Critical Environmental Flow Thresholds for the Coldwater River

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1. Introduction

The purposes of this document are; (1) to review biological concepts that are relevant for setting critical environmental flow thresholds (CEFT); and (2) to describe and apply methods for setting the CEFT to assist drought response planning for the Coldwater River. The recommended CEFT could be adjusted in the future based on experience and additional factors including temperature within the reaches of interest.

1.1 Two related but distinct terminologies: the critical period concept versus the critical environmental flow threshold

1.1.1 The critical period concept

When setting the environmental flow needs, it is important to understand the critical period concept as a habitat bottle neck in fish population limitations. The critical period is a phase of high density-dependent mortality through territorial defence (Allen 1969, Grant and Kramer 1990) during which the strength of a year class is determined (May 1974). The critical period has three components including a species specific life-stage, a time period, and a mechanism for mortality. Flow-related mortality mechanisms can occur in summer or winter (Nickelson et al. 1992a); thus all low flow seasons should be considered as candidate bottlenecks (Figure **1**).

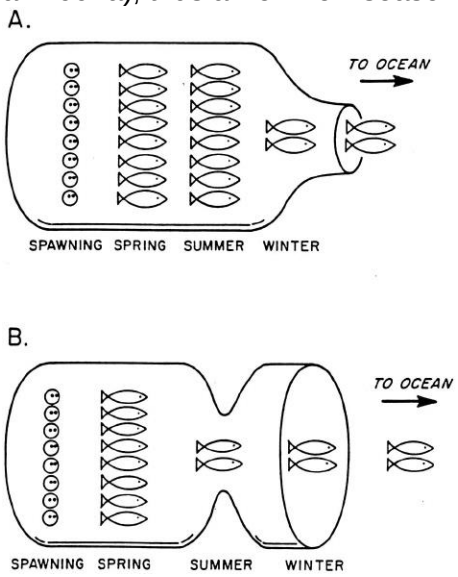

Figure 1. **Habitat bottlenecks occurring during (A) the winter, and (B) the summer.** Reproduced from (Nickelson et al. 1992b).

In California streams that support juvenile salmon and steelhead, the critical period includes the summer season when living space and food resources for juvenile age classes are limited by streamflow and water temperatures (Burns 1972). Similarly, in Wyoming streams that support juvenile and adult salmonids, stream flow levels during the six week period between August 1 and September 15 determine the habitat space and thus stream carrying capacity (Binns 1982). The terms “summer critical period streamflow” is used when the critical period concept is applied to environmental flow needs assessments. It is important to also consider all possible mortality mechanisms such as streamflow, food limitations, temperature and predation when identifying the limiting factors that determine age- or size-specific population dynamics. If such

processes are important, additional considerations may be warranted. Inadequate stream discharge during the critical period streamflow have been related to diminished numbers and biomass of salmonids supported by a given stream (Binns 1982, Binns and Eiserman 1979). Persistent flow deficits can contribute towards poor fish abundance.

1.1.2 Critical Environmental Flow Threshold

During times of water scarcity, the Water Sustainability Act (WSA) provides legislative provisions to prevent irreversible harm to the aquatic ecosystem streams by protecting the remaining flow through restricting water users. In the WSA, the critical environmental flow threshold is defined as the flow level below which significant harm to the aquatic ecosystem is likely to occur (see the glossary for exact wording). Thus, it is a flow threshold within a specific critical period below which accelerated mortality rates resulting from reduced water levels are expected to cause an irreversible decline in the population of concern.

2. Methods for setting critical environmental flow thresholds

2.1 Water Supply

The main two steps to quantify the water supply are to:

1. Estimate the residual Long Term Mean Annual Discharge (LT MAD) for the 14 year standard period from 1996 – 2010; and
2. For highly regulated streams such as the Coldwater River, naturalize the LT MAD.

We used several different approaches for estimating the residual LT MAD for this station lacking records throughout the entire standard period from 1996 – 2010 and then compare findings. The three approaches included: (1) applying a correction factor to known years; and (2) using the 36 years of record between 1965 and 2013; and (3) correction by average percent increase between the Coldwater River near Brookmere station and the Coldwater River at Merritt station

Flow naturalization requires information on the actual water demand. Two types of water users include institutional and agricultural. Institutional water users include purveyors, from which actual water use records are often available. Such records are not typically available from agricultural users. In the Province of British Columbia, the standard approach for determining the agricultural water demand is to apply a water demand model. See:
http://waterbucket.ca/aw/2015/03/05/agriculture-water-demand-model/
Such models have been used to estimate agricultural demand in the most areas of the province where water shortages due to agricultural use are known to occur. These models rely on the best existing information on factors including:

1. the extent of irrigated land by crop type;
2. evapotranspiration based on climate;
3. water holding capacity based on soil type;
4. irrigation efficiency; and
5. whether the supply is sourced the surface through a POD on a water body or from a groundwater well.

As a result, the value provided by the model is an estimate. There are several important considerations when using these estimates for flow naturalization purposes. First, where a

significant portion of demand is provided by groundwater, it can be difficult to determine the percentage of that supply that is obtained from hydraulically connected aquifers; however, such an estimate should be developed. Secondly, the demand is variable from year to year depending on the climate. A water metering program coupled with detailed information on aquifer type is the only way to obtain the true demand over several years. In most cases, this level of information is not available. Therefore, the first step in the exercise will be to work with BC Agriculture to determine the best available source of agricultural water demand information for your area of interest.

2.2 How much water do the fish need for survival

To assess the degree to which current or proposed water use will limit production during the summer juvenile rearing stage, a statistic with a proven relationship to salmonid productivity during this life stage was selected. In Washington State, the minimum of the 60-day average discharge during the summer rearing period is related to juvenile salmonid productivity (Beecher et al. 2010). A slightly modified 30-day mean was applied for the Coldwater River.

These are the steps that were followed to determine the water supply and CEFT:

3. Calculate relevant benchmark flows including 5, 10 and 20 % LT MAD.
4. Calculate the rolling 30-day mean flow for each day within the entire period of record.
5. Select a subset of dates for calculating the critical period streamflow (CPSF) of interest (e.g., summer CPSF = July 1 – Sept. 30, winter CPSF = Nov. 1 – Feb. 28).
6. For each year, identify the minimum value for the rolling 30-day mean flow within each critical period of interest. For regulated streams, this single value for each year represents the **residual** 30-day mean low flow for the critical period of interest (e.g, summer CPSF).
7. For the years of record, estimate the 1-in-20 year low flow from the annual series of 30-day mean low flows.
8. For regulated streams, naturalize the lowest value for the annual 30-day mean residual low flow. As an important perception check, flow records prior to flow regulation on the same stream may be useful to realize what flow restoration or rebound is possible. Neighbouring streams with natural flow regime may also be used with the same purpose.
9. Examine the distribution of minimum values in comparison to relevant benchmark flows (5, 10 and 20 % LT MAD).
10. Compare: (1) the lowest value of the 30-day mean residual low flow; (2) the lowest value of the 30-day mean naturalized low flow; and (3) 5% LT MAD. Whichever is greater is the critical environmental flow threshold for juvenile salmonids.
11. Refer to the frequency distribution information to determine the return interval for the critical flow.
12. Compare results from this desk-top approach with results from field-based studies

3. Results

3.1 Residual LT MAD

The results from these three methods are:
(1) correction factor approach = 8.2 m^3/s (Table 1);
(2) Residual LT MAD from 36 years of record = 8.1 m^3/s (Table 2); and
(3) application of average % difference: 6.7 m^3/s * 1.17 = 7.8 m^3/s (Table 3).

We selected the median value of 8.1 m^3/s as the residual LT MAD for Coldwater River at Merritt.

Table 1.Estimating LT MAD for Coldwater at Merritt during the standard period of 1996 – 2010 by applying a yearly correction factor.

Year	Brookmere[1] MAD (cms)	Brookmere LT MAD (cms)	Brookmere Correction Factor	Merritt[2] MAD (cms)	Merritt LT MAD from Correction Factor	Merritt MAD - Brookmere MAD (cms)	Brookmere to Merritt (% increase)
1965	3.0	6.7	0.45	7.2	16.0	4.2	58%
1968	9.1	6.7	1.35	12.3	9.1	3.2	26%
1969	6.3	6.7	0.94	7.7	8.1	1.3	17%
1970	4.8	6.7	0.72	5.9	8.3	1.1	19%
1971	8.8	6.7	1.32	11.2	8.5	2.3	21%
1972	11.0	6.7	1.64	14.7	9.0	3.7	25%
1973	4.0	6.7	0.60	5.1	8.4	1.0	20%
1974	9.0	6.7	1.34	12.9	9.6	3.9	30%
1975	8.3	6.7	1.23	10.7	8.7	2.5	23%
1976	8.3	6.7	1.24	10.2	8.2	1.8	18%
1977	4.2	6.7	0.63	4.6	7.3	0.4	9%
1978	6.4	6.7	0.96	8.0	8.3	1.6	20%
1979	4.4	6.7	0.65	5.4	8.3	1.0	19%
1980	6.7	6.7	1.01	8.5	8.4	1.7	20%
1981	6.2	6.7	0.92	7.7	8.3	1.5	19%
1982	7.0	6.7	1.05	8.6	8.2	1.6	18%
1983	6.2	6.7	0.93	7.5	8.1	1.3	17%
1984	5.8	6.7	0.86	6.2	7.2	0.4	7%
1985	5.6	6.7	0.84	6.6	7.9	1.0	15%
1986	6.6	6.7	0.99	8.0	8.1	1.4	17%
1987	5.6	6.7	0.84	7.2	8.6	1.6	22%
1988	5.6	6.7	0.83	6.5	7.9	1.0	15%
1989	7.3	6.7	1.09	8.4	7.7	1.1	13%
1990	8.8	6.7	1.31	9.8	7.5	1.0	11%
1991	9.6	6.7	1.44	11.4	7.9	1.7	15%
1992	5.3	6.7	0.78	5.9	7.5	0.6	11%
1993	4.5	6.7	0.67	4.8	7.2	0.3	6%
1994	5.0	6.7	0.74	5.3	7.2	0.4	7%
2006	6.8	6.7	1.01	7.0	7.0	0.3	4%
2007	9.0	6.7	1.35	10.8	8.0	1.7	16%
2008	6.1	6.7	0.90	6.4	7.1	0.3	5%
2009	4.1	6.7	0.61	4.0	6.7	0.0	0%
2010	6.7	6.7	1.00	7.4	7.4	0.7	10%
2011	8.1	6.7	1.20	9.1	7.6	1.1	12%
2012	8.4	6.7	1.25	11.5	9.2	3.1	27%
2013	6.7	6.7	1.01	7.3	7.3	0.6	8%
Average	**6.6**		**0.99**	**8.1**	**8.2**	**1.5**	**17%**

3.2 Water Demand and Naturalized LT MAD

For the purposes of flow naturalization for the Coldwater River at Merritt, the most recent estimates of annual and summer water demand were obtained from the study titled "Nicola River Watershed Present and Future Water Demand Study" (Summit Environmental Consultants Inc. 2007). For naturalizing the LT MAD, the total water use was estimated as 0.191 m^3/s (Table 2 and Table 3). This value was added to the residual LT MAD to provide an estimate of the naturalized LT MAD (Table 6).

Table 2. Summary of estimated annual water demand by sector for the Coldwater River basin (Summit 2007).

Sector	Annual demand
Agriculture	2948 ML/year
Industrial	80 ML/year
Business	83 ML/year
Domestic	2068 ML/year
Institutional	213 ML/year
Recreation	637 ML/year
Total	**6029 ML/year**
Total	**0.191 m^3/s**

Table 3. Summary of monthly water demand by sector for the Coldwater River basin (Summit 2007).

Month	Agricultural (m^3/s)	Total (m^3/s)
jan	0.000	0.062
Feb	0.000	0.056
mar	0.000	0.061
apr	0.013	0.100
may	0.186	0.307
jun	0.241	0.364
jul	0.276	0.453
aug	**0.232**	**0.393**
sep	0.127	0.227
oct	0.038	0.107
nov	0.000	0.061
dec	0.000	0.061
Average	**NA**	**0.188**

Table 4. Correction factor (by year) for adjusting mean annual discharge to the standard time period based on records for WSC station Coldwater at Brookmere.

Year	Coldwater at Brookmere	
	MAD	% of LT MAD
1996	7.6	113.5
1997	9.3	138.4
1998	5.9	88.9
1999	10.5	157.6
200	5.8	86.2
2001	4.1	60.7
2002	8.5	127.1
2003	5.9	87.8
2004	5.9	88.0
2005	4.3	64.6
2006	6.8	101.1
2007	9.0	135.2
2008	6.1	90.5
2009	4.1	60.6
2010	6.7	99.9
Average	6.7	100.0

Applying Regional Runoff Estimates

A number of regional runoff models are available for validation of your estimates of LT MAD (e.g., Coulson and Obedkoff 1998, Ptolemy 2011). The work by Ptolemy (2011) is noteworthy because it was based on flow information from streams with short periods of record, seasonal records, and is summarized at the ecosection scale; in contrast, Coulson and Obedkoff (1998) limited their analysis to stations with annual records for longer periods. A characterization of unit runoff is available for the region (Figure 2) and also specifically for the Coldwater River watershed (Figure 3). Based on this approach, the long-term mean annual flow for the Coldwater River at Merritt is 8.69 m^3/s (Table 5).

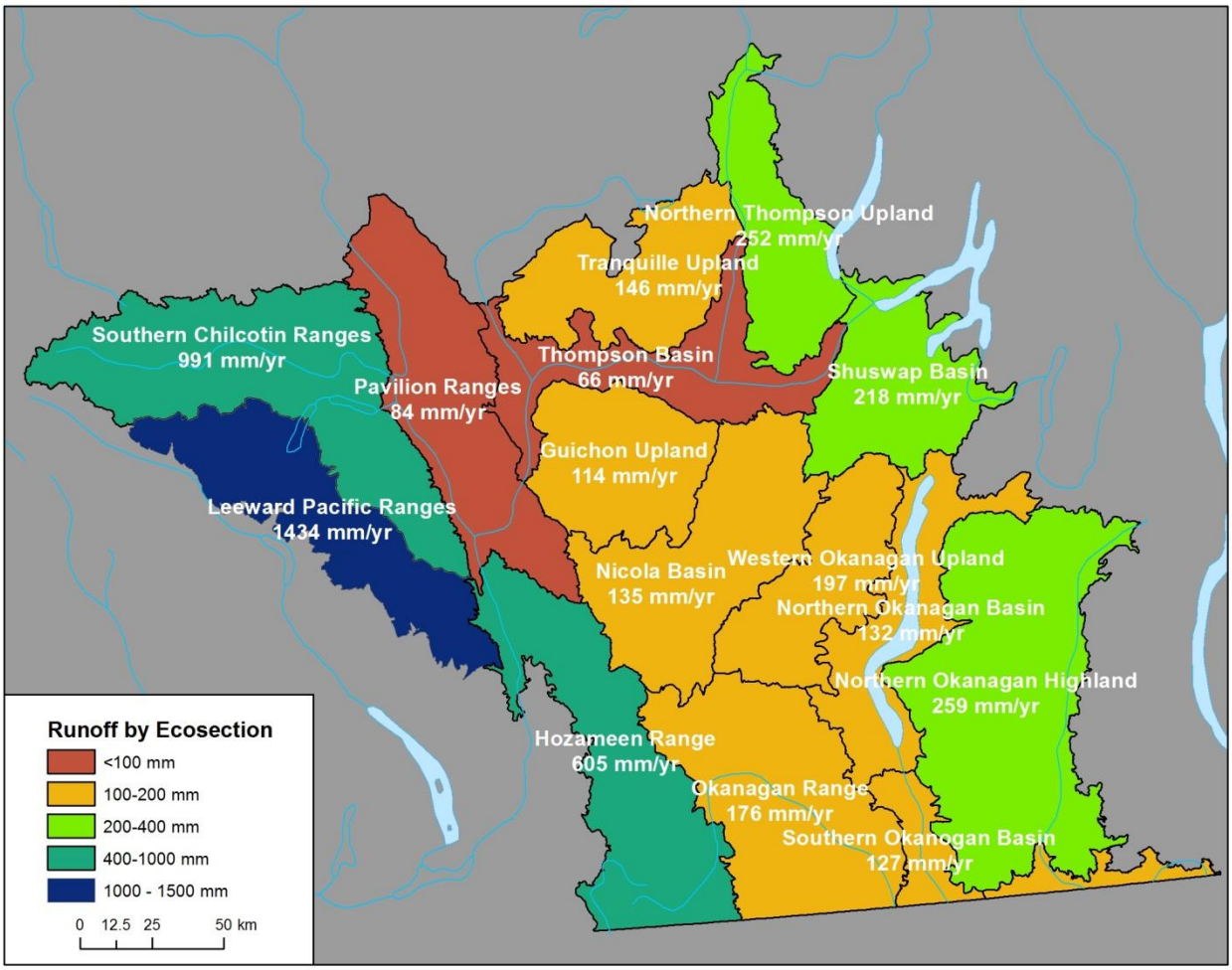

Figure 2. Predicted annual runoff by ecosection within the Southern Interior EcoProvince (Ptolemy 2011)

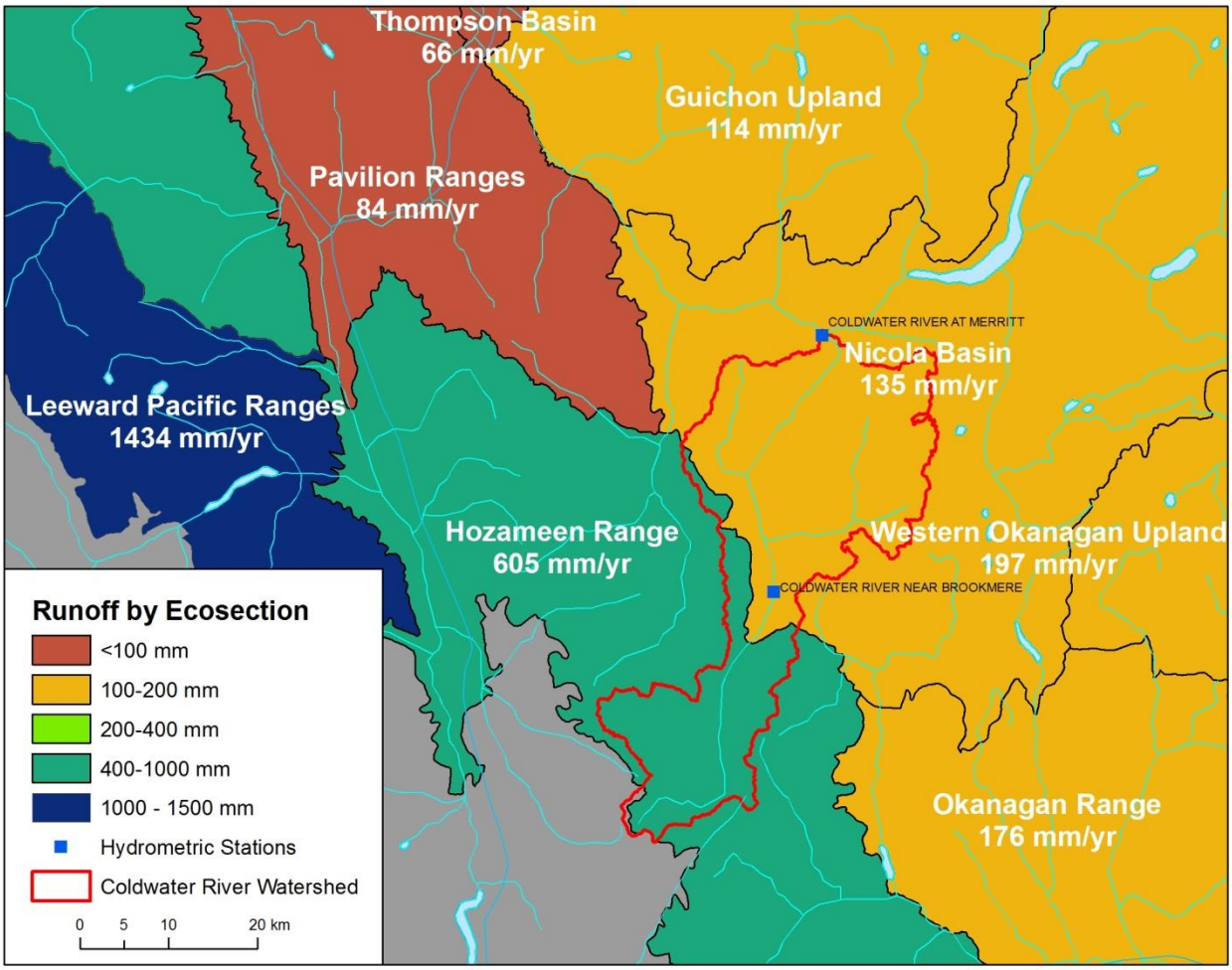

Figure 3. Coldwater River watershed boundary and runoff by ecosection from (Ptolemy 2011).

Table 5. Estimate of long-term mean annual discharge for the Coldwater River based on runoff estimates from Ptolemy (2011).

Ecoregion	Ecosection	Mean runoff (mm/year)	Area (km^2)	Long-term Mean Annual Discharge (m^3/s)
Thompson-Okanagan Plateau	Nicola Basin	135.31	591.72	2.54
Northern Cascade Range	Hozameen Range	604.81	320.57	6.15
Total			912.28	8.69

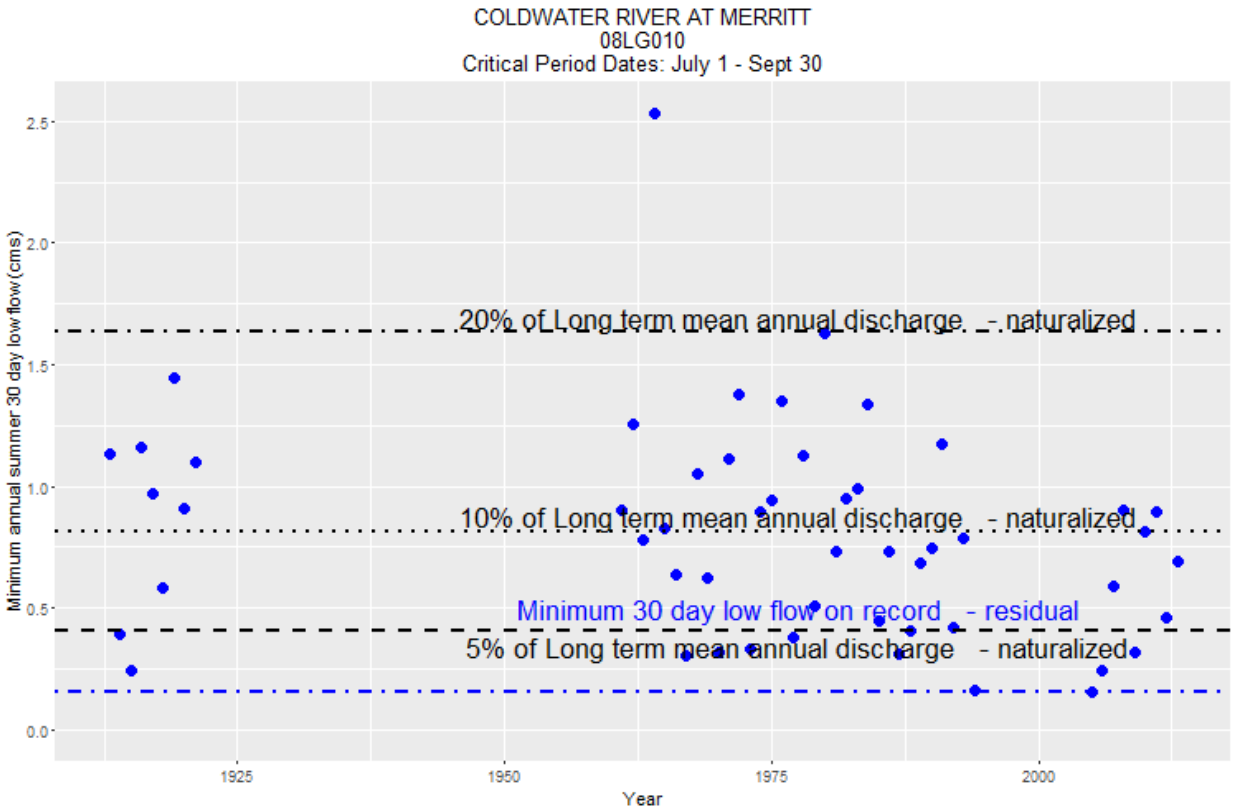

Figure 4. Plot of summer 30-day low flows by year with 5, 10 and 20 % LT MAD benchmark flows.

Table 6. Flow statistics for Coldwater River at Merritt (08LG010) for the period of record from 1913-2013 and Critical Environmental Flow Thresholds.

Flow statistic	Value (m^3/s)
Residual LT MAD	8.16
Estimated annual demand	0.19
Naturalized LT MAD	8.35
5 % LT MAD	0.42
10 % LT MAD	0.84
20 % LT MAD	1.67
Minimum value of 30-day low flow - residual	0.16
Average date of 30-day low flow	Sept. 8
Date weighted estimate of demand	0.27
Minimum value of 30-day low flow - naturalized	0.43
Critical Environmental Flow Threshold: Steelhead, Chinook and Coho Juveniles	0.43
Critical Environmental Flow Threshold: Chinook Spawning	0.84

Over the long-term it is helpful to understand the frequency at which flows could be expected to drop below the CEFTs that are stated in Table 6. Based on the low-flow frequency analysis, a 30-day summer low flow of 0.4 m^3/s, which is representative of the CEFT for juvenile Steelhead, Chinook and Coho coincides with a 5 year return period, while a 30-day summer low flow of 0.8 m^3/s, which is representative of the CEFT for spawning Chinook salmon coincides with a 2 year return period (Table 7). This values indicate that flows in the Coldwater River at Merritt (08LG010) are expected to drop below CEFT on a routine basis.

Table 7. Frequency analysis for 30 day summer low flow based on analysis of records from WSC Station Coldwater River at Merritt (08LG010) using HEC SSP.

Computed 30 day summer low flow (m^3/s)	Expected 30 day summer low flow (m^3/s)	Percent chance non-exceedance	Return Period	Confidence limits (0.05) (m^3/s)	Confidence limits (0.95) (m^3/s)
2.7	2.8	99	1.01	3.6	2.1
1.9	2.0	95	1.053	2.5	1.6
1.6	1.6	90	1.111	2	1.3
1.3	1.3	80	1.25	1.5	1.1
0.8	0.8	50	2	0.9	0.7
0.4	0.4	20	5	0.5	0.4
0.3	0.3	10	10	0.4	0.2
0.2	0.2	5	20	0.3	0.2
0.2	0.2	2	50	0.2	0.1
0.1	0.1	1	100	0.2	0.1
0.1	0.1	0.5	200	0.1	0.1
0.1	0.1	0.2	500	0.1	0

3.4 Comparison of Results from Office-Based Presumptive Standards with Field-Based Measures of Usable Area

Flow needs for in the Nicola River and its principal tributaries including the Coldwater River and Spius Creek were previously examined using transect-based studies (Kosakoski and Hamilton 1982). Usable habitat was quantified across a range of flows from 0.28 – 4.25 m^3/s. During the August to November period for the Coldwater River at the WSC Station 08LG010, these authors set the fisheries resource maintenance flow or a flow that would provide adequate flows for juvenile rearing for all species and for chinook salmon spawning at 1.42 m^3/s.

For the chinook salmon spawning life stage, there is an 83% reduction in usable habitat between the CEFT of 0.84 m^3/s and the maintenance flow of 1.42 m^3/s (Table 8). This substantial reduction highlights the degree to which the water supply limits the spawning potential within the lower reaches of the Coldwater River. The chinook salmon have several adaptations whereby they avoid impacts. The main adaptation of the early run chinook salmon is that they typically migrate into the upper reaches during May – July and avoid the lower reaches. The later run will only enter the Coldwater River for spawning when flows are sufficient to provide migration starting in mid-August. To conserve these populations, it is important to confirm their presence/absence in the lower reaches during the irrigation period.

For the four target juvenile salmonid life stages in the Coldwater River, the differences between usable habitat between the CEFT of 0.43 m^3/s and the maintenance flow of 1.42 m^3/s differ among species and life stages, with steelhead parr the experiencing the greatest decline with 55% less habitat than at optimal (Table 8). This reduction is expected because suitable habitat for steelhead parr has higher depth and velocity ranges in comparison to the others (see Kosakoski and Hamilton Table 8). The rate of decline in usable habitat was also the steepest for steelhead parr indicating that habitat conditions are rapidly deteriorating when flows are at the CEFT of 0.43 m^3/s.

Table 8. Comparison of usable habitat by species and life stage between the fisheries resource maintenance flow and the proposed critical environmental flow threshold for transects near Water Survey of Canada Station Coldwater River near Merritt (08LG010) based on Kosakoski and Hamilton (1982).

Species and Life Stage	Usable area at 1.42 m^3/s (ft^2/100 ft)	Usable area at 0.84 m^3/s (ft^2/100 ft)	Usable area at 0.43 m^3/s (ft^2/100 ft)	Percent Reduction
Chinook spawning	1200	200	NA	83%
Coho rearing	800	NA	700	13%
Chinook rearing	1200	NA	800	33%
Steelhead fry	3700	NA	3200	14%
Steelhead parr	4700	NA	2100	55%

4. Bibliography

Allen, K.R. 1969. Limitations on production in salmonid populations in streams. Symposium on salmon and trout in streams, pp. 3-18.

Beecher, H.A., Caldwell, B.A., DeMond, S.B., Seiler, D., and Boessow, S.N. 2010. An empirical assessment of PHABSIM using long-term monitoring of coho salmon smolt production in Bingham Creek, Washington. North American Journal of Fisheries Management **30**(6): 1529-1543 Available from TEST.

Binns, A. 1982. Habitat quality index procedures manual. *Edited by* Wyoming Game and Fish Department. p. 204.

Binns, N.A., and Eiserman, F.M. 1979. Quantification of fluvial trout habitat in Wyoming. Transactions of the American Fisheries Society **108**(3): 215-228.

Burns, J.W. 1972. Some effects of logging and associated road construction on northern California streams. Transactions of the American Fisheries Society **101**(1): 1-17.

Coulson, C.H., and Obedkoff, W. 1998. British Columbia streamflow inventory, Water Inventory Section, Resources Inventory Branch, Victoria, B.C.

Grant, J.W.A., and Kramer, D.L. 1990. Territory size as a predictor of the upper limit to population density of juvenile salmonids in streams. Canadian Journal of Fisheries and Aquatic Sciences **47**(9): 1724-1737.

Kosakoski, G.T. and Hamilton, R.E. 1982. Water requirements for the fisheries resource of the Nicola River, B.C. Canadian Manuscript Report of Fisheries and Aquatic Sciences No. 1680.

May, R.C. 1974. Larval mortality in marine fishes and the critical period concept. *In* The early life history of fish. Springer. pp. 3-19.

Nickelson, T.E., Rodgers, J.D., Johnson, S.L., and Solazzi, M.F. 1992a. Seasonal changes in habitat use by juvenile coho salmon (*Oncorhynchus kisutch*) in Oregon coastal streams. Canadian Journal of Fisheries and Aquatic Sciences **49**(4): 783-789 Available from http://dx.doi.org/10.1139/f92-088.

Nickelson, T.E., Solazzi, M.F., Johnson, S.L., and Rodgers, J.D. 1992b. An approach to determining stream carrying capacity and limiting habitat for coho salmon (*Oncorhynchus kisutch*). Proceedings of the coho workshop, Nanaimo, B.C., May 26-28, 1992. , pp. 251-260.

Ptolemy, R. 2011. Oneway analysis of annual unit runoff (mm/yr) by ecosection for the Southern Interior ecoprovince, Ministry of Environment, Victoria, B.C.

Summit Environmental Consultants Inc. 2007. Nicola River watershed present and future water demand study, Prepared for: Nicola Watershed Community Round Table, Vernon, B.C.

5. Glossary

“critical period” is a phase of high mortality during which the strength of a year class is determined.

"critical environmental flow threshold": (WSA), in relation to the flow of water in a stream, means the volume of water flow below which significant or irreversible harm to the aquatic ecosystem of the stream is likely to occur;

Section 86 Declaration of a significant water shortage provides for restrictions to all water users to protect the critical environmental flow threshold.

"critical environmental flow threshold": (biological), it is a flow threshold within a specific critical period below which a jump in mortality rates are expected to cause an irreversible decline in the population of concern.