Appendix C - Supplemental Information on the Okanagan Tennant Method

Adaptation of the B.C.-Modified Tennant method to create an "Okanagan Tennant method" is recommended as the basic EFN-setting technique for the Okanagan Basin. An overview of the Okanagan Tennant method is provided in Section 5 of the main report. This appendix provides supplemental information (including examples) to facilitate a better understanding of the method.

Instream Presumptive Flow Standards

The B.C.-Modified Tennant method uses %LT mad as per Table C-1 to specify the monthly (or shorter duration) flow that will meet the EFN requirements for the applicable species life stages and ecological processes as per fish periodicity tables. The flow standards are based on comparison of habitats to flows and ecological functions to flows across a variety of stream specific studies in B.C. (Ptolemy and Lewis 2002). Local data as available was also used by nhc (2001) to further refine the modified Tennant EFN recommendations in the Okanagan.

Table C-1
Instream Presumptive Flow Standards as per Ptolemy 2016c

Biological or Physical Requirement	Percent Mean Annual Discharge (%LT mad)	Duration per Annum
Short-term Biological Maintenance	10%	days
Juvenile summer-fall rearing	20%	months
Over-wintering	20%	months
Riffle Optimization	20%	months
Incubation	20%	months
Kokanee spawning	20%	days to weeks
Smolt Emigration	20%	weeks
Gamefish Passage at Partial Barriers	50% to 100%	days
Large Fish Spawning / Migration	%LT mad = 148*LT mad$^{-0.36}$	Days to weeks
Off-channel Connectivity / Riparian Function	100%	weeks
Channel Geomorphology / Sediment Flushing	>400%	1 to 2 days

Note: The formula for Large Fish Spawning / Migration calculates variable %LT mad based on the LT mad values for each stream to account for larger fish in larger streams. For example, %LT mad for Mission Creek is calculated as 71% based on 148 x LT mad of 7.6 to the power of -0.36.

Percent LT mad vs. Percentile Flows

Consideration of median flows is recommended for use in conjunction with the presumptive flow standards to further customize the Okanagan Tennant EFNs for each Okanagan stream. Median monthly flows for six relatively natural streams (i.e. watersheds with typical forest harvesting, but no significant flow regulation or diversions) are summarized in Table C-2, along with the Tennant targets for Okanagan streams provided in nhc (2001) and as shown in Table 4-1. All of these stations are still active, with records starting as early as 1965, but available records for some of the stations end at 2011. As such the comparison was standardized by limiting the comparison to the 40-year period 1972 to 2011. Vaseux, Shatford, Camp, Trepanier, and Coldstream creeks are in the Okanagan watershed, while Vance Creek is in the Shuswap watershed, directly adjacent to the Okanagan watershed near Lumby. All of the median and percentile values in the following tables are calculated from the daily data records using the “Percentile” formulas in Excel.

Table C-2
Median monthly flow comparison to Tennant EFNs for six Okanagan streams, 1972 to 2011

Month	Vaseux	Shatford	Camp	Trepanier	Coldstream	Vance	Average	Tennant
Jan	12%	14%	28%	21%	18%	17%	18%	20%
Feb	11%	13%	26%	21%	19%	16%	18%	20%
Mar	14%	16%	32%	26%	30%	30%	25%	20%
Apr	51%	33%	107%	87%	182%	195%	109%	100%
May	361%	282%	351%	428%	337%	351%	352%	200%
Jun	271%	338%	162%	191%	153%	191%	218%	100%
Jul	62%	92%	69%	65%	74%	66%	71%	40%
Aug	20%	34%	35%	33%	32%	27%	30%	30%
Sep	16%	21%	29%	29%	23%	20%	23%	25%
Oct	18%	22%	30%	27%	24%	20%	23%	20%
Nov	18%	21%	30%	25%	25%	21%	23%	20%
Dec	14%	16%	28%	23%	20%	19%	20%	20%

NB: Values are presented as percent of LT mad (long term mean annual discharge)

Table C-2 demonstrates that the modified Tennant approach provides monthly EFN values that are close to median monthly flows in Okanagan streams, except in the four highest flow months (April through July). Table C-2 also shows that the streams vary in their monthly flows (as %LT mad). For example, the January average for the six streams is 18%LT mad (very close to the Tennant-recommended 20%), but the direct comparability of the Tennant values to median flows is better for some streams than others - with median January flows ranging from 12%LT mad in Vaseux Creek to 28%LT mad in Camp Creek.

Adjusting EFNs for Natural Flow Variation

Table C-3 demonstrates the 20th percentile monthly flows for comparison to the median flows in Table C-2 and the Tennant percentages from nhc (2001). Note that the 20th percentile flows which approximate a 5-year low flow, are significantly smaller than the median flows, with flows at <10% LT mad in the winter months in some of the streams; and April to June flows that range from 25% (April) to 40% (May) of the median flows.

Table C-3
20th percentile monthly flow comparison to Tennant EFNs for six Okanagan streams, 1972 to 2011

Month	Vaseux	Shatford	Camp	Trepanier	Coldstream	Vance	Average	Tennant
Jan	8%	9%	18%	15%	9%	9%	11%	20%
Feb	7%	9%	19%	14%	9%	9%	11%	20%
Mar	8%	11%	21%	16%	13%	12%	14%	20%
Apr	13%	14%	33%	32%	36%	36%	27%	100%
May	155%	75%	153%	175%	134%	171%	144%	200%
Jun	84%	105%	71%	74%	76%	83%	82%	100%
Jul	19%	29%	29%	29%	30%	29%	28%	40%
Aug	8%	10%	20%	16%	14%	13%	13%	30%
Sep	7%	8%	18%	15%	11%	10%	12%	25%
Oct	10%	12%	20%	16%	13%	10%	14%	20%
Nov	9%	10%	20%	16%	13%	10%	13%	20%
Dec	9%	10%	18%	15%	12%	8%	12%	20%
Annual	62%	54%	71%	63%	65%	67%	64%	

N.B.: values are presented as percent LT mad (long term mean annual discharge)

The minimum monthly flows shown in Table C-4 are significantly smaller again than 20th percentile monthly flows, with the lowest monthly flows at 1% LT mad in Shatford Creek and most streams having a number of months with minimum flows of 5% LT mad or less. Note that the minimum monthly flows are the extreme low flows as they represent the lowest daily flow in each month over the 40-year time period. Minimum annual flows range from 32% LT mad in Shatford Creek to 47% LT mad in Trepanier Creek.

Table C-4
Minimum monthly flow comparison to Tennant EFNs for six Okanagan streams, 1972 to 2011

Month	Vaseux	Shatford	Camp	Trepanier	Coldstream	Vance	Average	Tennant
Jan	4%	4%	9%	10%	5%	4%	6%	20%
Feb	4%	3%	12%	9%	4%	4%	6%	20%
Mar	4%	5%	15%	12%	4%	5%	8%	20%
Apr	5%	7%	15%	16%	7%	8%	10%	100%
May	16%	16%	52%	59%	55%	89%	48%	200%
Jun	22%	20%	36%	29%	26%	20%	25%	100%
Jul	9%	9%	15%	15%	17%	11%	12%	40%
Aug	3%	3%	11%	12%	6%	5%	6%	30%
Sep	2%	1%	11%	10%	2%	4%	5%	25%
Oct	4%	2%	11%	11%	4%	4%	6%	20%
Nov	6%	4%	13%	10%	6%	6%	7%	20%
Dec	5%	2%	9%	5%	7%	6%	6%	20%
Annual	41%	32%	44%	47%	39%	40%	41%	

N.B.: values are presented as percent LT mad (long term mean annual discharge)

Recalling that the flow regimes for the creeks chosen for Tables C-2, C-3, and C-4 are natural. the 20th percentile and the minimum monthly flows shown in Tables C-3 and C-4 illustrate the fact that EFNs set with the Modified Tennant method will exceed natural low flows for significant periods each year in lower flow years.

For real-time operational management purposes in dry years, we recommend that the EFN be considered to drop to match the natural flow. In these situations, the “natural flow EFNs” can be considered in relation to historic percentile flows such as those shown in Table C-5 for Camp Creek. Values are shown as % LT mad in this example, but could be considered as flows in m^3/s if desired. Values that correspond to or slightly exceed the modified Tennant targets in nhc (2001) are shown with yellow background. For Camp Creek, it is noteworthy that the Tennant targets are satisfied with relatively low percentile flows in most months, which will not be typical of all Okanagan streams based on the range of median flows in Table C-2.

Associated Environmental

Table C-5
Range of Monthly Flows from Minimum to Median for Camp Creek 1965 to 2014.

Month	Min	P5	P10	P15	P20	P25	P30	P35	P40	P45	Median
Jan	9%	18%	20%	22%	23%	24%	25%	26%	26%	28%	29%
Feb	13%	19%	20%	22%	22%	23%	24%	25%	26%	26%	28%
Mar	8%	20%	22%	23%	24%	25%	26%	28%	28%	30%	32%
Apr	16%	30%	35%	38%	42%	48%	54%	62%	72%	81%	96%
May	52%	128%	162%	202%	222%	241%	269%	299%	321%	350%	381%
Jun	39%	62%	78%	90%	102%	112%	123%	136%	149%	166%	182%
Jul	16%	26%	32%	37%	41%	47%	54%	58%	64%	68%	73%
Aug	11%	18%	21%	23%	25%	27%	28%	30%	32%	35%	38%
Sep	11%	16%	19%	22%	23%	24%	25%	26%	28%	30%	32%
Oct	12%	18%	21%	23%	24%	25%	27%	28%	30%	31%	32%
Nov	14%	20%	21%	23%	25%	26%	28%	29%	30%	31%	32%
Dec	10%	18%	20%	21%	22%	24%	25%	26%	27%	28%	30%

N.B.: values are presented as percent LT mad (long term mean annual discharge)

The Camp Creek example is based on real data, but is intended solely as an example of how flows vary from minimum (in this case over a 50-year period) to median on a monthly basis. If weekly time steps are used for some or all time periods, more columns would be needed and differences from one-time period to the next would be much smaller. Percentiles could also be calculated on any frequency desired such as in 2 percentile increments rather than 5 percentile increments if finer detail is desired. Further, showing median as the highest value in the range is entirely arbitrary. The table could just as easily include the entire flow range, or only the flows below the EFN target values.

Assessing Impacts of Flows Below EFN Values

Flows vary naturally from month to month and year to year as demonstrated in Tables C-3, C-4 and C-5, and habitat values and ecological functions will also vary accordingly. Flow reductions due to water allocation (diversion and / or storage) will further impact habitat and ecological functions, with the greatest risk at the lowest flow values because values are already at low levels naturally. Methods for evaluation of habitat and ecological function impacts due to flow changes and reductions are discussed in more detail in Appendix D.

Other Considerations for EFN Setting using Okanagan Tennant Method

EFN in the Lowest High Value Reach Establishes Base EFN for Entire Stream:
The EFN values applicable to the lower elevation high value reach(es) of each stream should be established prior to any upstream water allocation / water use evaluation. The rationale for this is that if the EFN for the most downstream high value reach is appropriate, a lower EFN flow regime cannot be applied in an upstream location and still meet the EFN in the high value downstream reach. For example, if the required EFN is the median monthly flow in the downstream high value reach, and this flow is 20%LT mad, an EFN target of less than 20%LT mad in an upstream reach is contrary to achieving 20%LT mad in the high value downstream reach. Further, if the risk determined from evaluation of residual flows vs. naturalized flows in the lower reach(es) indicates high risk from existing allocation, then that risk already applies to the entire stream. This concept demands that the most critical habitat locations be accurately identified, and this step must be done on a case-by case basis.

Naturalized Flows:
Implementation of the recommended Okanagan Tennant method requires a natural or naturalized flow record with a long enough period of record for calculating percentile flows. Estimates of natural or naturalized streamflow were developed for most Okanagan tributaries during the Phase 2 Water Supply and Demand Project, completed in 2010 (Summit 2010), and are shown for each of the 19 target tributaries chosen for the present study in Appendices F through X.

Allocated vs. Actual Water Use:
It is important to differentiate between the volume of water that has been licenced for use and the volume that is actually used, because most of the large water utilities in the Okanagan use less than half of their allocated water. Actual use is required to naturalize residual flows, and determining impacts of existing water use. However, it is also important to evaluate the impacts of the allocated, but not currently utilized allocation, as part of any assessment of new applications. The volume of allocated, but currently unutilized water volumes is far greater than most applications that would be routinely considered on most Okanagan streams. As such, allocated but unused water must also be considered.

DRAFT: Using Limiting Factors to Link the Fish Periodicity Chart and Hydrologic Indices in an EFN Setting Procedure

Richard McCleary, Apr. 7, 2016

This draft discussion paper was developed by Richard McCleary of FLNRO in April 2016. It is reproduced here as it provides useful guidance on an alternative approach to selecting time periods for the Okanagan Tennant and Okanagan WUW EFN-setting methods. The document is referenced in the main report as follows:

McCleary, R. 2016. Draft: Using Limiting Factors to Link the Fish Periodicity Chart and Hydrologic Indices in an EFN Setting Procedure. Discussion paper provided April 8, 2016. Richard McCleary: Regional Aquatic Ecologist, Thompson-Okanagan Region, Ministry of Forests, Lands and Natural Resource Operations, Kamloops, B.C.

The first step when selecting the hydrologic analysis parameters for use in the EFN analysis is to confirm the specific flow-related questions or hypotheses. It is essential that the selected hydrologic parameters provide a means to assess how the current and proposed flows influence the factors that limit biological productivity specific to the species and stream of concern. For example, in Mission Creek, specific flow-related constraints for Rainbow Trout production occur during adult migration, spawning, and summer juvenile rearing (Wightman and Taylor 1978). The limiting factors include both flow quantities and flow ramping practices (Wightman and Taylor 1978). In Mission Creek, flow-related constraints for Kokanee occur during the adult migration, spawning, and incubation (Wightman and Sebastian 1979).
Ideally, a single hydrologic statistic will be selecting for evaluating the specific hydrological process associated with each limiting factor. For example, to determine the degree to which flow quantity limits Rainbow Trout production during the migration and spawning period, an appropriate statistic could be the number of days during the period with flows above the target flow threshold (Table 1). To identify potential population impacts from adult fish stranding resulting from dam operation in Mission Creek, a second statistic could be the maximum down-ramping rate during the receding limb of the freshet (Table 1). This statistic can be calculated from the daily water level readings from the Water Survey of Canada gauging station of interest. 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 could be considered. 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 average is suggested in the Mission Creek example (Table 1).

Using the limiting factor approach, it is also possible to identify a biological response indicator that can be used to assess the actual biological outcome from the conditions associated with each hydrologic indicator (Table 1), creating an opportunity for an effectiveness evaluation of the flow regime. For example, in Mission Creek, to assess the effectiveness of summer flow provisions, the abundance of size of age 1+ Rainbow Trout parr could be measured (Table 1). Such indicators would follow standard procedures used for fisheries or other biological investigations.

In summary, EFN science is a blend of biology and hydrology. Opportunities to improve the integration of these two disciplines are required. The limiting factor approach creates a linkage between the fish periodicity chart and the hydrological analysis. When compared to a hydrological analysis that uses mean monthly flows, an approach that uses hydrologic indices that are linked to limiting factors may provide stronger rationale and justification for decisions and better opportunities for evaluations. This approach may also help to reduce the total number of hydrologic indices from 12 (one for each month) to a smaller set that is well suited for incorporation into water management operations typical of major watersheds in the Okanagan. Application of this approach in streams without detailed hydrologic records will remain a challenge but could still prove useful.

Table 1: Life history stages, example limiting factors, hydrologic indicators and biological indicators for Kokanee and Rainbow Trout in Mission Creek for use in environmental flow needs assessments.

Species/ Event	Life Stage	Known Limiting Factor	References	LT mad (m^3/s)	Target Flow (B.C.-Modified Tenant - % LT mad)	Target Flow (B.C.-Modified Tenant - m^3/s)	Hydrologic Indicator #1	Hydrologic Indicator #2	Hydrologic Indicator #3	Hydrologic Indicator #4	Biologic Response Indicator #1
Kokanee	Adult migration	Yes	Wightman and Taylor 1978	7.5	20	1.5	Number of days during migration period with flow above target				Enumeration of adult spawners
	Spawning	Yes	Wightman and Taylor 1978	7.5	20	1.5	Number of days during spawning period with flow above target				Egg deposition
	Incubation	Yes	Wightman and Taylor 1978	7.5	20	1.5	Minimum of the 30-day average discharge during winter incubation period	Maximum downramping rate when flows les than target	Minimum instantaneous flow		Fry outmigration
	Rearing	No		7.5	NA	NA					
	Juvenile migration	No		7.5	20	NA					

Species/ Event	Life Stage	Known Limiting Factor	References	LT mad (m^3/s)	Target Flow (B.C.-Modified Tenant - % LT mad)	Target Flow (B.C.-Modified Tenant - m^3/s)	Hydrologic Indicator #1	Hydrologic Indicator #2	Hydrologic Indicator #3	Hydrologic Indicator #4	Biologic Response Indicator #1
Rainbow trout	Adult migration	Yes	Wightman and Sebastian 1979	7.5	72	5.4	Number of days during migration period with flow above target	Maximum downramping rate during freshet recession (Mission Creek June 1992, fish kill of adult adfluvial rainbow trout due to stranding)			Enumeration of adult spawners (historically completed at fishway at Smithson-Alphonse Dam)
	Spawning	Yes	Wightman and Sebastian 1979	7.5	72	5.4	Number of days during spawning period with flow above target				Proportion of adult spawners by year class
	Incubation	No		7.5	20	1.5	Minimum of the 30-day average discharge during spring/summer incubation period	Maximum downramping rate when flows les than target	Minimum instantaneous flow		Egg-to-fry survival
	Rearing	Yes	Wightman and Sebastian 1979	7.5	20	1.5	Minimum of the 30-day average discharge during summer rearing period	Maximum downramping rate when flows les than target	Minimum instantaneous flow	Number of days with temperatures greater than lethal threshold	Abundance and size of 1+ parr

Species/ Event	Life Stage	Known Limiting Factor	References	LT mad (m^3/s)	Target Flow (B.C.-Modified Tenant - % LT mad)	Target Flow (B.C.-Modified Tenant - m^3/s)	Hydrologic Indicator #1	Hydrologic Indicator #2	Hydrologic Indicator #3	Hydrologic Indicator #4	Biologic Response Indicator #1
Rainbow trout	Over-wintering	No		7.5	20	1.5	Minimum of the 30-day average discharge during winter rearing period	Maximum downramping rate when flows les than target	Minimum instantaneous flow		
	Juvenile migration	No		7.5	20	1.5	Minimum of the 30-day average discharge during migration period	Maximum downramping rate when flows les than target	Minimum instantaneous flow		

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