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Environmental Flow Needs Determination, Nicomekl-Serpentine Watersheds, Lower Mainland B.C.

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EXECUTIVE SUMMARY

This report outlines a screening-level Environmental Flow Needs (EFN) study for the Nicomekl and Serpentine rivers, located in the Fraser Valley, British Columbia. This study was completed for the British Columbia (BC) Ministry of Water, Land and Resource Stewardship (WLRS) in 2019 and complements a monthly water budget assessment for the two watersheds completed in 2020 (Nunn, et al., 2025). Together these two studies are initial steps in a process roadmap intended to lead to sustainable water allocation in the Nicomekl and Serpentine watersheds, prepared by the Fraser Basin Council (2018).

The rivers drain 325 km^2 of agricultural and relatively impervious land (residential, commercial, and urban) before flowing into Mud Bay. The headwaters are primarily groundwater-fed, and the lowland floodplains are heavily used by agriculture. The natural drainage pattern and water balance have been highly modified by drainage ditches and culverts, sea dams, water pumps, and other municipal water infrastructure.

This report includes determination of EFNs for the Nicomekl and Serpentine rivers at key locations and characterization of assigned EFN thresholds. The study is based on an assessment of hydrometric data, fish/aquatic species presence and periodicity, cumulative licensed demand of water, estimated cumulative actual demand and naturalization of flows, and potential impacts to downstream aquatic species and their habitat. Two screening-level EFN methods were evaluated: the BC Modified Tennant and BC Recommended Instream Flow Methods. Generally, the BC Modified Tennant was found to be more conservative than the BC Instream Flow threshold approach for fish bearing streams, and it provides for less water withdrawal in higher flow months. Both methods indicate that from late spring (April) to fall (October) natural flows are comparable to or less than calculated EFN thresholds, and no water withdrawal should occur over this period. The BC-Modified Tennant EFN thresholds are recommended for the Serpentine and Nicomekl rivers. This method provides a more conservative result, relies less on daily flow data, and considers more local fisheries biological (i.e., life-history, bioperiod) and physical information.

This screening-level assessment was based on limited data. A high-quality, extensive streamflow record is available mid-watershed on the Nicomekl River, but stream gauging has been essentially absent on other portions of the Nicomekl River or the Serpentine River as a whole. Flow naturalization considered licensed surface water use and potential additional non-licensed withdrawals for agricultural purposes but did not explicitly consider other non-agricultural groundwater uses in the watersheds (i.e., municipal and commercial uses). Inclusion of all water withdrawals in updated flow naturalization is recommended but will require numerical groundwater flow modelling, as discussed in Nunn et al. (2025).

It is also noted that the BC Modified Tennant method for EFN threshold determination is a generalized method to satisfy biological requirements of fish throughout the province. Methods to refine EFN threshold determination based on specific Lower Mainland conditions should therefore be explored. Further investigation to better predict the risk of anticipated future water reductions may also be required given that Nicomekl and Serpentine rivers are classified as very sensitive streams under BC's *Environmental Flow Needs Policy Environmental Risk Management Framework* (FLNR and MOE 2016), given the presence of sensitive aquatic species with high cultural and ecological value (e.g., Coho Salmon, Coastal Cutthroat Trout), and given the limited data available. Specifically, it may be appropriate to conduct a detailed Instream Flow Assessment for the headwaters of the Serpentine River, and the Middle and Upper reaches of the Nicomekl River.

CONTENTS

FIGURES

TABLES

ACRONYMS

BC	British Columbia
CCT	Coastal Cutthroat Trout
DFO	Fisheries & Oceans Canada
EcoCat	Ecological Reports Catalogue (B.C. ENV)
EFN	Environmental Flow Needs
FIDQ	Fisheries Inventories Data Queries
IFA	Instream Flow Assessment
IFR	Instream Flow Requirements
iMapBC	Province of British Columbia online geographic data mapping application
MAD	Mean annual discharge
MAP	Mean annual precipitation
MAT	Mean annual temperature
MedMD	Median monthly discharge
MMD	Mean monthly discharge
NDMI	Normalized Difference Moisture Index
NDTI	Normalized Difference Tillage Index
NDVI	Normalized Difference Vegetation Index
PSRI	Plant Senescence Reflectance Index
RF	Random Forest
WLRS	Ministry of Water, Land and Resource Stewardship
WSA	*Water Sustainability Act*
WSC	Water Survey of Canada
WY	Water Year

1. INTRODUCTION

This report proposes Environmental Flow Needs (EFN) thresholds for the Nicomekl and Serpentine rivers, located in the Fraser Valley, British Columbia (BC). These coarse screening-level EFN thresholds were determined in 2019 by Hatfield Consultants (Hatfield) at the request of the BC Ministry of Water, Land and Resource Stewardship (WLRS) and include an assessment of water demand, water supply, and fish and fish habitat in each watershed. Environmental Flow Needs (also referred to historically as Instream Flow Requirements [IFR] in BC) are defined as the volume and timing of water flow required for proper functioning of the aquatic ecosystem of the stream (*Water Sustainability Act;* WSA 2016). WLRS intends to use the proposed EFN thresholds in consideration of issuing future water licences. This determination of EFN thresholds complements water budget modelling for the two watersheds completed in 2020 (Nunn, et al. 2025). Together, these two studies build on previously compiled data (Hatfield 2017) and are initial steps in the Fraser Basin Council (2018) process roadmap intended to lead to sustainable water allocation in the Nicomekl and Serpentine watersheds.

1.1 Background and Setting

In total, the Nicomekl and Serpentine rivers drain 325 km^2 of agricultural and relatively impervious land (residential, commercial, and urban), draining into Mud Bay (Figure 1). The headwaters are primarily groundwater-fed, and the lowland floodplains are heavily used by agriculture. The natural drainage pattern and water balance have been highly modified by drainage ditches and culverts, sea dams, water pumps, and other municipal water infrastructure. Water quality and quantity concerns include:

- Both rivers are classified as ‘fully recorded’, i.e., no further surface water licences have recently been considered;
- The influence of groundwater withdrawals on streamflow;
- Flooding, and increases in flood frequency and magnitude due to climate change (increasing sea level and runoff in storm events);
- Water quality stressors, including contaminated runoff (*Escherichia coli*, fecal coliform, pesticides/fertilizers, nitrates), arsenic in groundwater, sediment from channel bank erosion, salinization of agricultural lands near the coast, increased loadings due to concentration caused by drought and water withdrawals, and low dissolved oxygen levels;
- Increasing urbanization and impervious land areas; and
- Stream bank stability.

Since 1996, WLRS has issued no new water licences in either watershed because of concerns of potential impacts of additional water diversions on the salmon populations in the rivers. Most of the water licenses issued pre-1996 are not reflective of the current amount and use of water. In addition, the actual number of surface water users may be greater than the water licenses issued pre-1996, considering unauthorized diversions. With the implementation of the WSA, all existing and new non-domestic groundwater users are required to apply for a water licence. The WSA requires that decisions on all water licences for new diversions (including currently unauthorized surface water diversions) must consider EFN. For groundwater users, EFN must be considered for new water licences where it is reasonably likely that the source aquifer is hydraulically connected to a stream.

1.2 Scope of the EFN Study

EFN or IFR values can be determined using a variety of methods, which are outlined in provincial guidance and other documents (e.g., Ptolemy and Lewis 2002, Hatfield et al. 2003, Lewis et al. 2004, Hatfield et al. 2007). The BC Modified Tennant Method and the BC Recommended Instream Flow Method (Hatfield et al. 2003) were used for EFN threshold determination. In view of the water management and licensing requirements, the purposes and scope of this Nicomekl- Serpentine EFN study were:

- The naturalization of gauged streamflows based on cumulative licensed demand and estimated cumulative actual demand, considering both surface water and groundwater use.
- The consideration of fish/aquatic species presence, fish/aquatic species periodicity, and impacts to downstream aquatic species and their habitat from estimated water use.
- The determination of EFNs for both the Nicomekl and Serpentine watersheds at key locations and characterization of assigned EFN thresholds as a metric (flow values, percentage of mean annual discharge, and as a percentile exceedance of natural daily flows over the period of interest).
- Comparison of the two selected methods for EFN determination based on data and information requirements and determined EFN thresholds.
- Identification of any data gaps, and recommendations for future consideration.

1.3 Report Organization

The following sections of this report outline: the methodology used to characterize the hydrology, fisheries resource values and EFN thresholds for the Nicomekl and Serpentine rivers (Section 2), streamflow, fish and fish habitat, and EFN results (Section 3); an analysis of data gaps and uncertainties (Section 4); and conclusions and recommendations (Sections 5 and 6).

Figure 1: Overview of the Nicomekl River watershed.

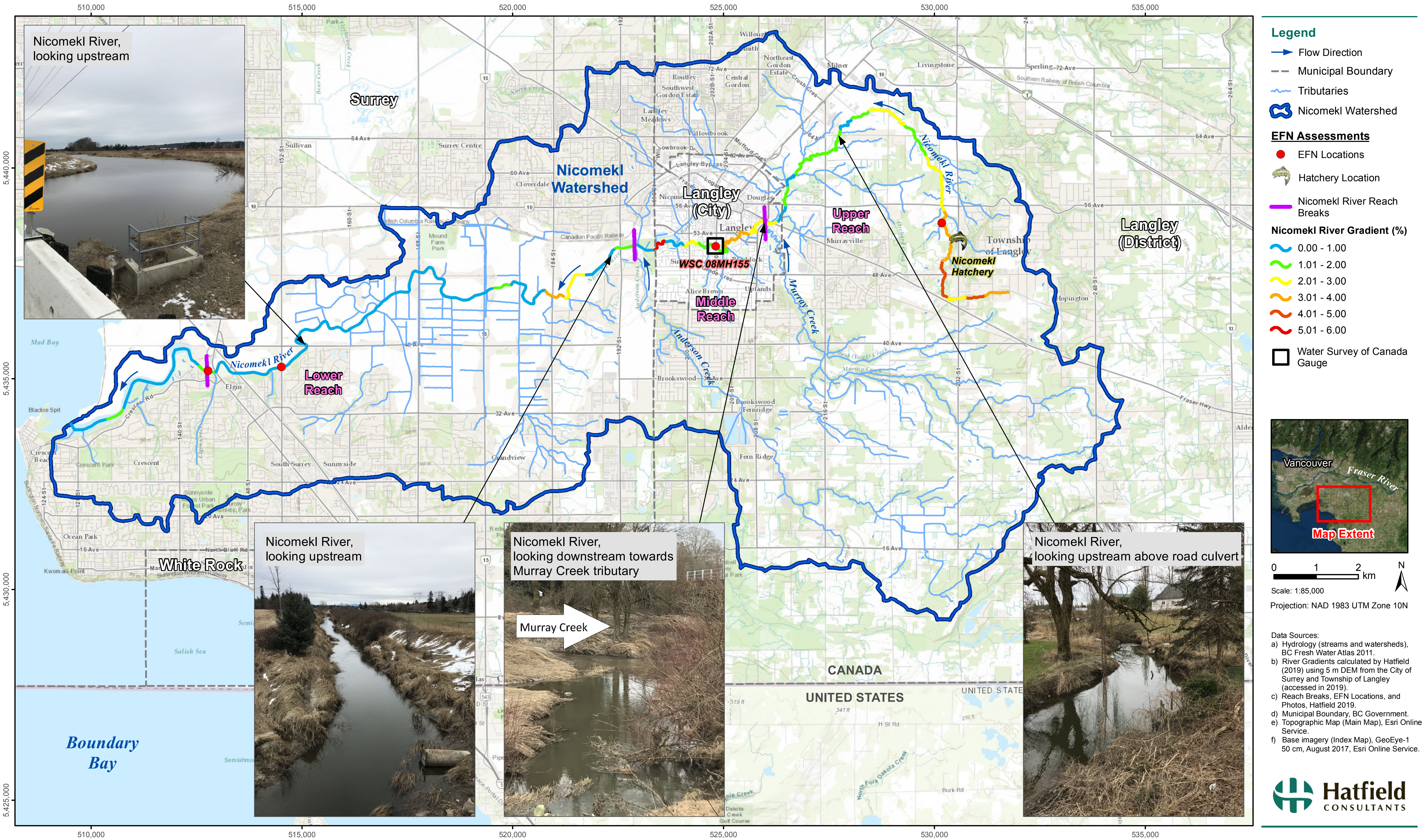
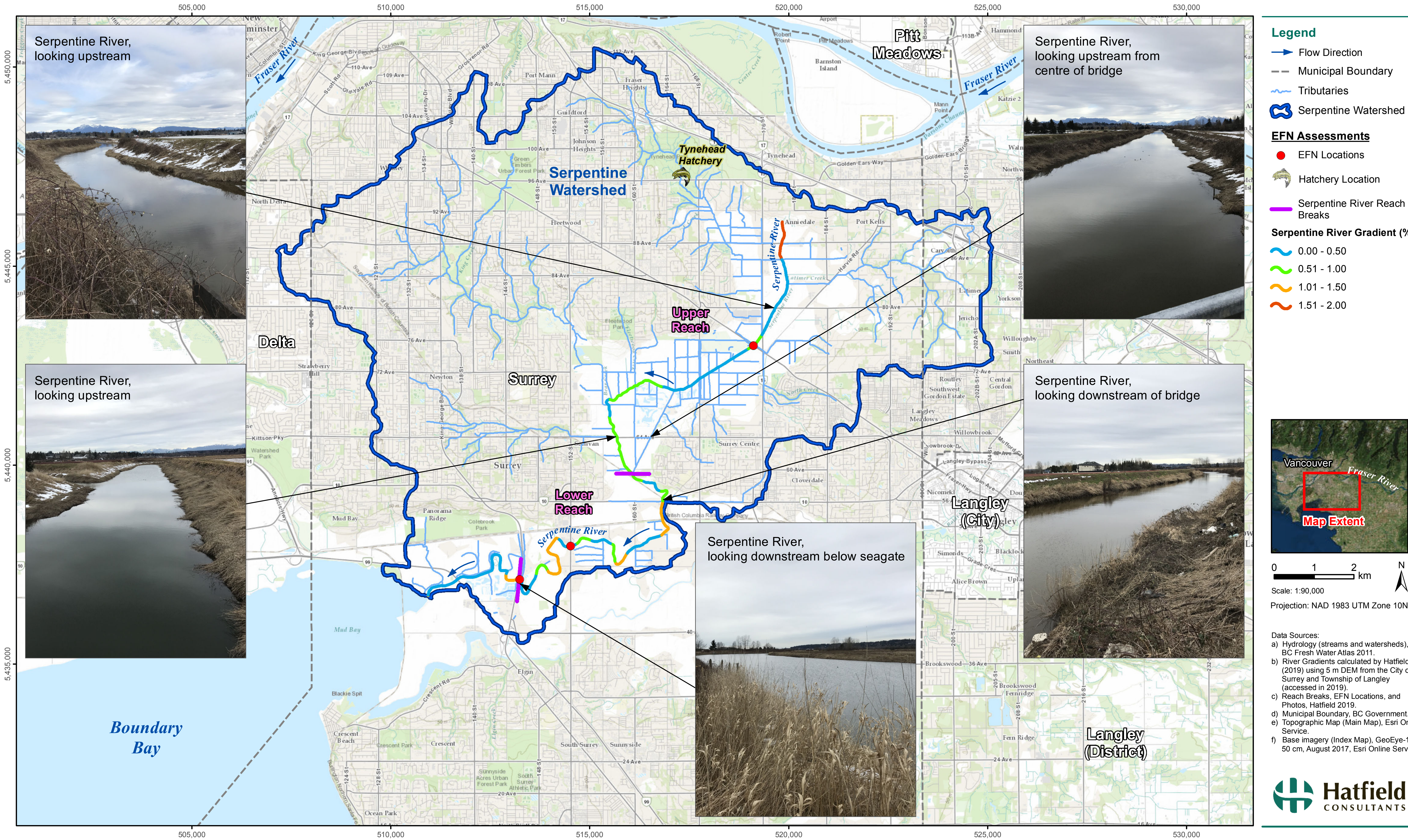


Figure 2: Overview of the Serpentine River watershed.



2. METHODOLOGY

2.1 Climate and Hydrological Characterization

A desktop assessment was conducted to characterize the hydrology of the Nicomekl and Serpentine rivers. This desktop evaluation was completed by:

1. Compiling the following information:
   - Historic streamflow data for the Nicomekl and Serpentine rivers (Water Survey of Canada, WSC); and
   - Climate data from the Cloverdale East (Langley) Environment Canada station.
2. Estimating the naturalized flow characteristics for the Nicomekl and Serpentine rivers, using a combination of:
   - Surface water licence data, from iMapBC;
   - Estimated water demand from agricultural areas, using:
     - Mapping of active farmland using satellite remote sensing analysis; and
     - BC Agriculture Water Calculator.

2.1.1 Compilation of Streamflow Data

A summary of the hydrometric monitoring programs on the Nicomekl and Serpentine rivers is presented in Table 1. For the Nicomekl River, WSC commissioned three different gauges, of which the last two (08MH105 and 08MH155) have operated mid-watershed near Langley City, collectively gauging flows largely uninterrupted for approximately 50 years. An earlier gauge (08MH050) operated further downstream, at 192nd Street, but flows gauged here were classified as regulated by WSC. For the Serpentine River, WSC commissioned a single gauge (08MH060) in the headwater area from 1961-1966, but this record was intermittent.

Near the mouth of both rivers, a sea-dam operates to prevent saltwater intrusion upstream during high-tides (except during infrequent flood events when the dams are breached), while allowing Nicomekl and Serpentine River flows to reach Mud Bay during low-tides. During high-tides, the dams generate backwater within the lowest reaches, and river levels exhibit hourly fluctuations consistent with tide-cycles, as monitored at a City of Surrey operated hydrometric station on the Serpentine River at Highway 10. A previous modelling study (City of Surrey 2012) estimated the flood flows and floodplain inundation for both watersheds, resulting from extreme-rainfall runoff during exceptional high-tide conditions, but no continuous hydrograph data were generated due to the flood frequency modelling technique applied.

Table 1: Hydrometric gauging programs on the Nicomekl and Serpentine rivers.

WSC gauge ID	Name	Agency	Record Period	Drainage Area (km^2)
Nicomekl River				
08MH050	Nicomekl River at 192nd Street	WSC	1952 - 1963	99.5
08MH105	Nicomekl River below Murray Creek	WSC	1965 - 1984	64.5
08MH155	Nicomekl River at 203 Street, Langley	WSC	1985 - 2014	70.0
Serpentine River				
08MH060	Serpentine River near Port Kells	WSC	1961 - 1966	13.0
-	Serpentine River at Hwy 10	City of Surrey	2000 - 2017	-

For the purpose of characterizing both gauged and naturalized flow regimes on the Nicomekl River, streamflow records from the two gauges near Langley City (08MH105 and 08MH155) were consolidated into a single flow time-series. For increased accuracy, the consolidation process included a small increase of 9% in flows gauged at 08MH105, to account for the increase in drainage area between this gauge location (70.0 km^2) and the former gauge location (64.5 km^2). The resulting, consolidated record length exceeds the 20-year minimum streamflow record length recommended for desktop EFN studies (Hatfield et al. 2003) thus the additional flow data from the initial Nicomekl River gauge (08MH050) were not included.

For the environmental flow needs determination, a total of five EFN assessment nodes were considered (Figure 1). The Middle Nicomekl assessment node (in Langley, at WSC Gauge) and Upper Serpentine assessment node (at Fraser Highway crossing) are located at key infrastructure points of interest in these watersheds; remaining assessment nodes were arbitrarily selected (i.e., in absence of hydrological or habitat considerations) away from these two main points of interest to illustrate a range of variability in flows across the watersheds (e.g., headwaters and/or downstream) and resulting EFN thresholds.

The location of the 08MH105 gauge, for which the consolidated flow record is applicable, was assumed equivalent to the EFN assessment node for the middle Nicomekl River Reach (Figure 1). The flow data were then linearly pro-rated by drainage area, to estimate flow conditions at the other two EFN assessment nodes on the river: downstream (drainage area 162 km^2) and upstream (drainage area 7 km^2). This consolidated flow data was also linearly pro-rated and used to estimate flow conditions at the two EFN assessment nodes on the Serpentine River (downstream, drainage area 132 km^2, and upstream, drainage area 52 km^2). Given the absence of long-term reliable hydrometric data for the Serpentine River, Serpentine River data was synthesized from Nicomekl River data as this technique that has been applied for similar scenarios (e.g., Rood and Hamilton 1994). Similarities in terrain, climate forcing, and land-use across each watershed theoretically result in close unit-area runoff contributions to each river, although the Serpentine River is likely flashier given the physical channelization of the river.

Water licences and inferred predominant water use and quantities (e.g., agricultural use, based on farmland areas) generally appear to be evenly distributed along each reach and watershed suggesting that the linear pro-rating approach is reasonable from a water demand influence on streamflow perspective. However, the linear pro-rating approach is not necessarily adequately precise to transfer the modelled records from O8MH105/155 to the other EFN assessment nodes, particularly those with much smaller drainage areas which may be flashier than the mid-watershed Nicomekl River location. Analysis of concurrent unit hydrographs of data from gauges summarized in Table 1 could theoretically offer insights regarding any need for refinement. However, as noted above, data records are either intermittent, discontinuous, or sites may be tidally influenced and/or impacted by anthropogenic activities, preventing meaningful comparisons of the limited historical data records. The linear pro-rating approach should therefore be considered provisional, and a refined approach to transpose the O8MH105/155 long-term data record to other locations will necessitate the collection of concurrent short-term data for sites of interest.

For the purposes of data review and presentation, the study uses the water year (WY) convention (e.g., ‘1983’ refers to the period from November 1, 1982, to October 31, 1983) as it includes a full winter season, rather than the two partial winter periods that fall within a calendar year. Throughout the report, reference to years and annual statistics indicates WY unless stated otherwise.

2.1.2 Flow Naturalization

Natural flows were estimated after consideration of both licensed surface water allocations and potential additional unauthorized agricultural water use from active farmland. Licensed surface water allocations are available from the provincial water licence database, obtained through the iMapBC online portal. There is likely some unlicensed surface water use for domestic purposes and some unauthorized water withdrawal and use. The volumes of these abstractions are unknown but potentially significant for the Nicomekl-Serpentine watersheds where a considerable amount of active farming occurs during growing season months.

The following sections outline the steps taken to estimate water volumes consumed both by licensed and non-licensed water users, and the integration of these volumes into the calculations of naturalized flows from which the EFN thresholds are determined. Two water demand scenarios are introduced for the EFN analysis, including:

- **Licensed-Case**: includes only licensed water allocations; and
- **Actual-Case**: includes both licensed water allocations, and estimates of non-licensed water demands.

The Licensed-Case scenario likely underestimates the total surface water use. The Actual-Case scenario includes non-registered water demand, resulting in higher naturalized flow estimates relative to the Licensed-Case scenario. Since the EFN thresholds are scaled to the naturalized flow estimates (described below), higher EFN thresholds are therefore predicted under the Actual-Case scenario.

2.1.2.1 Surface Water Allocations

Surface water allocation data were downloaded from the iMapBC online portal (accessed February 7, 2019). The original datasets totaled 316 and 137 surface water authorization records for the Nicomekl and Serpentine watersheds, respectively, each with metadata arranged in separate fields. Key metadata used for analysis included:

- Licence status;
- Status date, effective (priority) date, and expiration date for the authorization;
- Maximum annual allocation amount; and
- Type of use and purpose of use.

Annual allocation totals were calculated by summing the totals of all allocations that were active within a given water year of the analysis period. The allocations were differentiated into two groups for the purposes of inferring the timing of water use:

- Seasonal water use: allocations coded with purpose uses:
    - 02F – Lawn, Fairway and Gardening: Watering;
    - 03A – Irrigation: Local Provider; and
    - 03B – Irrigation: Private.
- Year-round water use: all remaining allocations.

The resulting total annual allocation amounts may also include a number of non-consumptive uses (e.g., water management/conservation), and thus overestimate of the actual annual volume of water withdrawn from a stream.

2.1.2.2 Mapping of Active Farmland

Active agricultural fields for the City of Surrey and Township of Langley were identified using a time series of the Sentinel-2 multispectral satellite data coupled with the Random Forest (RF) machine learning algorithm. Random Forest is a powerful multivariate, non-linear and non-parametric ensemble machine learning approach that allows for fusion and aggregation of data from a wide variety of sources and types (Breiman 2001, Breiman 2002) and is well suited for remote sensing classification analyses.

Active agricultural fields were identified based on the premise that active fields will exhibit considerable spectral variability during the growing season in line with changes in biomass related to different stages of the growing season. To capture the seasonal variability, we acquired Sentinel-2 imagery throughout the spring, summer, and fall seasons for 2017-2018 and processed the imagery to atmospherically corrected ground reflectance (i.e., level 2 processing).

Several spectral indices that are related to vegetation vigor and crop residue cover were computed. The Normalized Difference Vegetation Index (NDVI), the Normalized Difference Moisture Index (NDMI), the Plant Senescence Reflectance Index (PSRI), and the Normalized Difference Tillage Index (NDTI) were calculated for images acquired in the spring, mid-summer, and fall.

The RF model was parameterized with the processed Sentinel-2 images and spectral indices, and up to 20,000 randomly distributed sample sites collected from areas manually interpreted by a remote sensing analyst as agricultural fields, water, urban areas, and forested areas. The results indicated that agricultural fields were classified at an estimated accuracy greater than 95% in the area covering the Serpentine and Nicomekl watersheds, based on the input training data (i.e., in-model out of bag classification accuracy).

2.1.2.3 Water Demand from Active Farmland

The BC Agriculture Water Calculator can be used to estimate the annual irrigation or livestock water demand for a farm. Irrigation water demand estimates are made based on the geographic location of the farm, as well as its soil type, crop type and type of irrigation.

Ten mapped farms (five from each watershed) were randomly selected and their monthly estimated water demand estimates were downloaded and averaged. These average monthly estimated water demand values were then upscaled and applied to all of the mapped active farmland areas in each watershed. This is considered a superior method than simply using published census statistics tabulating irrigation volumes at the provincial level (e.g., Statistics Canada 2011). The final monthly water use totals from these areas were reduced to account for the proportion of farms which have surface water licences, estimated visually by superimposing the location of water licences and mapped farm areas. While on an individual farm basis, the independent BC Agriculture Water Calculator may yield water demand estimates that are higher than licensed surface water use quantities, on a watershed basis it was found that projected seasonal water use from active farmland with water licenses for the ‘Licensed-Case’ (Section 3.3) closely matched licensed surface water allocations.

Mapped farm areas occur throughout the two watersheds (except for urban areas, such as Langley City) suggesting that the water demand estimates can be pro-rated to other locations of the study (i.e., supporting the linear pro-rating approach). The mapped areas, and associated water demand estimates, are both representative of contemporary conditions in each watershed, but both were assumed to remain unchanged throughout the entire analysis period (1963 - 2016). Some changes in non-licensed farmland water use through time would be expected due to changes in farmland area, crop types and water consumption (as irrigation technologies have become more efficient). Decreases in farmland area over time might be expected with increased urban development in the study area, but evidence for this from census data is mixed, which shows both increases and decreases in total land farmed suggesting a dependence on location in the region (e.g., Metro Vancouver 2012). Pressures from urban development appear to be less important than under-utilization of the available agricultural land base (e.g., Mullinix et al. 2013). There is also a change occurring towards more intensive commodities such as greenhouses and poultry, while other crops and livestock have declined (Township of Langley 2019). These factors complicate assessment of changes in water demand from active farmland over time.

The average monthly estimated water demand values were converted to relative monthly contributions throughout a given year (increasing from zero outside of the growing season to a peak of 36% in July, with over 85% occurring from June to August). These values were used to scale the registered surface water allocations classified as 'seasonal', to allow for monthly water demand variations (i.e., with a peak in summer demand) rather than simply dividing the available annual sums equally across all calendar months.

2.1.2.4 Calculation of Daily Naturalized Flows

Daily flows were naturalized to consider the effects of ongoing water withdrawals, by adding estimated, historic and current water use volumes to the observed flows under a 'Licensed Case' and 'Actual Case' scenario.

Monthly water use for the 'Actual-Case' scenario outlined above was calculated by summing the following data sets:

1. Licensed surface water allocations classified as 'year-round' (i.e., annual allocation volumes distributed equally across months, variable between years);
2. Licensed surface water allocations classified as 'seasonal' (i.e., annual allocation volumes weighted by the relative monthly distribution of irrigation water demand estimates, variable between years); and
3. Estimated monthly water demands from unlicensed active farmland areas (constant between years).

The 'Licensed-Case' water demand scenario only included licensed allocations (i.e., did not include the last of these data sets in the calculations).

For both scenarios, the resulting monthly water demand sums were converted to an equivalent flow rate (in m^3/s) and assigned to the 15^{th} (i.e., midpoint) of each month through the analysis period (1963–2016). Linear interpolation between these monthly values generated daily estimated water demand sums. These daily sums were then added to the concurrent estimated gauged values to generate the estimated daily naturalized flows at each EFN assessment node.

2.2 Fish and Fish Habitat Evaluation

A desktop mapping analysis was initially performed to delineate macrohabitat (reach scale) features from the headwaters to the river outlets into Mud Bay. Macrohabitat reach breaks were defined using criteria described in Lewis et al. (2004) classified as "homogeneous section of stream channel, characterized by uniform discharge, gradient, channel morphology, channel confinement, and streambed and bank materials." Other physical features that were noted included changes in stream gradient, changes in discharge (often where a significant tributary enters the mainstem), and discernable barriers to fish movement. Reach output from the desktop mapping exercise were field verified during a stream walk on February 27, 2019, along with select segments of both rivers.

Publicly available information was reviewed to identify and characterize fish species' presence, distribution, life history, and habitat use for both rivers. Bioperiod and periodicity information was compiled for the relevant species from available literature to support the evaluation and determination of EFN thresholds. Key sources included:

- Local information available from the Serpentine Enhancement Society (2019) and Nicomekl Hatchery (2018);
- Publicly available online databases, including cohoBC (Government of BC 2019a), City of Surrey Online Mapping System (COSMOS, City of Surrey, 2019), Fisheries Inventory Data Queries (FIDQ, Government of BC 2019b), HabitatWizard online mapping tool (Government of BC 2019c), EcoCat Ecological Reports Catalogue (MOE 2019), and BC Species and Ecosystems Explorer (BC CDC 2019);
- Fisheries and Oceans Canada manuscripts and reports on the Lower Mainland streams and rivers; and
- Published and unpublished reports on specific species, such as Coho Salmon, *Oncorhynchus kisutch* (Sandercock 1991) and Coastal Cutthroat Trout, *O. clarkii clarkii* (Slaney and Roberts 2005).

2.3 Environmental Flow Needs Determination

The BC Modified Tennant Method and the BC Recommended Instream Flow Method (Hatfield et al. 2003) were used for EFN threshold determination.

The BC Modified Tennant Method is a made-in-BC modification to the original Tennant Method (which specifies EFN values as a percentage of mean annual discharge (MAD) for different habitat conditions; (e.g., severely degraded, poor or minimum, fair, good, etc.). The BC Modified Tennant Method incorporates local biological and physical information to develop criteria to satisfy biological requirements of fish throughout the region for evaluating environmental flow needs. Key fish species are considered and the highest EFN values and protection for aquatic species were selected and proposed as the final recommended EFN values for the Nicomekl and Serpentine rivers. The flow recommendations (i.e., EFN, expressed as a %MAD or formula) adopted from this method are illustrated in Table 2.

With this method, an EFN schedule was developed with respect to fish bioperiods (i.e., identification of critical stream flow periods) for the species of interest, flow data, and any site-specific ecological needs. Different flow needs (calculated as %MAD) are prescribed to specified time blocks corresponding to different fish species life stages (based on the species periodicity/bioperiods). For the migration and spawning bioperiod, prescribed flows can range from 30% to 200% MAD based on stream size (Hatfield et al. 2003). The formula adopted herein to calculate the migration/spawning EFN (see Table 2) reasonably applies to larger fish spawning.

Table 2: Flow recommendations adopted from the BC Modified Tennant Method.

Bioperiod	**Flow Recommendation (% of MAD)**
Juvenile Rearing	20
Adult Rearing	55
Over-wintering	20
Incubation	20
Migration and Spawning	$148 \times MAD^{-0.36}$*

*Note: Flow recommendation for large spawning fish from Ptolemy and Lewis (2002).

The BC Recommended Instream Flow Threshold method (Hatfield et al. 2003) specifies environmental flow thresholds for fish bearing streams according to mean monthly discharge (MMD), as follows:

- During the lowest flow month, flow threshold is 90^{th} percentile of MMD;
- During the highest flow month, flow threshold is 20^{th} percentile of MMD; and
- All other months, the percentile is calculated according to formula [1]:

$$90 - \left[\left(\frac{median_i - median_{min}}{median_{max} - median_{min}}\right) \times (90 - 20)\right] \qquad [1]$$

where, $median_i$ is the median of mean daily flows for month i, $median_{min}$ is the month of lowest median flows, and $median_{max}$ is the month of highest median flows. These thresholds are intended to maintain the most important features of a natural hydrograph from a biological and physical perspective, protecting low flow periods regardless of season, and to provide high flow events to maintain gross stream morphology and instream and riparian habitat (Hatfield et al. 2003).

EFN values were calculated for selected assessment points within each of five identified macro-reaches within the Nicomekl and Serpentine rivers.

3. RESULTS AND DISCUSSION

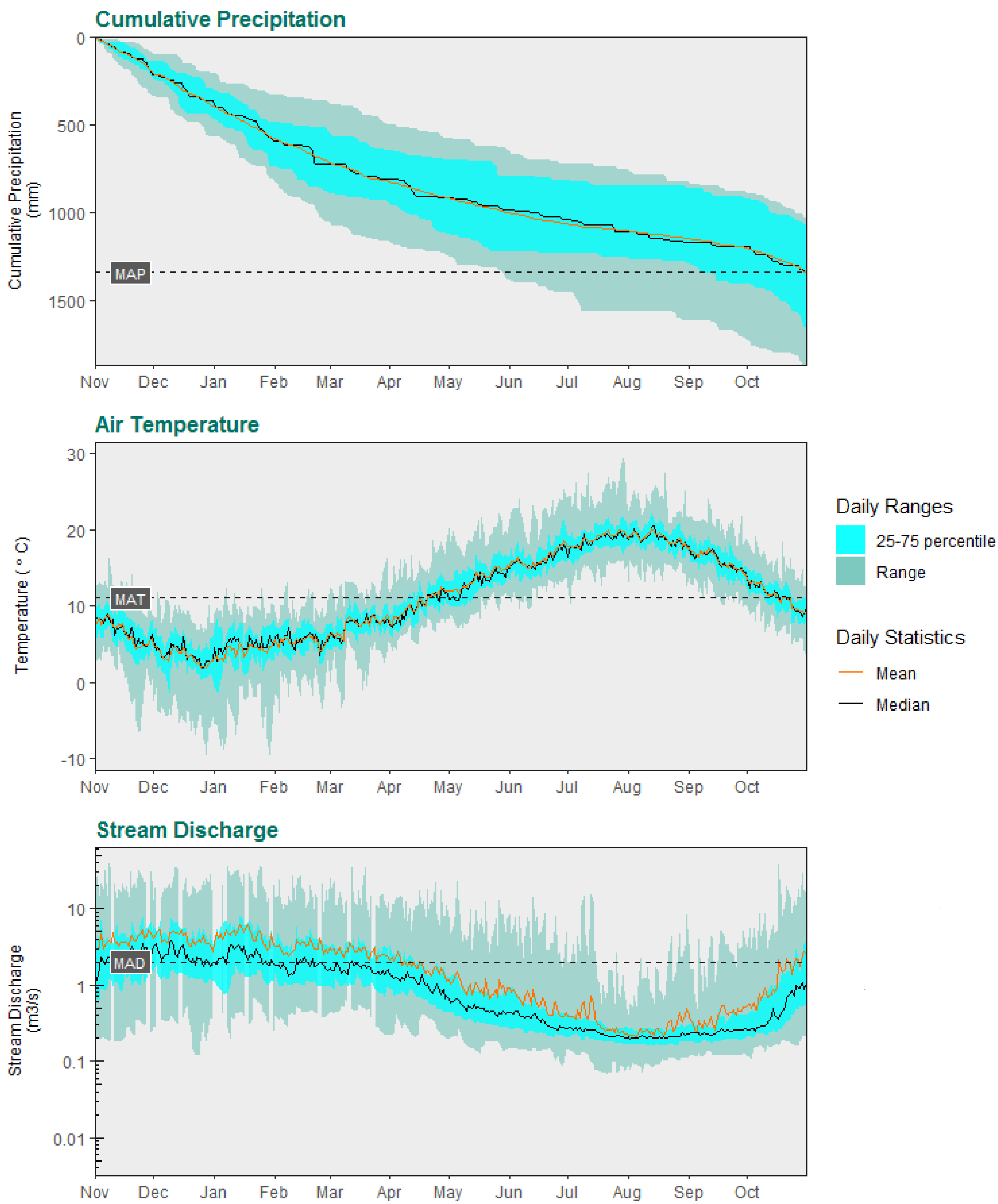
3.1 Climate

The climatic conditions in the study watersheds are typical of Pacific Northwest climate patterns and are represented by numerous climate stations including the nearby Cloverdale East Climate Station, 2 km from Langley City. Figure 3 displays the long-term (1964-2016) daily statistics of precipitation and temperature recorded at Cloverdale East. Daily temperatures typically reach their minimum of near +2°C in late December and their maximum of approximately +20°C by early August. Mean annual temperature (MAT) is approximately 11°C. Mean annual precipitation (MAP) is approximately 1340 mm, of which two-thirds occurs in the first half of the water year (November to April) and the remaining third from May to October. Mean monthly precipitation sums for July, August and September are all under 60 mm and represent the driest months of the year. Snowpack accumulation is uncommon during winter, and flows are primarily driven by rainfall inputs and groundwater baseflow.

3.2 Streamflows

The consolidated, gauged flow time-series for the Nicomekl River at the mid-watershed gauge 08MH155 contained 18,084 daily flow values in total, equivalent to a record length of approximately 50 years. Figure 3 displays the resulting year-round hydrologic regime on a daily timeframe. The highest and lowest flows occur during winter and summer months, respectively, consistent with the seasonal pattern of (primarily) rainfall inputs as described above. The long-term mean annual discharge (MAD) was calculated as 2.0 m^3/s. Mean monthly discharges (MMD) ranged from above 4 m^3/s in December and January to below 1 m^3/s from May to October (minimum 0.28 m^3/s in August). Daily flow values have ranged from 0.07 m^3/s to 61.6 m^3/s.

The pro-rated MAD values for the other established EFN nodes along the Nicomekl River were 4.6 m^3/s and 0.2 m^3/s at the lower and upper reaches, respectively. The MAD values for the established EFN nodes along the Serpentine River, estimated by pro-rating the Nicomekl River data, were 3.5 and 1.5m^3/s for the lower and upper reaches, respectively.



Note: Daily precipitation and temperature data from Cloverdale East Climate Station (Environment Canada Station 1101708); 1965-2016; data gaps are excluded (not infilled) from analysis. Daily flow data from consolidated Nicomekl River flow record; 1965-2014. note the use of log-axis applied. Corresponding long-term Mean Annual Precipitation (MAP), Temperature (MAT) and Discharge (MAD) given.

Figure 3: Daily cumulative precipitation statistics, temperature statistics, and flow statistics from the Nicomekl River watershed.

3.3 Water Demand

The monthly and annual water demand estimates are displayed in Figure 4 for the Licensed-Case and Actual-Case scenarios, specific to the assessment locations in the lower reaches of both study rivers. Agricultural Land Use Inventory Maps (2010) for the Township of Langley area cover the Nicomekl watershed east from Langley City, indicating that the headwater areas contain predominantly mixed-use farming consisting of forage and pasture activities, and some cultivation of field-crops (e.g., blueberries). While a small portion of land cover overall, several greenhouses and crop barns are concentrated close to the upper Nicomekl River.

In both watersheds, licensed water volumes increased considerably prior to 2000 but have remained essentially constant after 2000 given that both rivers are currently classified as 'fully recorded', i.e., no further surface water licenses have recently been considered. The average water demand, determined for the 10 farms assessed across the two watersheds using the BC agriculture calculator, was 4,257 m^3 per hectare, with a relatively limited spread between farms (standard deviation 677 m^3). This is slightly higher than the provincial-scale estimate of irrigation water use (3,046 m^3 per hectare; Statistics Canada 2011), resulting in a higher naturalized MAD and corresponding EFN thresholds (i.e., more protective of the aquatic environment).

The proportion of licensed year-round and seasonal water demands was higher and lower, respectively, in the Serpentine watershed relative to the Nicomekl watershed. The proportion of watershed actively used for agriculture (i.e., with associated seasonal water demands) was estimated to be 34% for Nicomekl watershed, and 18% for Serpentine watershed; the higher coverage of urban areas (lower coverage of irrigated areas) in the Serpentine would support relatively greater year-round water use in this watershed. During July (peak water demand), the unlicensed water demand (Actual-Case) was approximately three times higher than the amount of estimated, licensed demand (Licensed-Case) in both watersheds. Potential demand variations at daily time scales were not considered with the adopted approach of interpolating water demands between the respective average monthly values assigned to the mid-point of each month (Section 2.1.2.4).

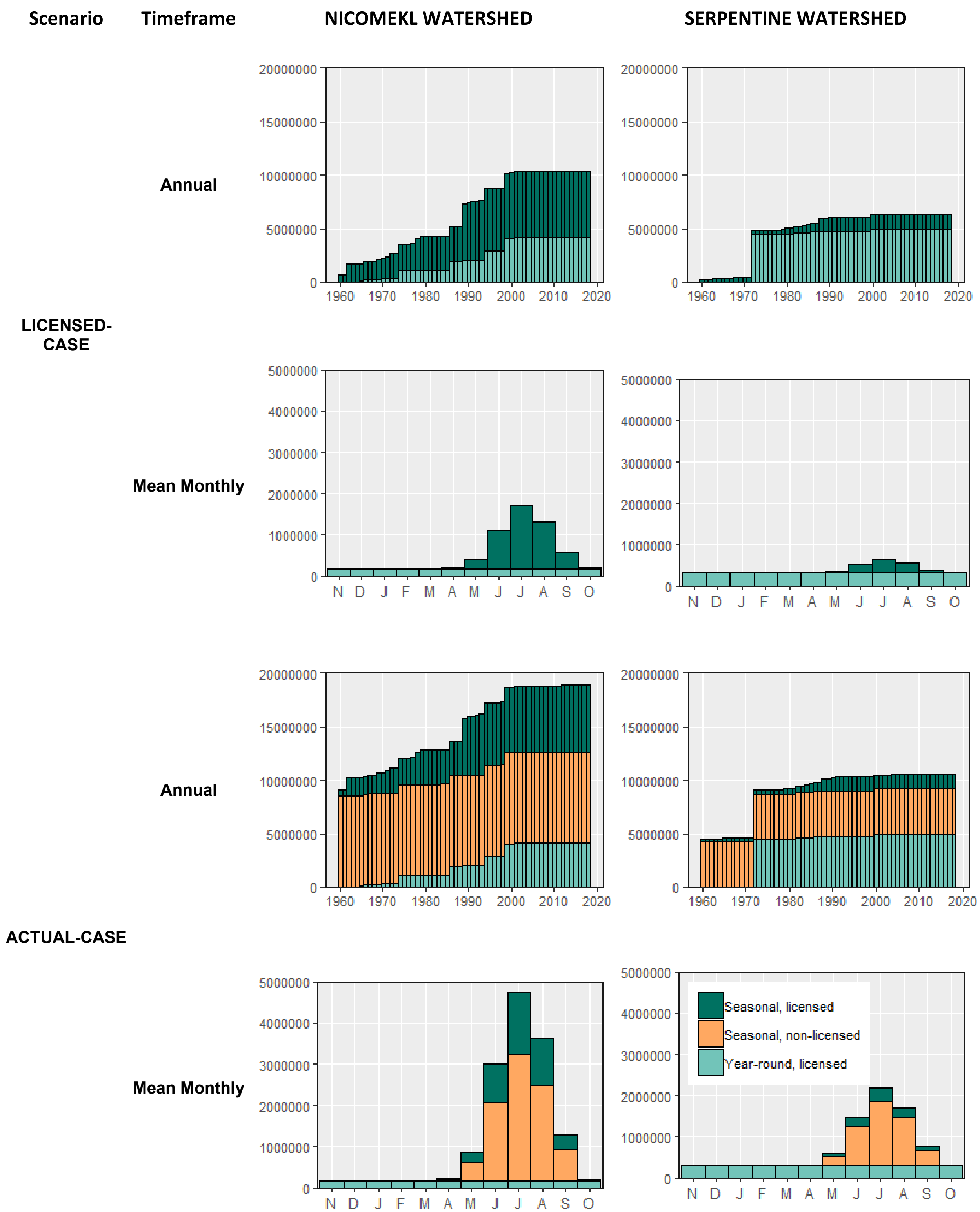


Figure 4: Water demand estimates (m³) for the Licensed-Case and Actual-Case scenarios at the lower reach assessment nodes.

3.4 Fish and Fish Habitat

3.4.1 Desktop Analysis

The Serpentine and the Nicomekl rivers support Chinook Salmon (*Oncorhynchus tshawytscha),* Coho Salmon*,* Chum Salmon (*O. keta),* as well as anadromous and resident Coastal Cutthroat Trout (CCT) and Rainbow Trout/Steelhead Trout (*O. mykiss;* DFO 1999a)*.* Pink Salmon (*O. gorbuscha*) have also been reported in the Nicomekl River (DFO, 1999a, 2007). Some of these fish populations are supplemented by hatcheries located in the headwaters of each river, which release Chinook, Coho, and Chum salmon, and Steelhead/Rainbow Trout annually (Serpentine Enhancement Society 2019, Nicomekl Hatchery 2018). Coarse fish species such as Threespine Stickleback (*Gasterosteus aculeatus*), Prickly Sculpin *(Cottus asper*), and Western Brook Lamprey *(Lampetra richardsoni)* also inhabit the Serpentine and Nicomekl rivers (DFO, 1999a).

Each river has been classified into macroreaches based on a combination of gradient, changes in discharge, and/or identified obstructions to fish movement using a combined desktop analysis and field verified (site photos in Appendix A). The Nicomekl River has been delineated into three main reaches (Figure 1):

- The Upper Reach extends from the headwaters near 56 Avenue and 232 Street to the confluence of Nicomekl River/Murray Creek near 208 Street and Fraser Highway. The gradient of this reach ranges from 0.0 to 6.0%. The site has some riparian cover from trees, shrubs and grasses. Channel form is slightly sinuous with muck substrate and evidence of downcutting.
- The Middle Reach extends from the Nicomekl/Murray confluence to the Nicomekl River/Anderson Creek confluence. This reach has a gradient ranging from 0.0 to 6.0%. Similar to the Upper Reach, this reach has some riparian cover with evidence of downcutting.
- The Lower Reach extends to the sea dam near King George Boulevard/Highway 99A. The majority of this reach is very low gradient (0.0 to 1.0%), with a few smaller portions that are up to 4.0% gradient. The Lower Reach break ends at the sea dam. The gates are closed at high tide and opened at low tide.

The Serpentine River has been delineated into two main reaches (Figure 2):

- The Upper Reach extends from the headwaters near 88 Avenue and 176 Street/Pacific Highway to about 500 m above the crossing of Serpentine River under 56 Avenue. This reach is low gradient (0.0 to 2.0%) and is highly modified: the mainstem is channelized, many tributaries join the mainstem through culverts and ditches, and there is minimal to no riparian and instream cover. The reach break represents a point where many sub-catchments flow into the Serpentine River, increasing discharge through the mainstem.
- The Lower Reach extends to the sea dam, near King George Boulevard/Highway 99A. This reach is low gradient (0.0 to 1.5%) with a sinuous channel form. The Lower Reach break ends at the sea dam, to exclude any tidal influence. The sea dam closes at high tide to prevent the intrusion of salt water but also blocks fish passage. At low tide the gates open, allowing the river to flow into the estuary and triggering aggregated fish to enter the river.

Generally, the mainstem provides a migratory corridor for fish to reach tributaries that offer much higher quality spawning and rearing habitat. The Upper Reach in the Nicomekl River has been documented as spawning habitat by DFO (1999a). However, no evidence of spawning habitat was noted during the limited site visit on February 27, 2019. Given that the field survey was not extensive, a conservative approach has been applied to the Upper Reach and deemed spawning habitat per DFO

(1999a). Dyke construction, channelization and regular channel maintenance have reduced spawning and rearing habitat, decreased riparian cover and instream features (e.g., large woody debris) (DFO 1999b, FLNR no date). It is expected that rearing fish will seek out suitable habitat with changing environmental conditions. For example, in urban areas juvenile Coho tend to migrate from areas where poor water quality and high temperatures inhibit their growth, to more suitable areas, such as deeper pools with adequate overhead cover (DFO 1999b).

3.4.2 Fish Periodicity

Criteria for timing and magnitude of instream flows are determined, in large part, by the seasonal timing of habitat use by fish in a particular stream reach. Reliable information on life-history timing and use of specific habitats in streams typically requires considerable effort over several years (Lewis et al. 2004). To date, these types of studies have not been conducted in the Serpentine or Nicomekl rivers, thus the estimation of fish periodicity for both systems has been based on existing literature (e.g., Sandercock 1991, Slaney and Roberts 2005) and local knowledge (e.g., Serpentine Enhancement Society 2019). A fish periodicity chart summarizing the estimated timing of key life-history phases for Coho Salmon and Coastal Cutthroat Trout is summarized in Table 3. These species were selected as they are most sensitive to flow (environmental) changes, thus they serve as umbrella species for deriving EFN thresholds. Providing sufficient flow for these species will indirectly protect the other species (listed above) that utilize both the Serpentine and Nicomekl mainstems.

Table 3: Life-history and periodicity for Coho Salmon and Coastal Cutthroat Trout for the Serpentine and Nicomekl rivers.

Species	Life-History	Life-History Stage	Bioperiod											
			Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Coho Salmon	Migratory	Spawning Migration [1,2]									■	■	■	
		Spawning [2]	■										■	■
		Egg Incubation [2]	■	■	■	■ (first half)								
		Juvenile Rearing (feeding) [2]			■	■	■	■	■	■	■	■	■	
		Juvenile Overwintering [2,3]	■	■										■
		Smolt Outmigration [1,2]		■ (second half)	■	■	■							
Coastal Cutthroat Trout	Resident/ Migratory (sea-run)	Spawning Migration [4]		■ (second half)	■	■ (first half)								
		Spawning [4]			■	■	■ (first half)							
		Egg Incubation [4]				■ (second half)	■	■						
		Adult Outmigration (sea-run) [4]				■	■							
		Rearing (feeding) [4]			■	■	■	■	■	■	■	■	■	
		Overwintering [3,4]	■	■										■
		Smolt Outmigration (sea-run) [4]			■	■	■	■						

[1] Serpentine Enhancement Society 2019.

[2] Sandercock 1991.

[3] Professional opinion based on local conditions.

[4] Slaney and Roberts 2005.

3.5 Environmental Flow Needs Threshold Determination

EFN threshold values were calculated for the five example assessment locations, within five macro-reaches on the Nicomekl and Serpentine rivers. As outlined in Section 2, the EFN assessment was done on modelled long-term daily naturalized flows for an approximate 50-year period, obtained by combining daily gauged flows with water demand data (estimated monthly, then downscaled to a daily time step). The EFN threshold values were subsequently calculated for a monthly timestep, using the BC Modified Tennant and the BC Recommended Instream Flow Methods. The resulting EFN threshold values are discussed in the following sections, and illustrated graphically for each established assessment location on the Nicomekl River (Figure 5 to Figure 7) and on Serpentine River (Figure 8 and Figure 9). Table 4 provides a tabulated summary of each EFN threshold value.

The BC Modified Tennant Method specifies different flow needs (%MAD) corresponding to different time blocks related to fish life stages and use (based on the species periodicity/bioperiods, shown in Table 3). When different fish life stages and use (and associated different flow need requirements) can occur at the same period of time (e.g., rearing, spawning, incubation and migration in May), the most conservative (highest) of the flow need requirements was selected for the EFN value. EFN values were selected based on periodicity of the two-representative species (Coho Salmon and Coastal Cutthroat Trout) and naturalized MAD values for the different reaches of the Serpentine and Nicomekl rivers. Coho Salmon and sea-run Coastal Cutthroat Trout are both considered 'large fish', therefore the spawning/migration equation for large fish was applied, as recommended by Ptolemy and Lewis (2002). Taking into account the most conservative flow requirements for bioperiod and the representative species, the EFN threshold values applied to the Nicomekl and Serpentine rivers are as follows:

- September 1 to April 30, %MAD calculated by: $148*MAD^{-0.36}$
- May 1 to August 31, 55% MAD.

It is noted that the migration and spawning bioperiod for Coastal Cutthroat Trout extends to mid-May (Table 3), but the corresponding threshold calculation was only extended to the end of April. In Figure 5 to Figure 9, the EFN thresholds are presented along with pertinent naturalized flow statistics, including MAD, MMD, the P10 to P90 and P20 to P80 percentile flow ranges (of which P20 and P90 are used within the BC Recommended Instream Flow Method). Separate plots are shown for each established macro-reach, to display the difference in naturalized flow statistics calculated using the Licensed-Case and Actual-Case water demand scenarios. The gauged MMD values, which represent the long-term average monthly water supply in each river, are shown for comparison in each figure. Figure 10 displays a complete overview of the monthly differences between gauged MMD values and each EFN threshold, for each macro-reach location and water demand scenario. Positive and negative values in Figure 10 indicate a monthly surplus and deficit of water supply relative to each calculated EFN threshold, respectively. The results and findings are discussed below.

3.5.1 Nicomekl River

3.5.1.1 BC Modified Tennant Method

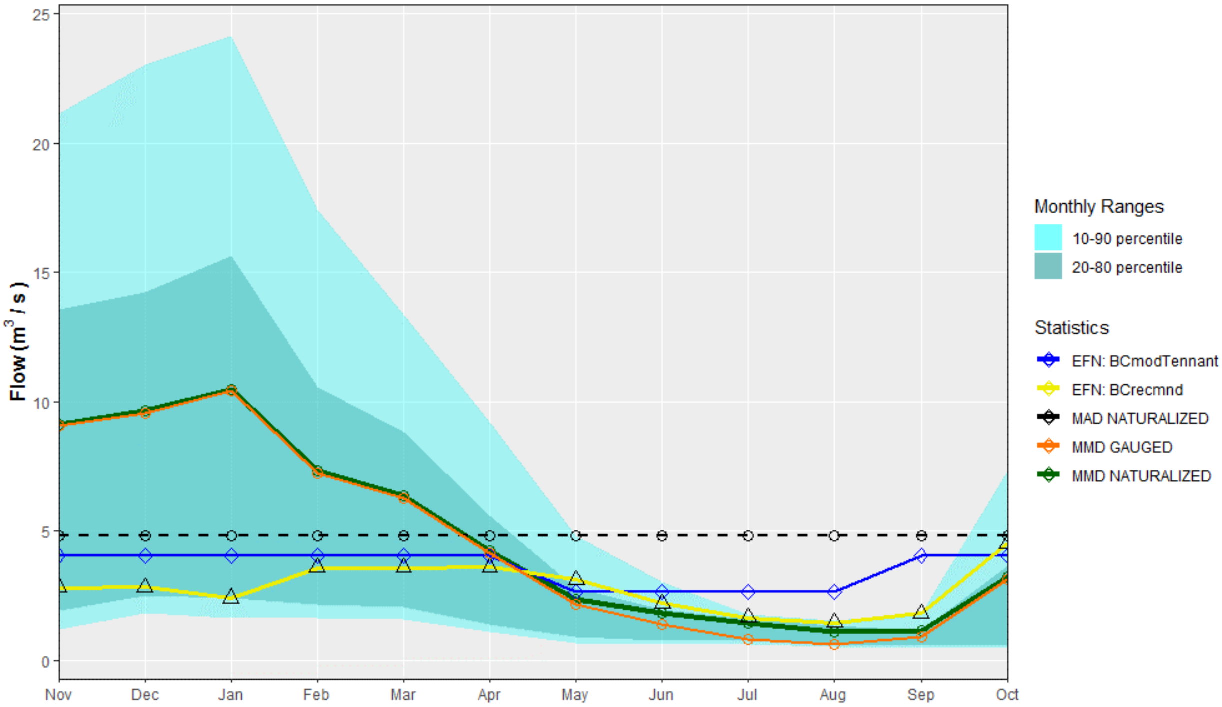
On the Lower Reach of the Nicomekl River, between September 1 and April 30, the spawning and migration EFN value corresponding to $148*4.80^{-0.36}$ (84% MAD) is 4.04 m^3/s for the Licensed-Case and $148*5.08^{-0.36}$ (82% MAD) or 4.19 m^3/s for the Actual-Case (shown in blue lines in the corresponding Figure 5 plots). On the Middle Reach of the Nicomekl River, between September 1 and April 30, the spawning and migration EFN value corresponding to $148*2.05^{-0.36}$ (114% MAD) is 2.35 m^3/s for the Licensed-Case and $148*2.19^{-0.36}$ (111% MAD) or 2.44 m^3/s for the Actual-Case (Figure 6). On the Upper Reach of the Nicomekl River, between September 1 and April 30, the spawning and migration EFN value corresponding to 148*$0.21^{-0.36}$ (259% MAD) is 0.545 m^3/s for the Licensed-Case and 148*$0.231^{-0.36}$ (251% MAD) or 0.579 m^3/s for the Actual-Case (Figure 7). The spawning and migration EFN threshold was selected to ensure sufficient flow for migration and spawning of Coastal Cutthroat Trout (February 15 to May 15) and Coho Salmon (September 1 to January 31). Spawning requires higher flows to allow access to suitable habitat, with larger fish tending to require deeper water. This EFN value will provide suitable flows for spawning adults.

The EFN threshold for rearing adults corresponds to 55% MAD, which applies from May 1 to August 31. In the Lower Reach of the Nicomekl River this value is equivalent to 2.64 m^3/s for the Licensed-Case and 2.79 m^3/s for the Actual-Case (Figure 5). In the Middle Reach of the Nicomekl River this value is equivalent to 1.13 m^3/s for the Licensed-Case and 1.20 m^3/s for the Actual-Case. In the Upper Reach of the Nicomekl River this value is equivalent to 0.116 m^3/s for the Licensed-Case and 0.127 m^3/s for the Actual-Case. Resident Coastal Cutthroat adults, as well as juvenile Coho Salmon and Coastal Cutthroat Trout are likely to use the Nicomekl River for rearing. Sea-run Coastal Cutthroat Trout are expected to out-migrate to the Pacific Ocean. During this time period fish will seek out suitable habitat with changing environmental conditions and adequate foraging opportunities. For example, in urban areas juvenile Coho Salmon tend to migrate from areas where poor water quality and high temperatures inhibit their growth, to more suitable areas, such as deeper pools with adequate overhead cover (DFO, 1999b). This type of habitat is less sensitive to changes in flow, thus this EFN value should provide sufficient water quantity to provide suitable habitat for all fish species inhabiting the Nicomekl River during this bioperiod.

3.5.1.2 BC Recommended Instream Flow Method

In the Lower Reach of the Nicomekl River during the lowest flow month (September), the EFN value is 1.82 m^3/s for the Licensed-Case record and 2.17 m^3/s for the Actual-Case record (shown in yellow lines in Figure 5 plots). In the Middle Reach of the Nicomekl River during the lowest flow month (September), the EFN value is 0.764 m^3/s for the Licensed-Case record and 0.926 m^3/s for the Actual-Case record (yellow lines in Figure 6 plots). In the Upper Reach of the Nicomekl River during the lowest flow month (September), the EFN value is 0.082 m^3/s for the Licensed-Case record and 0.322 m^3/s for the Actual-Case record (lowest flow in October, yellow lines in Figure 7 plots). Under the Actual-Case record, the highest EFN value occurs in October in all three reaches, corresponding to 6.30 m^3/s in the Lower Reach (Figure 5), 2.71 m^3/s in the Middle Reach (Figure 6), and 0.322 m^3/s in the Upper Reach (Figure 7). Similarly, under the Licensed-Case record, the highest EFN value also occurs during October in the Lower Reach (4.54 m^3/s, Figure 5) and Middle Reach (1.95 m^3/s, Figure 6), and Upper Reach (0.215 m^3/s, Figure 7).

Licensed-Case Scenario



Actual-Case Scenario

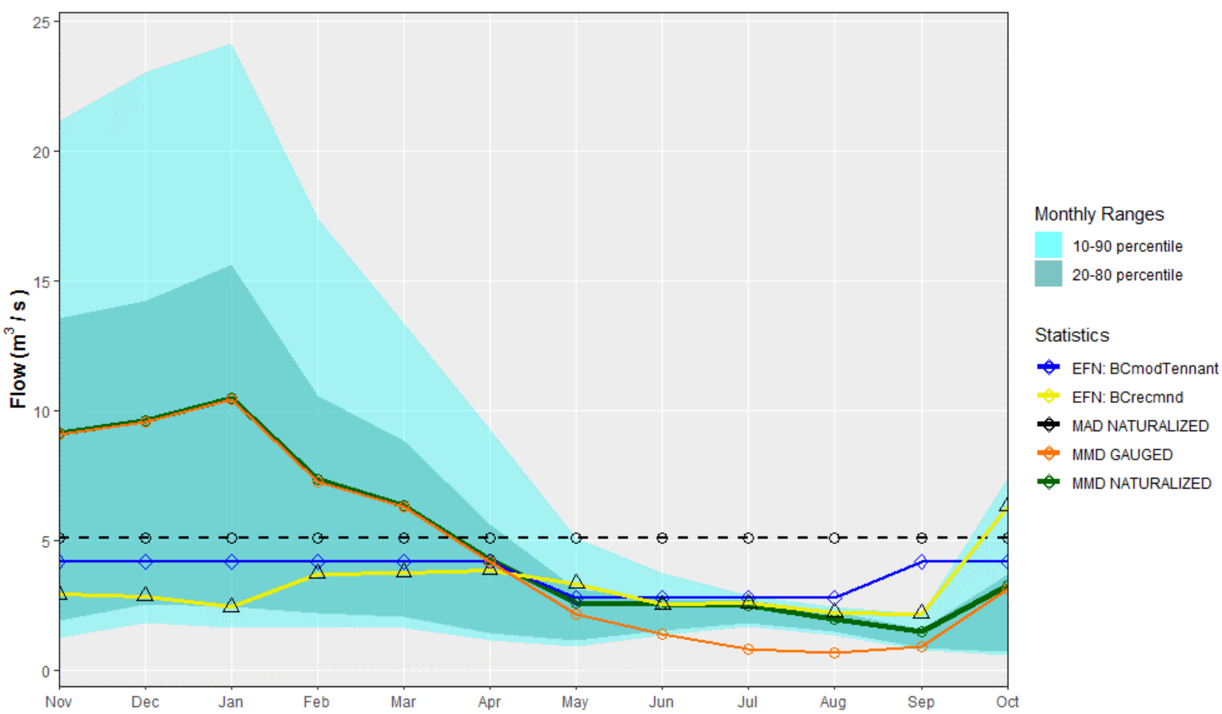
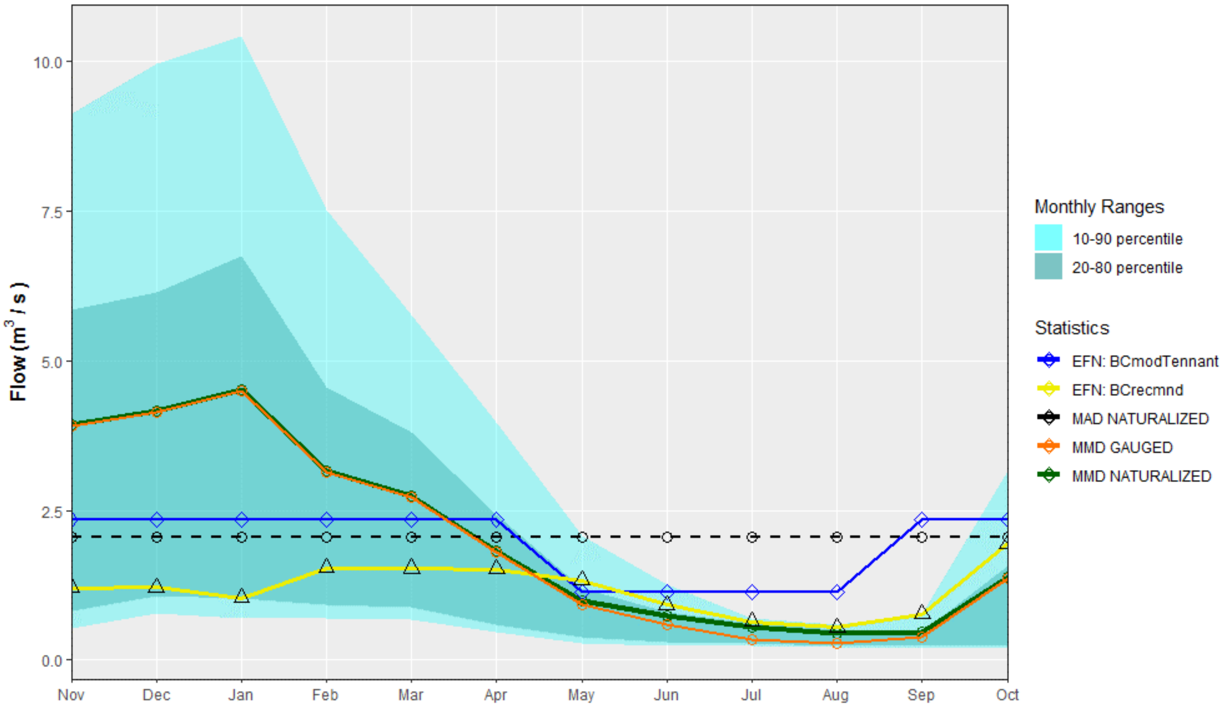


Figure 5: EFN values calculated for Lower Nicomekl River Reach together with naturalized monthly flow ranges.

Licensed-Case Scenario



Actual-Case Scenario

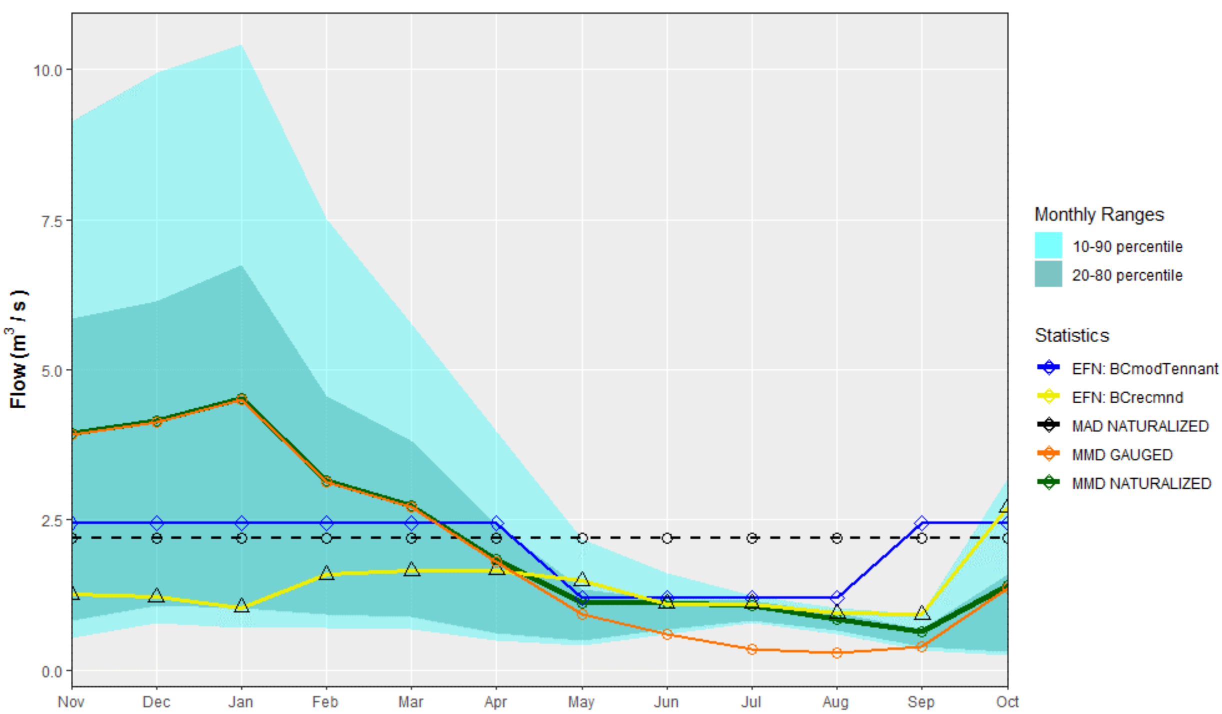
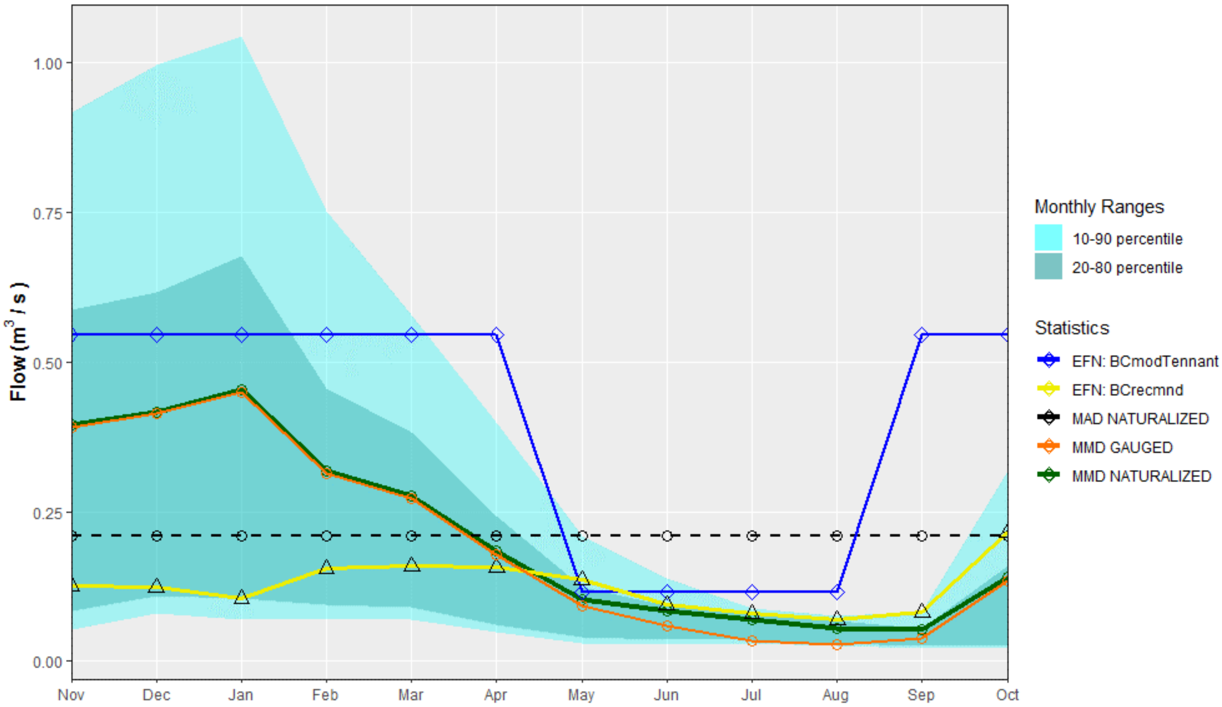


Figure 6: EFN values calculated for Middle Nicomekl River Reach together with naturalized monthly flow ranges.

Licensed-Case Scenario



Actual-Case Scenario

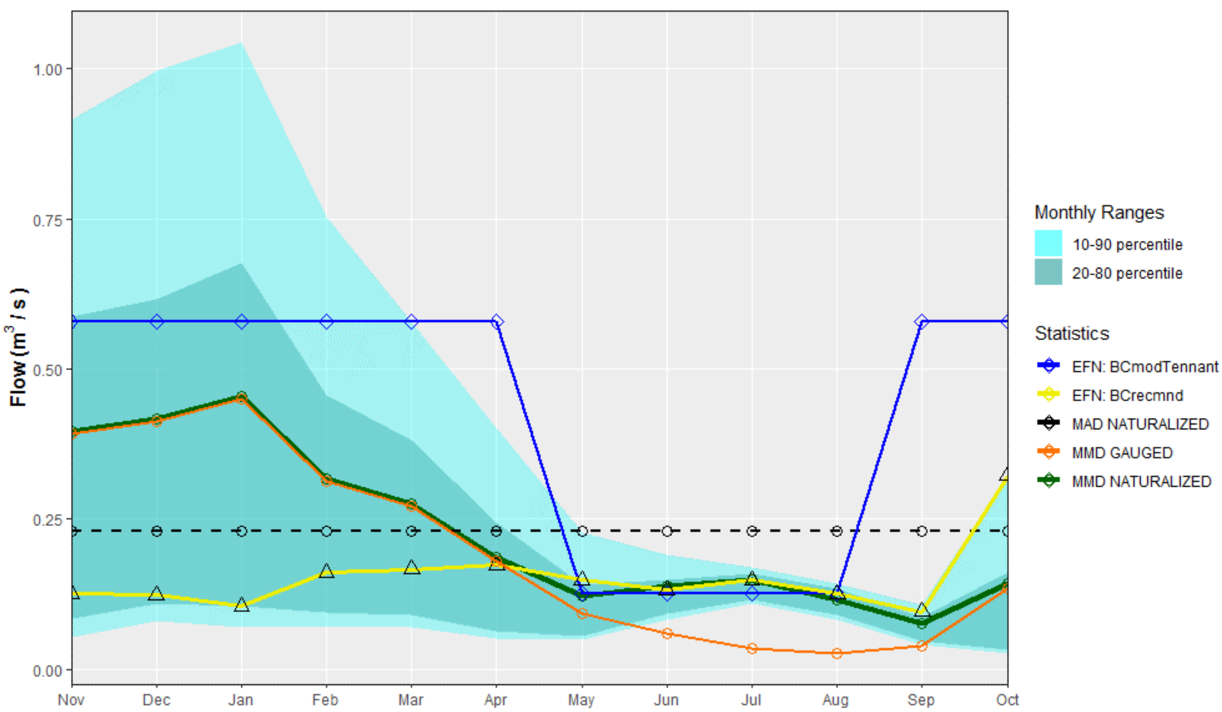


Figure 7: EFN values calculated for Upper Nicomekl River Reach together with naturalized monthly flow ranges.

3.5.2 Serpentine River

3.5.2.1 BC Modified Tennant Method

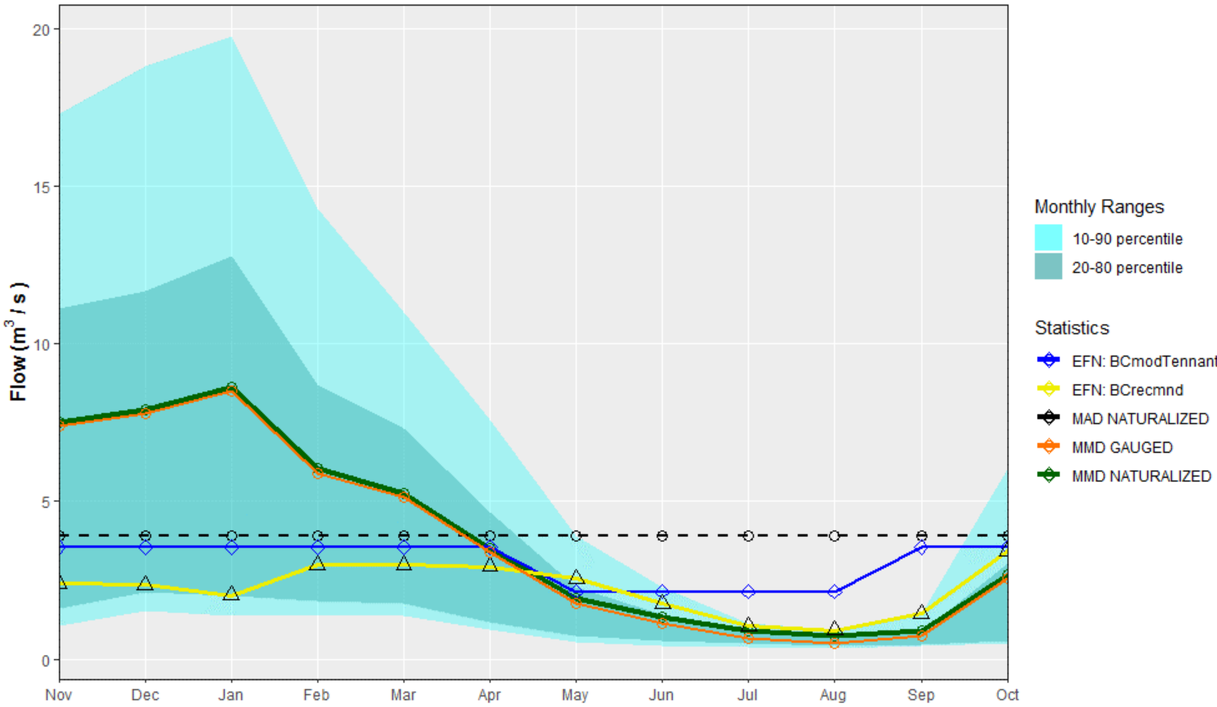
On the Lower Reach of the Serpentine River, between September 1 and April 30, the spawning and migration EFN value corresponding to $148*3.90^{-0.36}$ (91% MAD) is 3.54 m^3/s for the Licensed-Case and $148*4.04^{-0.36}$ (90% MAD) or 3.62 m^3/s for the Actual-Case (shown in blue lines in the corresponding Figure 8 plots). On the Upper Reach of the Serpentine River, between September 1 and April 30, the spawning and migration EFN value corresponding to $148*1.55^{-0.36}$ (126% MAD) is 1.96 m^3/s for the Licensed-Case and $148*1.57^{-0.36}$ (126% MAD) or 1.98 m^3/s for the Actual-Case (Figure 9 plots). The spawning and migration EFN threshold has been selected to ensure sufficient flow for migration and spawning of Coastal Cutthroat Trout (February 15 to May 15) and Coho Salmon (September 1 to January 31). Spawning requires higher flows to allow access to suitable habitat, with larger fish tending to require deeper water. This EFN value will provide suitable flows for spawning adults.

The EFN threshold for rearing adults corresponds to 55% MAD, which applies from May 1 to August 31. In the Lower Reach of the Serpentine River this value is equivalent to 2.15 m^3/s for the Licensed-Case and 2.22 m^3/s for the Actual-Case (Figure 8). In the Upper Reach of the Serpentine River this value is equivalent to 0.850 m^3/s for the Licensed-Case and 0.865 m^3/s for the Actual-Case (Figure 9). Resident Coastal Cutthroat adults, as well as juvenile Coho Salmon and Coastal Cutthroat Trout are likely to use the Serpentine River for rearing. Sea-run Coastal Cutthroat Trout are expected to out-migrate to the Pacific Ocean. During this time period fish will seek out suitable habitat with changing environmental conditions and adequate foraging opportunities. It is our opinion this EFN value will provide suitable flows for rearing adults and juveniles.

3.5.2.2 BC Recommended Instream Flow Method

The BC Recommended Instream Flow Method was also applied to the Lower and the Upper Reach on the Serpentine River. In the Lower Reach of the Serpentine River during the lowest flow month (September), the EFN value is 1.46 m^3/s for the Licensed-Case and 1.61 m^3/s for the Actual-Case (yellow lines in Figure 8 plots). In the Upper Reach of the Serpentine River during the lowest flow month (September), the EFN value is 0.583 m^3/s for the Licensed-Case and 0.615 m^3/s for the Actual-Case (yellow lines in Figure 9 plots). The highest EFN value occurs in October in both reaches, corresponding to 4.08 m^3/s in the Lower Reach and 1.47 m^3/s in the Upper Reach for the Actual-Case, and 3.44 m^3/s in the Lower Reach and 1.36 m^3/s in the Upper Reach for the Licensed-Case.

Licensed-Case Scenario



Actual-Case Scenario

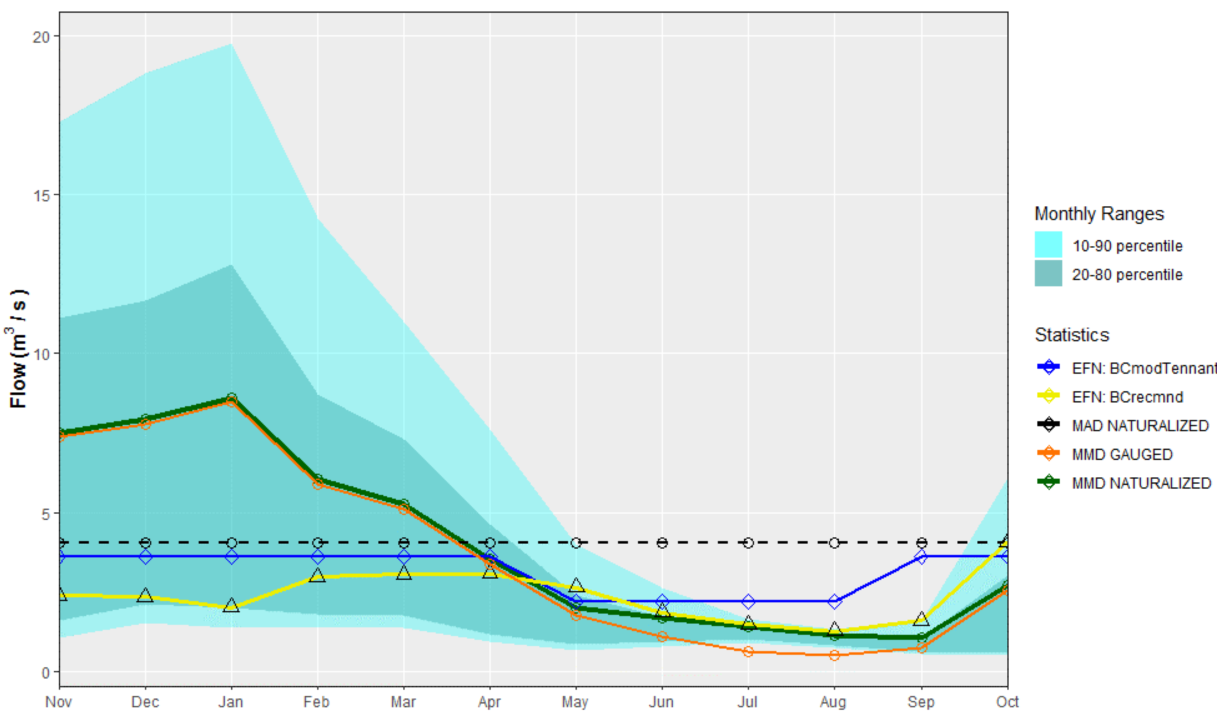
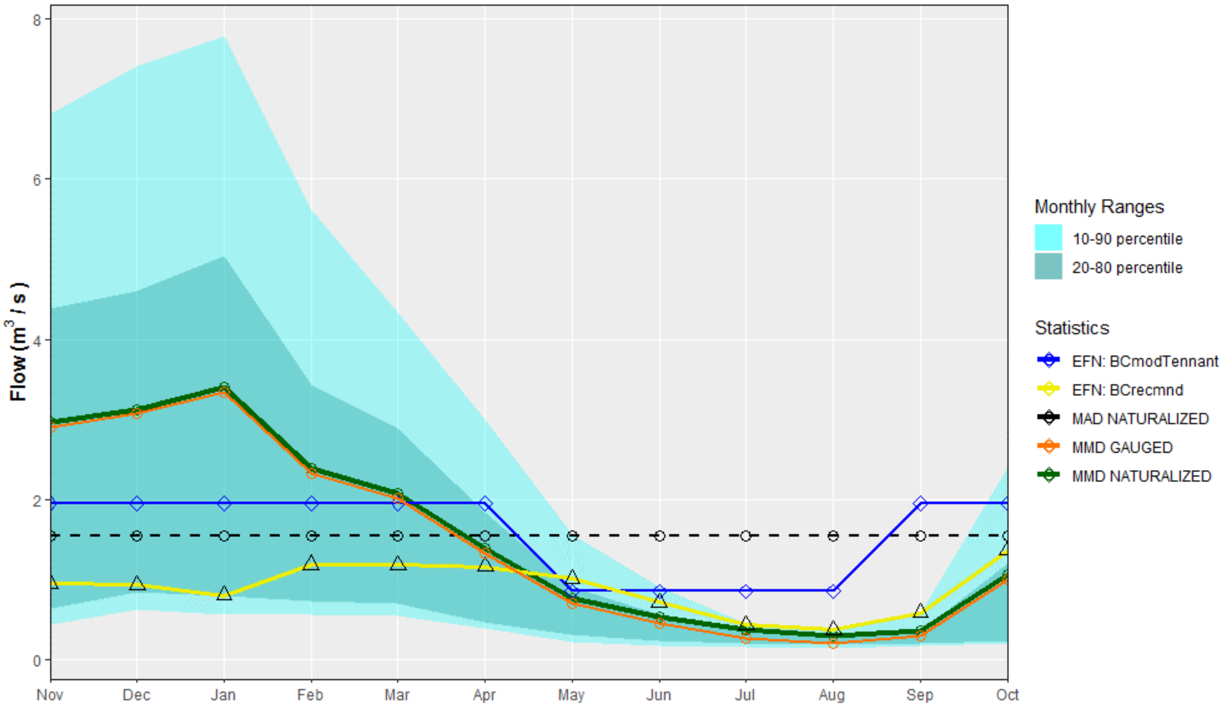


Figure 8: EFN values calculated for Lower Serpentine River Reach together with naturalized monthly flow ranges.

Licensed-Case Scenario



Actual-Case Scenario

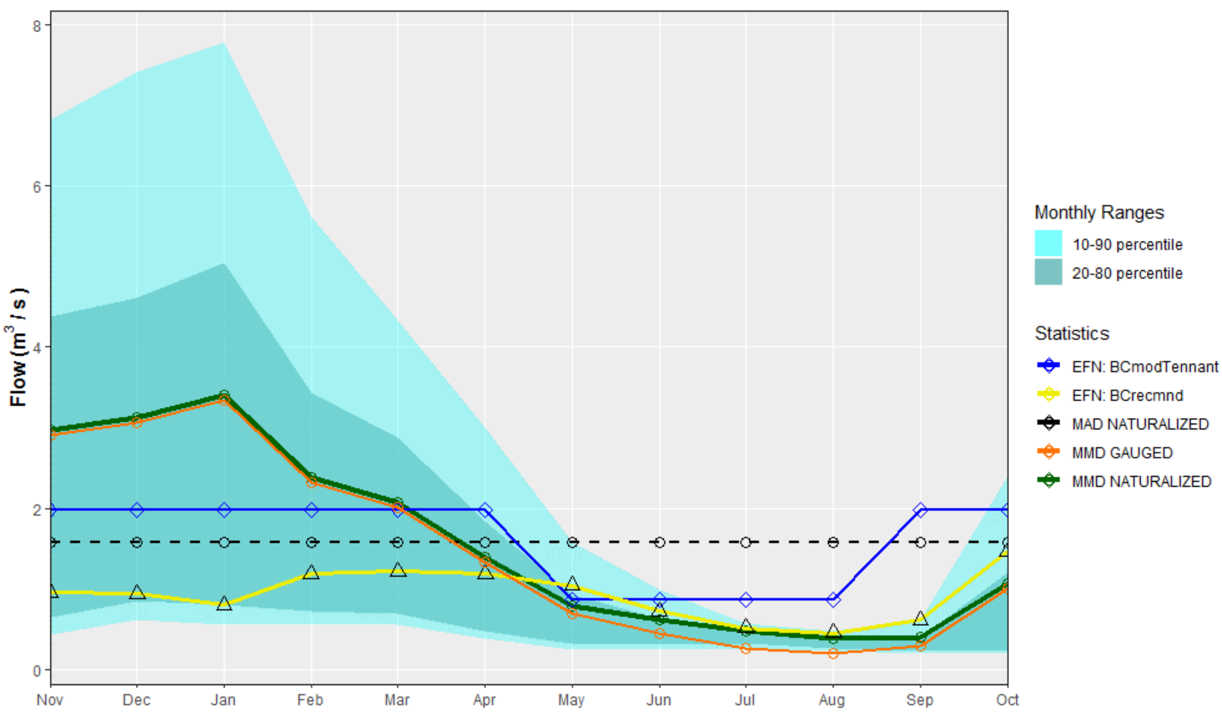


Figure 9: EFN values calculated for Upper Serpentine River Reach together with naturalized monthly flow ranges.

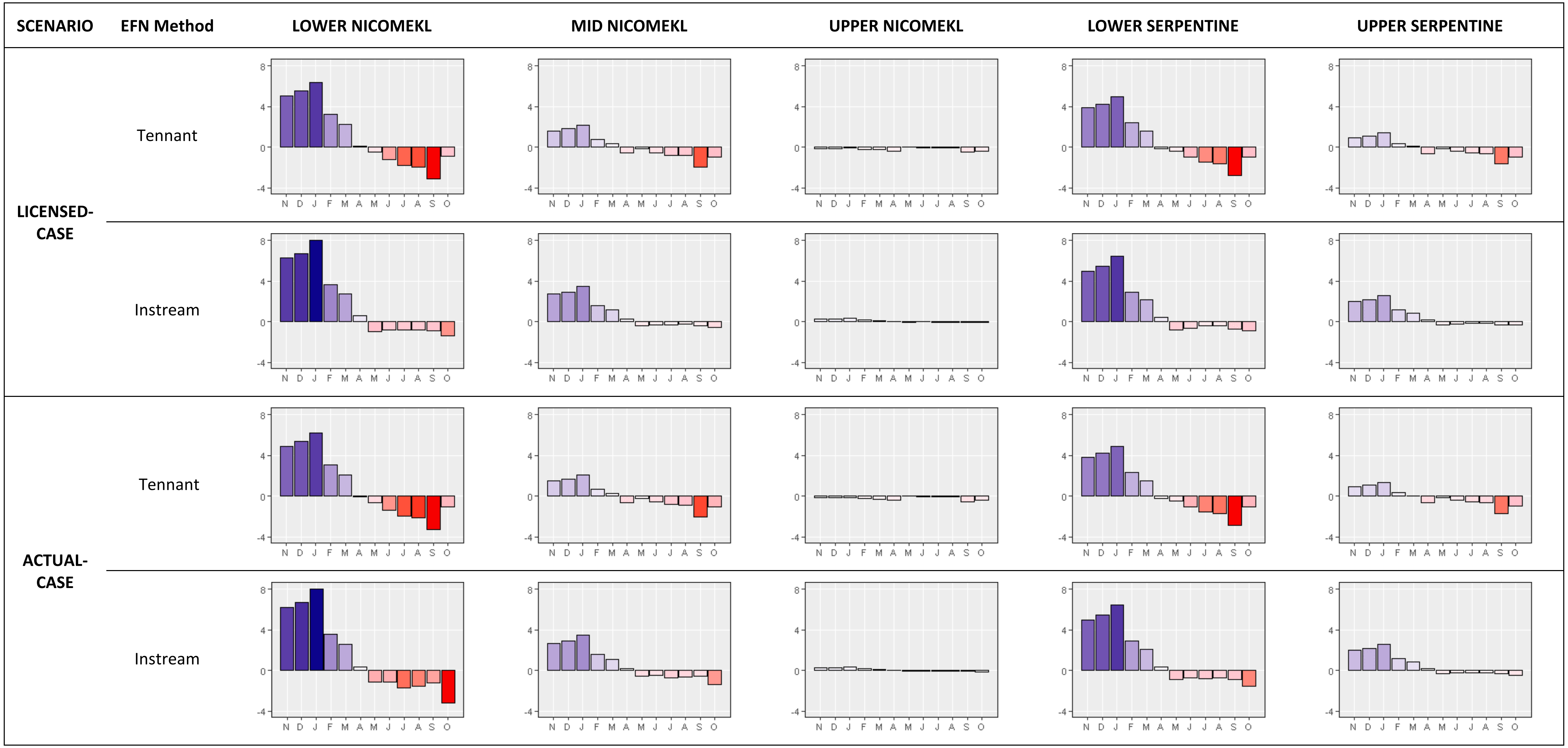


Figure 10: Average monthly difference between gauged MMD and naturalized EFN thresholds (in m^3/s) for all study reaches.

3.5.3 Summary

The BC Modified Tennant Method and the BC Recommended Instream Flow Method follow two differing approaches to determining environmental flow needs for systems that inhabit fish. Generally, the BC Modified Tennant is more conservative than the BC Instream Flow threshold approach for fish bearing streams. Since the BC Recommended Instream Flow Method is less conservative than the BC Modified Tennant Method, it provides for greater water withdrawal in higher flow months. The BC Modified Tennant Method does yield EFN values that exceed naturalized flows in the low flow months whereas the BC Recommended Instream Flow Method provides results at upper end of natural monthly flows during these months. Regardless, flow deficit results for both methods (Figure 10) indicate that no water withdrawal should occur from late spring (April) to fall (October). The BC Modified Tennant method considers more ecological data (e.g., species, life-history, periodicity), thus is likely more applicable for protecting fisheries values as it considers the ecological use specific to the system. The inclusion of an ecological flow threshold (flushing/connectivity) as recommended by Hatfield et al. (2003) was also considered but given that both river systems do not experience flows greater than about 200% MAD, this method was not used as the flows experienced in each system are not sufficient.

A summary of environmental flow thresholds (broken down on a monthly timescale) calculated for the five example assessment locations, within each of five macro-reaches, is provided in Table 4. It is noted that these EFN values are provided as examples, and not intended to be applied at other sites within these reaches. If EFN values are required at alternate sites within these rivers, these tabulated EFN values should be pro-rated based on their relative catchment area compared to the assessment locations. Both water licences and farmland are generally evenly distributed along each example reach and watershed, except for the urban areas (e.g., Langley City). A linear pro-rating of water demand, naturalized flows, and ultimately the EFN values in Table 4, is therefore recommended if EFN values are required at other sites. The resulting uncertainties associated with this linear prorating are consistent with a coarse desktop based EFN threshold determination. Only a detailed, field-based assessment including site-specific monitoring of flow, hydraulic and habitat characteristics will serve to reduce these uncertainties that dominate naturalized flows and EFN thresholds in most months of the year except potentially July/August (i.e., when water demand becomes a significant factor for naturalized flows).

The EFN values are selected to take into account the impacts to downstream aquatic species and their habitat. As pressure on upper reaches is increased (e.g., increased water extraction), the EFN values will change within that reach as well as the downstream reaches. The BC Modified Tennant Method is more conservative (protective) of aquatic habitat and changes in flow which could impact aquatic species and their habitat. Generally, riffle (i.e., spawning) habitat is most sensitive to changes in flow. To date, riffle habitat has not been detected in the lower reaches of either the Nicomekl or Serpentine rivers. Spawning habitat has been documented in the Upper Reach of the Nicomekl River and multiple tributaries of both rivers (DFO 1999a), establishing streamflow gauges in these areas would considerably reduce the uncertainties in EFN thresholds derived for these important areas. More generally, as the catchment size decreases relative to the reference gauge (i.e., 95 km^2), the precision of pro-rated streamflows diminishes. It is also expected that the sensitivity of a watershed to flow extraction increases as its drainage area decreases. Any changes in flow above the Upper Nicomekl River Reach (i.e., in the tributaries) are therefore beyond the scope of this EFN determination.

Table 4: Summary of calculated environmental flow threshold values (m^3/s) applying the BC Modified Tennant Method (Tennant) and the BC Recommended Instream Flow Method (Instream) for inferred naturalized flows based on a) Licensed-Case and the b) Actual-Case scenarios.

a) Licensed-Case

Month	Nicomekl River						Serpentine River			
	Lower		Middle		Upper		Lower		Upper	
	Tennant	Instream	Tennant	Instream	Tennant	Instream	Tennant	Instream	Tennant	Instream
Jan	4.04	2.41	2.35	1.04	0.55	0.13	3.54	2.02	1.96	0.80
Feb	4.04	3.58	2.35	1.54	0.55	0.12	3.54	3.00	1.96	1.19
Mar	4.04	3.57	2.35	1.53	0.55	0.11	3.54	2.99	1.96	1.19
Apr	4.04	3.59	2.35	1.52	0.55	0.16	3.54	2.93	1.96	1.16
May	2.64	3.12	1.13	1.33	0.55	0.16	2.15	2.55	0.85	1.01
Jun	2.64	2.19	1.13	0.92	0.55	0.16	2.15	1.77	0.85	0.71
Jul	2.64	1.65	1.13	0.64	0.12	0.14	2.15	1.06	0.85	0.43
Aug	2.64	1.45	1.13	0.55	0.12	0.10	2.15	0.92	0.85	0.38
Sep	4.04	1.82	2.35	0.76	0.12	0.08	3.54	1.45	1.96	0.58
Oct	4.04	4.54	2.35	1.95	0.12	0.07	3.54	3.44	1.96	1.36
Nov	4.04	2.81	2.35	1.20	0.55	0.08	3.54	2.40	1.96	0.95
Dec	4.04	2.84	2.35	1.22	0.55	0.22	3.54	2.36	1.96	0.94

b) Actual-Case

Month	Nicomekl River						Serpentine River			
	Lower		Middle		Upper		Lower		Upper	
	Tennant	Instream	Tennant	Instream	Tennant	Instream	Tennant	Instream	Tennant	Instream
Jan	4.19	2.41	2.44	1.04	0.58	0.11	3.62	2.02	1.98	0.80
Feb	4.19	3.70	2.44	1.59	0.58	0.16	3.62	3.00	1.98	1.19
Mar	4.19	3.75	2.44	1.65	0.58	0.17	3.62	3.08	1.98	1.22
Apr	4.19	3.85	2.44	1.66	0.58	0.17	3.62	3.08	1.98	1.19
May	2.79	3.32	1.20	1.48	0.13	0.15	2.22	2.65	0.87	1.04
Jun	2.79	2.52	1.20	1.10	0.13	0.13	2.22	1.87	0.87	0.72
Jul	2.79	2.56	1.20	1.10	0.13	0.15	2.22	1.49	0.87	0.51
Aug	2.79	2.21	1.20	0.94	0.13	0.13	2.22	1.28	0.87	0.45
Sep	4.19	2.17	2.44	0.93	0.58	0.10	3.62	1.61	1.98	0.62
Oct	4.19	6.30	2.44	2.71	0.58	0.32	3.62	4.08	1.98	1.47
Nov	4.19	2.90	2.44	1.25	0.58	0.13	3.62	2.40	1.98	0.95
Dec	4.19	2.84	2.44	1.22	0.58	0.12	3.62	2.36	1.98	0.94

4. DATA GAPS AND UNCERTAINTIES

4.1 Historical Unlicensed Water Demand

While there are uncertainties present within licensed water allocations (i.e., the proportion actual consumed, and not returned to the environment), the uncertainties and data gaps within unlicensed water demands (particularly irrigation) are generally much larger. Unlike licensed water demands, unlicensed water volumes are not known spatially across the watershed (although they can be indirectly estimated from land use data as done herein), or temporally through the study period.

In this assessment, unlicensed water demands were estimated for actively farmed areas which constitute important proportions of each watershed. An Actual-Case assumption was applied throughout this assessment in which it was assumed that remotely sensed actively farmed areas (as of 2018) were consuming water equal to a rate estimated using the BC Agriculture database. Spatially, while a slight reduction was applied to account for areas with irrigation-based licences already present, the remaining amounts likely overestimate actual water demands given that all mapped farm areas do not require the full irrigation amounts applied from the BC Agricultural database. Temporally, the unlicensed water demand was assumed to be the same from year to year. While unlicensed water demands are likely higher in 2018 than in the 1960s and 1970s (consistent with the rise in allocated water volumes), there may be some reductions due to increasing urbanization and the efficiency of irrigation technology.

The estimation method applied therefore likely overestimates the amount of unlicensed water demand across each watershed. This results in estimates of naturalized flows and ultimately EFN thresholds which are biased high (i.e., conservative with respect to the level of protection afforded to fish habitat).

4.2 Groundwater Demand

Actual historical and current groundwater demand data for the Nicomekl and Serpentine watersheds are not available. As such, quantification of groundwater demand is an information gap for water balance studies. This gap is addressed in the companion study by Nunn et al. (2025) who provide a preliminary desk-top based estimate of groundwater demand in the watersheds, including non-agricultural uses such as municipal and commercial groundwater use. Field surveys are also suggested as another means of quantifying groundwater demand.

For the purposes of establishing EFN thresholds for the two systems, all inferred unlicensed water use for agricultural purposes was assumed to come from surface water withdrawal or if derived from groundwater pumping, have an instantaneous and directly correlated impact on stream flow. This does not reflect that a significant proportion of this unlicensed water demand may be met by groundwater pumping. Groundwater pumping could potentially have limited or no impacts on stream flows (e.g., for hydraulically unconnected aquifers or confined aquifers); and there may be a significant lag time between pumping and instream effects. This is also investigated further in Nunn et al. (2025).

4.3 Water Service Areas

A portion of the existing water demand in the study area is associated with municipal water service areas. However, there is uncertainty related to actual extent of these areas and the degree to which water demand is met by municipal supply in these areas. Water demand in serviced areas may be met by municipal water sources which originate from outside of the watershed. As such, this demand may not directly impact surface water flows or groundwater, or the water balance of the study area.

The following specific data gaps are related to water service and disposal within the Nicomekl and Serpentine watersheds:

- Information regarding the City of Surrey water service areas is available (City of Surrey 2017). However, water service areas in the Township of Langley cannot be readily confirmed by available data;
- In some areas, a significant source of municipal water supply is from groundwater (e.g., the Township of Langley is groundwater). Detailed information regarding the impacts from groundwater withdrawal and connectivity to surface watercourses in the study area is not readily available (this is addressed further in Nunn et al. 2025); and
- While the majority of the population and industry within the Cities of Langley and Surrey are serviced by an extensive sanitary sewer network that is connected to the Metro Vancouver network (i.e., effluent is directed outside of the study area), a portion of this demand may be retained/discharged into the watershed as return flows (e.g., from irrigation).

4.4 Return Flows

Return flows have not been quantified and are not accounted for in this screening assessment. These could be unaccounted inputs into a water balance, as could leaks from associated infrastructure. These potential inputs could potentially be assessed as part of a sensitivity analysis, using available published estimates online (e.g., of estimated water loss volumes through leaks, etc.).

5. CONCLUSIONS

The BC Recommended Instream Flow Threshold Method and BC Modified Tennant Method suggest that water is available for withdrawal in the winter during high flows, whereas no water is available for withdrawal during the low-flow summer months. The differences between the two approaches are primarily related to the amount of water potentially available for use during high flows and transitionary periods in spring and fall, with the BC Modified Tennant thresholds offering a more conservative (protective) threshold. Example EFN values were calculated for five assessment locations, within five macro-reaches, on the Nicomekl and Serpentine Rivers. Possible approaches to calculating EFN values that would apply to specific sites could include pro-rating these EFN values by the relative catchment area for a site of interest (e.g., identified Point of Diversion within a future water license application), or determination of a conservative, screening EFN value (based on MAD at the bottom of each reach) that could be applied to the upgradient portions of that reach.

6. RECOMMENDATIONS

The BC-Modified Tennant EFN thresholds are recommended for the Serpentine and Nicomekl rivers. This method provides a more conservative result, relies less on daily flow data, and considers more local fisheries biological (i.e., life-history, bioperiod) and physical information.

If water withdrawals are requested during the low-flow months, it is recommended that a more detailed hydrologic analysis and/or detailed instream flow study be completed. This screening level assessment was based on limited regional data (i.e., a high-quality, extensive streamflow record is only available mid-watershed on the Nicomekl River, stream gauging has been essentially absent in other portions of the Nicomekl River and the Serpentine River as a whole). These local studies would provide the data necessary to generate more fine-resolution, reach-specific thresholds.

A full quality assurance and quality control analysis should also be conducted on each individual hydrometric record comprising the consolidated Serpentine River and Nicomekl river records; especially:

- Gauged flows at hydrometric stations were likely impacted by unknown water withdrawals from the surrounding catchment, and unknown inputs from roadside ditch runoff, and should be naturalized using withdrawal data and estimates of ditch contributions if possible;
- Numerous periods of missing or constant (flatlined) flows remain within the raw data, and the accuracy of remaining data remains unverified. Standard hydrometric data production techniques (e.g., as outlined by BC MOE 2009, and WSC 2001) should be documented as best as possible, at a minimum to include the following items:
  - Comparison of continuous water level records against manual water level surveys (e.g., weir staff gauge readings);
  - Documentation of monitoring station rating curves, and any shifts applied through time to account for transient changes in stream controls (e.g., ice, or cycles of sediment scour and deposition); and
  - Comparison of generated continuous hydrographs, with available manual flow measurements of calculated measurement accuracy.

The EFN threshold values should then be updated following any revisions made to the hydrologic record for the Serpentine and Nicomekl rivers. Flow naturalization conducted herein considered licensed surface water use and potential additional non-licensed withdrawals for agricultural purposes but did not explicitly consider other non-agricultural groundwater uses in the watersheds (i.e., municipal and commercial uses). Inclusion of all water withdrawals in updated flow naturalization is recommended but will require numerical groundwater flow modelling, as discussed in Nunn et al. (2025).

It is noted that the BC Modified Tennant and the Okanagan Tennant methods (currently the only example of a customized BC Modified Tennant) are based on snowmelt-fed catchments with a snowmelt freshet and high flows occurring in spring. The flow regimes of the Nicomekl and Serpentine rivers are distinctly different and are almost fully rain-fed and tidally influenced. High flows occur in winter and last through spring, and water levels drop earlier in the year. The lowermost reaches of many Lower Mainland watercourses are subject to diurnal tidal backwatering and/or salinity changes. Due to these distinct characteristics, it is recommended to consider alternative approaches for establishing EFN thresholds for Lower Mainland watersheds depending on whether a catchment is exclusively rain-fed, influenced from snowpack, or reaches are tidal influenced (salt water or freshwater). Furthermore, methods to increase the precision of EFN threshold designation should be explored. Mean annual discharge is a coarse estimate that is often heavily skewed by high-flow periods. For desktop approaches, using a more fine-scale estimate such as median monthly discharge (MedMD) to set EFN thresholds (as %MedMD) would likely provide better resolution for low-flow and transitionary periods.

It may be appropriate to conduct a detailed Instream Flow Assessment (IFA), applying a methodology consistent with the British Columbia Instream Flow Guidelines (Lewis et al. 2004, Hatfield et al. 2003), for the headwaters of the Serpentine River, and the Middle and Upper reaches of the Nicomekl River. Under BC's Environmental Flow Needs Policy (FLNR and MOE 2016), these reaches are classified as very sensitive streams, given the reaches are <10 m^3/s MAD and there are sensitive aquatic species present with high cultural and ecological value (e.g., Coho Salmon, Coastal Cutthroat Trout). Together with noted uncertainties in headwater flow regimes, these confounding factors appear to warrant further investigation to better predict the risk of anticipated future water reductions, in particular during critical stream flow periods.

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APPENDIX A. SITE PHOTOS (FEBRUARY 27, 2019)

Photo 1. Looking upstream at the Serpentine River from 80 Avenue bridge crossing on February 27, 2019.

Photo 2. River right bank (facing upstream) and 80 Avenue bridge crossing over the Serpentine River on February 27, 2019.

Photo 3. Looking downstream at the Serpentine River from 168 Street bridge crossing on February 27, 2019.

Photo 4. Looking upstream at the 168 Street bridge crossing over the Serpentine River on February 27, 2019.

Photo 5. Looking upstream at Serpentine River from 64 Avenue bridge crossing on February 27, 2019. Note tributary confluence on the left.

Photo 6. Looking downstream at the Serpentine River from 56 Avenue bridge crossing on February 27, 2019.

Photo 7. Looking downstream at the Serpentine River from King George Boulevard/Highway 99A bridge crossing on February 27, 2019.

Photo 8. Looking downstream at the Serpentine River below the sea dam on February 27, 2019 (near the King George Boulevard/Highway 99A bridge crossing).

Photo 9. Looking upstream at the Nicomekl River from 64 Avenue culvert crossing (east of 224 Street) on February 27, 2019.

Photo 10. Looking downstream at the Nicomekl River from 64 Avenue culvert crossing (west of 224 Street) on February 27, 2019.

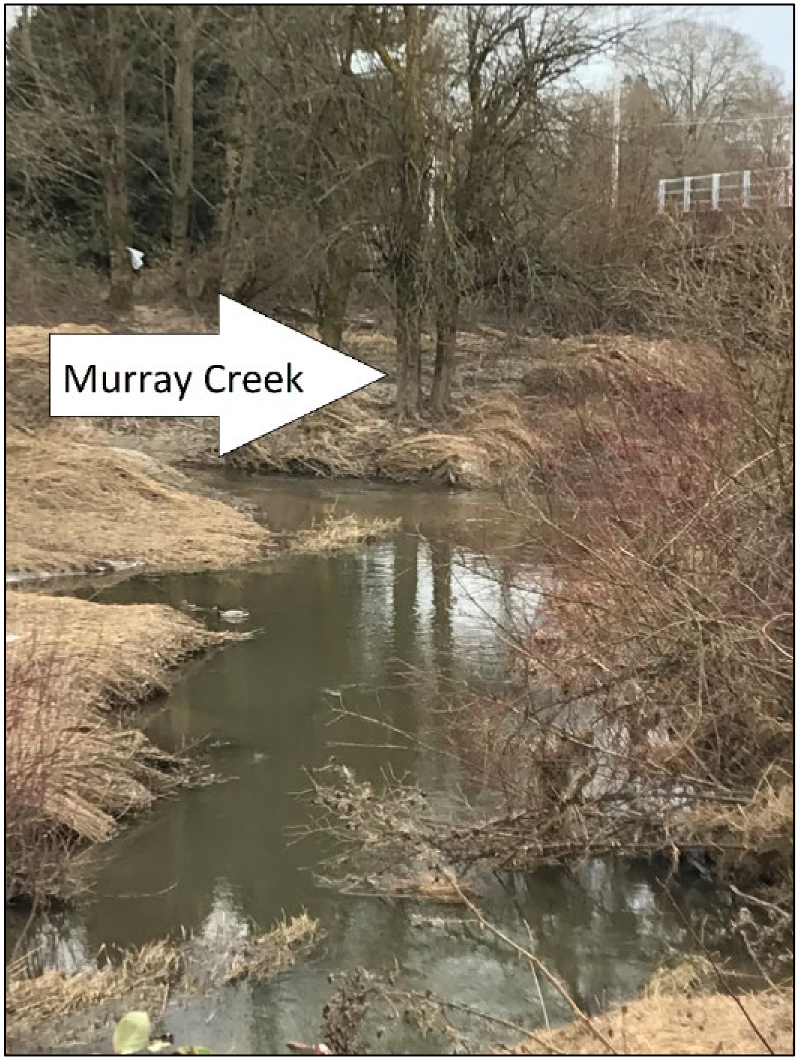

Photo 11. Looking downstream at the Nicomekl River from 208 Street crossing on February 27, 2019. White arrow shows Murray Creek confluence.

Photo 12. Looking downstream at Murray Creek. Confluence with Nicomekl River is in the background. Photo taken on February 27, 2019.

Photo 13. Looking upstream at the Nicomekl River from footbridge crossing south of 201a Street on February 27, 2019.

Photo 14. Looking downstream at the Nicomekl River from footbridge crossing south of 201a Street on February 27, 2019.

Photo 15. Looking downstream at the Nicomekl River from 192 Street crossing on February 27, 2019.

Photo 16. Looking upstream at the Nicomekl River from 40 Avenue crossing on February 27, 2019.

Photo 17. Looking upstream at the Nicomekl River immediately upstream of the sea dam on February 27, 2019 (near the King George Boulevard/Highway 99A bridge crossing).

Photo 18. Looking downstream at the Nicomekl River immediately downstream of the sea dam on February 27, 2019.