38	1.16	4.17
1984	111	20JUN	04NOV	730	4,527	81,054	0.07	1.31	4.50	0.90	5.59
1985	106	18JUN	08NOV	500	2,902	52,989	0.09	1.19	4.64	0.94	5.48
1986	103	18JUN	11OCT	338	1,802	34,788	0.11	1.87	3.94	0.97	5.18

(Continued)

Table 2. Annual migration statistics for adult Sockeye migrants passing Wells Dam, 1967-2019, documenting migration period and length, mean and maximum daily migrant and migration rate (%) estimates, and total escapement from daily observations (Source: CBR-DART). Note: 1979 excluded from multi-year statistics due to outlier migrant count (75% of annual migrants - 19,762 fish - occurred on 01-Aug-79).

	Wells Dam										
	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											
1987	107	08JUN	13NOV	375	1,950	40,120	0.16	1.85	3.41	0.93	4.86
1988	117	20JUN	31OCT	290	1,953	33,978	0.11	1.36	3.58	0.85	5.75
1989	92	15JUN	03OCT	174	958	15,976	0.25	1.94	4.04	1.09	6.00
1990	78	08JUN	18OCT	98	459	7,609	0.29	2.17	4.89	1.28	6.03
1991	83	01JUL	10OCT	331	2,301	27,490	0.27	1.54	5.13	1.20	8.37
1992	117	01JUN	30OCT	359	2,436	41,950	0.10	1.23	4.00	0.85	5.81
1993	93	16JUN	28SEP	299	1,679	27,849	0.19	1.75	4.43	1.08	6.03
1994	72	22JUN	25OCT	23	97	1,666	0.45	2.28	5.52	1.39	5.82
1995	74	22JUN	07SEP	66	477	4,892	0.51	1.72	4.78	1.35	9.75
1996	78	22JUN	30SEP	227	1,313	17,703	0.29	1.76	6.65	1.28	7.42
1997	88	29JUN	12OCT	280	1,476	24,601	0.17	1.93	4.46	1.14	6.00
1998	103	21JUN	09OCT	43	532	4,390	0.23	1.23	3.58	0.97	12.12
1999	85	22JUN	19SEP	144	748	12,224	0.38	1.47	5.23	1.18	6.12
2000	93	11JUN	19SEP	645	5,011	59,944	0.13	1.09	5.98	1.08	8.36
2001	98	14JUN	25SEP	760	6,601	74,486	0.12	1.05	5.31	1.02	8.86
2002	81	23JUN	08OCT	132	717	10,659	0.28	1.74	5.22	1.23	6.73
2003	63	22JUN	25AUG	460	2,343	28,965	0.42	2.53	5.39	1.59	8.09
2004	101	14JUN	11OCT	767	5,095	77,492	0.06	1.22	5.37	0.99	6.57
2005	110	17JUN	23OCT	505	4,269	55,553	0.06	1.03	4.37	0.91	7.68

(Continued)

	Wells Dam										
	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											
2005	110	17JUN	23OCT	505	4,269	55,553	0.06	1.03	4.37	0.91	7.68
2006	113	17JUN	27OCT	195	1,387	22,075	0.07	0.82	4.67	0.88	6.28
2007	101	13JUN	13OCT	221	1,469	22,272	0.12	1.47	5.39	0.99	6.60
2008	98	08JUN	22OCT	1,687	12,852	165,334	0.03	0.61	7.01	1.02	7.77
2009	96	15JUN	19OCT	1,406	9,699	134,937	0.05	1.23	5.13	1.04	7.19
2010	110	12JUN	26OCT	2,652	22,989	291,764	0.01	0.45	6.65	0.91	7.88
2011	76	16JUN	12SEP	1,467	7,328	111,507	0.17	2.48	5.54	1.32	6.57
2012	102	15JUN	09OCT	3,197	27,815	326,104	0.02	0.55	6.52	0.98	8.53
2013	107	12JUN	20OCT	1,215	6,471	129,993	0.06	1.10	4.32	0.93	4.98
2014	68	15JUN	23AUG	7,211	29,811	490,318	0.50	2.81	5.49	1.47	6.08
2015	112	07JUN	27SEP	1,669	14,714	186,964	0.13	0.56	5.55	0.89	7.87
2016	118	05JUN	25OCT	1,831	16,581	216,036	0.04	0.71	5.66	0.85	7.68
2017	96	10JUN	15OCT	441	3,238	42,298	0.06	1.28	5.36	1.04	7.66
2018	113	10JUN	26OCT	1,360	11,201	153,638	0.03	0.96	4.32	0.88	7.29
2019	115	13JUN	19OCT	433	3,006	49,838	0.04	0.93	5.08	0.87	6.03
1967-2019	5,034	03JUL	19OCT	727	29,811	3,658,955	0.15	1.41	4.83	1.03	12.12

Table 2, continued. Annual migration statistics for adult Sockeye migrants passing Wells Dam, 1967-2019, documenting migration period and length, mean and maximum daily migrant and migration rate (%) estimates, and total escapement from daily observations (Source: CBR-DART). Note: 1979 excluded from multi-year statistics due to outlier migrant count (75% of annual migrants - 19,762 fish - occurred on 01-Aug-79).

Return year	Wells Counts	US Catch Above Wells	Canadian Catch Above Wells*	Total Catch Above Wells	Wells Adjusted Count (Wells minus US Catch Above Wells)	Okanagan Escapement Estimate (AUC)	Total Terminal Migrants: AUC + CDN Catch Above Wells	Total Terminal Migrants as % of Wells Counts	**Total Terminal Migrants as % of Wells Adjusted**	Canadian Catch as % of Terminal Migrants
1961	7,554	635	500	1,135	6,919	3,462	3,962	52.5	**57.3**	12.6
1962	12,243	950	500	1,450	11,293	6,648	7,148	58.4	**63.3**	7.0
1963	45,159	1,445	500	1,945	43,714	26,646	27,146	60.1	**62.1**	1.8
1964	39,478	970	500	1,470	38,508	23,406	23,906	60.6	**62.1**	2.1
1965	30,655	1,506	500	2,006	29,149	18,784	19,284	62.9	**66.2**	2.6
1966	128,000	1,650	500	2,150	126,350	69,781	70,281	54.9	**55.6**	0.7
1967	113,232	8,442	500	8,942	104,790	25,305	25,805	22.8	**24.6**	1.9
1968	81,530	4,400	500	4,900	77,130	45,436	45,936	56.3	**59.6**	1.1
1969	17,352	660	500	1,160	16,692	11,815	12,315	71.0	**73.8**	4.1
1970	50,667	1,629	500	2,129	49,038	29,268	29,768	58.8	**60.7**	1.7
1971	48,172	1,910	500	2,410	46,262	53,370	53,870	111.8	**116.4**	0.9
1972	33,398	1,300	500	1,800	32,098	21,925	22,425	67.1	**69.9**	2.2
1973	37,178	4,600	500	5,100	32,578	12,904	13,404	36.1	**41.1**	3.7
1974	16,716	1,300	500	1,800	15,416	13,434	13,934	83.4	**90.4**	3.6
1975	22,286	1,250	500	1,750	21,036	16,716	17,216	77.2	**81.8**	2.9
1976	27,619	1,000	500	1,500	26,619	23,160	23,660	85.7	**88.9**	2.1
1977	21,973	1,000	500	1,500	20,973	11,970	12,470	56.7	**59.5**	4.0
1978	7,644	1,300	500	1,800	6,344	1,932	2,432	31.8	**38.3**	20.6
1979	26,655	2,500	500	3,000	24,155	16,689	17,189	64.5	**71.2**	2.9
1980	26,573	1,033	500	1,533	25,540	16,646	17,146	64.5	**67.1**	2.9
1981	28,234	730	500	1,230	27,504	17,516	18,016	63.8	**65.5**	2.8
1982	19,005	590	500	1,090	18,415	12,681	13,181	69.4	**71.6**	3.8
1983	27,925	728	500	1,228	27,197	10,015	10,515	37.7	**38.7**	4.8
1984	81,054	2,548	500	3,048	78,506	49,160	49,660	61.3	**63.3**	1.0
1985	52,989	1,044	500	1,544	51,945	29,137	29,637	55.9	**57.1**	1.7
1986	34,788	94	200	294	34,694	21,753	21,953	63.1	**63.3**	0.9
1987	40,120	68	200	268	40,052	31,649	31,849	79.4	**79.5**	0.6
1988	33,978	25	200	225	33,953	20,525	20,725	61.0	**61.0**	1.0
1989	15,976	24	200	224	15,952	16,787	16,987	106.3	**106.5**	1.2
1990	7,609	21	200	221	7,588	6,316	6,516	85.6	**85.9**	3.1
1991	27,490	26	200	226	27,464	14,442	14,642	53.3	**53.3**	1.4
1992	41,951	25	200	225	41,926	33,184	33,384	79.6	**79.6**	0.6
1993	27,894	20	200	220	27,874	17,338	17,538	62.9	**62.9**	1.1
1994	1,666	137	200	337	1,529	3,597	3,797	227.9	**248.4**	5.3
1995	4,892	66	200	266	4,826	5,972	6,172	126.2	**127.9**	3.2
1996	17,701	60	200	260	17,641	15,950	16,150	91.2	**91.5**	1.2
1997	24,621	21	200	221	24,600	16,661	16,861	68.5	**68.5**	1.2
1998	4,666	20	200	220	4,646	2,048	2,248	48.2	**48.4**	8.9
1999	12,388	0	200	200	12,388	6,907	7,107	57.4	**57.4**	2.8

Table 3. Estimated annual Sockeye catch and escapement of Okanagan Sockeye spawning grounds, with percent of Wells counts accounted for as AUC escapement units in the terminal spawning area plus Sockeye catch in areas proximal to this, 1961-2018. See METHODS: SOCKEYE MIGRATION DATA section for more information.

Return Year	Wells Counts	US Catch Above Wells	Canadian Catch Above Wells*	Total Catch Above Wells	Wells Adjusted Count (Wells minus US Catch Above Wells)	Okanagan Escapement Estimate (AUC)	Total Terminal Migrants: AUC + CDN Catch Above Wells	Total Terminal Migrants as % of Wells Counts	**Total Terminal Migrants as % of Wells Adjusted**	Canadian Catch as % of Terminal Migrants
2000	59,944	12	200	212	59,932	26,596	26,796	44.7	**44.7**	0.7
2001	74,486	0	200	200	74,486	44,991	45,191	60.7	**60.7**	0.4
2002	10,659	3	200	203	10,656	4,898	5,098	47.8	**47.8**	3.9
2003	29,374	46	200	246	29,328	18,896	19,096	65.0	**65.1**	1.0
2004	78,053	136	200	336	77,917	40,908	41,108	52.7	**52.8**	0.5
2005	55,553	175	200	375	55,378	31,536	31,736	57.1	**57.3**	0.6
2006	22,075	81	200	281	21,994	20,819	21,019	95.2	**95.6**	1.0
2007	22,272	247	200	447	22,025	13,504	13,704	61.5	**62.2**	1.5
2008	165,328	1,385	4,437	5,822	163,943	127,602	132,039	79.9	**80.5**	3.4
2009	134,937	18,139	2,746	20,885	116,798	64,141	66,887	49.6	**57.3**	4.1
2010	291,764	27,192	19,252	46,444	264,572	209,974	229,226	78.6	**86.6**	8.4
2011	111,507	3,420	7,396	10,816	108,087	77,650	85,046	76.3	**78.7**	8.7
2012	326,102	40,408	64,410	104,818	285,694	94,071	158,481	48.6	**55.5**	40.6
2013	129,993	10,550	5,275	15,825	119,443	36,557	41,832	32.2	**35.0**	12.6
2014	490,802	45,765	46,488	92,253	445,037	146,701	193,189	39.4	**43.4**	24.1
2015	186,964	48,638	1,278	49,916	138,326	10,443	11,721	6.3	**8.5**	10.9
2016	216,031	8,129	80,735	88,864	207,902	55,190	135,925	62.9	**65.4**	59.4
2017	42,298	4,990	2,777	7,767	37,308	10,040	12,817	30.3	**34.4**	21.7
2018	153,637	26,253	16,079	42,332	127,384	31,000	47,079	30.6	**37.0**	34.2
All Year Avg	67,255	4,850	4,617	9,467	62,405	31,835	36,452	64.7	**67.4**	6.3
1998-07	36,947	72	200	272	36,875	21,110	21,310	59.0	**59.2**	2.1
2008-18	204,488	21,352	22,807	44,158	183,136	78,488	101,295	48.6	**52.9**	20.7

Table 3, cont'd. Estimated annual Sockeye catch and escapement of Okanagan Sockeye spawning grounds, with percent of Wells counts accounted for as AUC escapement units in the terminal spawning area plus Sockeye catch in areas proximal to this, 1961-2018. See METHODS: Sockeye Migration Data section for more information.

	Zosel Dam											
	Date			Sockeye Migrants				Migration Rate (%)				
	Days	Min Date	Max Date	P50	Mean Daily	Max Daily	Annual Total	P50	P75	P95	Mean Daily	Max
Year												
1937	24	20JUL	13AUG	15	94	494	2,249	0.6	4.9	17.5	4.2	22.0
1944	25	02AUG	27AUG	13	36	176	896	1.5	6.0	17.5	4.0	19.6
1952	39	20JUL	31AUG	68	77	287	3,006	2.3	4.1	6.7	2.6	9.5
1953	39	21JUL	28AUG	1,551	1,732	5,765	67,542	2.3	4.2	7.7	2.6	8.5
1954	37	23JUL	31AUG	101	105	386	3,881	2.6	3.2	8.0	2.7	9.9
1962	24	24JUL	22AUG	17	39	155	944	1.7	5.9	14.3	4.2	16.4
1963	44	16JUL	29AUG	154	364	1,900	16,033	1.0	4.3	6.3	2.3	11.9
1992	47	05JUL	06SEP	222	892	5,142	41,902	0.5	3.5	7.9	2.1	12.2
1993	38	17JUL	23AUG	803	869	4,728	33,018	2.4	3.8	7.3	2.6	14.3
2006	42	16JUL	07SEP	26	441	5,853	18,507	0.1	0.5	17.6	2.3	30.7
2007	54	16JUL	07SEP	46	324	1,899	17,505	0.3	2.3	9.5	1.8	10.7
2008	70	28JUN	06SEP	166	1,212	11,371	84,843	0.2	0.6	8.4	1.4	13.3
2009	61	29JUN	07SEP	248	980	9,160	59,789	0.4	1.6	7.6	1.6	15.0
2010	68	30JUN	07SEP	223	3,046	34,793	207,143	0.1	1.0	8.0	1.5	16.7
2014	68	29JUN	07SEP	214	4,732	72,245	321,799	0.1	0.3	8.4	1.5	22.2
2015	49	18JUL	07SEP	103	698	4,985	34,186	0.3	3.1	7.6	1.9	13.2
2016	63	28JUN	06SEP	466	2,797	38,807	176,231	0.3	1.5	7.4	1.5	21.4
1937-2016		28JUN	07SEP	119	1,376	72,245	1089474	0.4	2.9	9.3	2.1	30.7

Table 4. Annual migration statistics for adult Sockeye for available years of daily migrant counts at Zosel Dam, limited to July-September to eliminate stragglers outside peak migration period (Source: CBR-DART).

	Okanagan River											
	Timing			Weekly Sockeye Migrants				Weekly Migration Rate (%)				
	Weeks	Start	Stop	Min	Mean	Max	Total	P50	P75	P95	Mean	Max
Year												
2000	9	08SEP00	03NOV	20	6,778	22,241	61,006	2.0	23.4	36.5	11.1	36.5
2001	9	09SEP01	04NOV	5	11,196	44,726	100,764	8.2	17.3	44.4	11.1	44.4
2002	8	16SEP02	04NOV	4	1,456	5,547	11,651	4.5	21.5	47.6	12.5	47.6
2003	8	23SEP03	11NOV	19	6,349	19,898	50,791	7.2	21.5	39.2	12.5	39.2
2004	8	22SEP04	10NOV	15	16,965	54,207	135,717	5.8	21.9	39.9	12.5	39.9
2005	8	16SEP05	04NOV	46	14,324	49,641	114,590	4.0	23.8	43.3	12.5	43.3
2006	7	23SEP06	04NOV	38	10,313	38,258	72,189	8.0	18.4	53.0	14.3	53.0
2007	6	07OCT07	11NOV	956	6,963	13,204	41,780	16.9	29.8	31.6	16.7	31.6
2008	8	22SEP08	10NOV	1,719	59,909	122,510	479,273	14.6	20.4	25.6	12.5	25.6
2009	11	23SEP09	02DEC	229	25,710	115,368	282,806	3.7	15.9	40.8	9.1	40.8
2010	8	09SEP10	04NOV	3,314	90,346	206,985	722,771	12.5	21.2	28.6	12.5	28.6
2011	9	16SEP11	11NOV	35	18,192	63,635	163,724	7.3	13.0	38.9	11.1	38.9
2012	9	22SEP12	17NOV	1,374	36,091	96,979	324,821	5.3	19.9	29.9	11.1	29.9
2013	8	23SEP13	11NOV	22	14,736	45,394	117,888	5.1	24.2	38.5	12.5	38.5
2014	6	07OCT14	11NOV	16274	86,303	148,759	517,819	18.3	28.0	28.7	16.7	28.7
2015	7	30SEP15	11NOV	226	4,324	12,475	30,270	6.1	27.3	41.2	14.3	41.2
2016	7	22SEP16	03NOV	40	25,184	89,476	176,287	6.5	28.7	50.8	14.3	50.8
2017	6	30SEP17	04NOV	596	5,194	9,450	31,166	17.3	28.1	30.3	16.7	30.3
2018	6	30SEP18	04NOV	670	17,205	34,813	103,230	16.3	30.5	33.7	16.7	33.7
2000-2018		08SEP	02DEC	4	23,909	206,985	3538543	7.5	22.4	39.9	12.8	53.0

Table 5. Annual migration statistics for Okanagan River adult Sockeye migrants, 2000-2018, documenting survey period and length, mean and maximum weekly migrant and migration rate (%) estimates, and total escapement from weekly observations on the spawning grounds (Survey details: Stockwell et al. 2020; Hyatt and Stockwell 2003).

	Value						Percentiles					
	Dates	Min	Mean	Max	Std	Skew	P5	P10	P25	P50	P90	P95
Year												
1966	62	15	48	104	29.4	0.6	15	16	23	36	93	101
1967	62	15	68	279	62.8	1.7	16	17	25	44	164	207
1968	62	27	71	214	52.3	1.4	27	30	33	49	171	183
1969	62	19	40	81	21.3	0.7	19	20	22	31	76	78
1970	62	8	25	78	17.4	1.5	9	10	12	19	54	62
1971	62	26	93	218	58.3	0.5	28	31	40	76	174	192
1972	62	81	209	501	127.6	0.9	89	95	100	152	425	439
1973	62	10	26	77	17.2	1.2	10	10	14	20	54	62
1974	62	39	163	377	98.2	0.6	45	53	92	131	314	328
1975	62	26	83	205	59.2	0.9	28	31	36	53	180	199
1976	62	89	160	328	75.3	1.0	91	95	102	121	286	303
1977	62	9	19	52	10.6	1.4	10	11	12	14	38	41
1978	62	24	69	195	45.8	1.1	25	27	35	50	142	163
1979	62	11	29	66	18.2	0.8	11	11	15	21	58	64
1980	62	23	57	134	31.6	0.7	24	25	29	45	105	112
1981	62	48	104	196	44.0	0.3	49	54	58	99	163	176
1982	62	69	140	279	66.4	0.8	70	72	91	103	244	263
1983	62	63	114	187	41.4	0.3	65	65	76	102	170	180
1984	62	44	103	300	61.0	1.3	45	47	59	79	199	226
1985	62	11	27	75	17.8	1.2	11	12	15	17	57	63
1986	62	36	66	106	18.9	0.3	41	45	52	60	91	97
1987	62	13	28	54	12.7	0.6	14	14	16	25	47	50
1988	62	11	33	91	23.1	1.0	12	12	14	21	69	78
1989	62	25	51	87	18.8	0.3	26	29	34	50	78	84
1990	62	70	137	294	67.3	1.0	75	79	85	113	254	272
1991	62	44	176	476	121.7	1.2	46	51	99	127	399	442
1992	62	13	38	77	18.8	0.4	14	15	25	34	66	69
1993	62	64	118	204	38.5	0.6	67	69	95	113	180	192
1994	62	14	31	69	18.7	0.9	14	16	17	21	63	65
1995	62	35	59	129	25.9	1.3	36	37	40	49	99	117
1996	62	50	117	279	70.3	1.1	52	54	63	86	238	270
1997	62	89	148	272	58.1	0.7	89	89	97	129	239	246
1998	62	23	67	194	51.5	1.1	23	24	26	43	157	168
1999	62	50	168	311	83.4	0.4	51	71	107	134	300	300
2000	62	24	66	159	43.6	0.9	25	26	29	51	139	147
2001	62	12	26	58	12.0	0.9	13	13	16	23	44	48
2002	62	22	77	263	61.0	1.3	23	24	34	49	163	194
2003	62	9	24	68	16.4	1.1	9	9	11	15	47	56

Table 6. Discharge statistics for observed and estimated data for the months of peak Sockeye migration (July-August) in the lower Okanogan River (near Malott: Station 12447200), 1966-2019. All-year flow rate thresholds: 10^{th} percentile ~20 cms; 90^{th} percentile ~ 170 cms.

	Value						Percentiles					
	Dates	Min	Mean	Max	Std	Skew	P5	P10	P25	P50	P90	P95
Year												
2004	62	19	41	100	21.8	1.1	19	20	23	32	69	87
2005	62	14	50	138	32.6	0.9	15	16	17	49	93	121
2006	62	13	41	124	30.1	0.8	14	14	18	25	82	87
2007	62	20	46	114	26.6	1.0	20	21	23	35	89	101
2008	62	21	59	182	43.9	1.7	22	25	29	43	138	165
2009	62	15	33	72	14.8	0.9	16	16	21	29	54	60
2010	62	26	67	209	43.2	1.5	26	28	37	50	127	161
2011	62	32	165	416	115.4	0.5	36	37	53	147	340	365
2012	62	31	148	337	93.3	0.5	41	47	56	136	272	320
2013	62	29	100	309	73.5	1.3	31	32	42	73	210	260
2014	62	27	71	199	42.5	1.4	29	33	40	57	133	167
2015	62	13	23	55	10.2	1.4	14	15	15	19	37	43
2016	62	22	63	103	29.0	-0.3	23	24	31	78	94	100
2017	62	41	88	168	33.5	0.5	41	44	64	88	134	152
2018	62	23	64	151	41.9	0.7	23	24	28	47	129	140
2019	62	17	32	66	14.8	0.8	18	18	20	26	54	61
All	3348	8	77	501	71.2	2.0	14	17	28	53	171	230

Table 6, cont'd. Discharge statistics for observed and estimated data for the months of peak Sockeye migration (July-August) in the lower Okanogan River (near Malott: Station 12447200), 1966-2019. All-year flow rate thresholds: 10^{th} percentile ~20 cms; 90^{th} percentile ~ 170 cms.

	Value						Percentiles					
	Dates	Min	Mean	Max	Std	Skew	P5	P10	P25	P50	P90	P95
Year												
2001	62	12	26	60	12.7	0.9	13	13	15	22	45	51
2002	62	23	75	243	56.6	1.2	24	24	33	46	164	179
2006	62	15	42	118	30.4	0.9	15	16	19	25	89	93
2007	62	19	46	116	27.9	1.0	19	20	22	32	92	104
2008	62	19	57	181	43.9	1.7	21	24	27	42	135	161
2009	62	15	33	75	15.7	0.9	16	16	21	29	57	63
2010	62	26	69	209	45.2	1.4	27	28	37	51	136	168
2011	62	32	162	413	114.1	0.5	35	37	49	142	337	362
2012	62	29	144	343	95.6	0.5	32	44	51	130	275	314
2013	62	27	93	309	72.9	1.4	28	29	37	64	197	259
2014	62	25	67	186	39.7	1.4	27	31	40	54	123	159
2015	57	14	22	50	8.3	1.3	15	15	16	19	34	39
2016	62	21	62	103	29.4	-0.3	21	22	29	78	92	97
2017	62	38	84	159	32.3	0.5	39	40	60	84	128	144
2019	62	16	32	69	15.7	0.8	17	18	19	26	56	61
All	5389	4	74	479	66.1	2.1	15	18	29	51	159	209

Table 7. Recent discharge statistics for the months of peak Sockeye migration (July-August) in the Okanogan River (near Tonasket: Station 12445000). All-year (1929-2019) observed July-August flow rate thresholds: 10^{th} percentile ~ 18 cms; 90^{th} percentile ~ 159 cms.

--------------- Location=Okanagan River (Oliver) ---------------

The UNIVARIATE Procedure
Variable: Flow (Flow)

Moments

N	6176	Sum Weights	6176
Mean	13.2727504	Sum Observations	81972.5068
Std Deviation	8.02077561	Variance	64.3328414
Skewness	2.72846067	Kurtosis	12.1114396
Uncorrected SS	1485255.92	Corrected SS	397255.296
Coeff Variation	60.4303957	Std Error Mean	0.10206168

Basic Statistical Measures

Location		Variability	
Mean	13.27275	Std Deviation	8.02078
Median	11.30000	Variance	64.33284
Mode	10.80000	Range	71.93000
		Interquartile Range	6.89000

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	130.0464	Pr > |t|	<.0001
Sign	M	3088	Pr >= |M|	<.0001
Signed Rank	S	9537288	Pr >= |S|	<.0001

Quantiles (Definition 5)

Level	Quantile
100% Max	74.20
99%	43.00
95%	26.90
90%	22.50
75% Q3	15.40
50% Median	11.30
25% Q1	8.51
10%	5.97
5%	5.38
1%	3.74
0% Min	2.27

Table 8. All-year discharge statistics for observed data from the spawn migration period (September-November) in the Okanagan River near Oliver (WSC Station 08NM085), 1944-2018.

The NPAR1WAY Procedure

Analysis of Variance for Variable WaterT
Classified by Variable Location

Location	N	Mean
Bonneville	68	18.050077
JohnDay	32	18.016640
McNary	48	17.533021

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Among	2	8.339916	4.169958	0.8782	0.4177
Within	145	688.501413	4.748286		

Wilcoxon Scores (Rank Sums) for Variable WaterT
Classified by Variable Location

Location	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
Bonneville	68	5328.0	5066.0	259.897416	78.352941
JohnDay	32	2495.0	2384.0	214.687370	77.968750
McNary	48	3203.0	3576.0	244.131112	66.729167

Kruskal-Wallis Test

Chi-Square	2.3361
DF	2
Pr > Chi-Square	0.3110

Table 9. Analysis of daily mean water temperatures in lower Columbia River at the Bonneville, John Day, and McNary dam forebays during Sockeye migration (June-July, 2004-2019).

	Water Temperature						Percentiles			
	Dates	Min	Mean	Max	Std	Skew	P25	P50	P75	P95
Year										
1986	61	16.70	18.77	20.50	1.07	-0.41	17.7	19.2	19.7	20.1
1987	61	14.70	18.82	21.50	1.86	-0.60	17.5	19.4	20.3	20.8
1988	61	14.65	18.19	21.86	2.18	-0.22	16.2	18.7	19.5	21.4
1989	61	14.16	18.72	23.10	2.23	0.18	17.6	18.4	20.1	22.8
1990	61	14.33	17.72	21.52	2.36	-0.07	14.9	18.2	19.8	21.2
1991	61	13.48	17.17	20.70	2.29	-0.04	15.1	17.1	19.4	20.1
1992	61	16.67	19.73	22.78	1.75	-0.25	18.3	20.0	21.1	22.2
1993	61	14.83	17.50	19.74	1.43	-0.44	16.4	17.7	18.5	19.4
1994	61	13.88	18.89	23.64	2.50	0.44	16.9	18.2	21.2	23.2
1995	61	15.60	18.15	21.48	1.95	0.33	16.2	17.8	20.1	21.2
1996	61	13.05	17.20	20.91	2.44	0.10	15.2	17.0	19.5	20.8
1997	61	13.99	17.27	21.01	2.18	0.18	15.5	16.6	19.2	20.8
1998	61	13.83	18.45	22.85	2.56	0.06	16.7	18.0	20.8	22.5
1999	61	13.52	16.64	19.77	1.82	0.03	15.2	16.4	18.2	19.7
2000	61	14.68	18.04	21.56	1.91	-0.13	16.4	18.5	19.4	20.7
2001	61	15.80	18.14	20.41	1.46	-0.01	16.8	18.2	19.3	20.3
2002	61	14.25	17.36	20.92	2.15	0.16	15.2	17.5	19.0	20.7
2003	61	14.64	18.34	22.47	2.24	0.23	16.4	18.0	20.3	21.7
2004	61	14.67	18.56	22.15	2.50	-0.17	15.5	19.2	21.0	22.0
2005	61	15.21	18.35	21.89	2.08	-0.02	16.4	18.6	20.1	21.5
2006	61	13.70	18.34	22.09	2.46	-0.14	16.2	18.5	20.4	21.9
2007	61	15.63	18.42	21.47	2.20	0.16	16.1	18.1	21.0	21.4
2008	61	12.92	16.75	20.02	2.55	-0.25	13.9	17.4	19.3	19.8
2009	61	15.32	18.25	23.15	2.15	0.48	16.5	17.7	19.6	22.4
2010	61	13.85	16.96	20.85	2.22	0.29	15.0	16.8	19.0	20.7
2011	61	12.62	15.85	19.24	1.86	-0.06	14.2	15.9	17.5	18.5
2012	61	13.64	16.50	19.64	1.96	0.13	14.8	16.1	18.4	19.4
2013	61	14.00	18.23	21.36	2.09	-0.11	16.8	18.0	20.3	21.1
2014	61	14.78	18.10	21.40	2.17	0.10	16.1	17.9	20.3	21.0
2015	61	17.15	20.81	22.87	1.75	-0.56	19.4	21.4	22.4	22.8
2016	61	15.90	19.02	21.94	1.55	0.06	17.7	19.1	20.2	21.6
2017	61	14.60	18.25	21.89	2.58	-0.12	15.2	18.5	20.6	21.7
2018	61	15.17	18.64	22.50	2.27	-0.06	16.1	18.8	20.4	21.9
2019	61	15.01	18.53	21.48	1.86	-0.05	17.2	18.4	20.3	21.3
All	2074	12.62	18.08	23.64	2.29	-0.03	16.2	18.1	19.9	21.7

Table 10. Annual summary of lower Columbia River daily mean water temperature at the Bonneville Dam forebay during Sockeye migration (June-July) (Source: CBR-DART). MEAN is average of daily mean temperatures from datalogger (1986-2019) for #DATES times per year. MIN and MAX are minimum and maximum of the daily mean temperatures (i.e., not observed extremes).

Monthly and Annual No. Peaks > 20c

		Freq POT20c Dates		Total Days
		Jun	Jul	
Decade	Year			
1980s	1986		6	6
	1987	2	21	23
	1988		12	12
	1989		18	18
1990s	1990		14	14
	1991		5	5
	1992	8	31	39
	1993			
	1994		20	20
	1995		16	16
	1996		10	10
	1997		7	7
	1998		18	18
	1999			
2000s	2000		11	11
	2001		7	7
	2002		11	11
	2003		19	19
	2004		20	20
2000s	2005		16	16
	2006		22	22
	2007		21	21
	2008		1	1
	2009		15	15
2010s	2010		8	8
	2011			
	2012			
	2013		18	18
	2014		20	20
	2015	7	31	38
	2016		21	21
	2017		22	22
	2018		20	20
	2019		19	19

Decadal Mean Monthly MWT Peaks > 20c

Site: Bonneville Forebay

	Years in Decade	Mean No. Days		Mean Annual Total
		Jun	Jul	
Decade				
1980s	3	0.7	15.0	15.7
1990s	8	1.0	12.8	13.8
2000s	10		14.3	14.3
2010s	9	0.8	15.4	16.2

Table 11. Frequency analysis of decadal mean number of dates per month (June-August) in which observed lower Columbia River mean water temperature in the Bonneville Dam forebay exceeded 20°C.

Annual Frequency & Duration of POT20c Events

		POT Event Duration (days)							
		N	Min	P05	P50	P95	Max	Avg	Std
Decade	Year								
1980s	1986	3	1	1	1.0	4	4	2.0	1.7
	1987	3	3	3	8.0	12	12	7.7	4.5
	1989	1	18	18	18.0	18	18	18.0	
	Total	7	1	1	4.0	18	18	6.7	6.4
1990s	Year								
	1992	1	39	39	39.0	39	39	39.0	
	1993	1	0	0	0.0	0	0	0.0	
	1994	1	20	20	20.0	20	20	20.0	
	1995	2	1	1	8.0	15	15	8.0	9.9
	1996	1	10	10	10.0	10	10	10.0	
	1997	1	7	7	7.0	7	7	7.0	
	1998	1	18	18	18.0	18	18	18.0	
	1999	1	0	0	0.0	0	0	0.0	
	Total	9	0	0	10.0	39	39	12.2	12.6
2000s	Year								
	2000	1	11	11	11.0	11	11	11.0	
	2001	1	7	7	7.0	7	7	7.0	
	2002	1	11	11	11.0	11	11	11.0	
	2003	1	19	19	19.0	19	19	19.0	
2000s	2004	1	20	20	20.0	20	20	20.0	
	2005	1	16	16	16.0	16	16	16.0	
	2006	1	22	22	22.0	22	22	22.0	
	2007	1	21	21	21.0	21	21	21.0	
	2008	1	1	1	1.0	1	1	1.0	
	2009	1	15	15	15.0	15	15	15.0	
	Total	10	1	1	15.5	22	22	14.3	6.8
2010s	Year								
	2010	1	8	8	8.0	8	8	8.0	
	2011	1	0	0	0.0	0	0	0.0	
	2012	1	0	0	0.0	0	0	0.0	
	2013	1	18	18	18.0	18	18	18.0	
	2014	1	20	20	20.0	20	20	20.0	
	2015	1	38	38	38.0	38	38	38.0	
	2016	2	8	8	10.5	13	13	10.5	3.5
	2017	2	2	2	11.0	20	20	11.0	12.7
	2019	1	19	19	19.0	19	19	19.0	
	Total	11	0	0	13.0	38	38	13.3	11.4
Total		37	0	0	11.0	38	39	12.1	9.8

Table 12. Min., mean and max. length (days) and total frequency of periods in which observed lower Columbia River mean water temperature in the BONNEVILLE DAM forebay continuously exceeded 20°C, by decade.

	Water Temperature						Percentiles			
	Dates	Min	Mean	Max	Std	Skew	P25	P50	P75	P95
Year										
1993	62	14.50	17.09	18.30	1.00	-0.82	16.2	17.5	17.8	18.2
1994	62	15.00	17.52	19.40	1.36	-0.56	16.4	17.8	18.8	19.0
1995	62	15.00	17.49	19.00	1.18	-0.51	16.4	17.8	18.4	18.9
1996	62	14.50	16.73	18.30	1.24	-0.44	15.6	17.2	17.8	18.3
1997	62	15.00	16.98	18.90	1.35	-0.06	15.6	17.1	18.3	18.9
1998	62	15.46	18.67	20.76	1.54	-0.52	17.2	19.1	19.9	20.3
1999	62	14.44	16.96	18.90	1.52	-0.37	15.6	17.2	18.3	18.9
2000	62	14.48	17.22	18.99	1.37	-0.55	16.2	17.5	18.5	18.7
2001	62	13.85	16.41	18.31	1.05	-0.14	15.7	16.3	17.4	17.9
2002	62	13.79	17.25	19.20	1.54	-0.62	16.3	17.4	18.6	19.2
2003	62	15.13	18.11	20.15	1.47	-0.54	16.9	18.5	19.4	19.8
2004	62	15.61	17.98	19.99	1.45	-0.44	17.1	18.3	19.4	19.7
2005	62	15.53	17.79	19.39	1.33	-0.31	16.6	18.1	19.1	19.4
2006	62	15.50	18.11	19.87	1.32	-0.35	16.8	18.4	19.4	19.8
2007	62	15.25	17.84	19.74	1.38	-0.29	16.5	18.2	19.0	19.7
2008	62	14.16	17.38	19.67	1.59	-0.50	16.1	17.9	18.8	19.4
2009	62	15.36	17.43	19.11	1.08	-0.51	16.5	17.6	18.3	18.9
2010	62	13.93	17.15	19.09	1.48	-0.73	15.9	17.6	18.4	18.8
2011	62	12.99	16.40	18.76	1.69	-0.41	14.9	16.8	17.8	18.6
2012	62	13.23	16.45	18.20	1.55	-0.72	15.2	17.2	17.9	18.1
2013	62	15.61	18.15	19.96	1.31	-0.49	16.7	18.3	19.3	19.7
2014	62	14.93	17.83	19.55	1.47	-0.47	16.4	18.6	19.2	19.4
2015	62	17.27	18.77	19.96	0.87	-0.41	17.7	19.0	19.5	19.8
2016	62	15.83	17.85	19.22	1.01	-0.45	16.8	18.3	18.6	19.1
2017	62	15.50	17.92	19.82	1.28	-0.11	17.0	17.9	19.2	19.7
2018	62	15.00	17.96	19.50	1.21	-0.88	17.3	18.4	19.0	19.2
2019	62	15.09	17.66	19.21	1.19	-0.54	16.8	17.9	18.7	19.1
All	1674	12.99	17.52	20.76	1.47	-0.43	16.4	17.8	18.7	19.6

Table 13. Annual summary of Columbia River daily mean water temperature at the Wells Dam forebay during Sockeye migration (July-August). MEAN is average of daily mean temperatures from datalogger (1993-2019) for #DATES times per year. MIN and MAX are minimum and maximum of the daily mean temperatures (i.e., not observed extremes).

Monthly and Annual No. Peaks > 18c

		Freq POT18c Dates				Total Days
		Jul	Aug	Sep	Oct	
Decade	Year					
1990s	1993		10	9	1	20
	1994		27	30	9	66
	1995		27	26		53
	1996		10	4		14
	1997		18	27		45
	1998	10	31	30	13	84
	1999		22	16		38
2000s	2000		26	24		50
	2001		3	16		19
	2002		23	17		40
	2003	6	31	19		56
	2004	3	31	16		50
	2005	1	31	16		48
	2006	8	31	18		57
	2007	3	31	17		51
	2008	1	26	16		43
	2009		19	26		45
2010s	2010		22	29		51
	2011		10	15		25
2010s	2012		8	18		26
	2013	9	31	29		69
	2014	3	31	30	12	76
	2015	14	31	23		68
	2016	5	31	30	3	69
	2017	1	30	30	1	62
	2018	4	31	28		63
	2019		30	27		57

Site: Wells Forebay

	Years in Decade	Mean No. Days				Mean Annual Total
		Jul	Aug	Sep	Oct	
Decade						
1990s	7	1.4	20.7	20.3	3.3	45.7
2000s	10	2.2	25.2	18.5		45.9
2010s	9	3.6	24.9	25.7	1.8	55.9

Table 14. Frequency analysis of decadal mean number of dates per month (July-October) in which observed Columbia River mean water temperature in the WELLS DAM forebay exceeded 18°C.

		POT Event Duration (days)							
		N	Min	P05	P50	P95	Max	Avg	Std
Decade	Year								
1990s	1993	6	1	1	2.5	7	7	3.2	2.1
	1994	1	66	66	66.0	66	66	66.0	
	1995	3	1	1	7.0	45	45	17.7	23.9
	1996	3	1	1	2.0	11	11	4.7	5.5
	1997	2	1	1	22.5	44	44	22.5	30.4
	1998	1	84	84	84.0	84	84	84.0	
	1999	3	1	1	14.0	23	23	12.7	11.1
	Total	19	1	1	4.0	84	84	16.8	24.7
2000s	Year								
	2000	3	3	3	13.0	34	34	16.7	15.8
	2001	2	9	9	9.5	10	10	9.5	0.7
	2002	1	40	40	40.0	40	40	40.0	
	2003	1	56	56	56.0	56	56	56.0	
	2004	2	2	2	25.0	48	48	25.0	32.5
	2005	1	48	48	48.0	48	48	48.0	
	2006	1	57	57	57.0	57	57	57.0	
	2007	1	51	51	51.0	51	51	51.0	
	2008	3	1	1	3.0	39	39	14.3	21.4
	2009	4	1	1	4.0	36	36	11.3	16.6
2010s	Year								
	2010	2	4	4	25.5	47	47	25.5	30.4
	2011	2	1	1	12.5	24	24	12.5	16.3
	2012	3	7	7	7.0	12	12	8.7	2.9
	2013	2	9	9	34.5	60	60	34.5	36.1
	2014	1	76	76	76.0	76	76	76.0	
	2015	1	68	68	68.0	68	68	68.0	
	2016	2	1	1	34.5	68	68	34.5	47.4
	2017	3	1	1	4.0	57	57	20.7	31.5
	2019	1	57	57	57.0	57	57	57.0	
	Total	17	1	1	12.0	76	76	29.6	28.9
Total		55	1	1	9.0	68	84	23.3	25.2

Table 15. Min., mean and max. length (days) and total frequency of periods in which observed Columbia River mean water temperature in the WELLS DAM forebay continuously exceeded 18°C, July-October, by decade.

	Water Temperature						Percentiles			
	Dates	Min	Mean	Max	Std	Skew	P25	P50	P75	P95
Year										
2005	36	20.33	23.05	25.10	1.29	-0.42	22.1	23.2	24.2	24.8
2006	54	17.53	22.30	26.69	1.84	0.57	21.1	21.9	22.9	26.1
2008	62	18.76	22.13	26.18	1.65	0.30	20.9	22.0	23.4	24.8
2009	62	19.25	23.01	26.99	1.96	0.41	21.6	22.8	24.1	26.7
2010	62	16.50	21.90	24.94	2.38	-0.87	20.5	22.5	23.9	24.5
2011	62	12.98	18.65	22.94	2.98	-0.23	15.8	19.6	21.3	22.7
2012	62	15.29	21.45	24.11	2.22	-1.23	20.5	22.0	23.2	23.8
2013	62	19.22	22.48	24.86	1.47	0.12	21.2	22.3	23.9	24.8
2014	62	16.56	21.74	23.96	1.74	-1.16	20.9	22.3	23.1	23.7
2015	62	18.12	23.72	27.08	2.37	-0.88	22.7	24.4	25.4	26.6
2016	62	19.91	22.33	25.20	1.38	0.27	21.2	22.1	23.4	24.7
2017	62	21.16	23.02	24.38	0.81	-0.58	22.7	23.0	23.6	24.2
2018	54	17.14	22.20	25.44	2.58	-0.67	19.6	23.2	24.1	25.4
2019	62	20.59	22.69	25.24	1.20	0.09	21.7	22.7	23.6	24.6
All	826	12.98	22.16	27.08	2.25	-0.99	21.1	22.5	23.6	25.2

Table 16. Annual summary of observed daily mean water temperature data for Okanogan River (at Malott, WA) during Sockeye migration (July-August) (Source: WA Dept. of Ecology: 2005-2006; USGS: 2008-2019). MEAN is average of daily mean temperatures from datalogger readings for #DATES times per year. MIN and MAX refer to daily mean temperatures (i.e., not observed extremes). Data commenced on July 27th in 2005; July 9th in 2006; July 12th in 2018.

	Water Temperature						Percentiles			
	Dates	Min	Mean	Max	Std	Skew	P25	P50	P75	P95
Year										
2008	62	18.90	21.86	23.74	1.04	-0.60	21.2	22.0	22.6	23.2
2009	62	19.55	22.57	25.74	1.56	0.29	21.3	22.7	23.4	25.3
2010	62	18.44	21.96	23.81	1.54	-0.95	21.2	22.6	23.1	23.6
2011	62	17.47	20.90	22.79	1.21	-0.36	20.1	20.9	22.0	22.7
2012	62	17.74	22.29	24.29	1.66	-1.30	21.4	22.8	23.4	24.0
2013	62	20.90	22.86	25.30	1.18	0.08	21.9	22.9	23.7	24.9
2014	62	20.40	23.06	25.20	1.20	-0.55	22.1	23.5	23.9	24.5
2015	62	18.10	22.79	25.30	1.57	-0.86	22.1	23.0	24.0	25.0
2016	62	20.67	22.02	24.48	0.93	0.62	21.3	21.9	22.6	23.6
2017	62	20.63	22.31	23.48	0.65	-0.40	21.9	22.4	22.9	23.2
2018	62	18.17	21.51	24.08	1.85	-0.46	20.2	21.7	23.0	23.9
All	682	17.47	22.19	25.74	1.47	-0.52	21.4	22.4	23.2	24.3

	Water Temperature						Percentiles			
	Dates	Min	Mean	Max	Std	Skew	P25	P50	P75	P95
Year										
2008	61	4.70	9.52	15.93	3.08	0.40	6.9	9.0	11.9	15.7
2009	61	3.10	8.78	15.25	2.94	0.40	6.1	8.4	10.9	14.0
2010	61	0.26	9.76	16.52	4.52	-0.55	7.9	10.6	12.5	16.3
2011	61	3.96	8.96	15.32	3.63	0.14	5.7	9.1	12.1	14.5
2012	61	4.91	10.10	16.41	3.12	0.06	7.2	10.3	13.2	14.1
2013	61	3.74	9.09	13.70	3.08	-0.38	7.3	9.2	11.6	12.9
2014	61	0.36	10.21	16.00	4.45	-0.43	5.1	11.0	14.1	15.7
2015	61	2.42	10.12	15.00	3.68	-0.58	7.4	11.2	13.3	14.6
2016	61	7.25	10.93	15.94	2.13	0.50	9.4	10.9	11.6	15.1
2017	61	5.18	8.74	15.09	2.96	0.45	6.0	8.7	11.0	13.8
2018	61	5.19	9.66	14.79	2.80	-0.22	6.8	10.5	11.6	13.3
All	671	0.26	9.62	16.52	3.42	-0.17	6.8	10.1	12.0	15.1

Table 17. Annual summary of observed daily mean water temperature data for Okanagan River (at Oliver) during Sockeye spawn migration (July-August, top; October-November, bottom). MEAN is average of daily mean temperatures from datalogger readings for #DATES. MIN and MAX refer to daily mean temperatures (i.e., not observed extremes).

	Calibration		Validation	
	Warming	Cooling	Warming	Cooling
	Observations	Observations	Observations	Observations
Year				
2005			3	63
2006			21	63
2007			0	56
2008	121	119		
2009	121	119		
2010			121	119
2011			121	119
2012			121	119
2013	121	119		
2014	121	119		
2015	121	119		
2016			121	119
2017	121	119		
2018	113	116		

	Calibration		Validation	
	Warming	Cooling	Warming	Cooling
	Observations	Observations	Observations	Observations
Year				
2008			118	112
2009	128	112		
2010	128	112		
2011			125	112
2012	128	112		
2013			128	112
2014	128	112		
2015	128	112		
2016			128	112
2017	128	112		
2018			128	112

Table 18. Number of annual water temperature observations available for Okanagan River air/water temperature analyses (at Malott (top); at Oliver (bottom)), partitioned into warming and cooling seasons for seasonal relationships. Air/water temperature model calibration data years were selected based on strength of association between air and water time-series and range of temperature observations.

OKMalott Air/Water Logistic (Intercept) Model - Warming Season 2005-2018 - Calibration

------------------------- Site=OKMalott Dataset=Calibration -------------------------

The NLIN Procedure

Source	DF	Sum of Squares	Mean Square	F Value	Approx Pr > F
Model	3	18484.8	6161.6	1469.63	<.0001
Error	835	3500.8	4.1926		
Corrected Total	838	21985.6			

Parameter	Estimate	Approx Std Error	Approximate 95% Confidence Limits	
alpha	25.9324	0.5646	24.8243	27.0405
beta	21.7925	0.2385	21.3244	22.2607
gamma	0.3792	0.0256	0.3289	0.4295
mu	10.3253	0.1614	10.0085	10.6422

OKMalott Air/Water Logistic (Intercept) Model - Cooling Season 2005-2018 - Calibration

------------------------- Site=OKMalott Dataset=Calibration -------------------------

The NLIN Procedure

Parameter	Estimate	Approx Std Error	Approximate 95% Confidence Limits	
alpha	29.2683	0.6433	28.0056	30.5311
beta	10.6185	0.3293	9.9722	11.2648
gamma	0.1135	0.00623	0.1013	0.1258
mu	-4.7441	0.9594	-6.6272	-2.8610

Source	DF	Sum of Squares	Mean Square	F Value	Approx Pr > F
Model	3	37419.1	12473.0	11258.6	<.0001
Error	826	915.1	1.1079		
Corrected Total	829	38334.2			

Season Numerator	Season Denominator	NSC Season Data	NSC All Data	NSC Season - NSC All	Result
4415.93	60319.83	0.92679	-5.44521	6.37200	Hysteresis detected

Table 19. Logistic regression output for air/water temperature relationship between the MALOTT AWN 7d-CMAT (air temperature index) and calibration data for Okanogan River (at Malott, WA) daily mean water temperatures: warming season (top); cooling season (bottom).

Dataset: Calibration

	Days	Observed	Estimated	O-E	O-E (%)
Year					
2008	62	57	39	18	32
2009	62	60	50	10	17
2013	62	61	61	0	0
2014	62	53	57	-4	-8
2015	62	53	56	-3	-6
2017	62	62	62	0	0
2018	54	39	44	-5	-13
Total	426	385	369	2	3

Dataset: Validation

	Days	Observed	Estimated	O-E	O-E (%)
Year					
2005	36	36	36	0	0
2006	54	51	42	9	18
2010	62	49	43	6	12
2011	62	28	33	-5	-18
2012	62	53	47	6	11
2016	62	61	40	21	34
Total	338	278	241	6	10

-------------------- Dataset=Calibration ----------------------

The TTEST Procedure

Difference: POT20_Obs - POT20_Est

N	Mean	Std Dev	Std Err	Minimum	Maximum
7	2.2857	8.5384	3.2272	-5.0000	18.0000

Mean	95% CL Mean		Std Dev	95% CL Std Dev	
2.2857	-5.6110	10.1824	8.5384	5.5021	18.8022

DF	t Value	Pr > |t|
6	0.71	0.5054

--------------------- Dataset=Validation ---------------------

The TTEST Procedure

Difference: POT20_Obs - POT20_Est

N	Mean	Std Dev	Std Err	Minimum	Maximum
6	6.1667	8.8412	3.6094	-5.0000	21.0000

Mean	95% CL Mean		Std Dev	95% CL Std Dev	
6.1667	-3.1116	15.4449	8.8412	5.5187	21.6840

DF	t Value	Pr > |t|
5	1.71	0.1482

Table 20. Comparison of annual frequency of observed versus estimated POT_{20} dates based on logistic regression model output for July-August in the Okanogan River (at Malott, WA) for calibration and validation years. T-tests indicate no overall difference (Pr > | t | > 0.05) in annual frequency in calibration or validation datasets using seasonal model parameters in Table 19.

OKOliver Air/Water Logistic (Intercept) Model - Warming Season 2008-2018 - Calibration

---------------------------- Site=OKOliver Dataset=Calibration ----------------------------

Source	DF	Sum of Squares	Mean Square	F Value	Approx Pr > F
Model	3	22270.9	7423.6	4123.30	<.0001
Error	764	1375.5	1.8004		
Corrected Total	767	23646.4			

Parameter	Estimate	Approx Std Error	Approximate 95% Confidence Limits	
alpha	26.8870	0.5449	25.8173	27.9567
beta	19.0404	0.2086	18.6308	19.4499
gamma	0.2272	0.0145	0.1987	0.2557
mu	6.7451	0.3880	5.9835	7.5068

OKOliver Air/Water Logistic (Intercept) Model - Cooling Season 2008-2018 - Calibration

---------------------------- Site=OKOliver Dataset=Calibration ----------------------------

Source	DF	Sum of Squares	Mean Square	F Value	Approx Pr > F
Model	3	21481.3	7160.4	5810.54	<.0001
Error	668	823.2	1.2323		
Corrected Total	671	22304.5			

Parameter	Estimate	Approx Std Error	Approximate 95% Confidence Limits	
alpha	29.4052	0.9363	27.5667	31.2436
beta	13.9038	0.3754	13.1667	14.6409
gamma	0.1210	0.00811	0.1051	0.1369
mu	0.3388	0.7259	-1.0865	1.7641

Goodness of Fit for Season Data & Hysteresis Check against NSC for All Data

---------------------------- Site=OKOliver Dataset=Calibration ----------------------------

Obs	Season Numerator	Season Denominator	NSC Season Data	NSC All Data	NSC Season - NSC All	Result
1	2198.70	45950.95	0.95215	0.91359	0.038561	Hysteresis detected

Table 21. Logistic regression output for air/water temperature relationship between the OLIVER STP 7d-CMAT (air temperature index) and calibration data for Okanagan River (at Oliver) daily mean water temperatures: seasons combined (top); warming season (middle); cooling season (bottom). Hysteresis detected.

OKMalott Air/Water Linear Model - Warming Season 2005-2018 - Calibration

------------------------------------ Site=OKMalott Dataset=Calibration Season=Warming ---------------------------------

The REG Procedure
Model: MODEL1
Dependent Variable: WaterT Daily MWT

Number of Observations Read 839
Number of Observations Used 839

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	16963	16963	2826.69	<.0001
Error	837	5022.78797	6.00094		
Corrected Total	838	21986			

Root MSE	2.44968	R-Square	0.7715
Dependent Mean	15.18005	Adj R-Sq	0.7713
Coeff Var	16.13751		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	95% Confidence Limits	
Intercept	Intercept	1	1.73957	0.26657	6.53	<.0001	1.21634	2.26279
Malott_7DMAT	7d-MAT	1	0.75831	0.01426	53.17	<.0001	0.73032	0.78631

------------------------------------ Site=OKMalott Dataset=Calibration Season=Cooling ---------------------------------

The REG Procedure
Model: MODEL1
Dependent Variable: WaterT Daily MWT

Number of Observations Read 830
Number of Observations Used 830

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	37239	37239	28164.7	<.0001
Error	828	1094.78467	1.32220		
Corrected Total	829	38334			

Root MSE	1.14987	R-Square	0.9714
Dependent Mean	14.88373	Adj R-Sq	0.9714
Coeff Var	7.72569		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	95% Confidence Limits	
Intercept	Intercept	1	3.19004	0.08030	39.73	<.0001	3.03243	3.34766
Malott_7DMAT	7d-MAT	1	0.84575	0.00504	167.82	<.0001	0.83585	0.85564

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Malott_7DMAT	1	54058.30906	54058.30906	14383.3	<.0001
Season	1	3204.29334	3204.29334	852.56	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Malott_7DMAT	1	2907.338780	2907.338780	791.28	<.0001
Season	1	125.842658	125.842658	34.25	<.0001
Malott_7DMAT*Season	1	143.947560	143.947560	39.18	<.0001

Table 22. Linear regression output for air/water temperature relationship between the MALOTT 7d-CMAT (air temperature index) and calibration data for Okanogan River (at Malott, WA) daily mean water temperatures: warming season (top); cooling season (middle). Type III sum of squares for season effect and season interaction effect are highly significant (bottom), indicating that seasonal regression slopes and intercepts are significantly different; therefore hysteresis exists and seasonal models provide the best fit to the data.

------------------- Site=OKOliver Dataset=Calibration Season=Warming ---------------------

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	9358.96513	9358.96513	4855.75	<.0001
Error	379	730.48384	1.92740		
Corrected Total	380	10089			

Root MSE	1.38831	R-Square	0.9276
Dependent Mean	15.46847	Adj R-Sq	0.9274
Coeff Var	8.97508		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	0.92457	0.22050	4.19	<.0001
Oliver_7DMAT	7d-MAT	1	0.85724	0.01230	69.68	<.0001

------------------- Site=OKOliver Dataset=Calibration Season=Cooling ---------------------

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	11256	11256	7627.78	<.0001
Error	334	492.87057	1.47566		
Corrected Total	335	11749			

Root MSE	1.21477	R-Square	0.9580
Dependent Mean	14.75725	Adj R-Sq	0.9579
Coeff Var	8.23167		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	4.36573	0.13619	32.06	<.0001
Oliver_7DMAT	7d-MAT	1	0.76026	0.00870	87.34	<.0001

--------------------------- Site=OKOliver Dataset=Calibration -----------------------------

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	20705.29715	6901.76572	4022.51	<.0001
Error	713	1223.35441	1.71578		
Corrected Total	716	21928.65156			

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Oliver_7DMAT	1	2491.651447	2491.651447	1452.19	<.0001
Season	1	313.305826	313.305826	182.60	<.0001
Oliver_7DMAT*Season	1	72.407471	72.407471	42.20	<.0001

Table 23. Linear regression output for air/water temperature relationship between the OLIVER STP 7d-CMAT (air temperature index) and calibration data for Okanagan River (at Oliver) daily mean water temperatures: warming season (top); cooling season (middle). Type III sum of squares for season effect and season interaction effect are highly significant (bottom), indicating that seasonal slopes are significantly different; therefore hysteresis exists and seasonal models provide the best fit to the data.

--------- Site=OKMalott Dataset=Validation Season=Warming ----------

Pearson Correlation Coefficients, N = 294
Prob > |r| under H0: Rho=0

	Logistic Model Water Temp	Linear Model Water Temp
WaterT Daily MWT	0.92558	0.85118
	<.0001	<.0001

Spearman Correlation Coefficients, N = 294
Prob > |r| under H0: Rho=0

	Logistic Model Water Temp	Linear Model Water Temp
WaterT Daily MWT	0.89120	0.89120
	<.0001	<.0001

--------- Site=OKMalott Dataset=Validation Season=Cooling ----------

Pearson Correlation Coefficients, N = 392
Prob > |r| under H0: Rho=0

	Logistic Model Water Temp	Linear Model Water Temp
WaterT Daily MWT	0.98590	0.98572
	<.0001	<.0001

Spearman Correlation Coefficients, N = 392
Prob > |r| under H0: Rho=0

	Logistic Model Water Temp	Linear Model Water Temp
WaterT Daily MWT	0.98117	0.98117
	<.0001	<.0001

Table 24. Comparison of Pearson (least squares) and Spearman (rank) correlation coefficients for observed versus estimated (from logistic and linear models) daily mean water temperature for air/water temperature relationships for validation data years (Table 18) in Okanogan River (at Malott, BC): warming season (top); cooling season (bottom). Analysis indicates improved predictive power for the logistic model type, especially in warming season.

Dataset: Calibration

	Days	Observed	Estimated	O-E	O-E (%)
Year					
2008	62	57	28	29	51
2009	62	60	41	19	32
2013	62	61	55	6	10
2014	62	53	52	1	2
2015	62	53	52	1	2
2017	62	62	54	8	13
2018	54	39	42	-3	-8
Total	426	385	324	9	14

Dataset: Validation

	Days	Observed	Estimated	O-E	O-E (%)
Year					
2005	36	36	31	5	14
2006	54	51	36	15	29
2010	62	49	31	18	37
2011	62	28	33	-5	-18
2012	62	53	39	14	26
2016	62	61	38	23	38
Total	338	278	208	12	21

-------------------- Dataset=Calibration --------------------

The TTEST Procedure

Difference: POT20_Obs - POT20_Est

N	Mean	Std Dev	Std Err	Minimum	Maximum
7	8.7143	11.4122	4.3134	-3.0000	29.0000

Mean	95% CL Mean		Std Dev	95% CL Std Dev	
8.7143	-1.8402	19.2688	11.4122	7.3539	25.1304

DF	t Value	Pr > |t|
6	2.02	0.0899

-------------------- Dataset=Validation --------------------

The TTEST Procedure

Difference: POT20_Obs - POT20_Est

N	Mean	Std Dev	Std Err	Minimum	Maximum
6	11.6667	10.0731	4.1123	-5.0000	23.0000

Mean	95% CL Mean		Std Dev	95% CL Std Dev	
11.6667	1.0956	22.2377	10.0731	6.2877	24.7053

DF	t Value	Pr > |t|
5	2.84	0.0364

Table 25. Comparison of annual frequency of $POT_{>20}$ for observed versus estimated (from linear model) daily mean water temperature in Okanogan River at Malott (July/August only). Calibration years (top), validation years (bottom).

--- Site=OKOliver Dataset=Validation Season=Warming ---

Pearson Correlation Coefficients
Prob > |r| under H0: Rho=0
Number of Observations

	Logistic Model Water Temp	Linear Model Water Temp
WaterT Daily MWT	0.96265 <.0001 245	0.94631 <.0001 245

Spearman Correlation Coefficients
Prob > |r| under H0: Rho=0
Number of Observations

	Logistic Model Water Temp	Linear Model Water Temp
WaterT Daily MWT	0.95373 <.0001 245	0.95373 <.0001 245

--- Site=OKOliver Dataset=Validation Season=Cooling ---

Pearson Correlation Coefficients
Prob > |r| under H0: Rho=0
Number of Observations

	Logistic Model Water Temp	Linear Model Water Temp
WaterT Daily MWT	0.98418 <.0001 223	0.98229 <.0001 223

Spearman Correlation Coefficients
Prob > |r| under H0: Rho=0
Number of Observations

	Logistic Model Water Temp	Linear Model Water Temp
WaterT Daily MWT	0.97545 <.0001 223	0.97545 <.0001 223

Table 26. Comparison of Pearson (least squares) and Spearman (rank) correlation coefficients for observed versus estimated (from logistic and linear models) daily mean water temperature for air/water temperature relationships for validation data years (Table 18) in Okanagan River (at Oliver): warming season (top); cooling season (bottom). Analysis indicates marginally improved predictive power for the logistic model type.

Monthly and Annual No. Peaks > 18c

		Freq POT18c Dates				Total Days
		Jul	Aug	Sep	Oct	
Decade	Year					
1990s	1993		10	9	1	20
	1994		27	30	9	66
	1995		27	26		53
	1996		10	4		14
	1997		18	27		45
	1998	10	31	30	13	84
	1999		22	16		38
2000s	2000		26	24		50
	2001		3	16		19
	2002		23	17		40
	2003	6	31	19		56
	2004	3	31	16		50
	2005	1	31	16		48
	2006	8	31	18		57
	2007	3	31	17		51
	2008	1	26	16		43
	2009		19	26		45
2010s	2010		22	29		51
	2011		10	15		25
2010s	2012		8	18		26
	2013	9	31	29		69
	2014	3	31	30	12	76
	2015	14	31	23		68
	2016	5	31	30	3	69
	2017	1	30	30	1	62
	2018	4	31	28		63
	2019		30	27		57

Decadal Mean Monthly MWT Peaks > 18c

Site: Wells Forebay

	Years in Decade	Mean No. Days				Mean Annual Total
		Jul	Aug	Sep	Oct	
Decade						
1990s	7	1.4	20.7	20.3	3.3	45.7
2000s	10	2.2	25.2	18.5		45.9
2010s	10	3.6	25.5	25.9	1.6	56.6

Table 27. Frequency analysis of decadal mean number of dates per month (July-October) in which estimated mean water temperature exceeded 18°C in the Wells Dam forebay.

Annual Frequency & Duration of POT18c Events

		POT Event Duration (days)							
		N	Min	P05	P50	P95	Max	Avg	Std
Decade	Year								
1990s	1993	6	1	1	2.5	7	7	3.2	2.1
	1994	1	66	66	66.0	66	66	66.0	
	1995	3	1	1	7.0	45	45	17.7	23.9
	1996	3	1	1	2.0	11	11	4.7	5.5
	1997	2	1	1	22.5	44	44	22.5	30.4
	1998	1	84	84	84.0	84	84	84.0	
	1999	3	1	1	14.0	23	23	12.7	11.1
	Total	19	1	1	4.0	84	84	16.8	24.7
2000s	Year								
	2000	3	3	3	13.0	34	34	16.7	15.8
	2001	2	9	9	9.5	10	10	9.5	0.7
	2002	1	40	40	40.0	40	40	40.0	
	2003	1	56	56	56.0	56	56	56.0	
	2004	2	2	2	25.0	48	48	25.0	32.5
	2005	1	48	48	48.0	48	48	48.0	
	2006	1	57	57	57.0	57	57	57.0	
	2007	1	51	51	51.0	51	51	51.0	
	2008	3	1	1	3.0	39	39	14.3	21.4
	2009	4	1	1	4.0	36	36	11.3	16.6
2000s		19	1	1	13.0	57	57	24.2	21.7
2010s	Year								
	2010	2	4	4	25.5	47	47	25.5	30.4
	2011	2	1	1	12.5	24	24	12.5	16.3
	2012	3	7	7	7.0	12	12	8.7	2.9
	2013	2	9	9	34.5	60	60	34.5	36.1
	2014	1	76	76	76.0	76	76	76.0	
	2015	1	68	68	68.0	68	68	68.0	
	2016	2	1	1	34.5	68	68	34.5	47.4
	2017	3	1	1	4.0	57	57	20.7	31.5
	2018	1	63	63	63.0	63	63	63.0	
	2019	1	57	57	57.0	57	57	57.0	
	Total	18	1	1	18.0	76	76	31.4	29.1
Total		56	1	1	9.5	68	84	24.0	25.6

Table 28. Min., median, mean and max. length (days) and total frequency of periods in which estimated mean water temperature (July-October) continuously exceeded 18°C in the Wells Dam forebay, by decade.

Decadal Mean Monthly MAT Peaks > 20c

Site: Oliver AHCCD

	Years in Decade	Mean No. Days				Mean Annual Total
		Jun	Jul	Aug	Sep	
Decade						
1920s	6	11.5	25.7	19.5	2.5	59.2
1930s	10	12.0	24.7	23.0	6.9	66.6
1940s	10	11.4	24.8	20.3	4.0	60.5
1950s	10	8.9	21.9	18.1	4.3	53.2
1960s	10	13.6	24.1	20.1	5.6	63.4
1970s	10	10.2	21.6	18.8	1.5	52.1
1980s	10	10.2	18.7	18.3	2.9	50.1
1990s	10	9.6	22.5	21.1	5.6	58.8
2000s	10	12.7	27.0	23.8	5.6	69.1
2010s	9	11.3	26.9	26.8	5.6	70.6

Decadal Mean Monthly MAT Peaks > 20c

Site: Malott AWN Air

	Years in Decade	Mean No. Days				Mean Annual Total
		Jun	Jul	Aug	Sep	
Decade						
1920s	6	10.8	24.8	18.3	2.2	56.2
1930s	10	11.1	23.8	22.0	6.0	62.9
1940s	10	9.3	23.1	18.4	3.0	53.8
1950s	10	7.7	21.0	16.3	3.6	48.6
1960s	10	12.3	22.5	19.4	4.5	58.7
1970s	10	9.3	20.4	17.7	1.3	48.7
1980s	10	9.6	18.1	17.3	2.2	47.2
1990s	10	8.8	22.1	20.8	4.7	56.4
2000s	10	12.3	26.7	23.4	5.2	67.6
2010s	9	11.2	26.4	26.2	5.3	69.2

Annual Frequency & Mean Duration (days) for POT20c Events

Site: Oliver AHCCD

	POT Event Duration (days)							
	N	Min	P05	P50	P95	Max	Avg	Std
Decade								
1920s	47	1	1	7.6	29	57	7.6	10.5
1930s	101	1	1	6.2	21	42	6.2	7.4
1940s	94	1	1	6.0	21	37	6.0	7.3
1950s	94	1	1	5.5	19	44	5.5	6.7
1960s	94	1	1	6.5	25	48	6.5	8.1
1970s	76	0	1	6.8	23	36	6.8	7.5
1980s	95	1	1	5.2	19	42	5.2	6.7
1990s	73	1	1	7.7	28	34	7.7	7.9
2000s	77	1	1	8.8	33	52	8.8	10.1
2010s	59	1	1	10.5	49	63	10.5	15.2
Total	810	0	1	6.9	25	63	6.9	8.7

Annual Frequency & Mean Duration (days) for POT20c Events

Site: Malott AWN Air

	POT Event Duration (days)							
	N	Min	P05	P50	P95	Max	Avg	Std
Decade								
1920s	49	1	1	6.5	28	43	6.5	8.5
1930s	103	1	1	5.6	19	29	5.6	5.9
1940s	94	1	1	5.4	21	37	5.4	7.0
1950s	88	1	1	5.1	18	25	5.1	5.5
1960s	94	1	1	5.9	21	47	5.9	7.2
1970s	78	0	1	5.9	23	34	5.9	7.0
1980s	92	1	1	4.8	18	41	4.8	6.2
1990s	74	1	1	7.1	26	34	7.1	7.5
2000s	84	1	1	7.5	24	50	7.5	8.9
2010s	59	1	1	9.9	49	62	9.9	14.1
Total	815	0	1	6.2	22	62	6.2	7.8

Table 29. Frequency analysis of decadal mean number of dates per month (June-October) in which estimated mean air temperature at exceeded 20°C at OLIVER AHCCD and MALOTT AWN stations. (top); Min., mean and max. length (days) and total frequency of periods in which estimated mean air temperature continuously exceeded 20°C, by decade (bottom).

Decadal Mean Monthly Peaks > 20c

Site: Okanogan River @ Malott

	Years in Decade	Mean No. Days				Mean Annual Total
		Jun	Jul	Aug	Sep	
Decade						
1920s	6	4.0	14.8	23.7	1.8	44.3
1930s	10	1.5	14.5	27.0	5.9	48.9
1940s	10	0.9	12.9	22.4	2.8	39.0
1950s	10	0.8	9.3	21.0	3.7	34.8
1960s	10	3.2	11.9	23.2	4.9	43.2
1970s	10	1.5	9.6	20.9	0.2	32.2
1980s	10	1.4	7.4	21.1	2.1	32.0
1990s	10	0.9	10.2	22.8	5.1	39.0
2000s	10	2.4	19.0	27.3	4.4	53.1
2010s	9	3.9	21.0	28.8	5.8	59.4

	POT Event Duration (days)							
	N	Min	P05	P50	P95	Max	Avg	Std
Decade								
1920s	19	1	1	11.9	41	41	11.9	11.3
1930s	24	1	1	17.2	46	47	17.2	14.5
1940s	24	2	2	14.7	34	38	14.7	12.4
1950s	19	1	1	15.9	49	49	15.9	15.5
1960s	24	1	1	14.5	33	48	14.5	13.1
1970s	20	1	2	15.2	46	46	15.2	13.2
1980s	20	1	2	14.2	33	33	14.2	10.1
1990s	21	1	1	15.7	46	47	15.7	13.5
2000s	27	2	2	17.1	42	55	17.1	14.6
2010s	17	2	2	26.4	62	62	26.4	18.2
Total	215	1	1	16.1	46	62	16.1	13.8

Table 30. Frequency analysis of decadal mean number of dates per month (June-September) in which estimated mean water temperature in the Okanogan River (at Malott, WA) exceeded 20°C (top); min., mean and max. length (days) and total frequency of periods in which estimated mean water temperature continuously exceeded 20°C during peak migration (July-August), by decade (bottom), and by year (next page).

		POT Event Duration (days)							
		N	Min	P25	P50	P75	Max	Avg	Std
Decade	Year								
1920s	1924	3	6	6	9.0	25	25	13.3	10.2
	1925	4	2	2	6.5	18	25	10.0	10.9
	1926	4	1	5	12.0	18	19	11.0	8.1
	1927	1	41	41	41.0	41	41	41.0	
	1928	4	1	2	4.5	15	23	8.3	10.2
	1929	3	2	2	4.0	23	23	9.7	11.6
	Total	19	1	2	8.0	23	41	11.9	11.3
1930s	Year								
	1930	4	4	6	9.0	17	24	11.5	8.7
	1931	1	46	46	46.0	46	46	46.0	
	1932	2	1	1	15.5	30	30	15.5	20.5
	1933	3	6	6	7.0	33	33	15.3	15.3
	1934	3	1	1	10.0	25	25	12.0	12.1
	1935	3	9	9	11.0	13	13	11.0	2.0
	1936	1	47	47	47.0	47	47	47.0	
	1937	3	3	3	18.0	22	22	14.3	10.0
	1938	2	10	10	23.0	36	36	23.0	18.4
	1939	2	1	1	19.5	38	38	19.5	26.2
1950s	1954	2	1	1	3.5	6	6	3.5	3.5
	1955	2	11	11	21.5	32	32	21.5	14.8
	1956	1	49	49	49.0	49	49	49.0	
	1957	2	3	3	7.5	12	12	7.5	6.4
	1958	2	1	1	24.5	48	48	24.5	33.2
	1959	3	2	2	14.0	15	15	10.3	7.2
	Total	19	1	3	12.0	27	49	15.9	15.5
1960s	Year								
	1960	1	48	48	48.0	48	48	48.0	
	1961	2	16	16	24.5	33	33	24.5	12.0
	1962	3	2	2	12.0	15	15	9.7	6.8
	1963	2	7	7	14.5	22	22	14.5	10.6
	1964	5	1	1	2.0	4	10	3.6	3.8
	1965	2	5	5	18.0	31	31	18.0	18.4
	1966	1	29	29	29.0	29	29	29.0	
	1967	4	1	4	6.0	19	32	11.3	14.0
	1968	2	8	8	14.5	21	21	14.5	9.2
	1969	2	8	8	18.5	29	29	18.5	14.8
1970s	Year								
	1970	2	17	17	25.0	33	33	25.0	11.3
	1971	1	46	46	46.0	46	46	46.0	
	1972	2	11	11	13.0	15	15	13.0	2.8
	1973	2	6	6	13.5	21	21	13.5	10.6
	1974	2	8	8	9.5	11	11	9.5	2.1
	1975	4	2	5	8.5	10	10	7.3	3.6
	1976	2	1	1	8.0	15	15	8.0	9.9
	1977	2	2	2	13.5	25	25	13.5	16.3
	1978	2	3	3	9.0	15	15	9.0	8.5
	1979	1	46	46	46.0	46	46	46.0	
	Total	20	1	7	11.0	19	46	15.2	13.2
1980s	Year								
	1980	2	8	8	11.0	14	14	11.0	4.2
	1981	2	2	2	15.5	29	29	15.5	19.1
	1982	2	12	12	12.5	13	13	12.5	0.7
	1983	1	23	23	23.0	23	23	23.0	
	1984	1	32	32	32.0	32	32	32.0	
	1985	4	2	3	7.5	16	21	9.5	8.6
	1986	1	33	33	33.0	33	33	33.0	
	1987	4	1	2	6.0	12	14	6.8	6.3
	1988	2	10	10	17.5	25	25	17.5	10.6
	1989	1	17	17	17.0	17	17	17.0	
	Total	20	1	6	12.5	22	33	14.2	10.1
1990s	Year								
	1990	2	7	7	15.5	24	24	15.5	12.0
	1991	2	6	6	16.5	27	27	16.5	14.8
	1992	3	1	1	11.0	11	11	7.7	5.8
	1993	1	24	24	24.0	24	24	24.0	
	1994	2	1	1	24.0	47	47	24.0	32.5
	1995	2	8	8	8.5	9	9	8.5	0.7
	1996	4	5	8	10.5	13	14	10.0	3.7
	1997	2	2	2	14.0	26	26	14.0	17.0
	1998	2	9	9	27.5	46	46	27.5	26.2
	1999	1	30	30	30.0	30	30	30.0	
2000s	Year								
	2000	3	2	2	5.0	21	21	9.3	10.2
	2001	3	8	8	12.0	23	23	14.3	7.8
	2002	3	3	3	20.0	25	25	16.0	11.5
	2003	1	55	55	55.0	55	55	55.0	
	2004	3	3	3	5.0	42	42	16.7	22.0
	2005	2	5	5	22.0	39	39	22.0	24.0
	2006	3	8	8	11.0	31	31	16.7	12.5
	2007	2	15	15	27.5	40	40	27.5	17.7
	2008	4	2	4	6.5	16	24	9.8	9.7
	2009	3	4	4	15.0	30	30	16.3	13.1
	Total	27	2	5	12.0	25	55	17.1	14.6
2010s	Year								
	2010	2	5	5	21.5	38	38	21.5	23.3
	2011	1	33	33	33.0	33	33	33.0	
	2012	3	2	2	14.0	31	31	15.7	14.6
	2013	2	13	13	30.5	48	48	30.5	24.7
	2014	2	20	20	28.5	37	37	28.5	12.0
	2015	2	23	23	28.0	33	33	28.0	7.1
	2016	2	2	2	20.0	38	38	20.0	25.5
	2017	1	62	62	62.0	62	62	62.0	
	2018	2	2	2	24.5	47	47	24.5	31.8
	Total	17	2	13	31.0	38	62	26.4	18.2
Total		215	1	5	11.0	25	62	16.1	13.8

Decadal Mean Monthly Peaks > 12c

Site: Okanagan River @ Oliver

	Years in Decade	Mean No. Days		Mean Annual Total
		Oct	Nov	
Decade				
1920s	6	8.8		8.8
1930s	10	13.9		13.9
1940s	10	13.1		13.1
1950s	10	8.7		8.7
1960s	10	13.7		13.7
1970s	10	9.9	0.1	10.0
1980s	10	9.4		9.4
1990s	10	12.3	0.2	12.5
2000s	10	14.2		14.2
2010s	9	12.6	1.4	14.0

Frequency & Mean Duration (days) of POT12c Events

Site: Okanagan River @ Oliver

	POT Event Duration (days)							
	N	Min	P05	P50	P95	Max	Avg	Std
Decade								
1920s	12	1	1	4.4	11	11	4.4	2.8
1930s	12	3	3	11.6	28	28	11.6	7.3
1940s	13	1	1	10.1	26	26	10.1	8.1
1950s	14	1	1	6.2	15	15	6.2	4.5
1960s	18	1	1	7.6	22	22	7.6	5.4
1970s	15	1	1	6.7	16	16	6.7	4.6
1980s	20	1	1	4.7	14	17	4.7	4.8
1990s	14	1	1	8.9	19	19	8.9	5.3
2000s	17	1	1	8.4	18	18	8.4	5.5
2010s	17	1	1	7.4	24	24	7.4	6.8
Total	152	1	1	7.5	19	28	7.5	5.9

Table 31. Frequency analysis of decadal mean number of dates per month (October - November) in which estimated mean water temperature in the Okanagan River (at Oliver) exceeded the optimum temperature for spawning: 12°C (top); min., mean and max. length (days) and total frequency of periods in which estimated mean water temperature continuously exceeded 12°C during the peak spawning migration period (Oct-Nov), by decade (bottom).

Frequency & Mean Duration (days) of POT12c Events

		POT Event Duration (days)							
		N	Min	P25	P50	P75	Max	Avg	Std
Decade	Year								
2000s	2000	2	3	3	8.0	13	13	8.0	7.1
	2001	1	5	5	5.0	5	5	5.0	
	2002	1	9	9	9.0	9	9	9.0	
	2003	2	11	11	11.0	11	11	11.0	0.0
	2004	1	17	17	17.0	17	17	17.0	
	2005	2	4	4	10.5	17	17	10.5	9.2
	2006	1	18	18	18.0	18	18	18.0	
	2007	3	1	1	1.0	9	9	3.7	4.6
	2008	2	7	7	7.0	7	7	7.0	0.0
	2009	2	4	4	4.5	5	5	4.5	0.7
	Total	17	1	4	7.0	11	18	8.4	5.5
2010s	Year								
	2010	1	13	13	13.0	13	13	13.0	
	2011	1	11	11	11.0	11	11	11.0	
	2012	3	4	4	4.0	13	13	7.0	5.2
	2013	2	1	1	1.0	1	1	1.0	0.0
	2014	2	2	2	13.0	24	24	13.0	15.6
	2015	1	20	20	20.0	20	20	20.0	
2010s	2016	3	3	3	7.0	8	8	6.0	2.6
	2017	2	4	4	5.5	7	7	5.5	2.1
	2018	2	2	2	2.0	2	2	2.0	0.0
	Total	17	1	2	4.0	11	24	7.4	6.8
Total		152	1	3	6.0	11	28	7.5	5.9

Table 32. Min., mean and max. length (days) and total frequency of periods in which estimated mean water temperature continuously exceeded 12°C during the peak spawning migration period (Oct-Nov), by year (2000 - 2018).

Decadal Mean Monthly Flow > 160 cms

Site: Okanogan River Std

	Years in Decade	Mean No. Days		Mean Annual Total
		Jul	Aug	
Decade				
1930s	10	3.4		3.4
1940s	10	3.0		3.0
1950s	10	10.9		10.9
1960s	10	3.2		3.2
1970s	10	10.6		10.6
1980s	10	5.3		5.3
1990s	10	12.1	0.2	12.3
2000s	10	1.2		1.2
2010s	10	7.9		7.9

Decadal Mean Monthly Flow < 20 cms

Site: Okanogan River Std

	Years in Decade	Mean No. Days		Mean Annual Total
		Jul	Aug	
Decade				
1930s	10	1.1	8.5	9.6
1940s	10	2.3	7.4	9.7
1950s	10		1.2	1.2
1960s	10		3.0	3.0
1970s	10	1.6	12.1	13.7
1980s	10	0.2	8.5	8.7
1990s	10	0.1	4.0	4.1
2000s	10	0.5	11.9	12.4
2010s	10	0.4	4.8	5.2

Table 33. Frequency analysis of decadal mean number of dates per month in which observed or estimated daily discharge in Okanogan River in July-August exceeded the 90^{th} percentile of flows, 160 cms (top) and fell below 20 cms (bottom).

		POT Event Duration (days)				
		N	Min	Avg	Max	Std
Decade	Year					
1930s	1930	1	26	26.0	26	
	1931	1	42	42.0	42	
	1934	1	1	1.0	1	
	1938	1	11	11.0	11	
	1939	3	1	5.3	11	5.1
	Total	7	1	13.7	42	15.2
1940s	Year					
	1940	1	54	54.0	54	
	1941	2	9	9.5	10	0.7
	1944	1	24	24.0	24	
	Total	4	9	24.3	54	21.0
1950s	Year					
	1958	1	12	12.0	12	
	Total	1	12	12.0	12	
1960s	Year					
	1966	1	12	12.0	12	
	1967	1	10	10.0	10	
	1969	1	8	8.0	8	
	Total	3	8	10.0	12	2.0
1970s	1970	1	36	36.0	36	
	1973	1	31	31.0	31	
	1977	1	41	41.0	41	
	1979	1	29	29.0	29	
	Total	4	29	34.3	41	5.4
1980s	Year					
	1985	1	33	33.0	33	
	1987	2	6	12.0	18	8.5
	1988	1	30	30.0	30	
	Total	4	6	21.8	33	12.3
1990s	Year					
	1992	1	13	13.0	13	
	1994	2	11	14.0	17	4.2
	Total	3	11	13.7	17	3.1
2000s	Year					
	2001	2	3	11.0	19	11.3
	2003	1	36	36.0	36	
	2004	1	6	6.0	6	
	2005	1	20	20.0	20	
	2006	1	25	25.0	25	
	2007	1	1	1.0	1	
	2009	2	6	7.0	8	1.4
	Total	9	1	13.8	36	11.8
2010s	Year					
	2015	1	35	35.0	35	
	2019	2	6	8.5	11	3.5
	Total	3	6	17.3	35	15.5
Total		38	1	17.8	54	13.5

Table 34. Min., mean and max. length (days) and total frequency of periods in which observed or estimated daily discharge in Okanogan River remained continuously below 20 cms in July and August, by decade.

		POT Event Duration (days)				
		N	Min	Avg	Max	Std
Decade	Year					
1930s	1933	1	18	18.0	18	
	1935	1	11	11.0	11	
	1937	1	5	5.0	5	
	Total	3	5	11.3	18	6.5
1940s	Year					
	1942	1	3	3.0	3	
	1943	1	13	13.0	13	
	1946	1	4	4.0	4	
	1948	1	10	10.0	10	
	Total	4	3	7.5	13	4.8
1950s	Year					
	1950	1	12	12.0	12	
	1951	1	9	9.0	9	
	1952	1	1	1.0	1	
	1953	1	12	12.0	12	
	1954	1	25	25.0	25	
	1955	1	21	21.0	21	
	1956	1	14	14.0	14	
	1959	1	15	15.0	15	
1950s		8	1	13.6	25	7.3
1960s	Year					
	1964	1	18	18.0	18	
	1967	1	7	7.0	7	
	1968	1	7	7.0	7	
	Total	3	7	10.7	18	6.4
1970s	Year					
	1971	2	2	5.0	8	4.2
	1972	1	30	30.0	30	
	1974	1	27	27.0	27	
	1975	1	12	12.0	12	
	1976	1	23	23.0	23	
	1978	1	4	4.0	4	
	Total	7	2	15.1	30	11.4
1980s	Year					
	1981	1	7	7.0	7	
	1982	1	23	23.0	23	
	1983	2	5	6.0	7	1.4
	1984	1	11	11.0	11	
Decade	Total					
1980s		5	5	10.6	23	7.3
1990s	Year					
	1990	1	17	17.0	17	
	1991	2	2	13.0	24	15.6
	1993	2	4	5.5	7	2.1
	1996	1	15	15.0	15	
	1997	2	1	11.0	21	14.1
	1998	2	1	2.5	4	2.1
	1999	1	27	27.0	27	
	Total	11	1	11.2	27	9.9
2000s	Year					
	2002	2	2	4.0	6	2.8
	2008	1	4	4.0	4	
	Total	3	2	4.0	6	2.0
2010s	Year					
	2010	1	4	4.0	4	
	2011	1	30	30.0	30	
	2012	1	26	26.0	26	
	2013	1	13	13.0	13	
2010s	2014	1	4	4.0	4	
	2017	1	2	2.0	2	
	Total	6	2	13.2	30	12.2
Total		50	1	11.6	30	8.7

Table 35. Min., mean and max. length (days) and total frequency of periods in which observed or estimated daily discharge in Okanogan River remained continuously above 160 cms in July and August, by decade.

Decadal Mean Monthly Flow < 6 cms

Site: Okanagan River

	Years in Decade	Mean No. Days			Mean Annual Total
		Sep	Oct	Nov	
Decade					
1930s	10				
1940s	10	3.2	3.1	0.9	7.2
1950s	10				
1960s	10	2.4	4.3	7.1	13.8
1970s	10	0.3	4.9	10.5	15.7
1980s	10	2.1	2.7	5.1	9.9
1990s	10			8.1	8.1
2000s	10		0.9	11.9	12.8
2010s	9			3.9	3.9

Annual Frequency & Mean Duration (days) for POT < 6 cms Events

	POT Event Duration (days)				
	N	Min	Avg	Max	Std
Decade					
1940s	3	2	24.0	63	33.9
1960s	10	1	13.8	39	13.8
1970s	11	1	14.5	59	19.0
1980s	6	2	16.5	48	18.5
1990s	11	1	7.5	27	7.4
2000s	9	2	14.6	39	13.7
2010s	5	1	7.2	25	10.2
Total	55	1	13.1	63	15.4

Table 36. Frequency analysis of decadal mean number of dates per month in which observed or estimated daily discharge in Okanagan River did not exceed the 10th percentile of flows, 6 cms in October - November (top); min., mean and max. length (days) and total frequency of periods in which observed or estimated daily discharge remained continuously below 6 cms in October - November, by decade (bottom).

		POT Event Duration (days)				
		N	Min	Avg	Max	Std
Decade	Year					
1940s	1944	2	7	35.0	63	39.6
	1945	1	2	2.0	2	
	Total	3	2	24.0	63	33.9
1960s	Year					
	1963	3	1	8.7	13	6.7
	1966	2	11	25.0	39	19.8
	1967	5	1	12.4	38	14.9
	Total	10	1	13.8	39	13.8
1970s	Year					
	1970	2	1	30.0	59	41.0
	1971	1	1	1.0	1	
	1973	3	3	16.7	38	18.7
	1974	1	2	2.0	2	
	1975	1	5	5.0	5	
	1977	2	2	7.5	13	7.8
	1979	1	26	26.0	26	
	Total	11	1	14.5	59	19.0
1980s	Year					
	1987	1	25	25.0	25	

		POT Event Duration (days)				
		N	Min	Avg	Max	Std
Decade	Year					
1980s	1988	5	2	14.8	48	20.1
	Total	6	2	16.5	48	18.5
1990s	Year					
	1990	3	2	4.0	5	1.7
	1991	2	5	9.0	13	5.7
	1992	1	27	27.0	27	
	1993	1	7	7.0	7	
	1994	2	1	5.5	10	6.4
	1996	2	2	4.0	6	2.8
	Total	11	1	7.5	27	7.4
2000s	Year					
	2002	2	2	3.0	4	1.4
	2003	1	39	39.0	39	
	2005	1	23	23.0	23	
	2006	1	28	28.0	28	
	2007	1	22	22.0	22	
	2009	3	2	4.3	8	3.2
	Total	9	2	14.6	39	13.7

		POT Event Duration (days)				
		N	Min	Avg	Max	Std
Decade	Year					
2010s	2010	1	3	3.0	3	
	2011	1	25	25.0	25	
	2012	3	1	2.7	6	2.9
	Total	5	1	7.2	25	10.2
Total		55	1	13.1	63	15.4

Table 37. Min., mean and max. length (days) and total frequency of periods in which observed or estimated daily discharge in Okanagan River did not exceed the 10th percentile of flows, 6 cms in September – November, by year.

Decadal Mean Monthly Flow > 23 cms

Site: Okanagan River

	Years in Decade	Mean No. Days			Mean Annual Total
		Sep	Oct	Nov	
Decade					
1930s	10				
1940s	10	5.5	6.2	4.1	15.8
1950s	10	4.3	1.3	4.4	10.0
1960s	10			0.2	0.2
1970s	10	3.0		5.1	8.1
1980s	10	4.6			4.6
1990s	10	8.5	2.1	3.0	13.6
2000s	10	5.6	0.2		5.8
2010s	9	3.6			3.6

Annual Frequency & Mean Duration (days) for POT > 23 cms Events

	POT Event Duration (days)				
	N	Min	Avg	Max	Std
Decade					
1940s	3	2	52.7	91	45.8
1950s	8	1	12.6	20	7.0
1960s	1	3	3.0	3	
1970s	4	8	20.3	29	8.8
1980s	6	1	7.7	20	6.9
1990s	7	6	19.6	51	15.6
2000s	5	8	11.8	16	3.2
2010s	3	6	10.7	14	4.2
Total	37	1	16.7	91	17.9

Table 38. Frequency analysis of decadal mean number of dates per month in which observed or estimated daily discharge in Okanagan River exceeded the 90th percentile of flows, 23 cms in September – November (top); min., mean and max. length (days) and total frequency of periods in which observed or estimated daily discharge remained continuously above 23 cms in September – November, by decade (bottom).

		POT Event Duration (days)				
		N	Min	Avg	Max	Std
Decade	Year					
1940s	1946	2	2	33.5	65	44.5
	1948	1	91	91.0	91	
	Total	3	2	52.7	91	45.8
1950s	Year					
	1954	5	1	12.2	20	7.1
	1955	1	16	16.0	16	
	1959	2	4	12.0	20	11.3
	Total	8	1	12.6	20	7.0
1960s	Year					
	1968	1	3	3.0	3	
	Total	1	3	3.0	3	
1970s	Year					
	1972	1	8	8.0	8	
	1976	2	22	25.5	29	4.9
	1978	1	22	22.0	22	
	Total	4	8	20.3	29	8.8
1980s	Year					
	1981	1	1	1.0	1	
	1982	1	20	20.0	20	
	1983	1	6	6.0	6	
	1984	1	7	7.0	7	
	1986	1	2	2.0	2	
	1989	1	10	10.0	10	
	Total	6	1	7.7	20	6.9
1990s	Year					
	1990	1	12	12.0	12	
	1993	1	13	13.0	13	
	1994	1	6	6.0	6	
	1995	1	15	15.0	15	
	1996	1	11	11.0	11	
	1997	2	29	40.0	51	15.6
	Total	7	6	19.6	51	15.6
2000s	Year					
	2000	1	14	14.0	14	
	2002	1	11	11.0	11	
	2004	1	8	8.0	8	
	2007	1	10	10.0	10	
	2008	1	16	16.0	16	
Decade	Total					
2000s		5	8	11.8	16	3.2
2010s	Year					
	2013	1	14	14.0	14	
	2016	1	6	6.0	6	
	2017	1	12	12.0	12	
	Total	3	6	10.7	14	4.2
Total		37	1	16.7	91	17.9

Table 39. Min., mean and max. length (days) and total frequency of periods in which observed or estimated daily discharge in Okanagan River remained continuously above 23 cms in September – November, by year.

FIGURES

Figure 1. Columbia River Basin, with river mainstem highlighted (Source: Wikipedia).

Figure 2. Dams of the Columbia River Basin (Source: USACE)

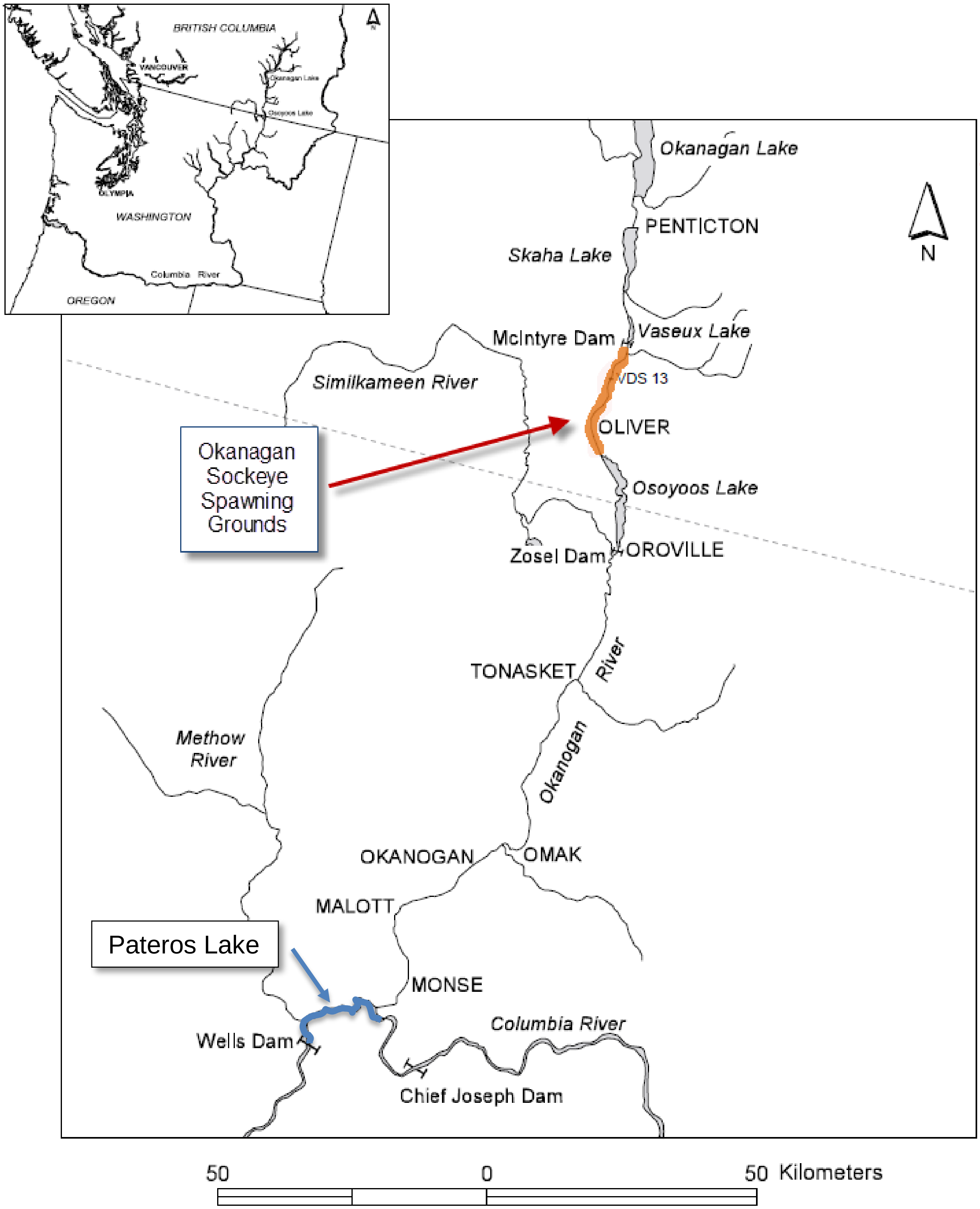


Figure 3. Okanagan River watershed and Sockeye holding area (Pateros Lake) and Okanagan River spawning grounds (Source: Hyatt and Stockwell 2003).

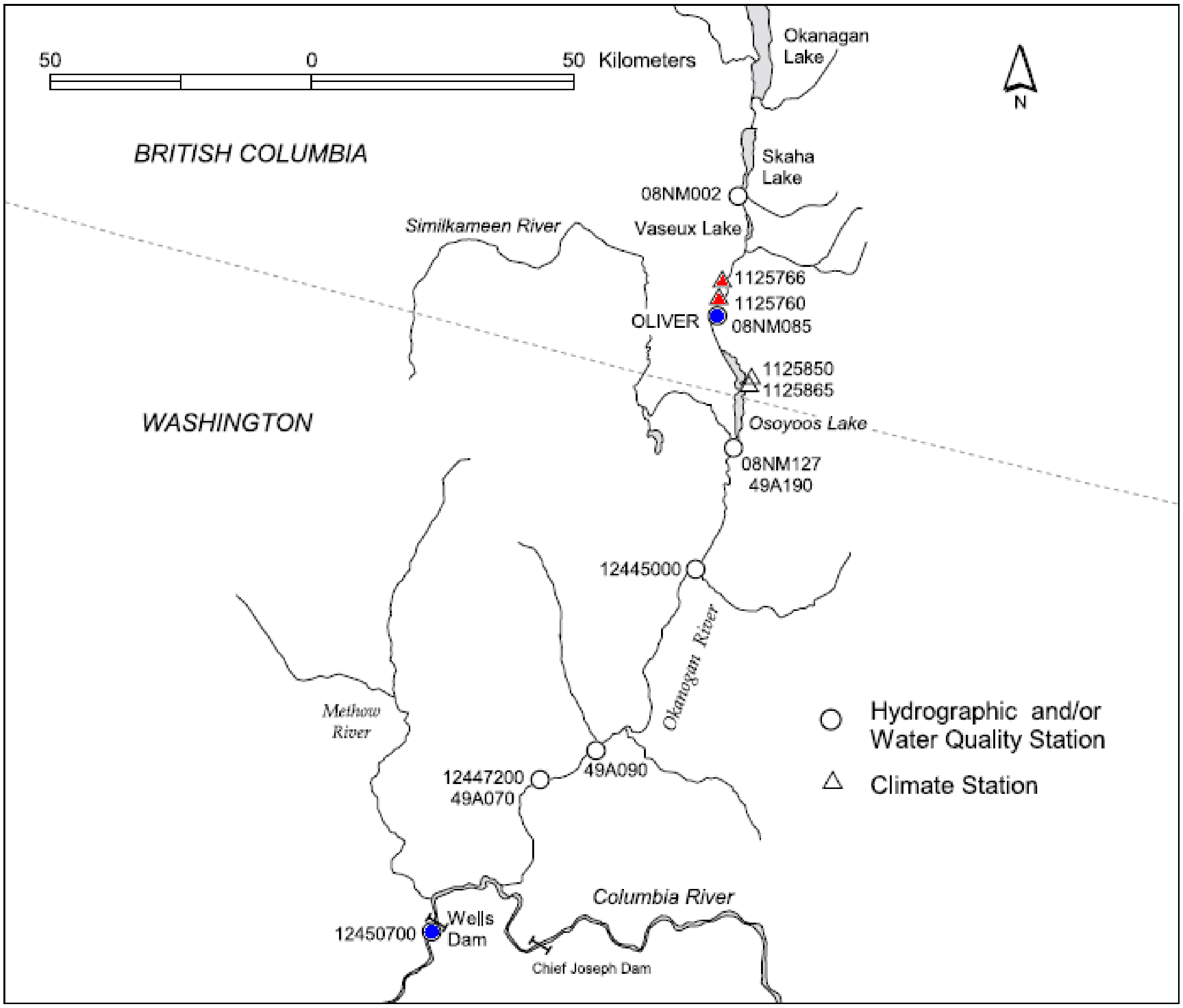


Figure 4. Okanagan watershed with key climate stations and water monitoring stations (Source: Stockwell et al. 2003).

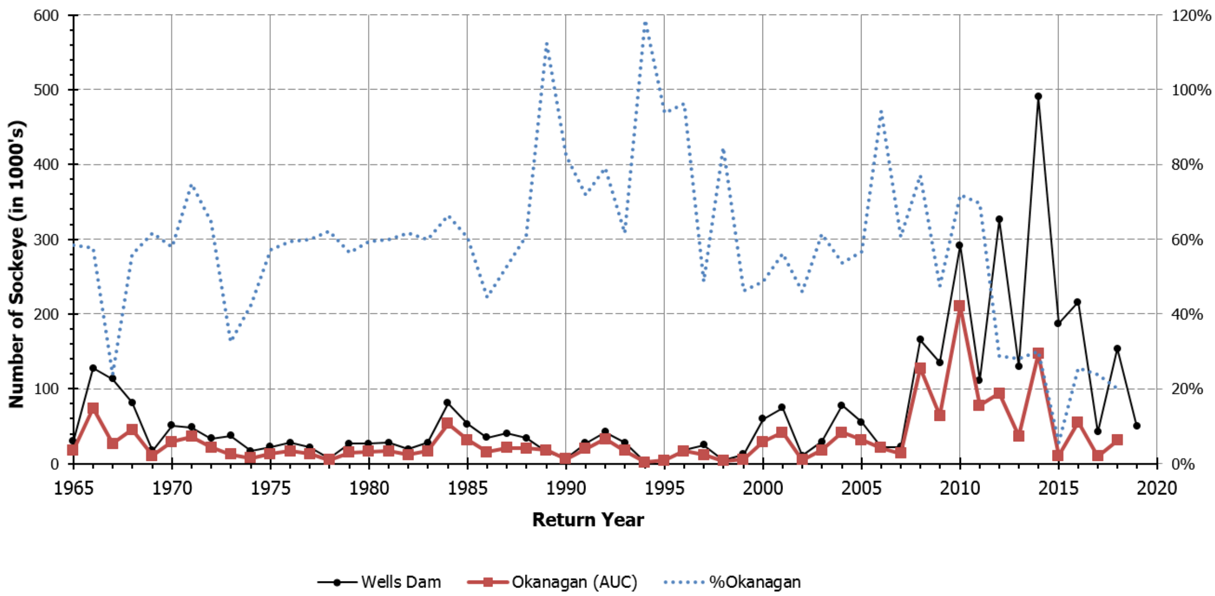


Figure 5. Estimated annual Sockeye escapement to the Okanagan River spawning grounds (red), versus enumerated Sockeye at Wells Dam (black), 1965-2018. Percentage of Okanagan Sockeye as a function of Wells Sockeye counts (dashed line).

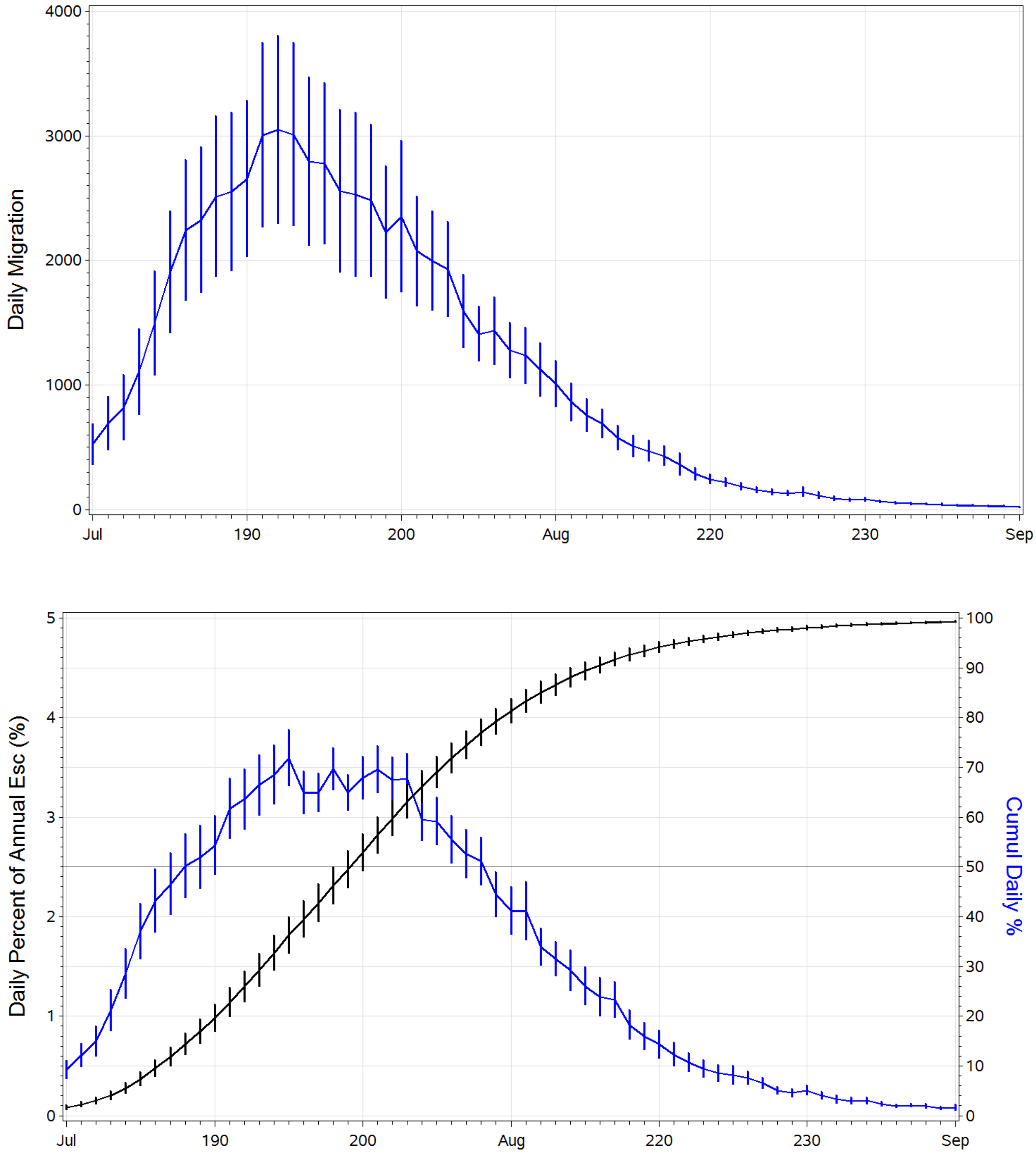


Figure 6. Migration timing for Sockeye at the Wells Dam for available years (1967-2019). Mean daily total migrants (top), and mean daily and cumulative % of total annual escapement (± standard error) (bottom). Time-to-50% ~ day 199 ~ July 20th.

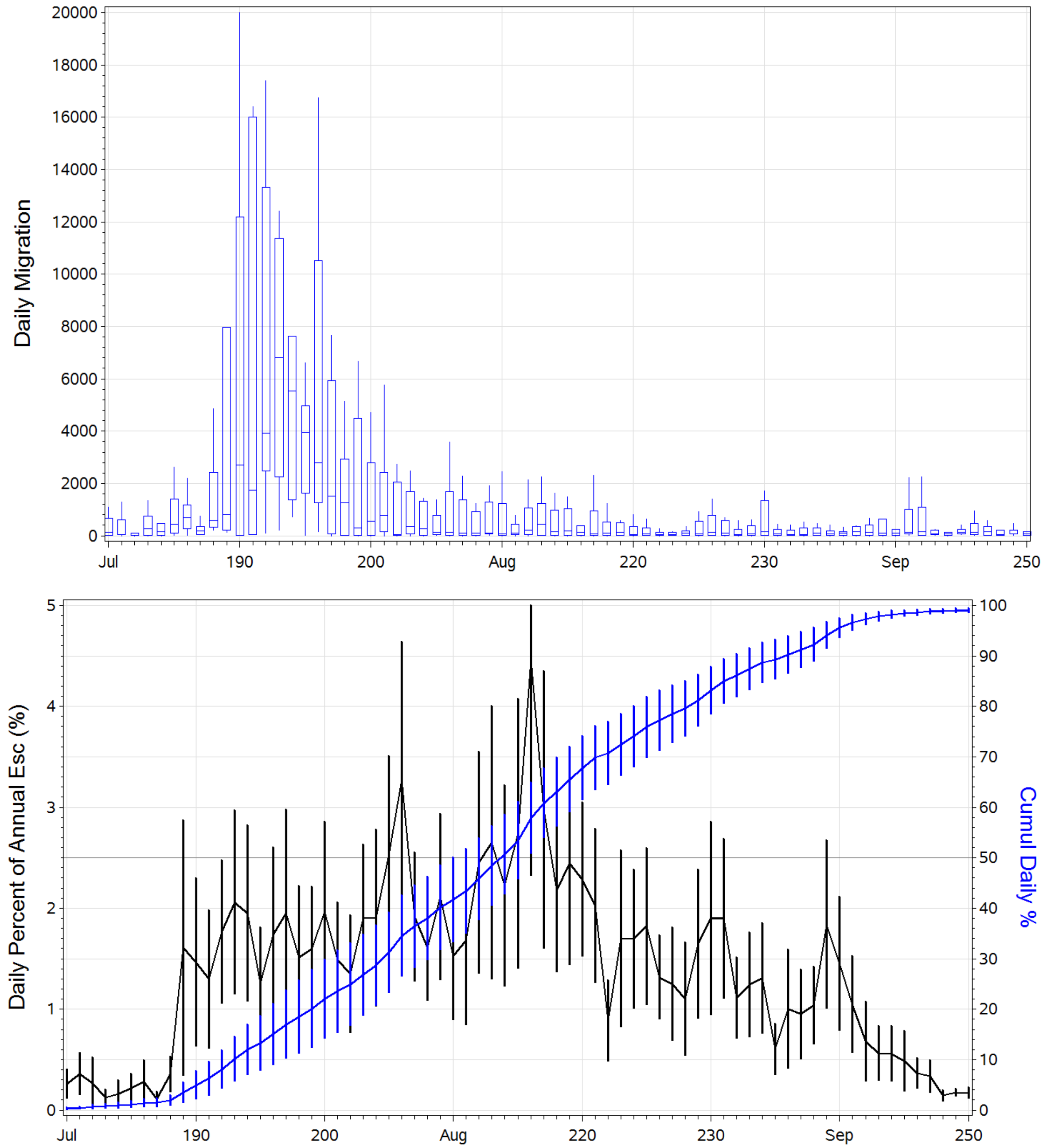


Figure 7. Migration timing for Okanagan River Sockeye at Zosel Dam for 18 available years (1937, 1944, 1952-1954, 1962-1963, 1992-1993, 2006-2010, 2014-2017). Mean daily total migrants (top), and mean daily and cumulative % of total annual escapement ± standard error (bottom). Unweighted time-to-50% across all years = day 214 ~ August 1-2.

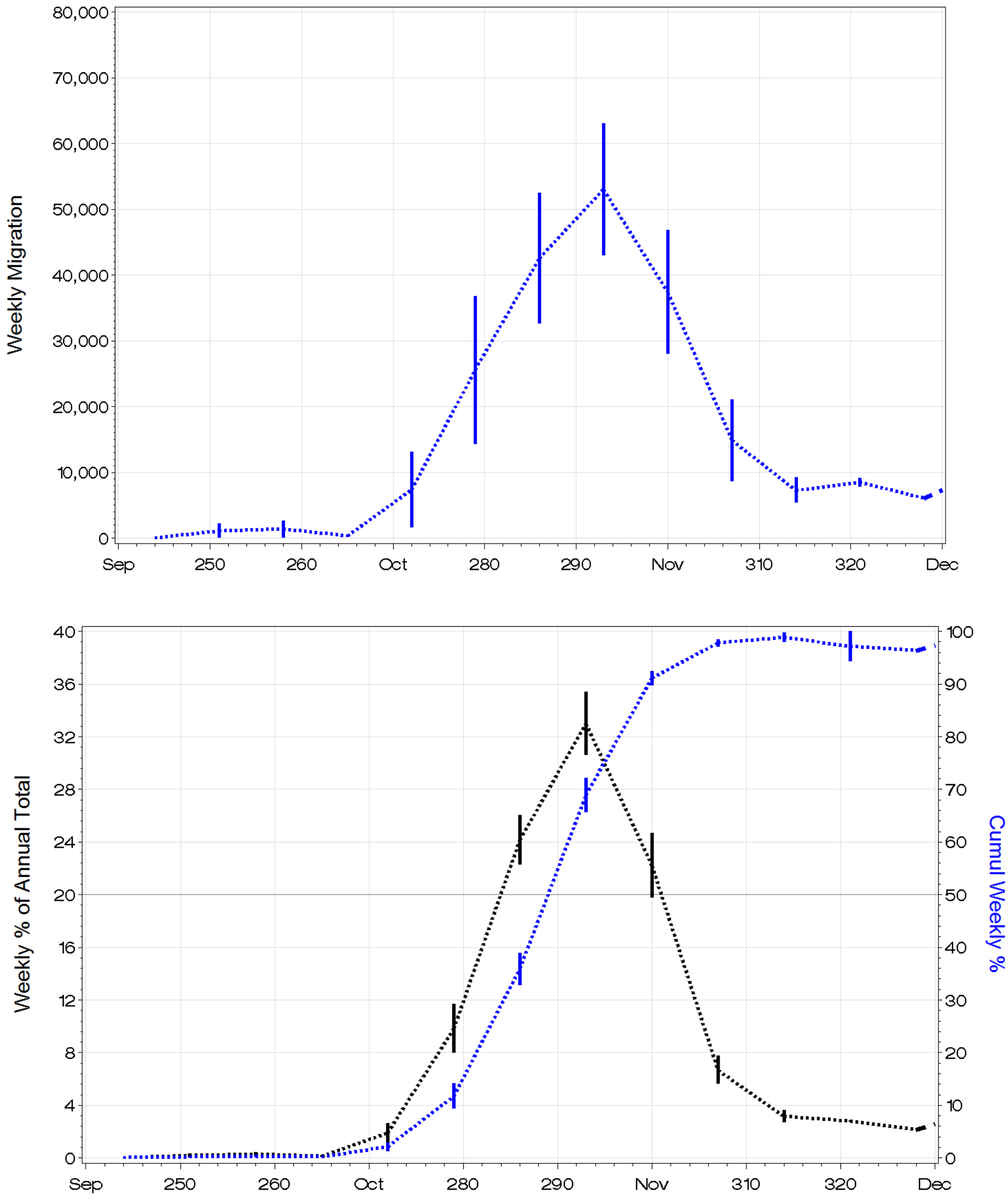


Figure 8. Migration timing onto the Okanagan River spawning grounds (2000 – 2018). Mean weekly total migrants (top), and mean weekly and cumulative weekly % of total annual escapement (± standard error) (bottom). Time-to-50% ~ day 288 ~ October 14th.

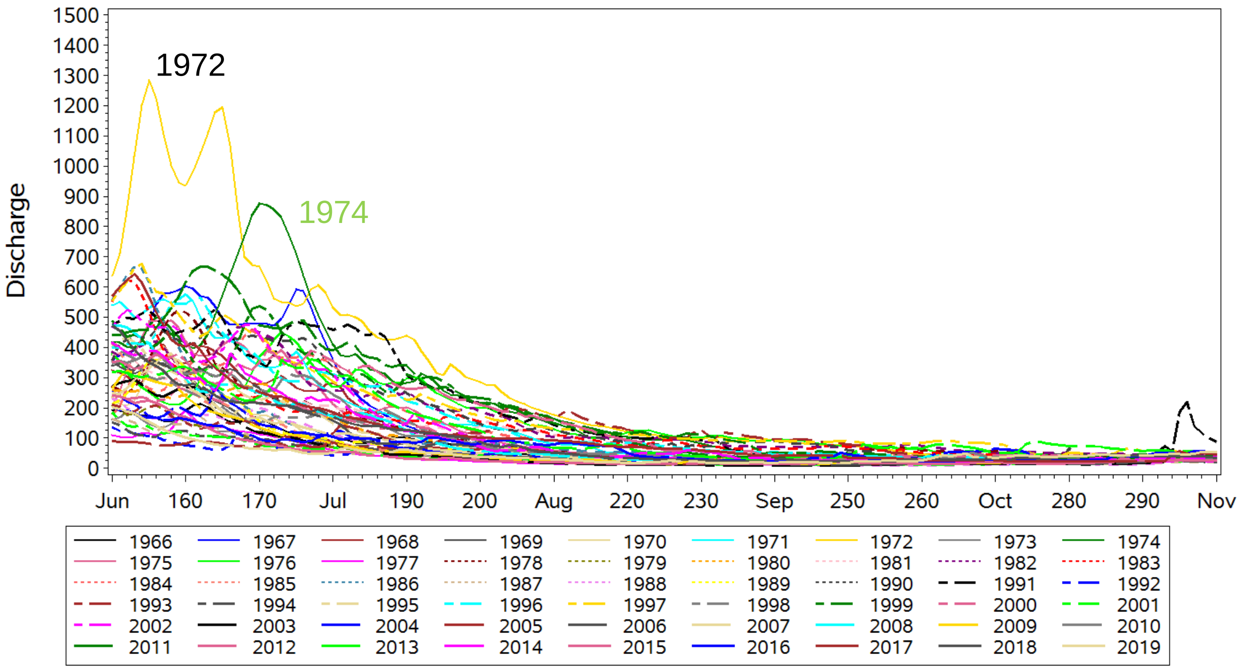


Figure 9. Observed annual daily mean discharge (m^3/s) for the Okanogan River at Malott (Station 12447200; 1966-2019).

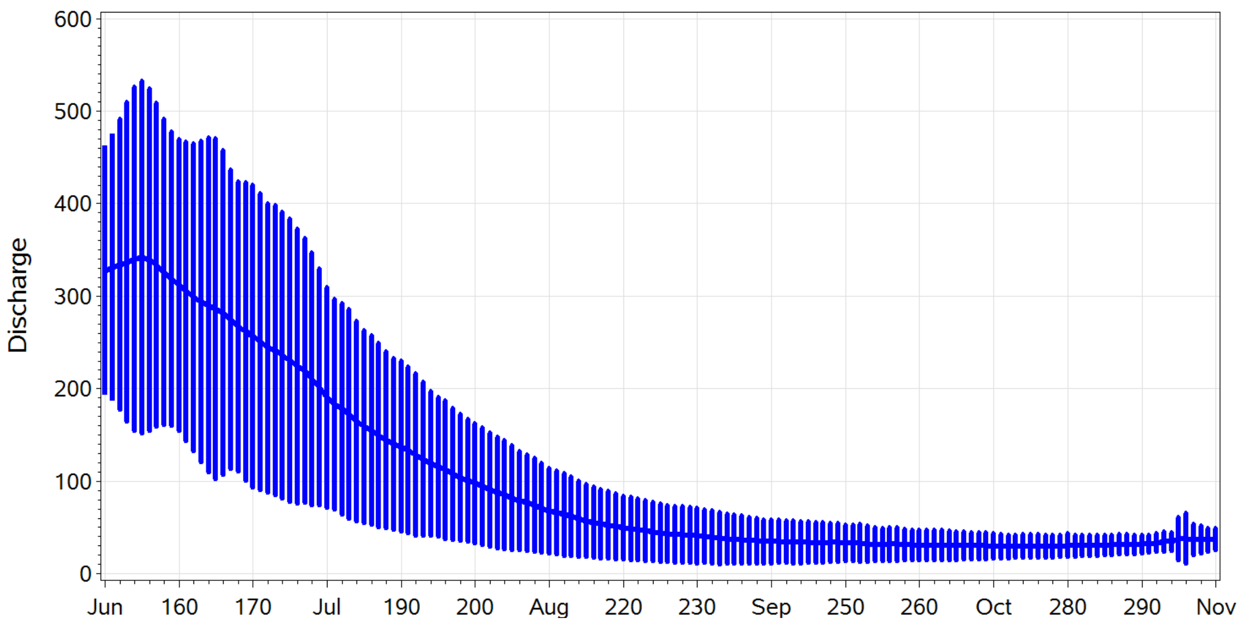


Figure 10. Observed daily mean discharge (m^3/s) ± 1 standard deviation for the Okanogan River at Malott (Station 12447200; 1966-2019).

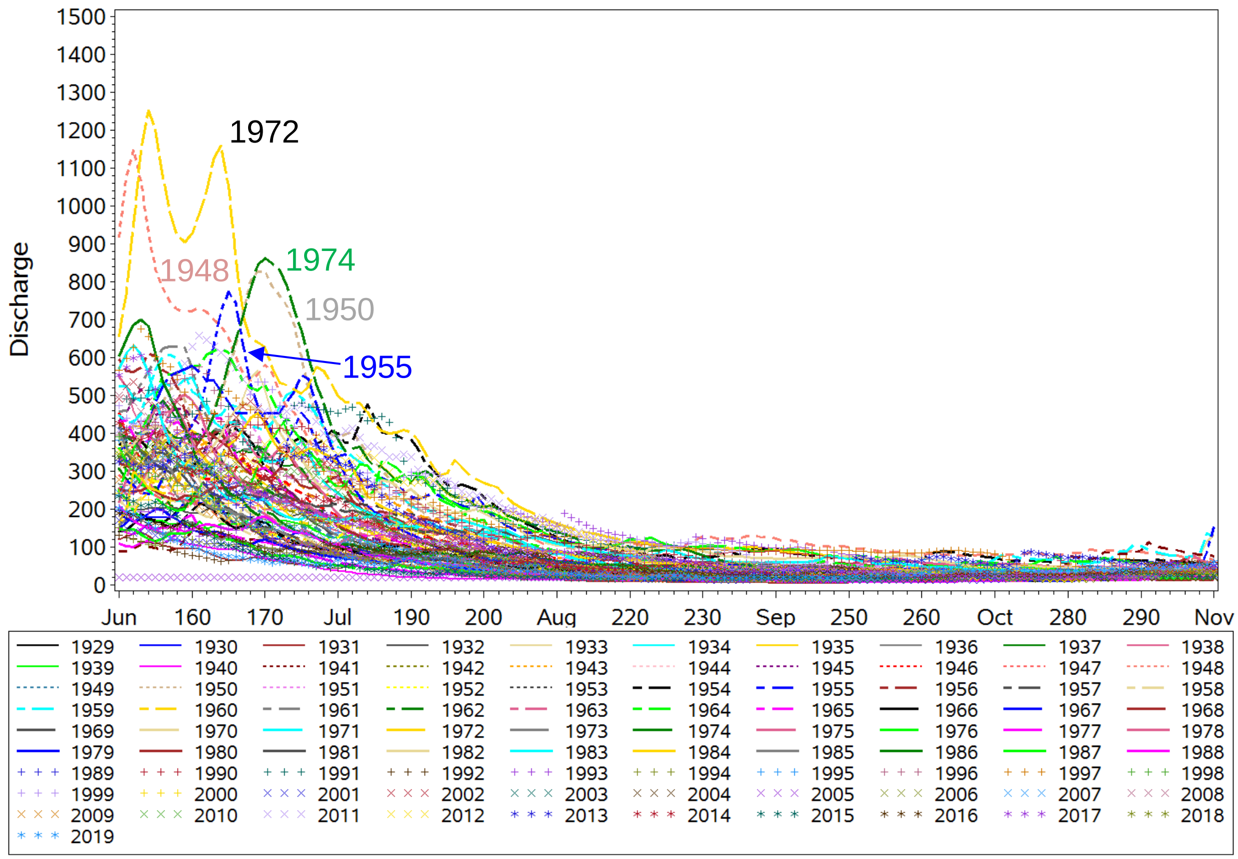


Figure 11. Observed annual daily mean discharge (m^3/s) for the Okanogan River at Tonasket (Station 12445000; 1929-2019).

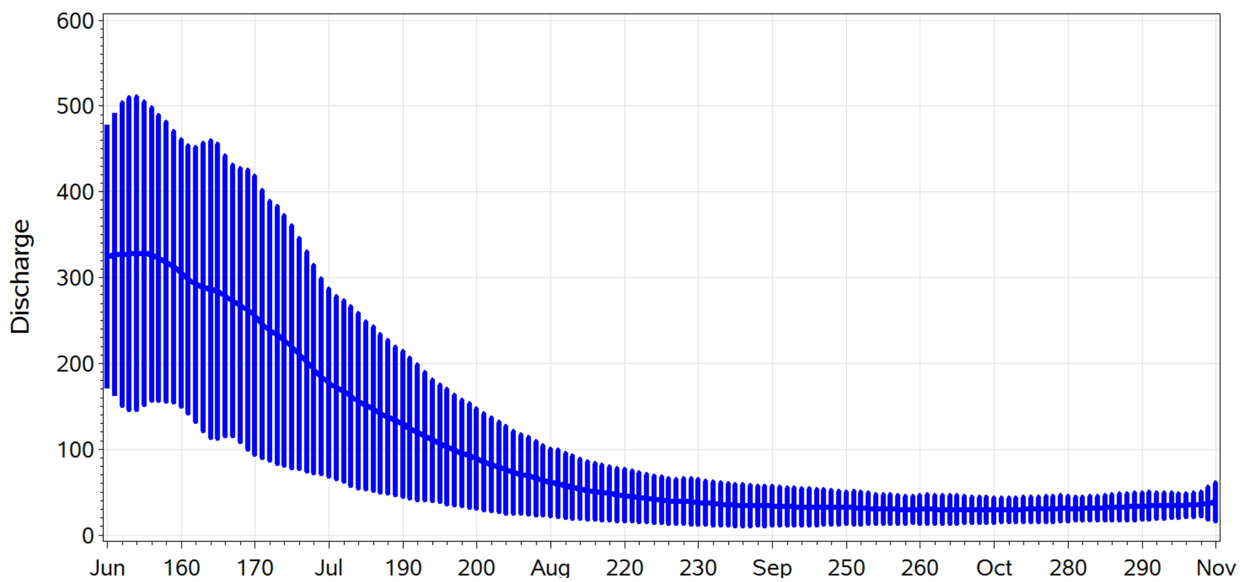


Figure 12. Observed daily mean discharge (m^3/s) ± 1 standard deviation for the Okanogan River at Tonasket (Station 12445000; 1929-2019).

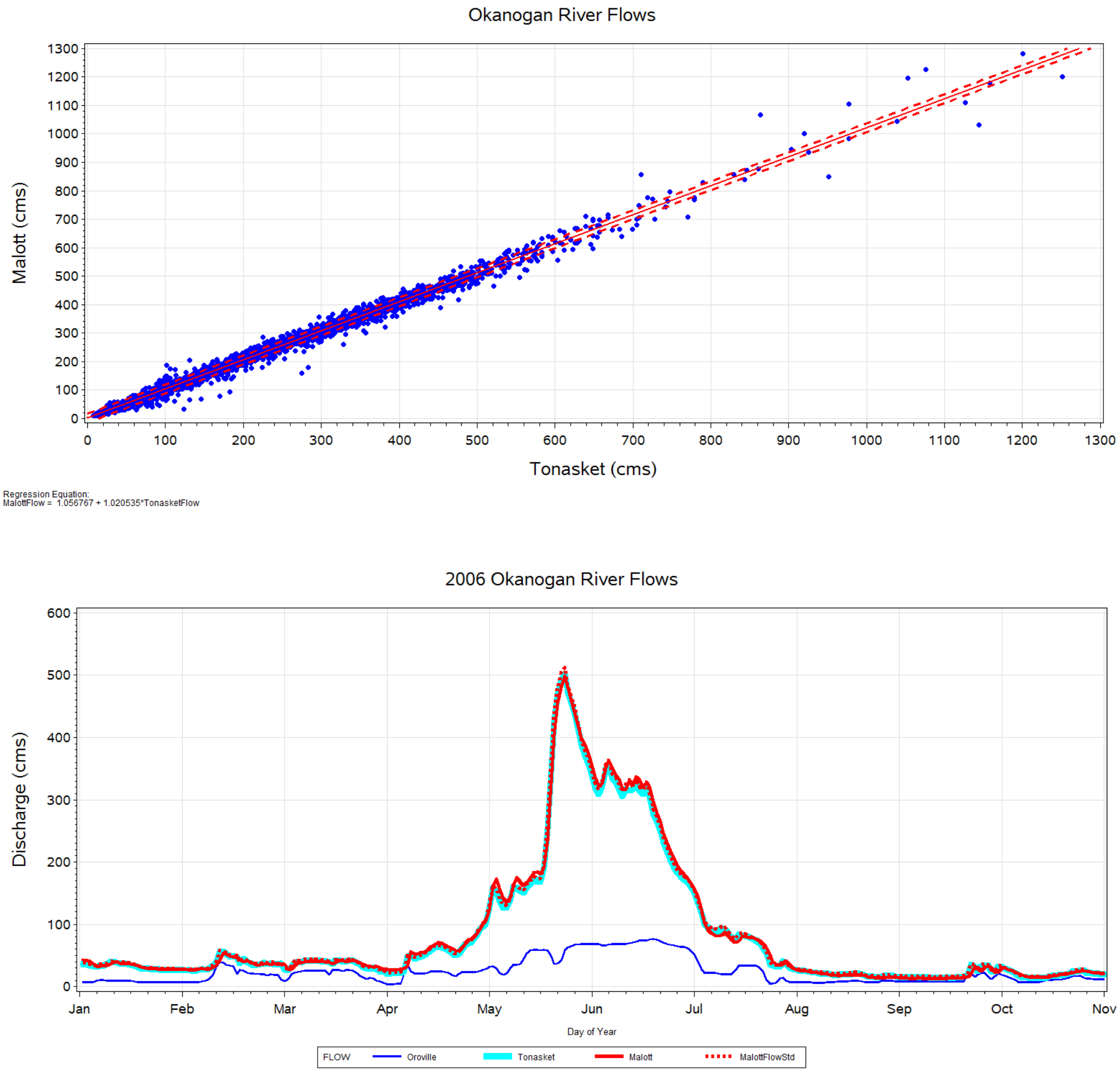


Figure 13. Linear relation for Okanogan River discharge at Malott as a function of Okanogan River discharge at Tonasket (1966-2019; top), and sample plot with observed Okanogan flow (solid lines) and estimated Malott flow (red dashed line). Same-day Okanogan discharge at Tonasket explains 99.5% of flow at Malott (a = 1.27; b = 1.02; r = 0.995; n = 18,193).

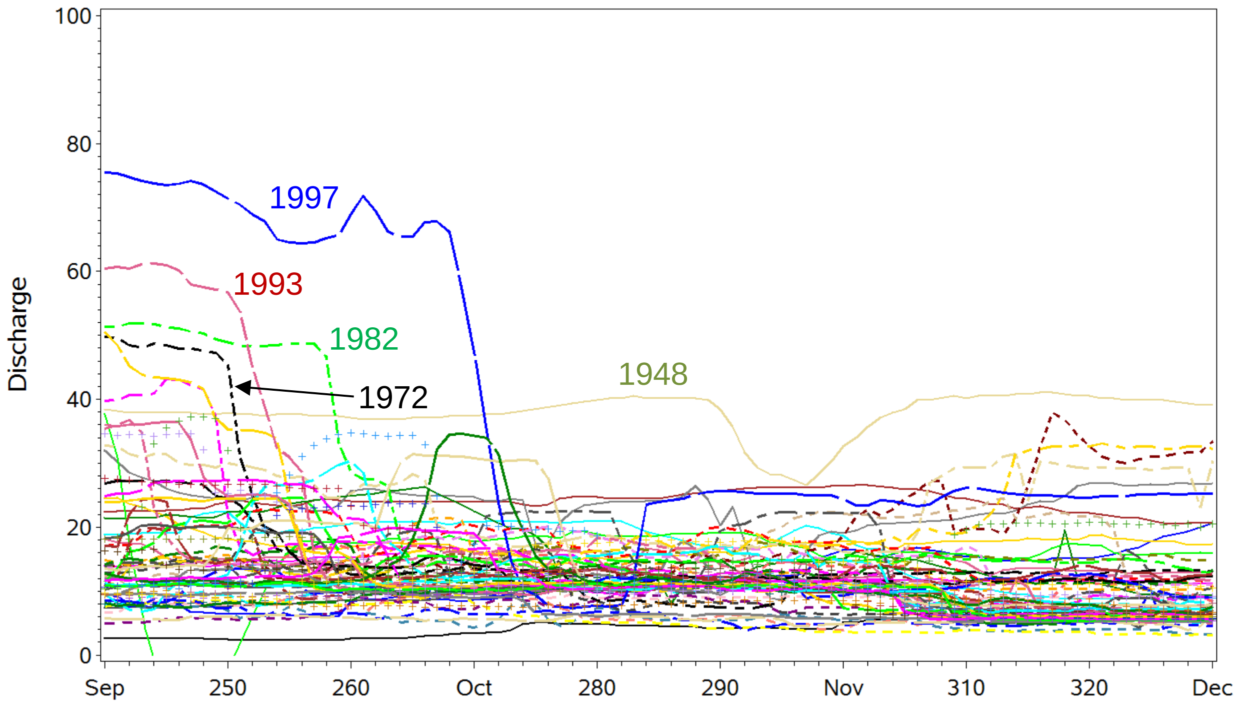


Figure 14. Observed annual daily mean discharge (m^3/s) for the Okanagan River at Oliver (WSC Station 08NM085; 1944-2019).

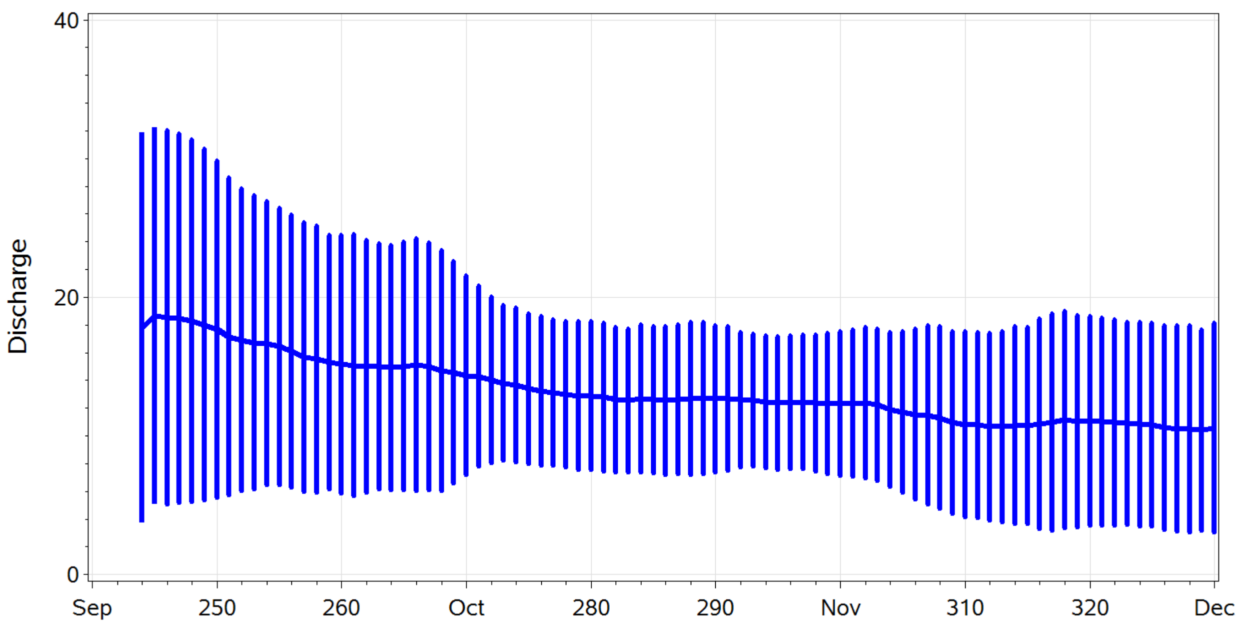


Figure 15. Observed daily mean discharge (m^3/s) ± 1 standard deviation for the Okanagan River at Oliver (WSC Station 08NM085; 1944-2019).

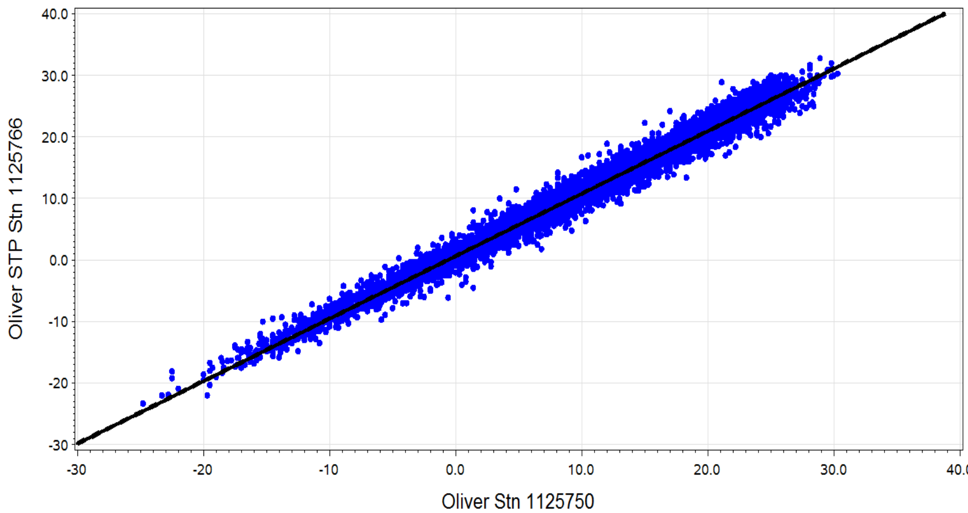


Figure 16. Observed daily mean air temperature at OLIVER STP station 1125766 as a linear function (Y = a + bX) of OLIVER station 1125760, 1938-1999 (n = 16753; r^2 = 0.986; a = 0.62; b = 1.016).

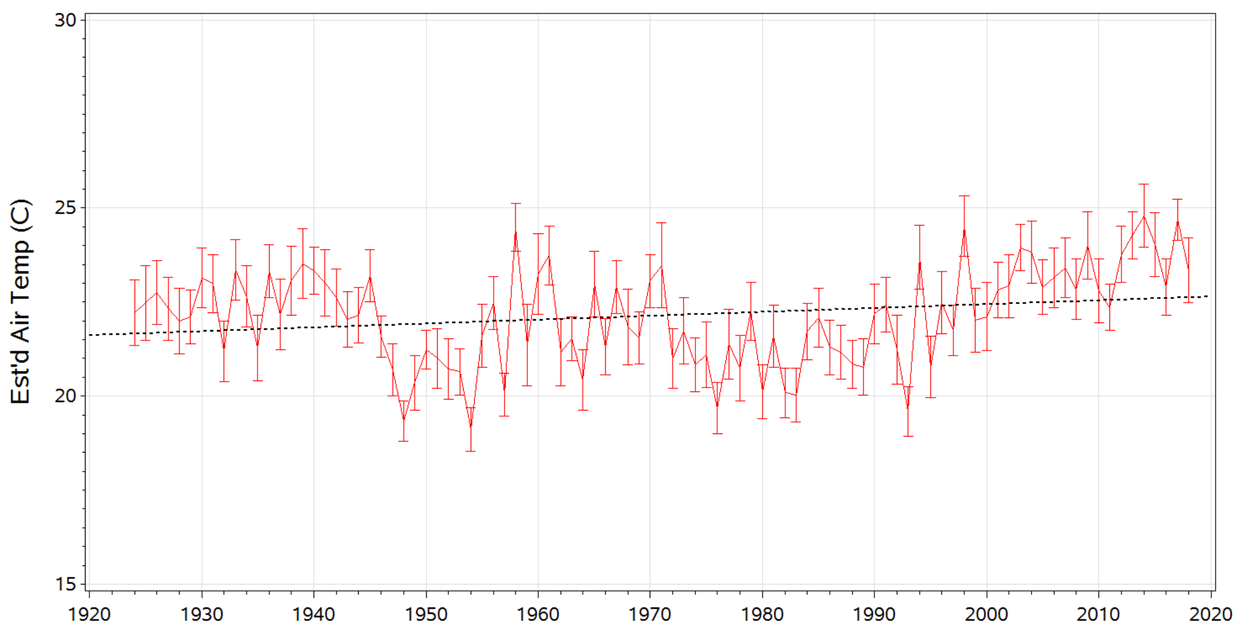


Figure 17. Trend in observed and estimated mean summer (July-August) air temperature at the Okanagan River near Oliver. Long-term warming trend is evident (Y = 2.0 + 0.01 * Year; r = 0.007; P < 0.001).

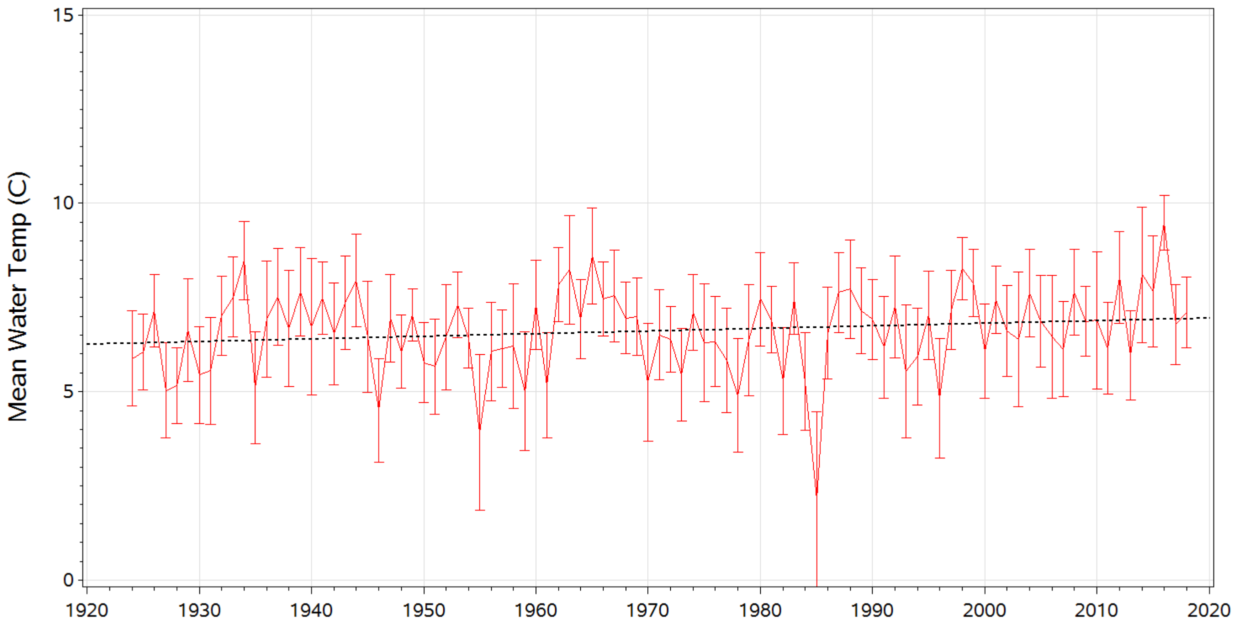


Figure 18. Trend in estimated mean fall air temperature, October-November, 1924-2018, at the Okanagan River near Oliver.

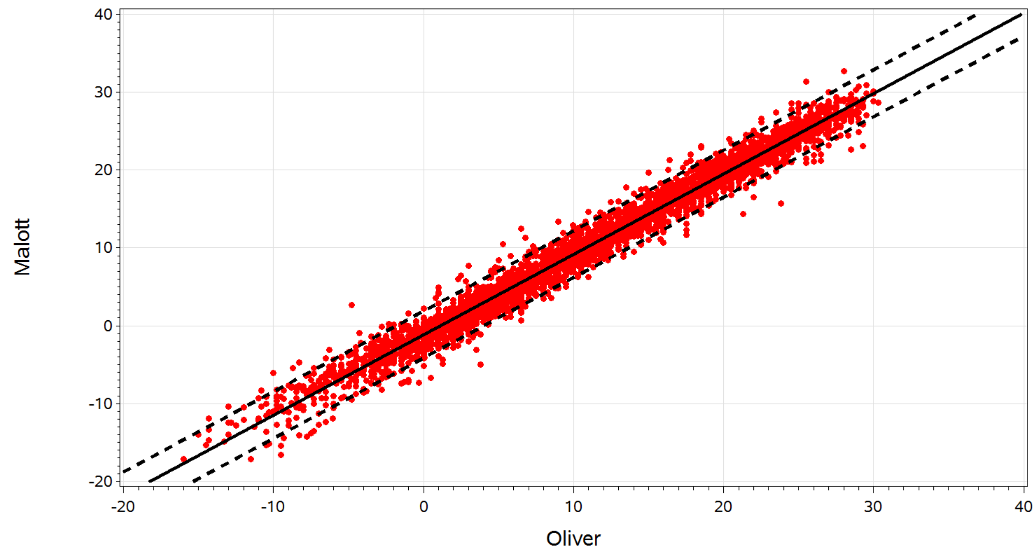


Figure 19. Observed daily mean air temperature at MALOTT (WA) AWN[57] station 330074 as a linear function (Y = a + bX) of OLIVER (BC) STP station 1125766, 2008-2018 (n = 4003; r^2 = 0.98; a = -1.15; b = 1.034).

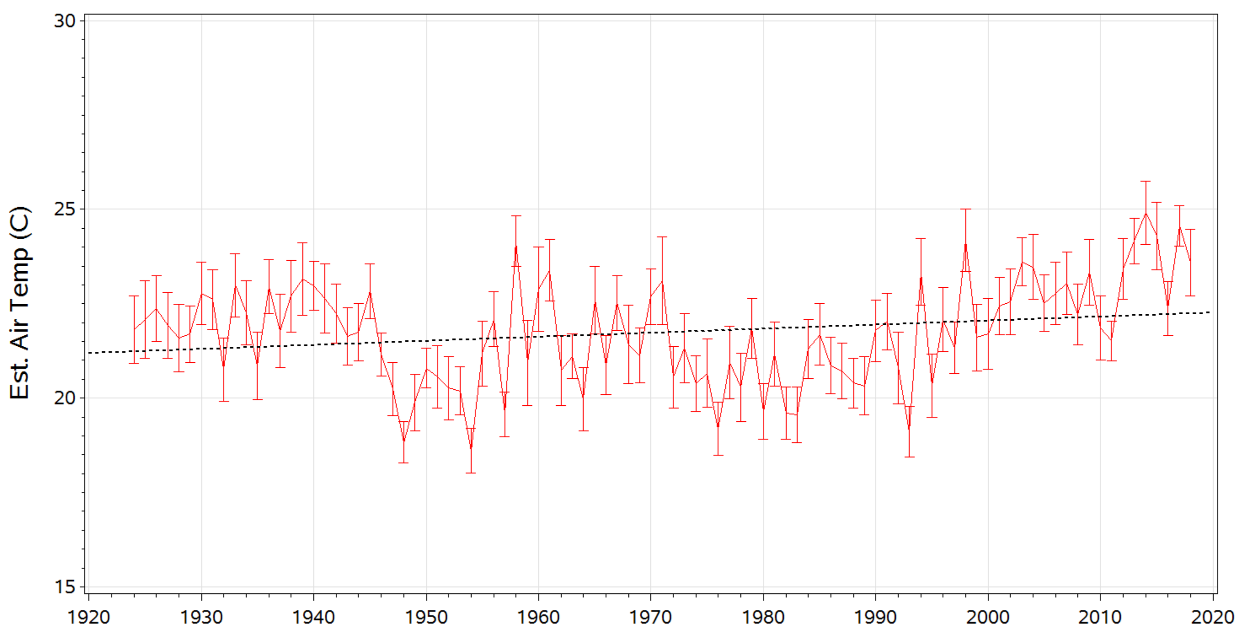


Figure 20. Trend in estimated mean summer (July-August) air temperature in the lower Okanogan River valley (MALOTT AWN station). Long-term warming trend is evident (Y = 0.3 + 0.01 * Year; r = 0.1; P < .001; n = 95 years).

[57] AWN (AgWeatherNet) – downloaded Nov 2019 from https://www.ncdc.noaa.gov/cdo-web/datatools/findstation

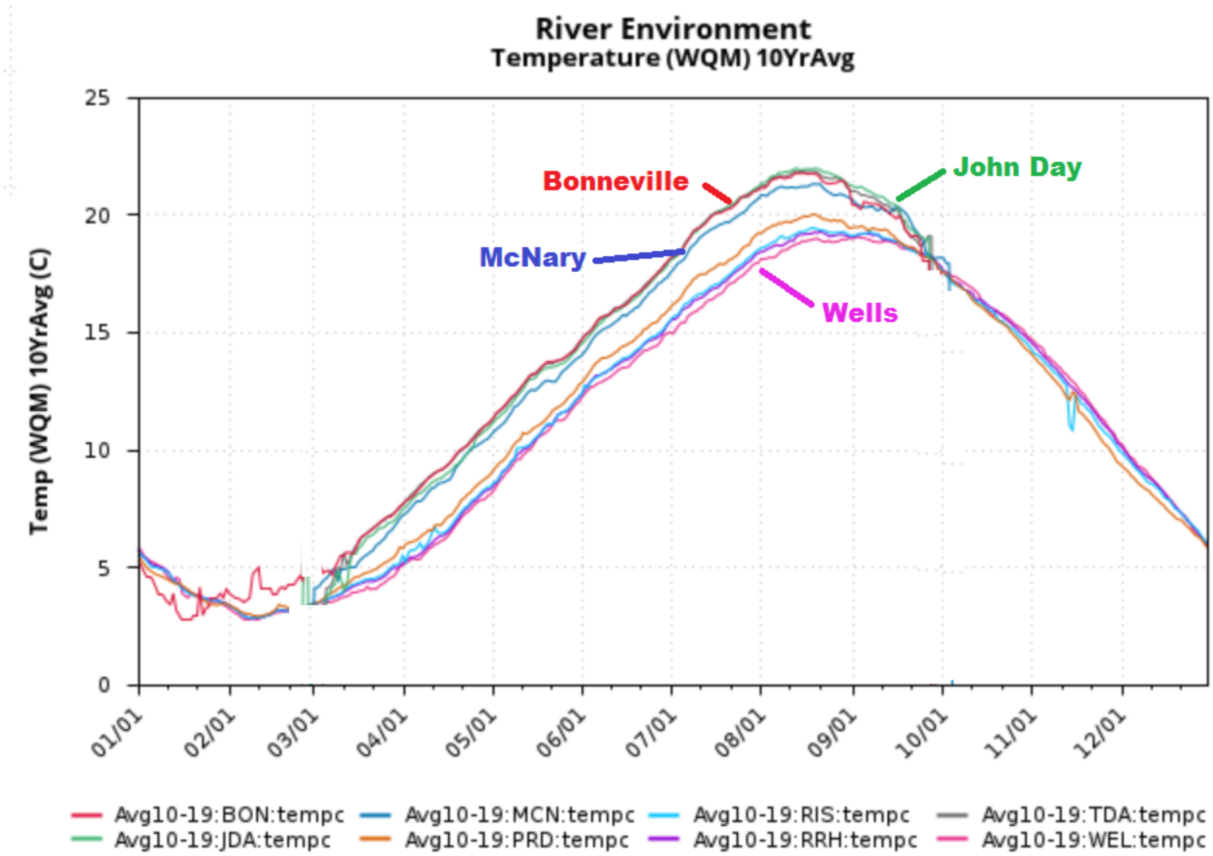


Figure 21. Comparison of mean daily water temperature (2010-2019) at several dams from the lower-Columbia (Bonneville Dam) to mid-Columbia River (Wells Dam) mainstem (Source: CBR DART).

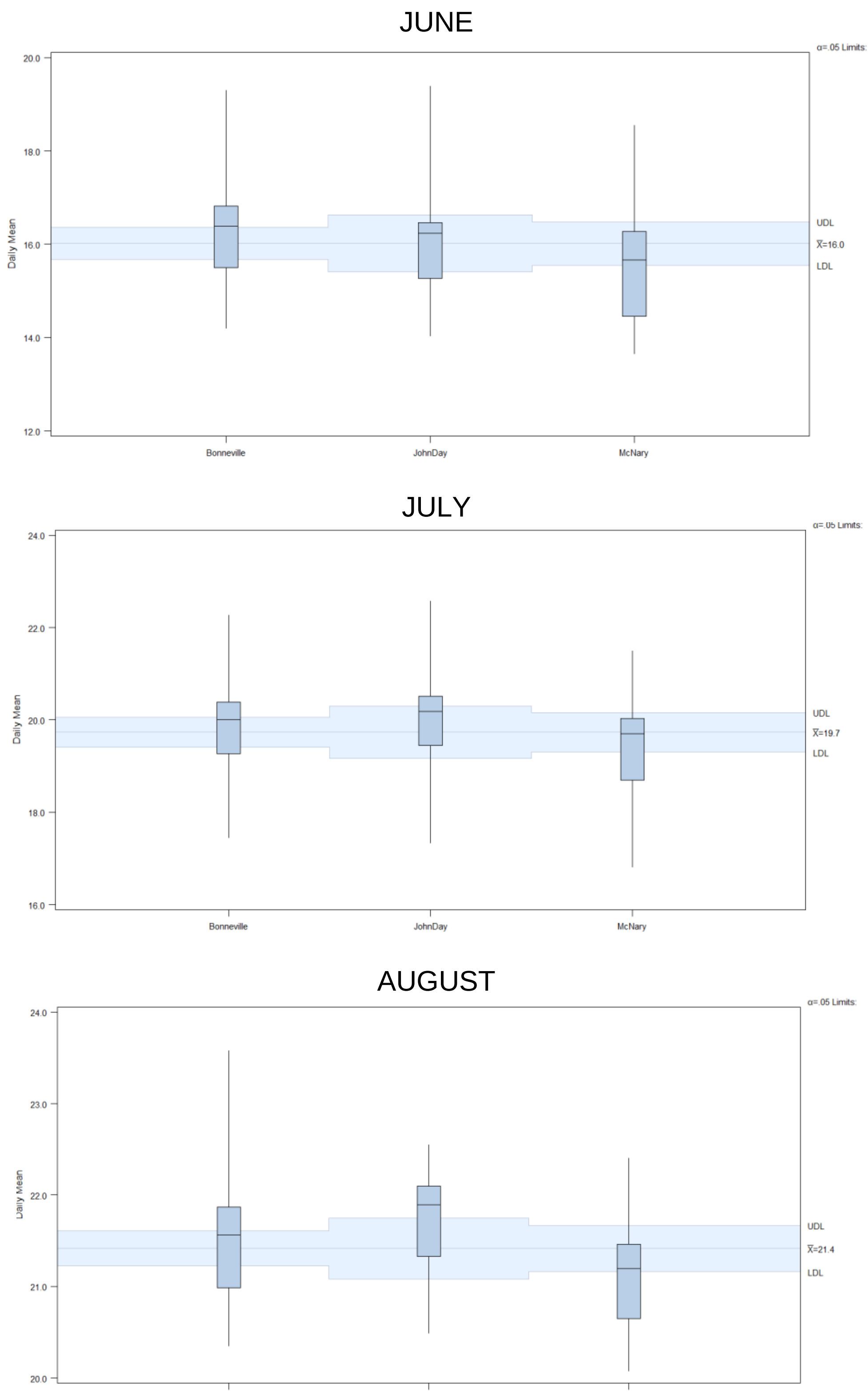
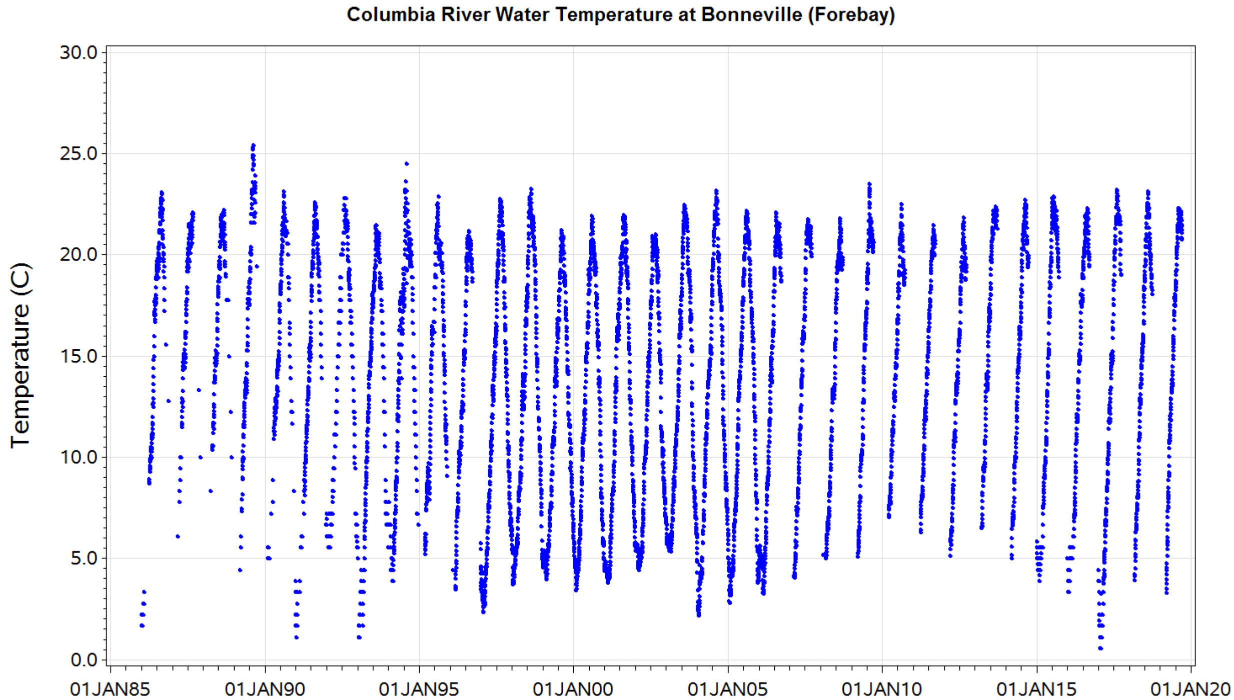


Figure 22. Between-dam analysis of mean water temperature deviations in the lower Columbia River during Sockeye salmon migration (June/July) and subsequent summer months (1996-2019) (Source: CBR DART).



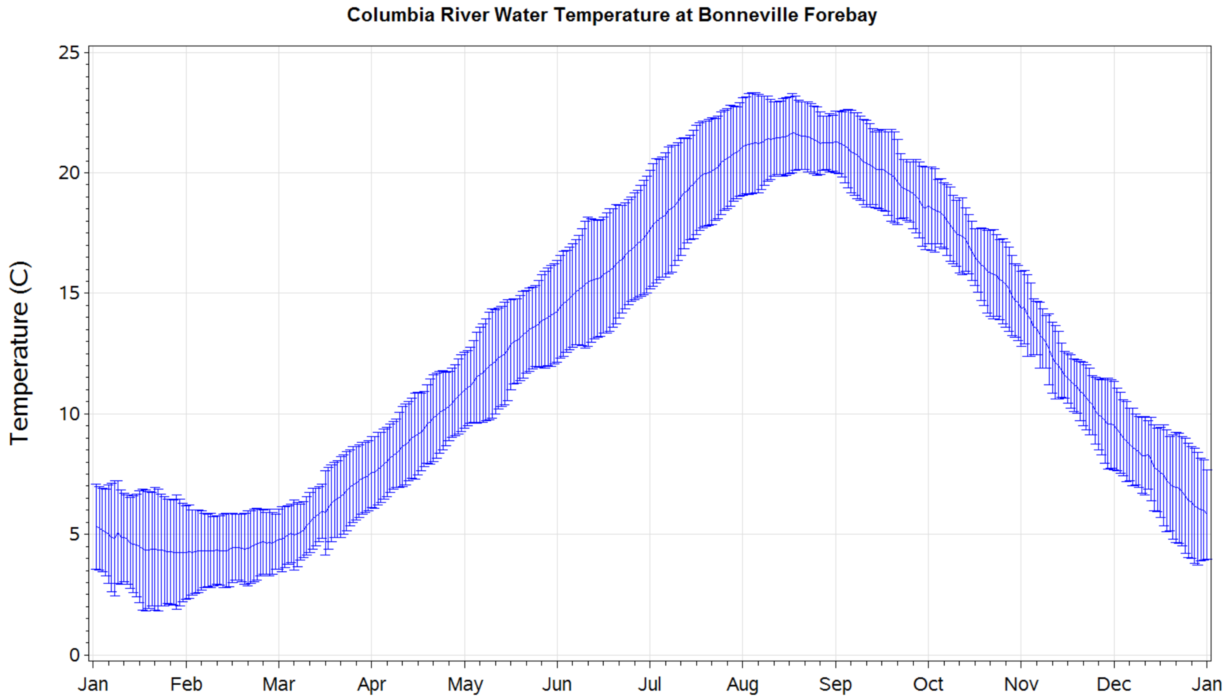


Figure 23. Daily mean water temperature ± 2 standard deviations in the lower Columbia River at Bonneville Dam Forebay (1986-2019) (Source: CBR DART).

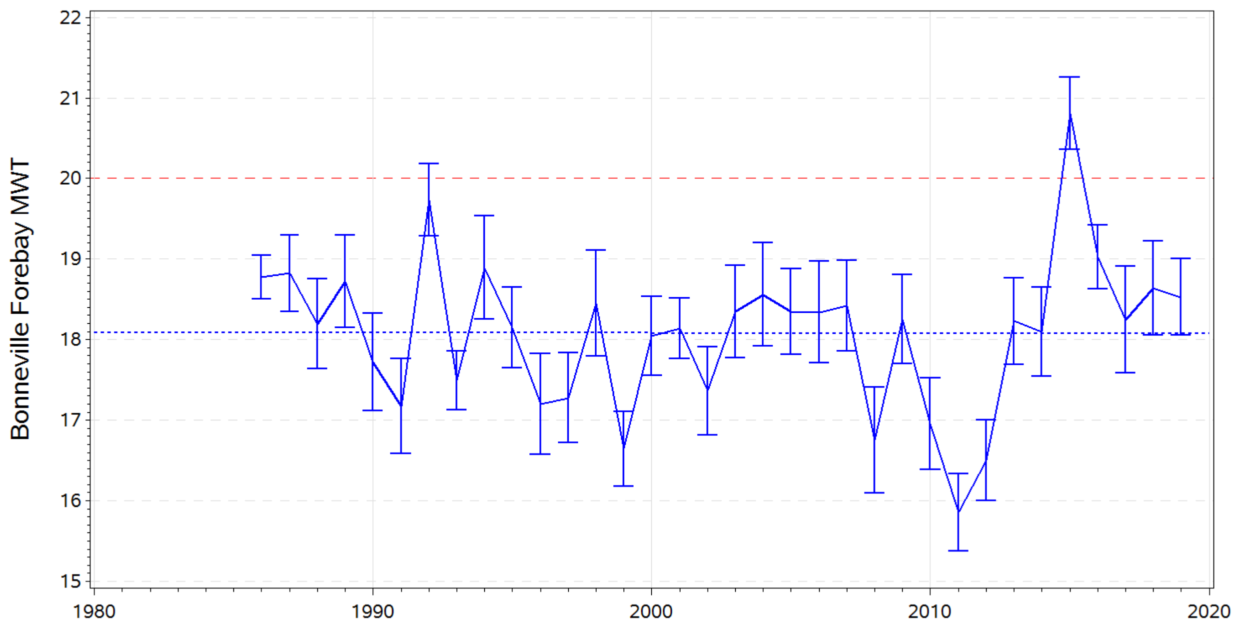


Figure 24. Daily mean water temperature ± 2 standard errors in the Columbia River at Bonneville Dam Forebay (June-July, 1986-2019) (Source: CBR DART[58]).

[58] Columbia Basin Research DART (Data Access in Real Time) www.cbr.washington.edu/dart. Downloaded: 01-Nov-2019.

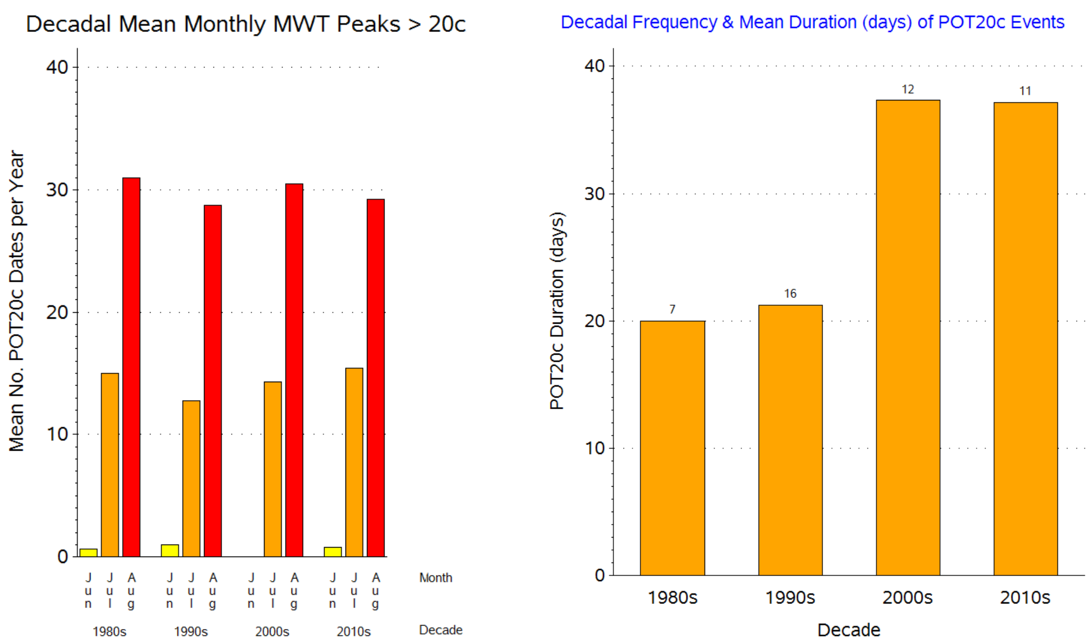


Figure 25. Frequency analysis of decadal mean number of dates per month in which mean water temperature (observed) in the Bonneville Dam forebay exceeded 20°C (left), and exceedance event duration (right), by decade, Jun-Jul-Aug, 1986-2019.

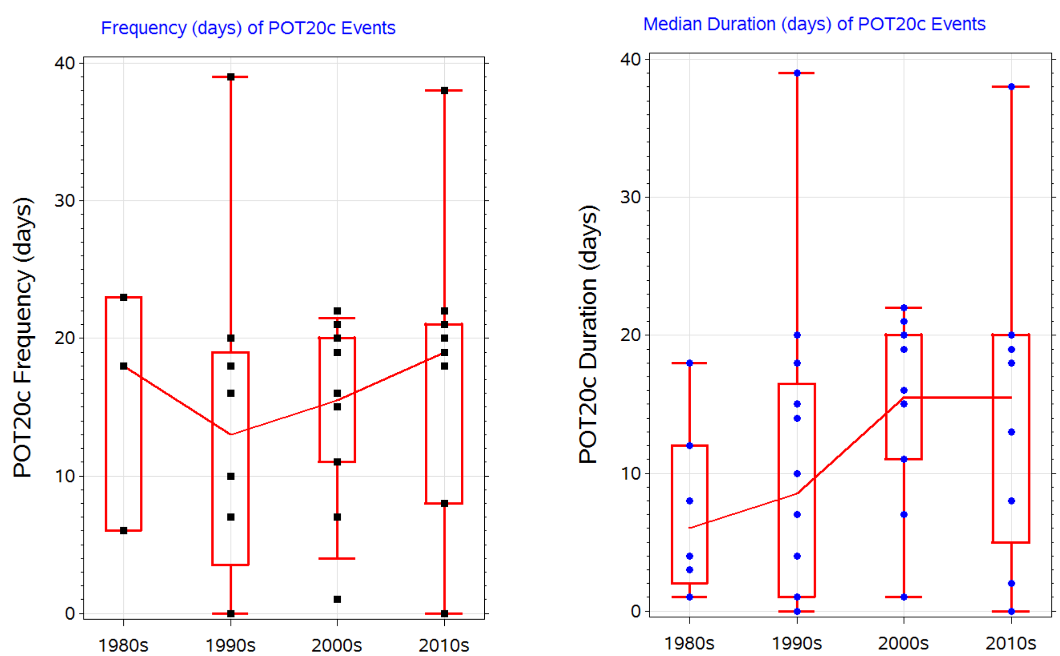


Figure 26. Frequency analysis of decadal mean number of dates in which observed mean water temperature in the Bonneville Dam forebay during adult Sockeye migration (June-July only) exceeded 20°C (left), and exceedance event duration (days), by decade, 1986-2019.

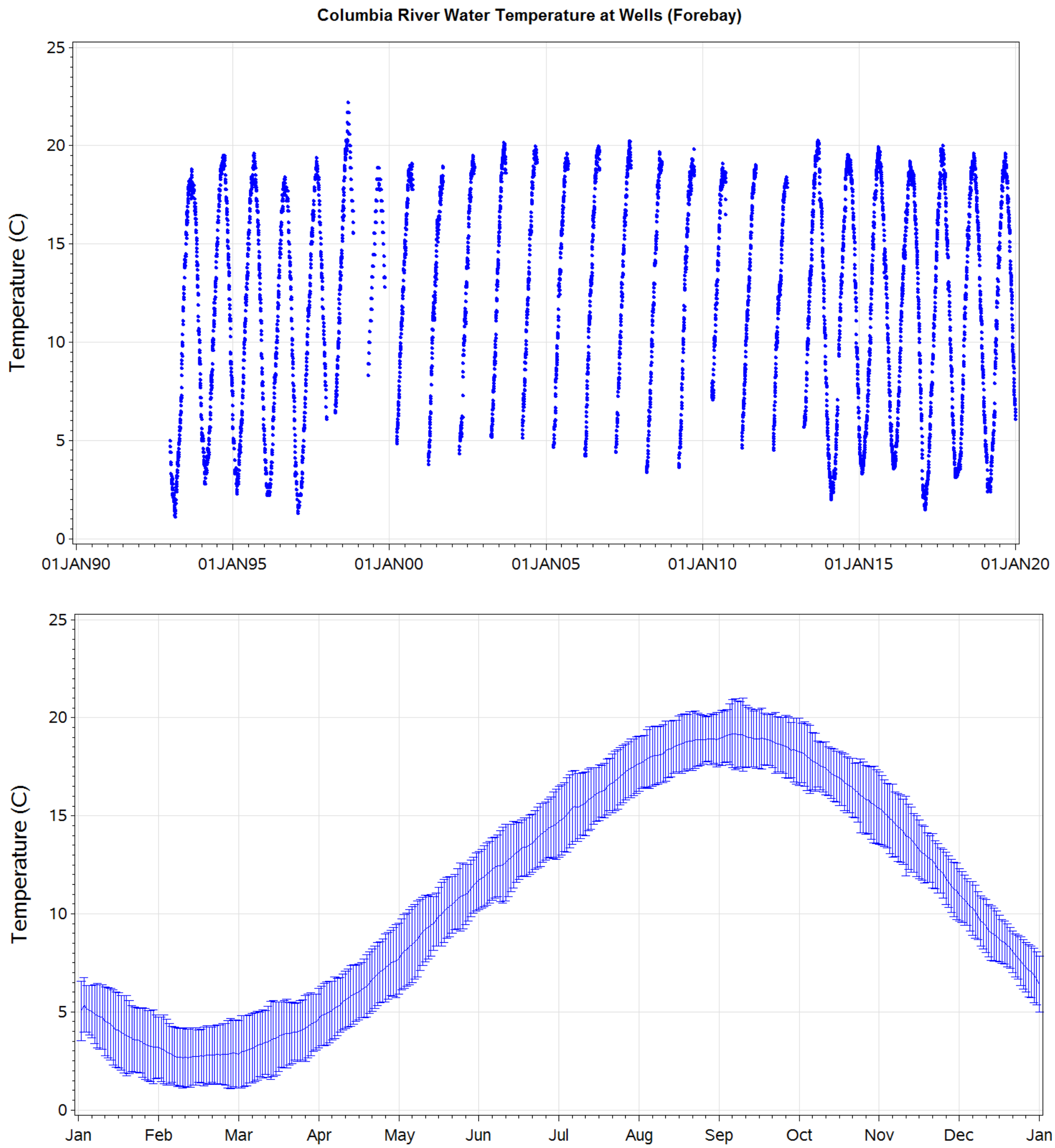


Figure 27. Daily mean water temperature ± 2 standard deviations in the Columbia River at Wells Dam Forebay (1993-2019) (Source: CBR DART[59]).

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[59] Columbia Basin Research DART (Data Access in Real Time) www.cbr.washington.edu/dart. Downloaded: 01-Nov-2019.

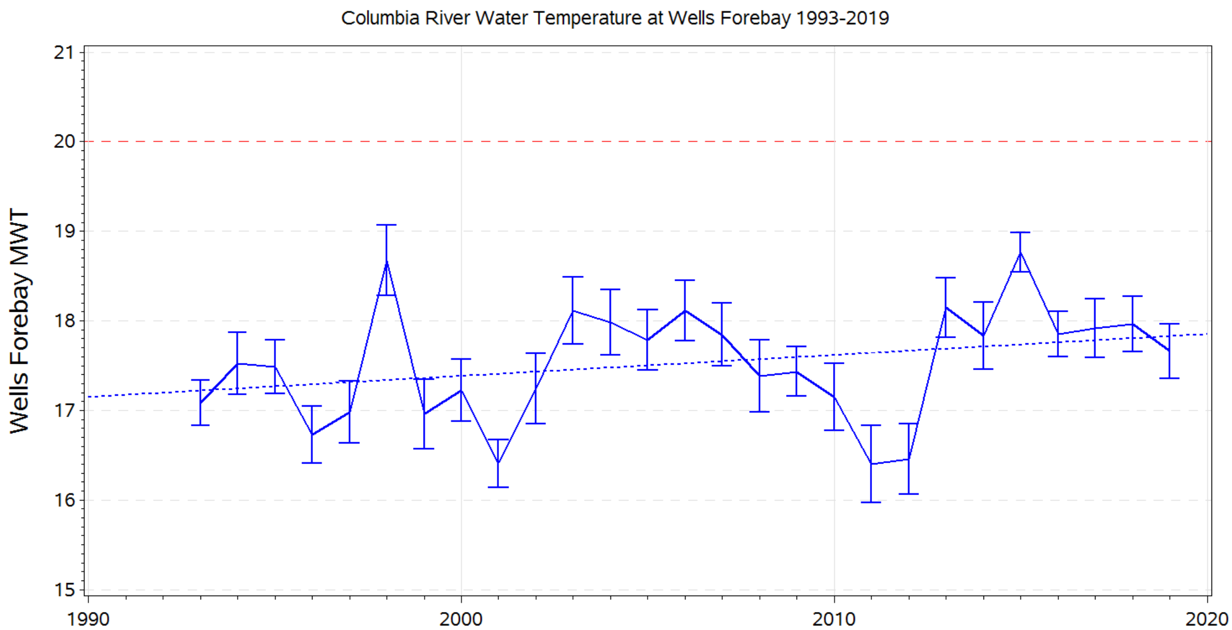


Figure 28. Trend in recorded Columbia River daily mean water temperature, July-August, 1993-2019, at the Wells Dam forebay. Weak warming trend is not statistically significant (Y = 0.02 * Year, r = 0.12).

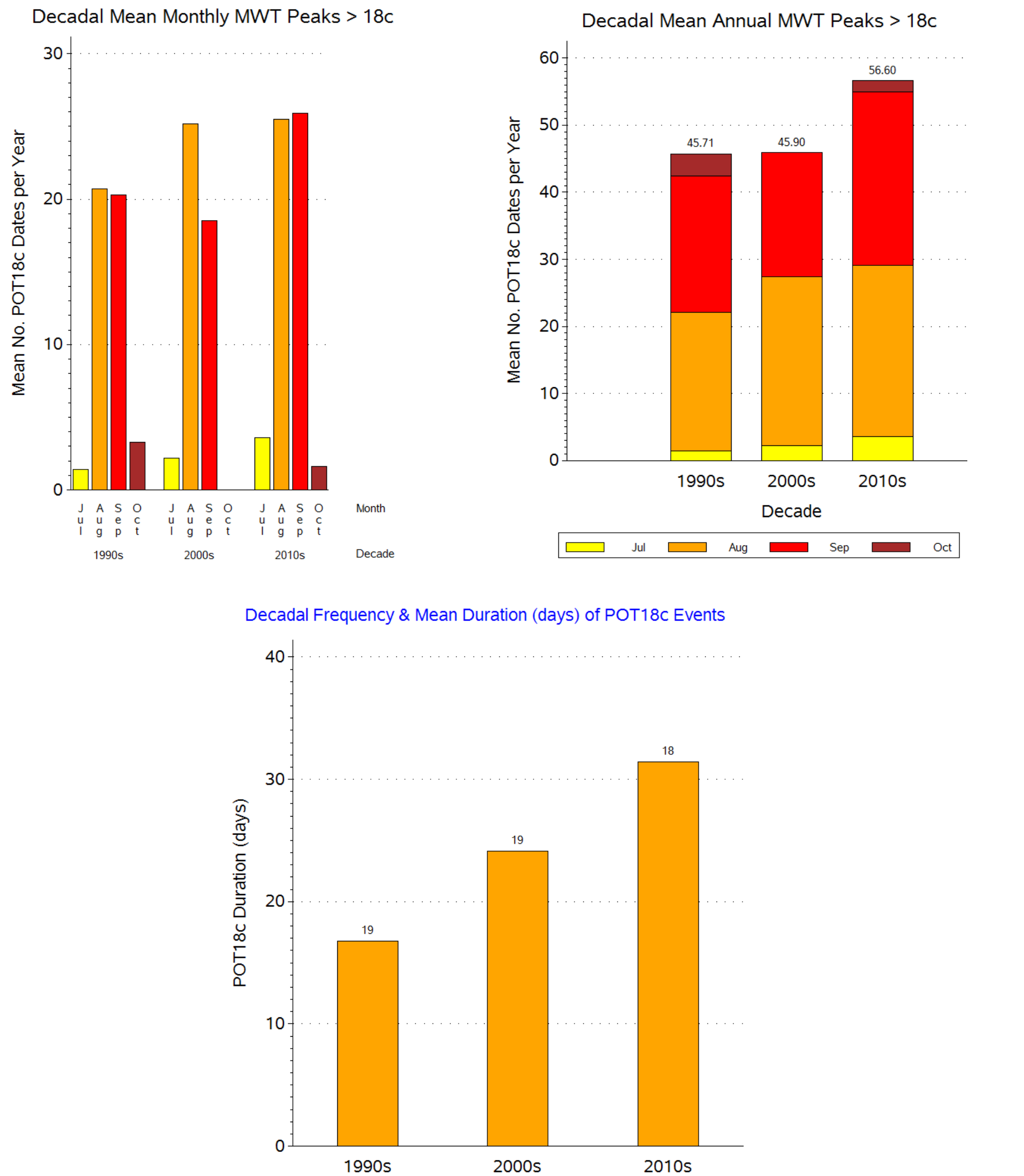


Figure 29. Frequency analysis of decadal mean number of dates per month (July-October) in which mean water temperature (observed) in the Wells Dam forebay exceeded 18°C (top), and exceedance event duration (bottom), by decade. Note: 1990s include 1993-1999 only.

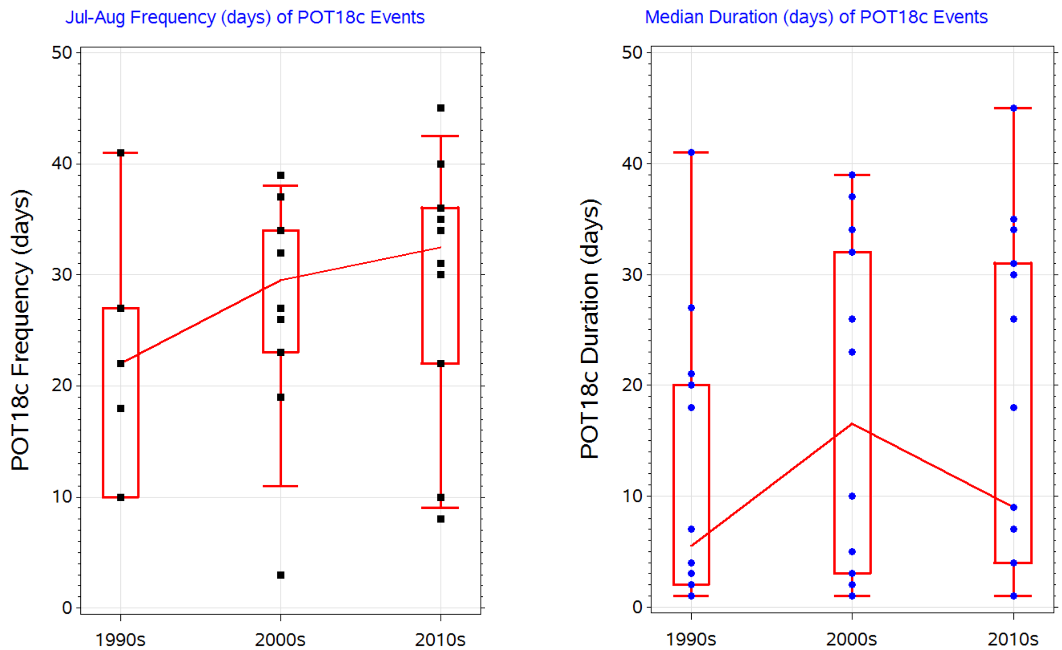


Figure 30. Frequency analysis of decadal mean number of dates in which observed mean water temperature in the Wells Dam forebay during adult Sockeye migration (July-August only) exceeded 18°C (left), and exceedance event duration (days), by decade (right). Note: 1990s include 1993-1999 only.

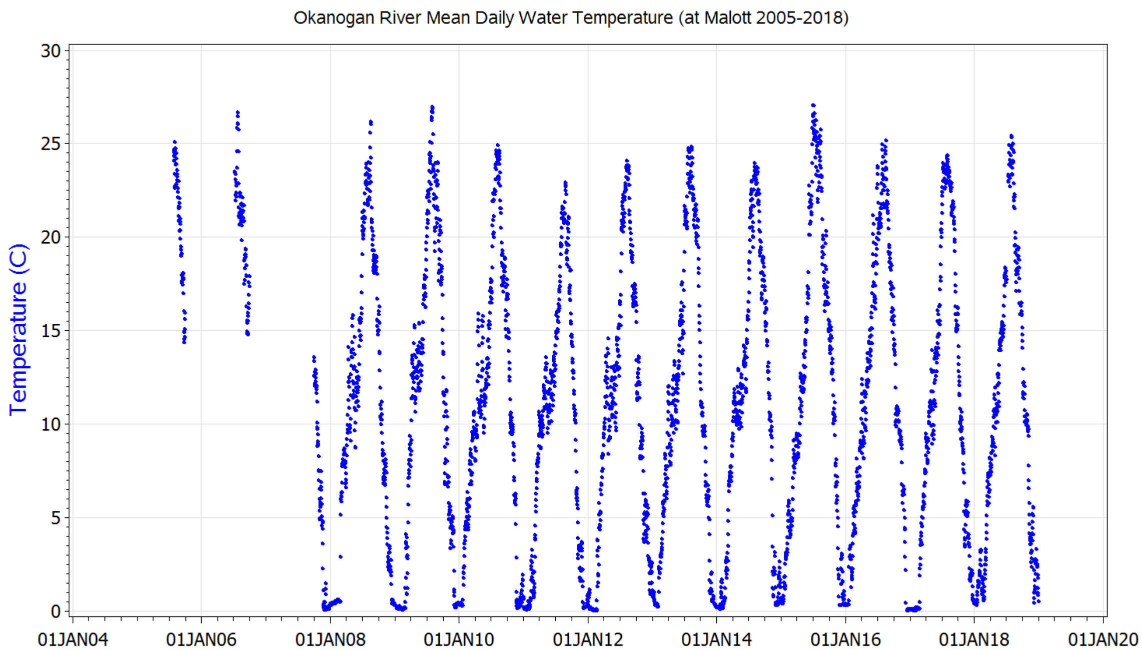


Figure 31. Daily mean water temperature, Okanogan River at Malott, WA (2005-2018).[60]

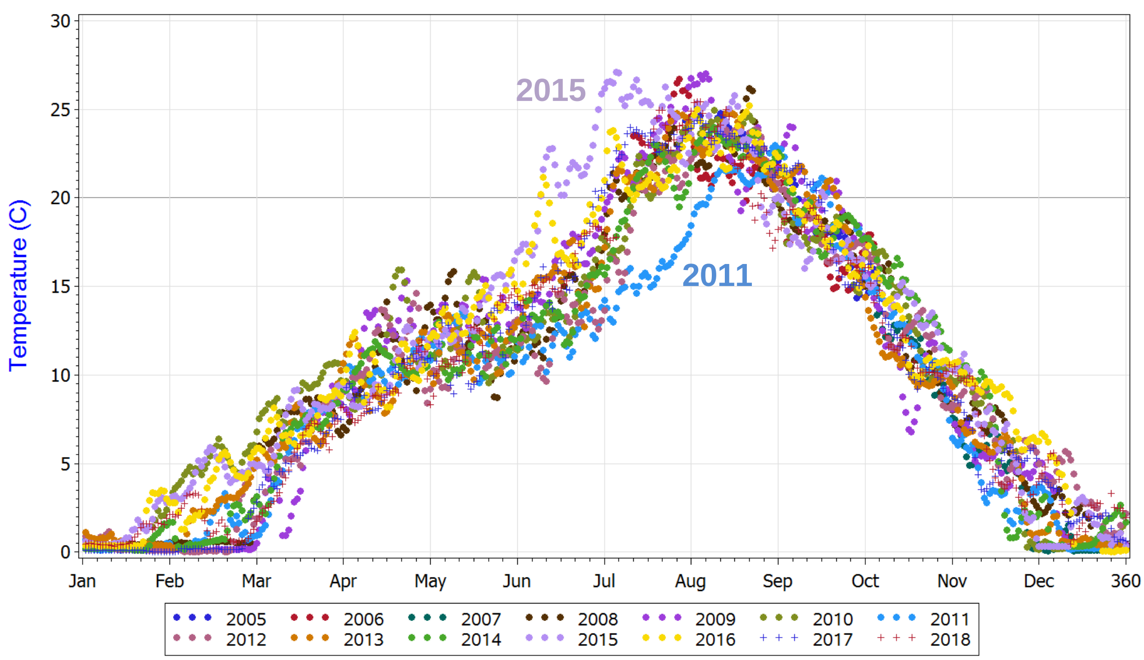


Figure 32. Annual thermograph of daily mean water temperature, Okanogan River at Malott, WA (2005-2018).

[60] Downloaded Nov 2019 (WQM station 49A190 2005-2006; USGS station 12447200).

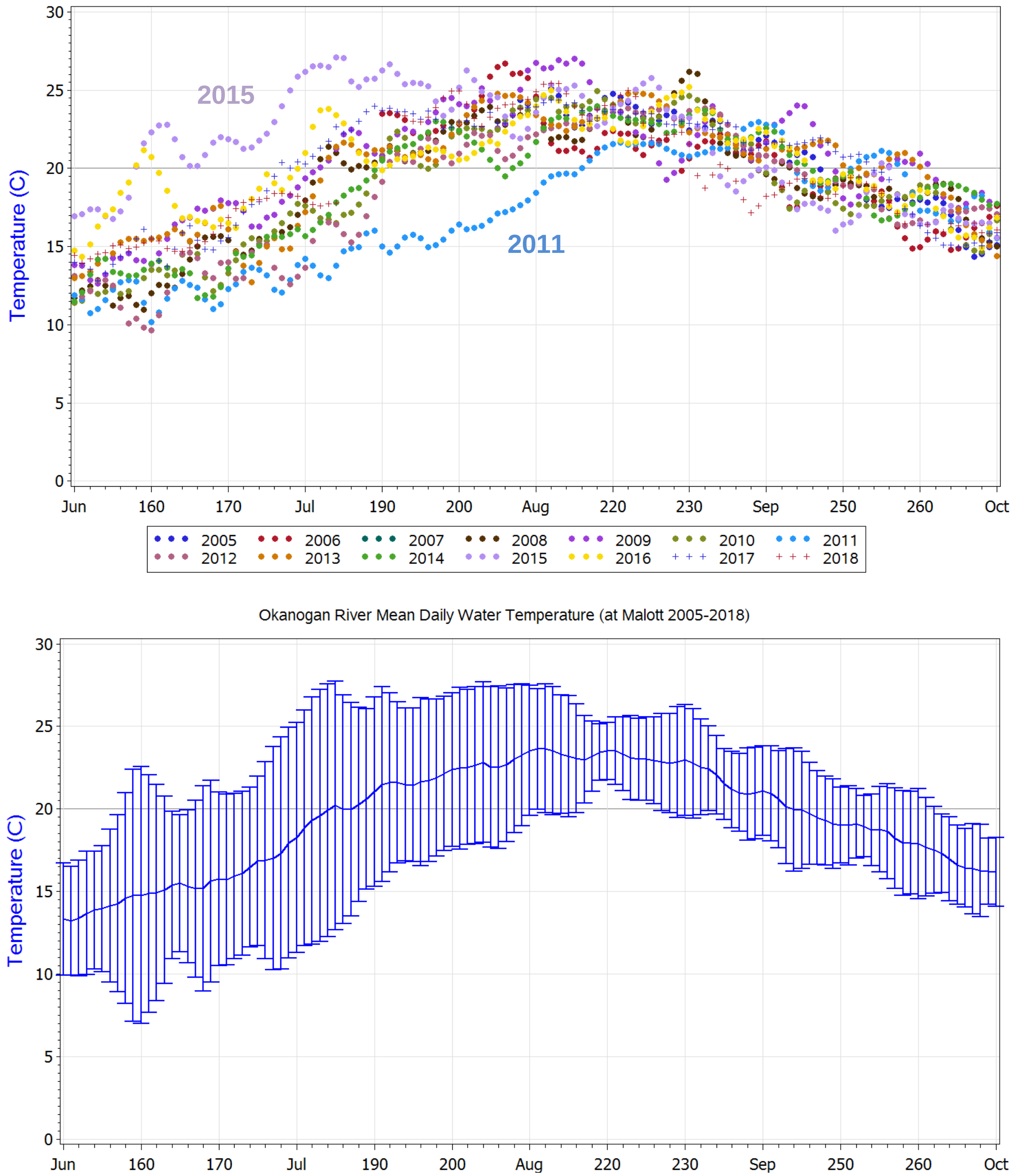


Figure 33. Daily mean water temperature (top), and multi-year daily mean water temperature ± 2 standard deviations (bottom) for June-September in the Okanogan River at Malott, WA (2005-2018).

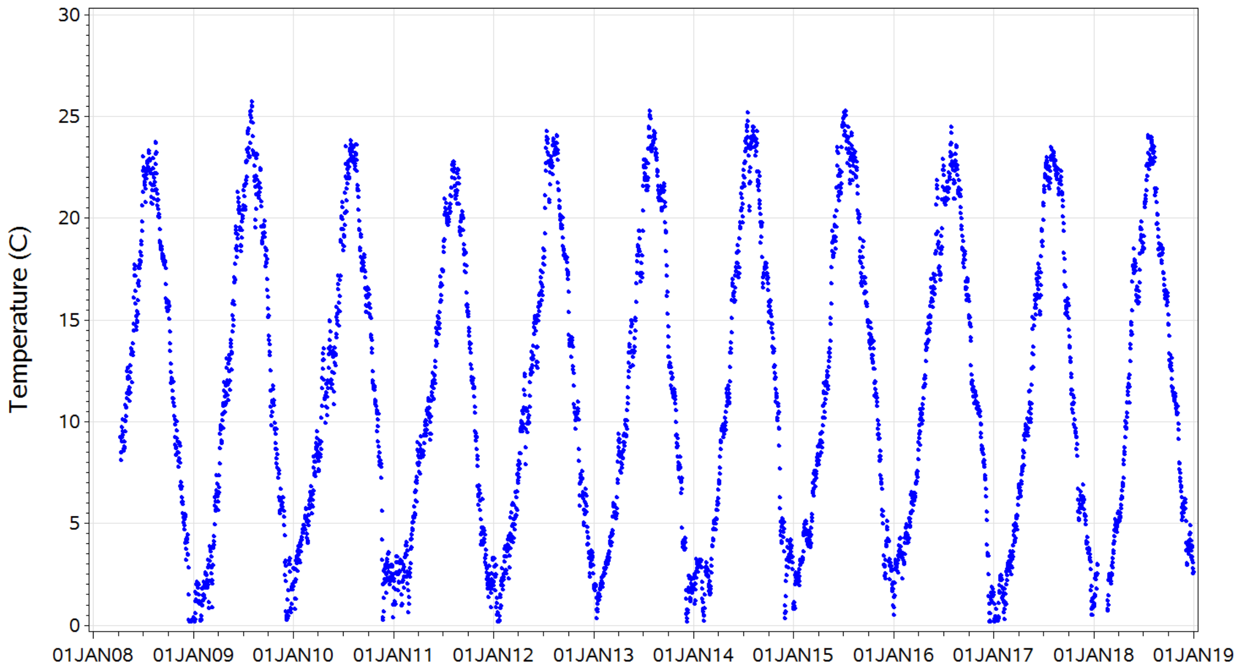


Figure 34. Daily mean water temperature time-series in the Okanagan River at Oliver, BC, 2008-2018.

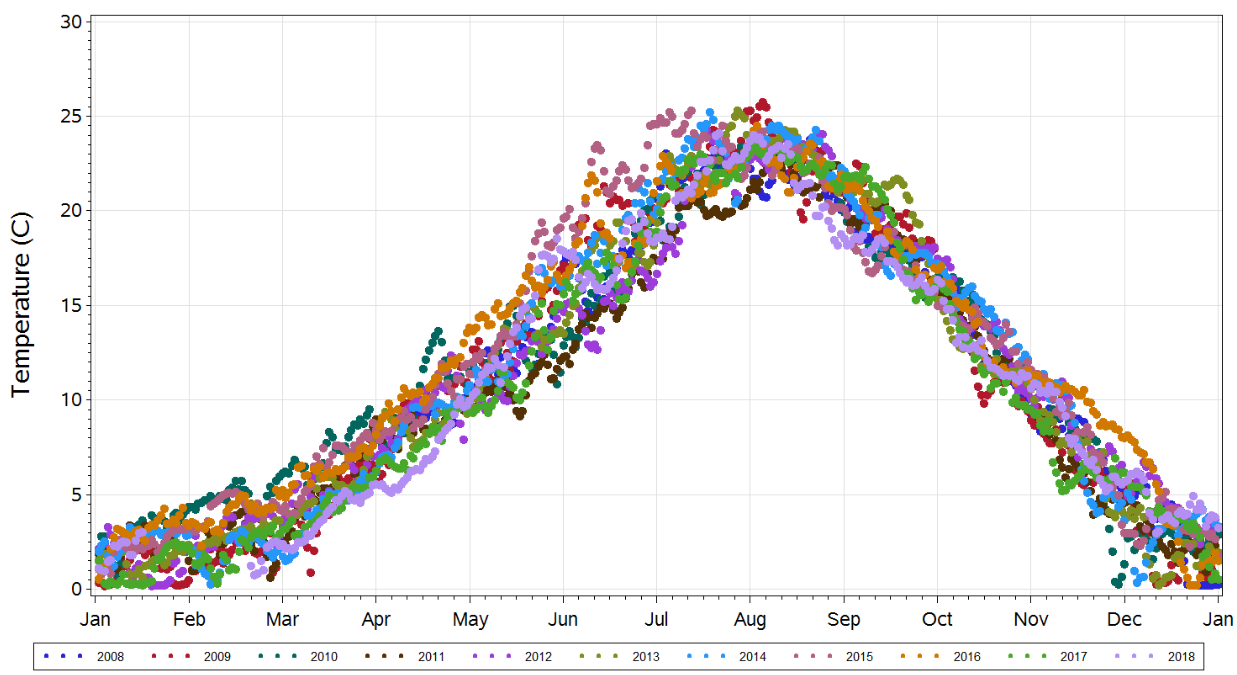


Figure 35. Annual thermograph of daily mean water temperature in the Okanagan River at Oliver, BC (2008-2018).

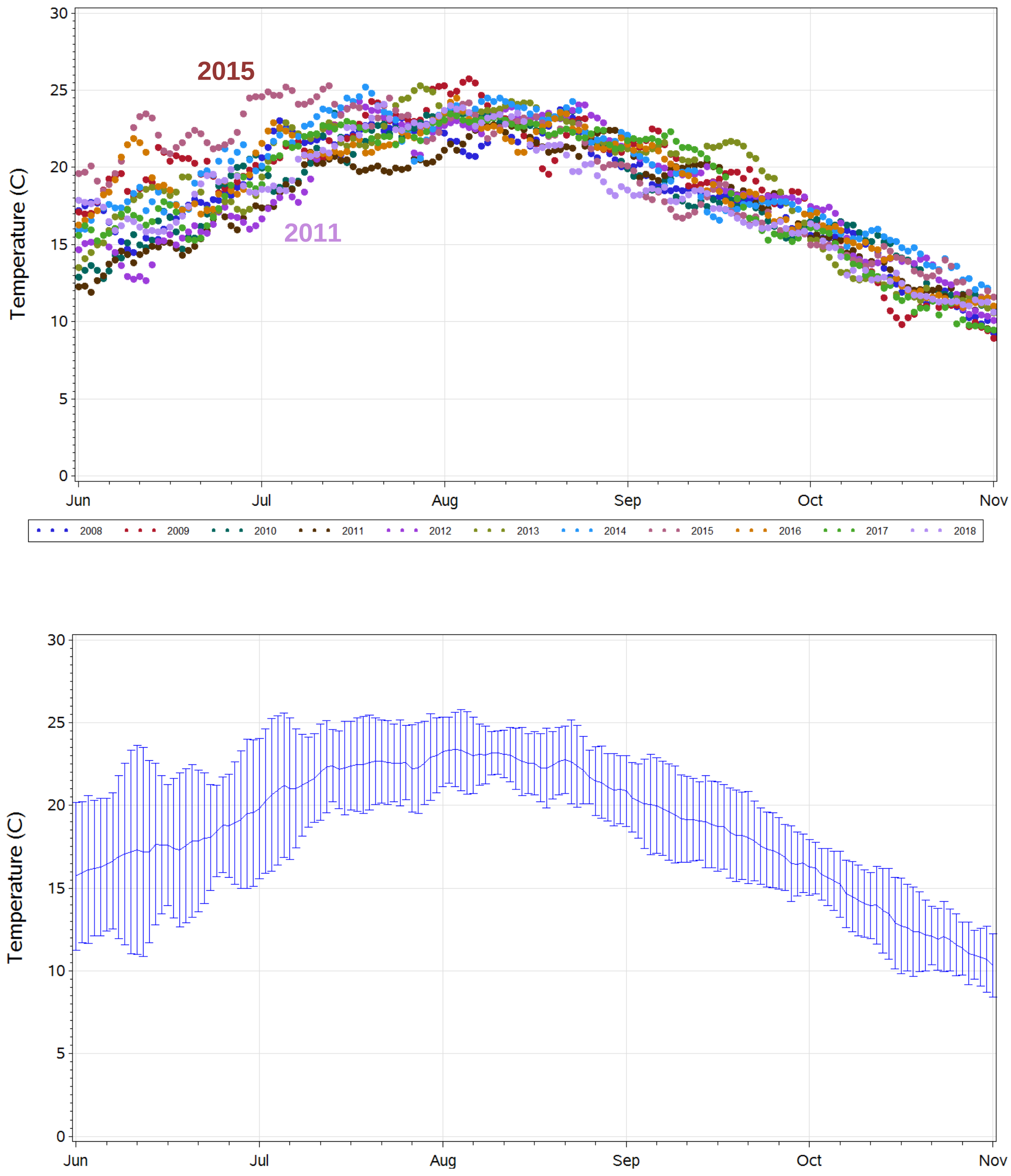


Figure 36. Daily mean water temperature (top), and multi-year daily mean water temperature ± 2 standard deviations (bottom) for June-September in the Okanagan River at Oliver, BC (2008-2018).

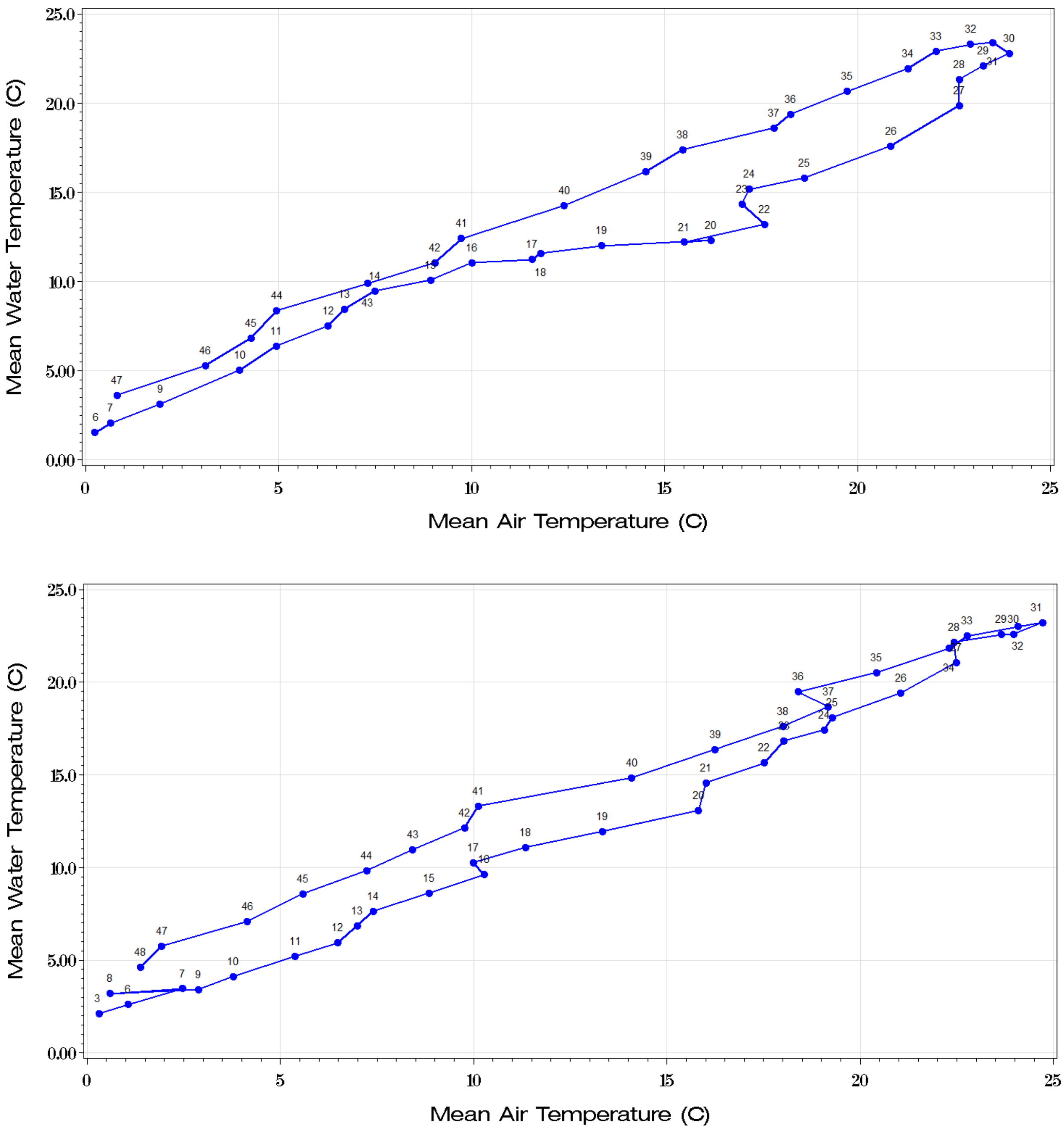


Figure 37. Derivation of seasonal turn-around point based on maximum weekly air temperature versus water temperature data for Okanogan River (Malott, top), and Okanagan River (Oliver, bottom). The seasonal turn-around point is in week 31 or day 217, approximately August 5th. The "warming season" therefore extends from April 1 to August 5th, followed by the "cooling season" from day 218-329, i.e., August 6th – November 25th.

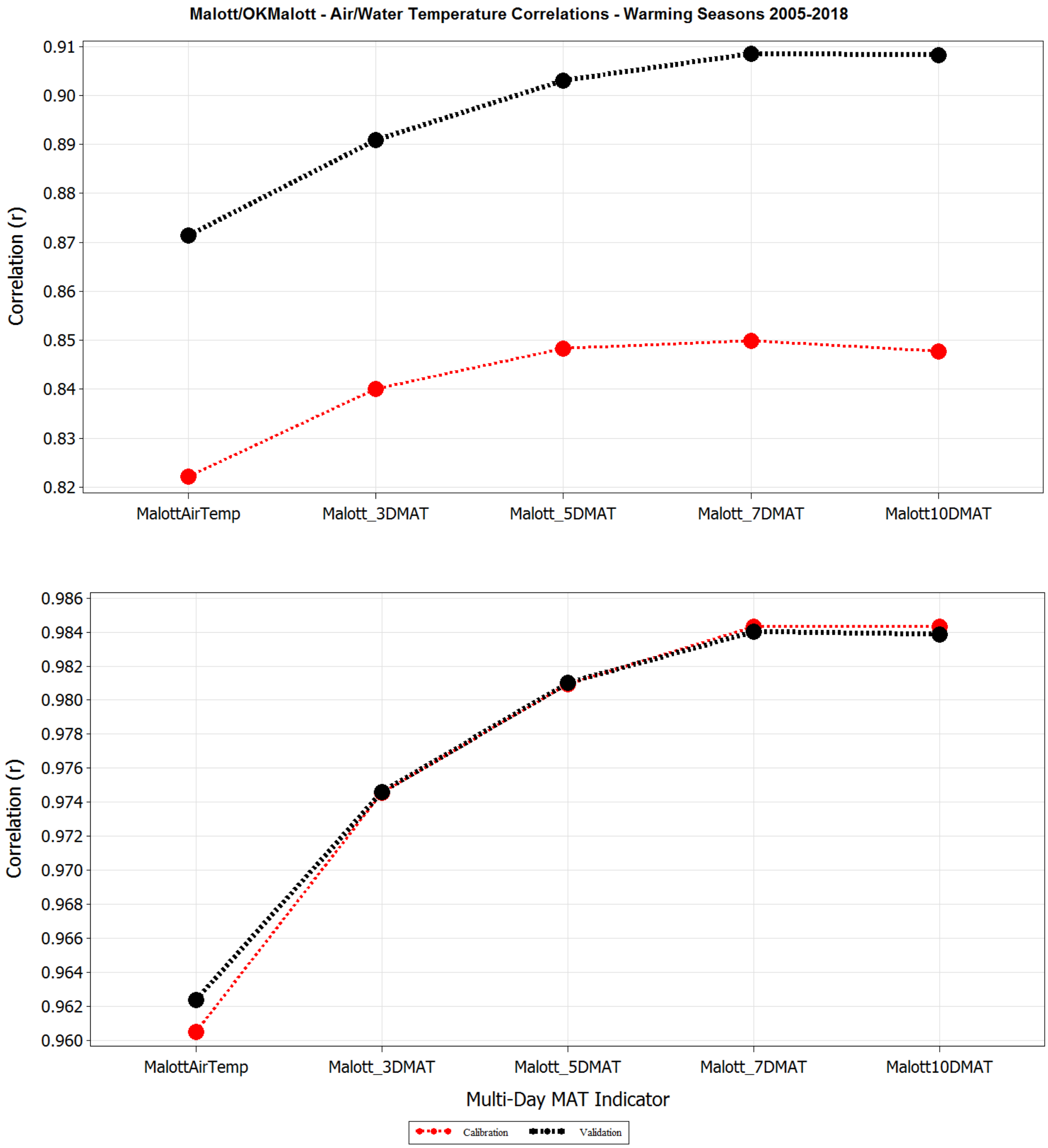


Figure 38. Derivation of optimum regional air temperature index for air/water temperature analyses, based on maximum all-year correlation between various MALOTT AWN multi-day mean air temperature indicators (MATs) with Okanogan River (at Malott, WA) daily mean water temperature (MWT) for calibration (red) and validation (black) data; warming season (top), cooling season (bottom).

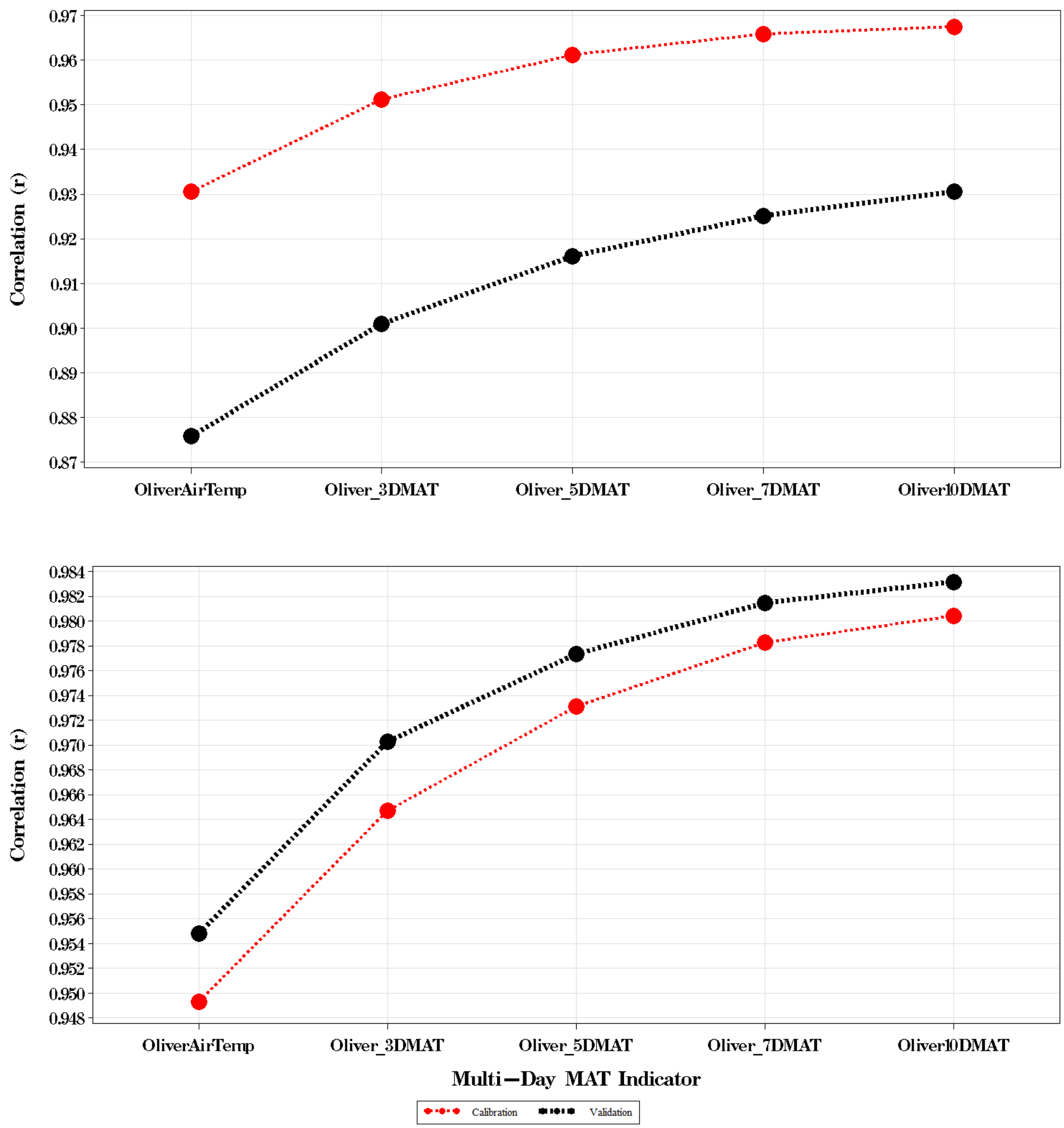


Figure 39. Derivation of optimum regional air temperature index for air/water temperature analyses, based on maximum all-year correlation between various OLIVER STP multi-day mean air temperature indicators (MATs) with Okanagan River (at Oliver) daily mean water temperature (MWT) for calibration (red) and validation (black) data; warming season (top), cooling season (bottom). OLIVER STP air temperature indicators include (l-r): Air Temp (same day mean); 3-day centered moving average air temperature (3D-MAT), 5D-MAT, 7D-MAT, and 10-DMAT. Overall, the 7D-MAT provides the best trade-off between correlation and multi-day averaging (which affects predictive power at longer period lengths).

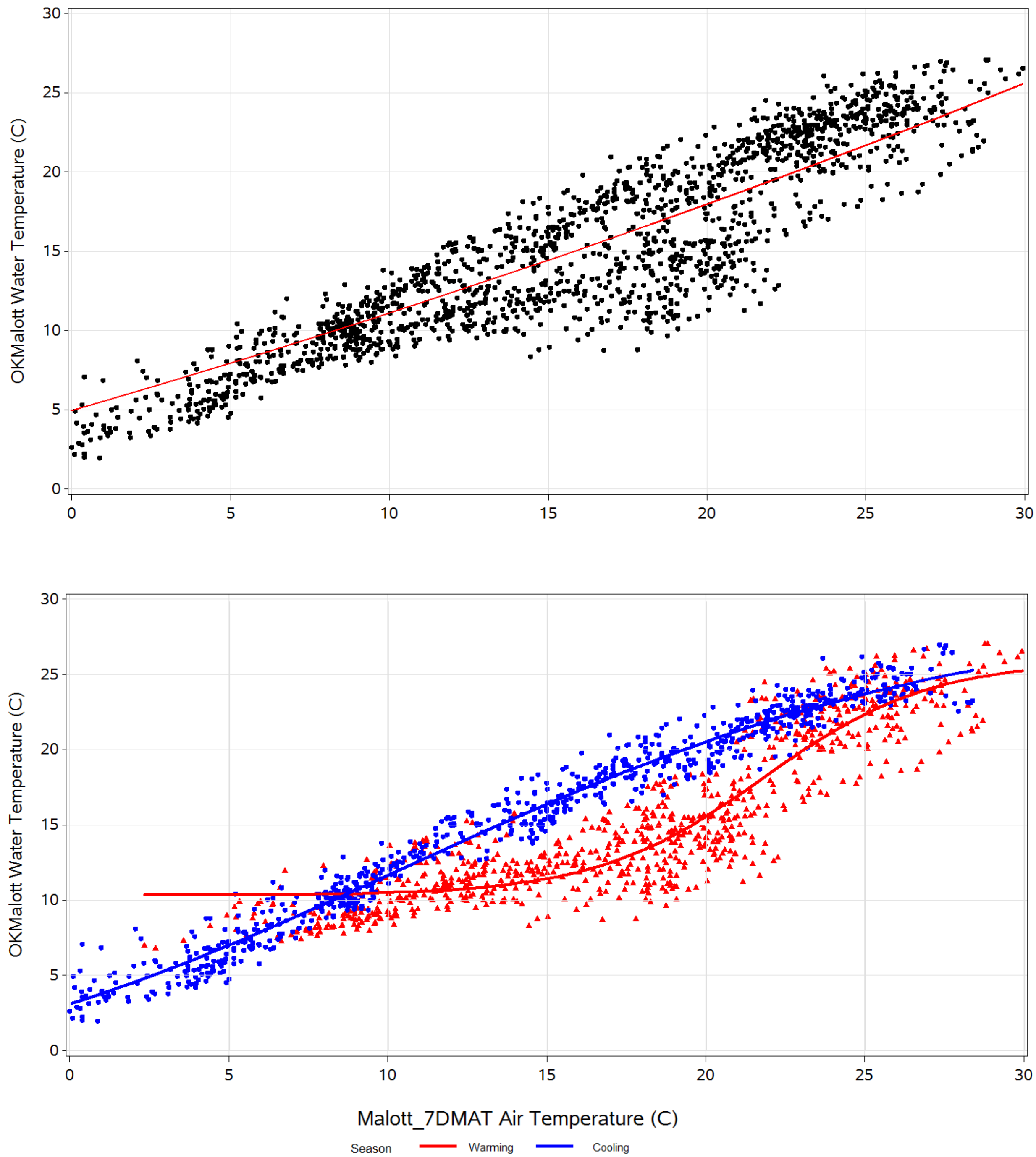


Figure 40. Logistic regression fits for air/water temperature relationship for Okanogan River (at Malott, WA) continuous daily mean water temperatures as a function of the Malott AWN 7d-CMAT (air temperature index), seasons combined (top); separate warming season (red) and cooling seasons (blue)(bottom). For calibration years, see Table 18; for logistic model coefficients: see Table 19.

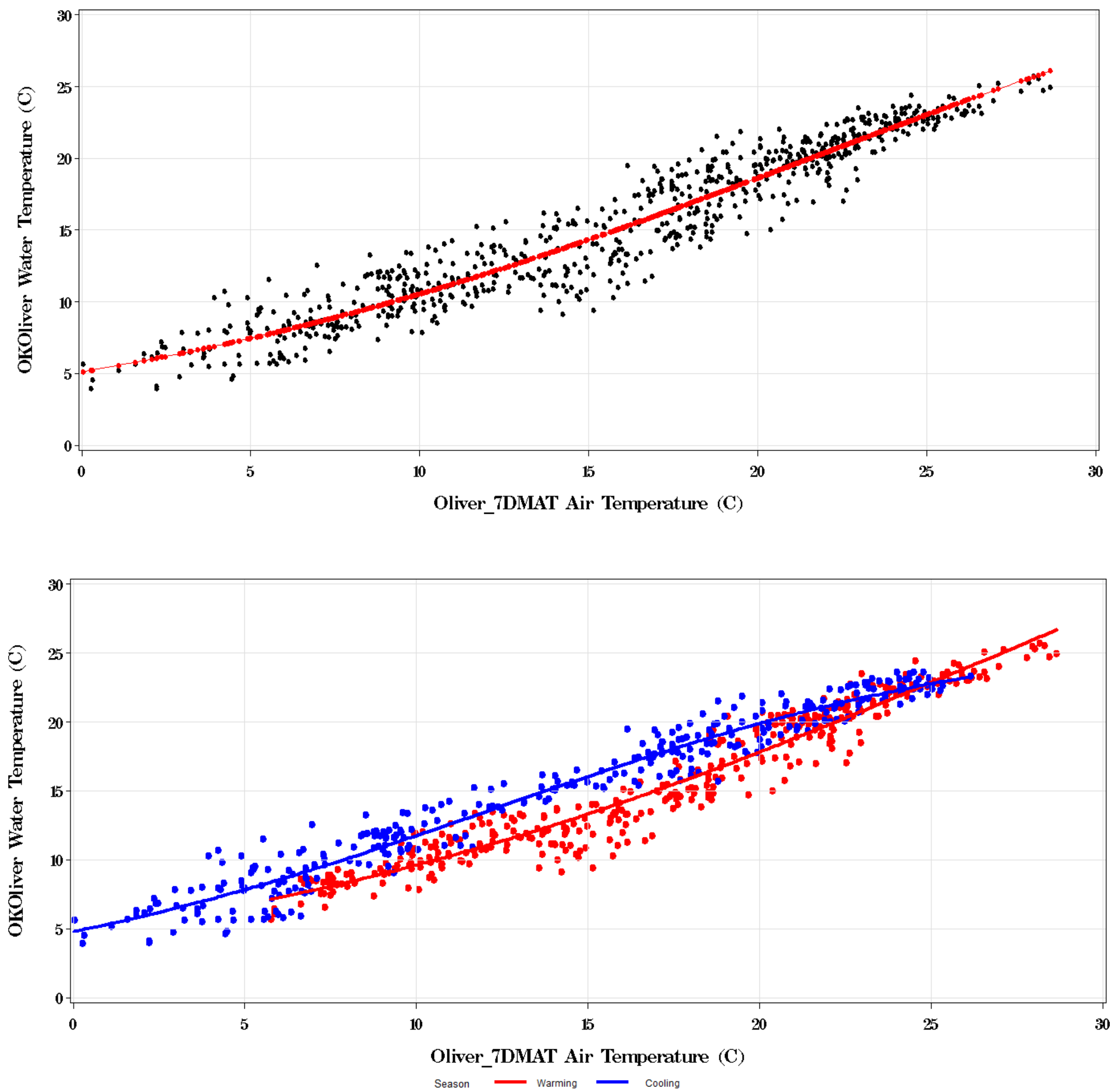


Figure 41. Logistic regression fits for air/water temperature relationship for Okanagan River (at Oliver) continuous daily mean water temperatures as a function of the OLIVER STP 7d-CMAT (air temperature index), seasons combined (top); separate warming season (red) and cooling seasons (blue)(bottom). For calibration years, see Table 18); for logistic model coefficients: see Table 21.

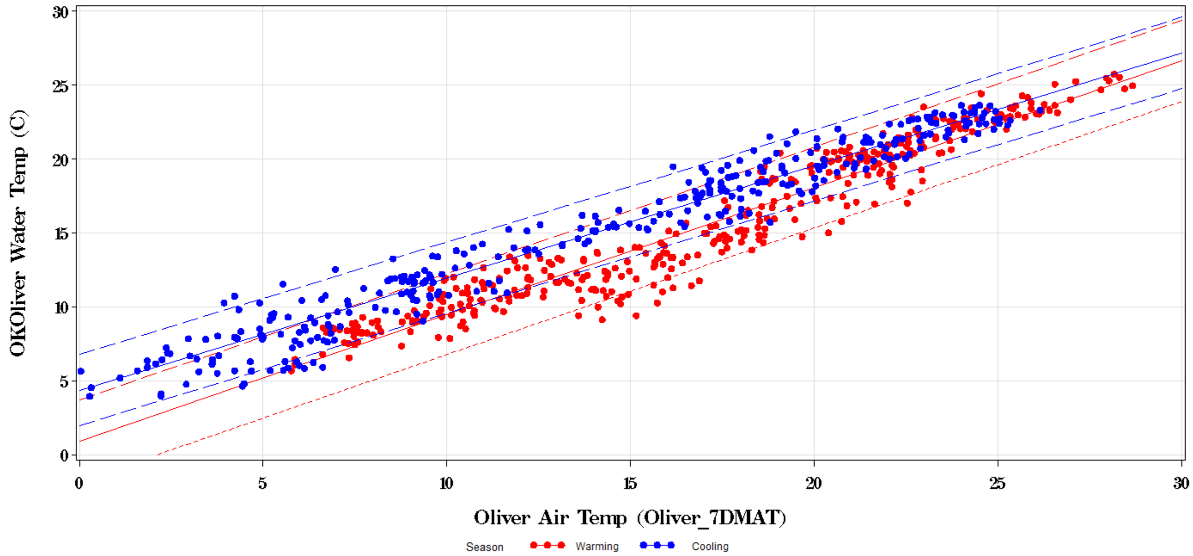


Figure 42. Linear regression fits for air/water temperature relationship for Okanagan River (at Oliver) continuous daily mean water temperatures as a function of the OLIVER STP 7d-CMAT (air temperature index), by season (warming season (red) and cooling season (blue)), for calibration years 2008-2011.

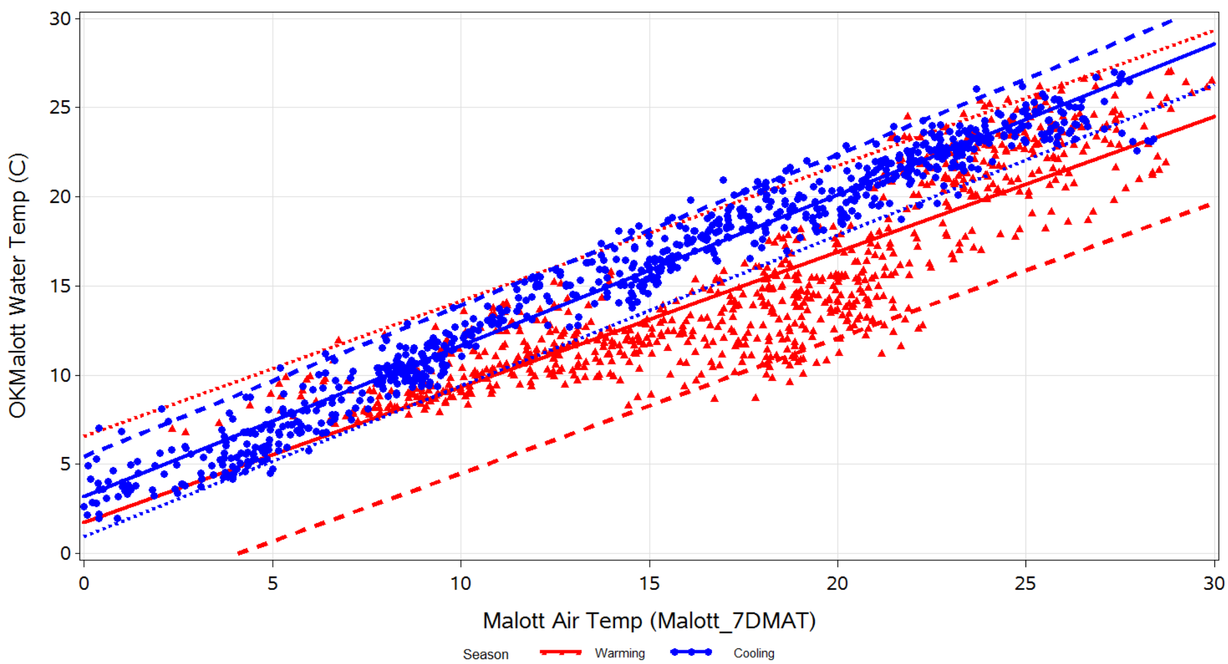


Figure 43. Linear regression fits for air/water temperature relationship for Okanogan River (at Malott, WA) continuous daily mean water temperatures as a function of the MALOTT 7d-CMAT (air temperature index) for calibration years (Table 18); warming season (red) and cooling seasons (blue).

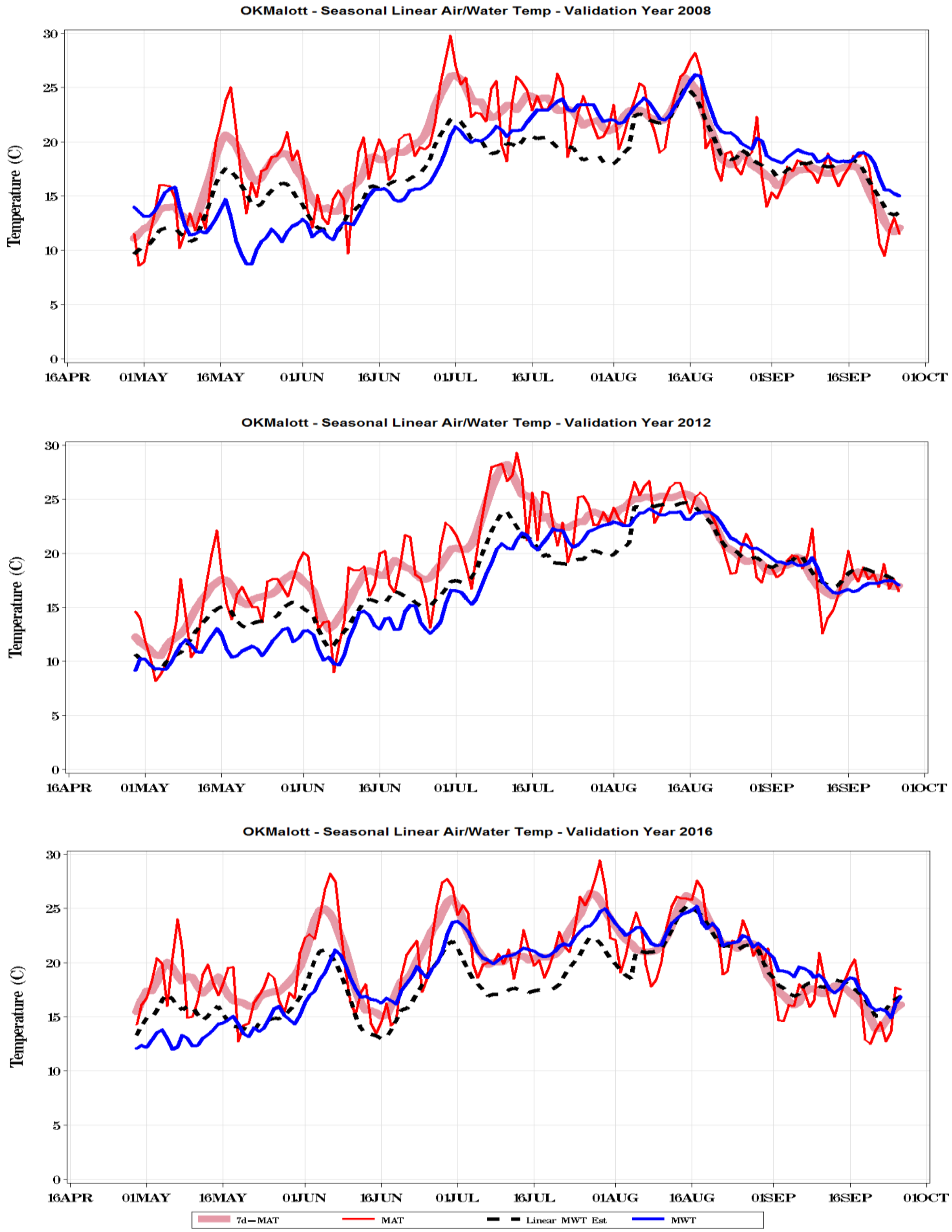


Figure 44. Observed (blue solid line) and estimated (black dashed line) daily mean water temperature and air temperature (red line), and 7-day MAT index (broad pink line) for validation years (2008, 2012, 2018) for Okanogan River (at Malott, WA).

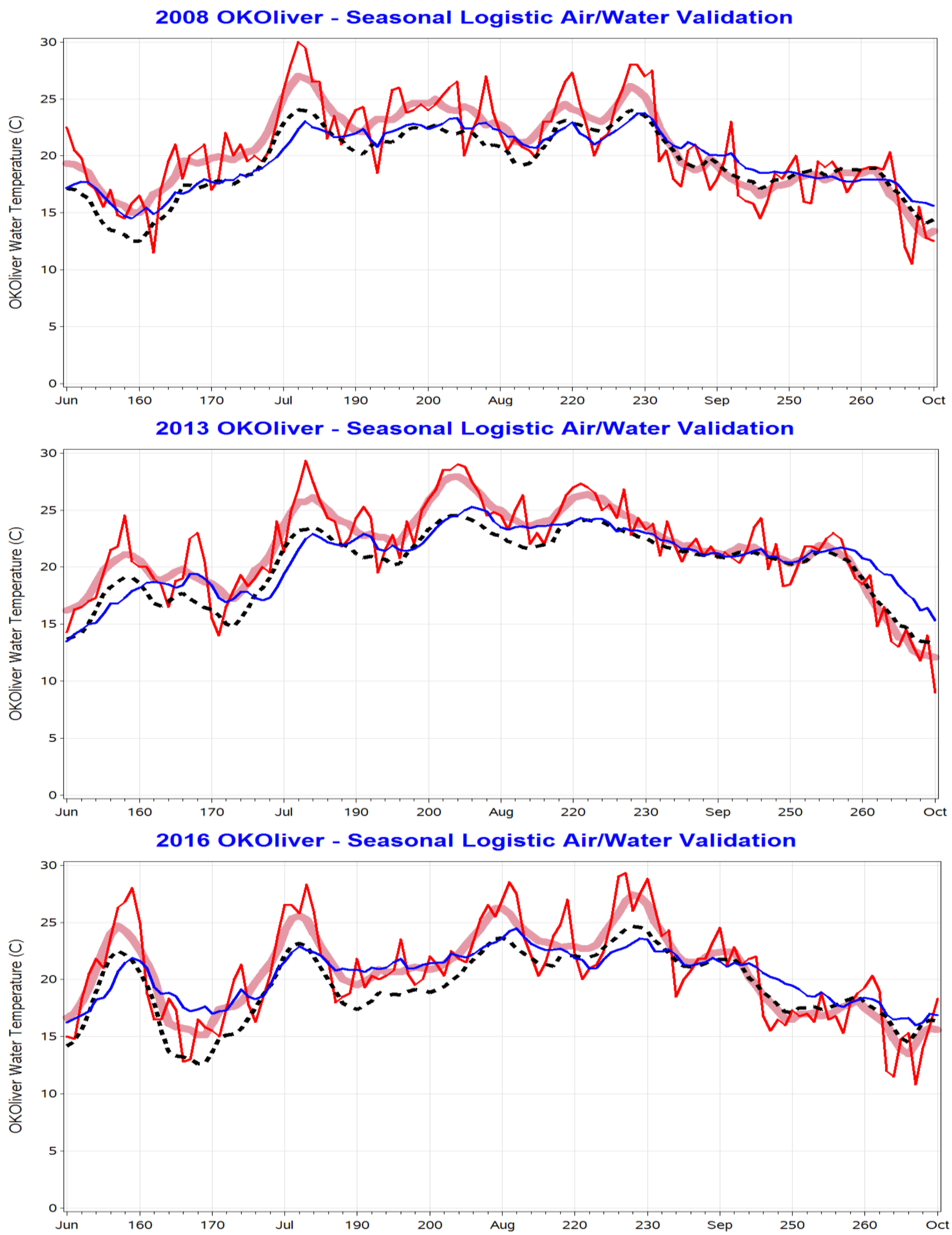
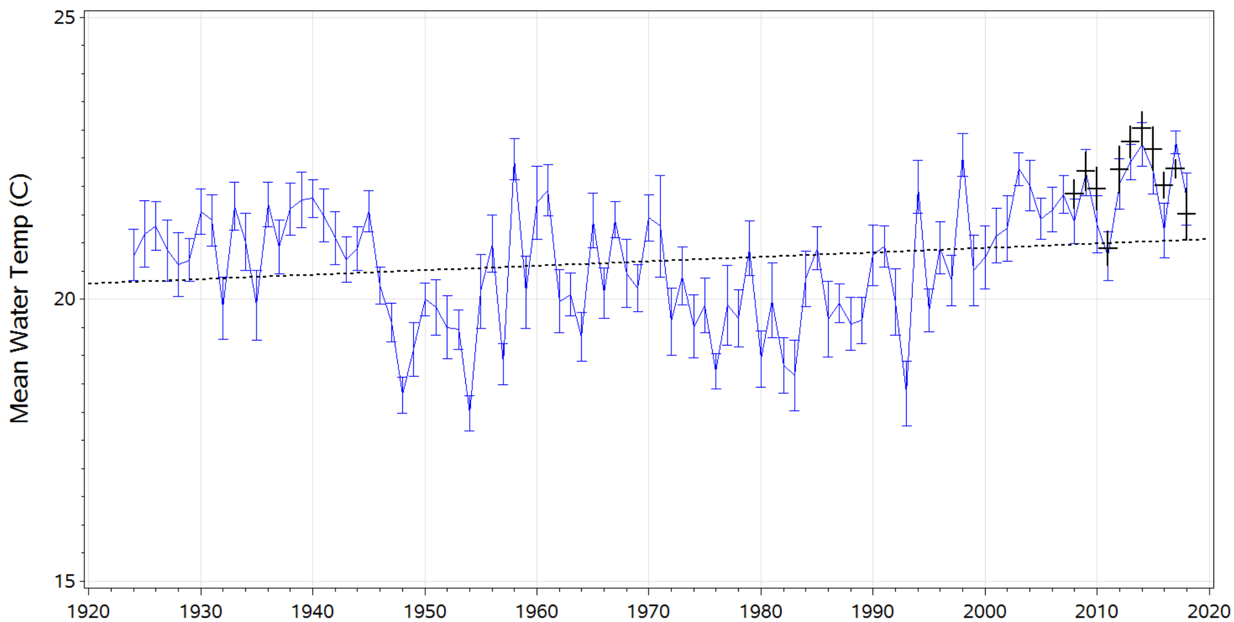


Figure 45. Observed (blue solid line) and estimated (black dashed line) daily mean water temperature and air temperature (red line), and 7-day MAT index (broad pink line) for validation years (2008, 2013, 2016) for Okanagan River (at Oliver, BC).



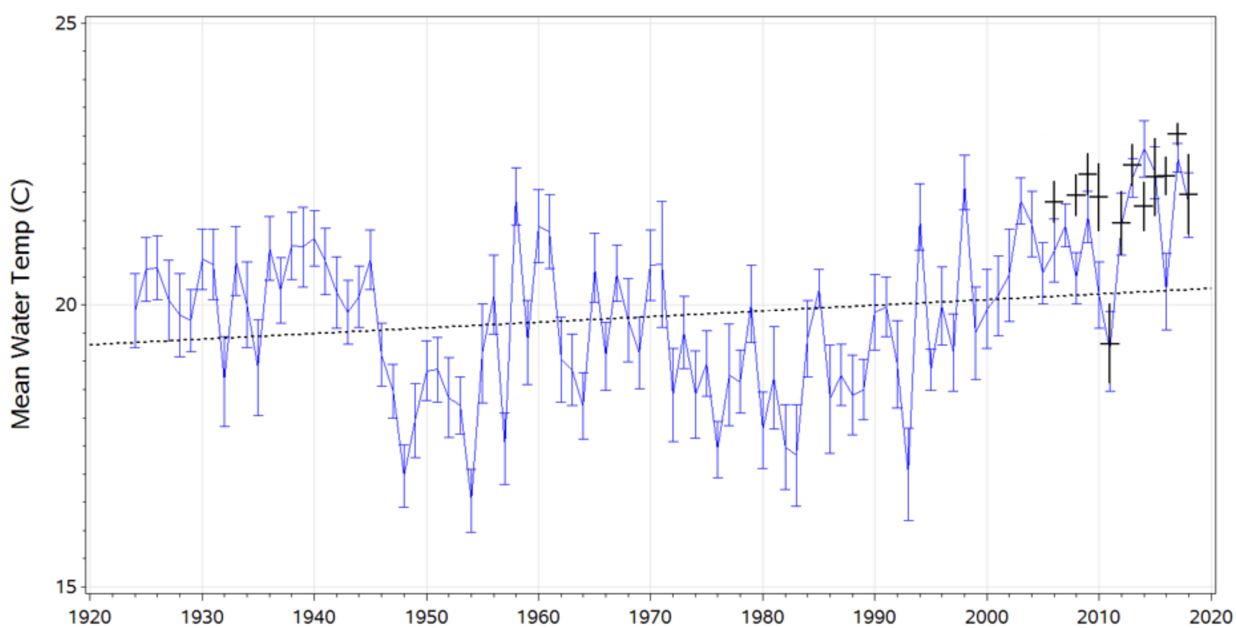


Figure 46. Trend in estimated mean water temperature (± 2 standard errors), July-August, 1924-2018, in the Okanagan River (at Oliver, top) and lower Okanogan River (at Malott, bottom). Observed July-August means (2006-2018) and standard errors (in black) generally reflect the conservative bias (underestimation) of summer temperature estimates.

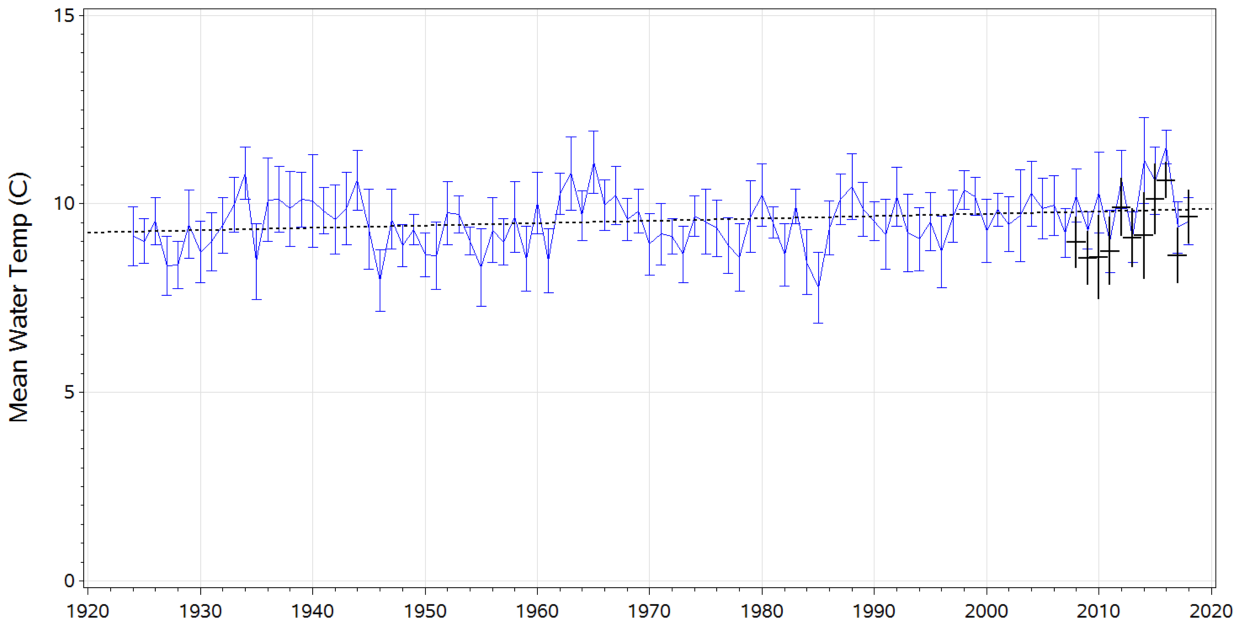


Figure 47. Trend in estimated mean water temperature, October-November, 1924-2018, in the Okanagan River near Oliver. Observed October-November water temperature means (2008-2018) and standard errors (in black) generally reflect an overestimation bias of fall temperature estimates.

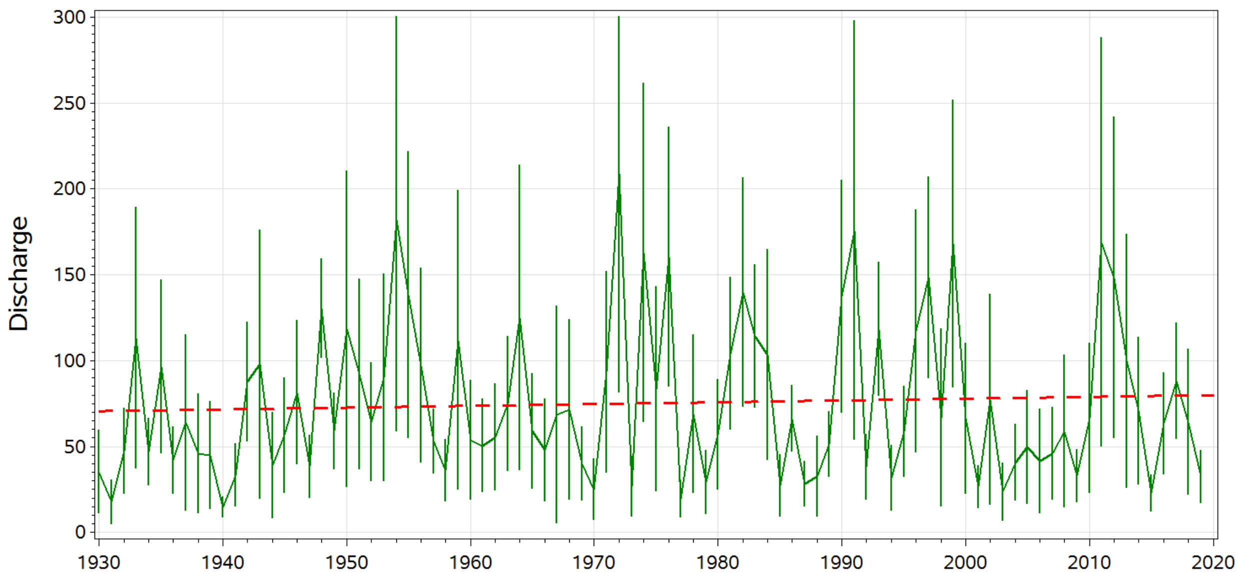


Figure 48. Trend in observed and estimated mean summer (July-August) discharge ± standard error, 1930-2018, in the lower Okanogan River near Malott.

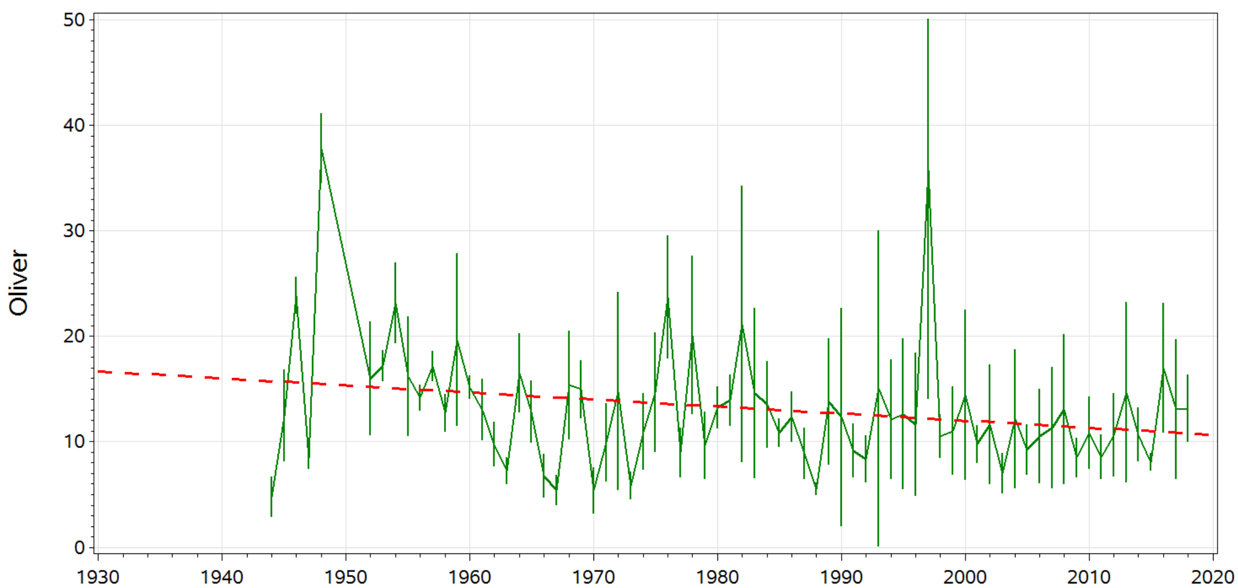
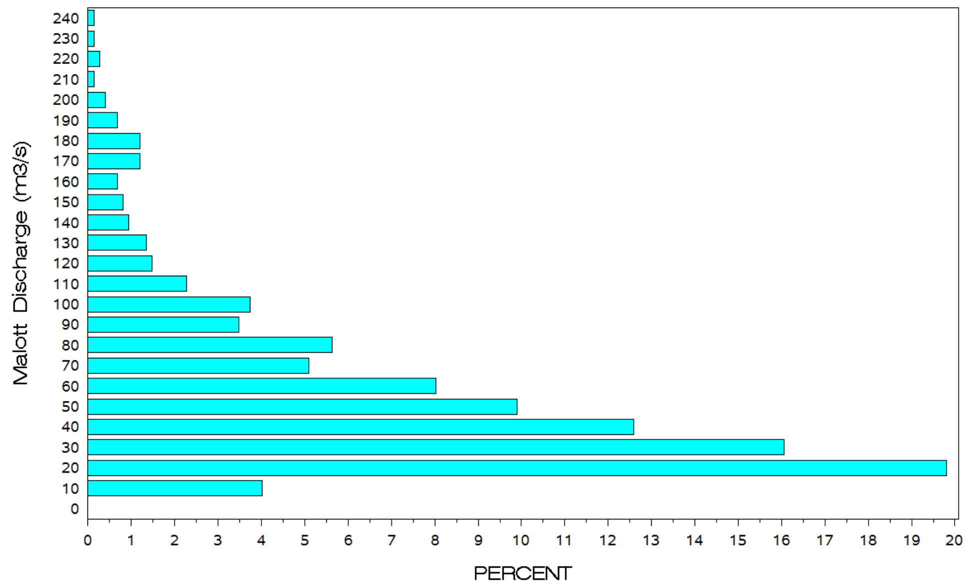
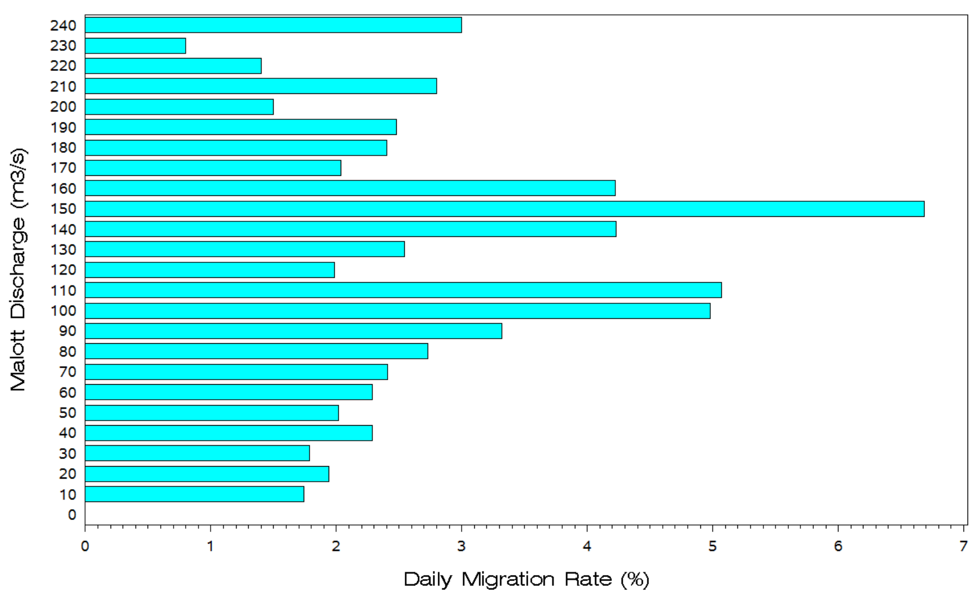


Figure 49. Trend in observed mean fall (September-November) discharge ± standard error, 1944-2018, in the Okanagan River near Oliver.



FREQ.	CUM. FREQ.	PCT.	CUM. PCT.
1	747	0.13	100.00
1	746	0.13	99.87
2	745	0.27	99.73
1	743	0.13	99.46
3	742	0.40	99.33
5	739	0.67	98.93
9	734	1.20	98.26
9	725	1.20	97.05
5	716	0.67	95.85
6	711	0.80	95.18
7	705	0.94	94.38
10	698	1.34	93.44
11	688	1.47	92.10
17	677	2.28	90.63
28	660	3.75	88.35
26	632	3.48	84.61
42	606	5.62	81.12
38	564	5.09	75.50
60	526	8.03	70.41
74	466	9.91	62.38
94	392	12.58	52.48
120	298	16.06	39.89
148	178	19.81	23.83
30	30	4.02	4.02
0	0	0.00	0.00

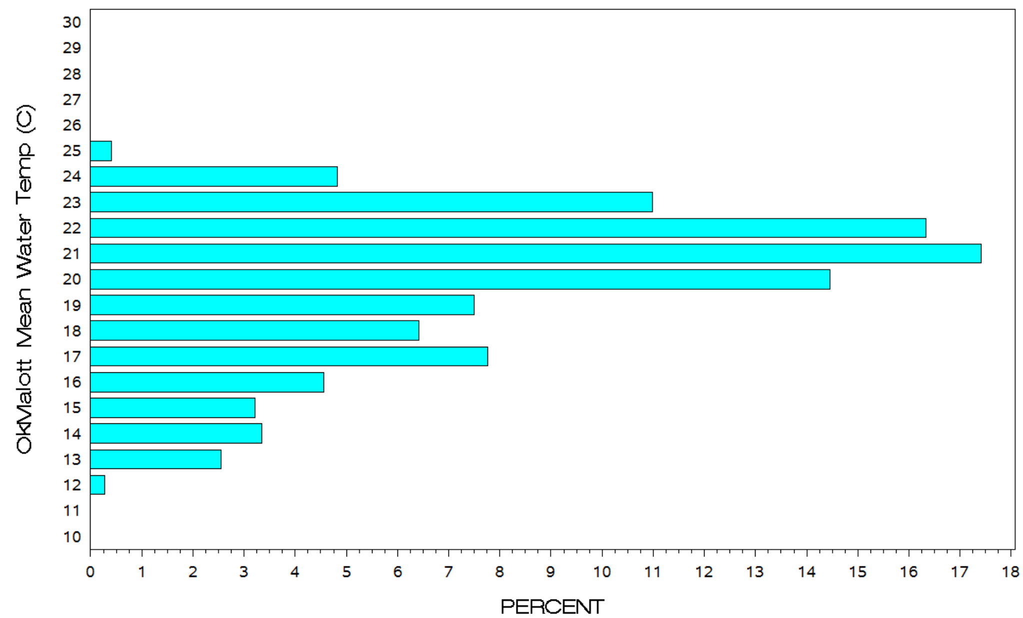
Figure 50. Frequency plot of select years[61] of historical Okanagan Sockeye migration (unweighted tally of non-zero migration dates, lagged back to Okanogan/Columbia confluence), at varying levels of Okanogan River (at Malott) discharge. 50% of dates of migration occurred below 50 cms.



FREQ.	Daily Migration Rate (%)
1	3.00
1	0.80
2	1.40
1	2.80
3	1.50
5	2.48
9	2.40
9	2.03
5	4.22
6	6.68
7	4.23
10	2.54
11	1.98
17	5.07
28	4.98
26	3.32
42	2.73
38	2.41
60	2.28
74	2.02
94	2.28
120	1.79
148	1.94
30	1.74
0	0.00

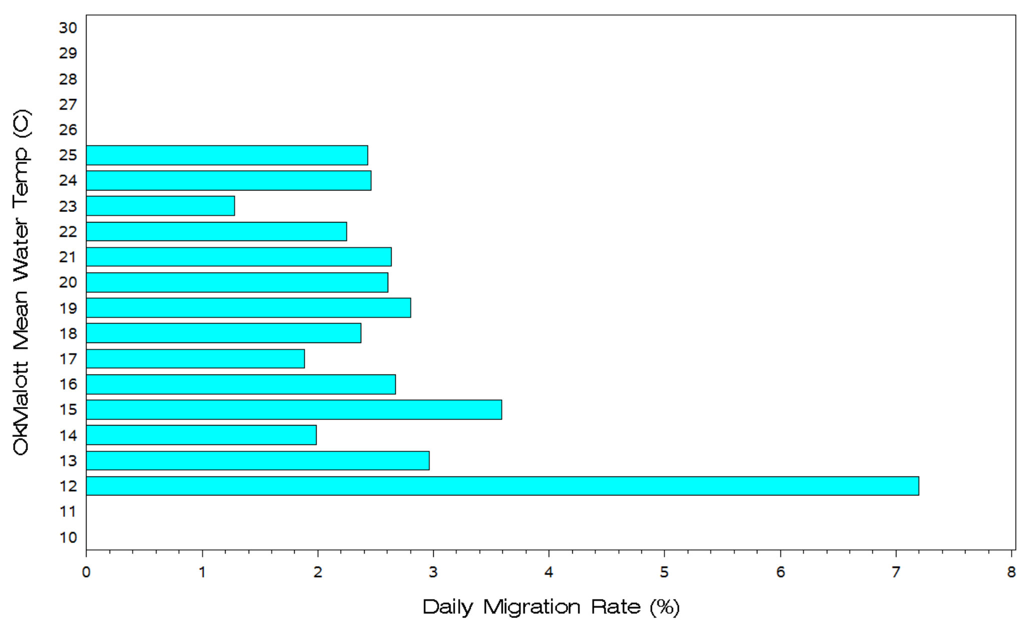
Figure 51. Frequency plot of select years of lagged Okanagan Sockeye migration dates (weighted by daily migration rate), at varying levels of Okanogan River (at Malott) discharge. “Moderate” daily migration rates (> 0.4%) were evident at all discharge levels, while “high” daily migration rates (>2.9%) occurred most frequently between 90-160 cms.

[61] Years where total escapement < 1,000 fish excluded (i.e., 1944, 1964).



Temp (C)	FREQ.	CUM. FREQ.	PCT.	CUM. PCT.
30	0	747	0.00	100.00
29	0	747	0.00	100.00
28	0	747	0.00	100.00
27	0	747	0.00	100.00
26	0	747	0.00	100.00
25	3	747	0.40	100.00
24	36	744	4.82	99.60
23	82	708	10.98	94.78
22	122	626	16.33	83.80
21	130	504	17.40	67.47
20	108	374	14.46	50.07
19	56	266	7.50	35.61
18	48	210	6.43	28.11
17	58	162	7.76	21.69
16	34	104	4.55	13.92
15	24	70	3.21	9.37
14	25	46	3.35	6.16
13	19	21	2.54	2.81
12	2	2	0.27	0.27
11	0	0	0.00	0.00
10	0	0	0.00	0.00

Figure 52. Frequency plot of select years[62] of historical Okanagan Sockeye migration (unweighted tally of non-zero migration dates), at varying levels of Okanogan River (Malott) water temperature. 60% of migration activity occurred at 20-23°C.



Temp (C)	FREQ.	Daily Migration Rate (%)
30	0	0.00
29	0	0.00
28	0	0.00
27	0	0.00
26	0	0.00
25	3	2.43
24	36	2.46
23	82	1.28
22	122	2.25
21	130	2.64
20	108	2.61
19	56	2.80
18	48	2.37
17	58	1.88
16	34	2.67
15	24	3.59
14	25	1.99
13	19	2.96
12	2	7.20
11	0	0.00
10	0	0.00

Figure 53. Frequency plot of select years of lagged Okanagan Sockeye migration dates (weighted by daily migration rate), at varying levels of Okanogan River water temperature. Significant daily migration rates occurred at a wide range of temperatures, with maximum rates at < 15°C.

[62] Years where total migrant counts were less than 1,000 fish were excluded (i.e., 1944, 1964).

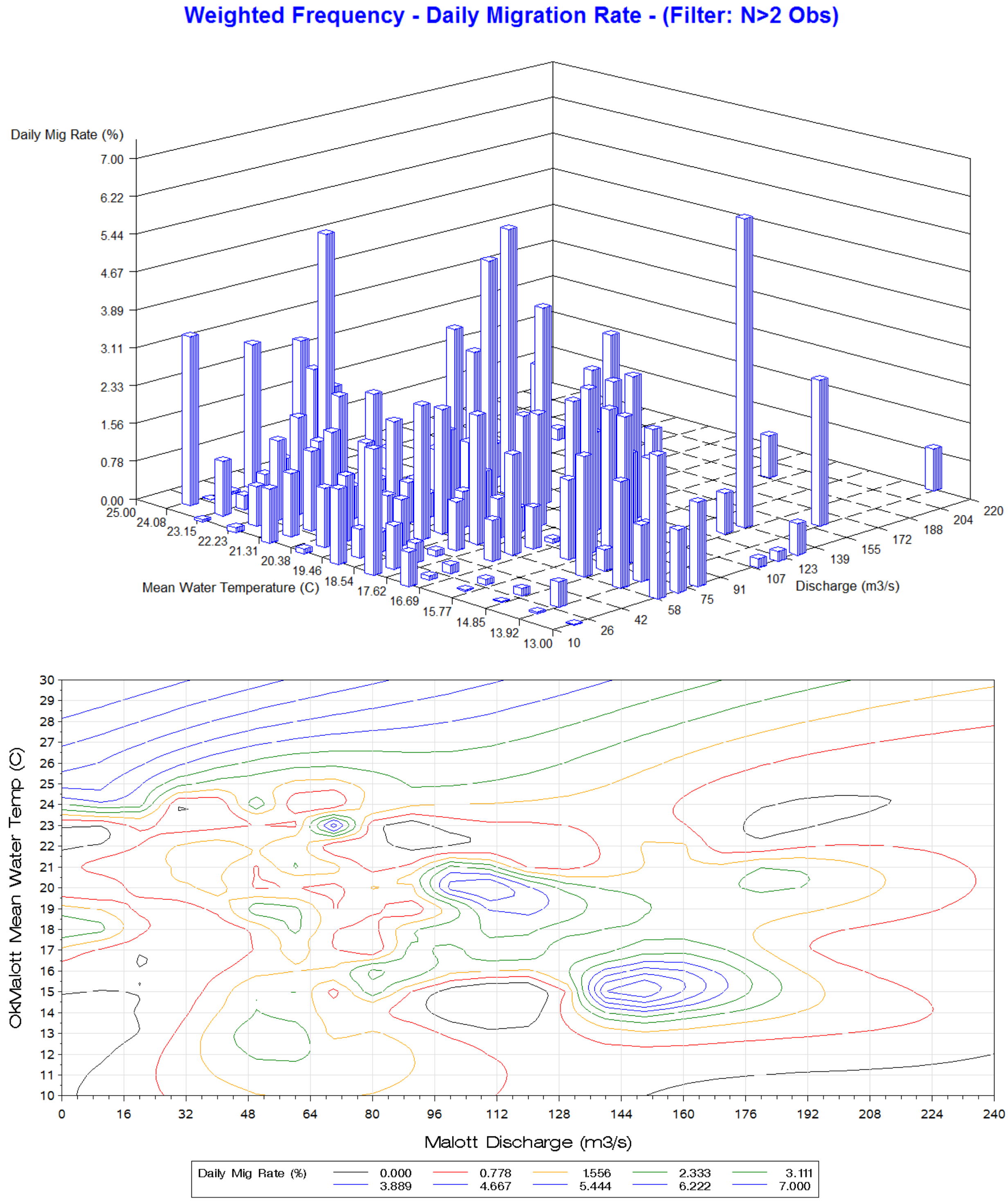


Figure 54. Distribution (top) and smoothed contour (bottom) of historical Okanagan Sockeye migration rates (daily %), at varying levels of Okanogan River (Malott) water temperature and discharge (filtered for a minimum of N=3 observations at each MWT x Flow point).

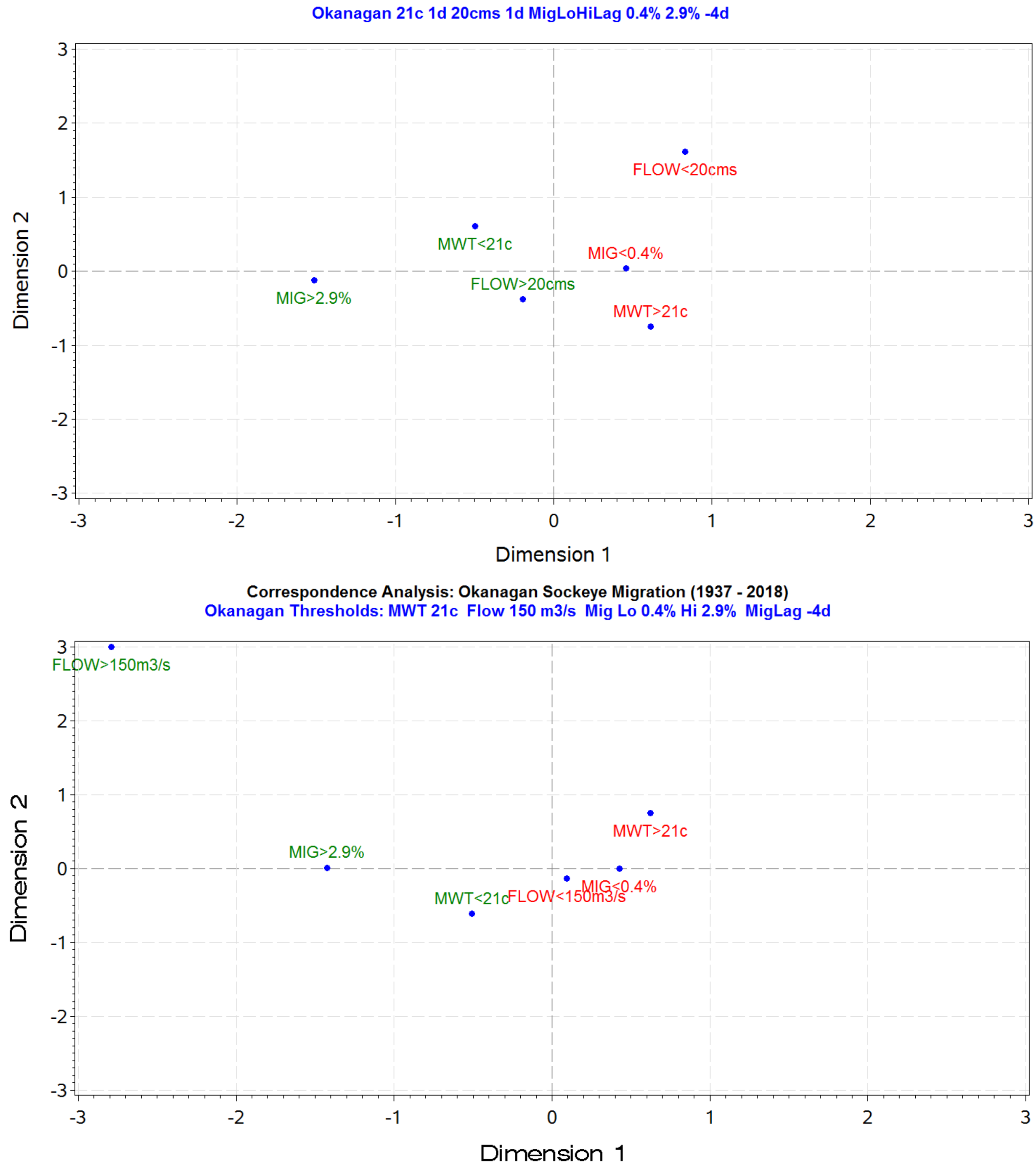


Figure 55. Correspondence analysis indicates low migration rates were most associated with high temperatures (> 21°C) and flows < 150 cms, while high migration rates were most associated with temperatures < 21°C, but relatively independent of flow levels.

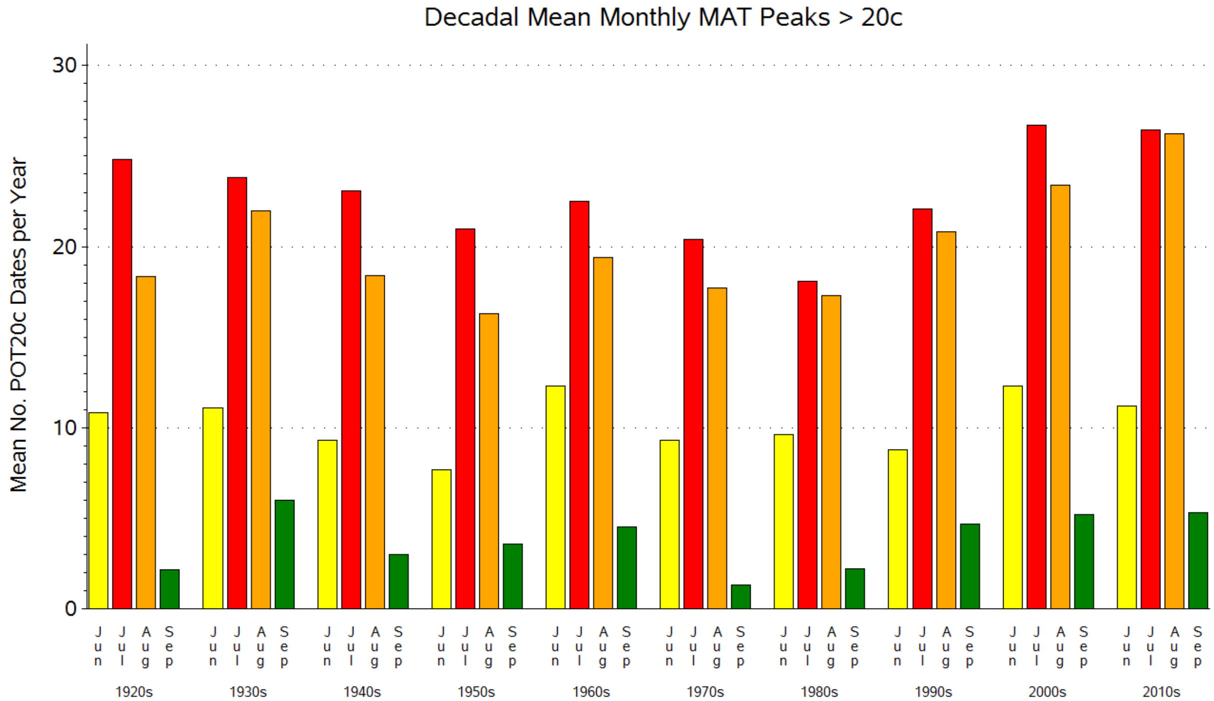


Figure 56. Frequency analysis of decadal mean number of dates per summer month in which mean air temperature (observed and estimated) at the MALOTT AWN station exceeded 20°C.

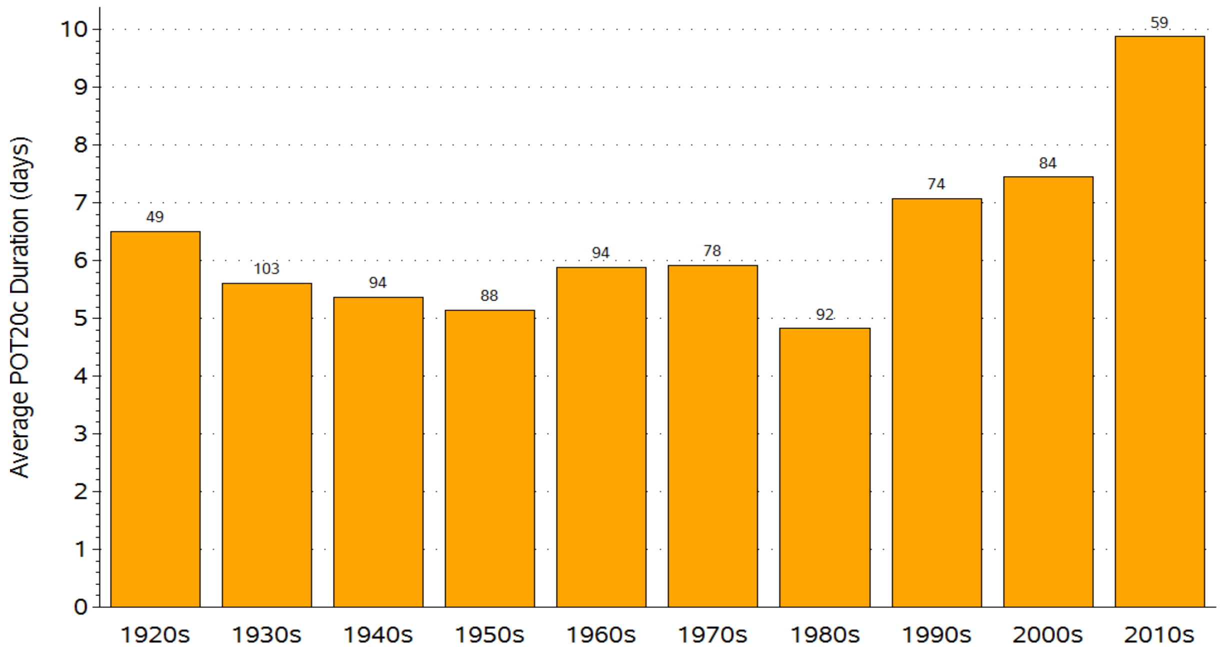


Figure 57. Mean period length (days) and mean decadal frequency of periods in which mean daily air temperature (observed and estimated) at MALOTT AWN station continuously exceeded 20°C during adult migration, by decade.

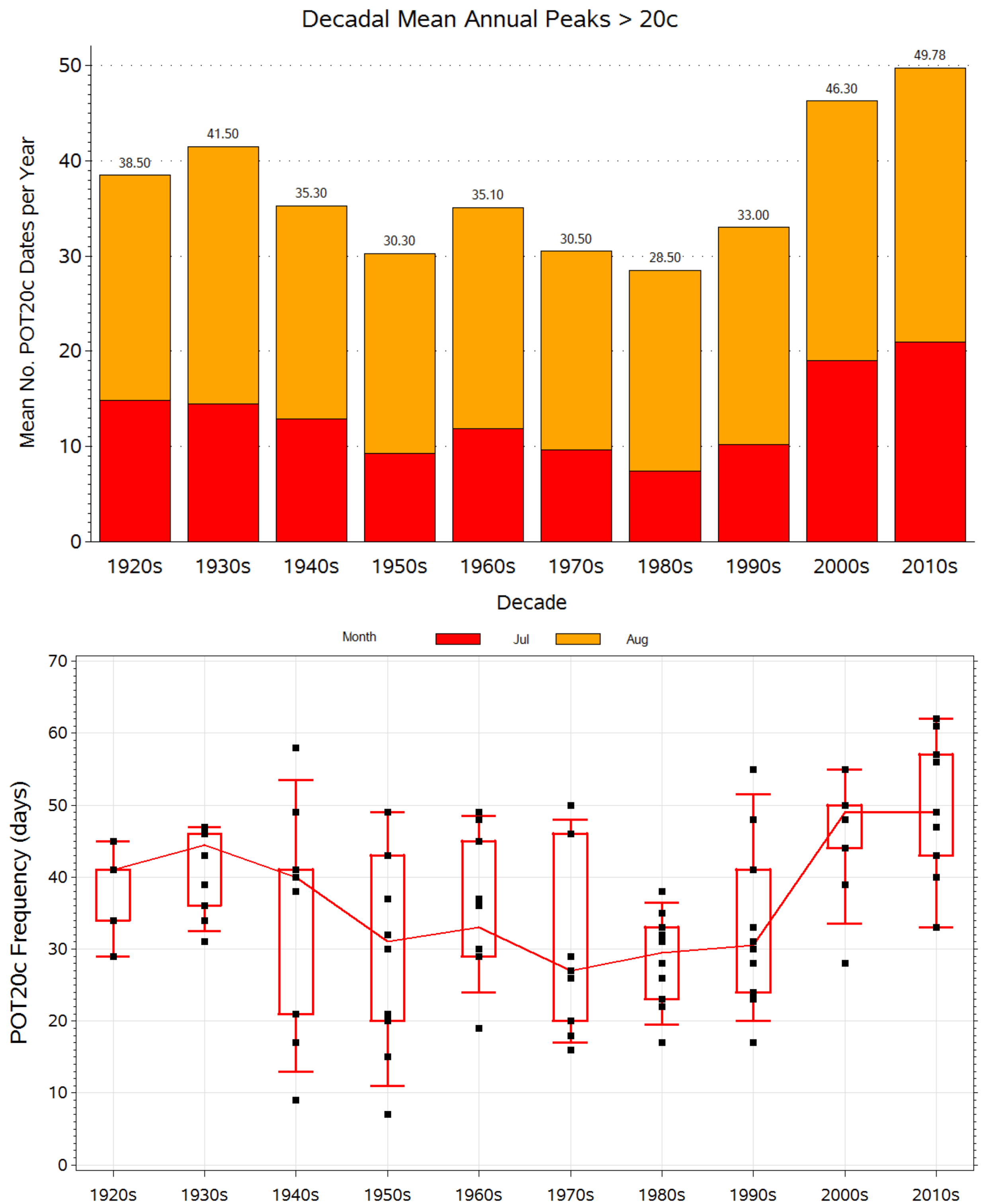


Figure 58. Frequency analysis of decadal mean (top) and median (bottom) number of dates during peak migration (July-August) in which estimated mean water temperature in Okanogan River (at Malott) exceeded 20°C. Stacked bars indicate cumulative number of $POT_{>20°C}$ dates per year, currently about 80% of July and August (~50 days per year).

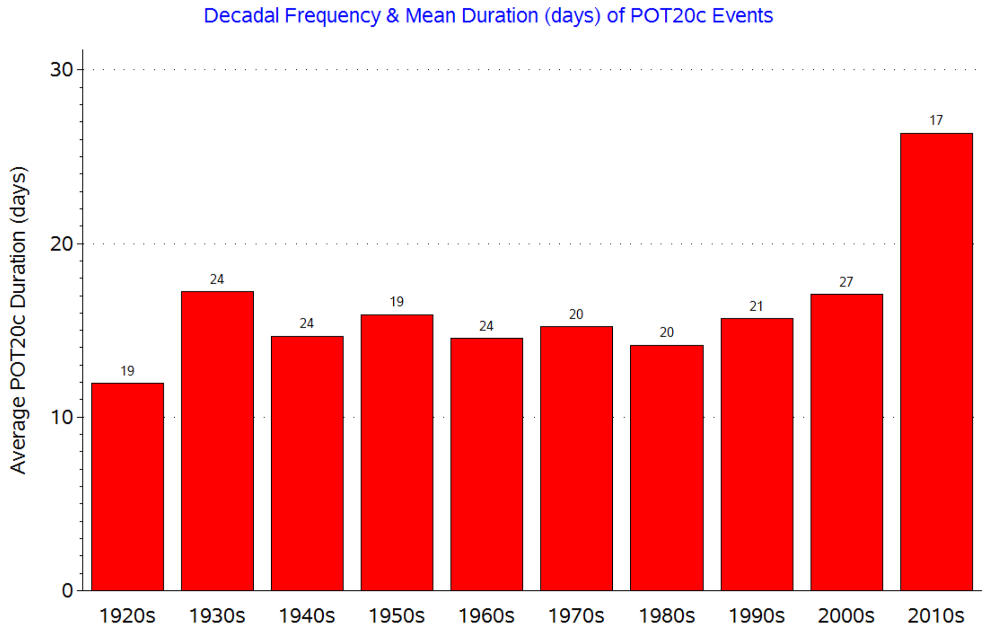


Figure 59. Mean length (days) and total decadal frequency of periods in which estimated daily mean water temperature in Okanogan River (at Malott) continuously exceeded 20°C. Average length of $POT_{>20°C}$ events has increased from an average of ~15 days pre-1990 to ~25 days in the past decade.

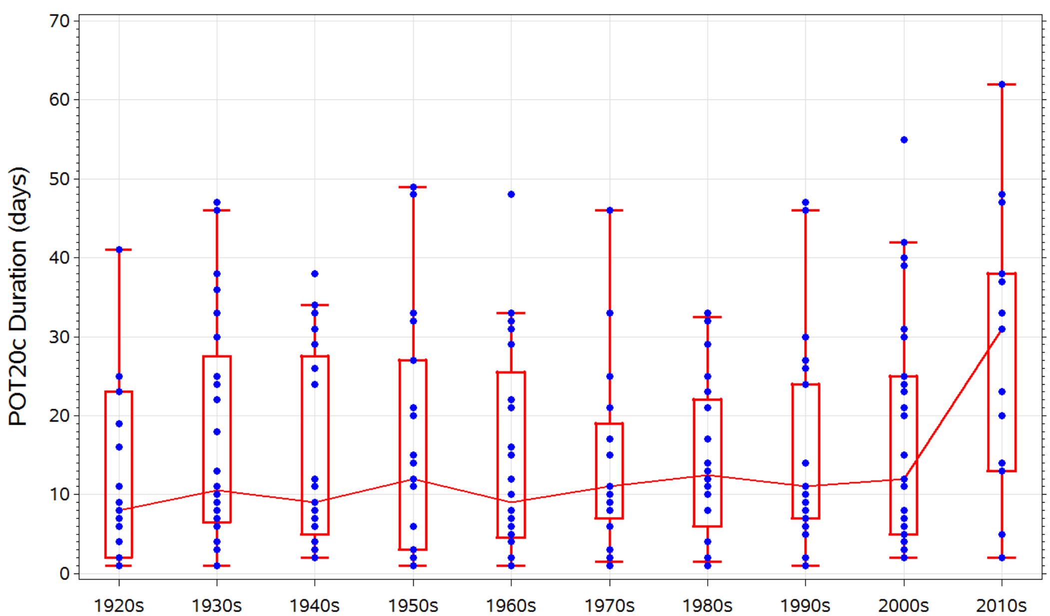


Figure 60. Median length (days) of periods in which estimated daily mean water temperature in Okanogan River (at Malott) continuously exceeded 20°C, by decade.

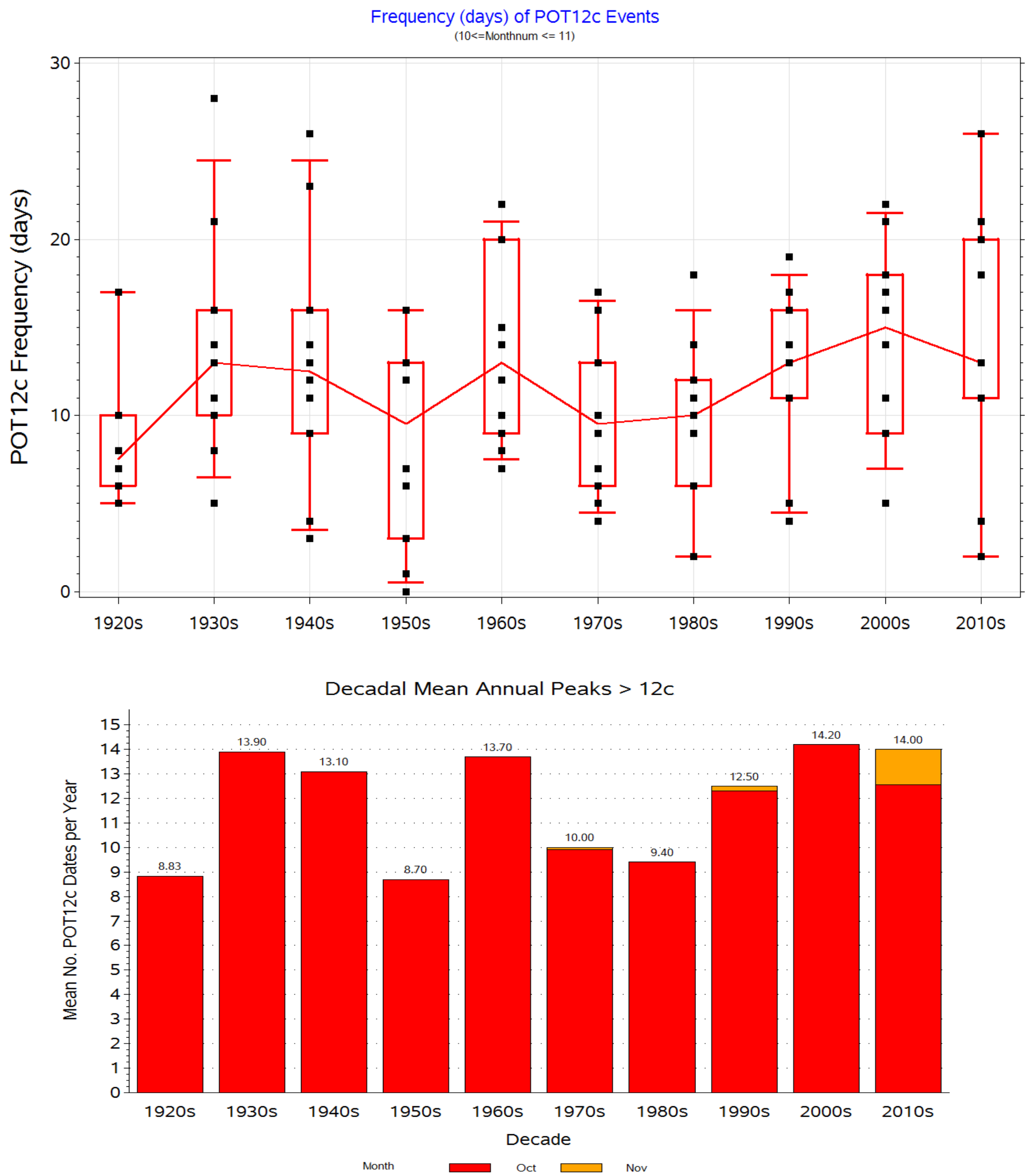
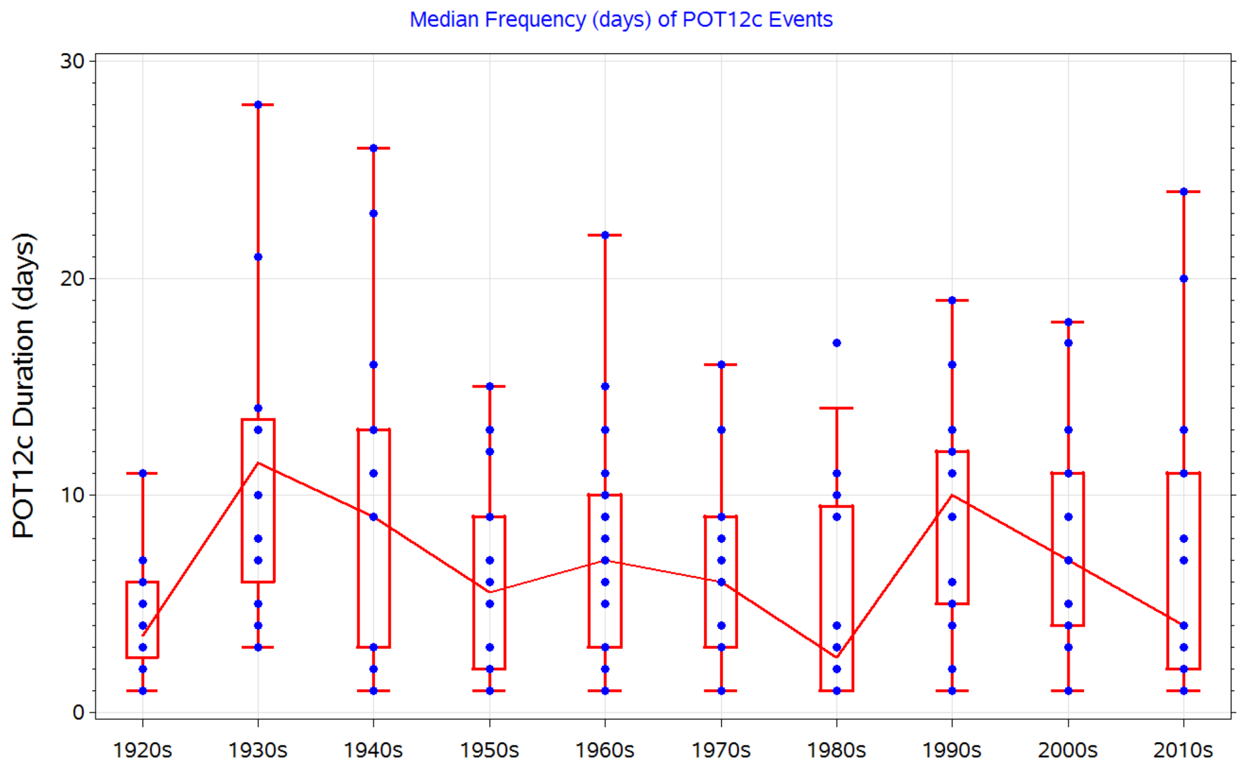


Figure 61. Frequency analysis of decadal mean number of dates per month in which mean water temperature (estimated) in Okanagan River (at Oliver) exceeded the optimum spawning temperature of 12°C. Stacked bars indicate cumulative number of $POT_{>12°C}$ dates per year.



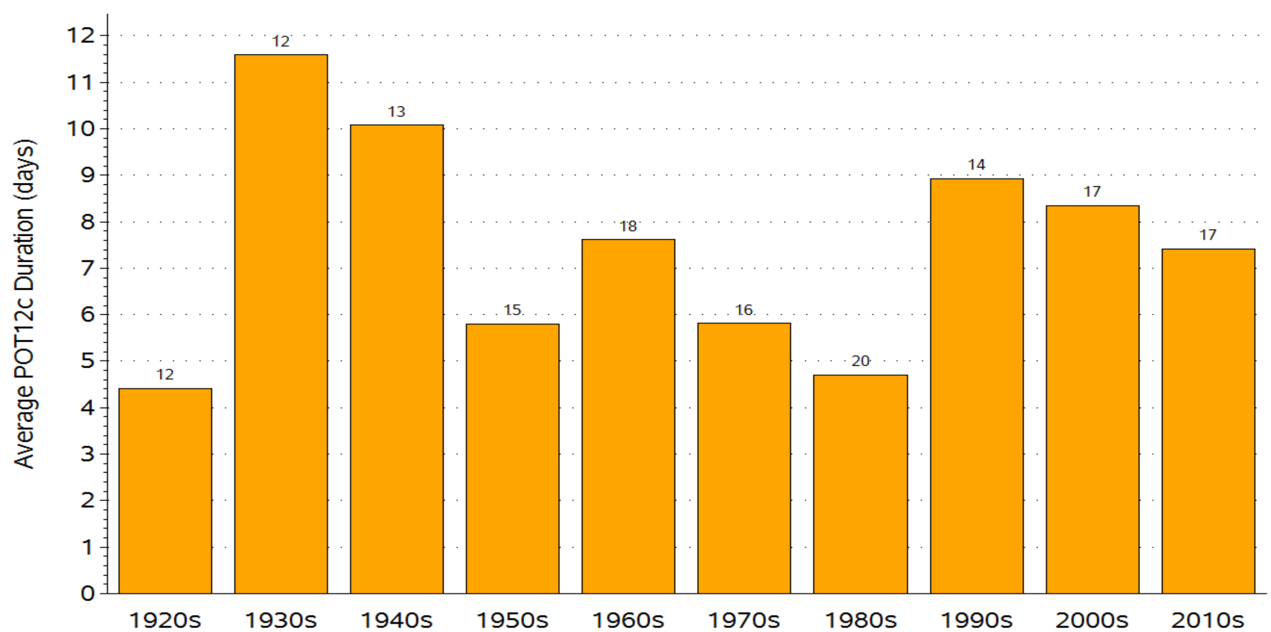


Figure 62. Median length (top) and mean length (days) and mean frequency of number of periods in which mean water temperature (estimated) in Okanagan River (at Oliver) continuously exceeded 12°C on the spawning grounds (October-November), by decade.

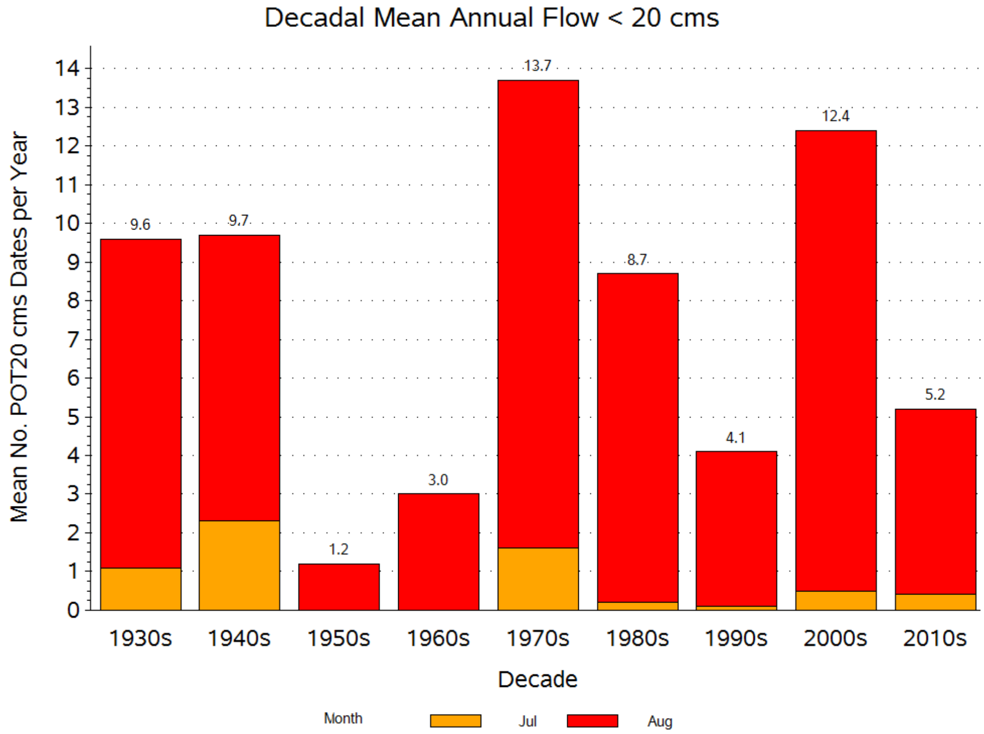


Figure 63. Frequency analysis of decadal mean number of "low flow" dates (below 10th percentile of July-August flows, ~20 cms) per month during adult migration in the Okanogan River near Malott.

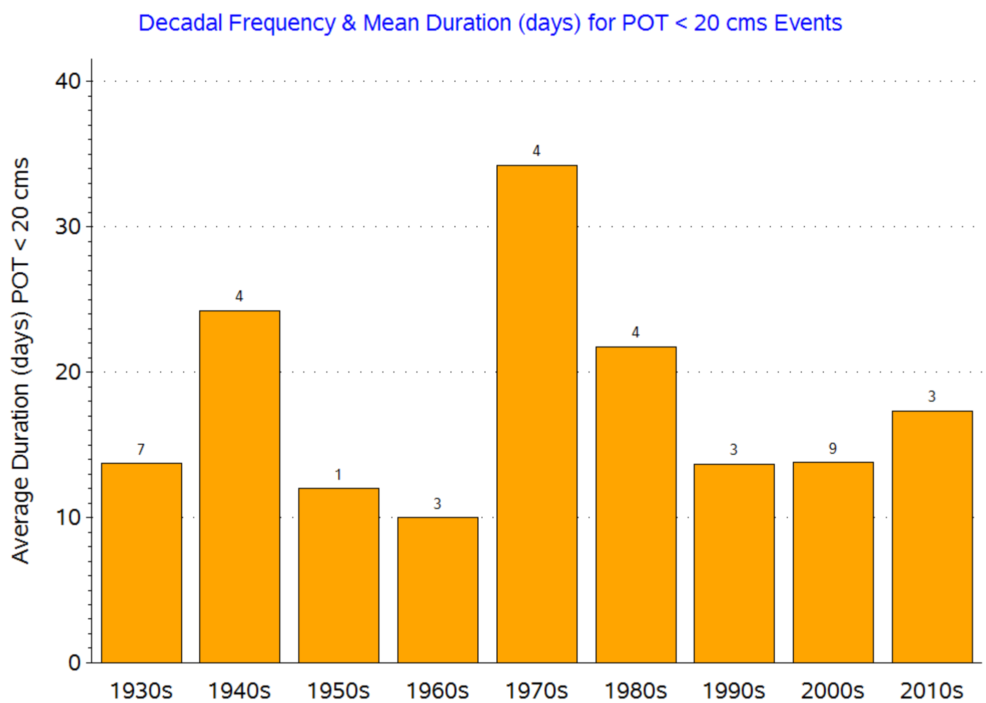


Figure 64. Mean length (days) and frequency of "low flow" periods in which Okanogan River discharge (at Malott) continuously remained below the 10th percentile of flows (~20 cms) during adult migration (July-August), by decade.

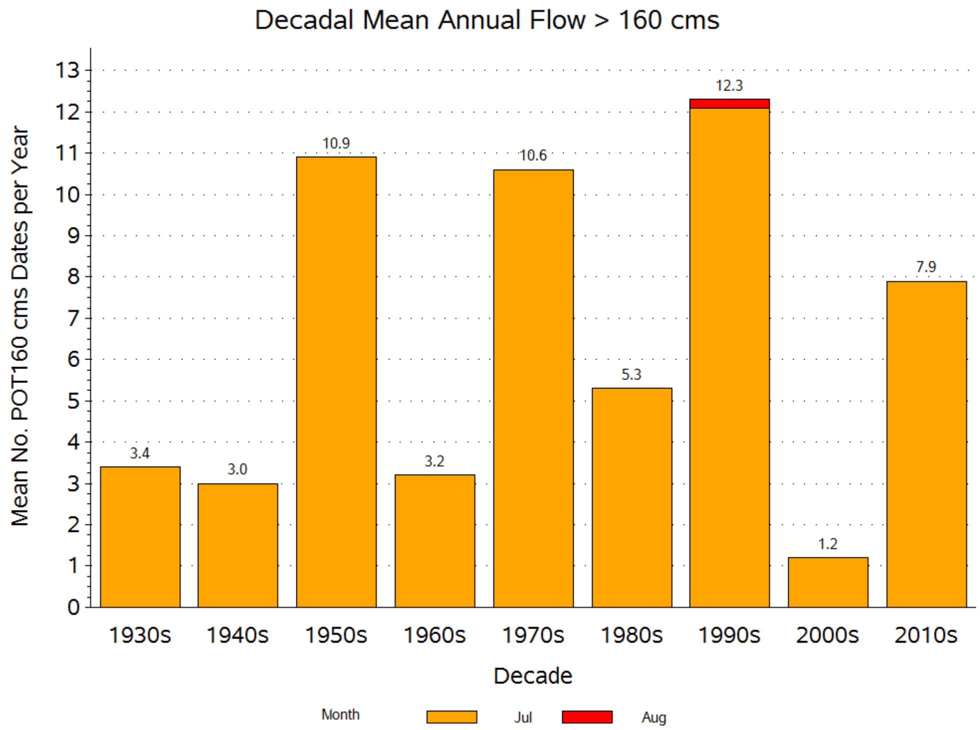


Figure 65. Frequency analysis of decadal mean number of "high flow" dates (above the 90th percentile of July-August flows, ~160 cms) per month during adult migration in the Okanogan River near Malott.

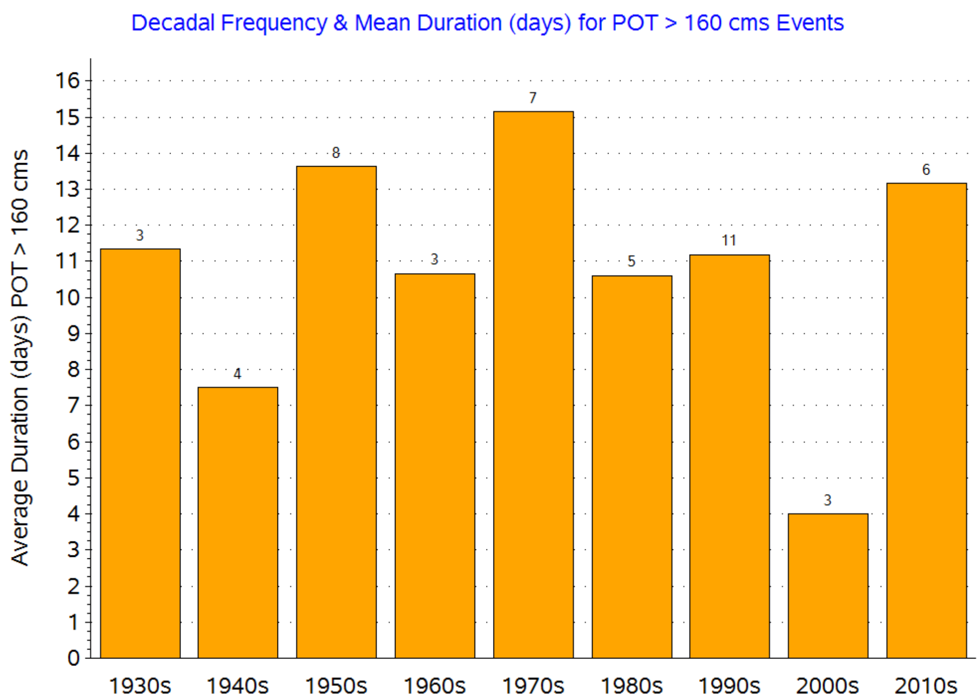


Figure 66. Mean length (days) and frequency of "high flow" periods in which Okanogan River discharge (at Malott) continuously remained above the 90th percentile of flows (~160 cms) during adult migration (July-August), by decade.

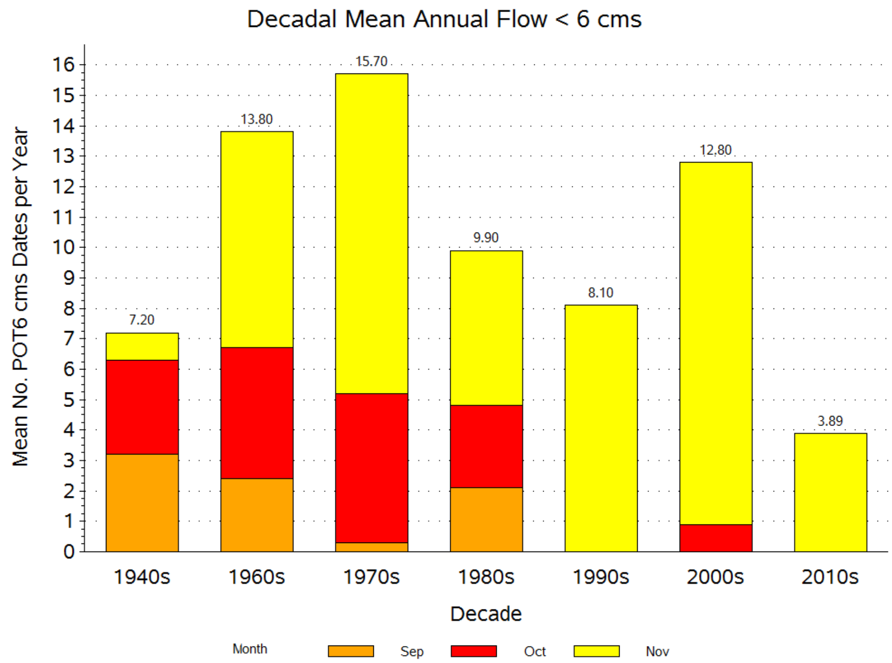


Figure 67. Frequency analysis of decadal mean number of “low flow” dates (below 10th percentile of fall flows, ~6 cms) per month on the spawning grounds (September-November) in the Okanagan River near Oliver, 1930 - 2019.

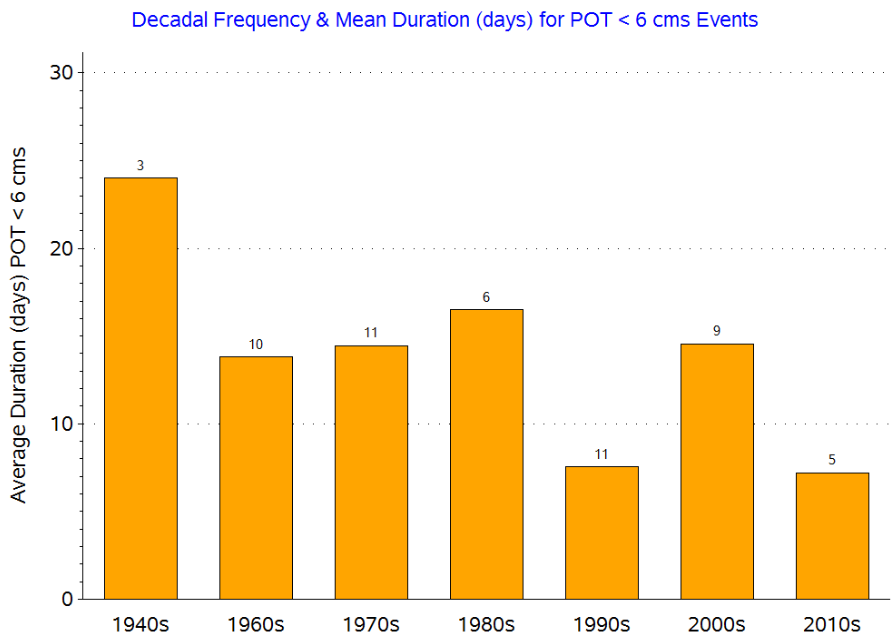


Figure 68. Mean length (days) and frequency of “low flow” periods in which Okanagan River discharge (at Oliver) continuously remained below the 10th percentile of flows (~6 cms) during spawning months (September - November), by decade.

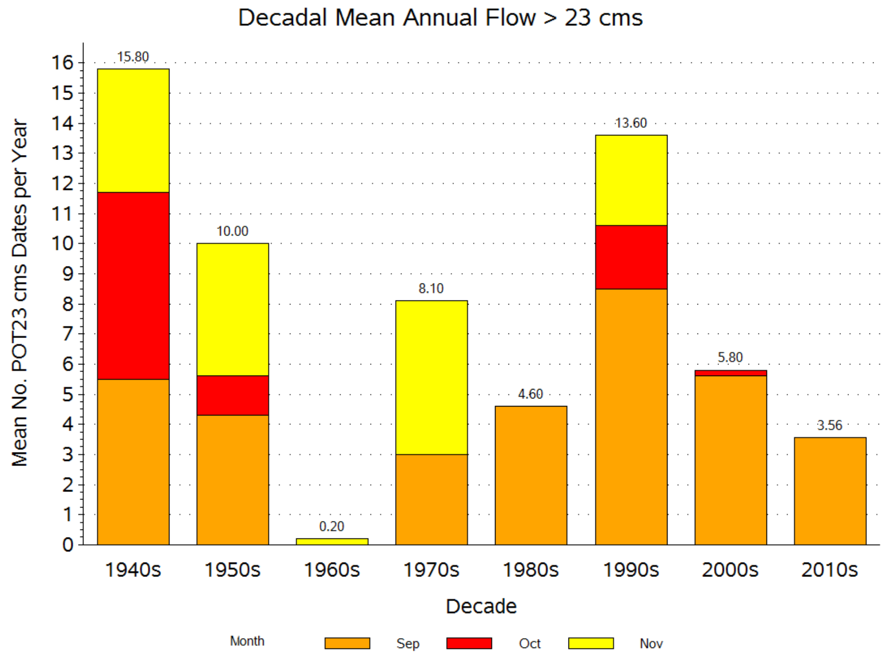


Figure 69. Frequency analysis of decadal mean number of “high flow” dates (above 90th percentile of fall flows, ~23 cms) per month on the spawning grounds (September-November) in the Okanagan River near Oliver.

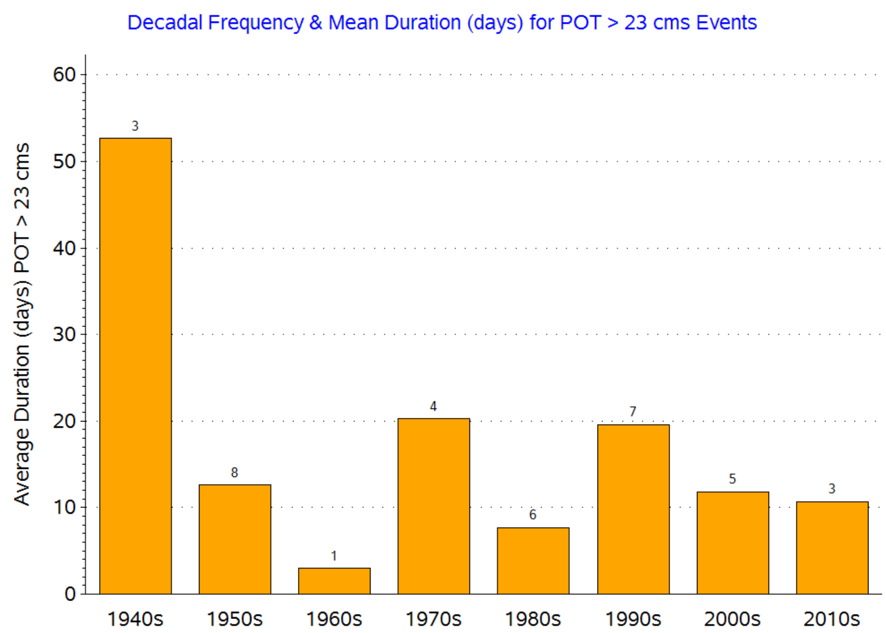
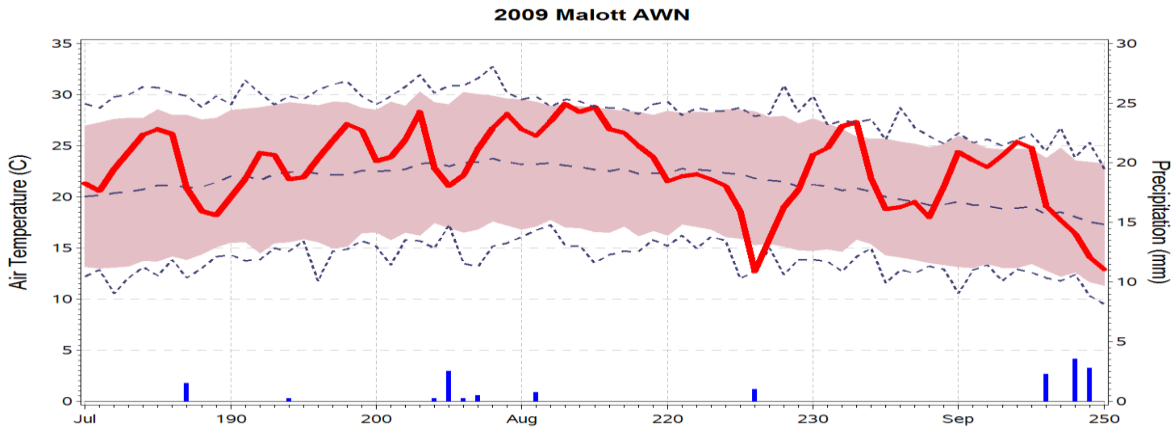


Figure 70. Mean length (days) and frequency of “high flow” periods in which Okanagan River discharge (at Oliver) continuously remained above the 90th percentile of flows (~23 cms) during spawning months (September - November), by decade.

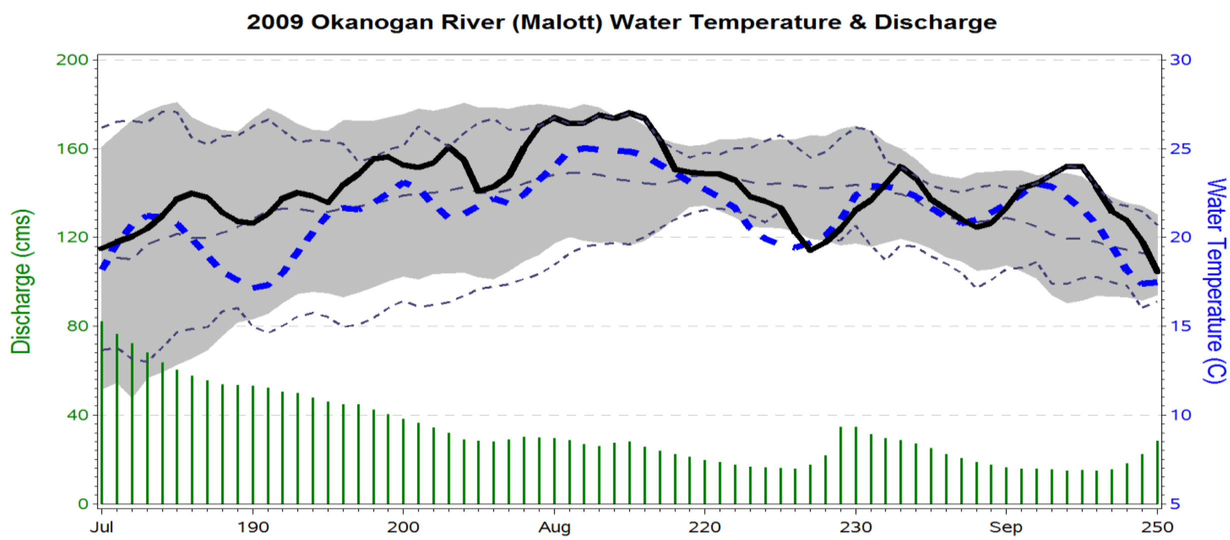
APPENDICES

Appendix A. Daily Sockeye migration in relation to environmental variables in the lower Okanogan River basin, for intermittent years of daily escapement data from 1937-2018.[63]

LEGEND PLOTS

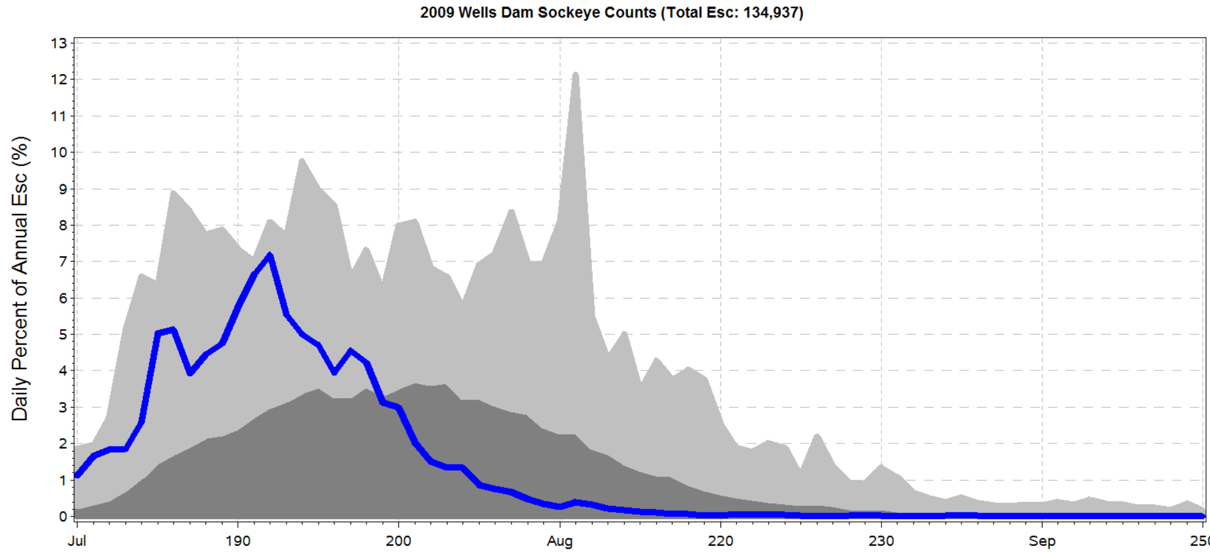


1. Meteorological data from the AWN meteorological station at Brewster, WA, for the lower Okanogan River (near the confluence with Columbia River). Observed and estimated **daily mean air temperature** (°C, red line), with historical daily mean and variance (dashed line and red area). (Precipitation available 2006-2018 only.)

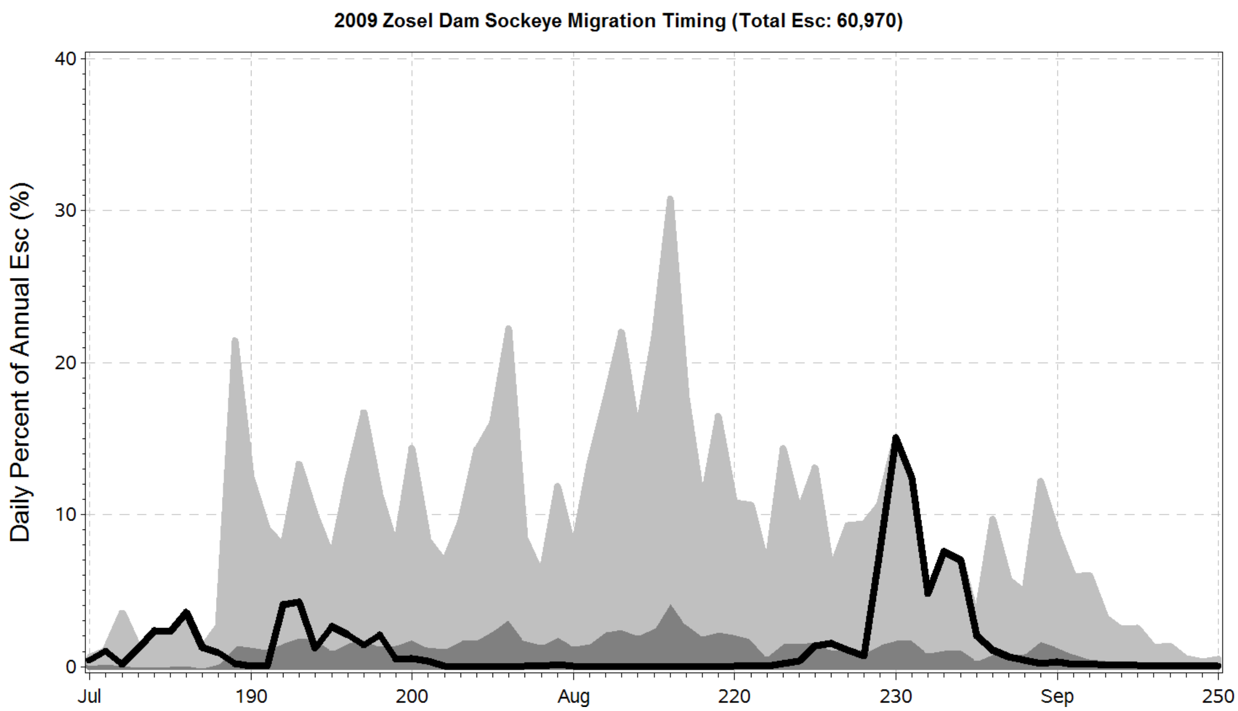


2. Physical data from the Okanogan River at Malott, WA. **Daily mean water temperature** (*observed*: solid black line; *estimated*: dashed blue line) with historical daily mean and variance (dashed line and shaded area), and **daily discharge** (cms) (green).

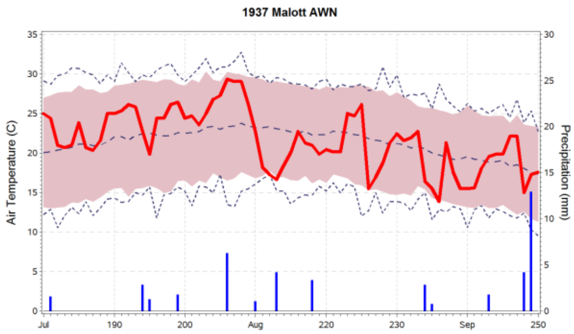
[63] Start of each month (horizontal axis) with day of year is approximate.

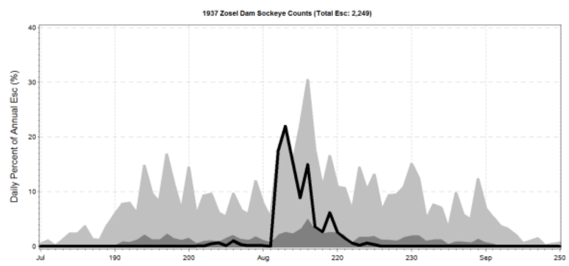


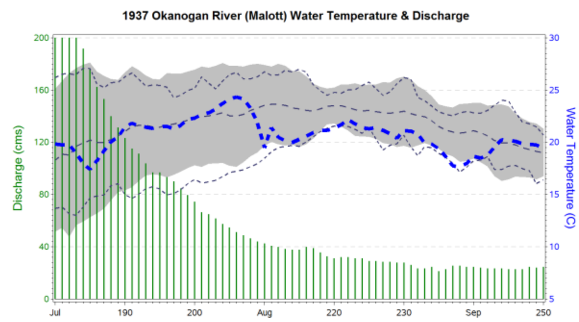
3. Sockeye **daily migration rates** as a percent (%) of annual escapement for Wells Dam (blue line). Mean daily migration rate (dark gray area) and maximum daily migration rate (light gray area) based on historical timing (1967-2012).

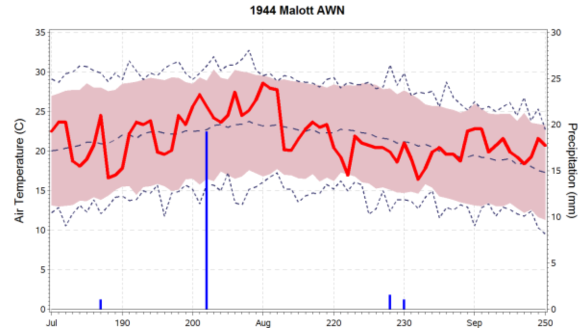


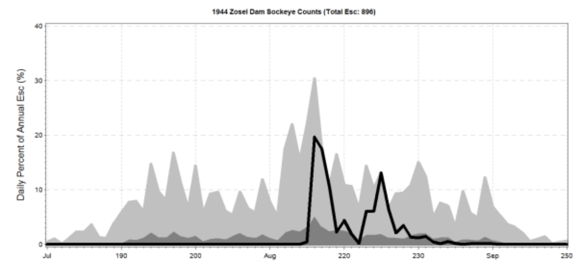
4. Sockeye **daily migration rates** as a percent (%) of annual migrant enumeration (black line) at ZOSEL DAM (OKANOGAN RIVER) for available years of daily counts (1937, 1944, 1952-1954, 1962-1963, 1992-1993, 2006-2010, 2014-2017). Mean daily migration rate (dark gray area) and maximum daily migration rate (light gray area).

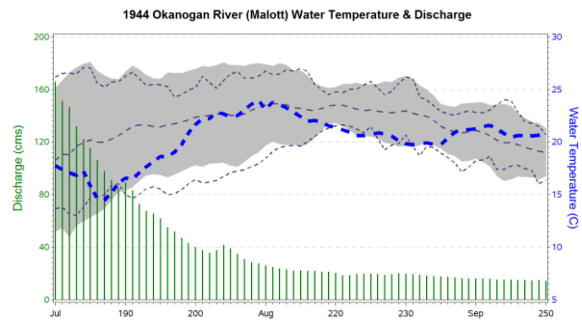

1937 Malott AWN
Air Temperature (C)
Precipitation (mm)
Jul
190
200
Aug
220
230
Sep
250

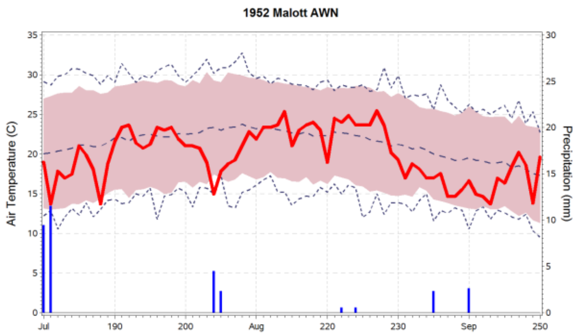

1937 Zosel Dam Sockeye Counts (Total Esc: 2,249)
Daily Percent of Annual Esc (%)

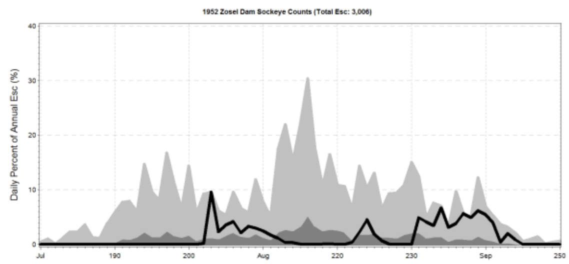

1937 Okanogan River (Malott) Water Temperature & Discharge
Discharge (cms)
Water Temperature (C)
Jul
190
200
Aug
220
230
Sep
250

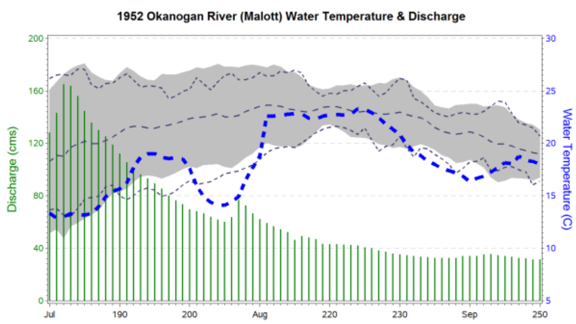

1944 Malott AWN
Air Temperature (C)
Precipitation (mm)
Jul
190
200
Aug
220
230
Sep
250

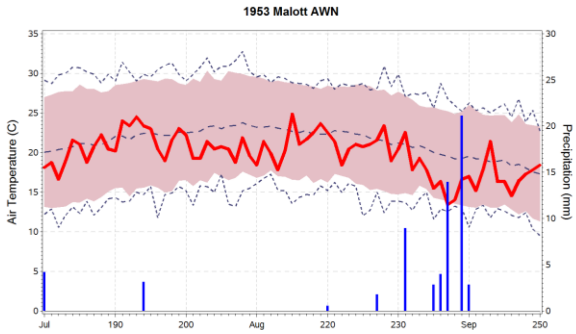

1944 Zosel Dam Sockeye Counts (Total Esc: 896)
Daily Percent of Annual Esc (%)

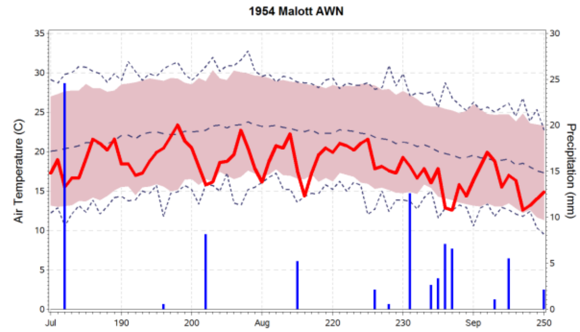

1944 Okanogan River (Malott) Water Temperature & Discharge
Discharge (cms)
Water Temperature (C)
Jul
190
200
Aug
220
230
Sep
250

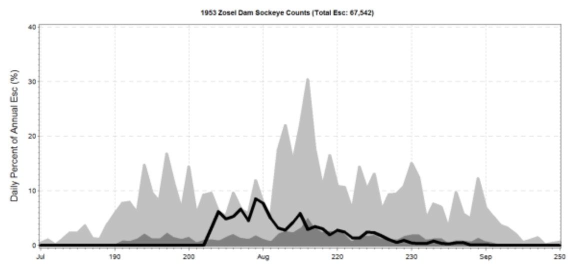

1952 Malott AWN
Air Temperature (C)
Precipitation (mm)
Jul
190
200
Aug
220
230
Sep
250

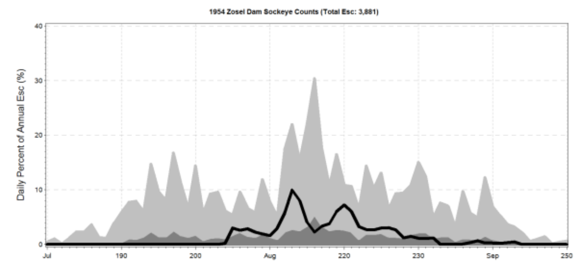

1952 Zosel Dam Sockeye Counts (Total Esc: 3,006)
Daily Percent of Annual Esc (%)
Jul
190
200
Aug
220
230
Sep
250

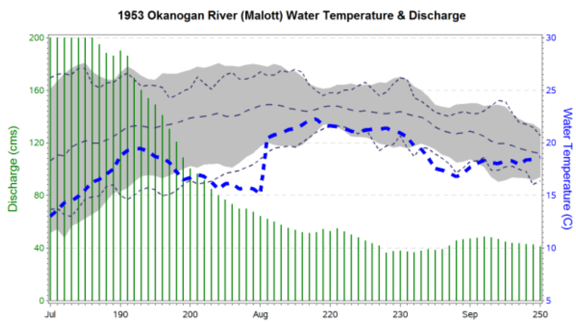

1952 Okanogan River (Malott) Water Temperature & Discharge
Discharge (cms)
Water Temperature (C)
Jul
190
200
Aug
220
230
Sep
250

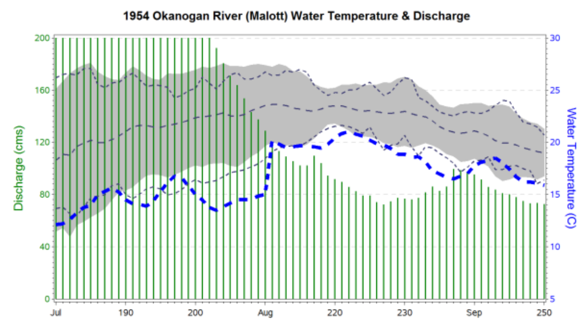

1953 Malott AWN
Air Temperature (C)
Precipitation (mm)
Jul
190
200
Aug
220
230
Sep
250

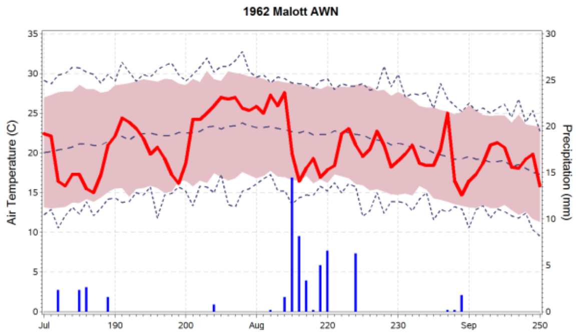

1954 Malott AWN
Air Temperature (C)
Precipitation (mm)
Jul
190
200
Aug
220
230
Sep
250

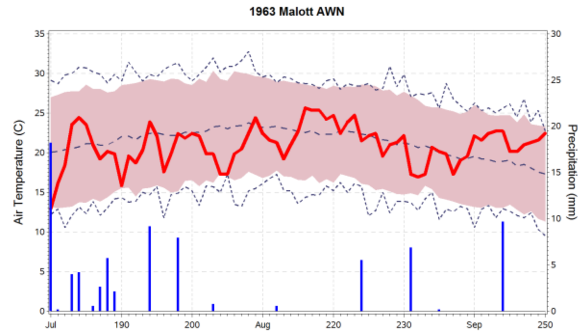

1953 Zosel Dam Sockeye Counts (Total Esc: 67,542)
Daily Percent of Annual Esc (%)

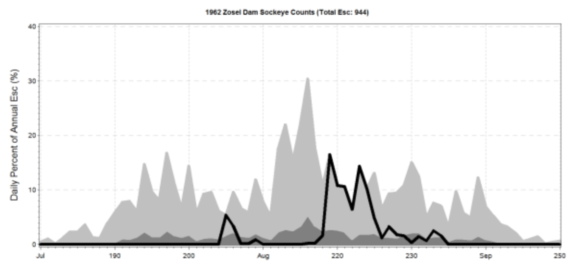

1954 Zosel Dam Sockeye Counts (Total Esc: 3,881)
Daily Percent of Annual Esc (%)

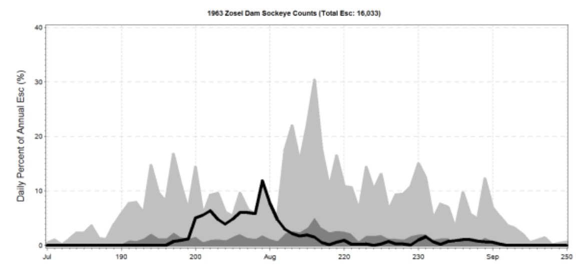

1953 Okanogan River (Malott) Water Temperature & Discharge
Discharge (cms)
Water Temperature (C)
Jul
190
200
Aug
220
230
Sep
250

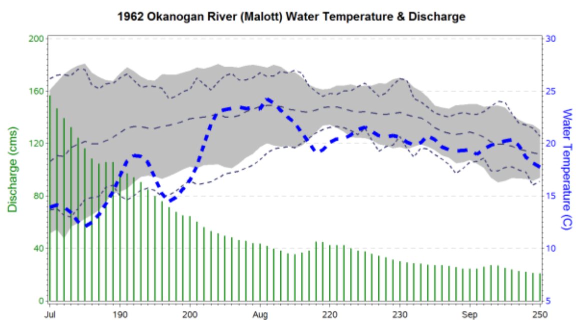

1954 Okanogan River (Malott) Water Temperature & Discharge
Discharge (cms)
Water Temperature (C)
Jul
190
200
Aug
220
230
Sep
250

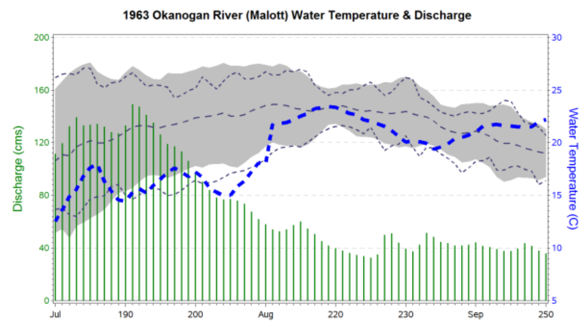

1962 Malott AWN
Air Temperature (C)
Precipitation (mm)
Jul
190
200
Aug
220
230
Sep
250


1963 Malott AWN
Air Temperature (C)
Precipitation (mm)
Jul
190
200
Aug
220
230
Sep
250

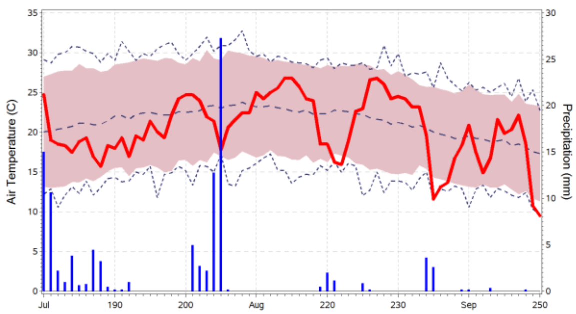

1962 Zosel Dam Sockeye Counts (Total Esc: 944)
Daily Percent of Annual Esc (%)


1963 Zosel Dam Sockeye Counts (Total Esc: 16,033)
Daily Percent of Annual Esc (%)

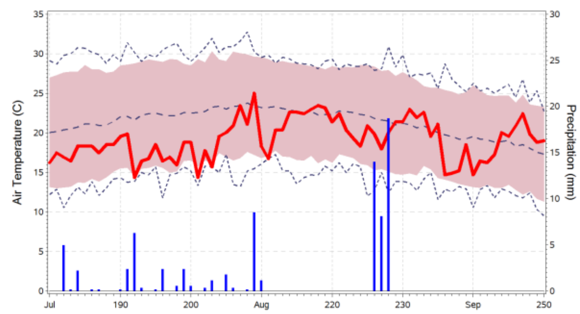

1962 Okanogan River (Malott) Water Temperature & Discharge
Discharge (cms)
Water Temperature (C)
Jul
190
200
Aug
220
230
Sep
250


1963 Okanogan River (Malott) Water Temperature & Discharge
Discharge (cms)
Water Temperature (C)
Jul
190
200
Aug
220
230
Sep
250

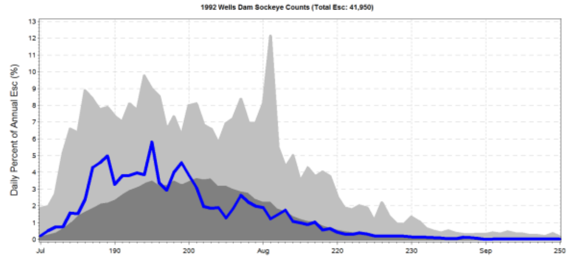
1992 Malott AWN



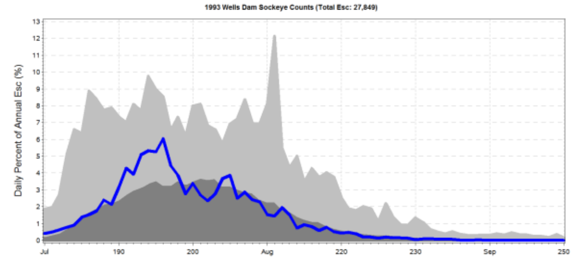
1993 Malott AWN



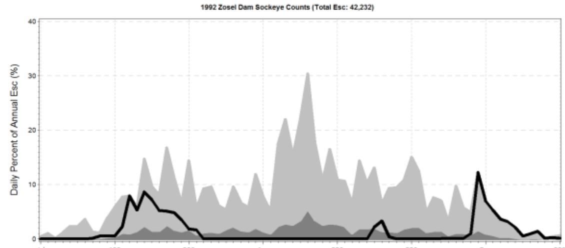
1992 Wells Dam Sockeye Counts (Total Esc: 41,950)



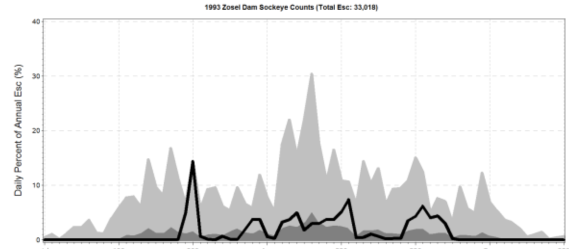
1993 Wells Dam Sockeye Counts (Total Esc: 27,849)



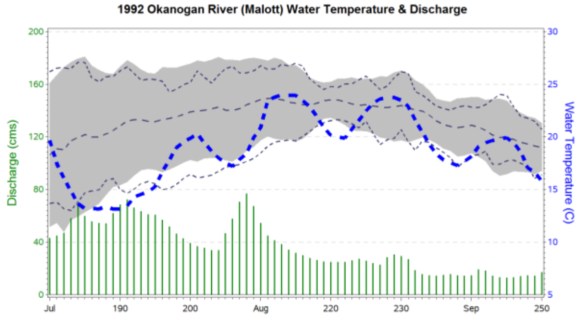
1992 Zosel Dam Sockeye Counts (Total Esc: 42,232)



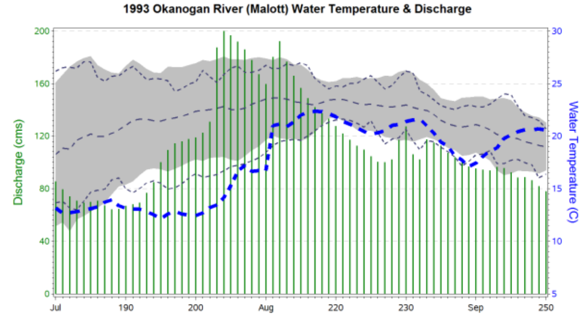
1993 Zosel Dam Sockeye Counts (Total Esc: 33,018)



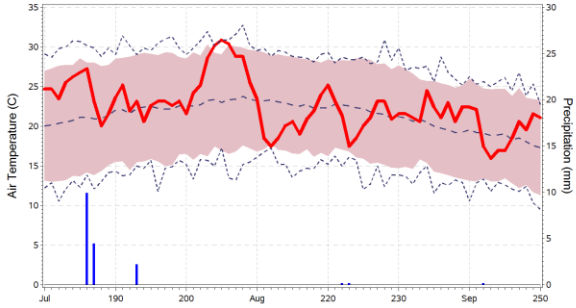
1992 Okanogan River (Malott) Water Temperature & Discharge



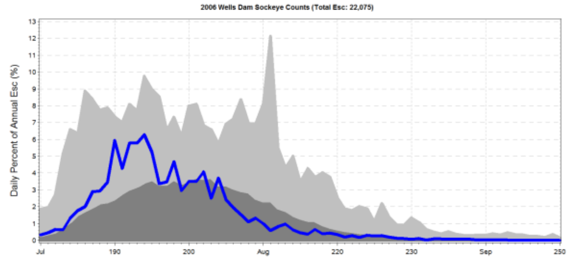
1993 Okanogan River (Malott) Water Temperature & Discharge



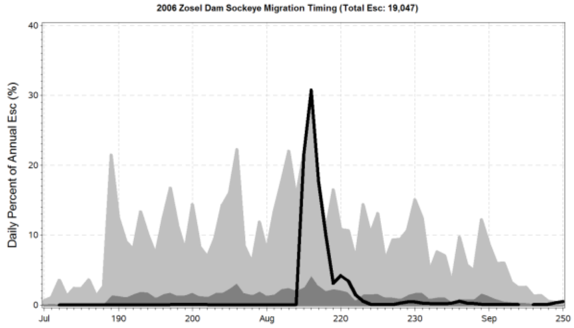
2006 Malott AWN



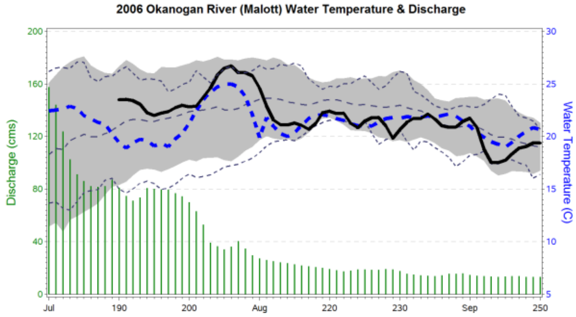
2006 Wells Dam Sockeye Counts (Total Esc: 22,075)



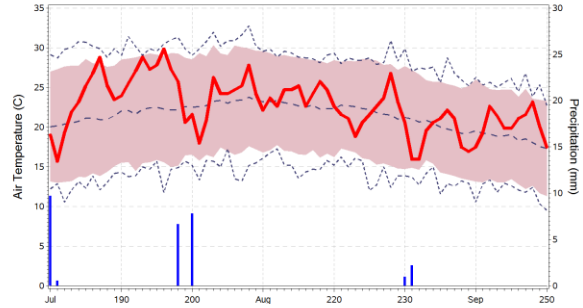
2006 Zosel Dam Sockeye Migration Timing (Total Esc: 19,047)



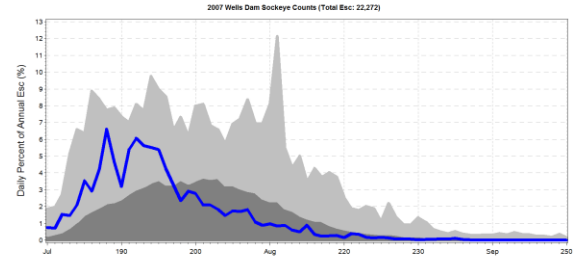
2006 Okanogan River (Malott) Water Temperature & Discharge



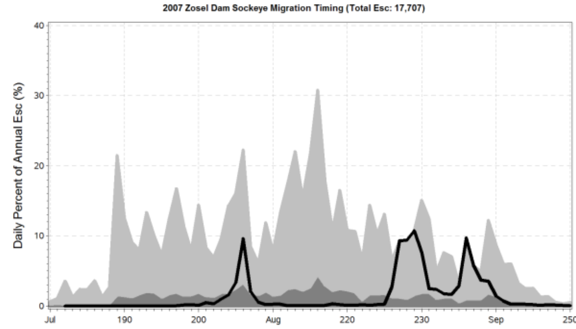
2007 Malott AWN



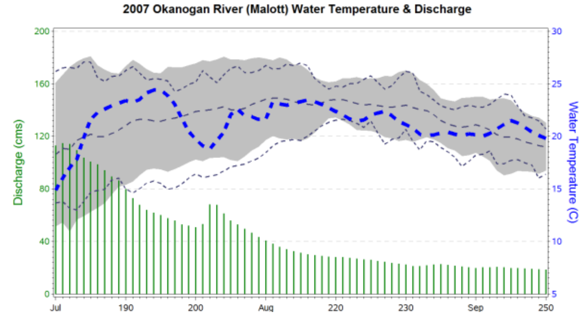
2007 Wells Dam Sockeye Counts (Total Esc: 22,272)

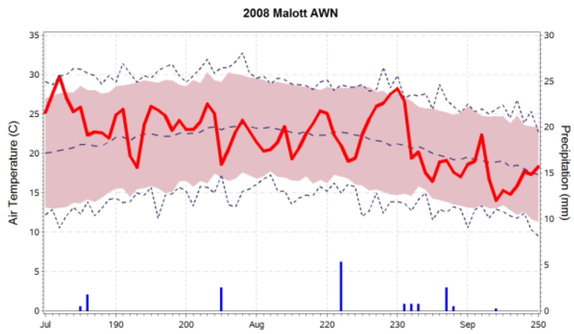


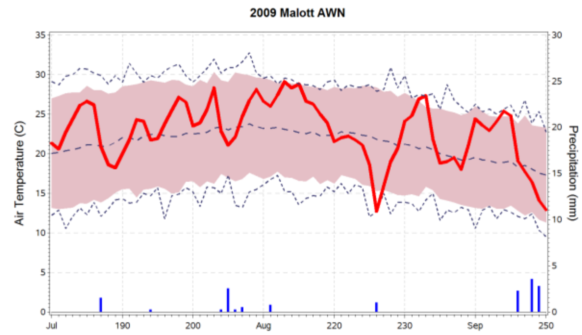
2007 Zosel Dam Sockeye Migration Timing (Total Esc: 17,707)

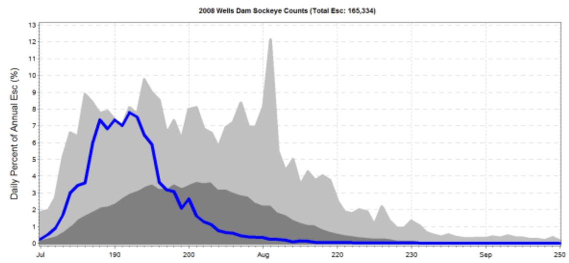


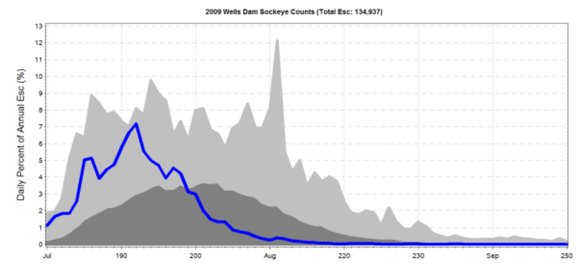
2007 Okanogan River (Malott) Water Temperature & Discharge

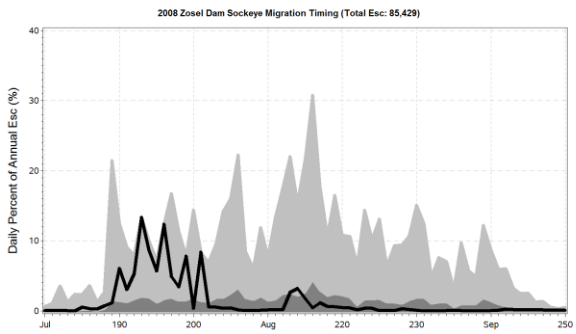


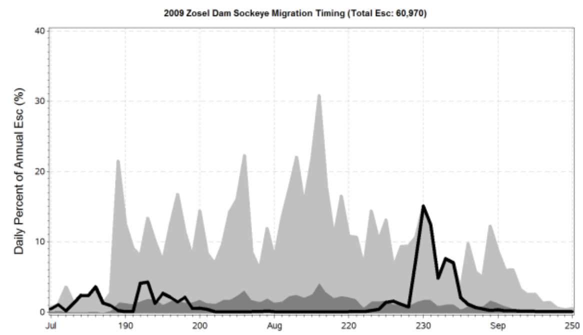

2008 Malott AWN
Air Temperature (C)
Precipitation (mm)
Jul
190
200
Aug
220
230
Sep
250

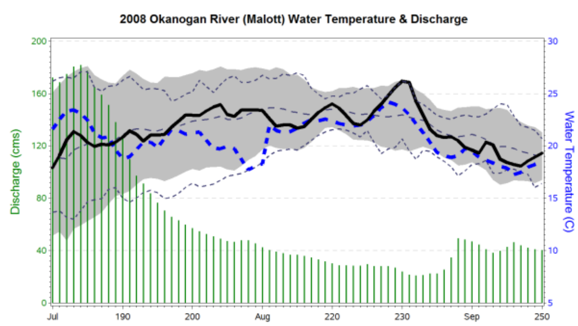

2009 Malott AWN
Air Temperature (C)
Precipitation (mm)
Jul
190
200
Aug
220
230
Sep
250

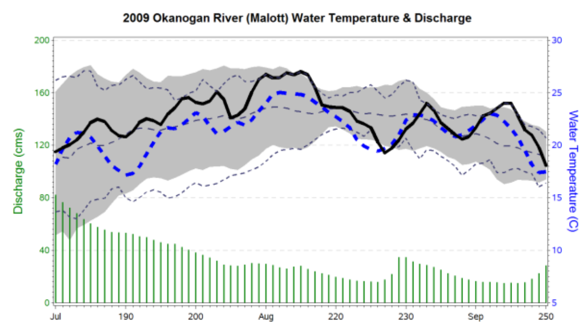

2008 Wells Dam Sockeye Counts (Total Esc: 165,334)
Daily Percent of Annual Esc (%)


2009 Wells Dam Sockeye Counts (Total Esc: 134,937)
Daily Percent of Annual Esc (%)

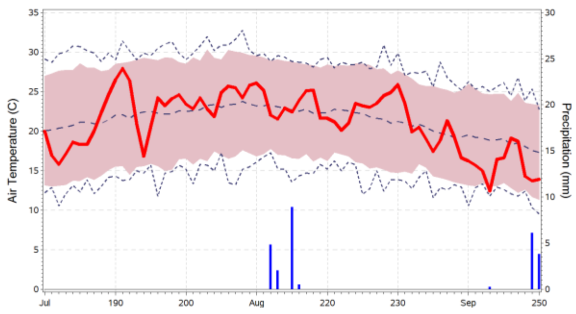

2008 Zosel Dam Sockeye Migration Timing (Total Esc: 85,429)
Daily Percent of Annual Esc (%)
Jul
190
200
Aug
220
230
Sep
250


2009 Zosel Dam Sockeye Migration Timing (Total Esc: 60,970)
Daily Percent of Annual Esc (%)
Jul
190
200
Aug
220
230
Sep
250

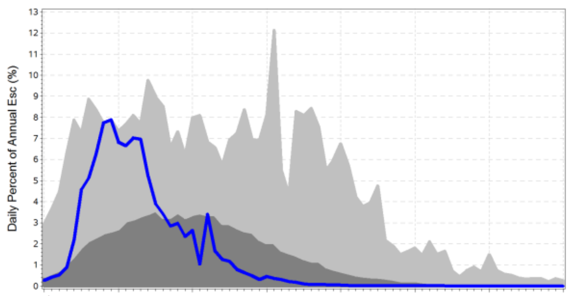

2008 Okanogan River (Malott) Water Temperature & Discharge
Discharge (cms)
Water Temperature (C)
Jul
190
200
Aug
220
230
Sep
250


2009 Okanogan River (Malott) Water Temperature & Discharge
Discharge (cms)
Water Temperature (C)
Jul
190
200
Aug
220
230
Sep
250

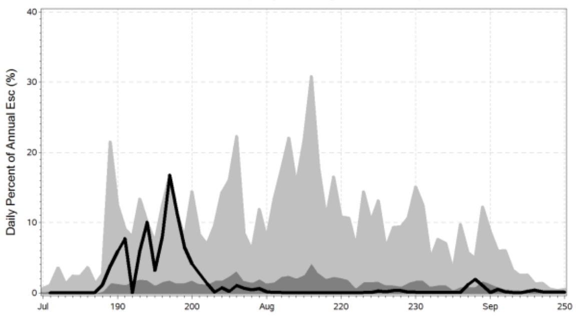
2010 Malott AWN



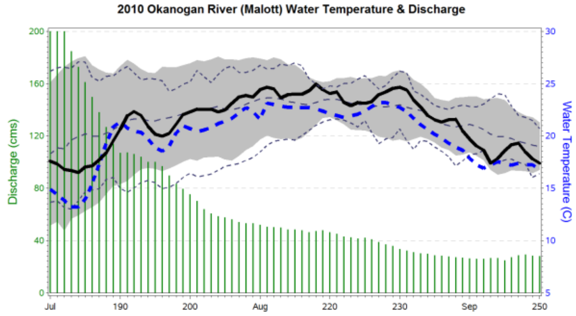
2010 Wells Dam Sockeye Counts (Total Esc: 291,764)



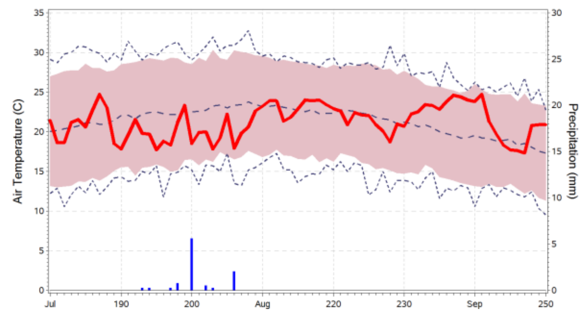
2010 Zosel Dam Sockeye Migration Timing (Total Esc: 208,311)



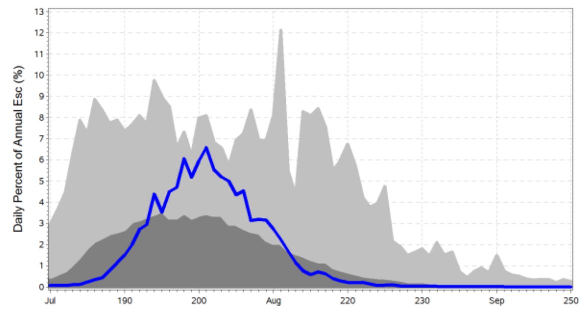
2010 Okanogan River (Malott) Water Temperature & Discharge



2011 Malott AWN

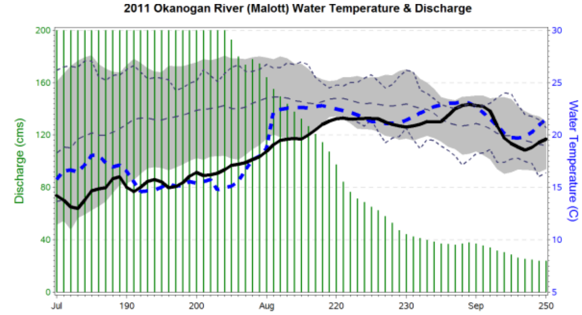


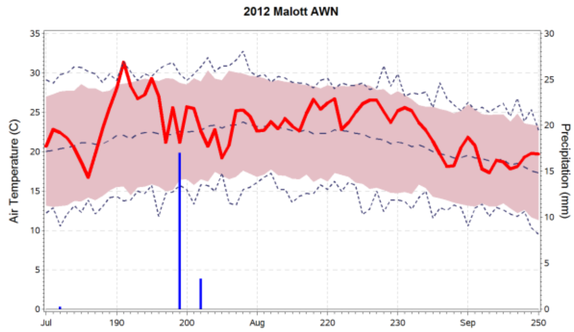
2011 Wells Dam Sockeye Counts (Total Esc: 111,507)

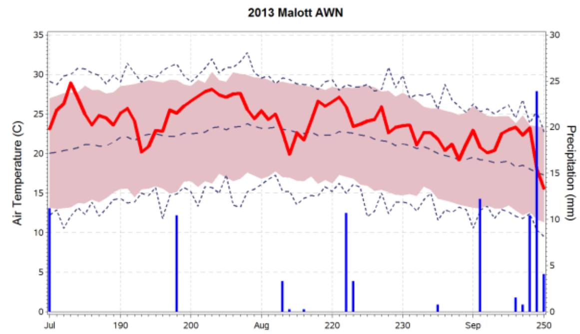


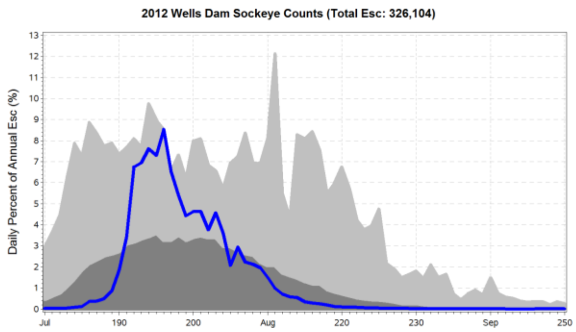
No 2011 Zosel Dam migration plot available

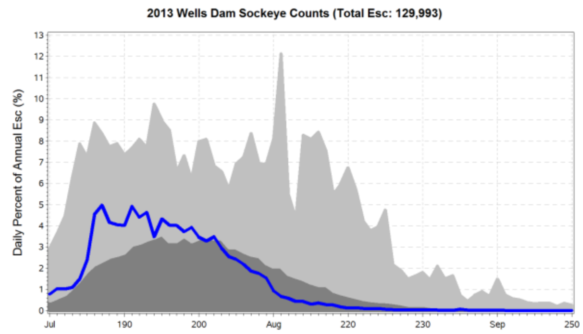
2011 Okanogan River (Malott) Water Temperature & Discharge





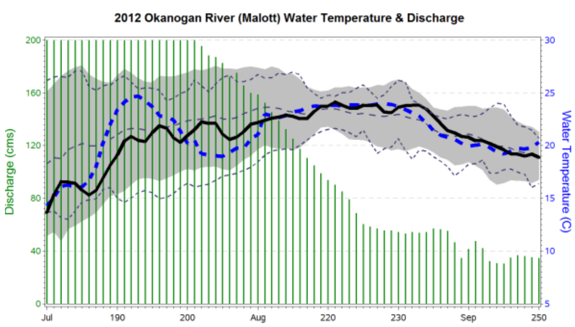


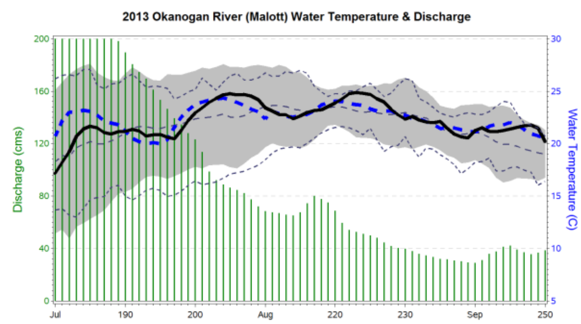




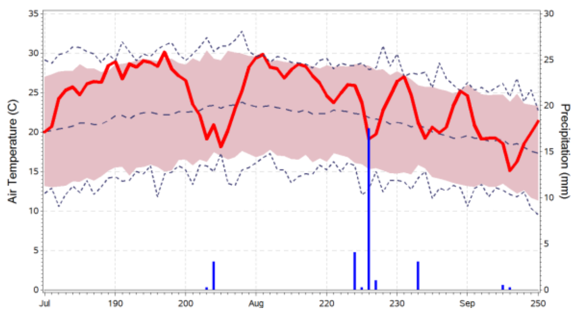
No 2012 Zosel Dam migration plot available

No 2013 Zosel Dam migration plot available

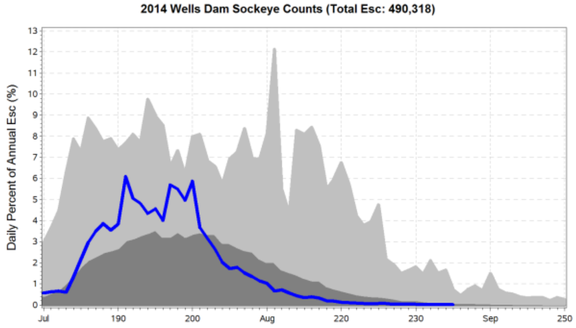




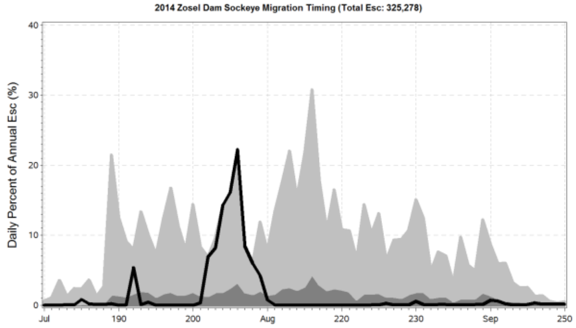
2014 Malott AWN



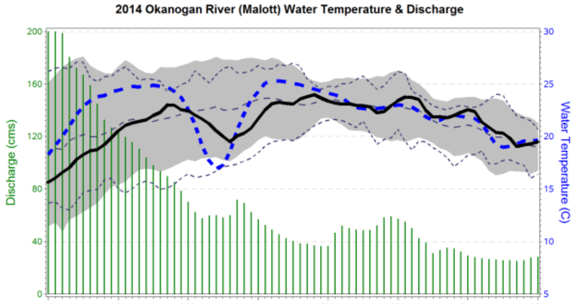
2014 Wells Dam Sockeye Counts (Total Esc: 490,318)



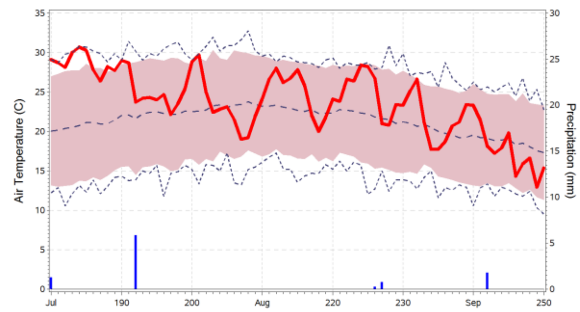
2014 Zosel Dam Sockeye Migration Timing (Total Esc: 325,278)



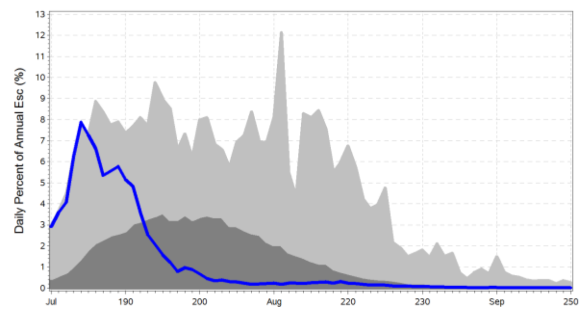
2014 Okanogan River (Malott) Water Temperature & Discharge



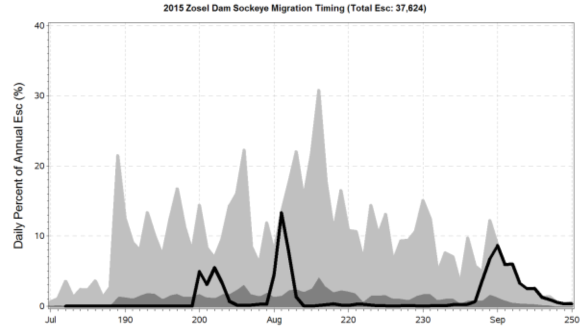
2015 Malott AWN



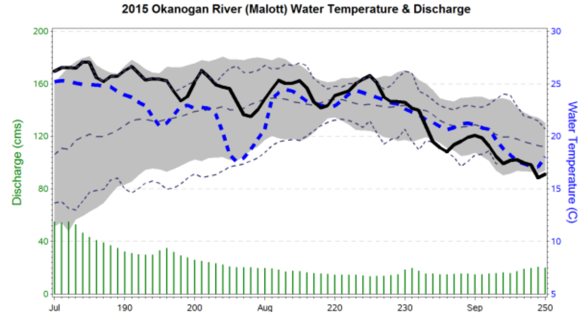
2015 Wells Dam Sockeye Counts (Total Esc: 186,964)

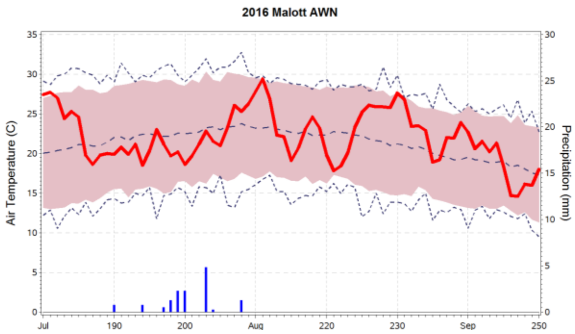


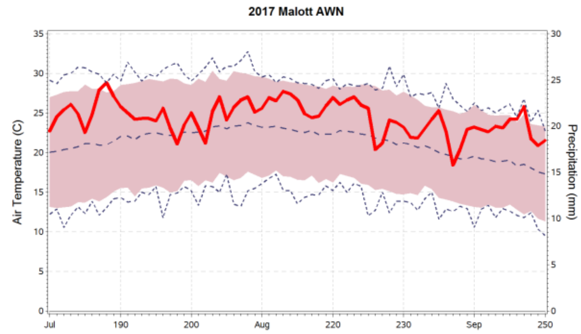
2015 Zosel Dam Sockeye Migration Timing (Total Esc: 37,624)

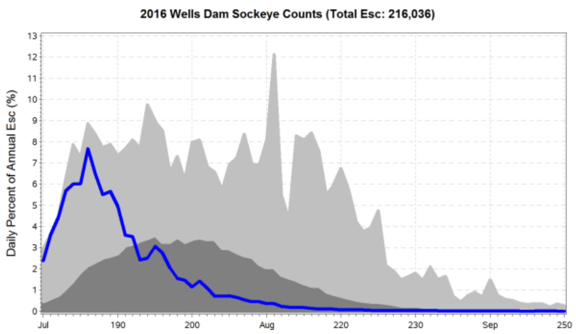


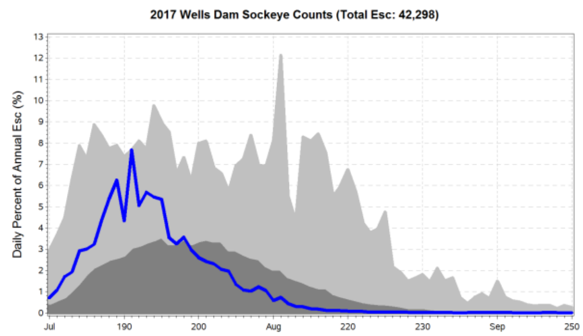
2015 Okanogan River (Malott) Water Temperature & Discharge

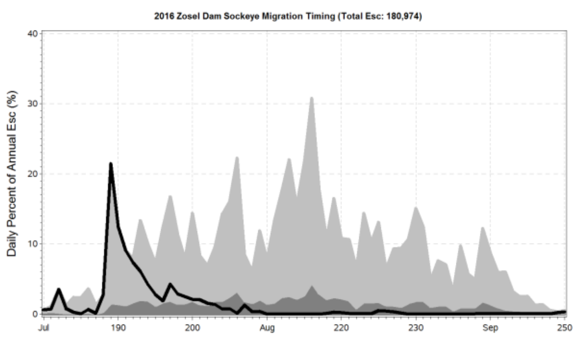




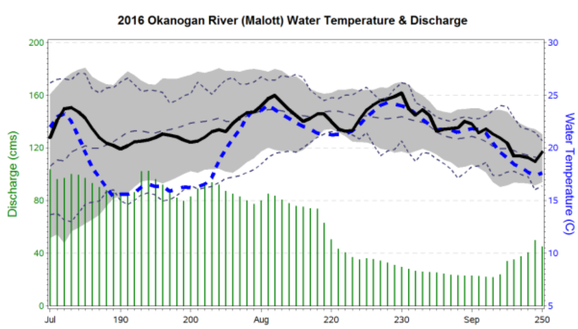


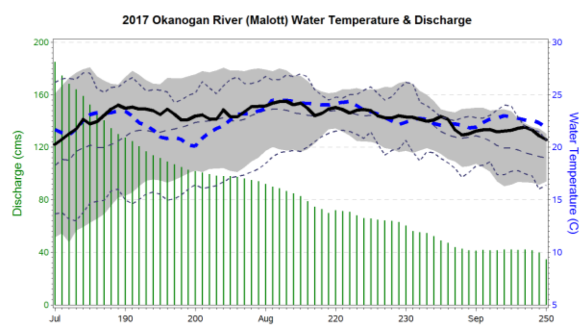


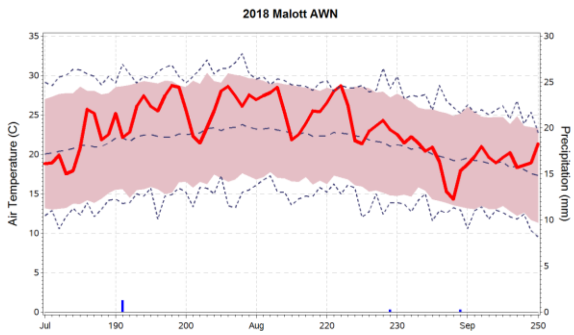


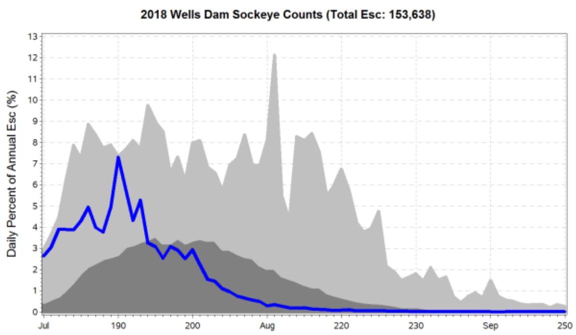


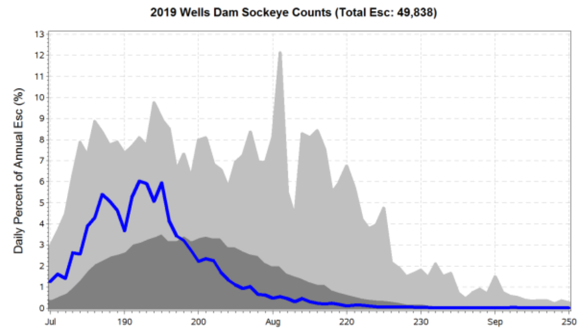
No Zosel Migration Data Available





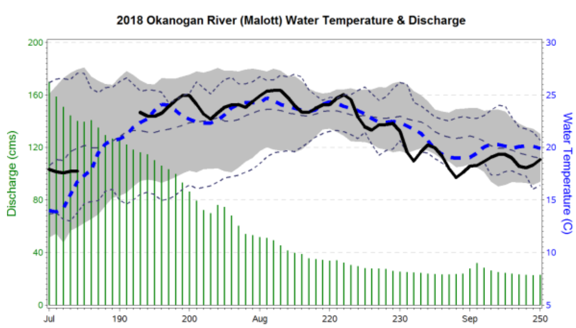


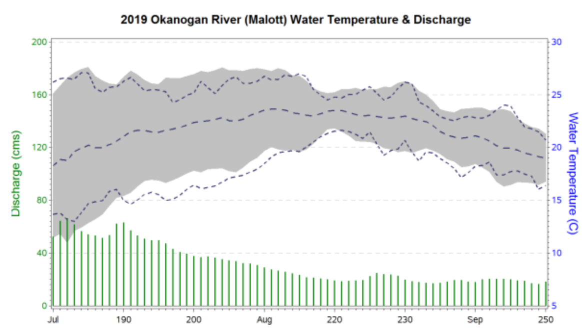




2018 Zosel migration (NO DATA)

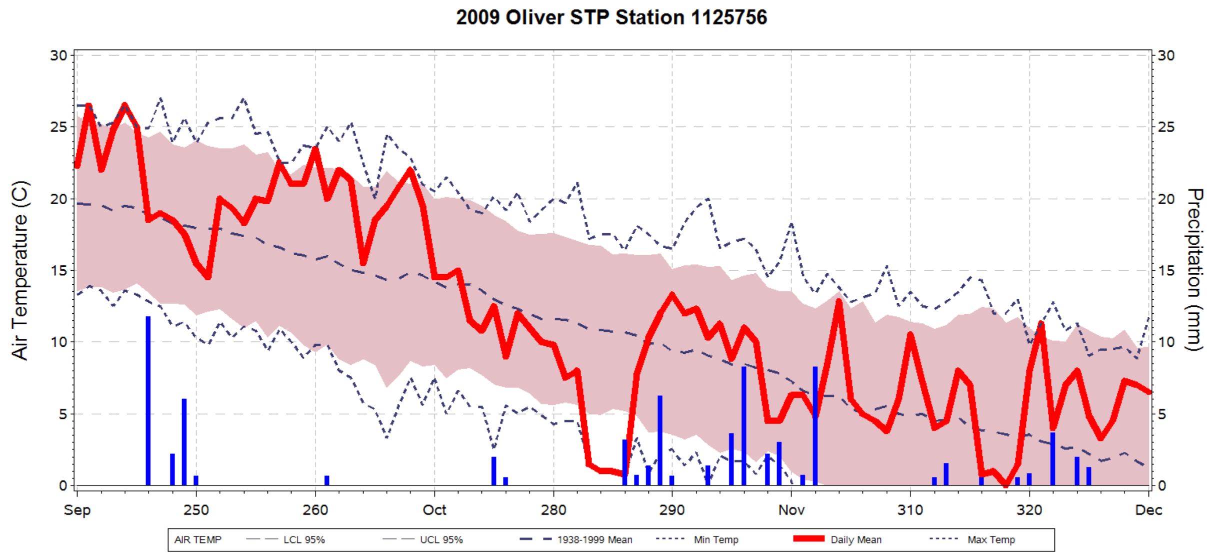
2019 Zosel migration (NO DATA)



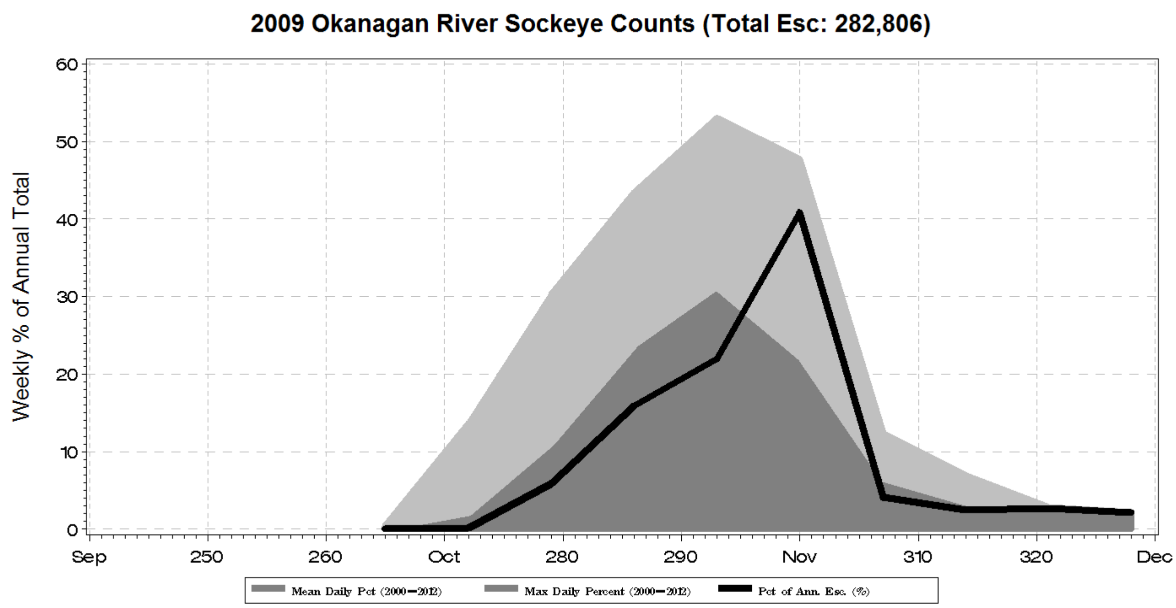


Appendix B. Weekly Okanagan Sockeye migration in relation to environmental variables in the Okanagan River watershed, by year, 2000-2018.

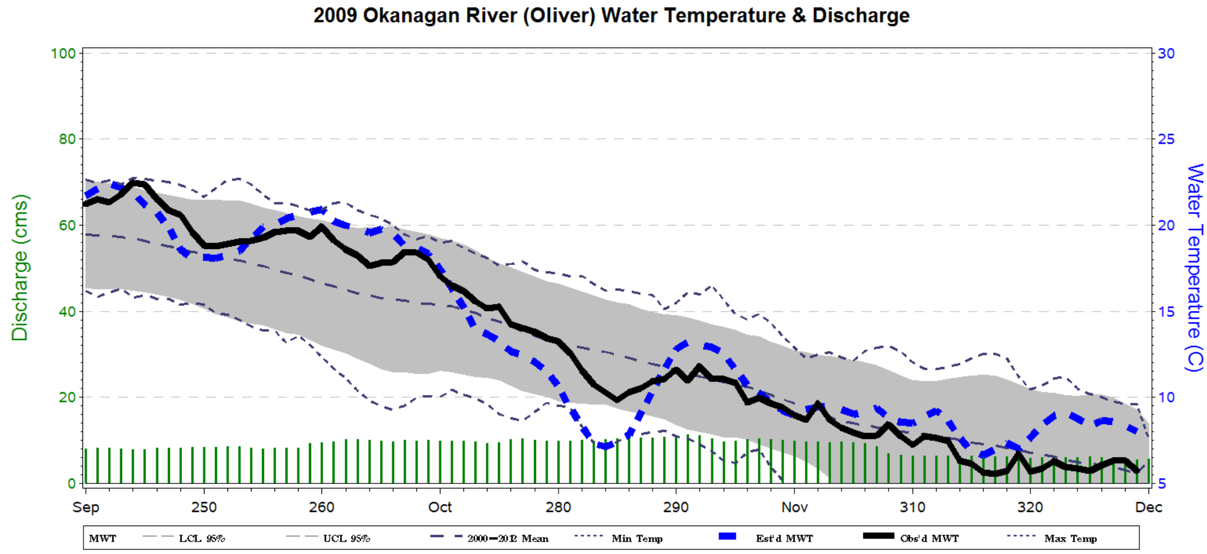
LEGEND PLOTS



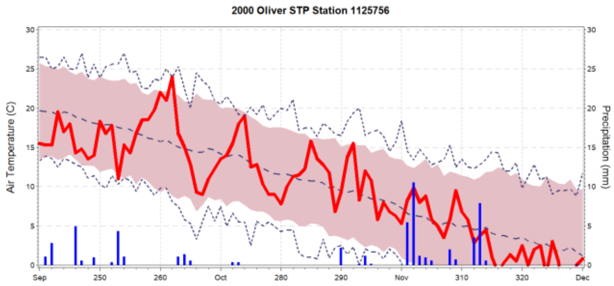
5. **Total daily precipitation** (mm, blue bars) and **daily mean air temperature** (°C, red line) at Environment Canada meteorological station Oliver STP 1125756, with historical daily mean and variance (dashed line and red area), 2000-2018.

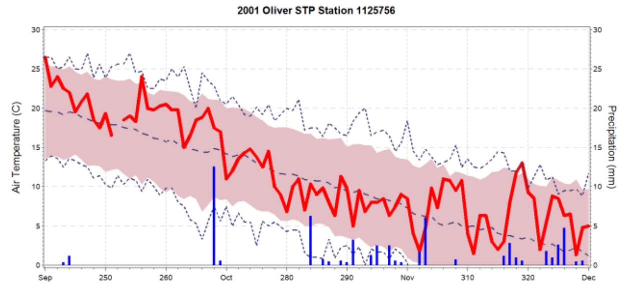


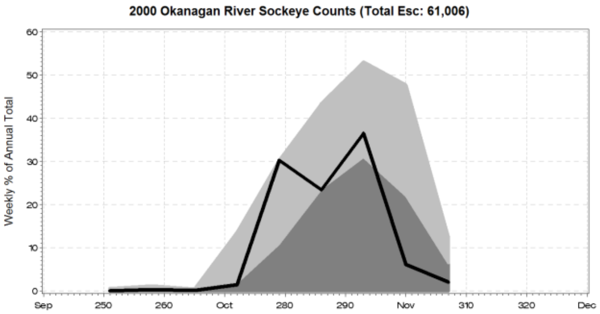
6. **Daily migration rates** as a percent (%) of annual stock escapement (black line), from daily Sockeye (adult + jack) migrants counted on the Okanagan River spawning grounds. Historical mean daily migration rate (dark gray area) and maximum daily migration rate (light gray area) over years 2000-2018.

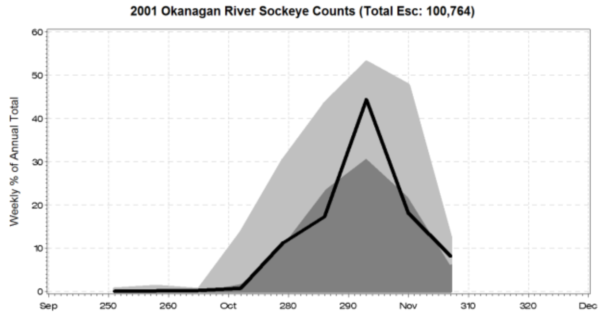


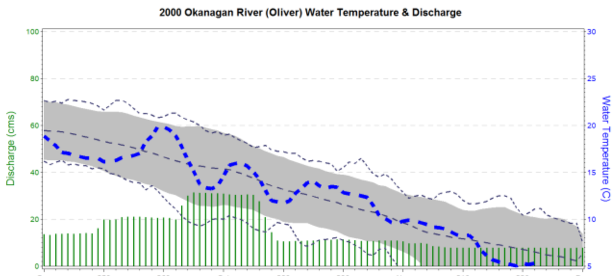
7. Physical data from the Okanagan River (at Oliver, BC. Daily mean water temperature (observed: solid black line; estimated: dashed blue line) with historical daily mean and variance (dashed line and shaded area), and daily discharge (cms) (green).

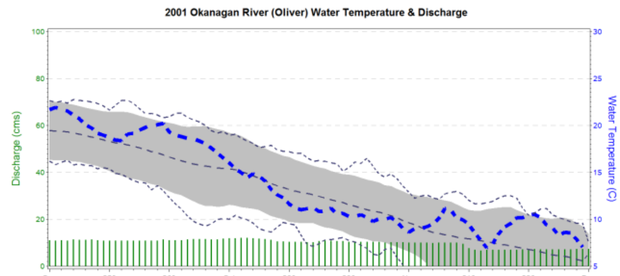

2000 Oliver STP Station 1125756
Air Temperature (C)
Precipitation (mm)
Sep
250
260
Oct
280
290
Nov
310
320
Dec

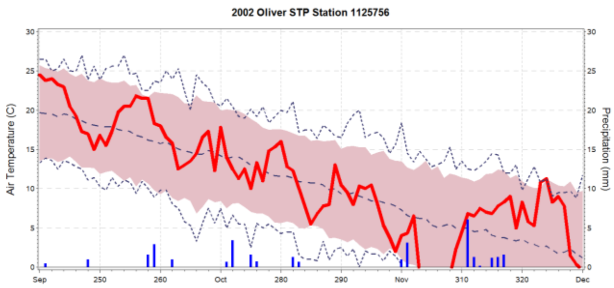

2001 Oliver STP Station 1125756
Air Temperature (C)
Precipitation (mm)
Sep
250
260
Oct
280
290
Nov
310
320
Dec

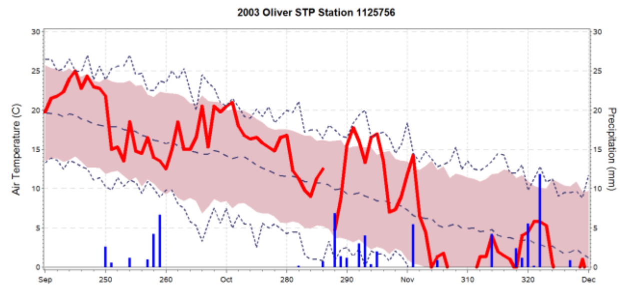

2000 Okanagan River Sockeye Counts (Total Esc: 61,006)
Weekly % of Annual Total
Sep
250
260
Oct
280
290
Nov
310
320
Dec

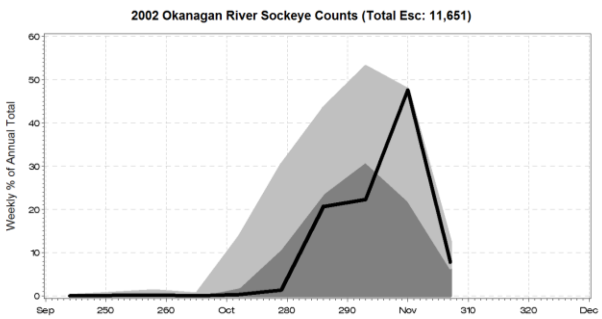

2001 Okanagan River Sockeye Counts (Total Esc: 100,764)
Weekly % of Annual Total
Sep
250
260
Oct
280
290
Nov
310
320
Dec

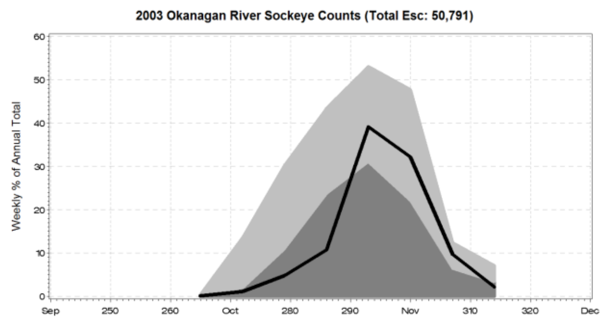

2000 Okanagan River (Oliver) Water Temperature & Discharge
Discharge (cms)
Water Temperature (C)
Sep
250
260
Oct
280
290
Nov
310
320
Dec

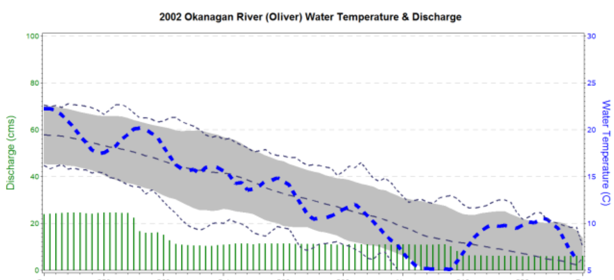

2001 Okanagan River (Oliver) Water Temperature & Discharge
Discharge (cms)
Water Temperature (C)
Sep
250
260
Oct
280
290
Nov
310
320
Dec

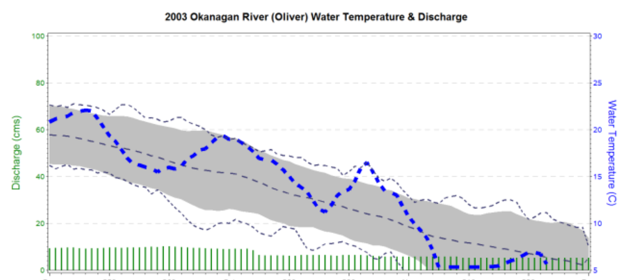

2002 Oliver STP Station 1125756
Air Temperature (C)
Precipitation (mm)
Sep
250
260
Oct
280
290
Nov
310
320
Dec

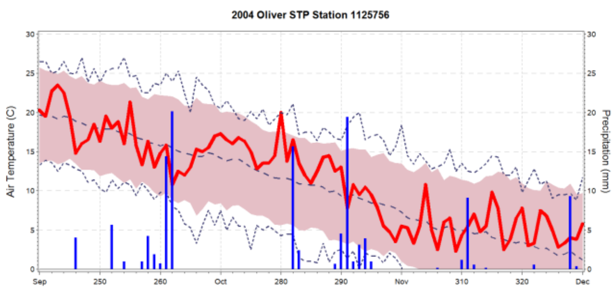

2003 Oliver STP Station 1125756
Air Temperature (C)
Precipitation (mm)
Sep
250
260
Oct
280
290
Nov
310
320
Dec

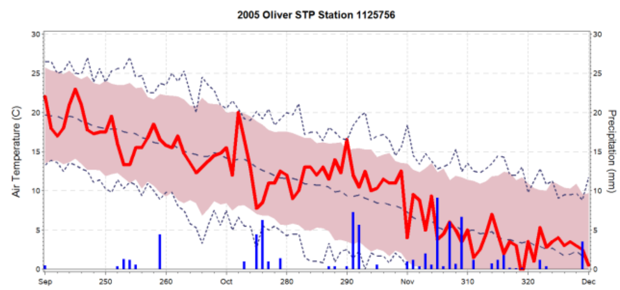

2002 Okanagan River Sockeye Counts (Total Esc: 11,651)
Weekly % of Annual Total
Sep
250
260
Oct
280
290
Nov
310
320
Dec

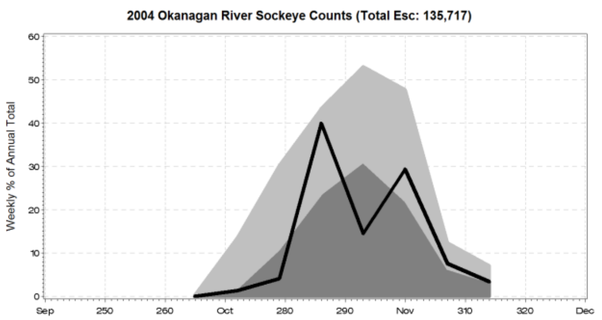

2003 Okanagan River Sockeye Counts (Total Esc: 50,791)
Weekly % of Annual Total
Sep
250
260
Oct
280
290
Nov
310
320
Dec

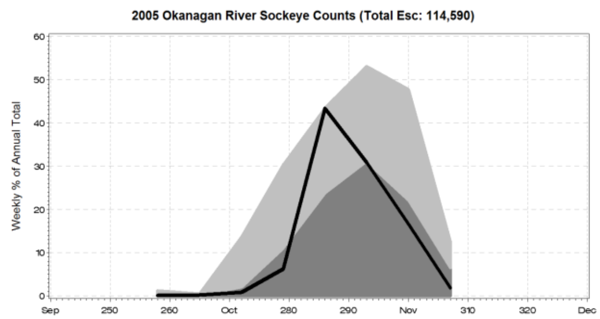

2002 Okanagan River (Oliver) Water Temperature & Discharge
Discharge (cms)
Water Temperature (C)
Sep
250
260
Oct
280
290
Nov
310
320
Dec

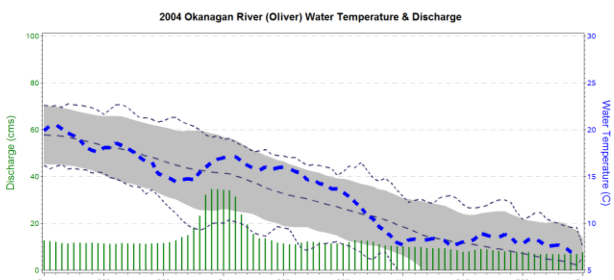

2003 Okanagan River (Oliver) Water Temperature & Discharge
Discharge (cms)
Water Temperature (C)
Sep
250
260
Oct
280
290
Nov
310
320
Dec

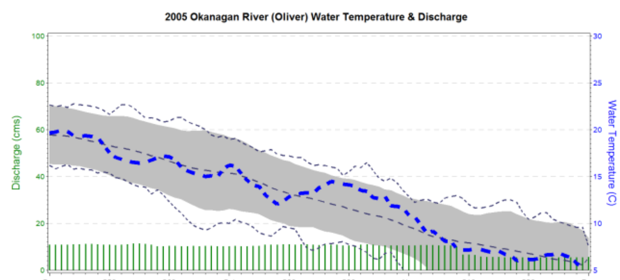

2004 Oliver STP Station 1125756
Air Temperature (C)
Precipitation (mm)
Sep
Oct
Nov
Dec

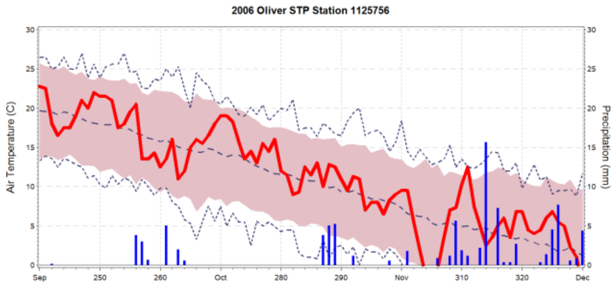

2005 Oliver STP Station 1125756
Air Temperature (C)
Precipitation (mm)
Sep
Oct
Nov
Dec

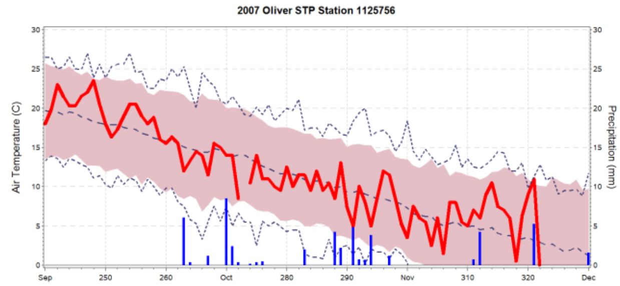

2004 Okanagan River Sockeye Counts (Total Esc: 135,717)
Weekly % of Annual Total
Sep
Oct
Nov
Dec

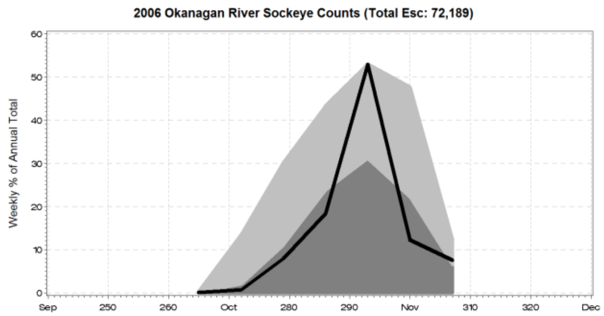

2005 Okanagan River Sockeye Counts (Total Esc: 114,590)
Weekly % of Annual Total
Sep
Oct
Nov
Dec

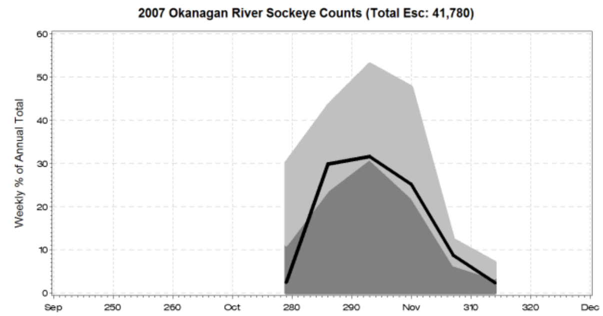

2004 Okanagan River (Oliver) Water Temperature & Discharge
Discharge (cms)
Water Temperature (C)
Sep
Oct
Nov
Dec

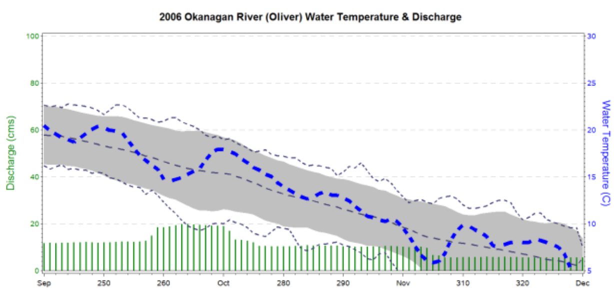

2005 Okanagan River (Oliver) Water Temperature & Discharge
Discharge (cms)
Water Temperature (C)
Sep
Oct
Nov
Dec

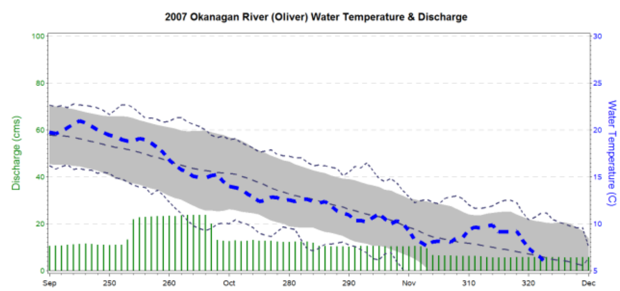

2006 Oliver STP Station 1125756
Air Temperature (C)
Precipitation (mm)
Sep
250
260
Oct
280
290
Nov
310
320
Dec

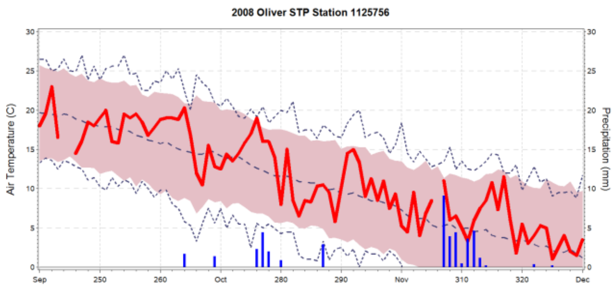

2007 Oliver STP Station 1125756
Air Temperature (C)
Precipitation (mm)
Sep
250
260
Oct
280
290
Nov
310
320
Dec

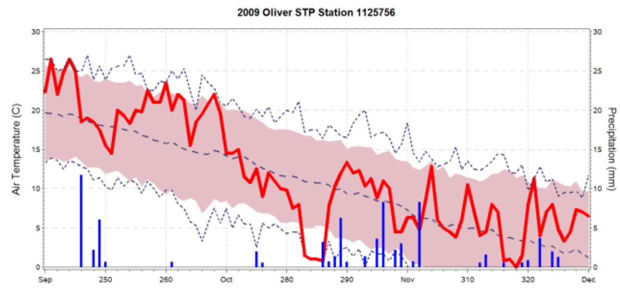

2006 Okanagan River Sockeye Counts (Total Esc: 72,189)
Weekly % of Annual Total
Sep
250
260
Oct
280
290
Nov
310
320
Dec

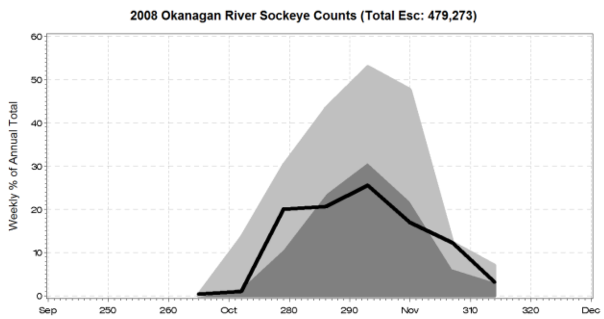

2007 Okanagan River Sockeye Counts (Total Esc: 41,780)
Weekly % of Annual Total
Sep
250
260
Oct
280
290
Nov
310
320
Dec

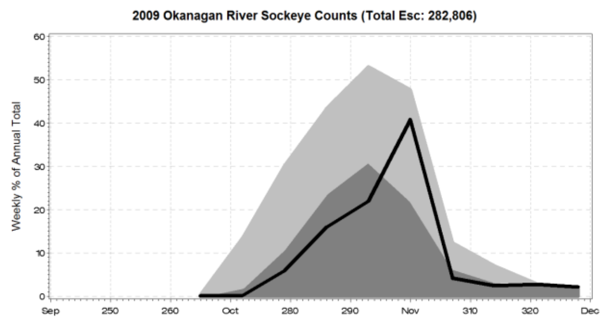

2006 Okanagan River (Oliver) Water Temperature & Discharge
Discharge (cms)
Water Temperature (C)
Sep
250
260
Oct
280
290
Nov
310
320
Dec

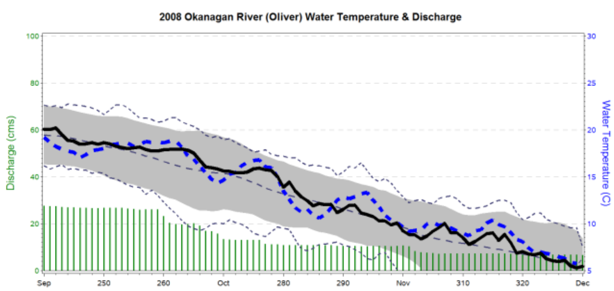

2007 Okanagan River (Oliver) Water Temperature & Discharge
Discharge (cms)
Water Temperature (C)
Sep
250
260
Oct
280
290
Nov
310
320
Dec

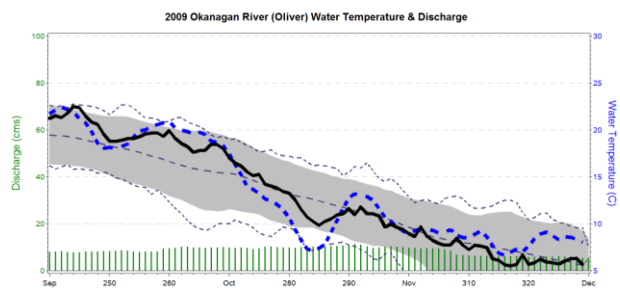

2008 Oliver STP Station 1125756
Air Temperature (C)
Precipitation (mm)
Sep
250
260
Oct
280
290
Nov
310
320
Dec

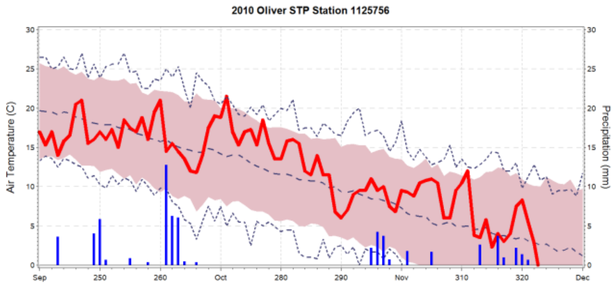

2009 Oliver STP Station 1125756
Air Temperature (C)
Precipitation (mm)
Sep
250
260
Oct
280
290
Nov
310
320
Dec

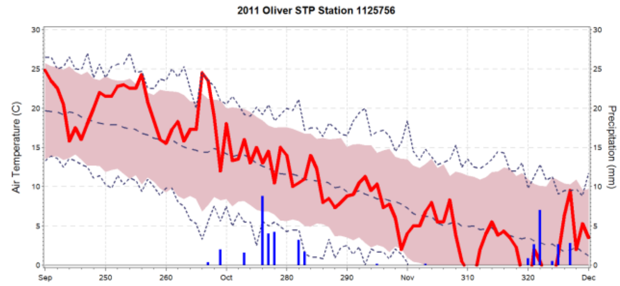

2008 Okanagan River Sockeye Counts (Total Esc: 479,273)
Weekly % of Annual Total
Sep
250
260
Oct
280
290
Nov
310
320
Dec

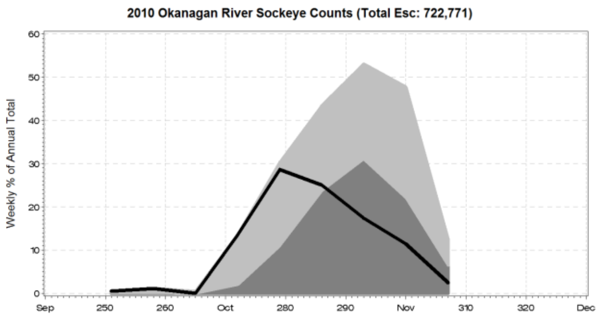

2009 Okanagan River Sockeye Counts (Total Esc: 282,806)
Weekly % of Annual Total
Sep
250
260
Oct
280
290
Nov
310
320
Dec

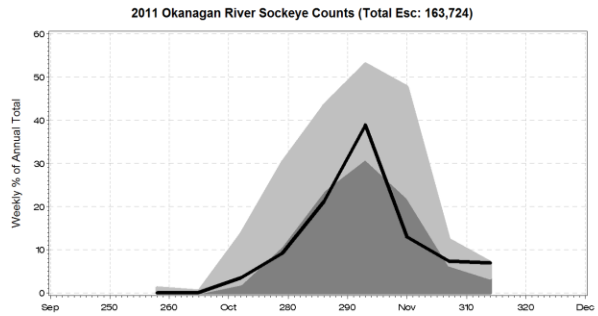

2008 Okanagan River (Oliver) Water Temperature & Discharge
Discharge (cms)
Water Temperature (C)
Sep
250
260
Oct
280
290
Nov
310
320
Dec

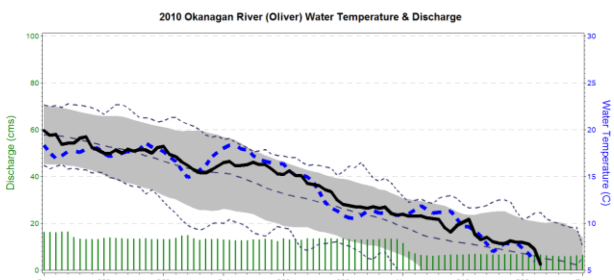

2009 Okanagan River (Oliver) Water Temperature & Discharge
Discharge (cms)
Water Temperature (C)
Sep
250
260
Oct
280
290
Nov
310
320
Dec

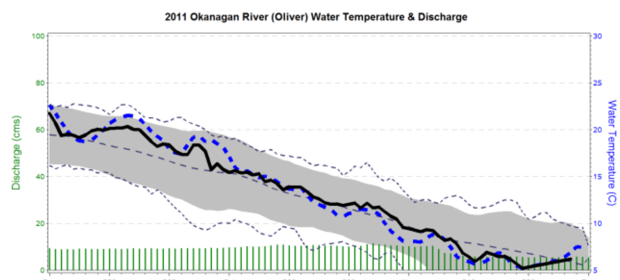

2010 Oliver STP Station 1125756
Air Temperature (C)
Precipitation (mm)
Sep
250
260
Oct
280
290
Nov
310
320
Dec

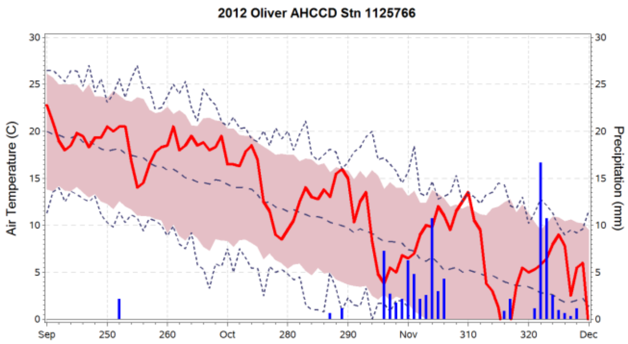

2011 Oliver STP Station 1125756
Air Temperature (C)
Precipitation (mm)
Sep
250
260
Oct
280
290
Nov
310
320
Dec

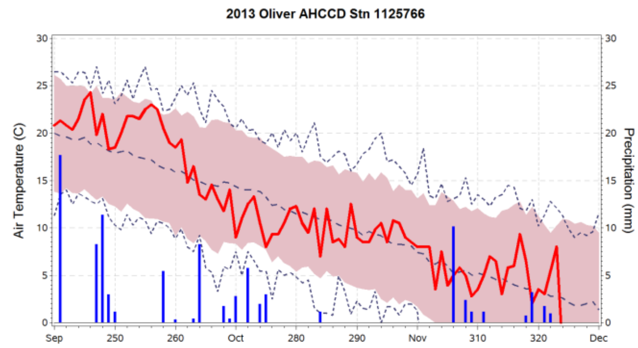

2010 Okanagan River Sockeye Counts (Total Esc: 722,771)
Weekly % of Annual Total
Sep
250
260
Oct
280
290
Nov
310
320
Dec

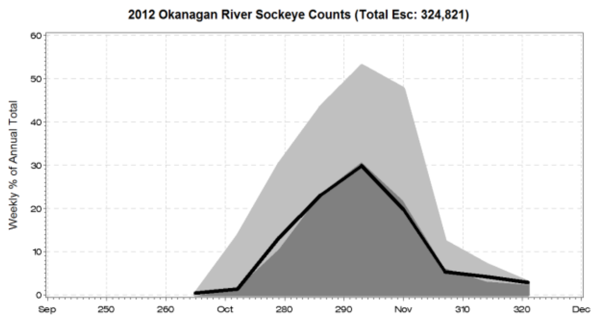

2011 Okanagan River Sockeye Counts (Total Esc: 163,724)
Weekly % of Annual Total
Sep
250
260
Oct
280
290
Nov
310
320
Dec

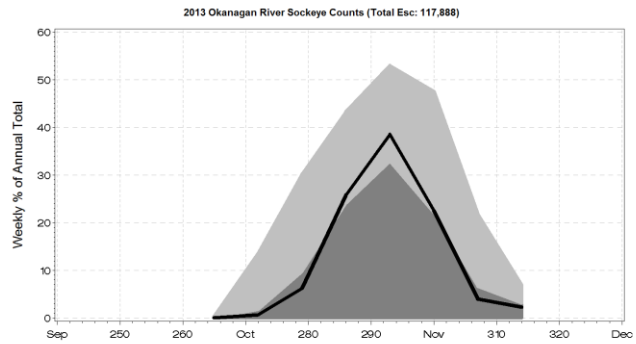

2010 Okanagan River (Oliver) Water Temperature & Discharge
Discharge (cms)
Water Temperature (C)
Sep
250
260
Oct
280
290
Nov
310
320
Dec

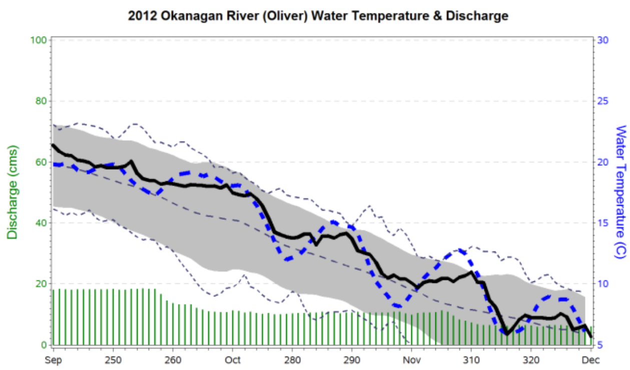

2011 Okanagan River (Oliver) Water Temperature & Discharge
Discharge (cms)
Water Temperature (C)
Sep
250
260
Oct
280
290
Nov
310
320
Dec

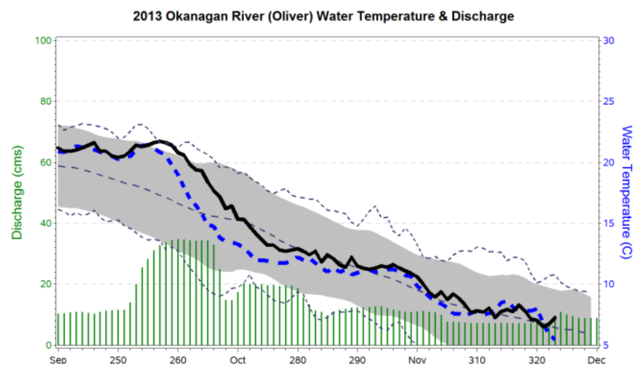

2012 Oliver AHCCD Stn 1125766
Air Temperature (C)
Precipitation (mm)
Sep
250
260
Oct
280
290
Nov
310
320
Dec


2013 Oliver AHCCD Stn 1125766
Air Temperature (C)
Precipitation (mm)
Sep
250
260
Oct
280
290
Nov
310
320
Dec

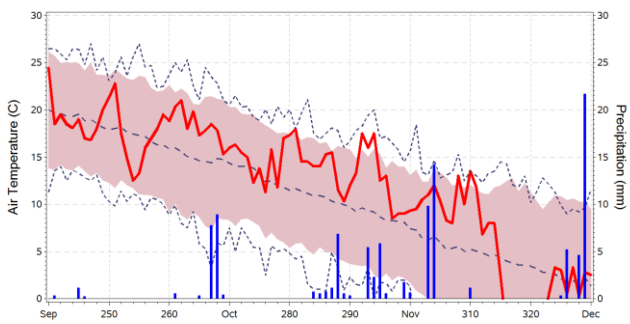

2012 Okanagan River Sockeye Counts (Total Esc: 324,821)
Weekly % of Annual Total
Sep
250
260
Oct
280
290
Nov
310
320
Dec


2013 Okanagan River Sockeye Counts (Total Esc: 117,888)
Weekly % of Annual Total
Sep
250
260
Oct
280
290
Nov
310
320
Dec

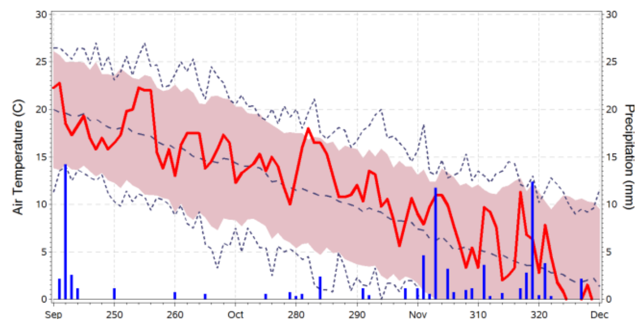

2012 Okanagan River (Oliver) Water Temperature & Discharge
Discharge (cms)
Water Temperature (C)
Sep
250
260
Oct
280
290
Nov
310
320
Dec


2013 Okanagan River (Oliver) Water Temperature & Discharge
Discharge (cms)
Water Temperature (C)
Sep
250
260
Oct
280
290
Nov
310
320
Dec

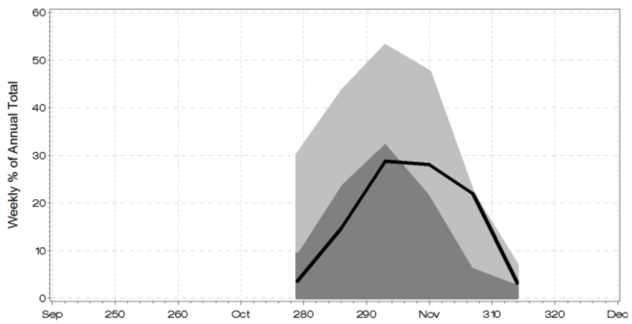
2014 Oliver AHCCD Stn 1125766



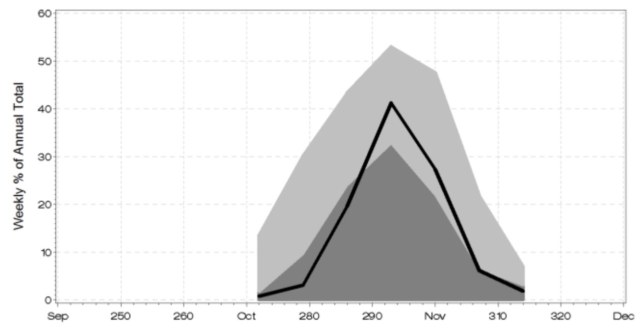
2015 Oliver AHCCD Stn 1125766



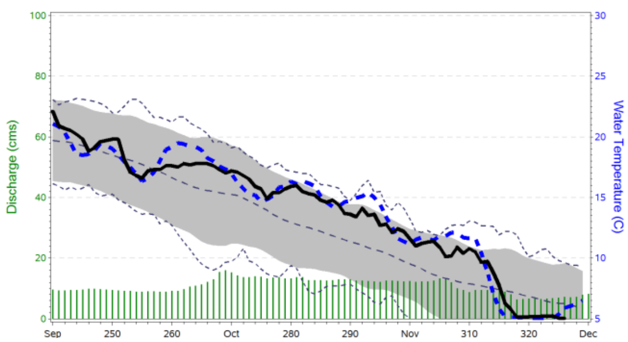
2014 Okanagan River Sockeye Counts (Total Esc: 517,819)



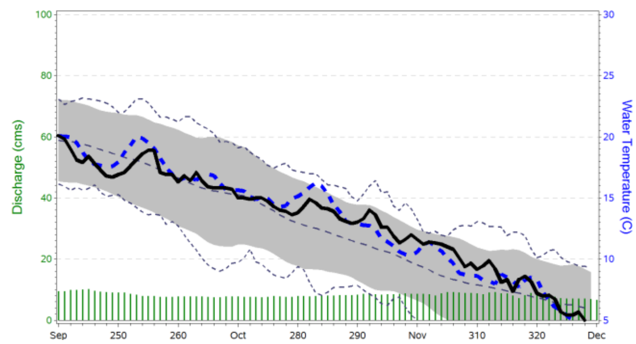
2015 Okanagan River Sockeye Counts (Total Esc: 30,270)

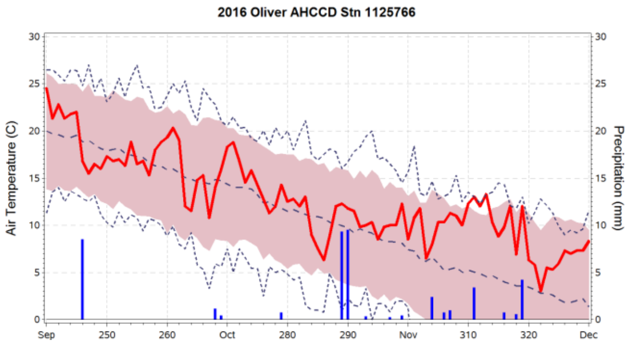


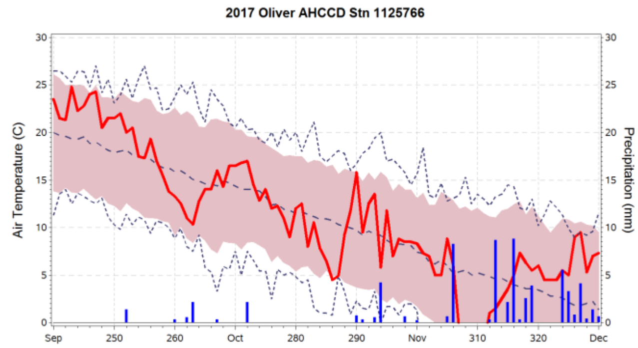
2014 Okanagan River (Oliver) Water Temperature & Discharge

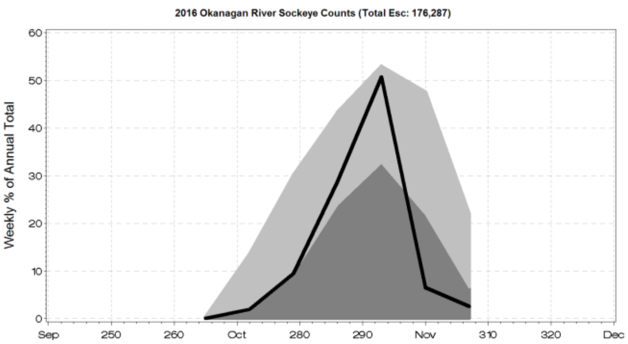


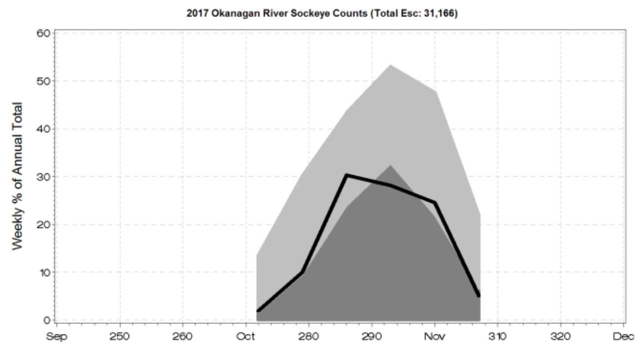
2015 Okanagan River (Oliver) Water Temperature & Discharge

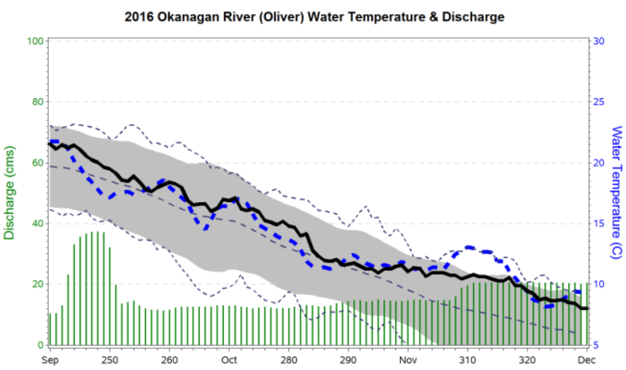


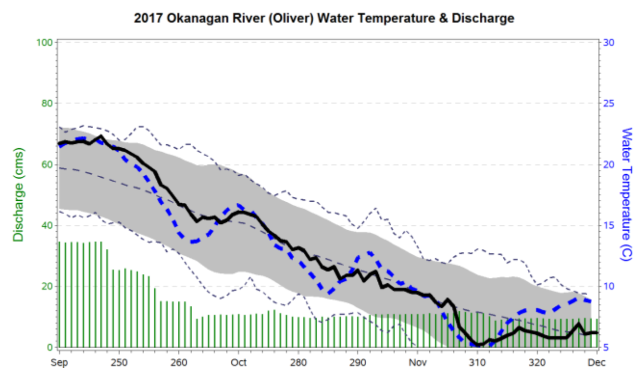

2016 Oliver AHCCD Stn 1125766
Air Temperature (C)
Precipitation (mm)
Sep
250
260
Oct
280
290
Nov
310
320
Dec


2017 Oliver AHCCD Stn 1125766
Air Temperature (C)
Precipitation (mm)
Sep
250
260
Oct
280
290
Nov
310
320
Dec

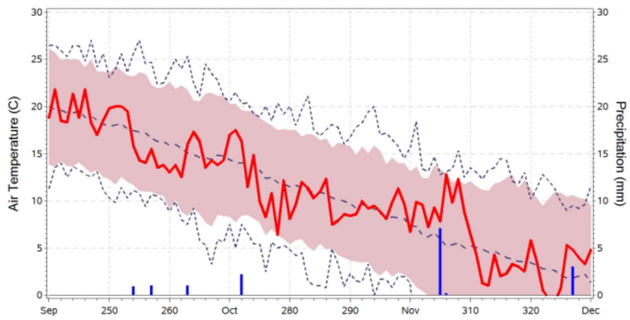

2016 Okanagan River Sockeye Counts (Total Esc: 176,287)
Weekly % of Annual Total
Sep
250
260
Oct
280
290
Nov
310
320
Dec


2017 Okanagan River Sockeye Counts (Total Esc: 31,166)
Weekly % of Annual Total
Sep
250
260
Oct
280
290
Nov
310
320
Dec

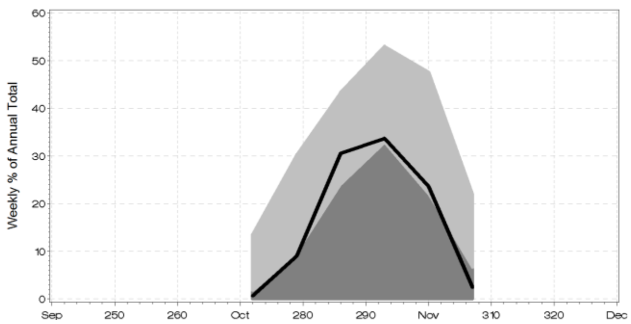

2016 Okanagan River (Oliver) Water Temperature & Discharge
Discharge (cms)
Water Temperature (C)
Sep
250
260
Oct
280
290
Nov
310
320
Dec


2017 Okanagan River (Oliver) Water Temperature & Discharge
Discharge (cms)
Water Temperature (C)
Sep
250
260
Oct
280
290
Nov
310
320
Dec

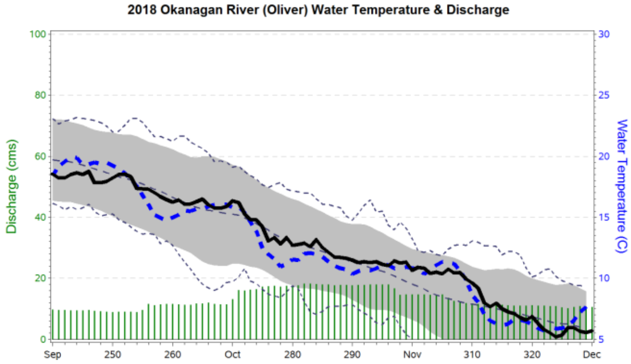
2018 Oliver AHCCD Stn 1125766



2018 Okanagan River Sockeye Counts (Total Esc: 103,230)



2018 Okanagan River (Oliver) Water Temperature & Discharge



Appendix C. Annual anomaly plots for: (a) Okanagan Sockeye migration enumerated at Zosel Dam (lagged 4 days back in time to the confluence of the Okanogan and Columbia Rivers); (b) forward-lagged (1 day) Okanogan River water temperature and (c) river discharge (flow level is factored by 0.10 to fit on y-axis).

Zero-line thresholds:

(a) Daily migration rate = 0.4% (50th percentile of non-zero daily migration rates (1937-2018);

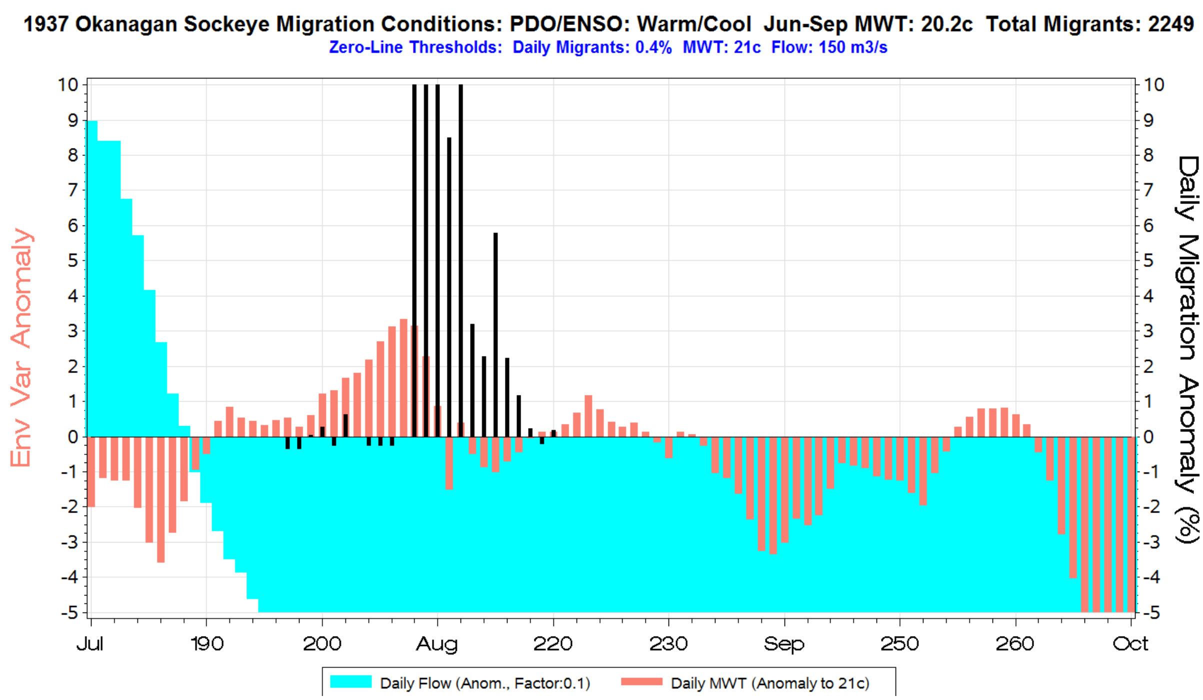
(b) Okanogan River (at Malott, WA) water temperature = 21°C;

(c) Lower Okanogan River discharge = 150 cms.

To convert anomalies to estimates, divide the bar height by the specified factor (if any) and add to the zero-line threshold:

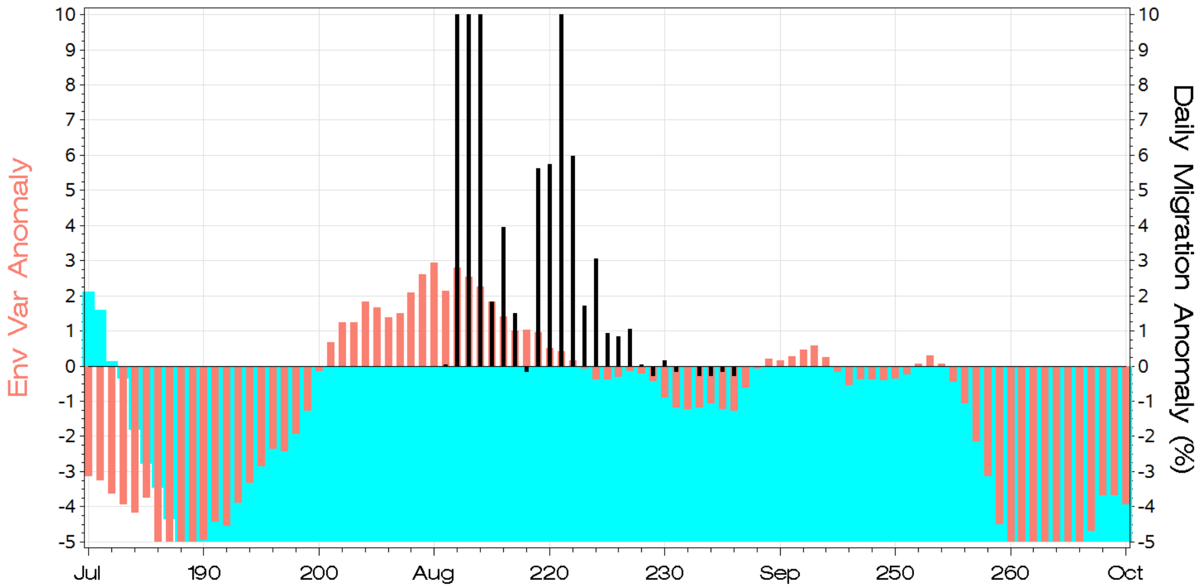
- first temperature bar (red) in 1937 represents -2 + 21 = 19°C
- first depth bar (blue) in 1937 represents +9 ÷ 0.1 + 150 = 240 cms
- sixth migration bar (black) in 1944 represents 1 + 0.4 = 1.4%

Note that bars extending beyond the vertical axis are truncated at the axis maxima.



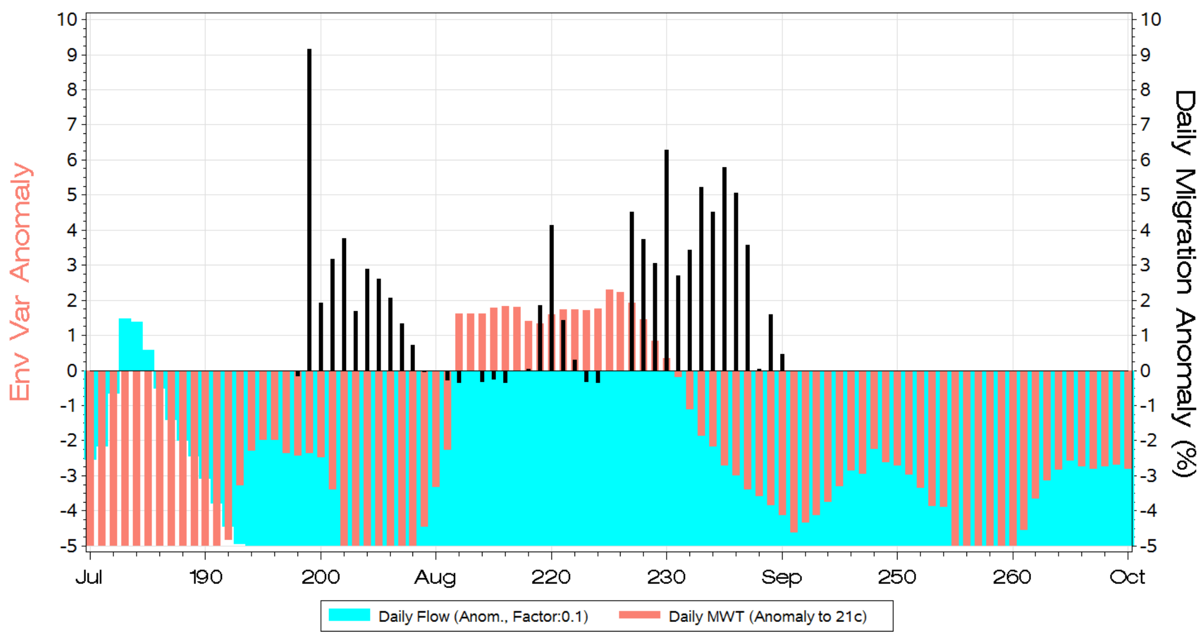
1944 Okanagan Sockeye Migration Conditions: PDO/ENSO: Warm/Neutral Jun-Sep MWT: 19.6c Total Migrants: 896

Zero-Line Thresholds: Daily Migrants: 0.4% MWT: 21c Flow: 150 m3/s

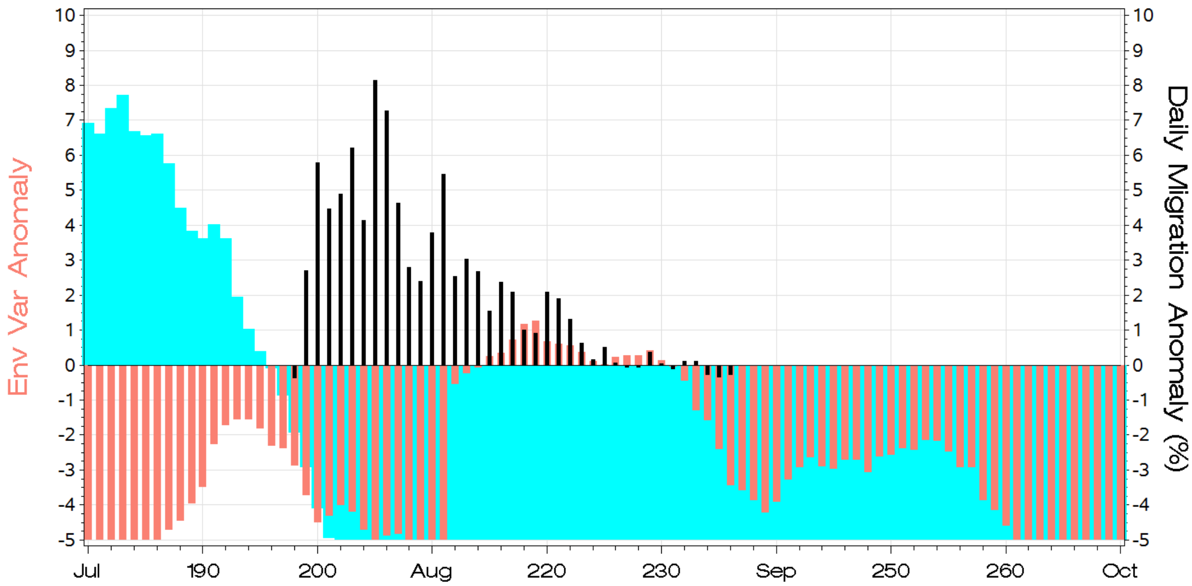


1952 Okanagan Sockeye Migration Conditions: PDO/ENSO: Cool/Warm Jun-Sep MWT: 18.0c Total Migrants: 3006

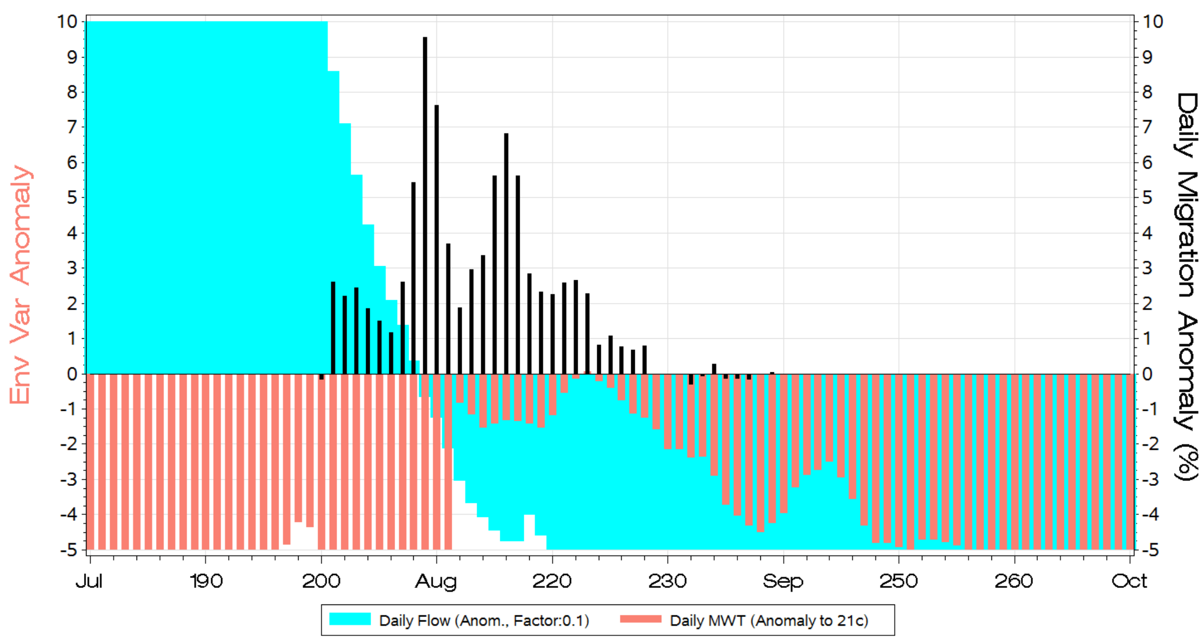
Zero-Line Thresholds: Daily Migrants: 0.4% MWT: 21c Flow: 150 m3/s

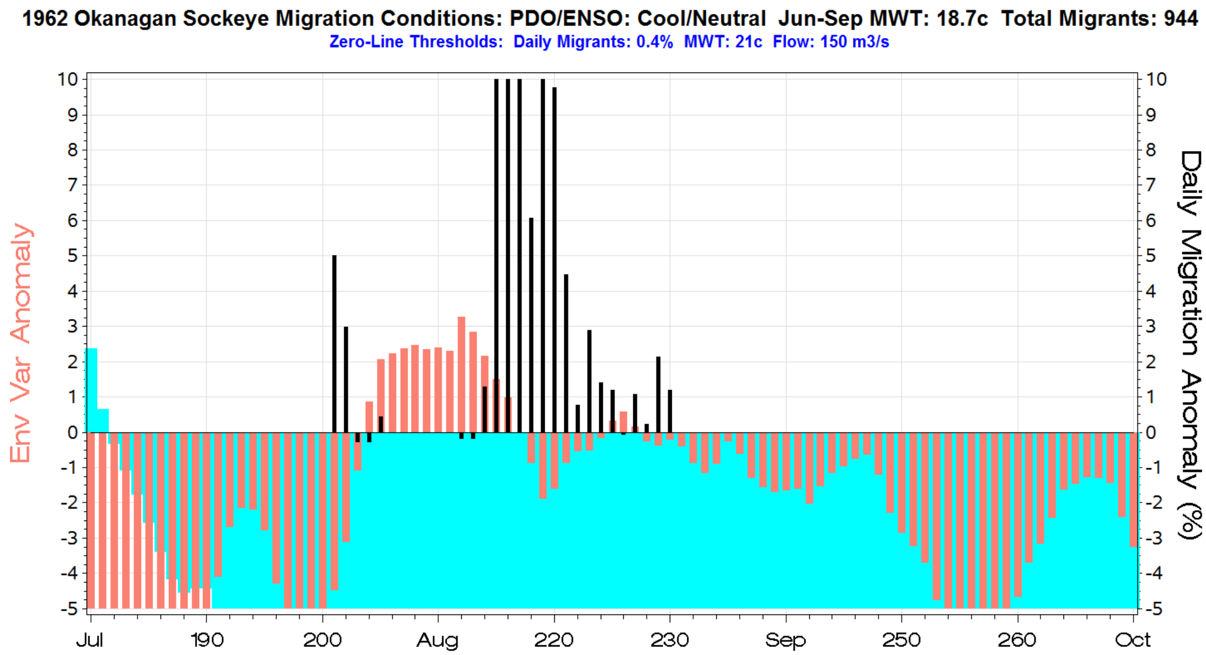


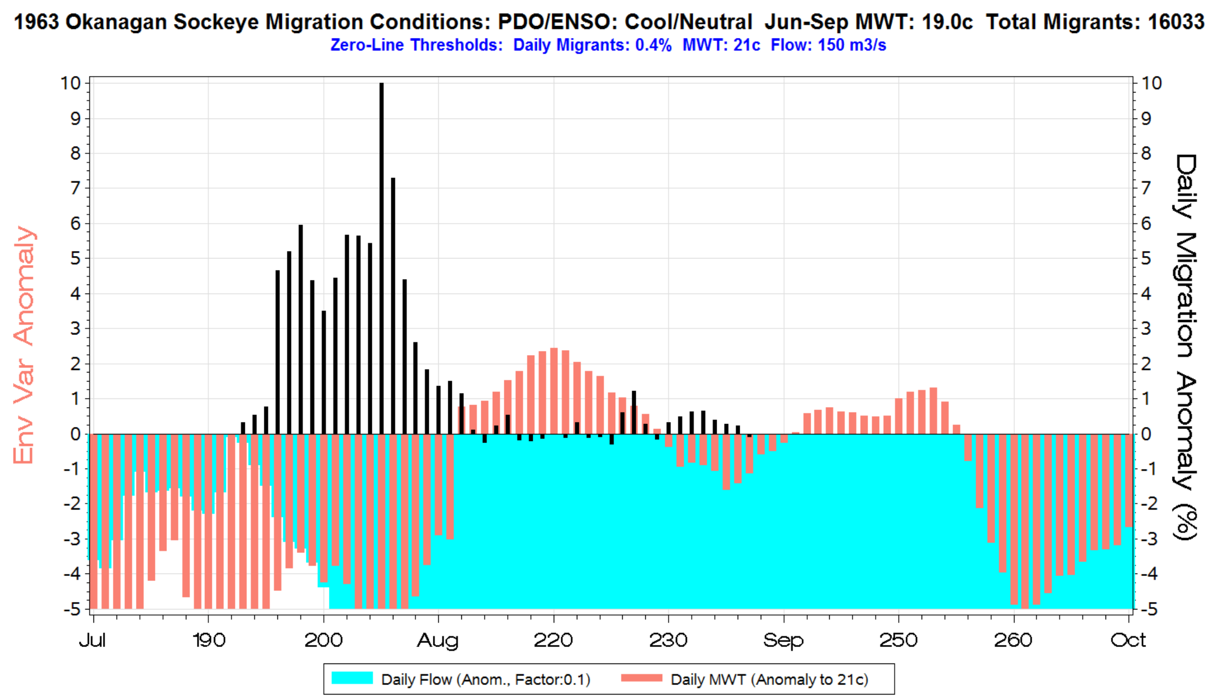
1953 Okanagan Sockeye Migration Conditions: PDO/ENSO: Cool/Neutral Jun-Sep MWT: 17.7c Total Migrants: 67542
Zero-Line Thresholds: Daily Migrants: 0.4% MWT: 21c Flow: 150 m3/s

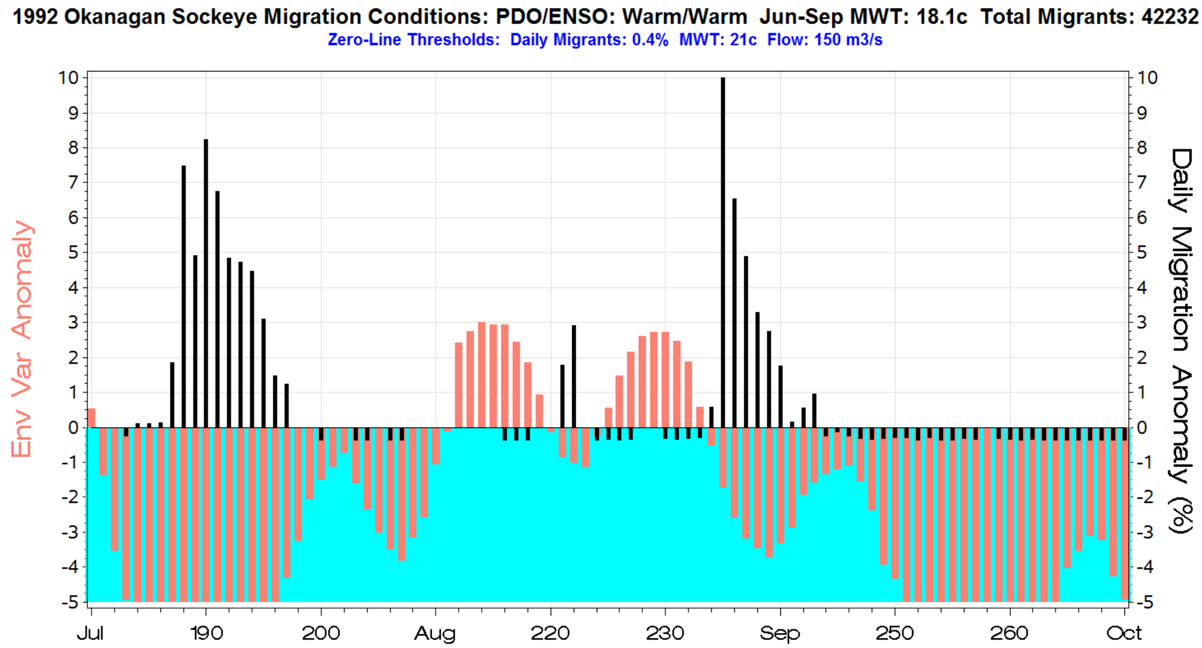


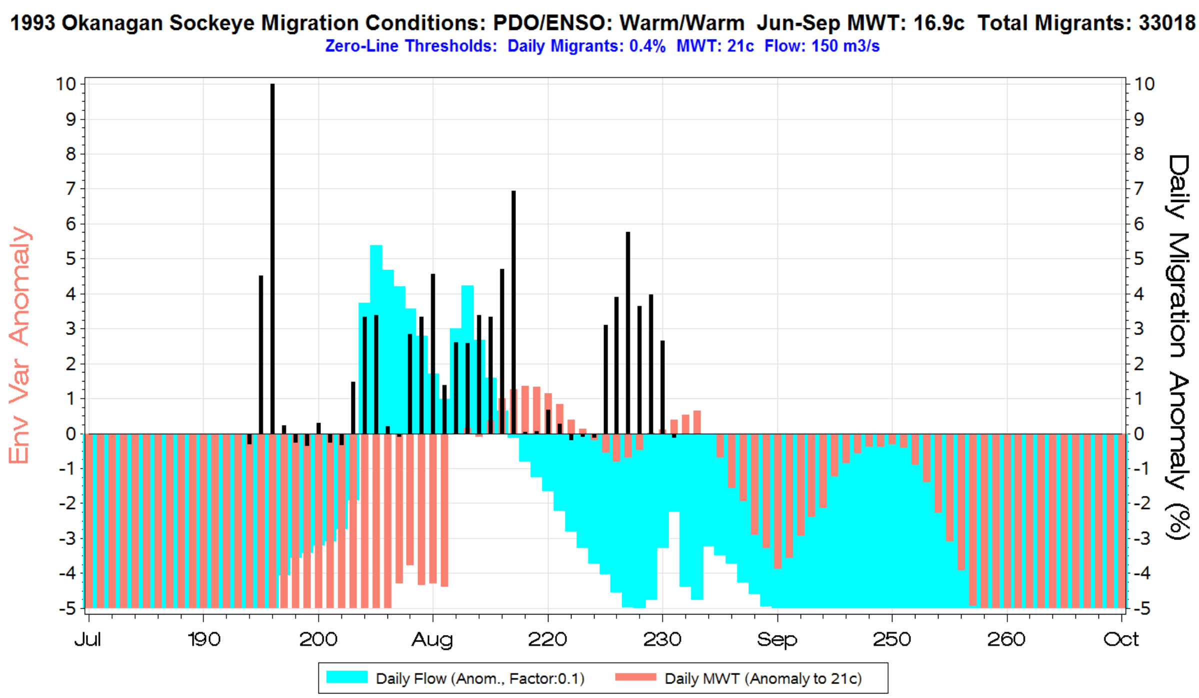
1954 Okanagan Sockeye Migration Conditions: PDO/ENSO: Cool/Warm Jun-Sep MWT: 16.5c Total Migrants: 3881
Zero-Line Thresholds: Daily Migrants: 0.4% MWT: 21c Flow: 150 m3/s

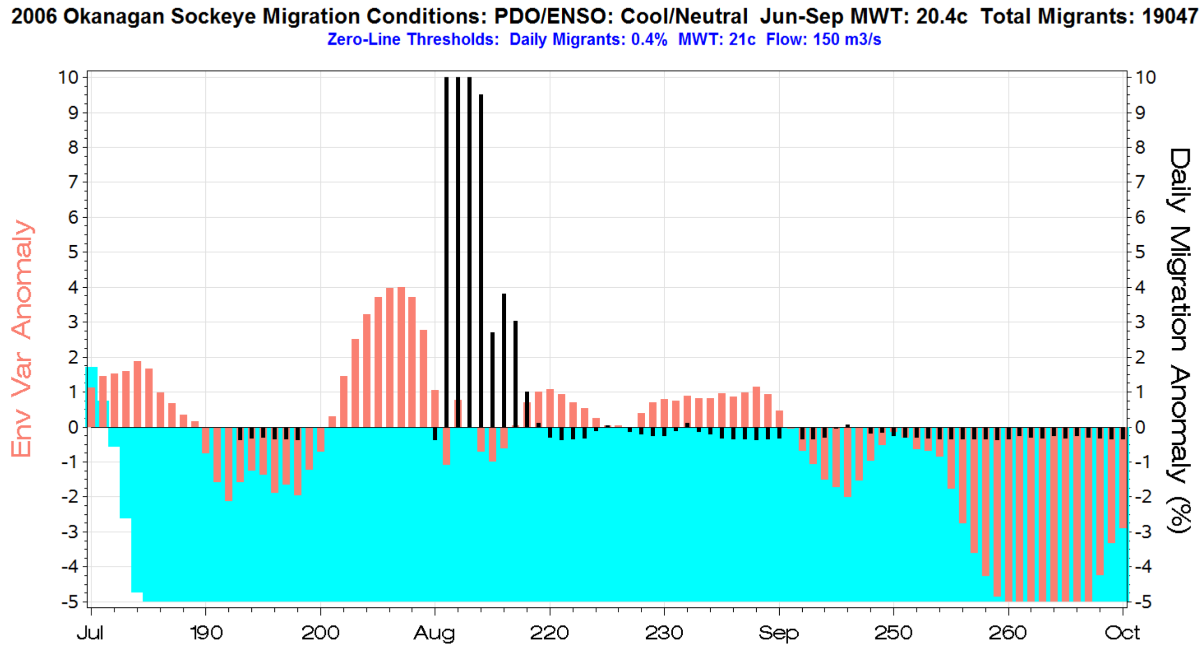


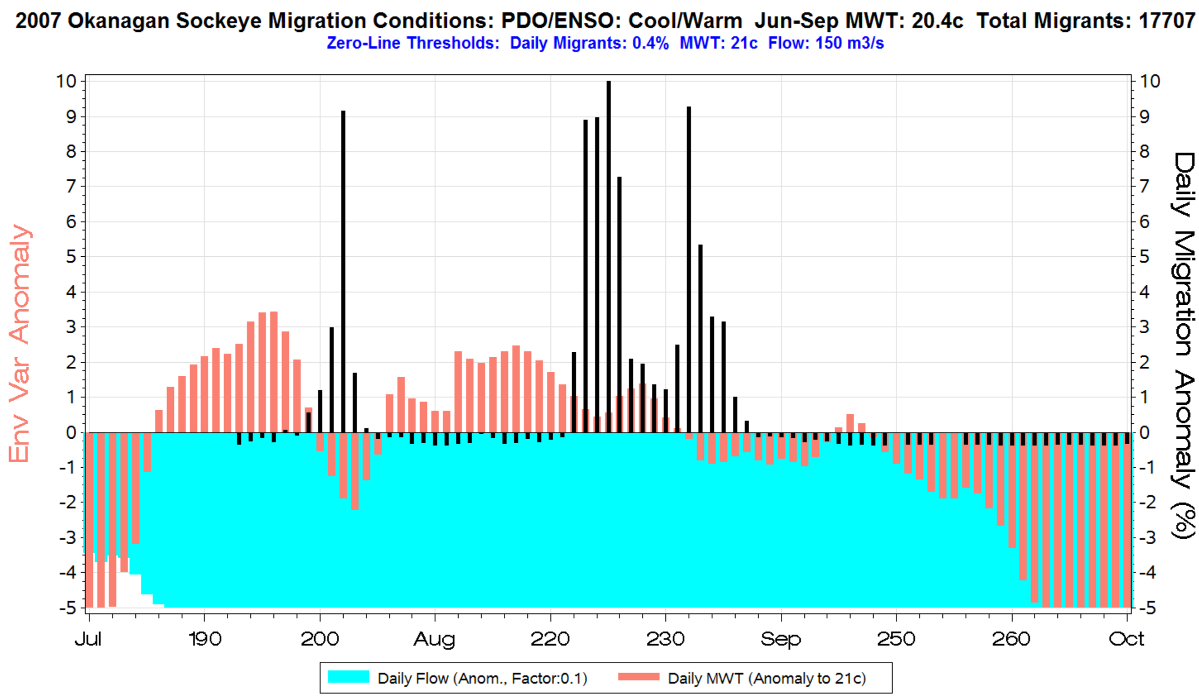

1962 Okanagan Sockeye Migration Conditions: PDO/ENSO: Cool/Neutral Jun-Sep MWT: 18.7c Total Migrants: 944
Zero-Line Thresholds: Daily Migrants: 0.4% MWT: 21c Flow: 150 m3/s
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct


1963 Okanagan Sockeye Migration Conditions: PDO/ENSO: Cool/Neutral Jun-Sep MWT: 19.0c Total Migrants: 16033
Zero-Line Thresholds: Daily Migrants: 0.4% MWT: 21c Flow: 150 m3/s
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct
Daily Flow (Anom., Factor:0.1)
Daily MWT (Anomaly to 21c)

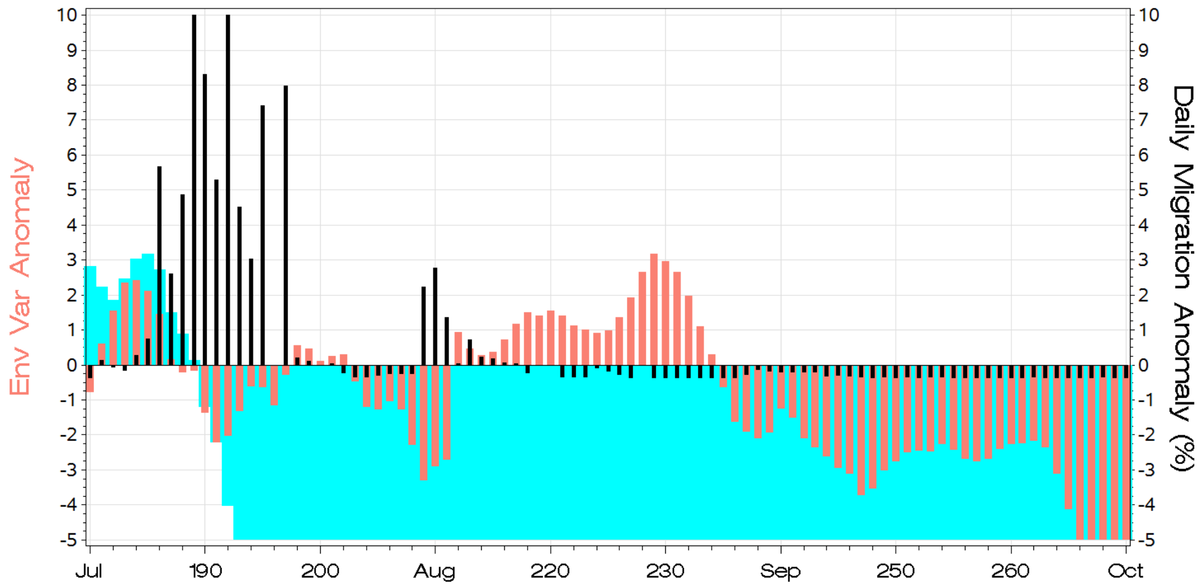

1992 Okanagan Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Jun-Sep MWT: 18.1c Total Migrants: 42232
Zero-Line Thresholds: Daily Migrants: 0.4% MWT: 21c Flow: 150 m3/s
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct


1993 Okanagan Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Jun-Sep MWT: 16.9c Total Migrants: 33018
Zero-Line Thresholds: Daily Migrants: 0.4% MWT: 21c Flow: 150 m3/s
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct
Daily Flow (Anom., Factor:0.1)
Daily MWT (Anomaly to 21c)

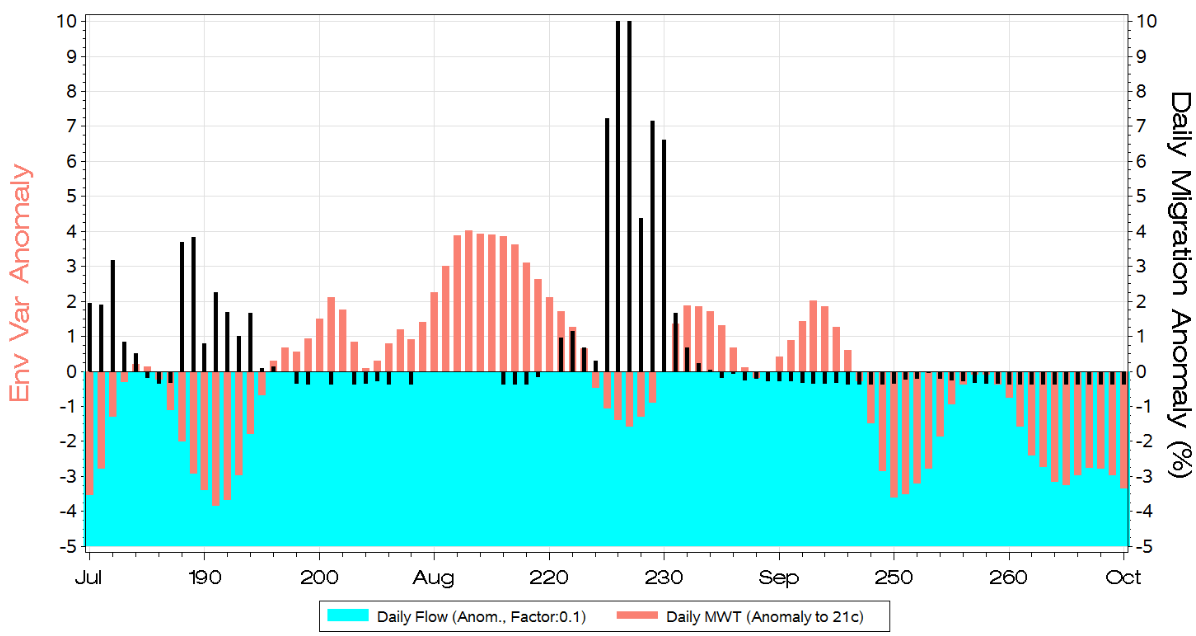

2006 Okanagan Sockeye Migration Conditions: PDO/ENSO: Cool/Neutral Jun-Sep MWT: 20.4c Total Migrants: 19047
Zero-Line Thresholds: Daily Migrants: 0.4% MWT: 21c Flow: 150 m3/s
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct


2007 Okanagan Sockeye Migration Conditions: PDO/ENSO: Cool/Warm Jun-Sep MWT: 20.4c Total Migrants: 17707
Zero-Line Thresholds: Daily Migrants: 0.4% MWT: 21c Flow: 150 m3/s
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct
Daily Flow (Anom., Factor:0.1)
Daily MWT (Anomaly to 21c)

2008 Okanagan Sockeye Migration Conditions: PDO/ENSO: Cool/Cool Jun-Sep MWT: 19.9c Total Migrants: 85429
Zero-Line Thresholds: Daily Migrants: 0.4% MWT: 21c Flow: 150 m3/s

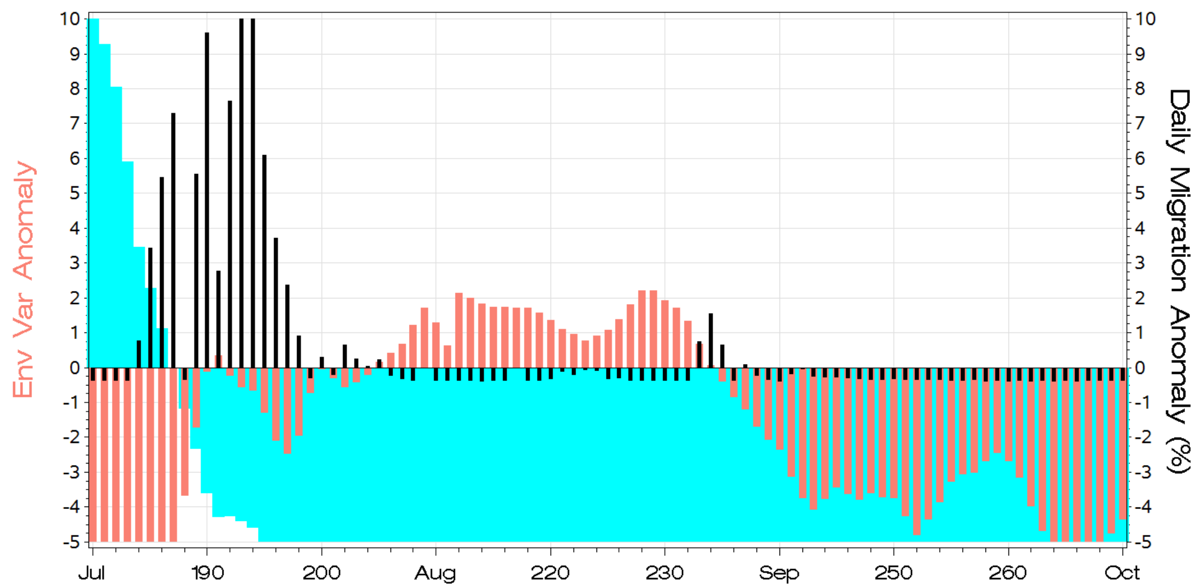


2009 Okanagan Sockeye Migration Conditions: PDO/ENSO: Cool/Neutral Jun-Sep MWT: 20.8c Total Migrants: 60970
Zero-Line Thresholds: Daily Migrants: 0.4% MWT: 21c Flow: 150 m3/s



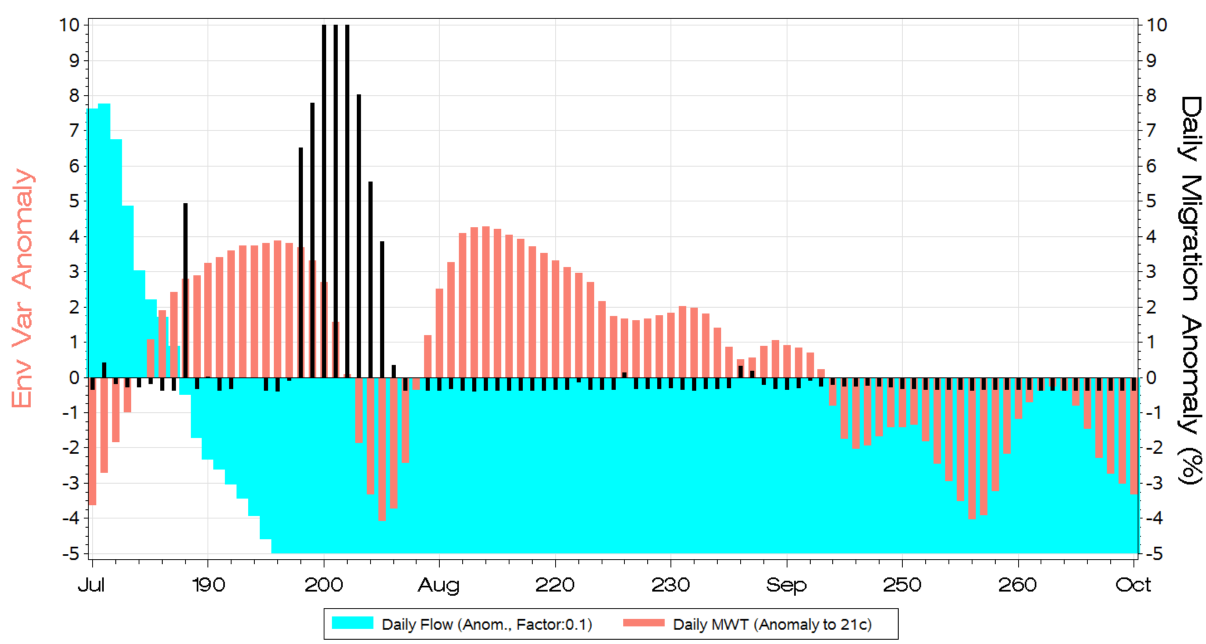
2010 Okanagan Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Jun-Sep MWT: 19.2c Total Migrants: 208311

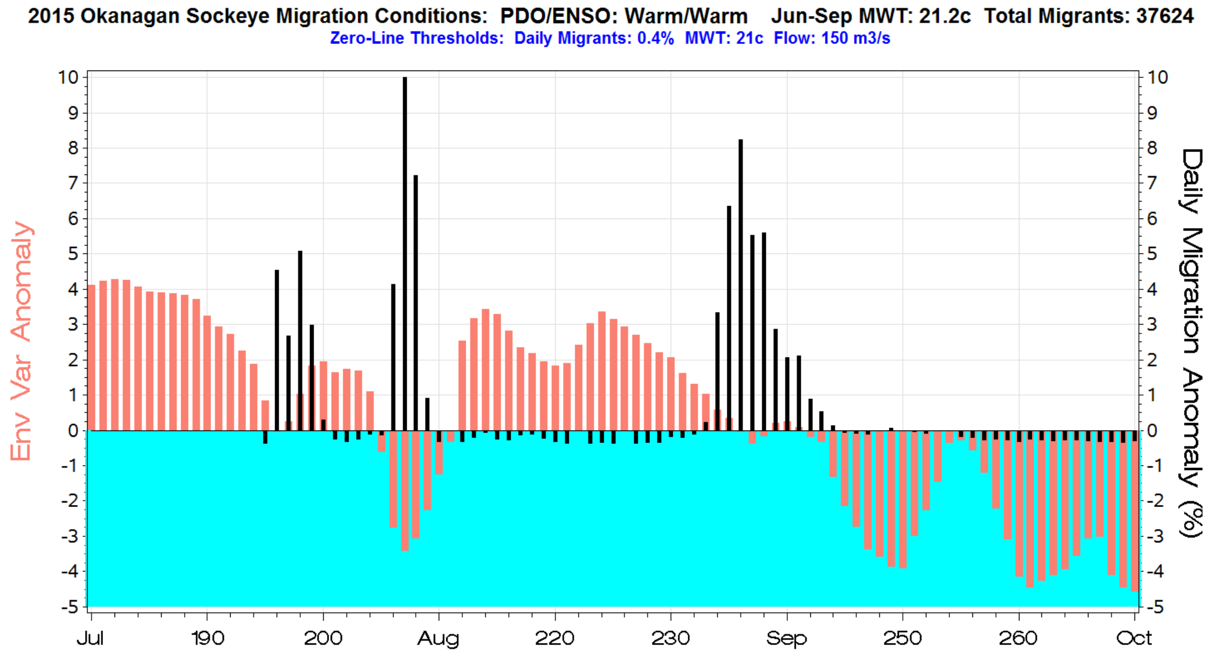
Zero-Line Thresholds: Daily Migrants: 0.4% MWT: 21c Flow: 150 m3/s

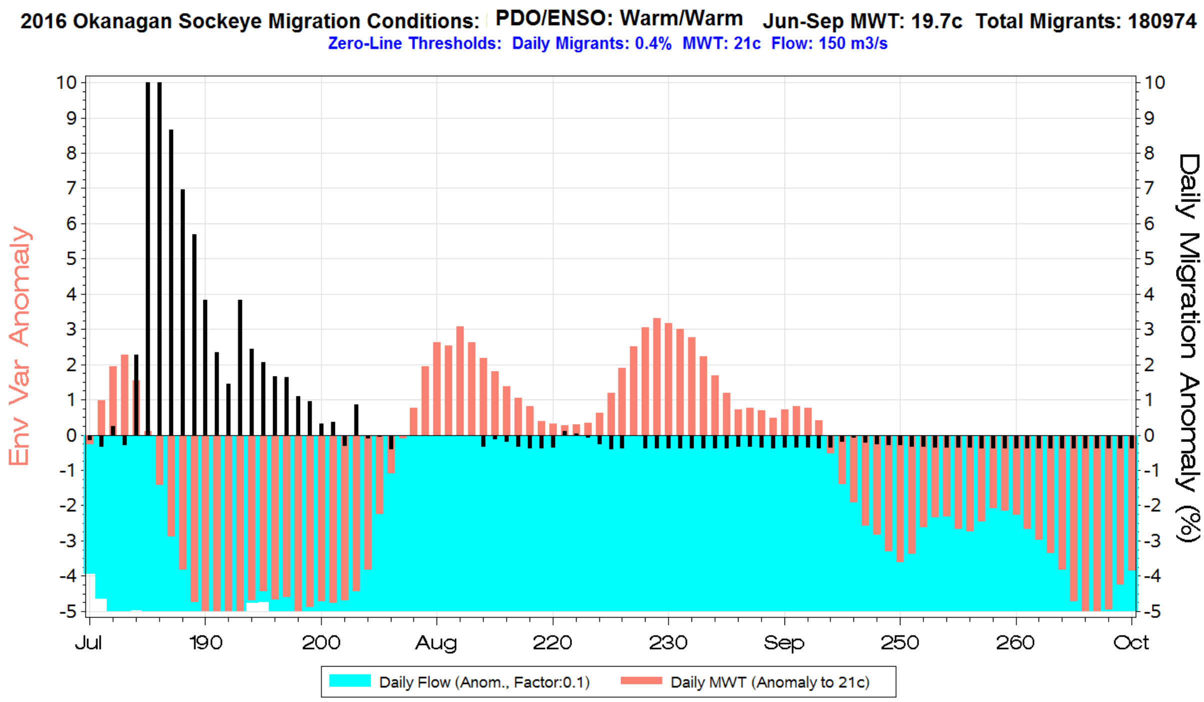


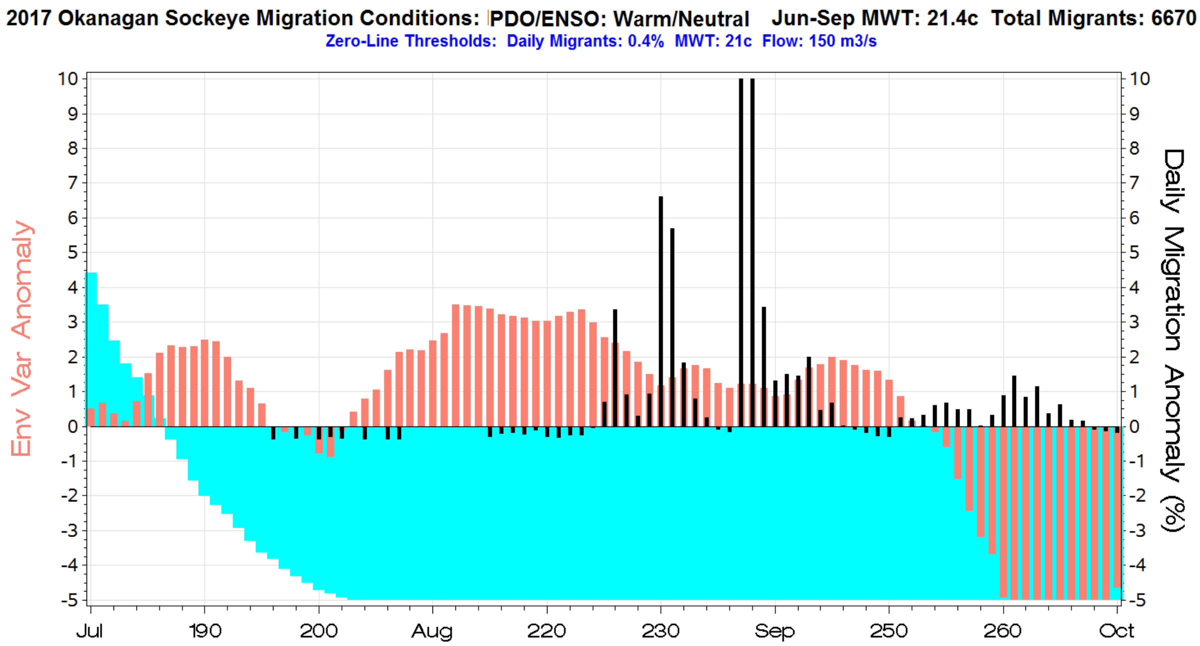
2014 Okanagan Sockeye Migration Conditions: PDO/ENSO: Warm/Neutral Jun-Sep MWT: 21.6c Total Migrants: 325278

Zero-Line Thresholds: Daily Migrants: 0.4% MWT: 21c Flow: 150 m3/s

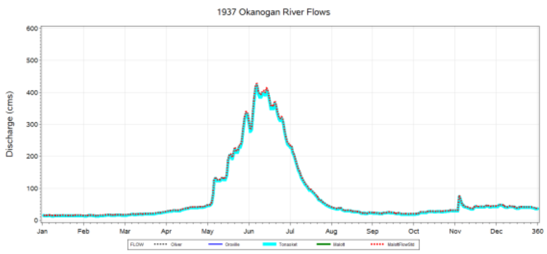


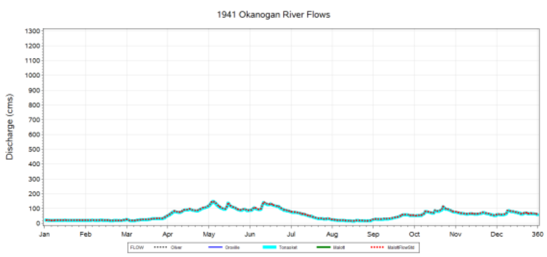

2015 Okanagan Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Jun-Sep MWT: 21.2c Total Migrants: 37624
Zero-Line Thresholds: Daily Migrants: 0.4% MWT: 21c Flow: 150 m3/s
Env Var Anomaly
Daily Migration Anomaly (%)
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
Jul
190
200
Aug
220
230
Sep
250
260
Oct

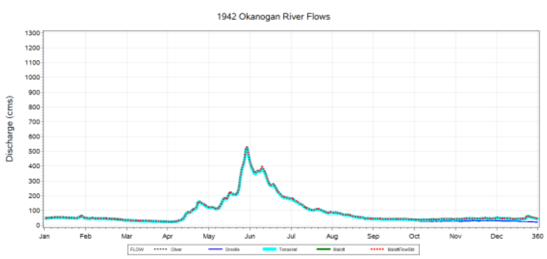

2016 Okanagan Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Jun-Sep MWT: 19.7c Total Migrants: 180974
Zero-Line Thresholds: Daily Migrants: 0.4% MWT: 21c Flow: 150 m3/s
Env Var Anomaly
Daily Migration Anomaly (%)
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
Jul
190
200
Aug
220
230
Sep
250
260
Oct
Daily Flow (Anom., Factor:0.1)
Daily MWT (Anomaly to 21c)

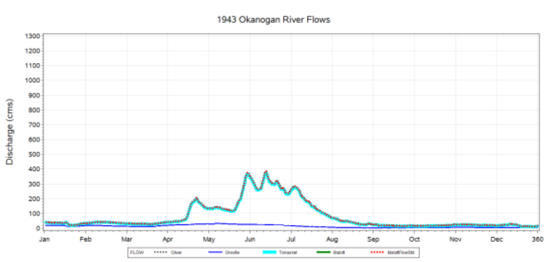

2017 Okanagan Sockeye Migration Conditions: PDO/ENSO: Warm/Neutral Jun-Sep MWT: 21.4c Total Migrants: 6670
Zero-Line Thresholds: Daily Migrants: 0.4% MWT: 21c Flow: 150 m3/s
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
250
260
Oct

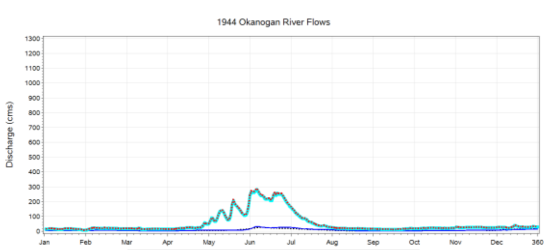
Appendix D. Daily discharge in the Okanagan watershed, by year, 1937, 1941-2012. Okanagan River at Oliver (dashed black); Okanogan River at Oroville upstream of confluence with Similkameen River (blue); Okanogan River at Tonasket (cyan); Okanogan River at Malott (green); estimated Okanogan River at Malott (dashed red).

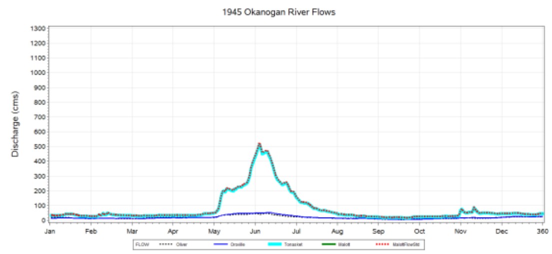


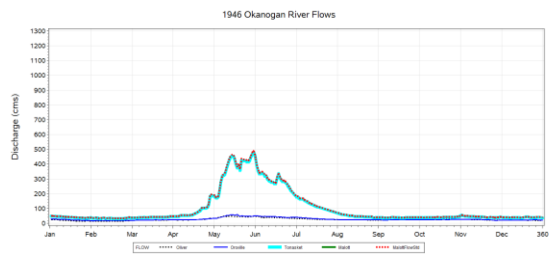


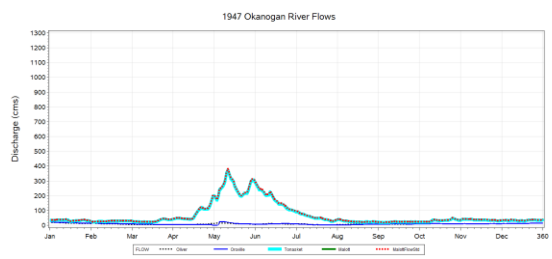


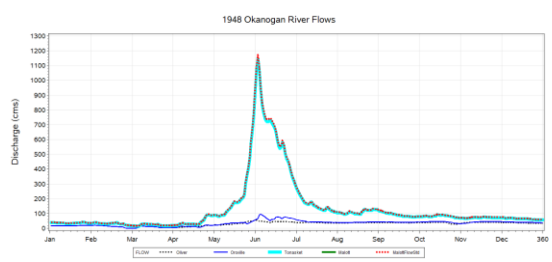


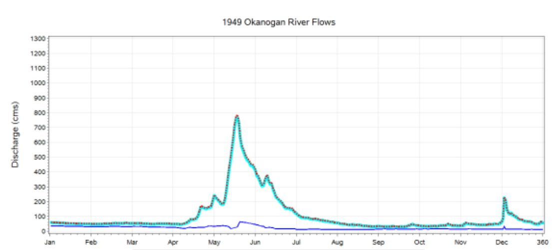


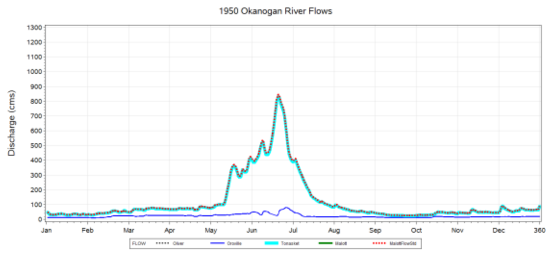


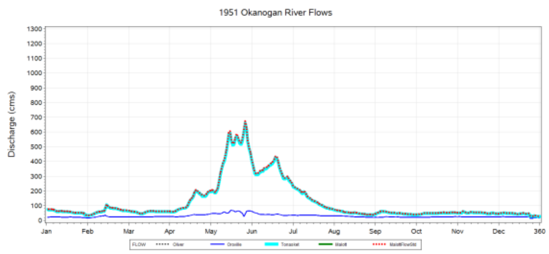


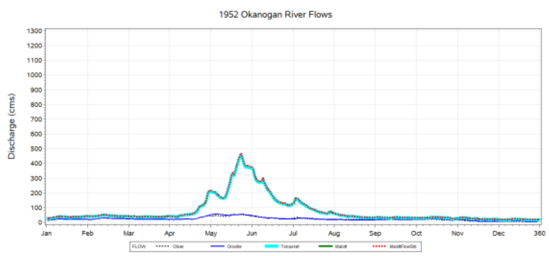


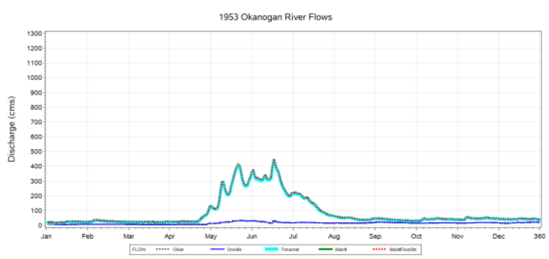


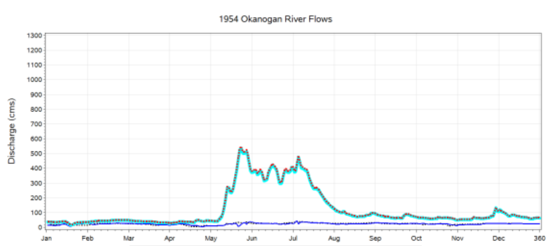


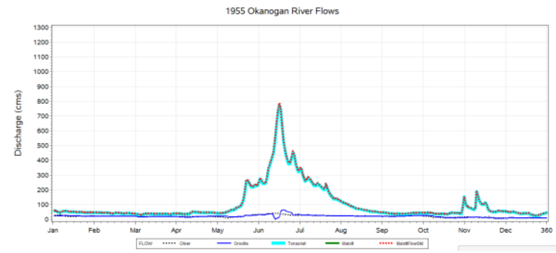

1950 Okanogan River Flows
Discharge (cms)

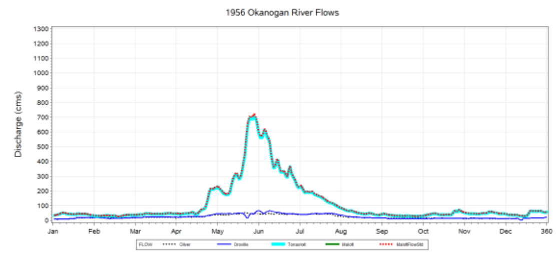

1951 Okanogan River Flows
Discharge (cms)

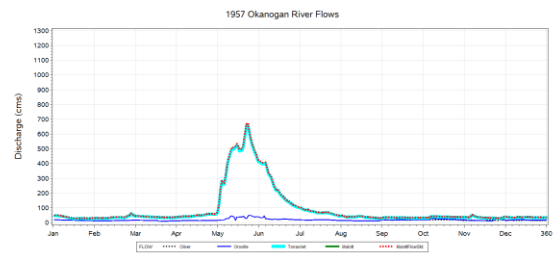

1952 Okanogan River Flows
Discharge (cms)

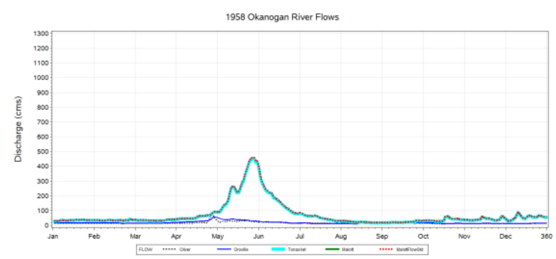

1953 Okanogan River Flows
Discharge (cms)

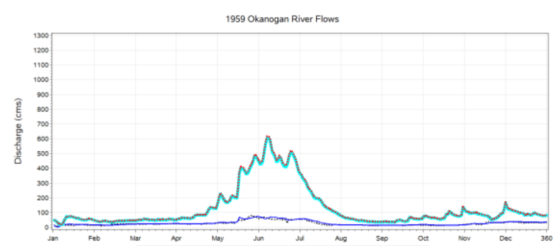

1954 Okanogan River Flows
Discharge (cms)

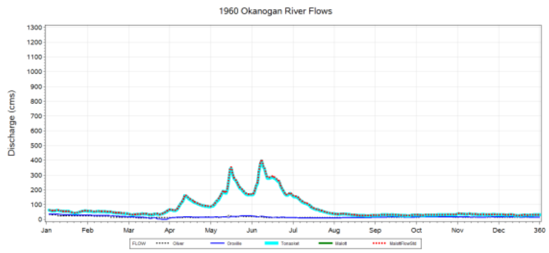

1955 Okanogan River Flows
Discharge (cms)

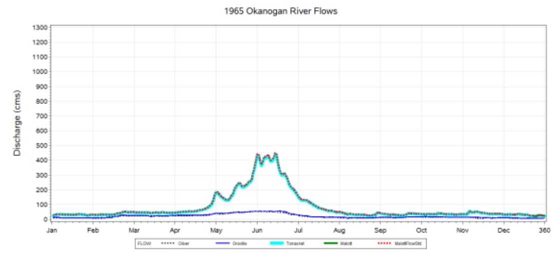

1956 Okanogan River Flows
Discharge (cms)


1957 Okanogan River Flows
Discharge (cms)


1958 Okanogan River Flows
Discharge (cms)


1959 Okanogan River Flows
Discharge (cms)


1960 Okanogan River Flows
Discharge (cms)
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360


1965 Okanogan River Flows
Discharge (cms)
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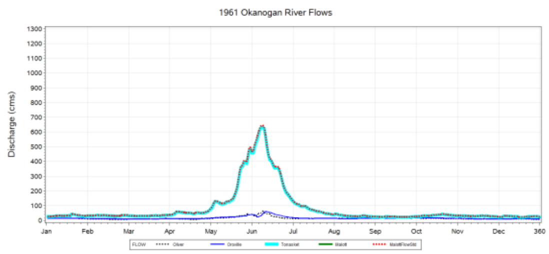
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360


1961 Okanogan River Flows
Discharge (cms)
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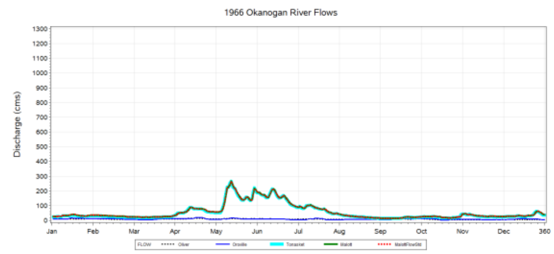
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360


1966 Okanogan River Flows
Discharge (cms)
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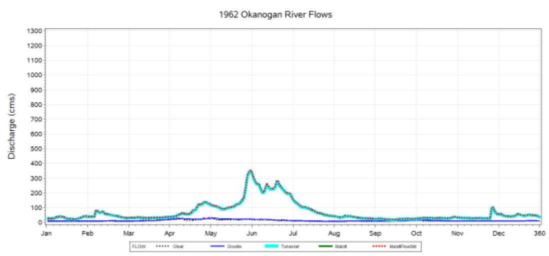
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360


1962 Okanogan River Flows
Discharge (cms)
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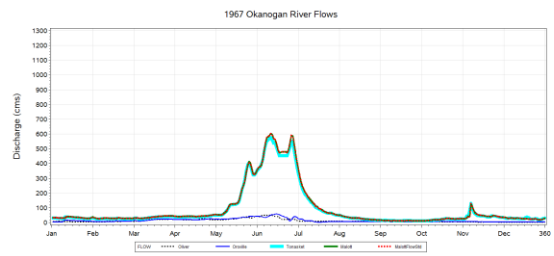
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360


1967 Okanogan River Flows
Discharge (cms)
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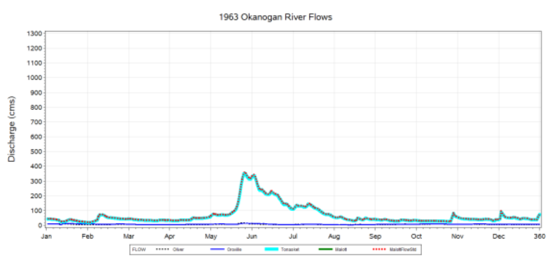
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360


1963 Okanogan River Flows
Discharge (cms)
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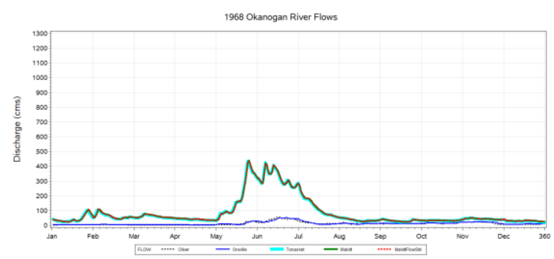
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360


1968 Okanogan River Flows
Discharge (cms)
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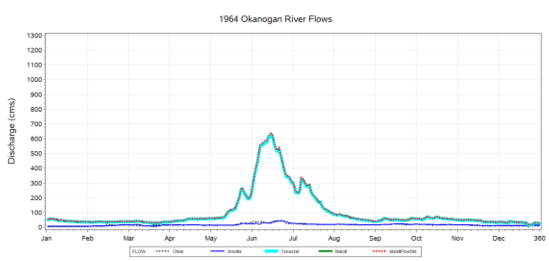
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360


1964 Okanogan River Flows
Discharge (cms)
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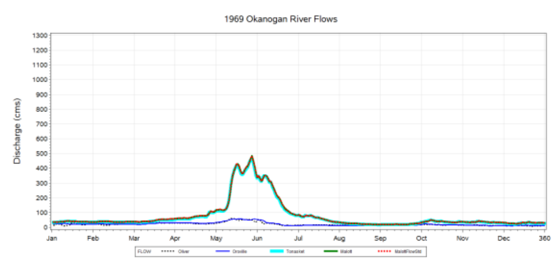
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360


1969 Okanogan River Flows
Discharge (cms)
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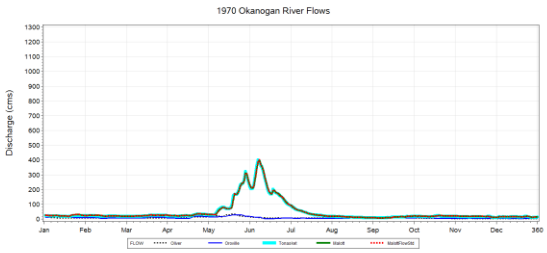
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360


1970 Okanogan River Flows
Discharge (cms)
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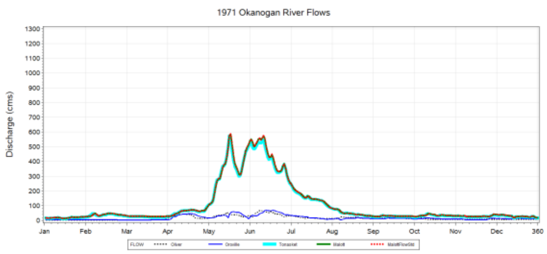
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360
FLOW Oliver Oroville Tonasket Malott MalottFlowStd


1971 Okanogan River Flows
Discharge (cms)
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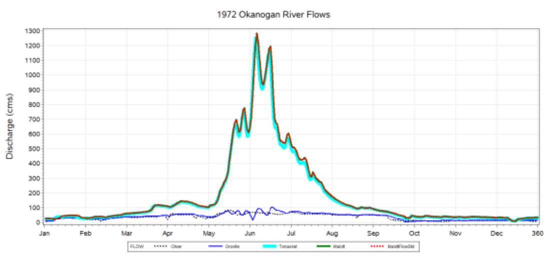
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360
FLOW Oliver Oroville Tonasket Malott MalottFlowStd


1972 Okanogan River Flows
Discharge (cms)
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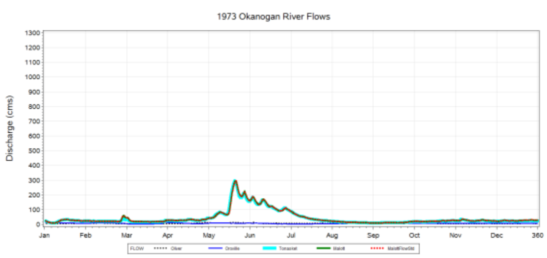
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360
FLOW Oliver Oroville Tonasket Malott MalottFlowStd


1973 Okanogan River Flows
Discharge (cms)
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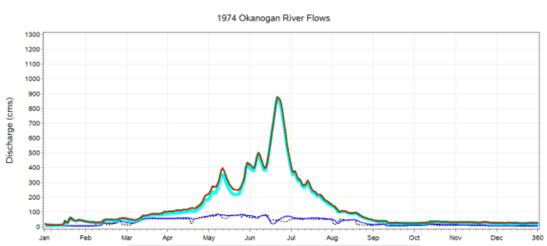
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360
FLOW Oliver Oroville Tonasket Malott MalottFlowStd


1974 Okanogan River Flows
Discharge (cms)
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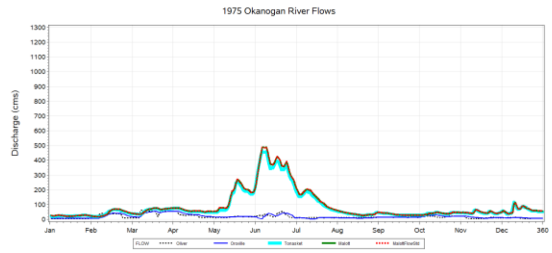
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360
FLOW Oliver Oroville Tonasket Malott MalottFlowStd


1975 Okanogan River Flows
Discharge (cms)
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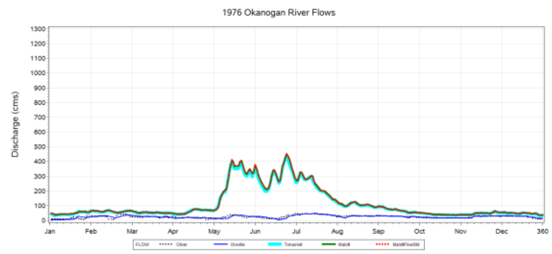
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360
FLOW Oliver Oroville Tonasket Malott MalottFlowStd


1976 Okanogan River Flows
Discharge (cms)
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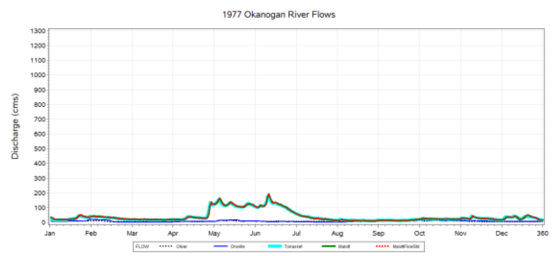
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360
FLOW Oliver Oroville Tonasket Malott MalottFlowStd


1977 Okanogan River Flows
Discharge (cms)
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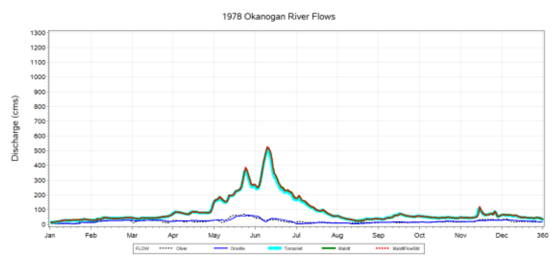
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360
FLOW Oliver Oroville Tonasket Malott MalottFlowStd


1978 Okanogan River Flows
Discharge (cms)
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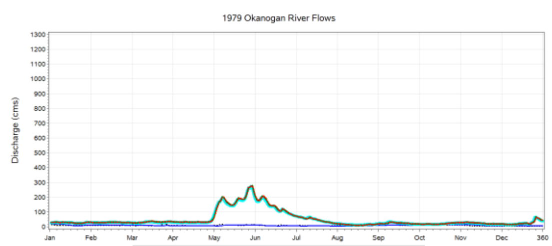
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360
FLOW Oliver Oroville Tonasket Malott MalottFlowStd


1979 Okanogan River Flows
Discharge (cms)
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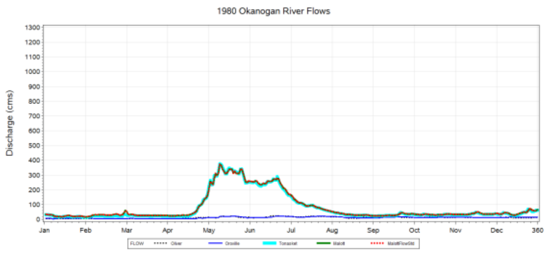
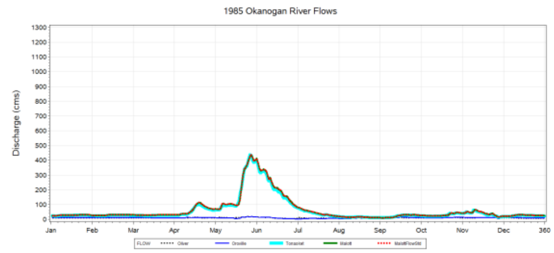
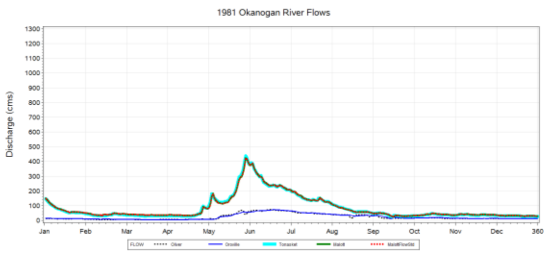
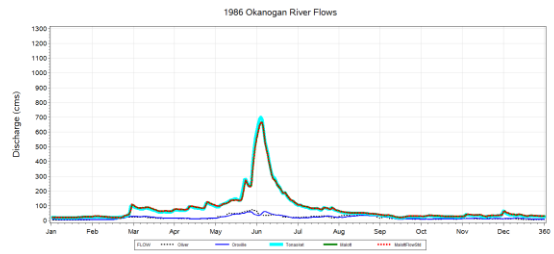
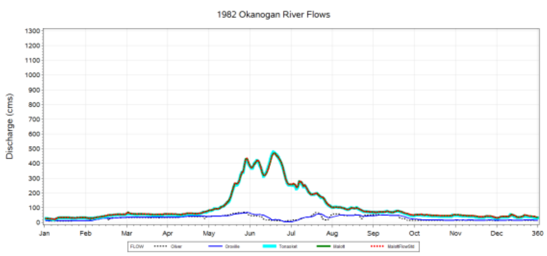
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360
FLOW Oliver Oroville Tonasket Malott MalottFlowStd

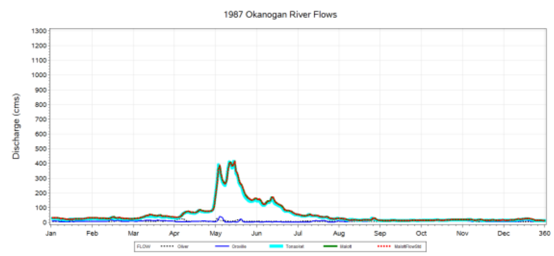

1980 Okanogan River Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

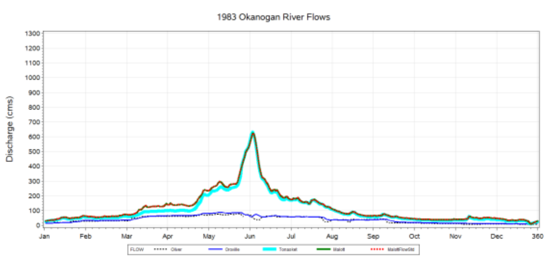

1985 Okanogan River Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

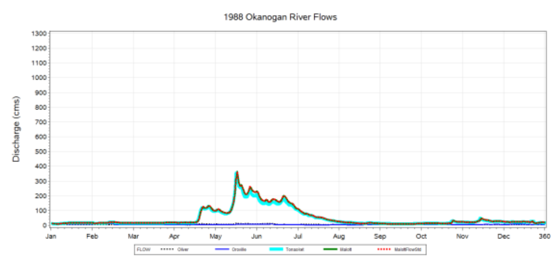

1981 Okanogan River Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

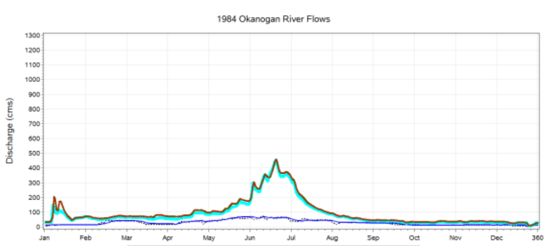

1986 Okanogan River Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

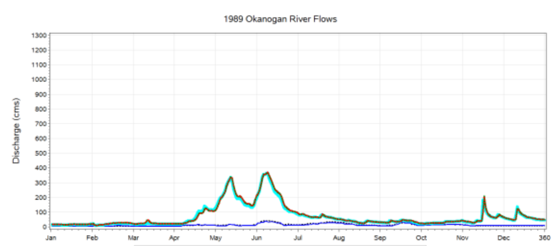

1982 Okanogan River Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

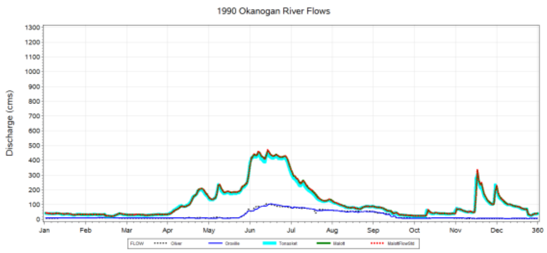

1987 Okanogan River Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

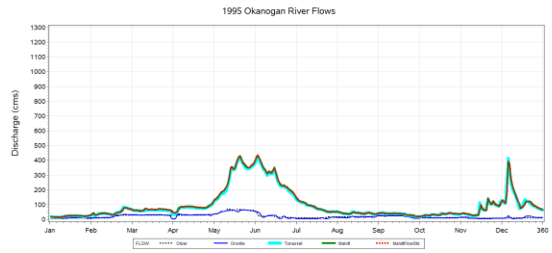

1983 Okanogan River Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

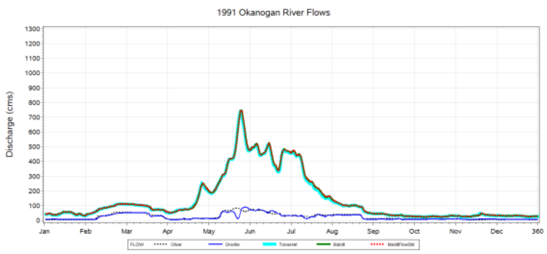

1988 Okanogan River Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

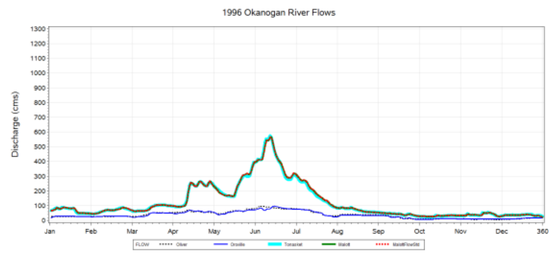

1984 Okanogan River Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

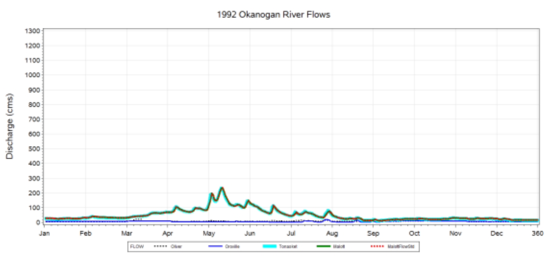

1989 Okanogan River Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

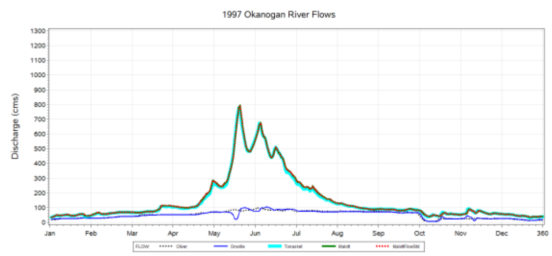

1990 Okanogan River Flows
Discharge (cms)

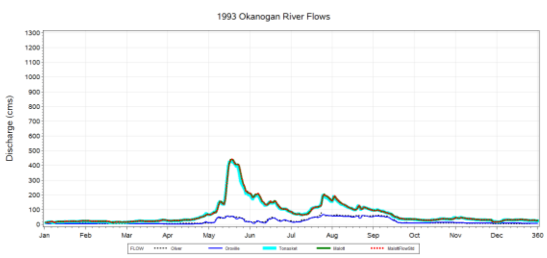

1995 Okanogan River Flows
Discharge (cms)

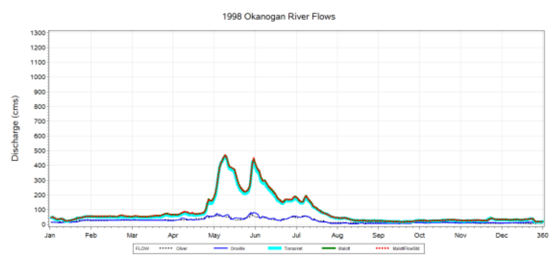

1991 Okanogan River Flows
Discharge (cms)

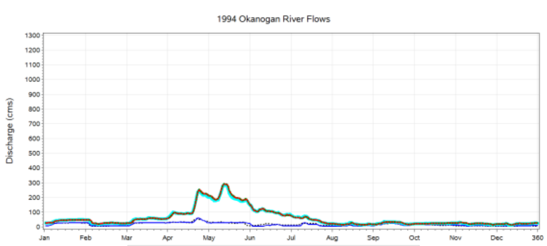

1996 Okanogan River Flows
Discharge (cms)

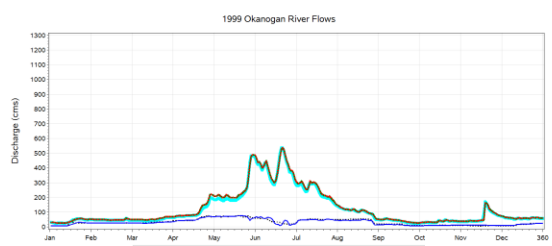

1992 Okanogan River Flows
Discharge (cms)

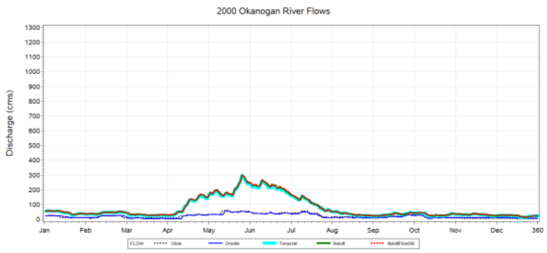

1997 Okanogan River Flows
Discharge (cms)

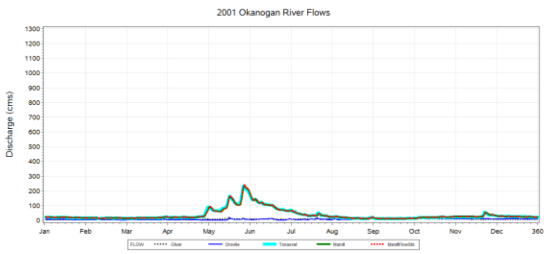

1993 Okanogan River Flows
Discharge (cms)

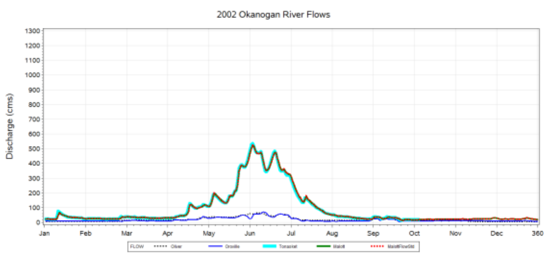

1998 Okanogan River Flows
Discharge (cms)

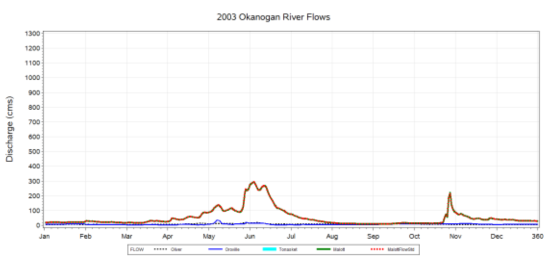

1994 Okanogan River Flows
Discharge (cms)

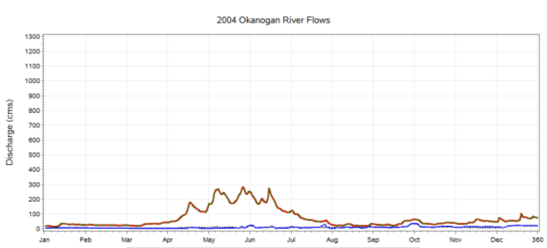

1999 Okanogan River Flows
Discharge (cms)

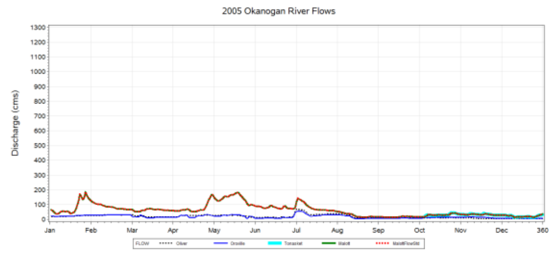

2000 Okanogan River Flows
Discharge (cms)
FLOW Oliver Oroville Tonasket Malott MalottFlowStd

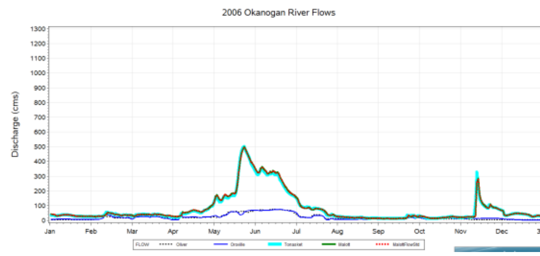

2001 Okanogan River Flows
Discharge (cms)

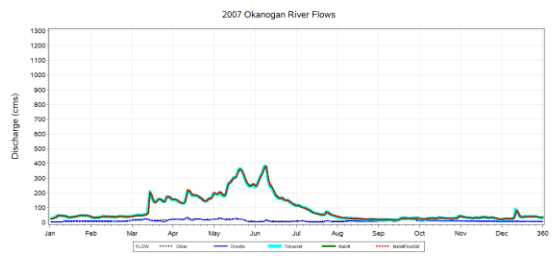

2002 Okanogan River Flows
Discharge (cms)

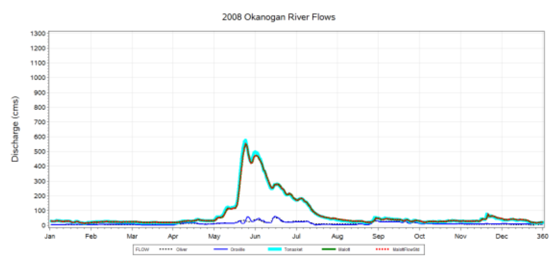

2003 Okanogan River Flows
Discharge (cms)

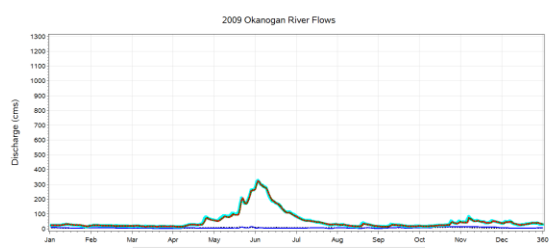

2004 Okanogan River Flows
Discharge (cms)

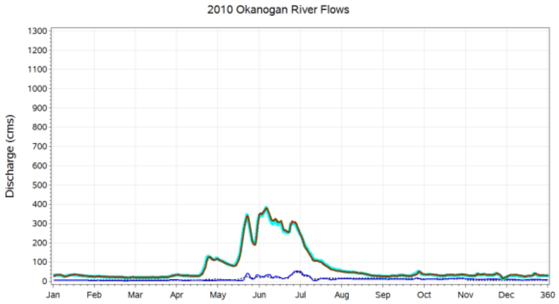

2005 Okanogan River Flows
Discharge (cms)

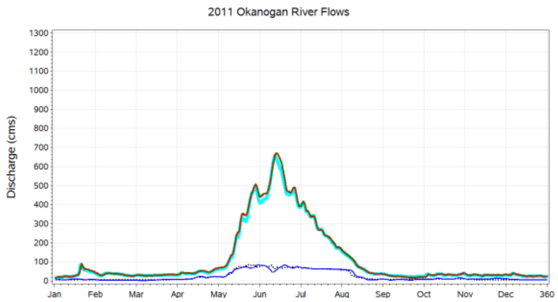

2006 Okanogan River Flows
Discharge (cms)

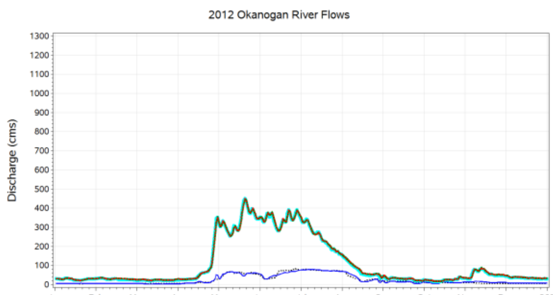

2007 Okanogan River Flows
Discharge (cms)

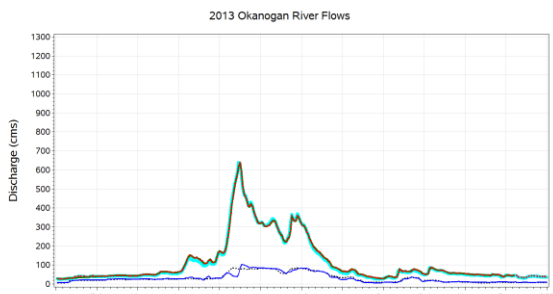

2008 Okanogan River Flows
Discharge (cms)

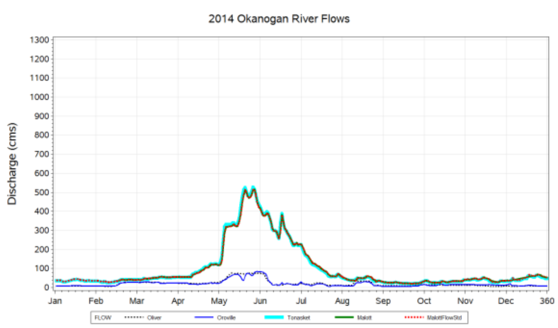

2009 Okanogan River Flows
Discharge (cms)

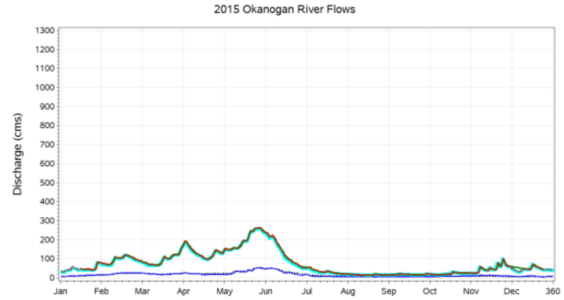

2010 Okanogan River Flows
Discharge (cms)

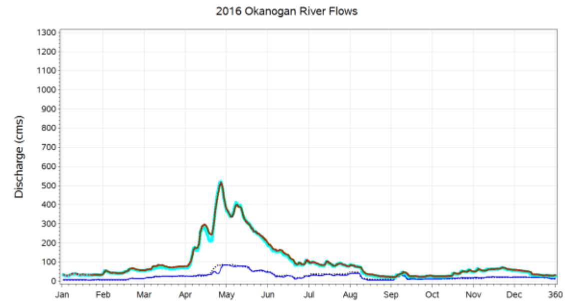

2011 Okanogan River Flows
Discharge (cms)

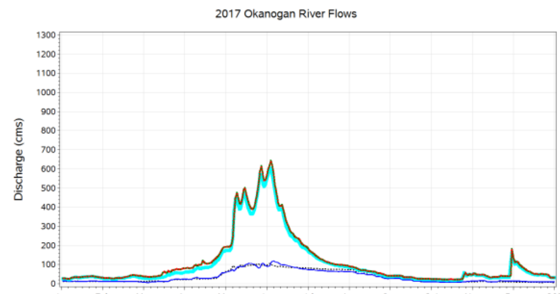

2012 Okanogan River Flows
Discharge (cms)

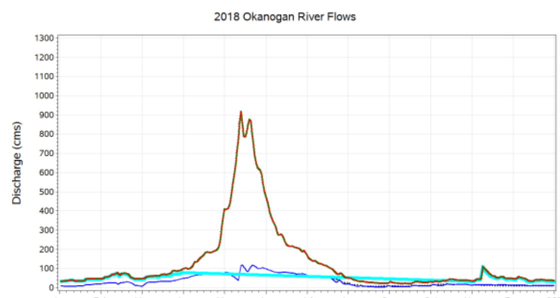

2013 Okanogan River Flows
Discharge (cms)

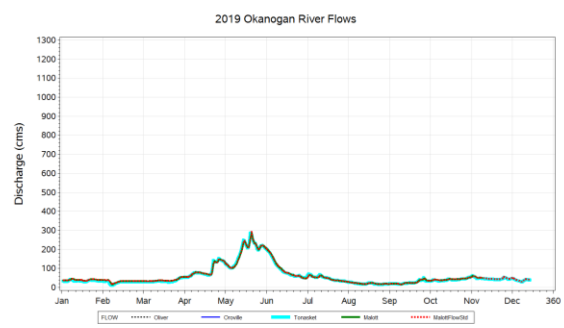

2014 Okanogan River Flows
Discharge (cms)
FLOW
Oliver
Oroville
Tonasket
Malott
MalottFlowStd


2015 Okanogan River Flows
Discharge (cms)

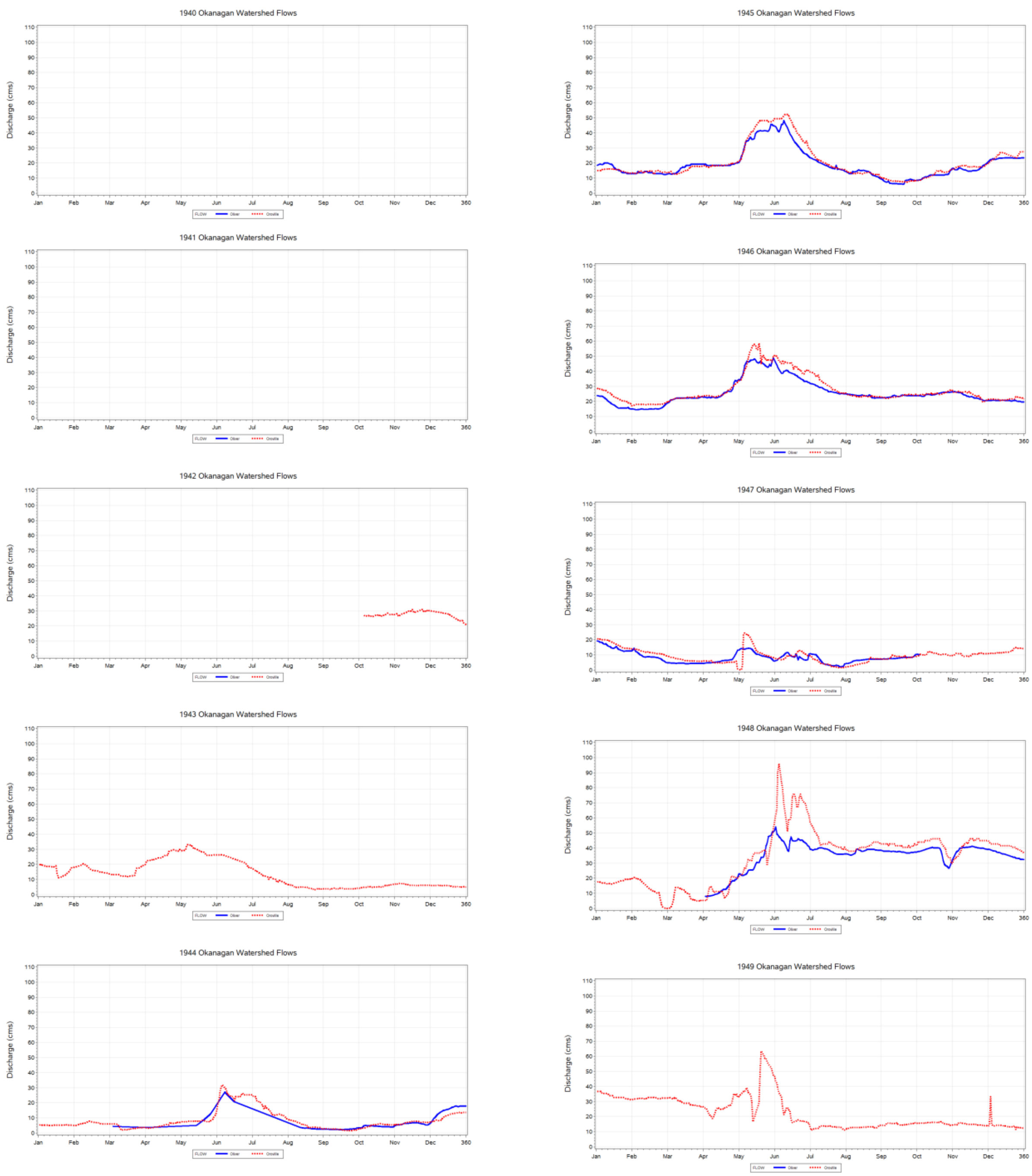

2016 Okanogan River Flows
Discharge (cms)

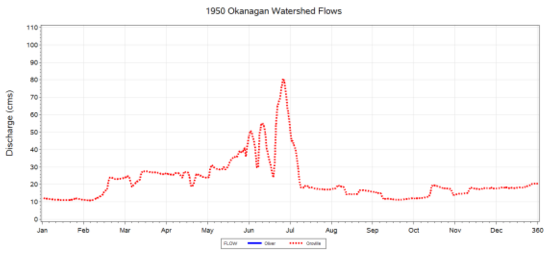

2017 Okanogan River Flows
Discharge (cms)

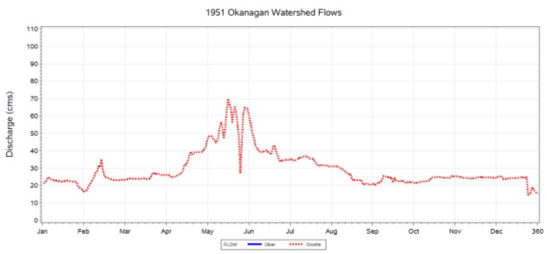

2018 Okanogan River Flows
Discharge (cms)

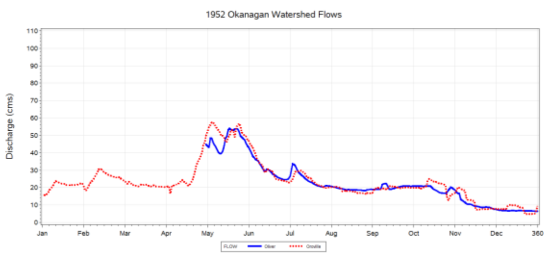

2019 Okanogan River Flows
Discharge (cms)
FLOW
Oliver
Oroville
Tonasket
Malott
MalottFlowStd

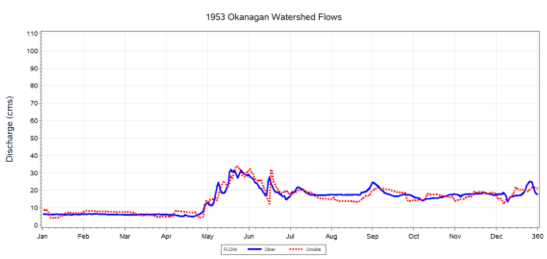
Appendix E. Daily discharge in the Okanagan watershed, by year, 1940-2012.
Okanagan River at Oliver (blue); Okanogan River at Oroville, upstream of confluence with Similkameen River (red).

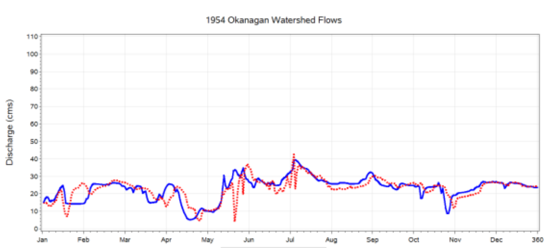


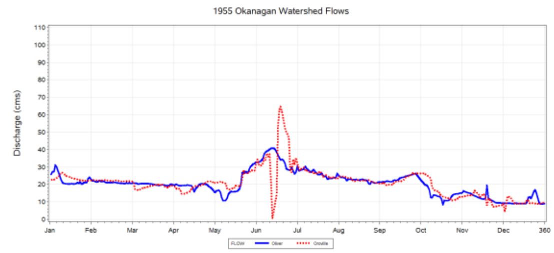

1950 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

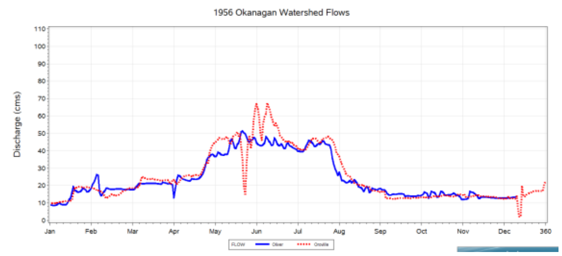

1951 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

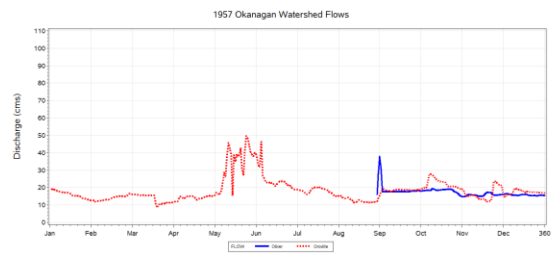

1952 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

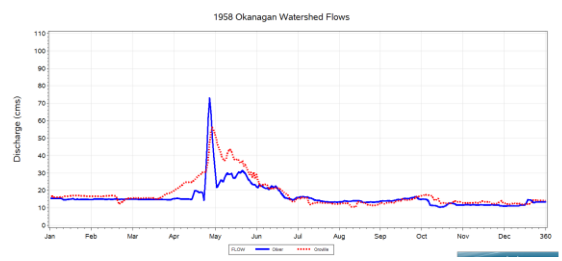

1953 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

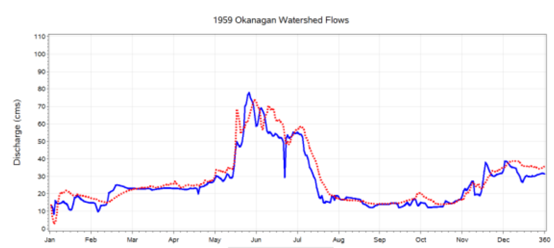

1954 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

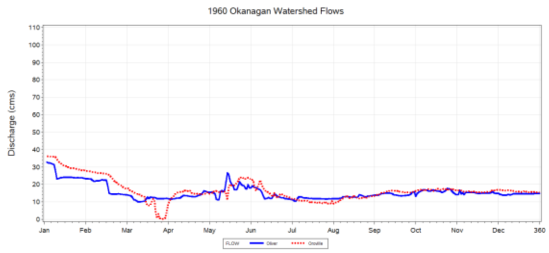

1955 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

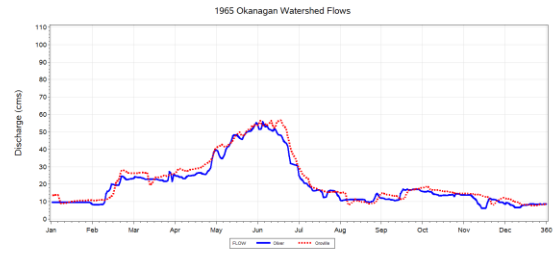

1956 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

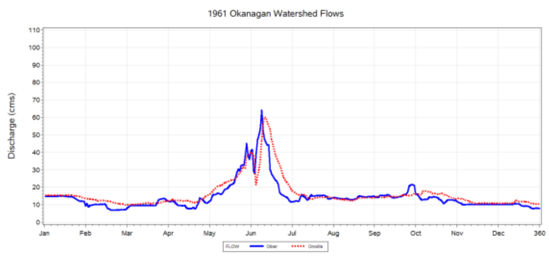

1957 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

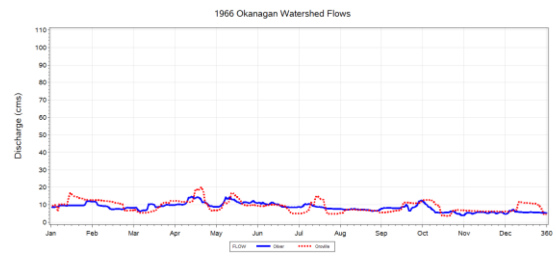

1958 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

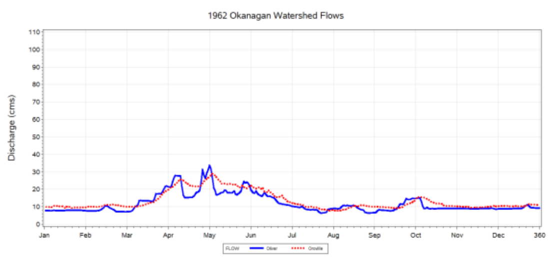

1959 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

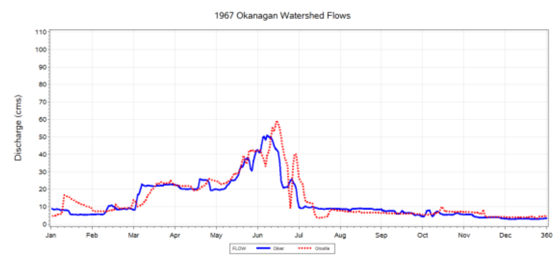

1960 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

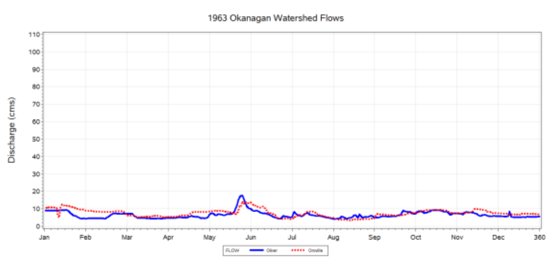

1965 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

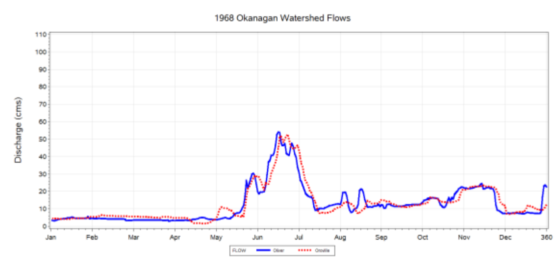

1961 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

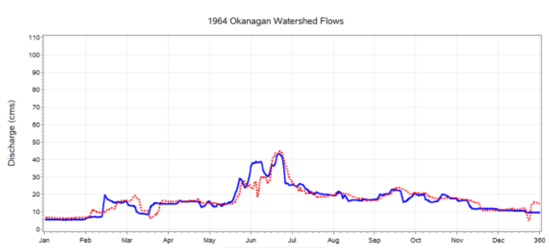

1966 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

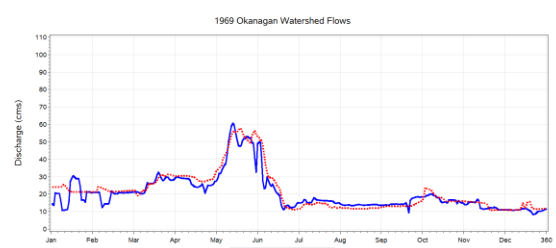

1962 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360


1967 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360


1963 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360


1968 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360


1964 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360


1969 Okanagan Watershed Flows
Discharge (cms)
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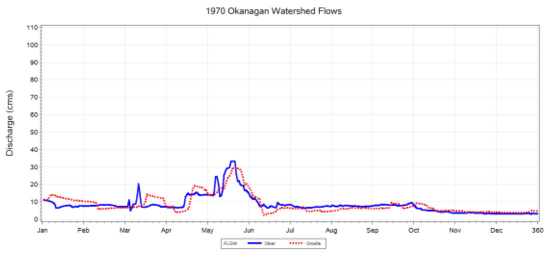
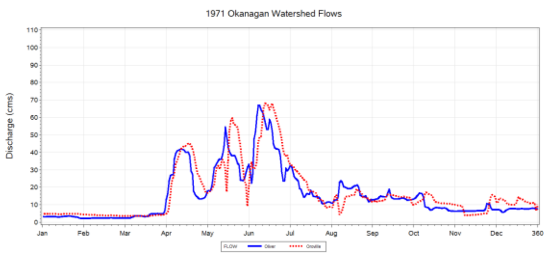

1970 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360


1971 Okanagan Watershed Flows
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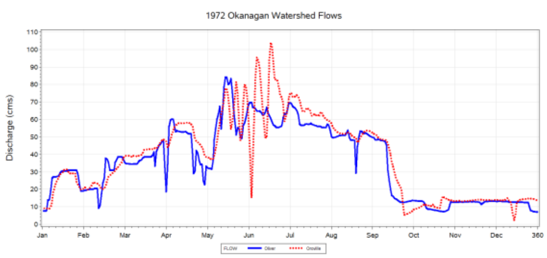
1972 Okanagan Watershed Flows
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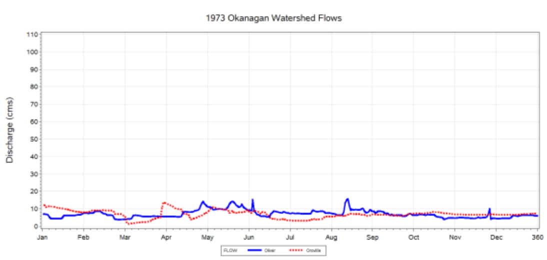
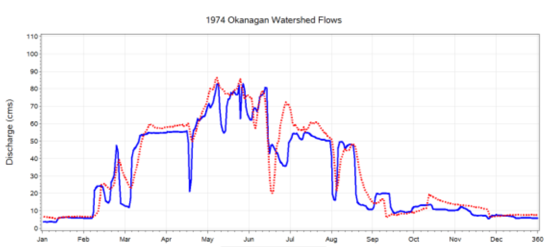

1973 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360


1974 Okanagan Watershed Flows
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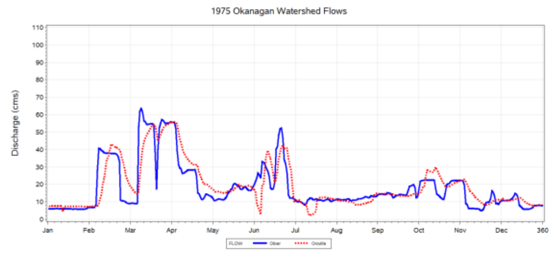
1975 Okanagan Watershed Flows
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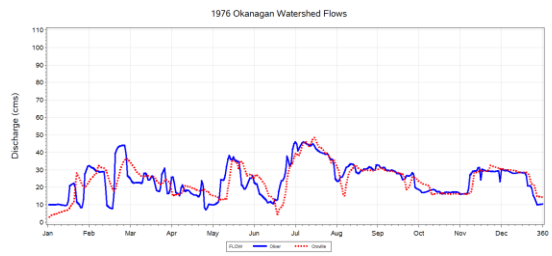
1976 Okanagan Watershed Flows
Discharge (cms)
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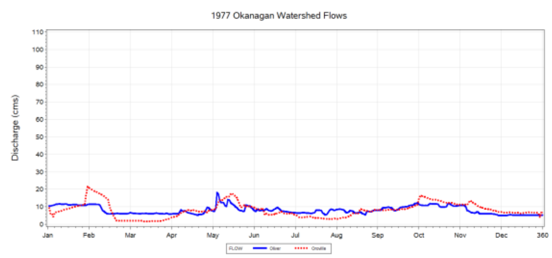
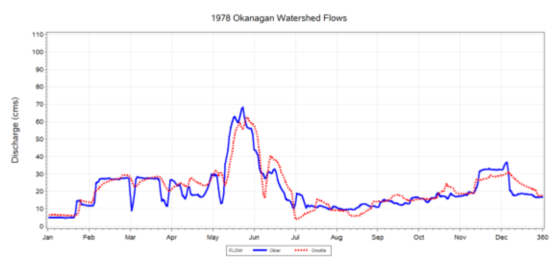
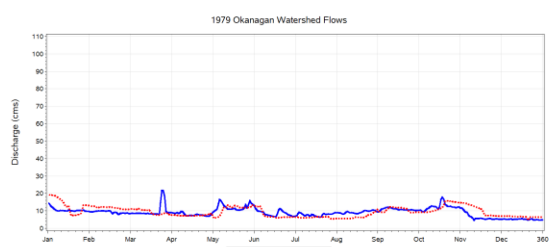
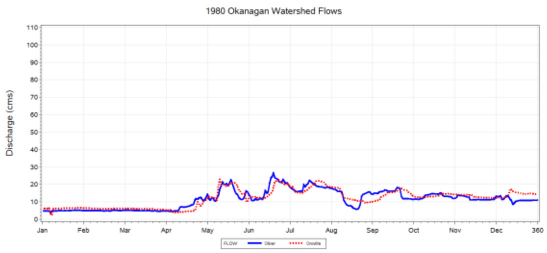
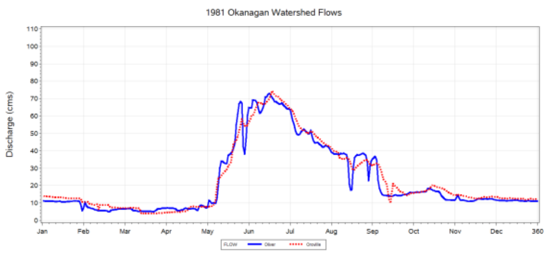
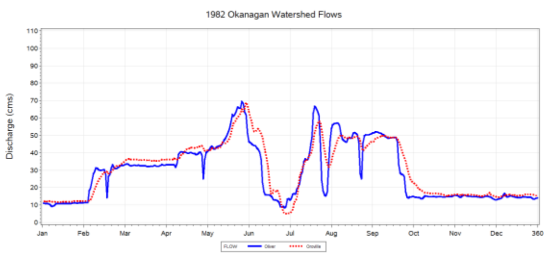

1977 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

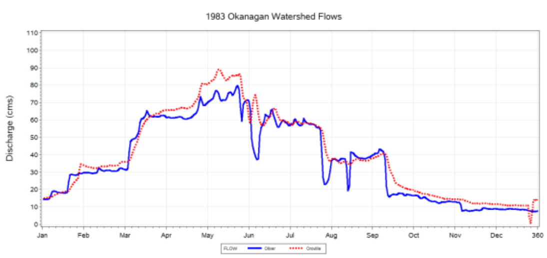

1978 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

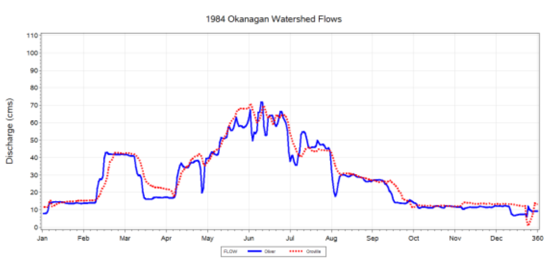

1979 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

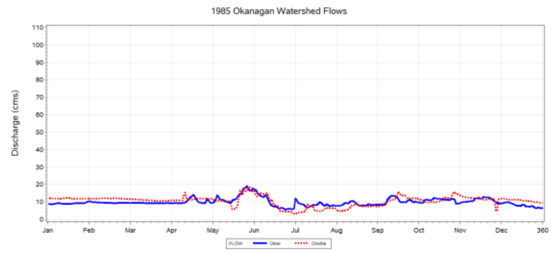

1980 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

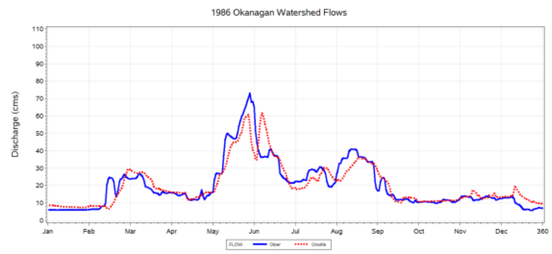

1981 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

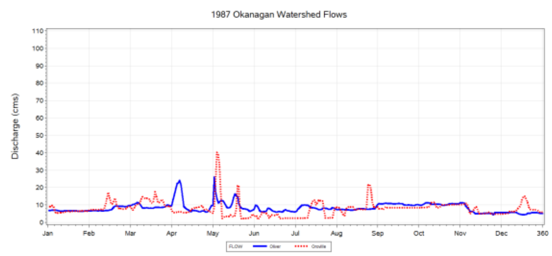

1982 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

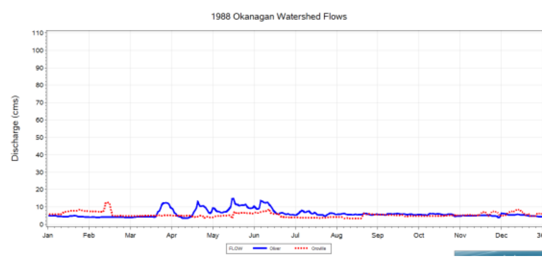

1983 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

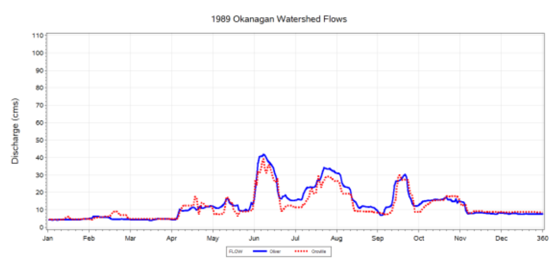

1984 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

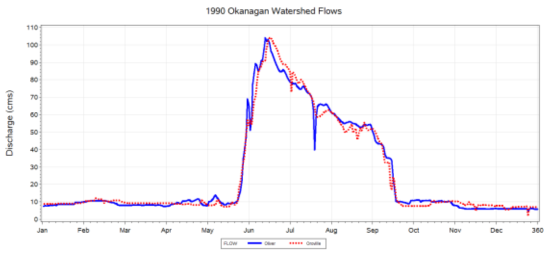

1985 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

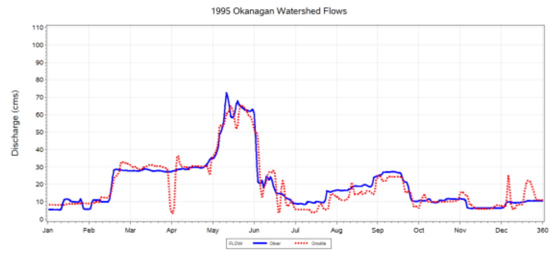

1986 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

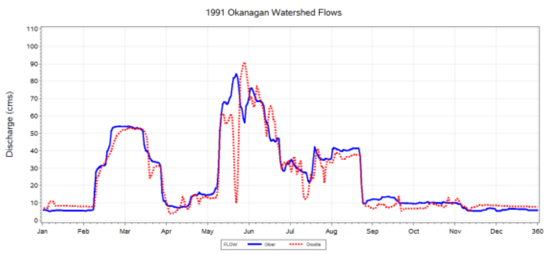

1987 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

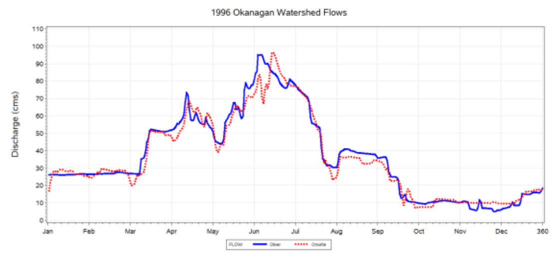

1988 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

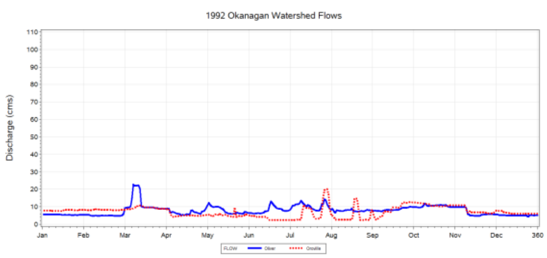

1989 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

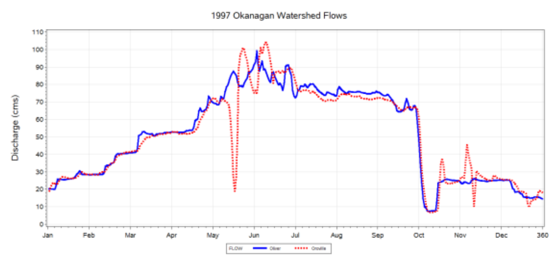

1990 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

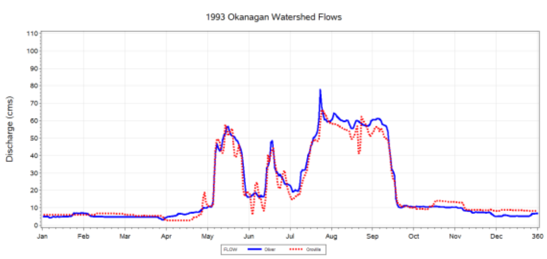

1995 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

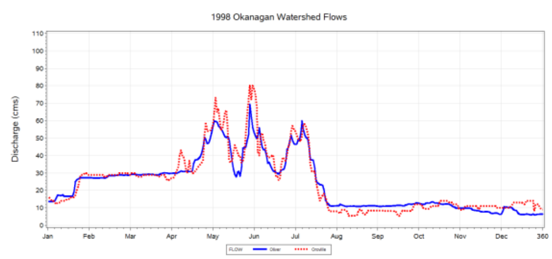

1991 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

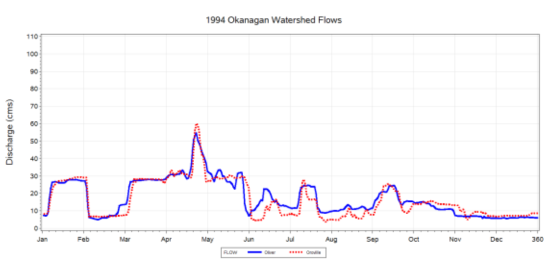

1996 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

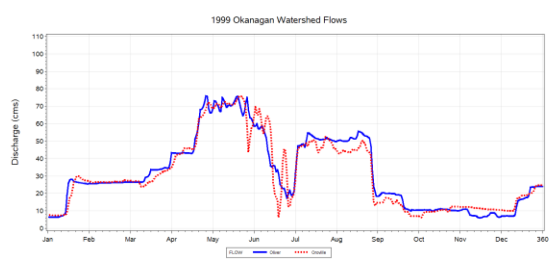

1992 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

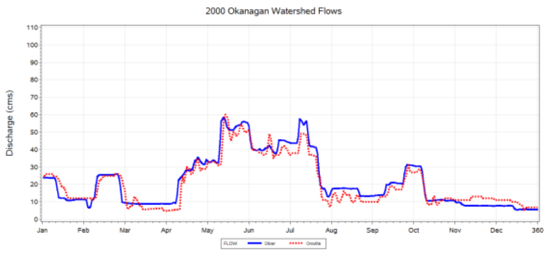

1997 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

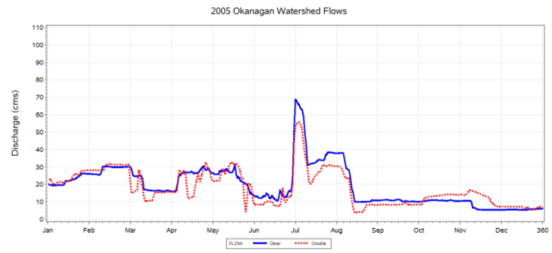

1993 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

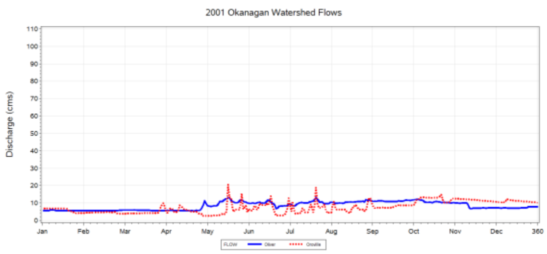

1998 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

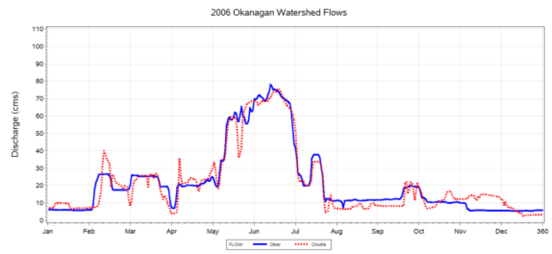

1994 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

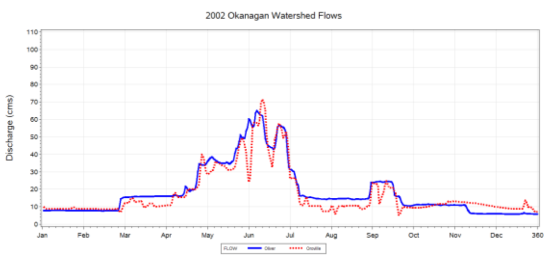

1999 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

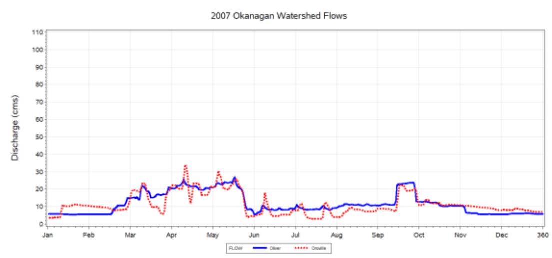

2000 Okanagan Watershed Flows
Discharge (cms)

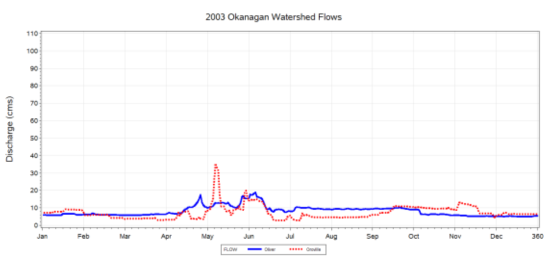

2005 Okanagan Watershed Flows
Discharge (cms)

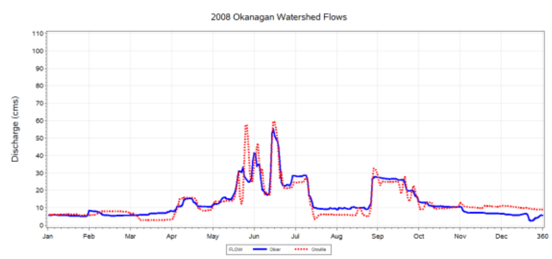

2001 Okanagan Watershed Flows
Discharge (cms)

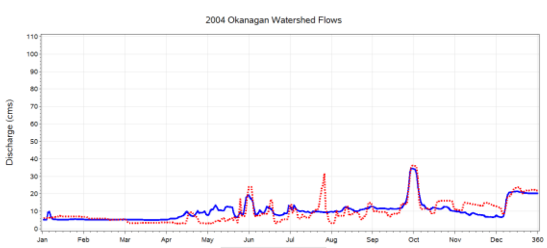

2006 Okanagan Watershed Flows
Discharge (cms)

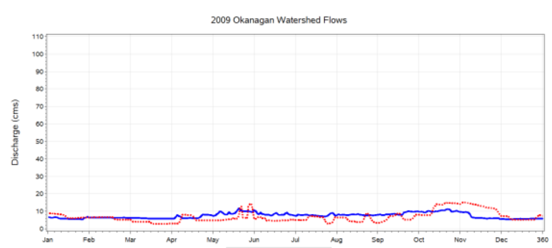

2002 Okanagan Watershed Flows
Discharge (cms)

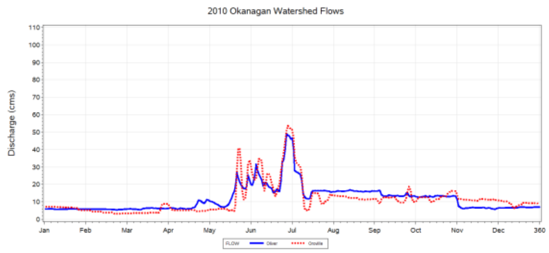

2007 Okanagan Watershed Flows
Discharge (cms)

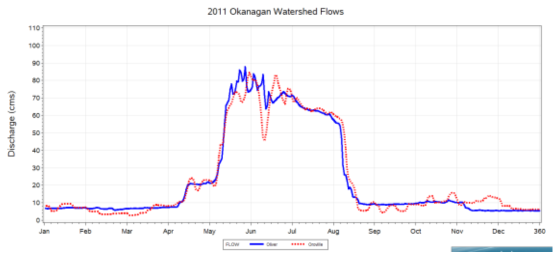

2003 Okanagan Watershed Flows
Discharge (cms)

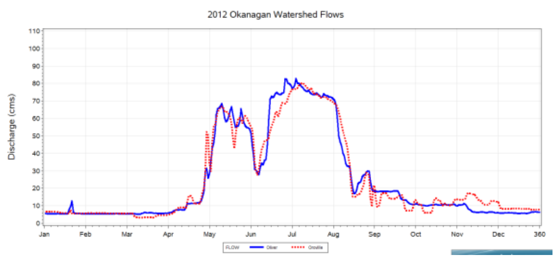

2008 Okanagan Watershed Flows
Discharge (cms)

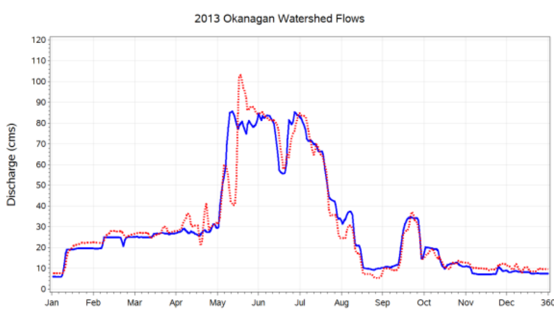

2004 Okanagan Watershed Flows
Discharge (cms)

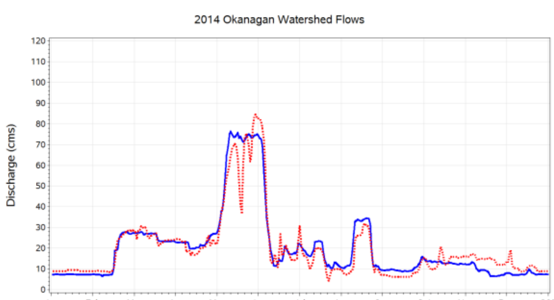

2009 Okanagan Watershed Flows
Discharge (cms)

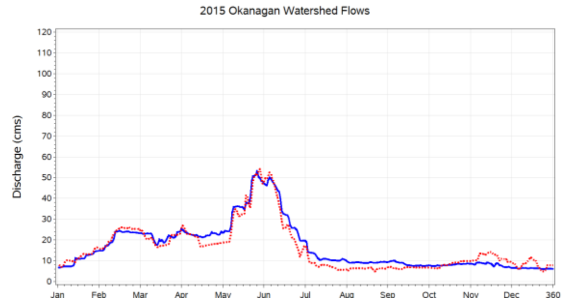

2010 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

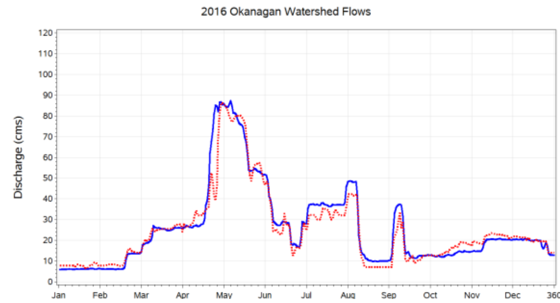

2011 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

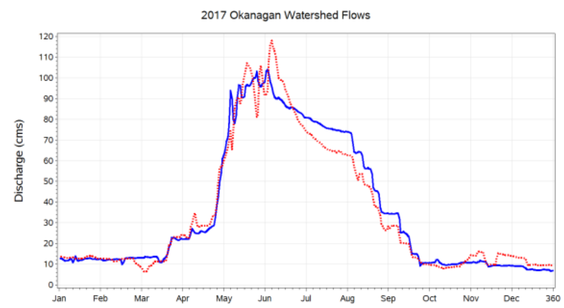

2012 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

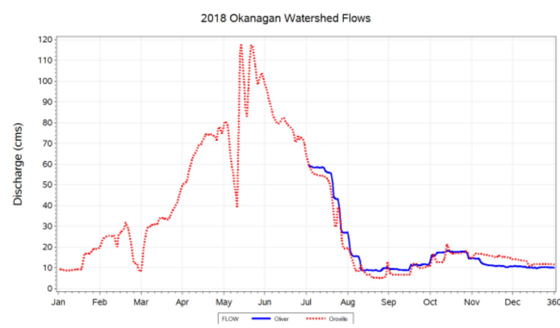

2013 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360


2014 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360


2015 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360


2016 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360


2017 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360


2018 Okanagan Watershed Flows
Discharge (cms)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec 360

Appendix F. Zosel Dam adult salmonid passage and enumeration notes. Colville Tribes Fish & Wildlife (OBMEP) Video and Live Counting.[64]

Columbia River DART
Adult Passage Inventory
Zosel
All Species

Species	Year Range	View	
Bull Trout	2013-2013	Year Details	All Projects
Chinook	2006-2017	Year Details	All Projects
Coho	2012-2017	Year Details	All Projects
Jack Chinook	2011-2017	Year Details	All Projects
Sockeye	2006-2017	Year Details	All Projects
Steelhead	2006-2016	Year Details	All Projects
Wild Steelhead	2006-2016	Year Details	All Projects
Species	**Year Range**	**View**	

http://www.cbr.washington.edu/node/876/popup?outputFormat=inventory&report=adult_inventory&proj=ZOS

- Zosel Dam 2017 data notes. In 2017, the Zosel Dam video system did not begin operating until August 21, 2017, when the spillway gates were finally lowered and fish resumed full use of the fishways. Therefore, all of the Steelhead run and the peak of the Sockeye run were not counted in 2017. Gates were open: March 23, 2017 through August 21, 2017.
- Zosel Dam 2016 data notes. In 2016, the Zosel Dam video system did not begin operating until June 1, 2016, when the spillway gates were finally lowered and fish resumed full use of the fishways. Therefore, most of the Steelhead run was not counted in 2016. Gates were open: April 8, 2016 through June 1, 2016.
- Zosel Dam 2015 data notes. In 2015, the Zosel Dam video system began operating on March 11, 2015, when the spillway gates were finally lowered and fish resumed full use of the fishways. Most of the Steelhead run was counted in 2015 but counts may have been affected when gates were open from March 23, 2015 through April 3, 2015 and May 22, 2015 through June 10, 2015.
- Zosel Dam 2014 data notes. In 2014, the Zosel Dam video system did not begin operating until June 5, 2014, when the spillway gates were finally lowered and fish resumed full use of the fishways. Therefore, most of the Steelhead run was not counted in 2014. Gates were open: February 15, 2014 through April 7, 2014 and May 3, 2014 through June 5, 2014.
- Zosel Dam 2011 - 2013 data notes. The Zosel Dam spillway gates were

[64] Start of each month (horizontal axis) with day of year is approximate.

opened to allow for spring runoff during which an unknown number of salmonids may have passed through the spillway undetected by the video system, for the periods of:

- May 7, 2011 through August 7, 2011
- April 26, 2012 through August 9, 2012
- and May 4, 2013 through July 20, 2013

- Zosel Dam 2010 data notes.
  1. Equipment failure resulted in a loss of data from the right bank ladder (half of the sampling area at Zosel Dam, WA) August 25th through October 31.
  2. Linear regression was used to estimate the missed number of Sockeye passing through the right bank ladder during the time data were lost (see Miller, B.M., J.L. Panther, and J.A. Arterburn. 2010. 2010 Annual Report. Confederated Tribes of the Colville Indian Reservation, Omak, WA. located at http://www.cctobmep.com/media/files/2010_OBMEP_Annual_Report.pdf).
  3. No Steelhead were observed in the left bank ladder during the time of equipment failure; therefore, no estimated number of missed steelhead were generated. Steelhead do not typically pass Zosel Dam during the time equipment failed.
  4. A relatively small number of Chinook were observed during the time of equipment failure, and it was not possible to use linear regression analysis to predict missed numbers of fish. Using the proportion of sockeye passing on the left versus the right bank ladders, potentially 127 Chinook passed the right bank ladder during the time equipment failed. However, there is no certainty associated with this number, therefore this estimate was not included in the total number of Chinook reported for 2010.

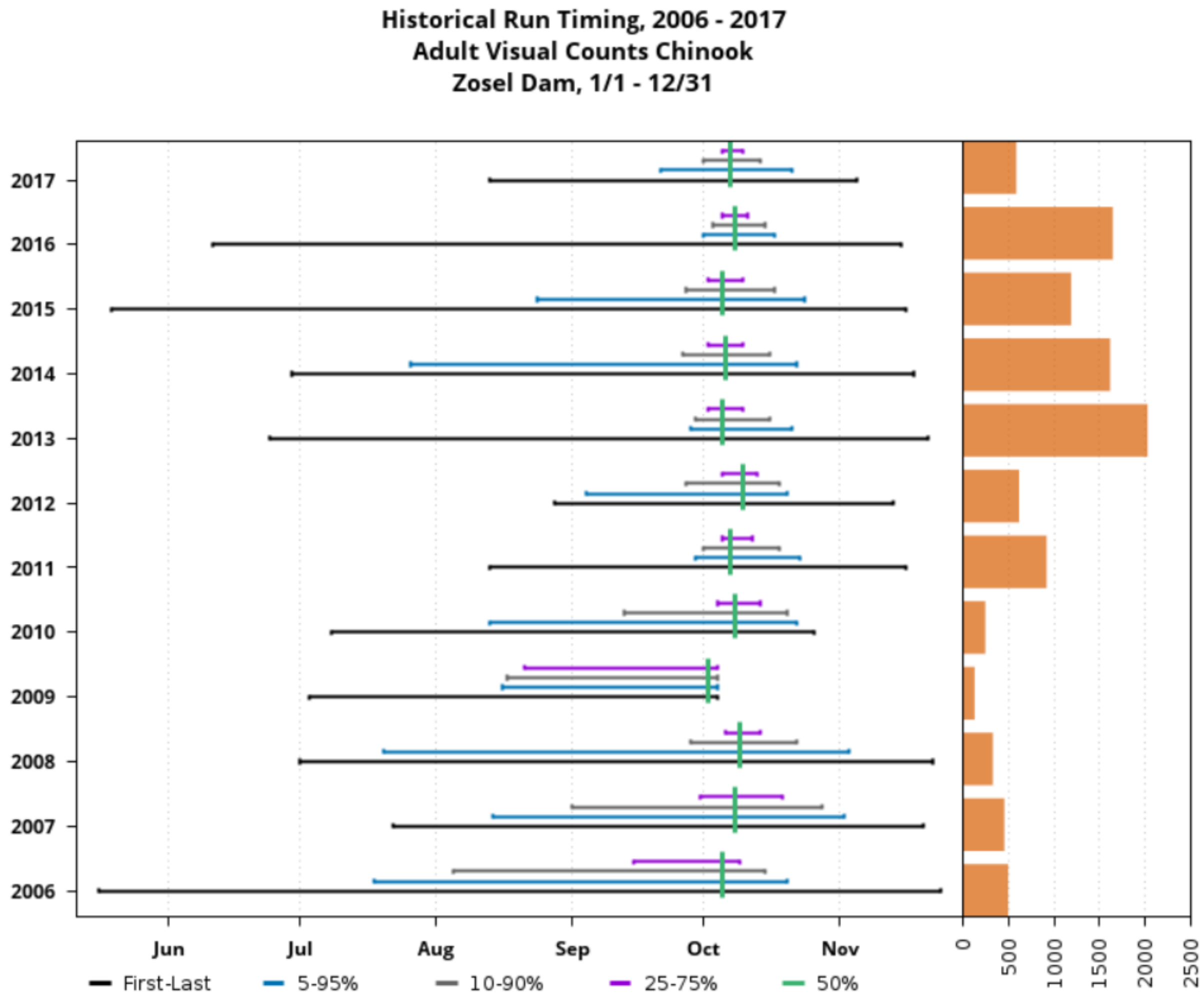
- Zosel Dam 2008 data notes. Zosel Dam estimated 2008 adult Sockeye passage counts missed due to equipment malfunction. At this time, missed sockeye counts are not reflected in DART query results, but have been incorporated into this report.
  - 15 May 12:00 - 20 May 12:00 = 0
  - 17 Jul 00:00 - 18 Jul 19:00 = 6,678
  - 09 Aug 10:00 - 12 Aug 12:00 = 649
  - 31 Aug 00:00 - 04 Sep 10:00 = 570
  - Total Missed Sockeye count = 7,897
  - Initial 2008 Sockeye count = 77,533
  - Revised 2008 Sockeye count = 85,430

Appendix G. Wells Dam adult salmonid passage enumeration notes. US Army Corps of Engineers (USACE) Video and Live Counting.

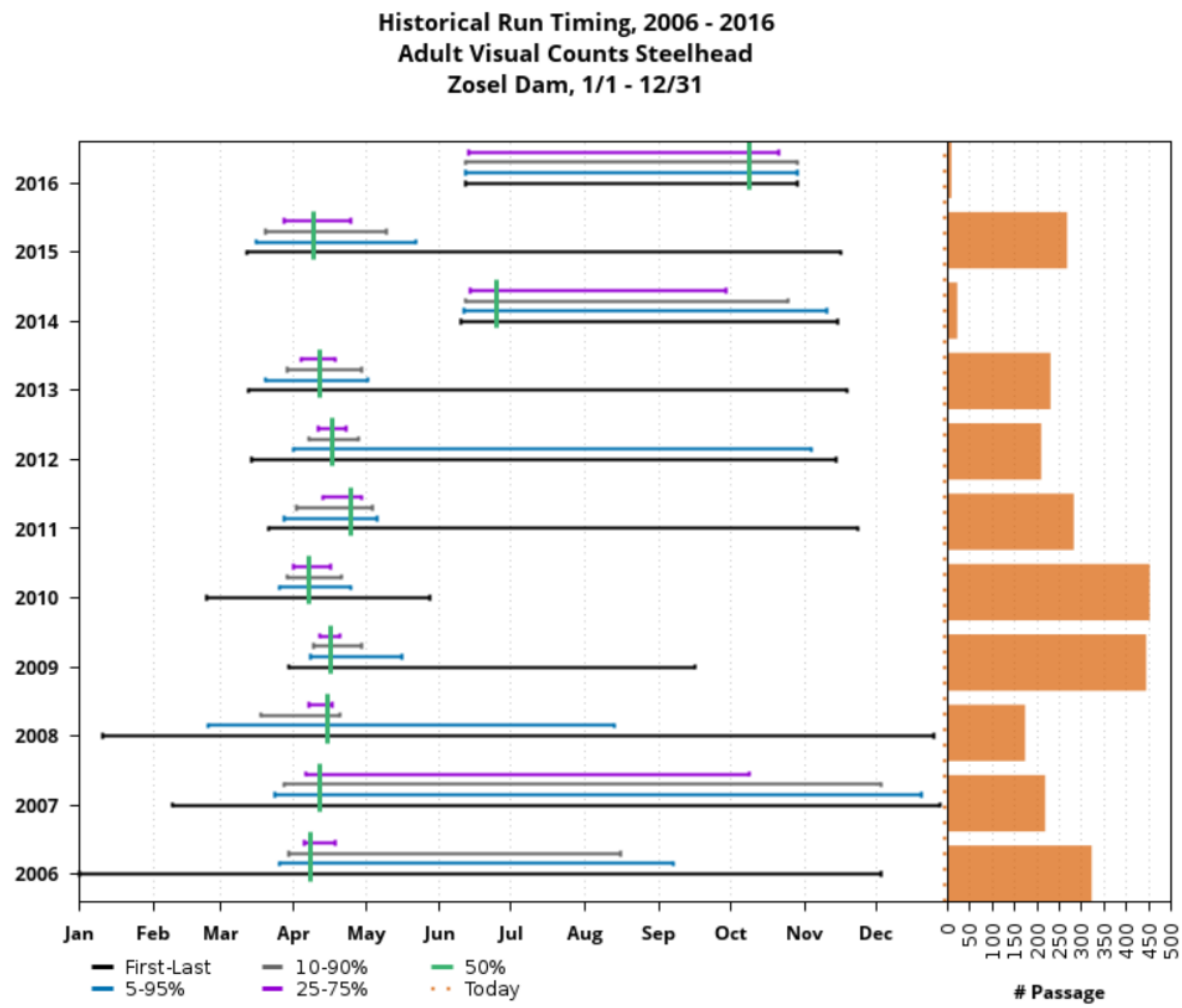
Columbia River DART
Adult Passage Inventory
Wells
All Species

Species	Year Range	View	
Bull Trout	2005-2019	Year Details	All Projects
Chinook	1977-2019	Year Details	All Projects
Chinook Minijacks	1994-2001	Year Details	All Projects
Coho	1977-2019	Year Details	All Projects
Jack Chinook	1977-2019	Year Details	All Projects
Jack Coho	1982-2019	Year Details	All Projects
Lamprey	1998-2019	Year Details	All Projects
Sockeye	1977-2019	Year Details	All Projects
Steelhead	1977-2019	Year Details	All Projects
Wild Steelhead	1998-2019	Year Details	All Projects
Species	**Year Range**	**View**	

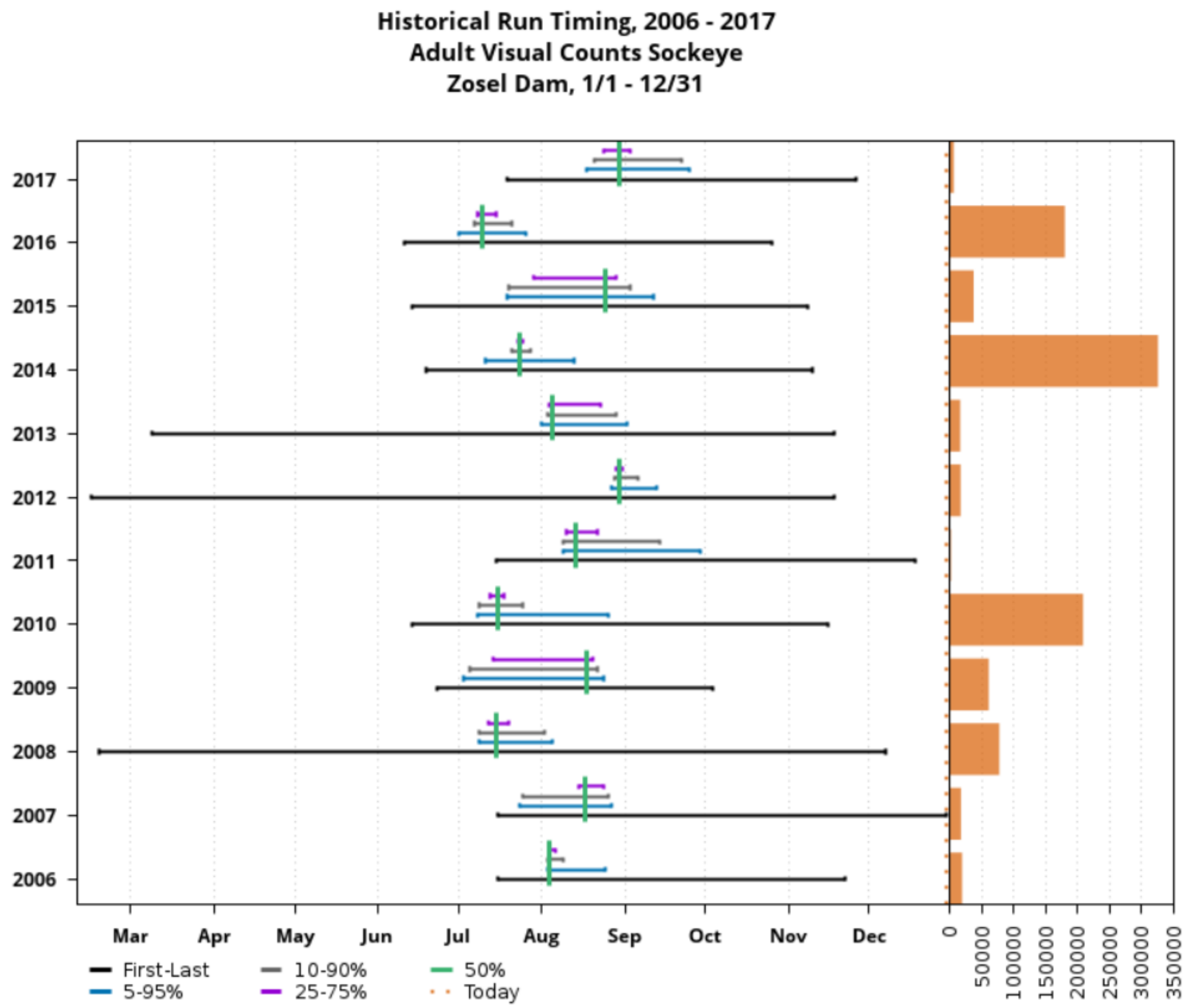
Appendix H. Zosel Dam adult Chinook passage timing, 2006-2017. US Army Corps of Engineers (USACE) Video and Live Counting.



Appendix I. Zosel Dam adult Steelhead passage timing, 2006-2016. US Army Corps of Engineers (USACE) Video and Live Counting.



Appendix J. Zosel Dam adult Sockeye passage timing, 2006-2017. US Army Corps of Engineers (USACE) Video and Live Counting.



Appendix K. Cochran-Mantel-Haenszel test statistic of General Association (CMH-GA) for stratified statistical analysis of the relationship between categorical levels of migration and temperature variables after controlling for discharge level. Maximum CMH-GA statistic (P_CMHGA < 0.0001) tends to occur for critical temperature threshold of 21°C at a wide range of discharge levels (20-120 cms) when daily migration data are lagged backward 3-4 days and temperature/discharge lagged forward one day to coincide at the mouth of the Okanogan River.

CMH-GA Statistics for Okanagan Sockeye and Okanogan River (OkMalott) Conditions

Mig Threshold	Mig Lag	Mwt Threshold	Mwt Lag	Flow Threshold	Flo Lag	_CMHGA_	DF_CMHGA	P_CMHGA
0.4%	-6	21c	1	20m3s	1	1.8563	1	0.17305
0.4%	-5	21c	1	20m3s	1	10.9424	1	0.00094
0.4%	-4	21c	1	20m3s	1	15.5729	1	0.00008
0.4%	-3	21c	1	20m3s	1	13.7827	1	0.00021
0.4%	-2	21c	1	20m3s	1	10.4341	1	0.00124
0.4%	-1	21c	1	20m3s	1	6.1309	1	0.01328
0.4%	0	21c	1	20m3s	1	2.4856	1	0.11489
0.4%	-6	21c	1	40m3s	1	1.8235	1	0.17690
0.4%	-5	21c	1	40m3s	1	10.0441	1	0.00153
0.4%	-4	21c	1	40m3s	1	14.5177	1	0.00014
0.4%	-3	21c	1	40m3s	1	12.8151	1	0.00034
0.4%	-2	21c	1	40m3s	1	9.3749	1	0.00220
0.4%	-1	21c	1	40m3s	1	5.6862	1	0.01710
0.4%	0	21c	1	40m3s	1	2.2791	1	0.13112
0.4%	-6	21c	1	60m3s	1	0.2500	1	0.61710
0.4%	-5	21c	1	60m3s	1	6.1184	1	0.01338
0.4%	-4	21c	1	60m3s	1	10.1767	1	0.00142
0.4%	-3	21c	1	60m3s	1	8.9396	1	0.00279
0.4%	-2	21c	1	60m3s	1	5.5538	1	0.01844
0.4%	-1	21c	1	60m3s	1	2.9438	1	0.08621
0.4%	0	21c	1	60m3s	1	0.7411	1	0.38931
0.4%	-6	21c	1	80m3s	1	0.0017	1	0.96758
0.4%	-5	21c	1	80m3s	1	5.1739	1	0.02293
0.4%	-4	21c	1	80m3s	1	9.6959	1	0.00185
0.4%	-3	21c	1	80m3s	1	8.1006	1	0.00443
0.4%	-2	21c	1	80m3s	1	5.7125	1	0.01684
0.4%	-1	21c	1	80m3s	1	3.0580	1	0.08034
0.4%	0	21c	1	80m3s	1	1.0119	1	0.31445
0.4%	-6	21c	1	100m3	1	0.1955	1	0.65835
0.4%	-5	21c	1	100m3	1	7.4844	1	0.00622
0.4%	-4	21c	1	100m3	1	13.0987	1	0.00030
0.4%	-3	21c	1	100m3	1	11.6855	1	0.00063
0.4%	-2	21c	1	100m3	1	9.4239	1	0.00214
0.4%	-1	21c	1	100m3	1	5.3128	1	0.02117
0.4%	0	21c	1	100m3	1	2.0693	1	0.15029
0.4%	-6	21c	1	120m3	1	1.8872	1	0.16952
0.4%	-5	21c	1	120m3	1	11.0165	1	0.00090
0.4%	-4	21c	1	120m3	1	16.2920	1	0.00005
0.4%	-3	21c	1	120m3	1	14.1110	1	0.00017
0.4%	-2	21c	1	120m3	1	10.2608	1	0.00136
0.4%	-1	21c	1	120m3	1	6.3632	1	0.01165
0.4%	0	21c	1	120m3	1	2.5541	1	0.11001

GLOSSARY

ACCASP	Aquatic Climate Change Adaptation Services Program (Canada)
AHCCD	Adjusted Homogenized Canadian Climate Data, from ECCC
AIC	Akaike Information Criterion
AWN	Agricultural Weather Network (WA)
BC	British Columbia
BPA	Bonneville Power Authority
CBR	Columbia Basin Research
CBR-DART	CBR Data Access in Real-Time
CBTFN	Columbia Basin Tribes and First Nations
CFS	Cubic feet per second
CMAT	Centred moving average mean air temperature; 7D-CMAT: centred 7-day moving average air temperature
CMH-GA	Cochran-Mantel-Haenszel test statistic of General Association
CMS	cubic metres per second, m^3/s
CR	Conversion Rate (survival estimate)
CRB	Columbia River Basin
CRITFC	Columbia River Inter-Tribal Fish Commission
CRT	Columbia River Treaty
CU	Conservation Unit (Canada)
DART	Direct Access in Real-Time (CBR)
DFO	Fisheries and Oceans Canada
ECCC	Environment and Climate Change Canada
EPA	Environmental Protection Agency (USA)
ESU	Evolutionary Significant Unit (USA)
GCRP	Global Change Research Program (USA)
ISAB	Independent Scientific Advisory Board
MAD	Mean Annual Discharge
MAE	Mean Absolute Error
MAT	Mean Air Temperature (daily)
MWT	Mean Water Temperature (daily)
NMFS	National Marine Fisheries Service (USA)
NOAA	National Oceanic and Atmospheric Administration (USA)
NSC	Nash-Sutcliffe Coefficient
NWIS	National Water Information System (USA)
NWPPC	Northwest Power Planning Council
OBMEP	Okanogan Basin Monitoring and Evaluation Program
OLRS	Okanagan Lake and River System
ONI	Oceanic Niño Index
PDO	Pacific Decadal Oscillation
PIT	Passive Integrated Transponder (tag)
$POT_{xx°C}$	Peak-Over-Threshold indicator for xx temperature threshold
QA	Quality Assurance
RMSE	Root Mean Squared Error
RKM	River KiloMeter
ROR	Run-Of-River (dam)
SAS ®	Statistical Analysis Software
STP	Meteorological station (ECCC)
TT50%	Time To 50% (passage)
UCUT	Upper Columbia United Tribes
USACE	US Army Corp of Engineers
USBR	US Bureau of Reclamation
USGS	US Geological Survey
WA	Washington State
WSC	Water Survey of Canada (hydrometrics)
WQM	Water Quality Monitoring station