Nicola Basin Fish/Water Management Tool Design Document

March 2021

Prepared for the Fraser Basin Council Society

Prepared for:

The Fraser Basin Council Society

Nicola Basin Fish/Water Management Tool

Design Document

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Suggested Citation:

Alexander, C.A.D., F. Poulsen, L. Uunila, and B.O. Ma. 2021. Nicola Basin Fish/Water Management Tool: Design Document. Prepared for the Fraser Basin Council Society, Kamloops, BC. 107 pp. + Appendices

Cover Photo:

Nicola Lake Dam (Jeptha Ball 2011).

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Fundamental terms and concepts

“Indicator”, “Performance indicator”, “Metric”, “Valued Ecosystem Component (VEC)”, or “Performance measure”

Throughout this document, the word "indicator" is used in a general sense as it commonly is in applied science, without specific reference to how different authors occasionally decide to customize meanings of this (plastic) word. In this report, an **"indicator"** is analogous to a **"performance indicator"**, or **"metric"**, or **"valued ecosystem component" (VEC)**. For our purposes, these words refer synonymously to any element of the environment that has ecological, economic, social or cultural significance. Subtleties and nuances as to whether an indicator "suggests, gets close to, approximates" but does not provide an objective "measure" are easily resolved by reviewing the actual definition for the indicator (or performance indicator, *etc.*). All of these terms are used to answer the question, 'how do I know' whether an action, or some fundamental natural driving conditions in the environment are causing things (that have value) to get better, worse or stay the same. The lack of a distinction between an **indicator**, or a **metric** is actually useful as it opens up more options as to what an acceptable way is to assess 'how do I know'. Decision makers, stakeholders, and members of the general public can make judgments and decisions with **"indicators"** just as well as **"metrics"** or **“performance measures”** so long as the terms are clearly defined and logically linked to something of value.

Historical flows

The measured empirical flows that occurred during the selected period of record. These flows often include a shifting mixture of modified, regulated, artificial (potentially "degraded") flows following construction and operation of dams, diversions, conveyance structures and pumping plants. Shifting climate change effects on precipitation and other hydrologic processes are also embedded. When the time series is long enough, it will also include a range of water year types and related flow variations that even though regulated, still manage to "show through" in the historic dataset.

Historical flows ≠ natural / pristine / unregulated / unmodified / unimpaired flows.

Natural flows

Natural flows represent the pristine, unmodified, unregulated, unaltered flows that would occur in the absence of any human presence, infrastructure, modifications, hydrosystem operations, water withdrawals and related land-use changes (e.g., forestry, agriculture). In this document, this is merely a theoretical concept. We do not propose using natural flows in our decision support modelling (because they are not available).

Unimpaired flows	Reverse engineered flows found by attempting to remove the effects of reservoirs and diversions on *existing hydrology time-series*. These flows are thought of as a proxy for natural flows. Challenges with these estimates are manifold, and include absence of the effects of levees, channelization 'improvements', wetland storage and related evaporation processes, forest practices, groundwater interactions, *etc*. **Unimpaired flow** estimates are typically not performed for a wide range of locations, are often monthly in temporal resolution, and typically rely on volume correlations, precipitation correlations, subbasin to subbasin extrapolations and other techniques that produce unquantifiable errors.

1 Introduction

The Nicola Water Management Tool (NWMT) is a web-based decision support system that improves water manager's ability to **balance multiple objectives** in **real-time** by allowing rapid exploration of: (1) **alternative weekly Dam release schedules** for the Nicola Lake Dam and (2) the potential **effects of voluntary water use cutbacks** in one or more of 8 non-overlapping aggregate drainage areas on Nicola Lake and Nicola River mainstem flows. As demonstrated in the Okanagan (Hyatt *et al.* 2015), the use of such a tool facilitates transparency surrounding the operation of Nicola Lake Dam, catalyzes cooperation and improved communication, and accelerates joint education of both water and fisheries managers regarding trade-offs amongst objectives and the science and values that underpin them.

This design document describes the submodels and analyses that were used to develop the NWMT.

1.1 History

This project was initially conceived during a one-day scoping and user requirements session at Fisheries and Oceans Canada in Kamloops on **October 16, 2006**, facilitated by Clint Alexander (ESSA). Information collected in 2006 was extensively updated during a follow-on technical feasibility study completed in **2008** (Alexander and Weickowski 2008). Representatives from Federal and Provincial government, the City of Merritt, First Nations, the Fraser Basin Council and ESSA met in Merritt on **June 18, 2014** to discuss options for developing a water and fish management decision support tool to aid Nicola Lake Dam operators and water users better manage flows to benefit anadromous salmon populations while balancing water use needs and resident fish. A prospectus for the project was provided **August 18, 2014**, which led to preliminary design work and a scoping meeting on **November 3, 2014** to begin to: (1) determine priorities for what species and water use attributes should be considered by the tool; and (2) identify data needs and scientific gaps to be overcome in order to create a prototype tool. To that end, the Parties (Nicola Tribal Association, FLNRORD, DFO) agreed to work in good faith towards achieving the NWMT project objectives that had been elicited by the Fraser Basin Council, leading to the signing of a **Project Charter in May 2015.** Subsequently, **a conceptual design workshop was held February 17-18, 2015** to consult with a broader range of technical experts on NWMT submodel components and decide on priorities for tool development (Alexander and Poulsen 2015). NWMT development was carried out between 2016 to 2018. A prototype web-based NWMT has was developed in 2015 and was **tested for the first time during summer 2016** and again in **late spring and summer 2017**. A major review workshop was held **October 26 & 27, 2016** that identified priorities for improving the tool followed by additional testing by water and fish managers in 2017. A few remaining refinements were identified subsequently in November 2017 that were integrated into the final tool that was **completed during the summer**

of 2018. **December 18, 2018** the Nicola Tribal Association, the Ministry of Forests, Lands, Natural Resource Operations & Rural Development (FLNRORD) Water Management Branch, FLNRORD Fish and Wildlife Branch, and Fisheries and Oceans Canada signed a **formal Terms of Reference** document that lays out general provisions, principles, participation guidelines and funding commitments for the long-term operational deployment and use of NWMT. These Terms of Reference are intended to amplify the value of this significant investment **long-term**.

The Parties have collectively funded 52% of a **~$450,000 shared investment** to successfully complete all major NWMT project phases: conceptual design, construction, user acceptance testing, final enhancements, quality assurance hardening and documentation. The remaining 48% of funding was provided by Environment Canada, via the Habitat Stewardship Program, the Thompson-Nicola Regional District, City of Merritt, Teck – Highland Valley Copper, Nooaitch Indian Band, and the Lower Nicola Indian Band.

1.2 Vision

Development and deployment of an environmental decision support system (DSS) to provide a real-time fish and water management tool to decision makers is **a proven means to improve the balance of water management decisions** affecting both human and natural systems (Hyatt *et al.* 2015). Developing the NWMT for the Nicola Basin will provide a risk assessment framework to integrate biophysical processes, deal with multiple species and geographic locations, anticipate socioeconomic outcomes of water management decisions, and increase cooperation among water users to improve fish and water management. Overall, building the NWMT has facilitated the inclusion and unification of a broader suite of biophysical, ecological, and socio-economic considerations into water management decision-making, thereby catalyzing clearer communication of flow targets, guidelines, and limits. NWMT's **heightened level of synthesis and integration removes obstacles to routinely taking these targets into account** during regular assessment of water release and use decisions (Hyatt et al. 2015).

Overall, the goal for this work is to facilitate the inclusion and unification of a broader suite of biophysical, ecological, and socio-economic considerations into water management decision-making, thereby catalyzing clearer communication of flow targets, guidelines and limits. This heightened level of synthesis and integration removes obstacles to routinely taking these targets into account during regular assessment of water release and use decisions (Hyatt *et al.* 2015). First and foremost, the NWMT DSS will provide a solution to the current inability of water managers to effectively use the *full range* of quantitative relationships and incoming information available to satisfy competing fish and water management objectives when time intervals for making trade-off decisions are short. Development and deployment of a NWMT DSS will facilitate an elevated level of ongoing, multi-party engagement in the regulation of Nicola Basin water supplies to achieve an improved balance of outcomes over competing objectives.

Jep Ball is the sixth person to operate Nicola Lake Dam since 1987, operating the system from 2000 to 2003 and again from 2008 to 2015. The current dam operator is Sarah Simon. The lack of operator continuity (staff turnover) is a practical matter that results in loss of considerable experience. In the Okanagan, the Okanagan FWMT has been cited by Brian Symonds and Des Anderson (FLNRO) as a major advance in more rapidly enabling new Dam operators to safely and efficiently learn nuances of day to day and week to week operations, and better balance trade-offs. This is due to the superior information integration versus reliance on "old school" rule curves, old operating plans and other simplified/stagnant information resources.

1.3 What is NWMT?

The NWMT is a web-based DSS for real time operations of weekly release schedules for Nicola Lake Dam and additionally, as a tool for exploring the potential effects of voluntary water use cutbacks in one or more of eight non-overlapping aggregate drainage areas on Nicola Lake and Nicola River mainstem flows. The NWMT DSS automates complex biophysical calculations and provide for highly intuitive visualizations of outcomes for a range of key performance indicators (e.g., akin to Hyatt *et al.* 2015). Starting with weekly net inflow forecasts from the water supply and hydrology submodel, the tool determines the in-lake and downstream consequences of these releases in terms of predicted flows at key index locations. Furthermore, providing a common base of assumptions, the web-based tool is a powerful new communication aid for stakeholder learning and outreach purposes. For example, when additional water releases are needed for fish migration, the tool is used to communicate these needs with downstream water users who are encouraged to reduce withdrawals. The synthesis of data provided by the NWMT also provides a simple method for these same water users to see the flow and ecosystem effects. The tool also provides managers with an easy way to track decisions, why they were made and what information was available at the time, e.g., the River Forecast Center (RFC) inflow forecast.

1.3.1 Management actions implemented

The NWMT hydrology and water balance submodel implements two management actions:

1. Alternative schedules of **weekly water releases** at Nicola Lake Dam; and
2. Alternative aggregated **water use changes downstream of Nicola Lake Dam**.

Management action No.2 — simulation of changes to aggregated water use — illustrates how decreases and increases in water use affect flows on the mainstem Nicola River. For example, when flows in the lower Nicola River are low in August, often as low as 3-4 m^3/s, an additional 0.5 m^3/s of cool groundwater (i.e., that is not extracted and used for irrigation) could produce significant fisheries benefits (Richard McCleary, pers. comm. 2015). Hence, in practice this action might be accomplished through changes to irrigation practices of individual water users (particularly users pumping aquifers that supply baseflows to the mainstem Nicola River). In the NWMT, this is merely a "what if" gaming feature, to illustrate the trade-off between water use volumes and the potential ecological benefits of this water if left in the mainstem Nicola River. Actual changes in water extractions are usually voluntary but may be influenced by local/provincial drought response level announcements, related news releases and/or local NGO communication. Reduced extraction can be regulated through the provincial Fish Protection Act, as occurred in the Nicola watershed in 2009. Surveys by agency staff, Water staff letters of request and direct phone calls, combined with local influence, successfully reduced water extraction. Thus, it may require a variety of outreach and education steps to realize any water use changes that might be highlighted by the NWMT.

As a given water year progresses, NWMT will incorporate available real-time hydrometric and groundwater monitoring data to self-correct forecasts and feed back this information into repeated NWMT DSS model runs that evaluate the continuously updated schedules of Nicola Dam releases and water use cut-backs. Real-time data will continuously measure the degree of departure from forecasted flows and water temperatures versus realized flows and water temperatures. Once requisite experience has been obtained, the water year and seasonal patterns of departures will be used to adjust the base models.

1.3.2 Advancements provided by NWMT

NWMT provides an advance to pre-2015 science and tooling for Dam operations and drought management evaluation used by the Ministry of Forests, Lands, Natural Resource Operations & Rural Development (FLNRORD) in several important ways:

(1) *EXPANDS STUDY AREA* — NWMT **expands the water management horizon** beyond Nicola Lake and the immediate outlet of the Dam to include the **Nicola River mainstem all the way to Spences Bridge** – a critical region for a variety of **fish and ecosystem objectives**. Hence, users of NWMT may now more comprehensively consider a larger study area and a broader suite of interconnected fish/water management responsibilities[1].

(2) *SUPERIOR INTEGRATED SCIENCE* — NWMT, and its real-time flow, lake level and water temperature data feeds and associated biophysical submodels to enable **more timely and better science-driven decisions, promote superior transparency, increase efficiency** via mathematical automation, **codify state-of-science knowledge**, and **continuously track the status of both physical and ecological assets**.

(3) *CLIMATE AWARE* – NWMT's hydrology submodel **continually incorporates hydrologic datasets** (daily) and as each year passes, **adds these new "patterns" into the tool** and makes them available for use in statistical matching algorithms in the future. While it will always be extremely difficult to predict "outlier" years (like the spring of 2017 and 2018), **this feature of NWMT is a novel capability not present in legacy systems that will help support adaptation to future climate change.**

(4) *TRANSPARENCY FOR SHARED COLLABORATIVE DECISION-MAKING* — NWMT **automates complex biophysical calculations** (inflow predictions, lake level responses, water temperatures, downstream flows) and rapidly provides **highly intuitive**

[1] Information on this region is substantially driven by unregulated tributary inflows and surface-groundwater interactions. NWMT quantifies the narrow but important windows of time where Dam operations and voluntary water-use cutbacks **can benefit objectives in these regions** of the Nicola River mainstem.

visualizations of multi-objective outcomes for a range of key performance indicators relevant to **First Nations** and **Provincial** and **Federal** Government fish/water managers.

- *With NWMT and approximately 2 hours of training, any university / college educated hydrologist, engineer or biologist can explore effects of alternative Dam operation and water use cut-back scenarios*. This **dramatically reduces knowledge silo issues** and assists FLNRORD in **reducing training costs** when dealing with staff turnover and onboarding new staff.

1.4 What NWMT is *not*

The NWMT is a decision support system (DSS) project, not an overall governance framework or policy exercise. NWMT is also **not** a "water licence allocation tool" (even though it for certain raises visibility on current constraints associated with meeting multiple objectives). In certain (dry) water years, these constraints will be very evident in the tool, and may contribute to new operational approaches or drought management plans. The NWMT DSS will **not** provide a basin-wide water balance and accounting model to assess consequences of alternative surface and groundwater use and allocation policies at the tributary sub-basin (or finer) resolution[2].

Section 2 of this design document identifies the scope and bounds of the DSS, which is **focused on Nicola Lake and the mainstem Nicola River.** The ability to evaluate questions related to consequences of issuing new water licences, changes to groundwater pumping (safe yields), results of adding new storage reservoirs, whether overall the Nicola Basin "has enough water", or effects of climate change in the 2050s, etc. **are beyond the scope of this project and tool**.

1.4.1 Long-term monitoring & research questions outside project scope

The many experts who contributed to the design of NWMT also identified a variety of research and monitoring needs in the Nicola Basin. For example, a **groundwater monitoring network** would allow mapping and monitoring of where river segments were gaining water and losing water to groundwater aquifers. Ideally this network would be real-time enabled. This research and source of data has multiple benefits that extend beyond the requirements of NWMT. While having this data would **improve** the capability and spatial resolution of the NWMT (and fish population management generally, with or without NWMT), establishing a groundwater monitoring network, related mapping, models and research of thermal refuge habitat is a longer-term research priority that should be pursued as parallel projects with or without NWMT.

Likewise, development of a state of the basin report on groundwater, a detailed groundwater model, and/or communicating a groundwater management strategy in the Nicola Basin are topics

[2] However, we *will* attempt to explore how highly aggregated net water use changes (increases/decreases) affect flows on the mainstem Nicola River.

beyond the scope of NWMT. Once such monitoring networks, studies, and models are available, these technical elements would enhance the capabilities of future versions of NWMT.

The Fraser Basin Council coordinates the Nicola Basin Research and Technical Collaborative that review science and monitoring needs annually.

2 Model Scope and Bounding

Every decision support system must include assumptions about what is included and excluded to keep the effort tractable. This involves seeking a balance of representative submodels and performance indicators given the state of scientific knowledge and the types of decisions the tool is meant to support, and budgetary resources. To avoid paralysis there is a practical need to constrain the modelling efforts to a domain well inside the universe of “all things that might matter”.

Complex decisions and associated trade-offs are easier when organized using formal structured decision-making (SDM) approaches to evaluate management alternatives. SDM is a systematic approach to evaluating alternatives that focuses on engaging experts and decision-makers in productive objective and decision-oriented dialogue for integrating and synthesizing scientific knowledge and risk preferences. **Management objectives** are statements describing the desired condition or state of the system that decision makers want to achieve. Clear objectives are needed to evaluate alternative **management scenarios** (or **alternatives**) and help distinguish which among them is the best. Consequences caused by various alternative actions are evaluated through representative **performance indicators** (or if you prefer, “measures” or "metrics" or “targets”). Having defined the intermediate driving variables that must be provided to other submodels (e.g., water temperatures to enable prediction of egg emergence in salmon), coupling and integrating the various subsystem models allows **consequences** of management alternatives to be evaluated over all objectives.

2.1 Objectives & performance indicators

The Parties and their invited experts completed a series of **rigorous structured objective and performance indicator elicitation workshops and peer review exercises** between 2015 – 2017 (Alexander and Poulsen, 2015). A major review workshop was held **October 26 & 27, 2016** that identified priorities for improving the tool followed by additional testing by water and fish managers in 2017. During this time, **participants carefully chose a representative range of focal species, socio-economic indicators, and ecosystem functions** over a broad geographic scale that together allow for rigorous characterization of consequences of different flow regimes. Based on this process, NWMT includes a total of **nineteen (19) performance indicators** across fish, water supply and use, and flood management objectives (Table 2-1). Details of these performance indicators are described in Section 3.

Table 2-1. Summary of management objectives and performance measures for the NWMT.

Category	Proposed objective(s)	Performance measures
Chinook salmon (CH)	(1) Manage flows to improve in-migration, spawning, incubation and rearing water quality for chinook (late run) salmon. Improve egg to smolt survival (spawning, incubation and rearing success)	▪ In-migration flows [CH1-MQ] ▪ Spawning flows [CH2-SQ] ▪ Incubation flows [CH8-IQ] ▪ Egg scour flows [CH7-ScourQ] ▪ Rearing flows [CH3-RQ]
Steelhead trout (ST)	(1) Manage flows to improve parr rearing water quantity for steelhead	▪ Parr rearing flows [ST1-RQ]
Coho salmon (CO)	(1) Manage flows to provide off-channel habitat connectivity for coho salmon	▪ Off-channel habitat connectivity flows [CO1-CQ]
Kokanee (KK)	(1) Manage upper Nicola River flows and Nicola Lake elevation to improve migration, spawning and incubation success	▪ Spawning passage flows [K1-SQ] ▪ Nicola Lake elevation [K3-LE] ▪ In-migration flows [K4-MQ]
Water supply & use	(1) Meet water licence and irrigation obligations while allowing for a reasonable balance of achievement of other multi-objective targets	▪ Water supply availability (Nicola Lake elevation) [WS1-Availability] ▪ Total downstream water use [Water use submodel]
Nicola Lake flood protection	(1) Manage/minimize flood risk around Nicola Lake while allowing for a reasonable balance of achievement of other multi-objective targets	▪ Nicola Lake flood protection [NLF1-Shoreline flooding]
Nicola Lake ice management	(1) Manage/minimize risk of zero flows due to ice as well as ice damage around Nicola Lake	▪ Nicola Lake ice blockage & zero flows [NLI1_Ice Blockage]
Nicola River flood protection	(1) Manage/minimize flood risk around Nicola River while allowing for a reasonable balance of achievement of other multi-objective targets	▪ Flood protection at City of Merritt [NRF1-Merritt flooding] ▪ Flood protection at downstream of Merritt [NRF2-Flooding downstream of Merritt]

NWMT provides a framework that allows new indicators to be added, and others dropped through time as knowledge evolves. Our approach to identifying the desired flow regime is therefore more aptly described as "functional" than "natural". By carefully choosing a representative range of socio-economic indicators, focal species and ecosystem functions over a broad geographic scale, variation and consequences of different flow regimes can be quantified and trade-offs brought into clearer focus.

In short, for the indicators in NWMT, it should be scientifically credible to state that if a certain favourable Nicola Basin flow regime were repeated year over year, the indicator would be clearly pushed towards a more or less desirable state.

Ultimately, ongoing adaptive management and long-term monitoring programs are required to continually test and improve conceptual models of all forms. Conceptual models and performance indicator algorithms used in NWMT can in the interim help determine whether different flow management actions are more likely than not to increase resilience and help species cope with ever changing conditions.

2.2 Spatial horizon and resolution

*Spatial **horizon** (def.)*: The geographic scope and boundary limits of the study area that will be included in the model. Areas outside of these bounds will not be considered.

*Spatial **resolution** (def.)*: The discrete spatial reporting unit for a performance indicator or physical variable (e.g., reach segment, cross-section, specific gauge location).

The spatial **horizon** of the NWMT includes Nicola Lake and upper Nicola River to Chapperon Lake and the mainstem Nicola River down to Spences Bridge (confluence of Thompson River) (Figure 2-1). The spatial **resolution** of the NWMT within this region is based on three factors:

1. where fish and water managers would most like to know about a particular performance indicator;
2. the areas and locations where we have reliable information about the biological relationships (for focal species indicators); and
3. the feasibility of obtaining or producing data about the physical driving variables necessary for calculation of focal species performance indicators.

The overlap between these three considerations determines the spatial resolution of performance indicators throughout NWMT's study area. In the mainstem Nicola River, locations of interest are situated at the outlet of Nicola Lake Dam just downstream of the confluences with three major tributaries (Coldwater Creek, Guichon Creek and Spius Creek), and just before the river joins the Thompson River at Spences Bridge. Combined with a location of interest at Nicola Lake, the hydrology and water balance submodel has seven locations of interest (Figure 2-2):

- Nicola Lake
- Upper Nicola River (including Douglas Lake to Chapperon Lake)
- Nicola River at Nicola Lake
- Nicola River at Merritt
- Nicola River at Guichon Creek
- Nicola River at Spius Creek
- Nicola River at Spences Bridge

For the fish submodel, the following reaches have been defined and are commonly referenced with regards to presumptive flow standards:

- Nicola River Thompson River to confluence Spius Creek (N1)
- Nicola River Spius to confluence Coldwater River (N2)
- Nicola River Coldwater to Nicola Lake Dam (N3)
- Upper Nicola River above Nicola Lake to Douglas Lake (N4)

Important challenges for the hydrology and water temperature submodels are to provide estimated flows and water temperatures for locations in between major confluences and to factor in localized processes such as the potential for localized cooling due to areas where groundwater gains are occurring.

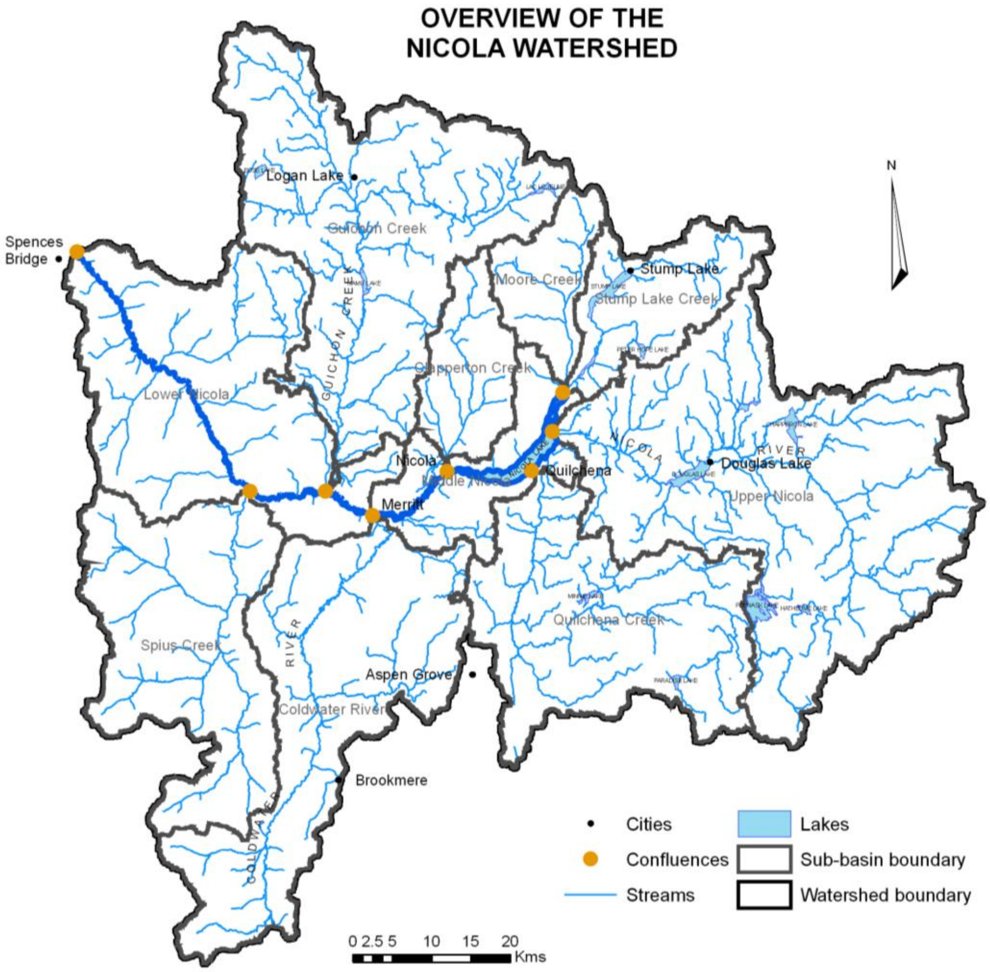


Figure 2-1. Overview of Nicola watershed. The dark blue shows the mainstem Nicola River downstream of Nicola Lake.

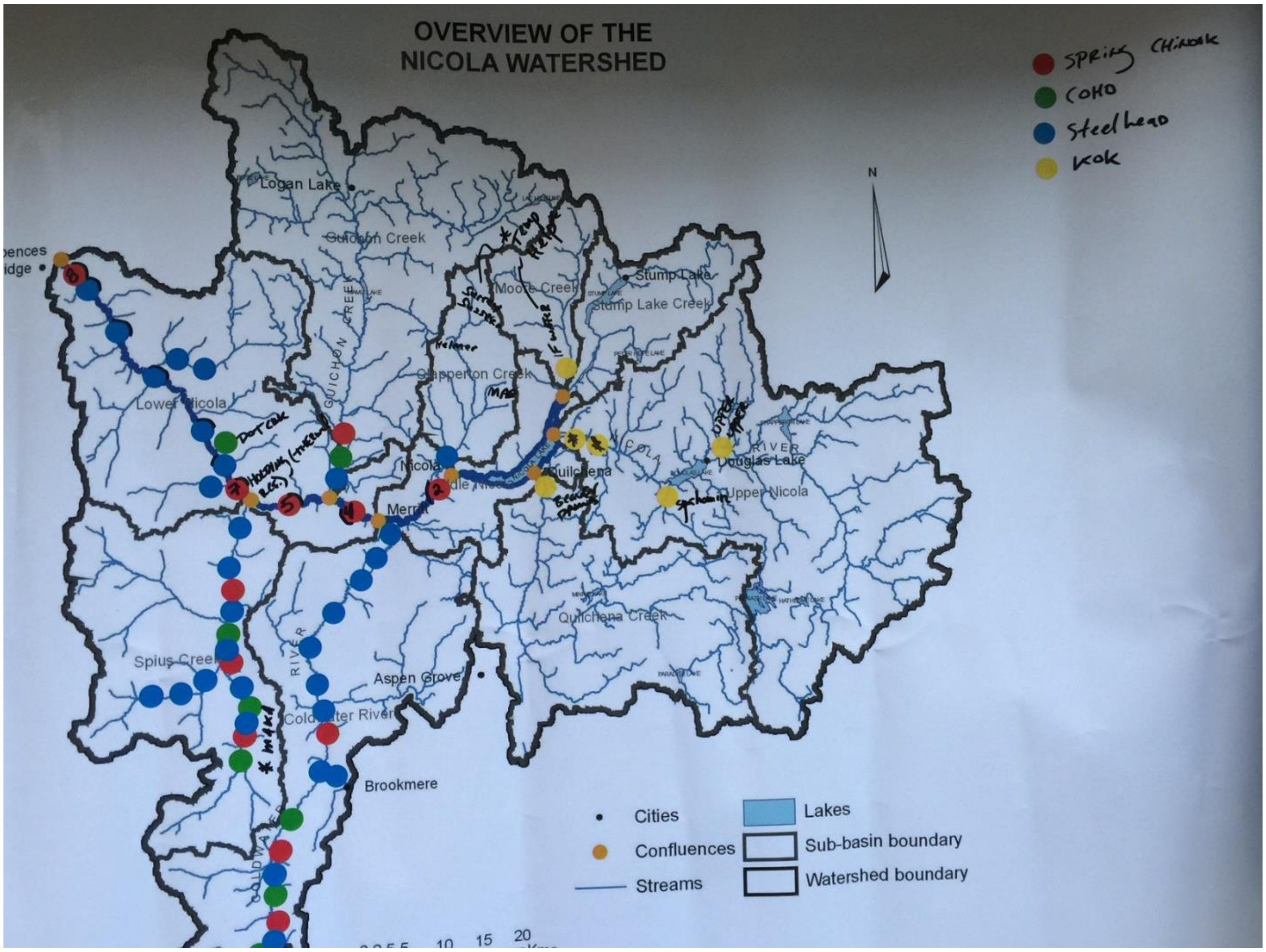


Figure 2-2. Locations of interest for the fish & ecosystem submodel. February 2015 workshop participants identified mixture of mainstem Nicola River and tributary habitats as being important to the priority fish species (chinook [late run], steelhead, coho salmon and kokanee). For the NWMT, only Nicola Lake, the upper Nicola River, and the mainstem Nicola River below Nicola Lake Dam are within scope.

2.3 Temporal horizon and resolution

Temporal ***horizon*** *(def.)*: The retrospective and/or prospective temporal limits of typical model simulations. For example, whether simulations will run for one year or 100 years.

Temporal ***resolution*** *(def.)*: The temporal unit of measure that is to be associated with each incremental estimate or prediction for a modelled performance indicator or variable, at a specific location. This is also commonly referred to as model time-step (e.g., hourly, daily, weekly, monthly, annually).

The temporal **horizon** of NWMT is **October 1st** of year n to **January 31st** of year n+2 (16 months) (e.g., October 1, 2017 to January 31, 2019). As an in-season management tool, NWMT will not be structured to perform multi-year planning simulations.

A fundamental concept in NWMT is that of a "**decision date**". By design, the tool will use the best information available for any decision date specified. A decision date is the specific calendar date beyond which a model user wishes to see a forecast of water release decision impacts. A water manager is not able to influence what has already happened, so NWMT ignores any water management decisions that may be specified prior to this date, and instead shows the actual real-time lake elevations, river flows and water temperatures that actually occurred. These water values will be obtained from real-time hydrometric stations and other real-time enabled field loggers operated by Water Survey of Canada and its partners or other freely available web service. The temporal **resolution** of NWMT is a daily time-step.

2.4 Submodel coupling and integration

The NWMT integrates various submodels, as shown below:

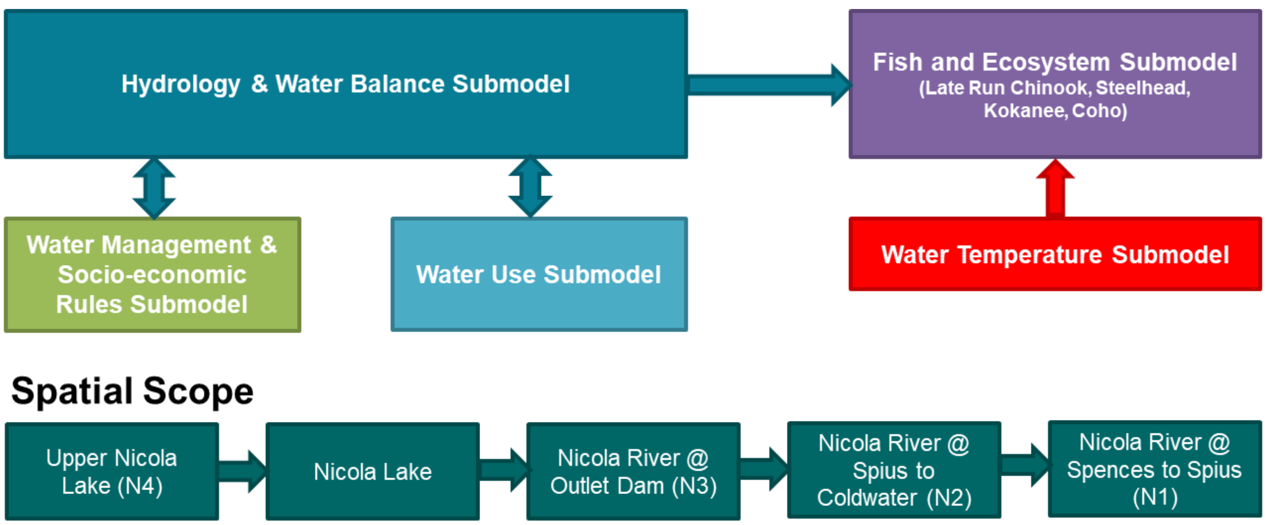


Figure 2-3. Conceptual diagram of submodel coupling in NWMT.

The hydrology and water balance submodel estimates the water level at Nicola Lake and discharge in the Nicola River at Merritt, Guichon Creek, Spius Creek and Spences Bridge over time. The estimated water levels are compared to objectives generated by other submodels. The fish and ecosystem submodel defines the objectives for important focal species. The water temperature submodel is a diagnostic to forecast water temperatures that could lead to potential migration inhibition and lethal temperatures to salmonids. The socio-economic rules submodel defines socio-economic objectives. Finally, the water use submodel enables water managers to simulate the potential impact of voluntary water use reductions. Each submodel is described in detail in Section 3.

Defining how NWMT's coupled submodels operate together was determined by considering four components (Figure 2-4): (1) user inputs from other submodels and other data, (2) management actions (only the water supply / hydrology submodel in this case), (3) generate information needed by other submodels, and (4) generate performance measures used for making decisions.

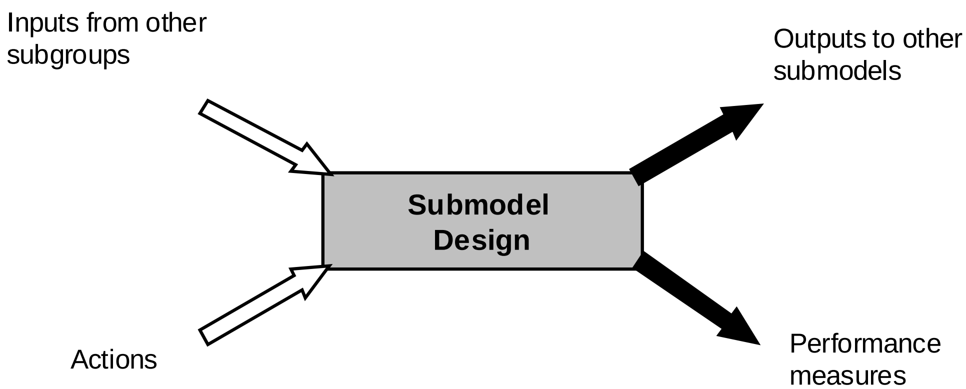


Figure 2-4. Responsibilities of each submodel.

A "looking outward matrix" was used to describe how the components of a system fit together, or the information transfers which need to occur between subgroups. A looking outward matrix is conceptualized as an array of subsystem components as shown in Table 2-2:

Table 2-2. Conceptual Looking outward matrix

From: \ To:	**Component 1**	**Component 2**	**Component 3**
Component 1		From 1 to 2	From 1 to 3
Component 2	From 2 to 1		From 2 to 3
Component 3	From 3 to 1	From 3 to 2	
Driving Variables			

Each cell in the matrix represents a potential transfer of information between components, e.g. output from the hydrological submodel being used as input to the fish and ecosystem submodel. The looking outward matrix for the NWMT is shown in Table 2-3.

Table 2-3. Looking Outward Matrix for NWMT.

To From	Fish and ecosystem	Socio-economic rules	Hydrology & Water Balance	Water use	Water temperature
Socio-economic rules					
Hydrology & Water Balance	Daily average forecasted flows in Nicola River downstream of Nicola Lake, in Upper Nicola River from Nicola Lake to Douglas Lake & Chapperon Lake and in Coldwater River. Weekly average forecasted Nicola Lake elevations.	Weekly average forecasted flow releases from Nicola Lake. Weekly average forecasted Nicola Lake elevations			Weekly average forecasted flows for Nicola River below Nicola Lake and Coldwater River, Guichon Creek and Spius Creek.
Water use			Weekly average forecasted water extractions from Nicola River downstream of Nicola Lake		
Water temperature	Weekly average forecasted temperature in Nicola River downstream of Nicola Lake				
Driving variables	Real-time daily air temperature from gauges.	Real-time daily air temperature from gauges.	Forecasted seasonal total inflow volume to Nicola Lake and from Coldwater River, Guichon Creek and Spius Creek. Real-time daily average flows	Expected water year type (average, dry or wet). Real-time daily average flows from gauges in Nicola River downstream of Nicola Lake	Real-time daily water and air temperature from gauges.

		from gauges in mainstem Nicola River and preferably major tributaries. Scheduled weekly releases from Nicola Lake.	and preferably major tributaries. Assumed changes in extractions.

3 NWMT Submodel Functional Details

3.1 Fish & Ecosystem Submodel

During phase 1 of the NWMT design, a variety of species were considered for inclusion in the model (Alexander and Poulsen 2015). For Nicola Basin salmon, seasonal variations in water conditions pose a variety of challenges during the period of freshwater residence (Alexander and Poulsen 2015). By season, these are:

- **Winter**: Threat of freezing both for eggs in gravel and for off-channel rearing juveniles. Anchor ice formation and “rain-on-snow” events often have a profound negative influence, as well as ice jam breakups and resulting scour.
- **Spring**: Freshet activity can lead to scour of incubating eggs, displacement of rearing fish, and stranding if freshets recede rapidly. Rapidly receding flows can also be an artifact of large dam adjustments (“Ramping”).
- **Summer**: Low flows and high stream temperatures exacerbated by solar radiation, and “heat sinks” (Nicola Lake). 26°C is lethal to salmonids (high temperatures reduce their ability to extract oxygen from the water). At temperature above 22°C adult salmon will not actively migrate. Late summer diurnal fluctuations in stream temperature can result in localized daytime stream temperatures exceeding 25°C and overnight temperatures sometimes remaining as warm as 20°C. Low flows exacerbate this situation. Groundwater-based thermal refugia are critical to salmon survival in these conditions and returning adult fish can only survive hot dry summers because of local, cooling groundwater inflows (WWSS 2009).
- **Fall**: Extended periods of low water result in disconnection of habitats which disrupts adult salmon spawning migration and obstructs the ability of rearing juveniles to re-distribute to over-winter habitats. It is important to maintain enough water in the river to support salmon migration and provide off-channel connectivity for juveniles where needed.

Groundwater is important to salmon survival throughout year, except during the freshet. Groundwater upwelling/discharge zones create thermally stabilized local habitats called thermal refugia that are critical to salmon survival in high water temperature conditions (Alexander and Poulsen 2015). Salmon fry and parr have been observed burrowing into substrate in groundwater upwelling areas to avoid thermal stress.

Streamflow patterns in the Nicola Basin indicate that natural patterns of streamflow are critically low during important life-history periods for local fish stocks. All systems have snowmelt-driven hydrographs, with low flow periods in late summer, fall and winter. In many years, flows during low flow periods are well below recommended minimum flows for maintenance of instream values such as fish habitat (Hatfield 2009). To ensure salmonid production potential of the Nicola River system was maintained, Kosakoski and Hamilton (1982) recommended: “There be no increase in water diversion from the Nicola mainstem, Spius Creek, and Coldwater River during low flow periods, and no new water diversion licences unless they are supported by storage.”

Rosenau and Angelo (2003) noted: "Since 1983 research has enabled a greater understanding of the instream fisheries needs in the Nicola River basin and it has become increasingly clear that even if the legal allocation limits are adhered to, the extraction of water now taking place is to the detriment of salmon and steelhead under some flow conditions. A moratorium on licensing further water for diversion or extraction is required if commitments by the federal and provincial government to protect fish stocks are to be upheld" (pg. 65).

3.1.1 Focal species

The fish and ecosystem submodel is designed to provide a reasonable representation of alternative hypotheses about the links between Nicola Dam flow management actions, downstream water use changes, and performance measures. **A central principle governing selection of which fish species to include is the ability to assert that key segments of life-history stages of the fish selected would be amenable to flow management control from Nicola Lake Dam.** Considering the relative contribution of Nicola Lake Dam flow releases versus unregulated tributary inflow downstream, the period of approximately the **first week of July to the last week of October** was determined to be when lower Nicola River flows are most influenced by Nicola Lake Dam operations (Figure 3-1).

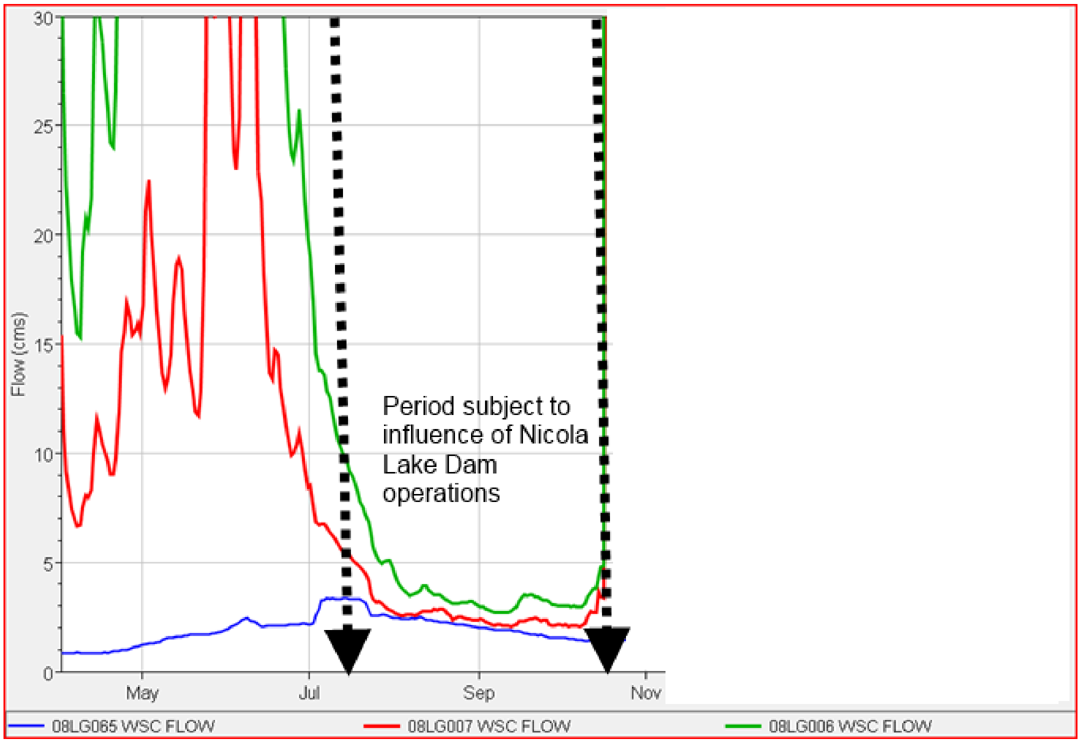


Figure 3-1. Approximate maximum time period (approx. **July 10 to October 21**) that Nicola Lake Dam flow releases control flows in lower Nicola River near confluence with the Thompson River. Blue line is the release from Nicola Lake Dam (WSC gauge 08LG065). Green line is the downstream flow at Spences Bridge (WSC gauge 08LG006). Red line is downstream flow of Merritt and Coldwater River (WSC gauge 08LG007). (Example is for a dry year.)

During phase 1 of the NWMT, anadromous salmon (chinook, coho, steelhead, pink, sockeye) and resident fish species (burbot, kokanee, rainbow trout, bull trout, mountain whitefish) were prioritized for inclusion, based upon screening criteria, and consideration of the importance to these species of Nicola Lake Dam flow releases (Figure 3-1), using a dotmocracy exercise (Alexander and Poulsen 2015). In order of priority, the resultant top four priority species for the initial version of NWMT were:

1. **Chinook (late run)** salmon (mainstem Nicola River below Nicola Lake Dam)
2. **Steelhead** (mainstem Nicola River below Nicola Lake Dam)
3. **Kokanee** (Nicola Lake tributaries)
4. **Coho salmon** (off-channel habitats connected to mainstem Nicola River below Nicola Lake Dam)

Chinook (late run) salmon were identified as being very vulnerable to summer flow and temperature stress issues. Chinook (late run) likely survive as adults only because of the thermal refugia created by influent groundwater. This run of chinook enters the Nicola River in the second or third week of April, arrival peaks in the third week of July, with spawning complete in September. Chinook juveniles have been observed burrowing into gravels in groundwater upwelling areas where temperatures are 16°-17°C, compared to surrounding river temperatures of 23°-25°C. They will remain in these cool areas throughout the day, coming out at night to feed if the stream cools sufficiently. When water temperature exceeds 24°C, adult chinook move from pools into better-oxygenated riffle habitats, where they stay until the temperature drops to 23°C, at which point they move back into pools because of associated lower rates of predation (Richard Bailey, pers. comm. 2015).

Thompson River **steelhead** have been in a depressed state since mid-1990s. Thompson steelhead are a unique and particularly prized race of anadromous trout in British Columbia. Adult steelhead begin their upstream migration into the Fraser River at the end of summer, the run peaks in numbers during mid-autumn, and the steelhead carry on up to the Thompson River where they enter a winter-holding pattern (Rosenau and Angelo 2003). The sub-populations of steelhead predominantly use the Deadman, Bonaparte and Nicola River tributaries. The stocks therein each have their own subtle but unique life-history characteristics (thought to have a genetic basis). Only a limited component of this steelhead stock complex is thought to spawn and/or rear in the mainstem Thompson River (Rosenau and Angelo 2003) and mainstem Thompson River has not been documented in adult and fry surveys in the 1980’s and extensive telemetry work (Al Caverly, pers. comm. 2015). Adult steelhead are known to spawn, and their progeny rear, in the Nicola River proper, and its two main tributaries, the Coldwater River and Spius Creek. The estimated abundance of steelhead spawning in the Nicola drainage ranges from 550 fish in 1992 to 3,300 in 1985. Most of the Nicola River basin steelhead have two to four years of freshwater rearing before going to sea (Nelson *et al.* 2001); however, no four year freshwater rearing fish was identified in hundreds of scales read in a later study (Al Caverly, pers. comm. 2015). Nicola River basin steelhead usually have either two or three years of marine growth before returning to freshwater to spawn (R. Bison, pers. comm., as cited in Rosenau and Angelo 2003). Some juvenile steelhead may be forced downstream and out of the Nicola River due to limited habitat availability; these fish may be rearing in the mainstem Thompson River. However, it is unclear exactly what role the Thompson River has in producing smolts from fish incubated in the tributary streams (Rosenau and Angelo 2003).

Kokanee from Nicola Lake and Douglas Lakes spawn in tributary streams in September. Significant numbers of resident kokanee spawn in the Upper Nicola River at Quilchena. Kokanee also rear in Nicola and Douglas Lakes and they spawn in the tributaries to these lakes. Adult kokanee prefer offshore habitats and are crepuscular (dawn and dusk) foragers (migrating up through the water column to feed, then back down into cool hypolimnion at night and during the day). Fall spawning is reported to occur primarily in three major tributaries to Nicola Lake: the Nicola River, Quilchena Creek and Moore Creek (Lorz and Northcote 1965; Kosakoski and Hamilton 1982; and iMapBC 2015). While there is no confirmed foreshore spawning for kokanee to date, there is likely some foreshore (or nearshore) use, based on the fact that so few stream spawners are seen for a lake the size of Nicola (Triton 2014). Spachamin Creek was identified as an important First Nation fishing site for kokanee and chinook. Fish subgroup participants commented that **the outflow from Douglas and releases from Chapperon Lake** can have impacts on kokanee survival. For example in 2009, when flows dropped to 2% of Mean Annual Discharge, a combination of Fish Protection Act water use restrictions and water releases from upstream reservoirs were required to maintain adequate migration flows (Richard McCleary, pers. comm. 2015).

Coho salmon are distributed throughout the Nicola River basin but in relatively small numbers. Interior Fraser Coho (IFC) were proposed for listing under the *Species at Risk Act* by the Committee on the Status of Endangered Wildlife in Canada. For largely politically driven reasons, IFC were not listed, however, their status has not changed appreciably since the late 1990s. Poor ocean survival has limited the recovery potential although modest increases in freshwater production have been observed over the past few years, likely influenced by changes in groundwater availability (Richard Bailey, pers. comm. 2015). However, coho are not strongly associated with the Nicola River mainstem, but are found throughout off-channel habitats, namely in the tributary subbasins of Spius, Coldwater and Guichon. Coho juveniles rear throughout the Nicola Basin watershed. Coho juveniles often use off-channel habitats such as beaver ponds that chinook and steelhead do not normally utilize, particularly during the overwintering period.

Burbot were considered, but not included because this species in Nicola Lake was not considered to be closely linked to flow management decisions at Nicola Lake Dam (Alexander and Poulsen 2015). Burbot, both juvenile and adult, are found in the Upper Nicola River and possibly elsewhere (Al Caverly, pers. comm. 2015), but the stream life history needs, contribution to the population and flow limitations are unknown. Subgroup participants commented that had this effort been a study of dredging options (which it is not), burbot may have been a higher priority. Other species predominantly associated with the major unregulated tributaries of the Nicola Basin (e.g., bull trout) were considered but ruled out based on the same rationale.

3.1.2 Critical life-history time periods

From the **first week of July to the last week of October**, the Nicola Lake dam has the largest influence on downstream flows. During phase 1 of the NWMT, periodicity charts were generated for the four priority focal species (Alexander and Poulsen 2015). The final periodicity charts are shown in Table 3-1 to Table 3-4. Key life-history events that overlap with the July to October period are highlighted. Details on the specific performance indicators for these focal species and life-history periods are discussed in Section 3.1.5.

Table 3-1. Chinook (late run) salmon life-history events that overlap July-October period when Nicola Lake Dam releases have influence on downstream flows. Relevant performance indicator codes are listed in last column. Dark gray shading indicates peak period. Light gray shading indicates active period.

WHERE: NICOLA RIVER MAINSTEM													
	J	F	M	A	M	J	J	A	S	O	N	D	
	Chinook (late run)												
In-Migration													CH1-MQ, CH4-MT
Spawning													CH2-SQ, CH5-ST
Eggs/Incubation													
Emergence													
Rearing													CH3-RQ, CH6-RT
Smolting													

Table 3-2. Steelhead life-history events that overlap July-October period when Nicola Lake Dam releases have influence on downstream flows. Relevant performance indicator codes are listed in last column.

WHERE: NICOLA RIVER MAINSTEM													
	J	F	M	A	M	J	J	A	S	O	N	D	
	Steelhead - widely dispersed species												
In-Migration													
Spawning													
Downstream Mig.													
Eggs/Incubation													
Emergence													
Rearing (0+) (fry)													
Rearing (1+) (parr)													ST1-RQ, ST2-RT
Smolting													

Table 3-3. Coho life-history events that overlap July-October period when Nicola Lake Dam releases have influence on downstream flows. Relevant performance indicator codes are listed in last column.

WHERE: NICOLA RIVER MAINSTEM													
	J	F	M	A	M	J	J	A	S	O	N	D	
	Coho												
In-Migration													
Spawning													
Eggs/Incubation													
Emergence													
Rearing (connectivity)													**CO1-CQ**
Smolting													

Table 3-4. Kokanee life-history events that can be influenced by Nicola Lake Dam releases. Relevant performance indicator codes are listed in last column.

WHERE: NICOLA LAKE & UPSTREAM TRIBS													
	J	F	M	A	M	J	J	A	S	O	N	D	
	Kokanee												
Staging/Holding													
Spawning													**K1-SQ**
Eggs/Incubation													**K2-Ice**
Emergence													
Outmigration to lake													

3.1.3 Ecological flow needs & presumptive flow standards

Ecological (or environmental) flows are concerned with access to and distribution of water to sustain the biodiversity and natural services provided by aquatic and riparian ecosystems. They refer to the quality, quantity, timing, and shape of flow regimes that support ecosystem functions, processes and resilience. Ecological flow assessments are concerned with determining the flow regime required (or the acceptable departure from the status quo flow regime) to maintain specified, valued features of the ecosystem. The natural flow paradigm treats flow as the "master variable" needed to drive natural variation of hydrologic regimes to protect native biodiversity and the evolutionary potential of aquatic and riparian ecosystems (Arthington *et al.* 1991, 2006; Richter *et al.* 1996, 1997; Stanford *et al.* 1996; Poff *et al.* 1997; IFC 2002; Postel and Richter 2003; Tharme 2003; Petts 2009; Fleenor *et al.* 2010; Carlisle *et al.* 2010; Poff and Zimmerman 2010; Poff *et al.* 2010). The greater the departure from natural flow conditions, the greater the ecological risk to be expected. Consideration of a single, minimum threshold flow, to the exclusion of other ecologically relevant flows (Tennant 1976), has been considered for some time to be an unacceptable approach to instream flow management. Because of the important functions of extreme flows and flow variation through time, maintaining a consistent base flow year after year is a management strategy that has also fallen from favour.

In the absence of data and methods that specify causally-reasoned functional flows for specific species and habitats in specific river segments (e.g., Alexander and Hyatt 2013; Alexander *et al.* 2014), the majority of ecological flow needs are filled by a "presumptive" flow standard (Richter *et al.* 2012). Virtually all presumptive flow setting methods utilize natural streamflow data as the starting point for identification of acceptable limits to water use. This often requires naturalizing regulated flow time-series by reverse engineering the flows to remove the effects of reservoirs and diversions on the existing hydrology time-series. These flows are then thought of as a proxy for natural flows. Aquatic ecologists then apply their observational knowledge of species and life-stage habitat preferences from multiple streams and rivers to suggest levels of departure from natural flows that are acceptable (e.g., varying percentiles of target flow for different seasonal time periods) (see various forms of "presumptive" methods, e.g., Tennant 1976, Bovee 1982, Kosakoski and Hamiton 1982, Jowett 1997, Hatfield and Bruce 2000, Ptolemy and Lewis 2002, Hatfield *et al.* 2003, Lewis *et al.* 2004, Hatfield 2009, Richter *et al.* 2012).

In the Nicola Basin, Kosakoski and Hamilton (1982) conducted detailed Instream Flow Incremental Methodology (IFIM) analyses of fish-flow issues using repeated measurements multiple transects on the Nicola and Coldwater Rivers. Their analyses led to flow recommendations for several points on both rivers and on several tributaries to the Nicola. This included the 1.69 m^3/s fisheries-rearing flows from Nicola Lake Dam between August and November and 1.13 m^3/s incubation flows from December to April that Kosakoski and Hamilton (1982) recommended. BC Ministry of Environment (MOE) published a strategic plan for the Nicola Watershed in 1983 (MOE 1983; as cited in Hatfield 2009) which included targets for instream flows (Table 3-5). The plan attempted to balance economic and environment objectives. It is not clear what rationale was used for the “fisheries maintenance flow” targets identified (Hatfield 2009).

Table 3-5. Generalized fisheries maintenance flows for locations in the Nicola watershed, from data collected by Kosakoski and Hamilton in 1982 and MOE in 1983.

	Environmental flow needs / Fisheries maintenance flows (not species specific) {Generally analogous to "minimum" instream flow requirements}		
Reach	Aug-Nov (Kosakoski and Hamilton 1982)	Dec-Apr (Kosakoski and Hamilton 1982)	Time period not specified (MOE 1983)
Nicola River Thompson River to confluence Spius Creek (N1)	5.66 m^3/s (19.0% of MAD)	5.66 m^3/s (19.0% of MAD)	5.66 m^3/s (19.0% of MAD)
Nicola River Spius to confluence Coldwater River (N2)	3.12 m^3/s (22.3% of MAD)	3.12 m^3/s (22.3% of MAD)	3.12 m^3/s (22.3% of MAD)
Nicola River Coldwater to Nicola Lake Dam (N3)	1.69 m^3/s (32.5% of MAD)	1.13 m^3/s (21.7% of MAD)	1.7 m^3/s (32.7% of MAD)
Upper Nicola River above Nicola Lake to Douglas Lake (N4)	0.78 m^3/s (14.4% of MAD)	0.78 m^3/s (14.4% of MAD)	0.80 m^3/s (14.8% of MAD)

In the recent Water Sustainability Act, "environmental flow needs" are defined as the volume and timing of water flow required for the proper functioning of the aquatic ecosystem of the stream. This definition is open to a wide array of different interpretations depending on risk tolerance and objectives. Research in environmental flow needs widely recognizes the importance of variable flow regimes, and critical lower *and* upper limits in flows that affect species and ecosystem functions. These different functional flows are required at varying levels of periodicity, not "every year". Environmental flow research frowns upon flow regimes pinned around a specific value. In the case of the Water Sustainability Act, "critical environmental flow thresholds" refer to the volume of water flow below which significant or irreversible harm to the aquatic ecosystem of the stream is likely to occur. Administratively, such standards are helpful because they provide simple rules for managers. In real world ecosystems, different flow standards are associated with a continuum of risk to different aquatic organisms, making it impractical to identify a single appropriate flow target. In NWMT, our approach identifies alternative ranges of flows that provide different levels of protection, and reports these to users of the tool rather than "pick" a single specific single flow standard (with all the attendant assumptions). Leveraging alternatives studies and methodologies, we are interested in presenting alternative flow standards (critical flows, minimum flows, fish maintenance flows, optimum flows) according to the objectives they serve, the species, and the level of protection associated with them. This approach allows users of NWMT to debate what level of risk and priority to place on environmental flow needs relative to consumptive and other objectives.

A review by Lewis *et al.* (2009), which factored in updated fish periodicity data (Hatfield 2009), found that the historical transect data collected by Kosakoski and Hamilton in 1982 and Ptolemy I in 1984 are generally in good alignment with the recent transect data collected by MOE from 2004 to 2007. Instream flow data collected by MOE in 2004-2007 followed the methods outlined in the BC Instream Flow Methodology (Lewis *et al.* 2004). Lewis *et al.* (2009) then used an IFIM approach to generate estimates of weighted useable width (WUW), applying habitat suitability index values for depth and mean velocity. Predicted WUW were derived by fitting lognormal relationships between WUW and flow (Bruce and Hatfield 2003) for each MOE transect location, species (chinook, steelhead and coho) and life-history stage (fry, parr and adults) (Lewis *et al.* 2009). Optimal flows for these species and life-history stages were also estimated using the meta-analysis method of Bruce and Hatfield (2003). **Lewis *et al.* (2009) concluded that any change being considered in minimum instream flow recommendations made by Kosakoski and Hamilton (1982) should be an increase in flows in September in order to support the critical spawning life-history stage of chinook in the Nicola River between Spius and Coldwater River confluences (N2).**

Lewis *et al.* (2009) used contemporary methods to generate weighted usable width versus flow, constructed using the most recent habitat suitability curves and combined transect data from Kosakoski and Hamilton (1982), Ptolemy (1984), and all suitable recent data from MOE (2004-2007). The Lewis *et al.* (2009) flow recommendations build on approaches identified in Lewis *et al.* (2004) and Bruce and Hatfield (2003) and generate minimum risk / optimal flows for fish based on these weigthed useable width (WUW) relationships. This is a higher standard of protection for fish survival and production than is provided by minimum instream flows (i.e., gives a presumptive flow standard that is more about "thriving" than "persisting"). The Lewis *et al.* (2009) findings are provided in Table 3-6, Table 3-7, and Table 3-8. An issue to review with these recommendations is the habitat suitability profile for chinook, which is based on larger bodied chinook of coastal British Columbia and Vancouver Island instead of the smaller-bodied chinook in the Nicola Watershed because more recent data represent habitat use rather than habitat preferences.

Table 3-6. Optimal instream flows for chinook (late run), steelhead and coho, Nicola River Thompson River to confluence Spius Creek (N1). *Source*: Lewis *et al.* (2009) and references therein.

	Nicola River Thompson River to confluence Spius Creek (N1)	**Nicola River Thompson River to confluence Spius Creek (N1)**	**Nicola River Thompson River to confluence Spius Creek (N1)**
Life-history stage	Chinook (late run)	Steelhead	Coho
In-migration	Use spawning flows	Use spawning flows	Use spawning flows
Spawning	Optimal: 10.9 m^3/s (Lewis *et al.* 2009)	Optimal: 12.6 m^3/s (Lewis *et al.* 2009)	Optimal: 10.1 m^3/s (Lewis *et al.* 2009)
Incubation (eggs)	N/A	N/A	N/A
Emergence	N/A	N/A	N/A
Rearing (0+) young of year (fry)	Optimal: 2.8 m^3/s (Lewis *et al.* 2009)	Optimal: 4.3 m^3/s (Lewis *et al.* 2009)	Optimal: 4.5 m^3/s (Lewis *et al.* 2009)
Rearing (1+) (parr)	Optimal: 6.4 m^3/s (Lewis *et al.* 2009)	Optimal: 8.2 m^3/s (Lewis *et al.* 2009)	Optimal: 6.3 m^3/s (Lewis *et al.* 2009)
Smolting	N/A	N/A	N/A
Outmigration	N/A	N/A	N/A

Table 3-7. Optimal instream flows for chinook (late run), steelhead and coho, Nicola River Spius to confluence Coldwater River (N2). *Source*: Lewis *et al.* (2009) and references therein.

	Nicola River Spius to confluence Coldwater River (N2)	**Nicola River Spius to confluence Coldwater River (N2)**	**Nicola River Spius to confluence Coldwater River (N2)**
Life-history stage	Chinook (late run)	Steelhead	Coho
In-migration	Use spawning flows	Use spawning flows	Use spawning flows
Spawning	Optimal: 11 m^3/s (Lewis *et al.* 2009)[3] Optimal: 6.8 m^3/s (Bruce and Hatfield 2003) Lewis *et al.* only recommend the values above for months *Aug - Sep*; maintain 3.12 m^3/s during Oct-Dec Optimal: 4.25 m^3/s (Kosakoski and Hamilton 1982)*	Optimal: 8.2 m^3/s (Lewis *et al.* 2009)	Optimal: 6.4 m^3/s (Lewis *et al.* 2009)
Incubation (eggs)	N/A	N/A	N/A
Emergence	N/A	N/A	N/A
Rearing (0+) young of year (fry)	Optimal: 1.1 m^3/s (Lewis *et al.* 2009) Optimal: 3.5 m^3/s (Bruce and Hatfield 2003) Optimal: 1.42 m^3/s (Kosakoski and Hamilton 1982)*	Optimal: 2.4 m^3/s (Bruce and Hatfield 2003) Optimal: 2.83 m^3/s (Kosakoski and Hamilton 1982)*	Optimal: 2.6 m^3/s (Lewis *et al.* 2009)
Rearing (1+) (parr)	Optimal: 3.5 m^3/s (Lewis *et al.* 2009)	Optimal: 7 m^3/s (Lewis *et al.* 2009) Optimal: 5.6 m^3/s (Bruce and Hatfield 2003)	Optimal: 4.0 m^3/s (Lewis *et al.* 2009)
Smolting	N/A	N/A	N/A
Outmigration	N/A	N/A	N/A

* Considered an underestimate by Lewis *et al.* (2009).

Table 3-8. Optimal instream flows for chinook (late run), steelhead and coho, Nicola River Coldwater to Nicola Lake Dam (N3). *Source*: Lewis *et al.* (2009) and references therein.

Life-history stage	**Nicola River Coldwater to Nicola Lake Dam (N3)** Chinook (late run)	**Nicola River Coldwater to Nicola Lake Dam (N3)** Steelhead	**Nicola River Coldwater to Nicola Lake Dam (N3)** Coho
In-migration	Use spawning flows	Use spawning flows	Use spawning flows
Spawning	Optimal: 3.4 m^3/s (Bruce and Hatfield 2003)* Optimal: 1.7 m^3/s (Kosakoski and Hamilton 1982)*	Optimal: 4.3 m^3/s (Lewis *et al.* 2009)	Optimal: 3.4 m^3/s (Lewis *et al.* 2009)
Incubation (eggs)	N/A	N/A	N/A
Emergence	N/A	N/A	N/A
Rearing (0+) young of year (fry)		Optimal: 1.0 m^3/s (Lewis *et al.* 2009)	Optimal: 1.1 m^3/s (Lewis *et al.* 2009)
Rearing (1+) (parr)	Optimal: 1.4 m^3/s (Lewis *et al.* 2009)	Optimal: 3.2 m^3/s (Lewis *et al.* 2009)	Optimal: 2.1 m^3/s (Lewis *et al.* 2009)
Smolting	N/A	N/A	N/A
Outmigration	N/A	N/A	N/A

* Considered an underestimate by Lewis *et al.* (2009).

The analysis of Lewis *et al.* (2009) supports the recommendation of Kosakoski and Hamilton (1982) "to ensure that the salmonid production potential of the Nicola River system is maintained, it is recommended that there be no increase in water diversion...during low flow periods, and no new water diversion licences unless they are supported by storage."

[3] Note: for Chinook adults, habitat suitability does not decline with flows greater than 11 m^3/s.

3.1.4 Not just flow – water temperatures

In addition to emphasizing the importance of **groundwater,** the importance of tracking and factoring in water temperature effects on fish is also considered in the NWMT (Alexander and Poulsen 2015). Currently, in NWMT, water temperatures are used as a diagnostic and not implemented in objectives (Section 3.5). The temperature sensitivities of the Nicola are well known and documented (see review by Peatt and Peatt 2013). Without intervention to address high stream temperatures in the Nicola, changes in fish community structure changes from the extirpation of temperature sensitive species including bull trout, chinook salmon and coho salmon, are likely to occur (Peatt and Peatt 2013). In recognition of the issue, the Province of British Columbia has identified the Nicola River Watershed as a candidate for designation as a Temperature Sensitive Stream under the Forest and Range Practices Act (Peatt and Peatt 2013). This designation would create a requirement to ensure trees are harvested on Crown Land within the riparian area in a manner that prevents adverse affects on fish. This designation would not apply to any riparian areas on private lands or other lands not managed by the Province for timber, thus the lower Coldwater and Nicola mainstem will not be afforded any direct protection through this designation.

Groundwater upwelling/discharge zones create **thermally stabilized local habitats** which are very important to salmon (Alexander and Poulsen 2015). Where a local river reach is **gaining** groundwater through lateral seep or springs, local water temperatures may be significantly cooled from the ambient stream temperature. For example, McGrath and Walsh (2012) found that maximum daily temperatures were on average 11.5°C lower in groundwater upwelling areas in the Nicola River than adjacent areas. This can provide critical refugia, and be the difference between survival and death. Other research has shown that redd site selection correlates strongly with groundwater–surface water interchange zones. In addition to thermal benefits, groundwater flow can also stop the formation of anchor ice during winter months.

Figure 3-2 shows key refuge locations where chinook congregate during high water temperature periods. With respect to water temperature management in the Nicola Basin, Richard Bailey identified the “double-edged sword” created by water storage in Nicola Lake. Providing more outflow during summer and fall often improves conditions for salmon, however, this can back-fire when the water released from Nicola Lake is too warm.

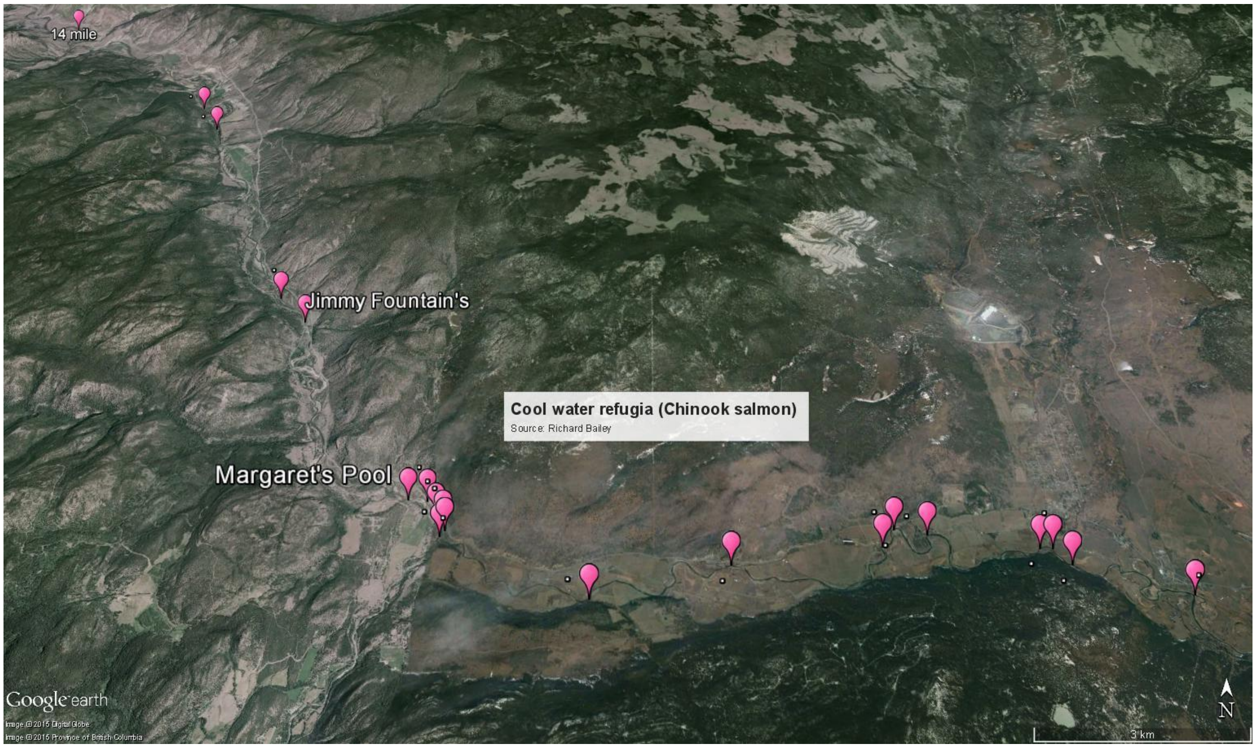


Figure 3-2. Cool water refugia locations used by chinook salmon during high water temperature periods. *Source*: Richard Bailey and Richard McCleary (pers. comm. 2015).

Thermal stress in salmon is any temperature change producing a significant alteration to biological functions and which lower probability of survival (Elliott 1981). Thermal stress was categorized by Fry (1947) (as cited by Elliott 1981) and Brett (1958) (as cited by Elliott 1981) as **lethal** (leading to death within the resistance time), **limiting** (restriction of essential metabolites or interference in energy metabolism or respiration), **inhibiting** (interference in normal functions such as reproduction, endocrine and ionic balance, and feeding functions caused by low or high temperatures), and **loading** (increased burden on metabolism that controls growth and activity). The latter three stresses can also be lethal when continued over a long period (Elliott 1981). Lethal stress can further be defined in different forms, such as incipient lethal temperature, and critical thermal maximum, etc. When food or oxygen are restricted (i.e., compounding stresses), the thermal stress thresholds may be further lowered. Furthermore, different life-history stages also have different temperature tolerances (Figure 3-3).

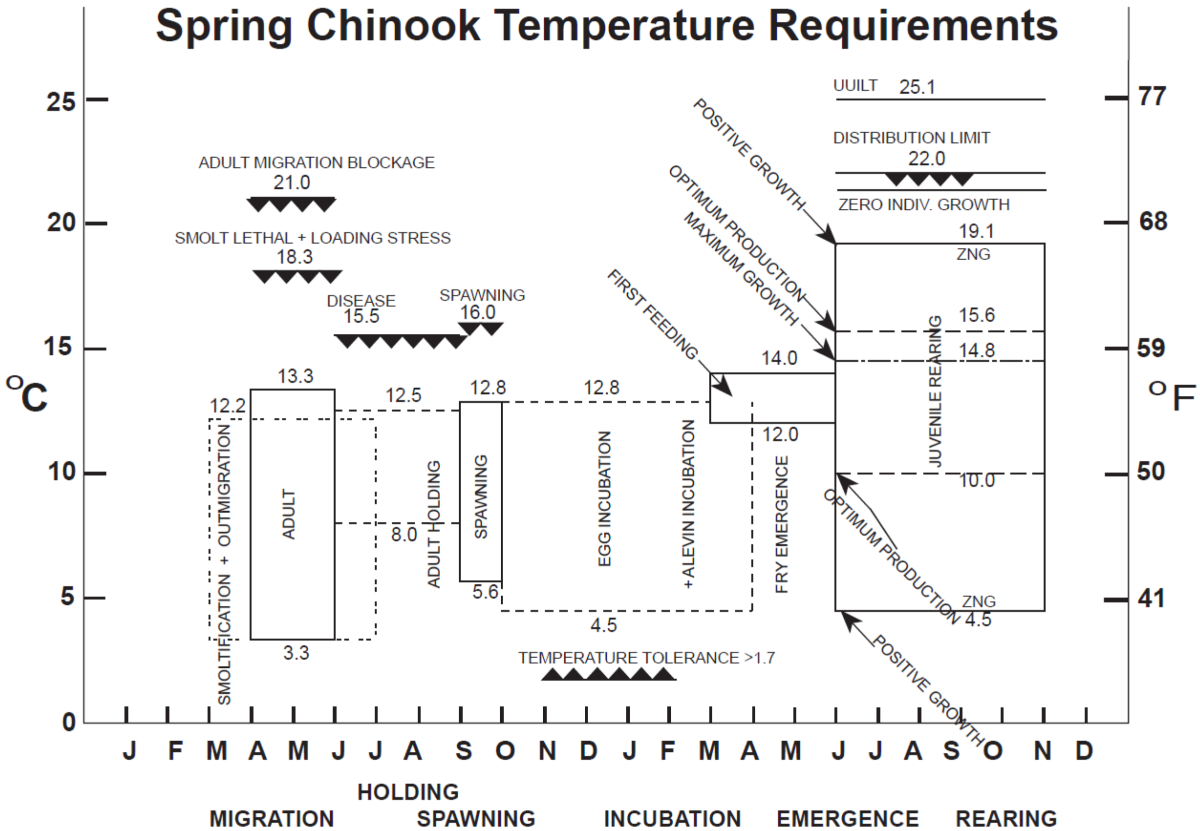


Figure 3-3. Example of temperature range tolerances, optima and limits for chinook (late run) salmon. *Source*: McCullough 1999.

Based on workshop discussions (Alexander and Poulsen 2015) and review of the literature, we recommend the maximum temperature limits shown in Table 3-9 and Table 3-10 for salmon using the mainstem Nicola River.

Table 3-9. Maximum temperature limits for salmon proposed for the Nicola Fish/Water Management Tool (NWMT) for Chinook salmon using the mainstem Nicola River. These limits can be used as diagnostics in NWMT.

Threshold	Threshold	Optimal Range	Evidence and/or Comment
Migration limit, migration delays	≥ 19.0°C	3.3°C to 19.0°C	Peatt and Peatt (2013). Adult salmon will not actively migrate when temperatures are at or above 22°C (Richard Bailey, pers. comm. 2015). Temperature should be below this threshold.
Spawning limit	≥ 13.9°C	3.3°C to 13.9°C	Peatt and Peatt (2013). Temperature should be below this threshold.
Juvenile Rearing and Growth	≥ 15.5°C	10.0°C to 15.5°C	Peatt and Peatt (2013). Temperature should be below this threshold.
Lethal	≥ 22.0°C		Peatt and Peatt (2013). Gills cannot extract oxygen (Richard Bailey, pers. comm. 2015). Nicola Lake can frequently hit temperatures in this range in August. Temperature should be below this threshold.

Table 3-10. Maximum temperature limits for salmon proposed for the Nicola Fish/Water Management Tool (NWMT) for Steelhead salmon using the mainstem Nicola River. These limits can be used as diagnostics in NWMT.

Threshold	Threshold	Optimal Range	Evidence and/or Comment
Spawning limit	**≥ 15.5°C**	**10.0°C to 15.5°C**	Peatt and Peatt (2013). Temperature should be below this threshold.
Juvenile Rearing and Growth	**≥ 18.0°C**	**16.0°C to 18.0°C**	Peatt and Peatt (2013). Temperature should be below this threshold.
Lethal	**≥ 24.0°C**		Peatt and Peatt (2013). Nicola Lake can frequently hit temperatures in this range in August. Temperature should be below this threshold.

3.1.5 Flow and temperature related performance indicators

The NWMT includes a total of fourteen (14) performance indicators for the four (4) priority focal species: chinook (late run) salmon, steelhead, kokanee and coho (Table 3-11). The locations that these performance measures are relevant, and the time-periods of relevance are crossreferenced in Table 3-11. For flow-related performance indicators (Table 3-11), the approach recommended was to define two threshold flows from minimum fisheries maintenance flows (Table 3-5) to optimal flows (Table 3-6, Table 3-7 and Table 3-8). This would generate the established "good", "fair", "poor" traffic light hazard warnings used to successful effect in the Okanagan FWMT (Hyatt *et al.* 2015).

Table 3-11. Flow-related performance measures identified by fish subgroup participants for the priority focal species. Location details can be found in the section for each performance indicator.

Focal species or Diagnostic	Flow related performance indicator	Code	Location	Relevant time-period
Chinook (late run)	In-migration flows	CH1-MQ	Nicola River Thompson River to confluence Spius Creek (N1)	See: Table 3-1
	Spawning flows	CH2-SQ	Nicola River Spius to confluence Coldwater River (N2)	See: Table 3-1
	Incubation flows	CH8-IQ	Nicola River Spius to confluence Coldwater River (N2)	See: Table 3-1
	Egg scour flows	CH7-ScourQ	Nicola River Coldwater to Nicola Lake Dam (N3)	See: Table 3-1
	Rearing flows	CH3-RQ	Nicola River Spius to confluence Coldwater River (N2)	See: Table 3-1
Steelhead	Parr rearing flows	ST1-RQ	Nicola River Thompson River to confluence Spius Creek (N1)	See: Table 3-2
Coho	Off-channel habitat connectivity flows	CO1-CQ	Nicola River Spius to confluence Coldwater River (N2)	See: Table 3-3

Focal species or Diagnostic	Flow related performance indicator	Code	Location	Relevant time-period
Kokanee	Spawning passage flows	K1-SQ	Upper Nicola River above Nicola Lake to Douglas Lake (N4)	See: Table 3-4
	Nicola Lake Elevation	K3-LE	Nicola Lake	See: Table 3-4
	In-migration flows	K4-MQ	Upper Nicola River above Nicola Lake to Douglas Lake (N4)	See: Table 3-4

Richard McCleary assembled Figure 3-4 that shows flows during summer low flow periods in years known to have generated significant stress and mortality on fish. These "bad year" flows are helpful when cross-referencing precisely where to place thresholds for the transition between "poor" and "fair". From this graph, the likelihood of harsh conditions can be seen to increase substantially when summer flows in the Nicola River near Spence's Bridge fall below approximately 6 m^3/s.

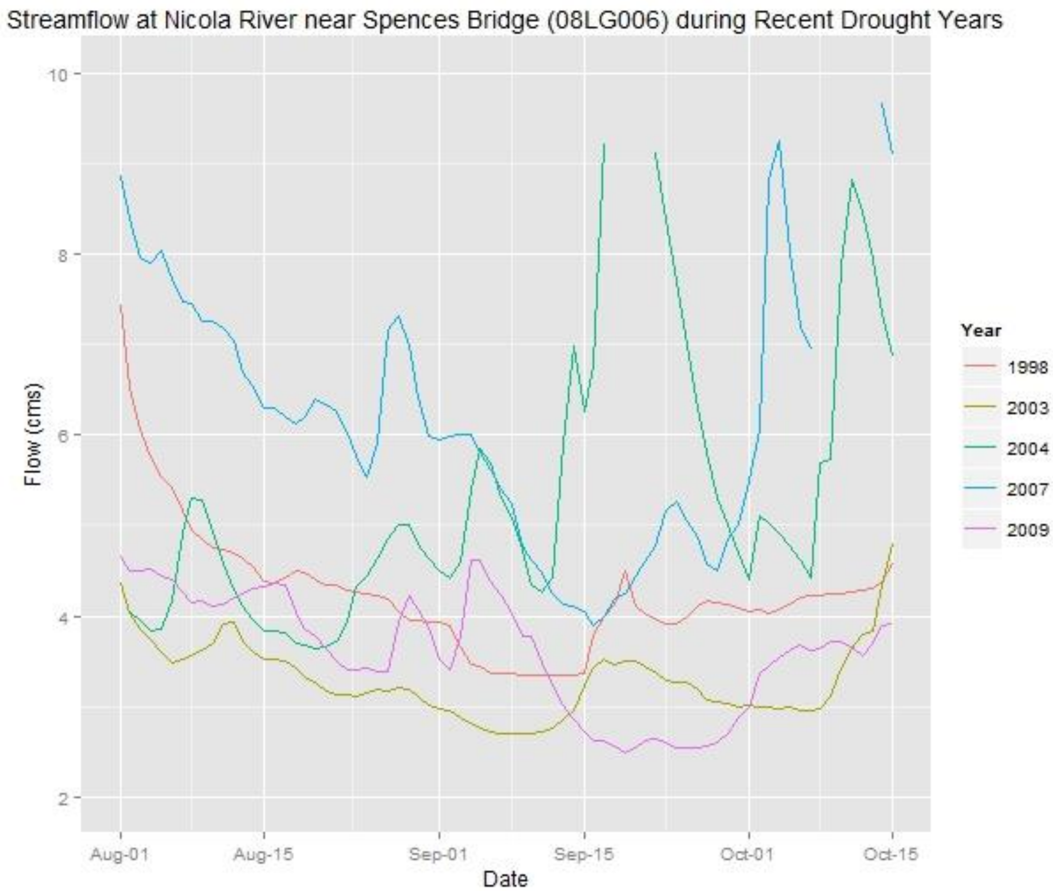


Figure 3-4. Flows during summer low flow periods in years known to have generated significant stress and in some cases mortality on fish.

Chinook (late run) - In-migration flows [CH1-MQ]

Draft presumptive standards for Chinook salmon (late run) in-migration attraction flows are provided in Table 3-12.

The optimal draft presumptive standards are the same as optimal spawning flows. The critical flow threshold was originally 5.66 m^3/s based on Kosakoski and Hamilton (1982) and was reduced to 4 m^3/s, the value used in 2015 and 2016, at a workshop on August 25 and 26, 2016. Based on professional experience, the time period relevant in critically dry years was determined as August 15 to September 5 (Table 3-13).

Table 3-12. Definition for chinook (late run) in-migration flows [CH1-MQ], reach N1.

CH1-MQ	Optimal	Fair	Critical	Key Evidence or Comments
Values:	**≥8.9m³/s**	**between**	**≤4 m³/s**	Optimal: Same as spawning flows. Critical: Expert opinion solicited at workshop on October 26th and 27th, 2016 (Appendix A)
Location:	Nicola River Thompson River to confluence Spius Creek (N1)			N1 flows indicative of flows experienced at confluence with Thompson River
Time period relevant:	See "In-migration" peak period Table 3-1			

Table 3-13. Definition for chinook (late run) in-migration flows [CH1-MQ], reach N1. **Critically dry years** only.

CH1-MQ	Optimal	Fair	Critical	Key Evidence or Comments
Values:	**≥8.9m³/s**	**between**	**≤4 m³/s**	Optimal: Same as spawning flows. Critical: Expert opinion solicited at workshop on August 25 and 26, 2016 (Appendix A)
Location:	Nicola River Thompson River to confluence Spius Creek (N1)			N1 flows indicative of flows experienced at confluence with Thompson River
Time period relevant:	August 15th to September 5th			Expert opinion solicited at workshop on August 25 and 26, 2016 (Appendix A)

Chinook (late run) - Spawning flows [CH2-SQ]

Draft presumptive standards for chinook (late run) salmon spawning flows are provided in Table 3-14. Kosakoski and Hamilton (1982) identified N2 as the critical reach in the Nicola River, and spawning chinook as the critical life-history stage (Lewis *et al.* 2009). The 2004-2007 MOE data support the conclusion that chinook adults have the highest flow requirements at a critical low flow spawning period in September. Kosakoski and Hamilton list the optimum flow for spawning chinook in the N2 reach (WSC gauge 08LG007) as 4.25 m³/s (31% Mean Annual Discharge (MAD), whereas the the relationships in Bruce and Hatfield (2003) suggest an optimal flow of 6.8 m³/s (49% MAD); both of these values contrast with optimum flows from more recent empirical data of 11 m³/s (80% MAD) (Lewis *et al.* 2009). Kosakoski and Hamilton (1982) recommended a minimum instream flow of 3.12 m³/s (23% MAD) for spawning chinook in the N2 reach. Lewis *et al.* (2009) recommended higher spawning flows (closer to optimum) for spawning chinook salmon in the months of August and September, while maintaining the Kosakoski and Hamilton minimum flow of 3.12 m³/s for the months of October through December, which are suitable for the rearing life-history stages of chinook, steelhead and coho.

Optimal threshold defined as average of optimal flows reported by Lewis *et al.* (2009) and Bruce and Hatfield (2003). Critical threshold defined Kosakoski and Hamilton (1982) minimum spawning flow.

Table 3-14. Definition for chinook (late run) spawning flows [CH2-SQ] indicator, reach N2.

CH2-SQ	Optimal	Fair	Critical	Key Evidence or Comments
Values:	**≥8.9m^3/s**	**between**	**≤3.12 m^3/s**	Optimal: Lewis et al. (2009) and Bruce and Hatfield (2003) optimal spawning flows for reach N2 Critical: Kosakoski and Hamilton (1982) minimum spawning flows
Location:	Nicola River Spius to confluence Coldwater River (N2)			N2 the critical reach
Time period relevant:	September 1st to 30th			Lewis *et al.* (2009). Higher min. flow recommended in months of August and September (only).

Chinook (late run) – Incubation flows [CH8-IQ]

Draft presumptive standards for chinook (late run) salmon incubation flows are provided in Table 3-15. The purpose of this indicator is to prevent the dewatering of eggs that occurs when water levels are below the initial level at the time of spawning. The management strategy is to reduce flows to a level that can be sustained throughout the incubation period as soon as spawning is complete. The indicator was identified during a 2-hour flow threshold refinement workshop with local experts (Richard Bailey, DFO and Richard McCleary, MFLNRO) on February 19, 2016. The critical flow threshold was identified at the same workshop based on expert opinion. No optimal threshold has been identified to date.

Table 3-15. Definition for chinook (late run) incubation flows, reach N2 [CH8-IQ].

CH8-IQ	Optimal	Fair	Critical	Key Evidence or Comments
Values:	**≥1.877 m^3/s**	…	**<1.877 m^3/s**	Expert opinion solicited at flow refinement threshold workshop on February 19, 2016 (Appendix A)
Location:	Nicola River Spius to confluence Coldwater River (N2)			
Time period relevant:	See "Eggs/Incubation" Table 3-1 October 1 to March 31			

Chinook (late run) - Egg scour flows [CH7-Scour]

Some subgroup participants referred to high flows scouring eggs during incubation below the dam (citing observations of gravel movement at high flows). Specific details on these thresholds were not offered at the workshop. Table 3-16 provides a basic structure for including this indicator.

Table 3-16. Definition for chinook (late run) incubating egg scouring flows, reach N3 [CH7-Scour].

CH7-Scour	Optimal	Fair	Critical	Key Evidence or Comments
Values:	**<24 m^3/s**	…	**≥35 m^3/s**	Optimal: Expert opinion solicited at workshop on October 26th and 27th, 2016 (Appendix A) Critical: Expert opinion solicited at workshop on October 26th and 27th, 2016 (Appendix A)
Location:	Nicola River Coldwater to Nicola Lake Dam (N3)			Spawning beds downstream of dam.
Time period relevant:	See "Eggs/Incubation" Table 3-1			

Chinook (late run) - Rearing flows [CH3-RQ]

Draft presumptive standards for chinook (late run) salmon rearing flows are provided in Table 3-17 and Table 3-18. There is an option to specify rearing flow targets for one key index river segment or all three.

Lewis *et al.* (2009) and Bruce and Hatfield (2003) reported optimal rearing flows for reach N2 of 1.1 m^3/s and 3.5 m^3/s respectively. Optimal flows are defined as an average of the two reported values (2.3 m^3/s).

Table 3-17. Definition for chinook (late run) rearing flows [CH3-RQ], reach N2.

CH3-RQ	Optimal	Fair	Critical	Key Evidence or Comments
Values:	**≥2.3m^3/s**	**between**	**≤1.13 m^3/s**	Optimal: Lewis *et al.* (2009) and Bruce and Hatfield (2003).
Location:	Nicola River Spius to confluence Coldwater River (N2)			
Time period relevant:	See "Rearing" Table 3-1			

Table 3-18. Definition for chinook (late run) rearing flows [CH3-RQ], reach N1.

CH3-RQ	Optimal	Fair	Critical	Key Evidence or Comments
Values:	**≥5.5m^3/s**	**between**	**≤3 m^3/s**	Presumptive flow standards, mixing concepts of "minimum fishery maintenance" flows and "optimal" flows to generate range of targets, "good", "fair", "poor".
Location:	Nicola River Thompson River to confluence Spius Creek (N1)			
Time period relevant:	See "Rearing" Table 3-1; All year.			

Steelhead - Parr rearing flows [ST1-RQ]

Draft presumptive standards for steelhead par rearing flows are provided in Table 3-19. Lewis *et al.* (2009) reported optimal flows for reach N1 of 4.3 m^3/s and 8.2 m^3/s for young of year and parr respectively (Table 3-6). Optimal flows were initially defined as the higher of the two reported values and later reduced to 5.5 m^3/s based on expert opinion solicited at workshop on August 25 and 26, 2016. Kosakoski and Hamilton (1982) reported fisheries maintenance flows of 5.66 m^3/s (Table 3-5), which is initially used to define critical flows and later reduced to 3 m^3/s based on expert opinion solicited at workshop on August 25 and 26, 2016.

Table 3-19. Definition for steelhead rearing flows [ST1-RQ], reach N1.

ST1-RQ	Optimal	Fair	Critical	Key Evidence or Comments
Values:	**≥5.5 m^3/s**	**between**	**≤3 m^3/s**	Optimal: Expert opinion solicited at workshop on October 26th and 27th, 2016 (Appendix A) Critical: Expert opinion solicited at workshop on October 26th and 27th, 2016 (Appendix A)
Location:	Nicola River Thompson River to confluence Spius Creek (N1)			
Time period relevant:	See "Rearing" Table 3-2			

Coho - Off-channel habitat connectivity flows [CO1-CQ]

Draft presumptive standards for coho off-channel habitat connectivity flows are provided in Table 3-20. Fish subgroup participants commented that if off-channels are groundwater fed, coho will want to access them. Ptolemy and Lewis (2002) reported good off-channel connectivity/riparian function flows of 100% MAD which the NWMT considers critical flows. The optimal flows of 200% is based on expert opinion solicited from local experts (Richard Bailey, DFO and Richard McCleary, MFLNRO) in a flow thresholds refinement workshop held on February 19, 2016.

Table 3-20. Definition for coho habitat connectivity flows [CO1-CQ], reach N1.

CO1-CQ	Optimal	Fair	Critical	Key Evidence or Comments
Values:	**≥59.6 m3/s 200% MAD**	**between**	**≤29.8 m3/s 100% MAD**	Optimal: Expert opinion solicited at workshop on October 26th and 27th, 2016 (Appendix A) Critical: Ptolemy and Lewis (2002)
Location:	Nicola River Thompson River to confluence Spius Creek (N1)			
Time period relevant:	See peak "Rearing (connectivity)" Table 3-3			

Kokanee - Spawning passage flows [K1-SQ]

Draft presumptive standards for kokanee spawning passage flows are provided in Table 3-21. These fish spawn in Upper Nicola River above Nicola Lake to Douglas Lake and to Chapperon Lake. Summer and fall spawning flows can be very low and very sensitive to irrigation withdrawals. Fish subgroup participants highlighted the summer of 2009, during which flows were reportedly very low (below 0.05 m^3/s). After a forced irrigation shutdown by provincial and federal order and flows were augmented with releases from an upstream reservoir, kokanee by the hundreds entered the Upper Nicola within hours. Prior to this, most irrigators had voluntarily stopped irrigation, recognizing the extreme drought and low flow conditions, but it was not sufficient for kokanee to gain access to the Upper Nicola (Al Caverly, pers. comm. 2015).

The critical threshold was initially defined as 0.2 m^3/s based on the 2009 Fish Protection Act Order. The critical threshold was later increased to 0.35 m^3/s and an optimal threshold of 0.54 m^3/s was added based on expert opinion solicited at a workshop on August 25 and 26, 2016

Table 3-21. Definition for kokanee spawning passage flows [K1-SQ], reach N4.

K1-SQ	Optimal	Fair	Critical	Key Evidence or Comments
Values	**≥0.54 m^3/s**	**between**	**≤0.35 m^3/s**	Critical: 2009 Fish Protection Act Order
Location:	Upper Nicola River above Nicola Lake to Douglas Lake to Chapperon Lake (N4)			
Time period relevant:	See "spawning" Table 3-4			

Kokanee - Nicola Lake elevation [K3-LE]

Draft presumptive standards for Nicola Lake target elevations during kokanee spawning are provided in Table 3-22. Below a certain lake elevation, kokanee spawners will have difficulty accessing the Upper Nicola River above Nicola Lake (N4). This elevation target is about providing access to N4; it is *not* about mortality of incubating shore spawning kokanee eggs (due to lake drawdown and dessication).

Table 3-22. Definition of target elevation for kokanee, Nicola Lake [K3-LE].

K3-LE	Optimal	Fair	Critical	Key Evidence or Comments
Values	**≥625.5 m**		**≤625 m**	Based on analysis of lake elevations in 2009 (poor year), 2010 (poor year) and 2007 (good year).
Location:	Nicola Lake			
Time period relevant:	See "spawning" Table 3-4			

Kokanee - In-migration flows [K4-MQ]

Draft presumptive standards for kokanee in-migration flows are provided in Table 3-23. The thresholds were defined during a workshop on August 25 and 26, 2016 with fish biologist as 15% and 10% of MAD for optimal and critical flows, respectively.

Table 3-23. Definition of kokanee in-migration flows [K4-MQ].

K3-LE	Optimal	Fair	Critical	Key Evidence or Comments
Values	**≥0.81 m^3/s**	**Between**	**≤0.54 m^3/s**	Optimal: 15% of MAD. Critical: 10% of MAD Expert opinion solicited at workshop on October 26th and 27th, 2016 (Appendix A)
Location:	N4			
Time period relevant:	20-Aug to 10-Sep			

3.1.6 Outputs & user interface

An example model output is shown in Figure 3-5. The main graph displays actual and forecast water temperature and discharge. Above the graph, performance indicators demonstrate the relative suitability and hazard risk of flows and water temperatures, using green (optimal), yellow (fair), and red (critical) symbology for each time period. When hovering over a graph element, additional information will be shown in a pop-up (see example in Figure 3-5)

The NWMT highlights the region selected with an inset map in the bottom left. To the left, the user can select between reports that summarize various model outputs (use the button to download model data). The NWMT will display any simulation errors above the graph.

Information for other Fish and Ecosystem Submodel performance indicators can be found by navigating to the appropriate report (see table Table 3-11).

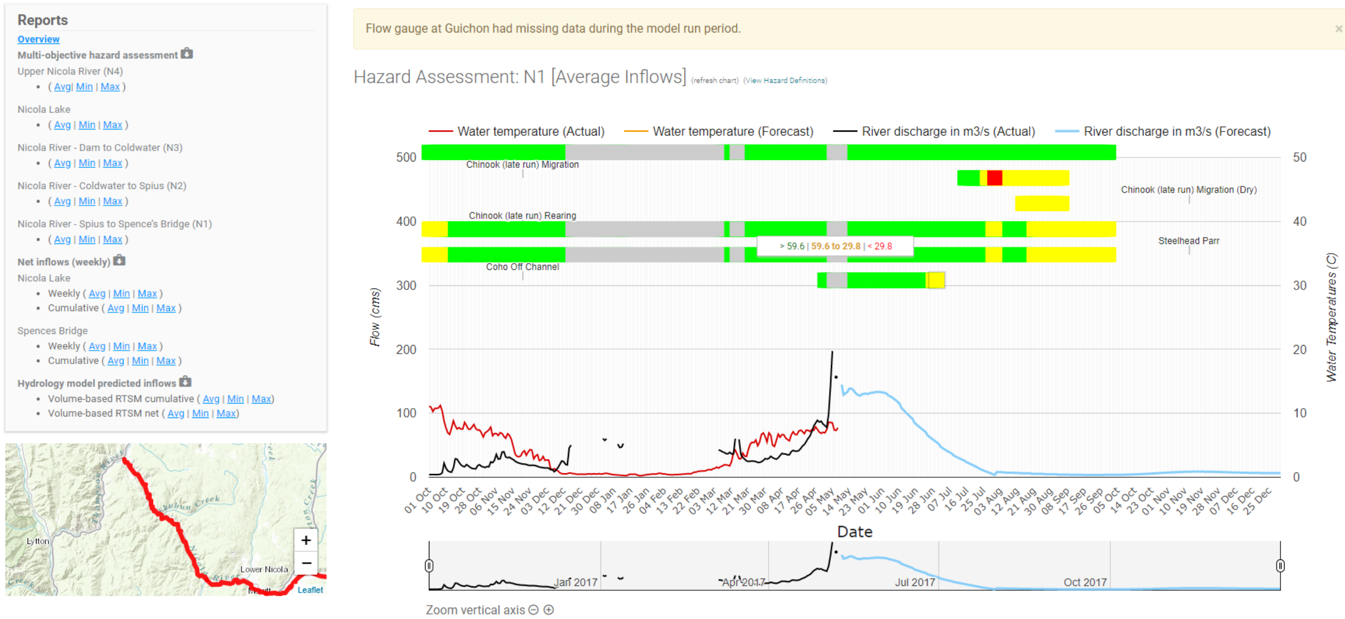


Figure 3-5. Results displayed by the NWMT for a hazard assessment of the N1 region, with forecasts based on average flows.

3.2 Socio-economic Rules Submodel

In 1985, Nicola Lake Dam was improved, and the improvements were partly paid for by the Department of Fisheries and Oceans. Improvements were intended for the joint benefit of the farmers, ranchers, and fisheries. Department of Fisheries and Oceans obtained access by license to approximately 1/3 of the stored water for fish, with the rest allocated to the Province of British Columbia for further allocation. Experience has shown that subsequent to the construction of the dam the potential water storage benefits have been limited by **incomplete dredging of the channel at the lake outlet, which would have allowed for more storage and negative drawdown**. Under the original (not completed) dam-design concept and proposed operating orders, the outlet to the lake would have been dredged in order to access negative storage, which is water below the normal lake elevation. Second, there are private property constraints on maximum lake levels (largely landscaping flooding) (Rosenau and Angelo 2003). Dredging the outlet to access negative storage would have other socio-economic and environmental effects that are currently poorly understood and a trade-off analysis has not occurred (Al Caverly pers. comm. 2015).

3.2.1 Nicola Lake water supply

The operation of the dam correlates with two major socio-economic objectives for Nicola Lake: (1) provision of water for irrigation use; and (2) flood protection. The two performance indicators associated with Nicola Lake and this submodel are thus "**Water supply availability**" and "**Nicola Lake flood protection**". (Fisheries objectives related to the dam are addressed in Section 3.1)

The status of lake elevations at any given time during the water year reflect how well or poorly these two objectives are being served.

Water supply availability [WS1-Availability]

When operating Nicola Lake Dam, there are four major **lake elevation targets** to consider (Figure 3-6):

1. Minimum "no-go" lake elevation
2. Full supply level (FSL)
3. Surcharge Storage (FSL to Crest of Overflow Spillway)
    - Water Surface Level (WSL) between FSL and Top of fishway, minor surcharge, typically happens on an annual basis
    - WSL above top of fishway, storage and releases adjusted as possible to minimize upstream and downstream flooding
4. Above Crest of spillway, gates fully open, and uncontrolled releases over spillway

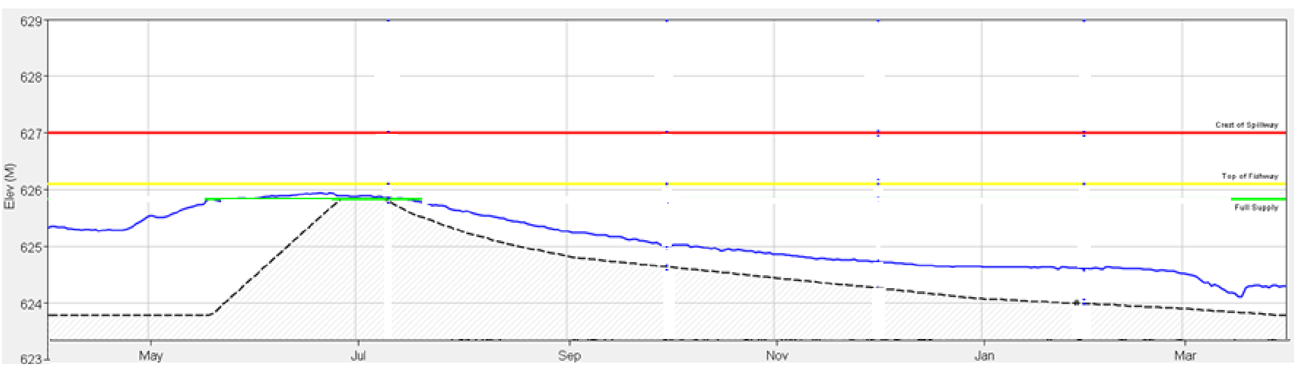


Figure 3-6. Key Nicola Lake water surface elevations by time of year.

The lower dotted black line in Figure 3-6 refers to the minimum target lake elevation (MTLE) during drought conditions. In general, operators never want to go below this elevation. This is considered a "**no go**" level. In the NWMT, any time the lake elevation fell below this level, the **water supply objective** would be flagged with a "**red**" (poor; unacceptable) performance.

The end of month target elevation (below which is defined as the critical elevation) is the same for all years from June to January and depend on observed lake levels and RFC inflow forecasts from February to May (Table 3-24). End of day target elevations are defined by linearly interpolating between end of month targets.

Table 3-24. Minimum target lake elevation (MTLE) calculation. Targets are the same for all years from June to January and depend on observed lake levels and RFC inflow forecasts from February to May. Source: MFLNRO (2014).

Month	End of Month Target Elevation	Comment
April	625.55 - 0.005 x V_{Apr}	V_{Apr} is forecasted inflow volume for April by the RFC
May	625.82 – [(625.83 - E_{May}) / 2]	E_{May} is observed lake level May 1st.
June	625.83	
July	625.83	
August	625.69	
September	625.54	
October	625.40	
November	625.26	
December	625.12	
January	624.98	
February	E_{Feb} - 0.002 x V_{Feb}	E_{Feb} is observed lake level February 1st. V_{Feb} is forecasted inflow volume for February by the RFC
March	625.55 - 0.005 x V_{Mar}	V_{Mar} is forecasted inflow volume for March by the RFC

The FSL is the target to **supply water** for all existing water licence holders (storage, irrigation, and other licensed uses). Operators aim to be at (or above) this level by late-June and remain at this level until mid-July. When this is the case, there is a very high probability of meeting agricultural irrigation and other water licence use requirements through the summer and fall. This is another **water supply** related guideline.

In practice, the "**green zone**" from a **water supply** perspective, is any lake elevation above the minimum flow line and below the top of fishway elevation (one could choose a higher elevation for this performance indicator; however, we recommend not defining a range that overlaps with surface elevations that are to be avoided for flood management purposes).

Table 3-25. Definition for Nicola Lake water supply.

Nicola Lake elevation	Optimal	Fair	Critical	Key Evidence or Comments
Values:	**≥ MTLE**		**< MTLE**	MFLNRO 2014 See Table 3-24 for definition of MTLE
Location:	Nicola Lake			
Time period relevant:	Any time (though in practice, this is a spring-time issue).			

3.2.2 Nicola Lake flood protection

Nicola Lake flood protection [NLF1-Shoreline flooding]

The top of fishway elevation is considered a visual cue to residential and cottage lakeside home owners and others to begin to worry about flooding around the lake. This is an appropriate "**yellow**" **flood warning level** for Nicola Lake (Jep Ball, pers. comm 2015; MFLNRO 2014). Jep Ball noted that at this level, issues around the lake are mostly landscaping problems, i.e., gardens, etc. rather than wet basements. The top of the fishway elevation is 626.10 m (MFLNRO 2014).

A truly hazardous and "**red**" (poor) performance level occurs at the crest of the spillway, the elevation at which it is assumed that lakeshore flooding becomes unacceptable to local residents (MFLNRO 2014). At this elevation, the overflow spillway begins to have flow through the riprap cap, and all Nicola Lake Dam gates should be fully open (they don't have to be but all efforts should be made to prevent an uncontrolled discharge over the emergency spillway). **This is the "red alert" level**. When the gates are fully open at this lake elevation, discharge approximates 110 m^3/s. At this level of flow, the **City of Merritt will definitely experience flood related damage** (Jep Ball, pers. comm. 2015). The elevation at the crest of the spillway is 626.50 m (MFLNRO 2014).

Table 3-26. Definition for Nicola Lake flood protection.

Merritt flood flows	Optimal	Fair	Critical	Key Evidence or Comments
Values:	**<626.1m**	**between**	**≥626.5 m**	MFLNRO 2014
Location:	Nicola Lake			
Time period relevant:	Any time (though in practice, this is a spring-time issue).			

3.2.3 Nicola Lake ice management

Nicola Lake ice blockage & zero flows [NLI1_Ice Blockage]

During long cold snaps between December and February (defined as more than one week at -20°C or colder), the risk of ice blockage of the non-dredged inlet channel to Nicola Lake Dam is significant if the lake level during this period is at **624 m or less** (Jep Ball, pers. comm. 2015) (Figure 3-7). When this occurs, there are zero flows from the dam which poses significant fisheries problems downstream.

Table 3-27. Definition for Nicola Lake ice blockage & zero flows.

Ice blockage & zero flows	Optimal	Fair	Critical	Key Evidence or Comments
Values:	**>624.5 m**	**<624.5 m***	**<624.5 m***	Jep Ball, pers. comm. 2015 * "Fair" when below 624.5 and air temperature below 20°C, "Critical" when below 20°C for 7 or more days.
Location:	Nicola Lake			
Time period relevant:	December to February			

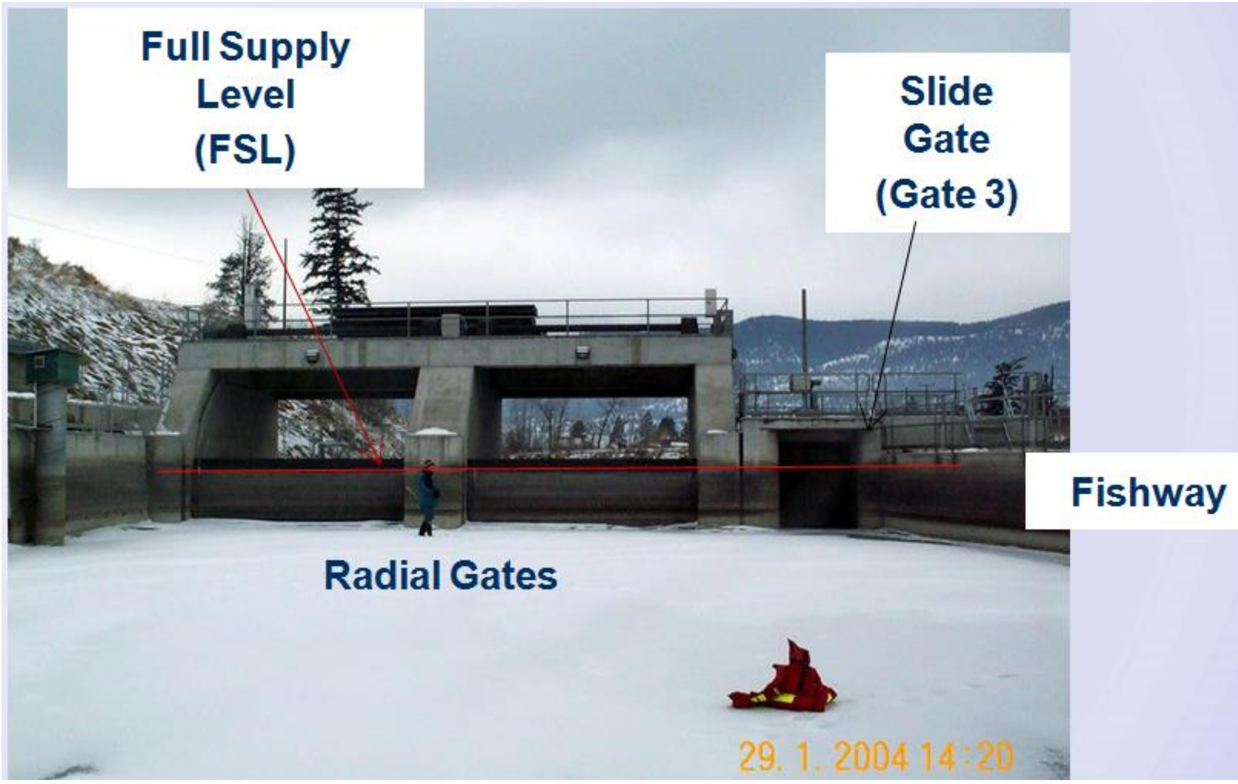


Figure 3-7. Example of icing condition, Nicola River immediately below Dam (January 1, 2004).

3.2.4 Nicola River flood flows

Flood protection at City of Merritt [NRF1-Merritt flooding]

Draft flood flow standards for the City of Merritt are provided in Table 3-28. Flooding at Merritt creates a variety of problems from sanitary sewer issues to property damage. There are also costs associated with sandbagging and prevention of damage (Jep Ball, pers. comm. 2015).

Experience indicates that 25 m^3/s produces bankfull conditions in Merritt. City warned if flow to exceed this rate so that plans for flood protection can be initiated. Merritt flood warning goes into effect at 30 m^3/s; sandbagging and other emergency protection is required. Note: Merritt experienced 50 m^3/s flood in 2002 with no reported major damage to structures. (Jep Ball, pers. comm. 2015).

Table 3-28. Definition for Nicola River flood flows, City of Merritt.

Merritt flood flows	Optimal	Fair	Critical	Key Evidence or Comments
Values:	**<24 m³/s**	**between**	**≥35 m³/s**	Experience indicates that 25 m³/s produces bankfull conditions in Merritt. Merritt flood warning goes into effect at 30 m³/s, sandbagging and other emergency protection is required. (Jep Ball, pers. comm. 2015). Note: Merritt experienced 50 m³/s flood in 2002 with no reported major damage to structures.
Location:	Merritt			
Time period relevant:	Any time (though in practice, this is a spring-time issue).			

Flood protection at downstream of Merritt [NRF2-Flooding downstream of Merritt]

Draft flood flow standards downstream of Merritt are provided in Table 3-29. Flooding downstream of Merritt is designed to evaluate flood risk for the Nooaitch Indian Band.

The optimal threshold is defined based on peak flows in 2017 (approximately 300 m^3/s) at the Spences Bridge guage (N1), which caused only very minor overbank flooding at Nooaitch. The critical tresholhold is defined as the historical maximum flow at the Spence's Bridge gauge (N1) which is approximately 380 m^3/s (Jep Ball, pers comm. 2017).

Table 3-29. Definition for Nicola River flood flows, downstream of Merritt.

Downstream of Merritt flood flows	Optimal	Fair	Critical	Key Evidence or Comments
Values:	**<300 m³/s**	**between**	**≥380 m³/s**	Optimal: Defined as peak flows in 2017 which caused only very minor overbank flooding at Nooaitch Critical: Defined as the historical maximum flow Jep Ball, pers. comm. 2017

Downstream of Merritt flood flows	Optimal	Fair	Critical	Key Evidence or Comments
Location:	N1			
Time period relevant:	Any time (though in practice, this is a spring-time issue).			

3.2.5 Outputs & user interface

An example model output is shown in figure Figure 3-8. The following socio-economic model outputs, and their locations (in parentheses) can be viewed in the NWMT:

- Water supply availability [WS1-Availability] (N1);
- Nicola Lake flood protection [NLF1-Shoreline flooding] (Nicola Lake);
- Nicola Lake ice blockage & zero flows [NLI1-Dessication Q] (Nicola Lake); and
- Nicola River flood protection [NRF1-Merritt flooding] (N3).

The user interface for Hazard Assessment Reports is described in Section 3.1.6.

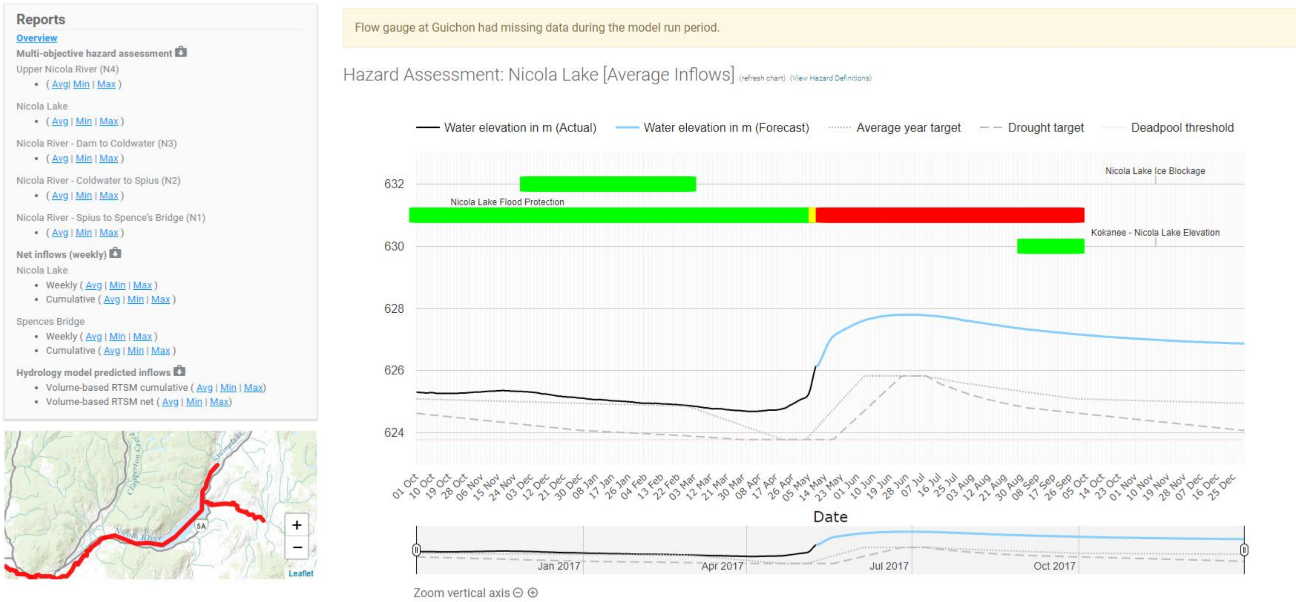


Figure 3-8. Results displayed by the NWMT for an example hazard assessment of Nicola Lake, with forecasts based on average flows. The model output displays observed (black) and forecasted (blue) lake elevations, the state of performance indicators at relevant periods throughout the year (green, yellow, and red bars), targets (grey lines), and the Deadpool threshold (rose coloured dotted line).

3.3 Hydrology & Water Balance Submodel

The overall objective of the hydrology and water balance submodel is to estimate the water level at Nicola Lake and discharge in the Nicola River at Merritt, Guichon Creek, Spius Creek and Spences Bridge over time.

In this section, we describe the approach to:

- estimate seasonal inflow for the Nicola Watershed;
- disaggregate the total seasonal inflow forecasts provided by the RFC into daily estimates;
- predict future daily changes in the elevation of Nicola Lake, based on the forecasts of daily lake inflow and a series of daily outflows at Nicola Lake specified by the user;
- predict future discharge in the mainstem Nicola River based on a user-defined weekly schedule of releases from Nicola Lake and forecast inflows from tributaries; and
- adjust predictions based on real-time data.

The methods presented in this section form the backbone of the Hydrology & Water Balance Submodel in the NWMT. The water year is split into a dominant period (Feb 1 to Jul 31) and a non-dominant period (Aug 1 to Jan 31), with approximately ~90% of the total annual inflow occurs during the dominant period.

3.3.1 Locations of interest

The spatial scope of the submodel includes Nicola Lake and the mainstem Nicola River from Nicola Lake Dam to the confluence with the Thompson River. Submodel calculations are performed at specific points of interest within the watershed. In the mainstem river, locations of interests are at the outlet of Nicola Lake, just upstream of the confluences with three major tributaries (Coldwater Creek, Guichon Creek and Spius Creek) and just before the river joins the Thompson River at Spences Bridge. Combined with a location of interest at Nicola Lake, the hydrology and water balance submodel has seven locations of interest:

- Nicola Lake
- Upper Nicola River at Nicola Lake (Reach N4)
- Nicola River at output of Nicola Lake (Reach N3)
- Nicola River just upstream of Coldwater
- Nicola River just upstream of Guichon Creek
- Nicola River just upstream of Spius Creek (Reach N2)
- Nicola River at Spences Bridge (Reach N1)

Management of the Nicola Lake/River system is primarily controlled by the Nicola Lake Dam and water extractions.

3.3.2 Data sources

Water Survey of Canada (WSC) has several gauges in the watershed with some dating back to 1911. For this study, gauges were selected that are either in the mainstem of the Nicola River or in major contributing subbasins (Coldwater, Guichon and Spius) close to the Nicola River. The selected gauges (Table 3-30, Figure 3-9) have between 20 and 50 complete years of data available (years without data missing for a single day). Four of the gauges (1 on Nicola Lake, 2 on Nicola River and 1 on Coldwater Creek) have real-time data available. The gauges in Guichon Creek and Spius Creek are proposed to be re-activated or established as real-time gauges.

Table 3-30. Selected Water Survey of Canada gauging stations in the Nicola River watershed. Selected stations are either in the mainstem of the Nicola River or in major contributing subbasins. Complete years are years without data missing for a single day.

Subbasin	Station id	Station Name	Period of record	Realtime data	Complete years
Upper Nicola	08LG049	Nicola River above Nicola Lake	1915 to current	Yes	43
Lower Nicola	08LG046	Nicola Lake near Nicola	1933 to current	Yes	44
Lower Nicola	08LG065	Nicola River at outlet of Nicola Lake	1983 to current	Yes	31
Coldwater	08LG010	Coldwater River at Merritt	1913 to current	Yes	39
Lower Nicola	08LG007	Nicola River near Merritt	1911 to 2007	No	51
Guichon	08LG004	Guichon Creek near Lower Nicola	1911 to 1984	No	20
Guichon	08LG067	Guichon Creek at the mouth	1984 to 2010	No	26
Spius	08LG008	Spius Creek near Canford	1911 to 2008	No	37
Lower Nicola	08LG006	Nicola River near Spences Bridge	1911 to current	Yes	50

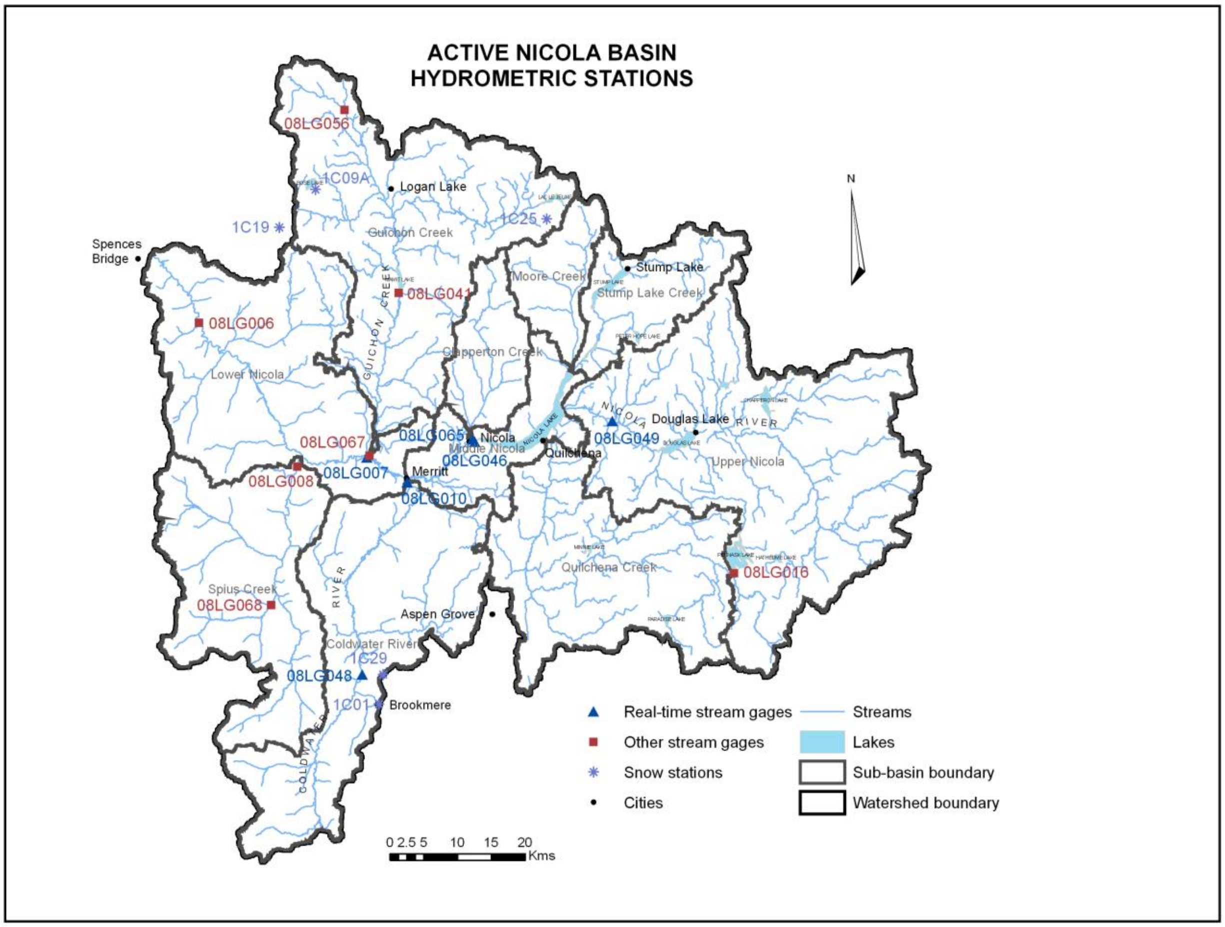


Figure 3-9. Map of Nicola basin hydrometric stations.

3.3.3 Volumetric inflow forecasting methods

Volumetric inflow forecasts are the key input into the NWMT. These forecasts are generated every year by the Government of British Columbia's River Forecast Centre (RFC) independently forecast inflows using a seasonal forecast model for the Nicola Watershed at four intervals. These externally-derived forecasts of the total inflow from the RFC are made February 1, March 1, April 1, and May 1 and cover the period from the forecast date to July 31. These forecasts are provided in the form of an expected value, a high and a low estimate (the high and low estimates represent the mean ±1 standard error (SE)).

The RFC seasonal forecast model currently forecasts the total runoff volume between February and July for two locations: inflow to Nicola Lake and Nicola River at Spences Bridge The forecast is updated monthly from February to May and spans the time from the date produced (e.g., March 1) to both June and July (e.g., for the March 1 forecast, the duration is from March 1 to June 1 and March 1 to July 1). These forecasts are provided in the form of an expected value, a high and a low estimate (the high and low estimates represent the mean ± 1 standard error). The seasonal forecast is based on principle components analysis (PCA) of snowpack, valley precipitation, antecedent streamflow, and a climate index. The climate index characterizes the intensity of an El Niño/Southern Oscillation (ENSO) event using a multivariate ENSO index (MEI). The approach is standardized and used by BC Hydro, Natural Resources Conservation Service (NRCS) and other agencies in the US and Canada for seasonal water supply forecasting. The PCA is completed in a program called VIPER. The current seasonal forecast model could be enhanced to provide forecasts for the entire water year and for more locations. Throughout the text, the forecast produced by the seasonal forecast model is called the “RFC forecast”.

River Forecast Centre
Ministry of Forests, Lands and Natural Resource Operations
Volume Runoff Forecast March 2015

Location		Mar - Jun Runoff				Mar - Jul Runoff				Mar - Sep Runoff			
		Forecast ($kdam^3$)	Normal (1981-2010) ($kdam^3$)	% of Normal	Std. Error ($kdam^3$)	Forecast ($kdam^3$)	Normal (1981-2010) ($kdam^3$)	% of Normal	Std. Error ($kdam^3$)	Forecast ($kdam^3$)	Normal (1981-2010) ($kdam^3$)	% of Normal	Std. Error ($kdam^3$)
Upper Fraser Basin	Fraser at McBride					3908	3786	103	331	5508	5252	105	390
	McGregor at Lower Canyon					3809	4087	93	490	4884	5132	95	639
	Fraser at Shelley					16585	16310	102	1494	20656	20369	101	1832
Middle Fraser Basin	Quesnel River at Quesnel					4574	4747	96	510	5904	6078	97	670
Thompson Basin	N. Thompson at McLure					8505	9190	93	536	10650	11359	94	826
	S. Thompson at Chase					6040	6111	99	566	7641	7678	100	832
	Thompson at Spences Bridge					15083	15775	96	1174	19087	19755	97	1814
Bulkley and Skeena	Bulkley at Quick					2829	2709	104	1361	3442	3306	104	1939
	Skeena at Usk					19984	19187	104	1335	24393	23531	104	1809
Nicola Lake	Inflows	98	126	78	31	111	143	78	35				
Nicola River	at Spences Bridge	366	523	70	82	401	591	68	103				
Similkameen River	at Nighthawk	1270	1342	95	158					1540	1652	93	184
	at Hedley	1003	1045	96	134					1162	1233	94	151
Okanagan and Kalamalka-Wood Lake	Okanagan Lake Inflow	404	470	86	89	422	497	85	110				
	Kalamalka-Wood Lake Inflow	20	31	63	12	19	33	59	15				

Note: 1 $kdam^3$=1,000,000 m^3
Note that missing values reflect that forecasts were not made for that time interval
Disclaimer: Seasonal forecasts were developed using a Principle Component Analysis of snow pack, climate and streamflow data.
There is inherent uncertainty in runoff forecasts including potential errors in data and the unpredictable nature of seasonal weather
Use at your own risk

Figure 3-10. Example output from the seasonal forecast model. The seasonal forecast model currently forecasts the total runoff volume from the date produced to both June and July for two locations in the Nicola Watershed. The forecasts provide an expected value and a standard error which can be used to provide a high and a low estimate.

An alternate method for generating the volumetric inflow forecast, also maintained by the RFC, is the Channel Links Evolution Explicit Routing (CLEVER) model. For the NWMT, this forecasting method was not used. Alexander and Poulsen (2015) provide more details on this method.

3.3.4 Disaggregating net inflows to daily flow

The hydrology and water balance submodel takes the form of a series of empirical relations which are intended to be run for a period of up to one year on a daily time-step where the "year" is defined as starting October 1 and ending September 30. As external inflow forecasts from RFC are not available until February 1, the effective definition of a year in this submodel was February 1 to January 31 (though any given simulation ends September 30). Model "runs" made on any day after February 1 include real-time data up to that point, which are used to adjust forecasts for the remaining period of the year. The submodel does not have multi-year capability.

3.3.5 Water balance equations

The Nicola Lake water balance provides the basis upon which net lake inflows (both historical and in real-time) are calculated. (Eq. 1 represents the general water balance for Nicola Lake.

$$I_i - O_i = \Delta S_i \qquad \text{(Eq. 1)}$$

where: Ii = net inflow to Nicola Lake for day i (m^3);
Oi = outflow from for day i (m^3); and
∆Si = change in storage volume of Nicola Lake between day i-1 and i (m^3).

Rearranging, net inflows to Nicola Lake are calculated on a daily basis using (Eq. 2).

$$I_i = O_i + \Delta S_i \qquad \text{(Eq. 2)}$$

To calculate ∆Si, a lake storage rating curve based on lake bathymetry and littoral zone topography was utilized (Figure 3-11 and (Eq. 3). This rating curve was derived from a storage capacity table provided by the River Forecast Centre (RFC). For each daily lake level (m, geodetic), a lake volume is calculated, and the difference from one day to the next forms the basis of the daily change in lake storage volume (i.e. ∆Si).

$$S_i = 1{,}955{,}357\mathrm{L}_i{}^2 - 2{,}418{,}660{,}556\mathrm{L}_i + 748{,}442{,}916{,}905 \qquad \text{(Eq. 3)}$$

where: Si = storage volume of Nicola Lake on day i (m^3); and
Li = Nicola Lake level (m, geodetic) on day i.

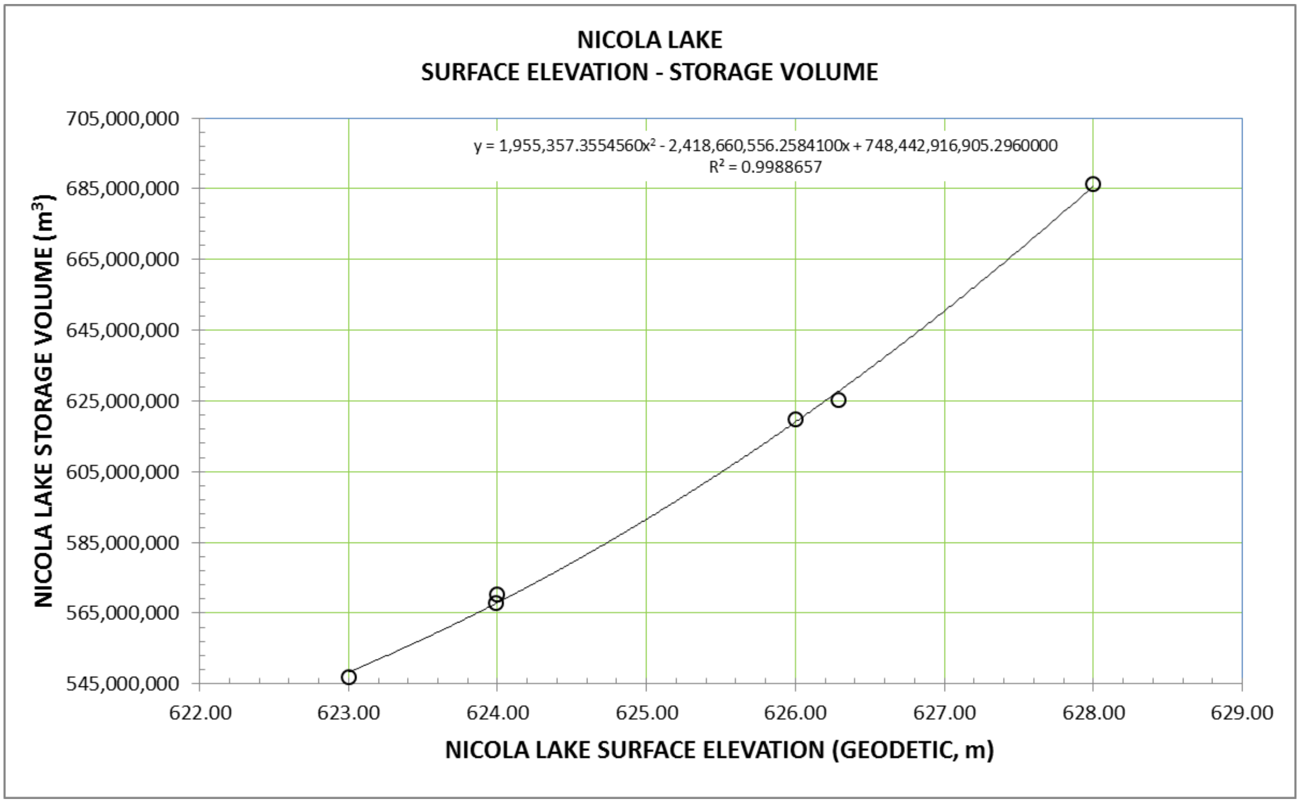


Figure 3-11. Nicola Lake surface elevation – storage volume rating curve. Data for this curve were obtained from the River Forecast Centre.

We used LOESS (LOcal regrESSion) smoothing to eliminate the noise in the daily data using the R statistical computing environment. The level of smoothing chosen (the alpha parameter, called 'span' in R) was selected by qualitative judgement (span=0.001), being careful to remove noise while preserving real variability. In the future, it may be beneficial to examine if further optimization of the smoothing parameters is warranted through more statistically rigorous means (e.g., information theoretic approaches of model fitting such as Akaike Information Criterion (AIC)).

The NWMT forecasts weekly estimates of the water level in Nicola Lake and discharge in the Nicola River at Merritt, Guichon Creek, Spius Creek and Spences Bridge based on simple water balance equations. The weekly estimates are based on weekly forecasted inflows to Nicola Lake and from the three major tributaries (Coldwater Creek, Guichon Creek and Spius Creek) as well as scheduled releases from Nicola Lake Dam. Direct evaporation and transpiration are assumed to be accounted for in the predicted net inflows from the seasonal forecast model. Direct evaporation and transpiration and seepage in the mainstem Nicola River is assumed negligible.

The flow in the Upper Nicola River is assumed equal to a fraction of the forecasted weekly disaggregated inflows for Nicola Lake (Eq. 4).The proportion of Nicola Lake inflows derived from Upper Nicola River ($\alpha_{Upper\ Nicola\ River}$) can be estimated from historical data. Extractions are not included because the forecasted net inflows to Nicola Lake already accounts for extractions.

$$Q_{Upper\ Nicola\ River} = I_{Nicola\ Lake} * \alpha_{Upper\ Nicola\ River} \tag{Eq. 4}$$

Where $Q_{Upper\ Nicola\ River}$ is the forecasted flow in the Upper Nicola River;
$I_{Nicola\ Lake}$ is weekly forecasted inflow to Nicola Lake; and
$\alpha_{Upper\ Nicola\ River}$ is proportion of Nicola Lake inflows derived from Upper Nicola River (e.g., not from Quilchena Creek or other major inflow streams).

The water volume in Nicola Lake is calculated using (Eq. 5). The volume is then converted to a water level elevation using the relationship in Figure 3-12.

$$V_{Nicola\ Lake,t=i+1} = V_{Nicola\ Lake,t=i} + I_{Nicola\ Lake} - Q_{Nicola\ Lake} \tag{Eq. 5}$$

Where $V_{Nicola\ Lake,t=i}$ is the volume in Nicola Lake at time I;
$I_{Nicola\ Lake}$ is weekly forecasted inflow to Nicola Lake; and
$Q_{Nicola\ Lake}$ is the weekly scheduled release from Nicola Lake Dam.

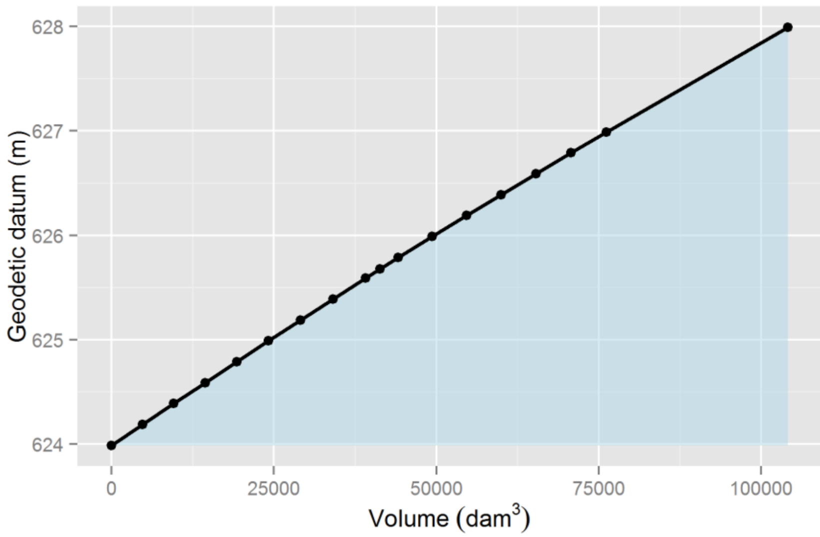


Figure 3-12. Storage-capacity curve for Nicola Lake. This relationship is used to convert the weekly forecasted volume to an elevation for Nicola Lake.

The downstream flows are calculated using (Eq. 6) to (Eq. 9). For each location represented by a confluence of the mainstem and a tributary, a simple water balance is assumed. Routing effects (peak lag and attenuation) are assumed negligible due to the weekly time step and inflow forecasts are net inflows based on flow measurements, so extractions are implicitly accounted for. There are no major tributaries between Spius Creek and Spences Bridge, so flows are only assumed to change due to extractions. Extractions are further described in Section 3.4.

$$Q_{Merritt} = Q_{Nicola\ Lake} + I_{Coldwater} - E_{Merritt} \qquad \text{(Eq. 6)}$$

$$Q_{Guichon} = Q_{Merritt} + I_{Guichon} - E_{Guichon} \qquad \text{(Eq. 7)}$$

$$Q_{Spius} = Q_{Guichon} + I_{Spius} - E_{Spius} \qquad \text{(Eq. 8)}$$

$$Q_{Spences\ Bridge} = Q_{Spius} - E_{Spences\ Bridge} \qquad \text{(Eq. 9)}$$

Where $Q_{Location\ of\ interest}$ is weekly flow at a location of interest,
$I_{Tributary}$ is weekly forecasted net inflow for a tributary, and
$E_{Locations\ of\ interest}$ is weekly forecasted extractions between point of interest and nearest upstream point of interest.

3.3.6 Generating hydrology model predictions

The hydrology submodel generates predictions of the timing and volume of net inflows for the dominant and non-dominant periods and for Nicola Lake and Nicola River. Predictions for Nicola Lake during the dominant period are calculated using the Real-Time Statistical Matching (RTSM) algorithm, while for the other spatial and temporal strata predictions are made using a historical average fit with short-term adjustment (Table 3-31).

Table 3-31. Summary of spatial and temporal scope of the Water Supply & Hydrology Submodel

	Temporal Scope	
Spatial Scope	**Aug 1 – Jan 31**	**Feb 1 – July 31**
Nicola Lake	Adjusted regression models	RTSM Model
Nicola River @ Merritt, Guichon Creek, Spius Creek and Spences Bridge	Adjusted regression models	RTSM Model

Nicola Lake & tributaries during the dominant period – RTSM approach

A real-time statistical matching (NWMT-RTSM) approach was developed to predict daily net inflows to **Nicola Lake and tributaries during the dominant period** (February 1 - July 31) based on the volumetric forecast (from the RFC or as a user-supplied value), the current inflow conditions, and historical inflows from 1983 onwards. As additional real-time information becomes available the list of years available for this matching will grow from 35.

It is important to recognize that the NWMT Hydrology submodel is principally a statistical model that utilizes external data provided by the RFC, as well as Water Survey of Canada. The accuracy of the NWMT remains fundamentally controlled by the accuracy of RFC inflow predictions.

There are two distinct predictions made in the RTSM approach:

1) **Volume-based prediction**: **This prediction is the default prediction of the RTSM model.** This is a prediction of inflow pattern based on the comparison of the volumetric forecast (by RFC forecast or user-supplied prediction) to historical volumetric inflows for the same period as the forecast. The model predictions are adjusted to respond to short-term weather conditions using real-time hydrometric data. *In all cases, the volume is adjusted to the volumetric forecast supplied by the RFC or user.*
2) **Pattern-based prediction**: **This prediction is displayed in the Diagnostics Tab of the NWMT UI.** This is a prediction of inflow pattern *and volume* based on a comparison of the pattern of inflow in the last 30 days compared to historical inflow patterns for the same 30 days. The model predictions are adjusted to respond to short-term weather conditions using real-time hydrometric data. Unlike the volume-based prediction, the pattern-based prediction can provide a different predicted volume than the volumetric forecast supplied by the RFC or user. Results of testing revealed that this prediction should not be the default prediction used by FWMT submodels because it tends to generate large week to week changes in forecasted total net inflow.

The final predicted daily inflow distributions for Nicola Lake from the decision date are the volume-based predictions. The pattern-based prediction represents an alternate hypothesis about the expected inflows during the dominant period. This is included in the “Diagnostics” tab for a given scenario and it is only present during the dominant period.

In situations where the RFC volumetric forecast is questioned by the water manager, we provide the ability to override the volumetric forecast using what we call ‘user-supplied forecast’. When this option is used, the water manager can specify a new mean volumetric inflow forecast with a maximum and minimum value. This information is used in a manner analogous to Step 2 – Predicting net inflow by comparing RFC forecasts to historical net inflows. That is, the user-defined range provides the information from the volumetric forecast to compare against historical cumulative net inflows from the decision date to July 31. The weighted prediction from this user-supplied forecast is based on how close the cumulative net inflow of each historical year is to the defined forecast. The predicted inflow hydrograph based on the user-supplied forecast supersedes the Step 1 and Step 2 predictions, i.e. the calculated net inflow by comparing historical data to current inflows in Step 1 is not used, but it still incorporates the real-time self-adjustment from Step 3 based on the current inflow data.

Further details for how the predictions are calculated are discussed below in the “Detailed Methods”.

Detailed Methods

For any given decision date, the new NWMT-RTSM approach bases the daily net inflow forecast on three available data sources: (1) historical data, treated as a “family” of cumulative inflow curves, (2) the (RFC) forecast or user-supplied prediction of the volumetric cumulative net inflow for the period, and (3) the daily inflow pattern from real-time data in the current year around the decision date. These sources of information are used to generate the **volume-based prediction** (NWMT default) and **pattern-based prediction** (NWMT diagnostic). The step-by-step methods for generating these predictions are summarized in Table 3-32 (Volume-based prediction) and Table 3-33 (Pattern-based prediction). These methods are explained in greater detail after.

Table 3-32. Volume-Based Prediction: Summary of key steps to the NWMT-RTSM model.

Model Step	Key Changes
Volume-Based Prediction (default prediction used by FWMT submodels)	This prediction is the default prediction of the RTSM model. This is a prediction of inflow pattern based on the comparison of the volumetric forecast (by RFC forecast or user-supplied prediction) to historical volumetric inflows for the same period as the forecast.
Step 1	Compare the volumetric forecast through to July 31 (from RFC or user-supplied) discounted by the current cumulative inflow up to the decision date against historical years to find the historical years most like the forecasted volume over the same period.
Step 2	Generate a weighted average curve based on the historical years found in Step 1 that have a similar Jul 31 volume.
Step 3	Apply a real-time self-adjustment to account for short-term weather patterns by matching the pattern of current inflows to the weighted average curve generated in Step 2.
Step 4	Apply a smoothing algorithm to the prediction.
Step 5	Adjust the final volume to align with the volumetric forecast.

Table 3-33. Pattern-Based Prediction: Summary of key steps to the NWMT-RTSM model.

Model Step	Key Changes
Pattern-Based Prediction (presented on Diagnostics tab as an alternative net inflow prediction/ hypothesis)	This prediction is displayed in the Diagnostics Tab of the NWMT UI. This is a prediction of inflow pattern *and volume* based on a comparison of the pattern of inflow in the last 30 days compared to historical inflow patterns for the same 30 days. Unlike the volume-based prediction, the pattern-based prediction can provide a different predicted volume than the volumetric forecast supplied by the RFC or user. Results of early testing revealed that this prediction should not be the default prediction used by NWMT submodels because it tends to generate large week to week changes in forecasted total net inflow.
Step 1	Compare the current inflow pattern and volume to historical inflow patterns over the last 30 days to find historical years most similar.
Step 2	Generate a weighted average curve based on the historical years found in Step 1 that are most like the current inflow pattern and volume.
Step 3	Apply a real-time self-adjustment to account for short-term weather patterns by matching the pattern of current inflows to the weighted average curve generated in Step 2.

Data Sources

The Nicola FWMT-RTSM model utilizes the key parameters shown in Table 3-34. Details on each of the three major input "layers" are summarized further below. The framework used to forecast Nicola Lake inflows is the same as that used to forecast major tributary runoff and runoff of Nicola River above Nicola Lake and near Spences Bridge. Only the input data differs.

Table 3-34. Key data sources for the Nicola FWMT Water Supply & Hydrology submodel (Dominant Period).

Data Source	Component	Description	Data used	Period considered
Historical	Lake	Historical net inflows to Nicola Lake	Daily (LOESS) smoothed inflows & daily smoothed cumulative inflows	Jan 1-Jul 31, 1983-2015[1]
	Tributary / River	Historical net runoff at: -Coldwater River at Merritt -Guichon Creek at the Mouth / Guichon Creek near Lower Nicola -Spius Creek near Canford -Nicola River above Nicola Lake -Nicola River near Spences Bridge	Daily (LOESS) smoothed runoffs & daily smoothed cumulative runoff	Jan 1-Jul 31
RFC	Lake	RFC volumetric inflow forecast for Nicola Lake	Expected value Upper estimate Lower estimate	Feb 1-Jul 31 Mar 1-Jul 31 Apr 1-Jul 31 May 1-Jul 31[2]
	Tributary / River	Major tributaries: -Synthesized RFC forecast[3] based on RFC volumetric runoff forecast for Nicola River near Spences Bridge Nicola River above Nicola Lake: -Synthesized RFC forecast[3] based on RFC inflow forecast for Nicola Lake	Expected value Upper estimate Lower estimate	Feb 1-Jul 31 Mar 1-Jul 31 Apr 1-Jul 31 May 1-Jul 31[2]
Real-time	Lake	Real-time daily net inflows to Nicola Lake[4]	30 days prior to decision date	Current year
	Tributary / River	Real-time daily net runoff at: -Coldwater River at Merritt -Guichon Creek at the Mouth -Spius Creek near Canford -Nicola River above Nicola Lake -Nicola River near Spences Bridge	30 days prior to decision date	Current year

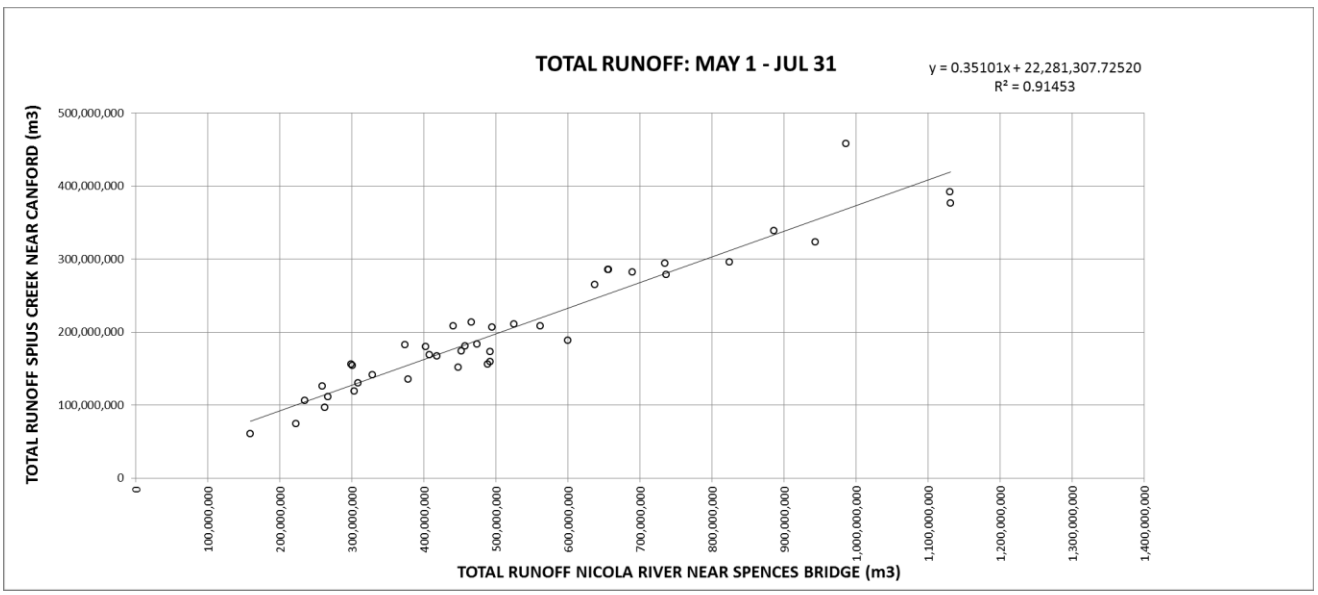
Notes:
1) Periodically, inflows after 2015 can be imported to the FWMT to extend the historical period upon which the model is based.
2) The new model has built in flexibility so that RFC forecasts on any date between Feb1 and Jul 31 may be used. This is beneficial should RFC forecasting methods and outputs change in future.

3) Synthesized RFC forecasts for Coldwater River, Guichon Creek and Spius Creek are based on linear regressions with RFC forecasts for Nicola River near Spences Bridge. Synthesized RFC forecasts for Nicola River above Nicola Lake are based on linear regressions with RFC forecasts for Nicola Lake inflow.
4) These are calculated based on the WSC real-time hydrometric data for Nicola Lake near Quilchena and Nicola River at outlet of Nicola Lake (i.e. use the lake water balance)

River Forecast Centre (RFC) Volumetric Inflow Forecast for Nicola Lake and Nicola River near Spences Bridge

The RFC provides forecasts of the net volume of water in cubic decametres[4] that is expected to flow into Nicola Lake and flow past Nicola River near Spences Bridge from the forecast date to the end of the forecast period (July 31). However, no information is currently provided by RFC on the expected temporal distribution of this net inflow or runoff. The Nicola FWMT Hydrology submodel's primary purpose is to fill this information gap. Forecast dates are typically February 1, March 1, April 1, and May 1, but occasionally additional forecasts and mid-month revisions are issued by the RFC. Each forecast includes an expected value and a standard error. Historical RFC forecasts are available from 1974 to present.

To use the RTSM model for Coldwater River, Guichon Creek, and Spius Creek, it was necessary to develop "synthesized" RFC forecasts for each of the tributaries. This was accomplished by identifying best-fit linear regression equations between total runoff of each tributary and total runoff of Nicola River near Spences Bridge for the RFC forecast periods: February 1 to July 31, March 1 to July 31, April 1 to July 31 and May 1 and July 31. An example for Spius Creek is provided in Figure 3-13. Similar equations were identified for Nicola River above Nicola Lake; however, the best-fit regression was fit to the RFC forecast inflow to Nicola Lake.



[4] 1 dam^3 = 1,000 m^3 = 1,000,000 L

Figure 3-13. Example of best-fit linear regression identified for determining the “synthesized” RFC forecast for Spius Creek for May 1 to July 31. Four such relations were identified for each of the major tributaries, including Coldwater River, Spius Creek, Guichon Creek, and Nicola River above Nicola Lake.

Volume-Based Prediction

Step 1: Compare the discounted volumetric forecast (from RFC or user-supplied) to historical years

The first step is to develop a volume-based prediction of the inflow distribution for the period from the decision date until the end of the dominant period is based on the comparison of the volumetric forecast provided by RFC for Nicola Lake (or the predicted volumetric forecast for Nicola River) and the historical net inflow data. The RFC (and predicted) forecasts provide total volumetric predictions of the most likely cumulative net inflow from the forecast date to July 31 (along with a minimum and maximum value). Forecasts are typically made four times in the dominant period (February 1, March 1, April 1, and May 1). These forecasts can be compared to the cumulative net inflow of historical data on July 31 to see which historical years are closest to the volumetric forecast. The historical years that are considered are within the range of half the standard error (SE) around the most likely RFC forecast. The quantitative fit is calculated using the absolute difference between the RFC forecast and the historical year cumulative net inflow on July 31. For a decision date that is after a forecast date, the RFC forecast value is adjusted by the cumulative net inflow that has occurred since the date of the last RFC forecast.

The NWMT-RTSM approach allows the input of new RFC forecasts on a daily basis, which can accommodate any change in the frequency of forecasts (i.e., more frequently than monthly). If current conditions are well above the predicted net inflow, the user can consider shifting to the ‘high’ RFC forecast (most likely RFC forecast + min/max) as the RFC input. If the current conditions are well below the predicted net inflow, the user can adjust to the ‘low’ RFC forecast (most likely RFC forecast – SE) as the RFC input.

Step 2: Generate a weighted average curve

The predicted net inflow from Step 1 is based on the weighted average of the historical years within the range of half the standard error (SE) around the most likely RFC forecast, where the weighting is the squared inverse of the difference between the absolute difference between the RFC forecast and the historical year cumulative net inflow on July 31. In other words, the historical years that are most similar to the RFC forecast on July 31 will have a larger weighting on the predicted net inflow from Step 2 within the range specified by the minimum and maximum values.

Step 3: Apply a real-time self-adjustment

The third step is to develop a prediction of net inflow distribution for the immediate future based on the trends in current real-time data. Recent real-time inflows are used in the revised approach to adjust forecasts in the short-term to mitigate the discrepancy between recent pattern of recorded inflows and the default predicted inflows from Step 1 and Step 2. This step is referred to as the real-time self-adjustment algorithm, which was adapted from a previous version of the model which adjusted forecasts on a weekly basis.

In this step, real-time **daily** net inflows over the past 7 days are used in a regression model to predict daily inflows for the short-term future (i.e., the next 7 days). We used net inflow data that is LOESS-smoothed (with an AIC-selected alpha value) to estimate the parameters for the regression model. Short-term inflow patterns are re-evaluated each day as additional real-time information becomes available within NWMT. In general, confidence in the predicted inflows is high immediately after the decision date (e.g. within the first day) and declines with time following a sigmoidal function (Figure 3-14). This short-term weighting is used to match recorded inflows to predicted inflows within the NWMT.

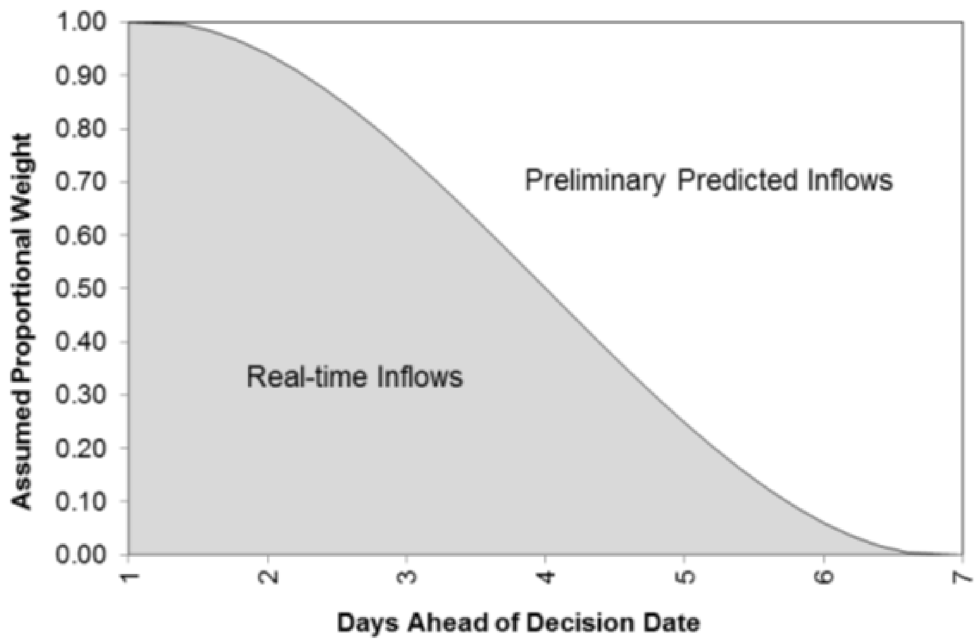


Figure 3-14. Proportional real-time adjustment weights assigned to the net inflow distribution that arises from the "preliminary" predicted inflow distribution arising from the combined historical and RFC inflow distributions.

Step 4: Apply a smoothing algorithm

Once Step 3 is complete, a raw model prediction is generated. This model prediction is then fit to an idealized hydrograph inflow curve shaped after the all-year average inflows. This curve is adjusted based on the leading accelerating curve, trailing decelerating curve, and then adjusted by the timing of the peak volume. This step acts to smooth the predicted hydrograph, thereby avoiding any overmatching to particular historical years.

Step 5: Adjust the final volume to align with the volumetric forecast

The smoothed prediction generated in Step 4 is then adjusted so that the cumulative volume predicted from the decision date until the end of the dominant period is equal to the forecasted volume discounted for the volume that has come in from the last known forecast and the current cumulative volume.

Summary

Following the step-wise process outlined above, a volume-based prediction from the RTSM Hydrology submodel is displayed in NWMT. An example of the resulting output is shown in Figure 3-15. In this figure, the light blue curve represents the outcome of the step-wise procedure. Colours of the other lines are the years that best match the volumetric forecast (Step 1). In this example, the volume-based prediction is lower than the best historical years because of the volume-matching applied in Step 5.

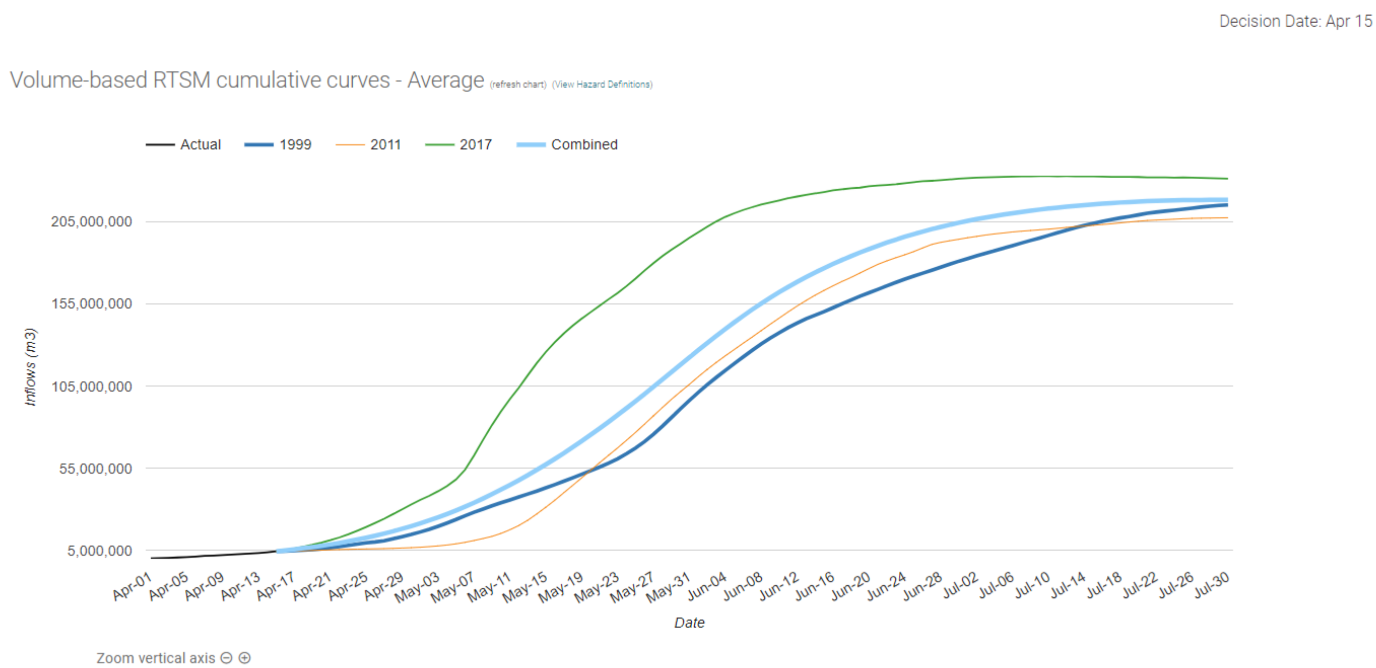


Figure 3-15. Example of the volume-based prediction from the RTSM hydrology submodel on decision date April 15, 2018.

Pattern-Based Prediction

Step 1: Compare current inflow pattern to historical patterns

The pattern-based prediction of the expected net inflow distribution for the period from the NWMT decision date until the end of the dominant period is based on the comparison of the current real-time data with the historical cumulative net inflow data. This is done by comparing the family of historic daily net inflows against the current year daily net inflow curve and calculating which historical years fit the current year data best. Fit is calculated using a root mean squared error

(RMSE) on net inflow hydrographs which are LOESS-smoothed (based on AIC-selected alpha values) up to the decision date whereby a smaller RMSE value means a relatively better fit (Eq. 10). The LOESS smoothing is applied to the net inflow data because of the inherent jaggedness of day-to-day variation in net inflows that could mask directional trends in the data.

$$RMSE_h = \sqrt{\frac{1}{n}\sum_{t=1}^{n}(y_t - \hat{y}_{ht})^2} \qquad \text{(Eq. 10)}$$

where: y_t is the observed cumulative net inflow value at time *t*;

$\hat{y}_{ht}$ is the historical cumulative net inflow value from year *h* on day *t*; and

n is the number of days observed up to the decision date of interest.

Step 2: Generate weighted average curve

The predicted net inflow from Step 1 is weighted based on the squared inverse of RMSE values of the top ten historical years that have the lowest RMSE values within the historic record. In other words, the years that are most like the current conditions will have a larger weighting on the predicted net inflow from Step 1. At each decision date, the predicted net inflow distribution based on matching with the top 10 historical cumulative inflows is re-evaluated. As additional real-time information becomes available the list of years available for this matching will grow from 47.

Step 3: Apply real-time self-adjustment

The real-time self-adjustment is applied in the same manner as Step 3 in the volume-based prediction.

Summary

Following the step-wise process outlined above, a pattern-based prediction from the RTSM Hydrology submodel is displayed in NWMT. An example of the resulting output is shown in Figure 3-16. In this figure, the light blue curve represents the outcome of the step-wise procedure. Colours of the other lines are the years that match best to the pattern of the current inflows (Step 1).

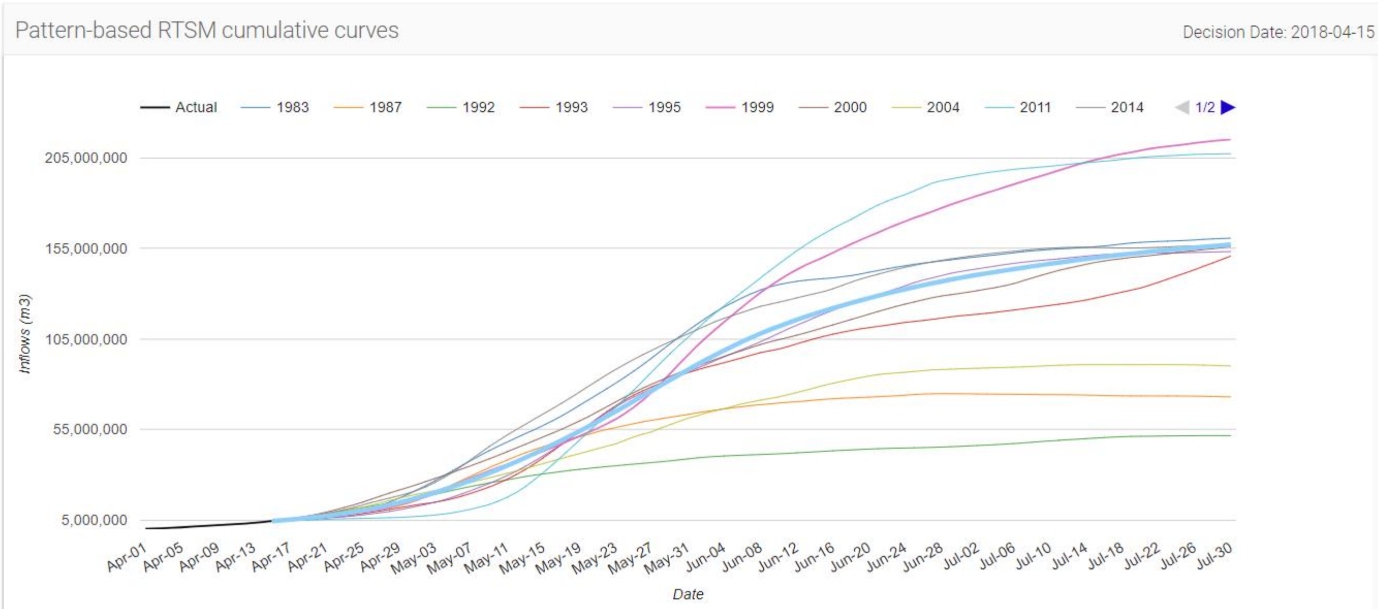


Figure 3-16. Example of pattern-based prediction on decision date April 15, 2018

Nicola Lake during non-dominant period – adjusted regression models

For Nicola Lake, total net inflow is of primary interest given the focus on water supply. During NWMT Operation in the Dominant or Non-Dominant Periods, net inflows to Nicola Lake in the non-dominant period are forecast according to the following steps:

1. Identify the July 16-31 Nicola Lake net volumetric inflow. This may be a forecast, measurement or combination of both.
2. Use best-fit regressions to predict the August 1 - January 31 net volumetric inflow (Figure 3-17). Three regressions are identified in Equations Eq. 11-Eq. 13 for expected, upper and lower estimates, respectively.

$$I_{TOTAL\ non\text{-}dom\ (exp)} = 2.36505\ I_{jul} + 3{,}410{,}430.07209\ (R^2 = 0.68) \quad \text{(Eq. 11)}$$

$$I_{TOTAL\ non\text{-}dom\ (upper)} = 0.0000000028\ I_{jul}{}^2 + 2.3500389102\ I_{jul} + 10{,}294{,}617.0918858\ (R^2 = 0.99) \quad \text{(Eq. 12)}$$

$$I_{TOTAL\ non\text{-}dom\ (upper)} = -0.0000000028\ I_{jul}{}^2 + 2.3800514946\ I_{jul} - 3{,}473{,}756.94771234\ (R^2 = 0.99) \quad \text{(Eq. 13)}$$

where:

I_{jul} = Total inflow for July 16 – 31 (m^3);
$I_{TOTAL\ non\text{-}dom\ (exp)}$ = Expected total inflow for August 1 – January 31 (m^3);
$I_{TOTAL\ non\text{-}dom\ (upper)}$ = Upper 95% prediction limit total inflow for August 1 – January 31 (m^3); and
$I_{TOTAL\ non\text{-}dom\ (lower)}$ =Lower 95% prediction limit total inflow for August 1 – January 31 (m^3),

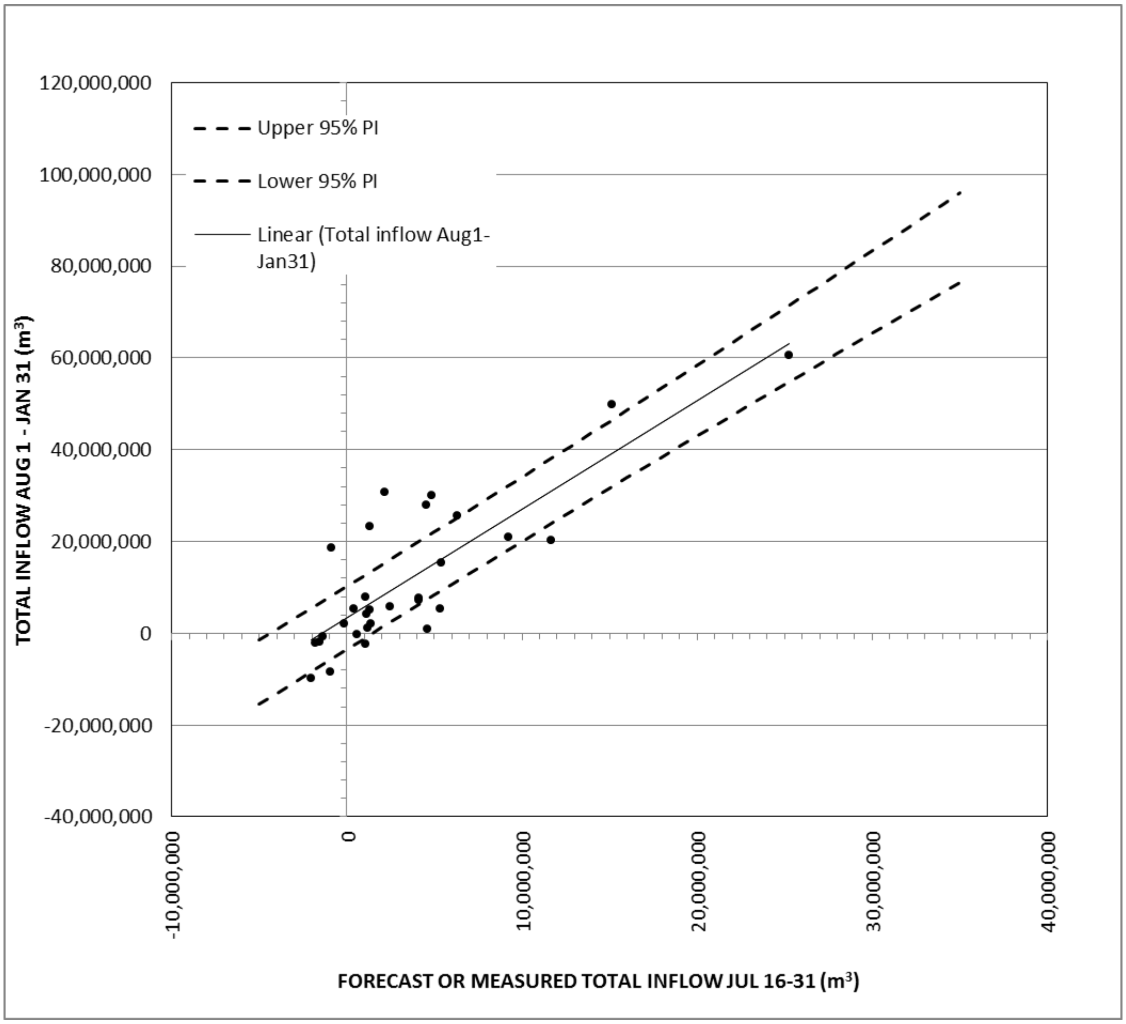


Figure 3-17. Best-fit linear regression and upper and lower 95% prediction limits for predicting total non-dominant period Nicola Lake inflow based on total July 16-31 inflow.

1. Calculate the difference between current year (expected, upper and lower estimates) and long-term mean August 1 – January 31 net volumetric inflow using Equations Eq. 14-Eq.16.

$$D_{TOTAL\ non\text{-}dom\ (exp)} = I_{TOTAL\ non\text{-}dom\ (exp)} - I_{TOTAL\ non\text{-}dom\ (mean)} \quad \text{(Eq. 14)}$$

$$D_{TOTAL\ non\text{-}dom\ (upper)} = I_{TOTAL\ non\text{-}dom\ (upper)} - I_{TOTAL\ non\text{-}dom\ (mean)} \quad \text{(Eq. 15)}$$

$$D_{TOTAL\ non\text{-}dom\ (lower)} = I_{TOTAL\ non\text{-}dom\ (lower)} - I_{TOTAL\ non\text{-}dom\ (mean)} \quad \text{(Eq. 16)}$$

where:

$D_{TOTAL\ non\text{-}dom\ (exp)}$ = Difference between expected total inflow and long-term mean inflow for August 1 – January 31 (m^3);

$D_{TOTAL\ non\text{-}dom\ (upper)}$ = Difference between upper 95% prediction limit total inflow and long-term mean inflow for August 1 – January 31 (m^3);

$D_{TOTAL\ non\text{-}dom\ (lower)}$ = Difference between lower 95% prediction limit total inflow and long-term mean inflow for August 1 – January 31 (m^3); and

$I_{TOTAL\ non\text{-}dom\ (mean)}$ = Long-term total mean inflow for August 1 - January 31 (m^3) = 11,838,388 m^3.

2. Determine the daily "adjustment" required to account for difference in the total non-dominant period inflow for the year of interest relative to the long-term mean. The daily adjustments are assumed to be equally distributed throughout the non-dominant period and are calculated according to Equations Eq. 17-Eq. 19.

$$\Delta I_{DAILY\ non\text{-}dom\ (exp)} = D_{TOTAL\ non\text{-}dom\ (exp)} / n_{non\text{-}dom} \quad \text{(Eq. 17)}$$

$$\Delta I_{DAILY\ non\text{-}dom\ (upper)} = D_{TOTAL\ non\text{-}dom\ (upper)} / n_{non\text{-}dom} \quad \text{(Eq. 18)}$$

$$\Delta I_{DAILY\ non\text{-}dom\ (lower)} = D_{TOTAL\ non\text{-}dom\ (lower)} / n_{non\text{-}dom} \quad \text{(Eq. 19)}$$

where:

$\Delta I_{DAILY\ non\text{-}dom\ (exp)}$ = Adjustment to long-term daily non-dominant period inflow based on the expected non-dominant period inflow for year of interest (m^3);

$\Delta I_{DAILY\ non\text{-}dom\ (upper)}$ = Adjustment to long-term daily non-dominant period inflow based on the upper 95% limit non-dominant period inflow for year of interest (m^3);

$\Delta I_{DAILY\ non\text{-}dom\ (lower)}$ = Adjustment to long-term daily non-dominant period inflow based on the lower 95% limit non-dominant period inflow for year of interest (m^3);

$D_{TOTAL\ non\text{-}dom\ (exp)}$ = Difference between expected total inflow and long-term mean inflow for August 1 – January 31 (m^3);

$D_{TOTAL\ non\text{-}dom\ (upper)}$ = Difference between upper 95% limit total inflow and long-term mean inflow for August 1 – January 31 (m^3);

$D_{TOTAL\ non\text{-}dom\ (lower)}$ = Difference between lower 95% limit total inflow and long-term mean inflow for August 1 – January 31 (m^3); and

$n_{non\text{-}dom}$ = Number of days in non-dominant period = 184.

3. For each of the expected, upper 95% and lower 95% prediction limits, determine the daily inflows throughout the non-dominant period using Equations Eq. 20-Eq. 22.

$$I_{DAILY\ non\text{-}dom\ (exp)i} = I_{DAILY\ non\text{-}dom\ (mean)i} + \Delta I_{DAILY\ non\text{-}dom\ (exp)} \quad \text{(Eq. 20)}$$

$$I_{DAILY\ non\text{-}dom\ (upper)i} = I_{DAILY\ non\text{-}dom\ (mean)i} + \Delta I_{DAILY\ non\text{-}dom\ (upper)} \quad \text{(Eq. 21)}$$

$$I_{DAILY\ non\text{-}dom\ (lower)i} = I_{DAILY\ non\text{-}dom\ (mean)i} + \Delta I_{DAILY\ non\text{-}dom\ (lower)} \quad \text{(Eq. 22)}$$

where:

$I_{DAILY\ non\text{-}dom\ (exp)i}$ = Non-dominant period daily inflow (expected) for day i (m^3);

$I_{DAILY\ non\text{-}dom\ (upper)i}$ = Non-dominant period daily inflow (upper 95% prediction limit) for day i (m^3);

$I_{DAILY\ non\text{-}dom\ (lower)i}$ = Non-dominant period daily inflow (lower 95% prediction limit) for day i (m^3); and

$I_{DAILY\ non\text{-}dom\ (mean)i}$ = Long-term (i.e. 1983-2017) non-dominant period daily mean inflow for day i (m^3). This data is plotted in Figure 3-18.

Regardless of the period in which the NWMT is operating in, a period is required to smoothly transition between measured real-time and predicted flows. Based on an examination of the data, a 7-day transition was identified as a reasonable period to adopt for such purposes. During this period, the real and predicted values are weighted according to Table 3-35.

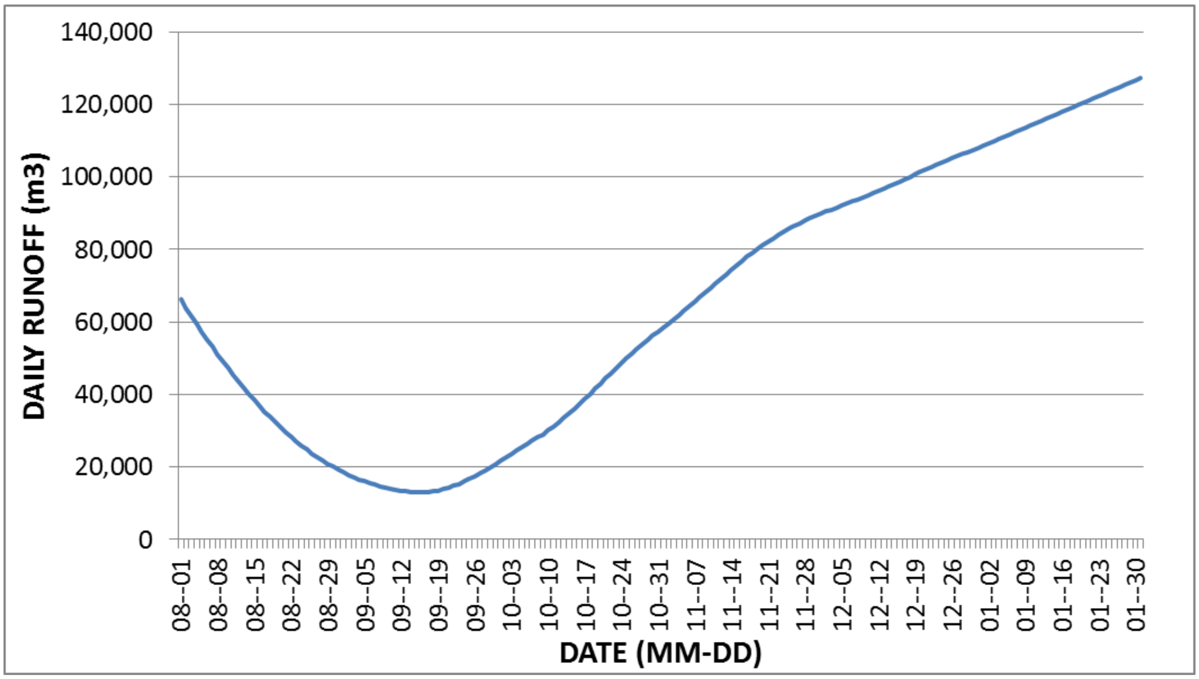


Figure 3-18. Long-term (1970-2014) non-dominant period daily mean net inflow to Nicola Lake.

Table 3-35. 7-day transition period weighting.

Day	Weight applied to Real-time Data	Weight applied to Predicted Data
1	6/7	1/7
2	5/7	2/7
3	4/7	3/7
4	3/7	4/7
5	2/7	5/7
6	1/7	6/7
7	0/7	7/7

Tributary Runoff during the non-dominant period

In each of the four main tributaries, baseflow is relevant for fisheries interests. Stormflow however is also relevant particularly in Coldwater River and Spius Creek, given their significant flow contribution to Nicola River. The approach used to model runoff from the four main tributaries is described in this section. The approach is organized into the following three sections:

1. Prediction of non-dominant period tributary runoff while the FWMT is operating in the dominant period. This applies to all four main tributaries.
2. Prediction of Guichon Creek and Upper Nicola runoff while the FWMT is operating in the non-dominant period. For these two regulated streams, there is no clear stormflow signal in the historical record. As a result, only baseflows, which are of primary fisheries interest, are modeled.
3. Prediction of Coldwater River and Spius Creek runoff while the FWMT is operating in the non-dominant period. For these two streams, both baseflow and stormflow runoff are modeled.

Prediction of non-dominant period tributary runoff while the FWMT is operating in the dominant period

During FWMT operation in the dominant period, non-dominant period tributary runoff is assumed static and based on the long-term reference flows identified below. These reference flows include:

- Minimum baseflow (i.e., lower estimate),
- Median (50th percentile) baseflow (i.e., expected value), and
- 75th percentile baseflow (i.e., upper estimate).

The long-term reference flows were derived by examining the historical records available for each tributary. For each tributary, baseflow separation was performed over the non-dominant period using the Web-based Hydrograph Analysis Tool (WHAT)[5]. LOESS (LOcal regrESSion)

[5] Lim, K.J., B.A. Engel, Tang, Z., Choi J., Kim, K., Muthurkrishnan, S. and Tripathy D. 2005. Automated Web Based Hydrograph Analysis Tool, WHAT. Journal of the American Water Resources Association, December 2005.

smoothing was then applied to eliminate noise in the daily baseflow data using the R statistical computing environment. The level of smoothing chosen (the alpha parameter, called 'span' in R) was selected by qualitative judgement, being careful to remove noise while preserving real variability[6]. An example of the reference flows for Coldwater River is shown in Figure 3-19.

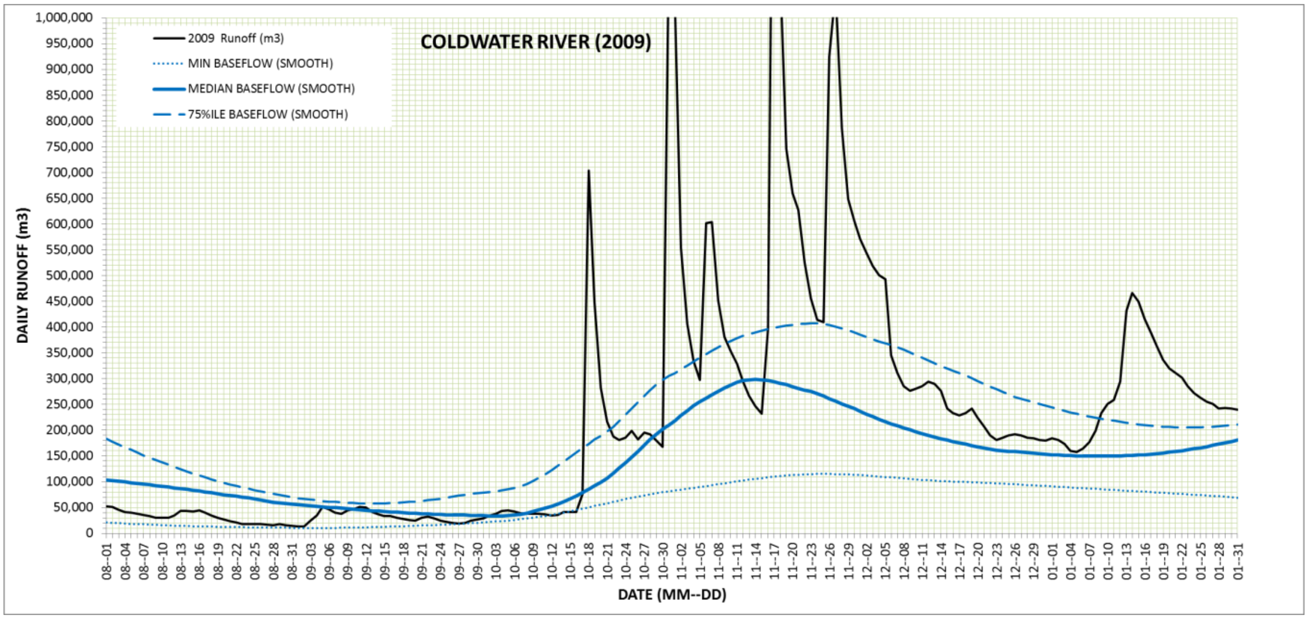


Figure 3-19. Long-term reference flows (i.e., minimum, median and 75th percentile baseflows) for Coldwater River. Actual flows for 2009 are also shown.

Prediction of Guichon Creek and Upper Nicola runoff while the FWMT is operating in the non-dominant period

During FWMT operation in the non-dominant period, both the long-term reference flows (identified above) and real-time data are utilized for Guichon Creek and Upper Nicola River. Although the long-term reference flows remain static, for each decision date, a transition from real-time data to the long-term reference flows is calculated for 7 days ahead (and re-calculated each day). The weighting is applied as described in Table 3-35.

Prediction of Coldwater River and Spius Creek runoff while the FWMT is operating in the non-dominant period

The approach used to model Coldwater River and Spius Creek flows is the same as that for Guichon Creek and Upper Nicola River with the exception that short-duration stormflows are monitored, and if a stormflow threshold is exceeded, then a stormflow recession (i.e., decay

[6] The LOESS spans adopted depended on the reference flow (e.g., min, median, 75th percentile) and location: Coldwater River ranged from 0.3 to 0.65, Spius Creek ranged from 0.5 to 0.75, Guichon Creek ranged from 0.5 to 0.75, and Upper Nicola River ranged from 0.75 to 1.0.

function) is applied. There are several reasons why we utilized a stormflow component in these two tributaries and not others. These reasons include:

- Coldwater River and Spius Creek represent the two largest streams contributing runoff to Nicola River,
- Coldwater River and Spius Creek have largely natural runoff patterns, without major influence of flow regulation.
- The historical records for Coldwater River and Spius Creek exhibit clear rainstorm signals, which are not evident in the other streams. Presumably, reservoir operations in the other streams and other watershed characteristics may be obscuring this signal on Guichon Creek and Upper Nicola River.

The stormflow component for Coldwater River and Spius Creek is applied in the FWMT through the following steps:

1. During the non-dominant period, if measured runoff on the decision date exceeds the storm threshold of 86,400 m^3 above the previous day (i.e., equivalent to an increase of 1 m^3/s) then the stormflow component is implemented. This threshold was identified by examining approximately 10-years of sample storms in each of the two streams.
2. Given that the vast number of stormflows are typically of short-duration (i.e. usually peaking in 1 day), by the time we observe an event over threshold it has usually peaked. We therefore utilize an optimized decay function to forecast the receding limb of the stormflow hydrograph in each of the two streams.
3. The decay function is described mathematically in Equation 23.

$$Q_t = Q_0 \cdot e^{-k \cdot t} \quad \text{(Eq. 23)}$$

where:

Q_t = Runoff on day t (m^3);
Q_0 = Runoff of day 0, immediately prior to the storm (m^3);
k = decay constant (this determines the pattern of the receding limb of the storm hydrograph and is a function of the physical characteristics of the watershed of interest); and t = day

Separate decay constants (k-values) were identified for Coldwater River and Spius Creek based on a sample of storms over the last 10 years+/-. Decay constants were derived in Excel using the Solver add-in. The objective for the solver was to maximize the Nash-Sutcliff Efficiency (NSE) for predicting the next 7 days of measured values based on Equation 2.17 by changing k. The decay constants and the NSE values for Coldwater River and Spius Creek are presented in Table 3-36. Various periods of decay were also assessed, with 7-days identified as a reasonable approximation for the range of storms in the 10 year +/- sample.

Table 3-36. Decay constants and Nash-Sutcliff Efficiency (NSE) identified for Coldwater River and Spius Creek

	Coldwater River	Spius Creek
k	0.36	0.35
NSE	0.93	0.86

As shown in Figure 3-20, the decay function is applied for 7 days following the initial exceedance of the storm threshold. On each day through this 7-day period, the decay function is applied to updated (real-time) runoff values.

At the end of the 7-day storm decay function, an additional 7-day transition period is applied to smoothly transition from the end of the storm to the long-term reference flow. This transition, which is shown as dashed red line in Figure 3-20 is weighted as outlined in Table 3-35.

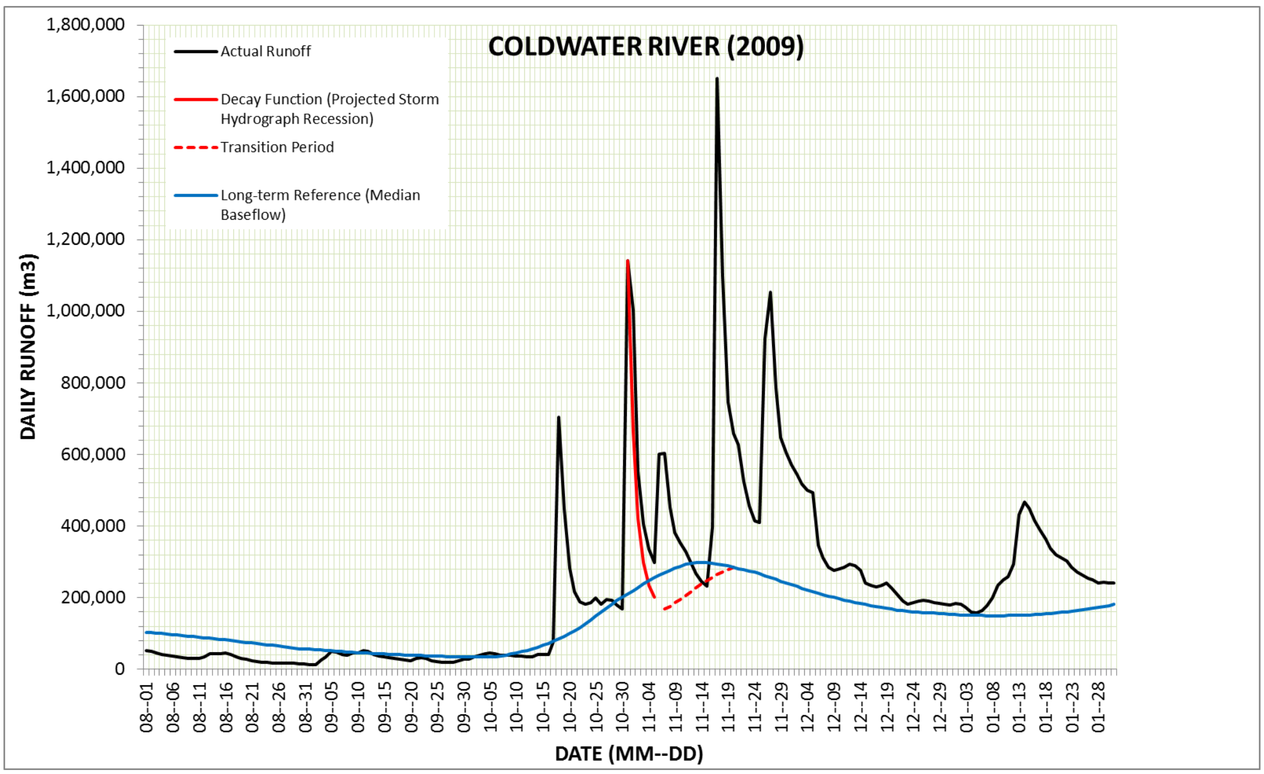


Figure 3-20. Example of the implementation of the stormflow component on October 31, 2009 following exceedance of the stormflow threshold. A seven-day recession is followed by a 7-day transition period towards the long-term reference. Note that this plot only shows the predicted flows (in red) as of October 31. For each day after that, real-time data is used to refine the predictions.

Estimation of Other Streamflow Gains to and Losses from Nicola River (excluding Major Tributaries)

Although the majority of the runoff produced in the Nicola River watershed is either captured or conveyed by the Upper Nicola River, Nicola Lake, and the three major tributaries (all of which are addressed above), minor tributaries, groundwater/aquifer interaction, and water withdrawals can also be important within the water budget of Nicola River depending on location and time of year. In order to provide an approximation of the magnitude of such gains and losses from the Nicola River, we referenced the work of Summit (2007)[7], Golder (2016)[8] and WMC (2008)[9], as well as the provincial water licence database. For each of the defined Nicola River segments, we tallied the estimated typical long-term daily gains (+) or losses (-) from the river (Table 3-37). It should be recognized that in any given year, the actual gains or losses may differ from the long-term estimates identified herein. However, the estimates provided are a reasonable first approximation and are suitable for the purposes of the NWMT.

Figure 3-21 presents plots for the four river segments below Nicola Lake and shows the relative magnitude of gains or losses of each component within the Nicola River Water Balance (excluding the major tributaries).

[7] Summit Environmental Consultants Ltd. 2007. Nicola River Watershed Present and Future Water Demand Study. Prepared for Nicola Watershed Community Round Table. Project 466-01.02. June 2007.
[8] Golder Associates. 2016. MOE Groundwater Science Study, Lower Nicola Valley Groundwater Budget. Submitted to Fraser Basin Council. March 7, 2016.
[9] Water Management Consultants (WMC). 2008. Nicola Watershed Water Budget Analysis. Prepared for Nicola Watershed Community Round Table. October 8, 2008. 7173-5.

Table 3-37. Components of the Nicola River water budget with a description of the estimation methods used. Refer to the schematic (Figure 2-1) for the location of each river segment.

River Segment [1]	Water Budget Component		Gain (+) Loss (-)	Description of Estimation Method(s)
Upstream of A	1	Nicola River above Nicola Lake (i.e. "Upper" Nicola River)	+	Streamflow contribution from Nicola River above Nicola Lake is assessed independently using the dominant and non-dominant period RTSM developed for major tributaries.
Between C & D	2	Clapperton Creek Net Runoff	+	Estimates are based on long-term (1967-2006) mean daily net runoff (m^3), which includes withdrawals (in this cases small domestic usage). Values are based on the WMC (2008b) water supply and demand model for Clapperton Creek. WMC data were in the form of monthly estimates, with the exception of August and September which are weekly. The model output was converted to daily time-step then smoothed using LOESS (span = 0.005). Some minor manual adjustments were made to ensure that smoothed summary statistics reconciled with the summary statistics of WMC (2008b). Independent streamflow measurements were performed by MOE for the period 2006-2010. They are generally consistent with the estimates provided herein but were not explicitly used in the estimates provided. Relations between total runoff (Feb1-Jul31, Mar1-Jul31, Apr1-Jul31, and May1-Jul31) of Nicola River at Spences Bridge and Clapperton Creek were examined. However, the relations are poor and suggest that RFC forecast is not a good predictor of Clapperton Creek streamflows. As a result, it is recommended that the static long-term average be used in the NWMT.
	3	Irrigation Withdrawals from Nicola River	-	Estimates are based on monthly average irrigation withdrawal rates from Appendix C of Golder (2016). The reported average rate is applied to each day of each respective month and converted to a volume (m^3). As an independent check, all current water licences for irrigation purposes along Nicola River segment C-D

River Segment [1]	Water Budget Component		Gain (+) Loss (-)	Description of Estimation Method(s)
		Segment C to D		were tallied. Total annual water licences (for irrigation) are 3,109,404 m^3. The total annual withdrawal calculated by Golder is 3,425,656 m^3, which is 10% higher than the total licenced quantity. As a result the use of Golder's values likely represents a slightly conservative estimate of irrigation water withdrawals.
	4	Stockwatering withdrawals from Nicola River Segment C to D	-	Estimates are based on stockwatering water licences for extraction from Nicola River Segment C-D.
	5	Industrial Withdrawals - Norgaard Ready Mix	-	Estimates are based on processing water licences held by Norgaard Ready Mix for extraction from Nicola River Segment C-D.
	6	Groundwater / aquifer interaction with Nicola River Segment C to D (- river loss, + river gain)	+/-	Estimates are based on Appendix C of Golder (2016) report: Lower Nicola Valley Groundwater Budget. Our independent review of MOE streamflow records at Norgaard (incomplete/seasonal record 2003-2007) and contemporaneous WSC streamflow records of Nicola River at outlet of Nicola Lake (08LG065) are inconclusive. The incomplete record and measurement error combined with the potential for irrigation withdrawals prevent any firm conclusions in this reach.
	7	Coldwater River	+	Streamflow contribution from Coldwater River is assessed independently using the dominant and non-dominant period runoff models developed for major tributaries.
Between D & E	8	Minor Tributary Inflow to Nicola River	+	Estimates are based on Appendix C of Golder (2016). Average monthly discharge was assumed equal to daily discharge, and then converted to volumetric runoff (m^3). No independent examination of minor tributary inflow was performed.

River Segment [1]		Water Budget Component	Gain (+) Loss (-)	Description of Estimation Method(s)
		Segment D to E		
	9	Irrigation Withdrawals Nicola River Segment D to E	-	Estimates are based on monthly average irrigation withdrawal rates from Appendix C of Golder (2016). The reported average rate was applied to each day of each respective month and converted to volume (m^3). As an independent check, all current water licences for irrigation purposes along Nicola River segment D-E were tallied. Total annual water licences on Nicola River (segment D-E) for irrigation purposes are 747,797 m^3. The total annual withdrawal calculated by Golder is 2,055,447 m^3, which 2.7 times higher than the total licenced quantity. Even if one were to include all irrigation licences on all springs and minor tributaries feeding Nicola River segment D-E, the total annual licenced quantity is 1,487,269 m^3. As a result the use of Golder's values appear to represent an overestimate of irrigation water withdrawals. **This component should be further examined to refine the current withdrawal estimates**.
	10	Domestic withdrawals from Nicola River Segment D to E	-	Estimates are based on domestic water licences for extraction from Nicola River Segment D-E.
	11	Groundwater / aquifer interaction with Nicola River Segment D to	+/-	Estimates are based on Appendix C of Golder (2016) report: Lower Nicola Valley Groundwater Budget.

River Segment [1]	Water Budget Component		Gain (+) Loss (-)	Description of Estimation Method(s)
		E (- river loss, + river gain)		
	12	Guichon Creek	+	Streamflow contribution from Guichon Creek is assessed independently using the dominant and non-dominant period runoff models developed for major tributaries.
Between E & F	13	Stumbles Creek	+	Estimates are based on Appendix C of Golder (2016). Average monthly discharge was assumed equal to daily discharge, and then converted to volumetric runoff (m^3). No independent examination of the flow contribution of this tributary was performed. Note the mouth of this tributary is located approximately 2 km downstream of Guichon Creek on the right (north) bank of Nicola River.
	14	Irrigation Withdrawals Nicola River Segment E to F	-	Estimates are based on monthly average irrigation withdrawal rates from Appendix C of Golder (2016). Reported average rate is applied to each day of each respective month and converted to volume (m^3). As an independent check, all current water licences for irrigation purposes along Nicola River segment E-F were tallied. Total annual water licences on Nicola River (segment E-F) for irrigation purposes are 2,481,904 m^3. (Stockwater licences are an additional 1,660 m^3/year). The total annual irrigation withdrawal calculated by Golder is 2,740,686 m^3, which is 10% higher than the total licenced quantity for irrigation. As a result the use of Golder's values likely represents an overestimate of irrigation water withdrawals.
	15	Industrial Withdrawals Craigmont Mine	-	Estimates are based on Summit (2007), Craigmont Mines actual use was recorded (in 2005) at 189,942 m^3/year. Assuming year-round operation, this equates to 520.0329 m^3/day. Note that Craigmont Mines (registered as Huldra Properties Inc.) hold a water licence for 5909.929 m^3/s, which is 11 times the actual reported water use. Also note that Golder (2016) reports a daily extraction by Craigmont Mines of 0.004 m^3/s, equivalent to 345.6 m^3/s (or about 66% of the estimate assumed herein).
	16	Stockwatering withdrawals from Nicola River	-	Estimates are based on stockwatering water licences for extraction from Nicola River Segment E-F.

River Segment [1]		Water Budget Component	Gain (+) Loss (-)	Description of Estimation Method(s)
		Segment E to F		
	17	Groundwater / aquifer interaction with Nicola River Segment E to F (- river loss, + river gain)	+/-	Estimates are based on Appendix C of Golder (2016) report: Lower Nicola Valley Groundwater Budget.
	18	Spius Creek	+	Streamflow contribution from Spius Creek is assessed independently using the dominant and non-dominant period runoff models developed for major tributaries.
Between F & G	19	Minor Tributary Inflow to Nicola River Segment F-G (includes Nuaitch, Shakelly, Gordon, Shakan, Skuhun, and Skeikut Creeks)	+	Based on Appendix C of Golder (2016). Average monthly discharge was assumed equal to daily discharge for the respective month. The model output was converted to daily volumetric runoff, which was then smoothed using LOESS (span 0.005). Checks were performed to ensure the monthly statistics based on the smoothed daily runoff curve reconciled with the Golder (2016) monthly estimates. No other independent examination of minor tributary inflow was performed.

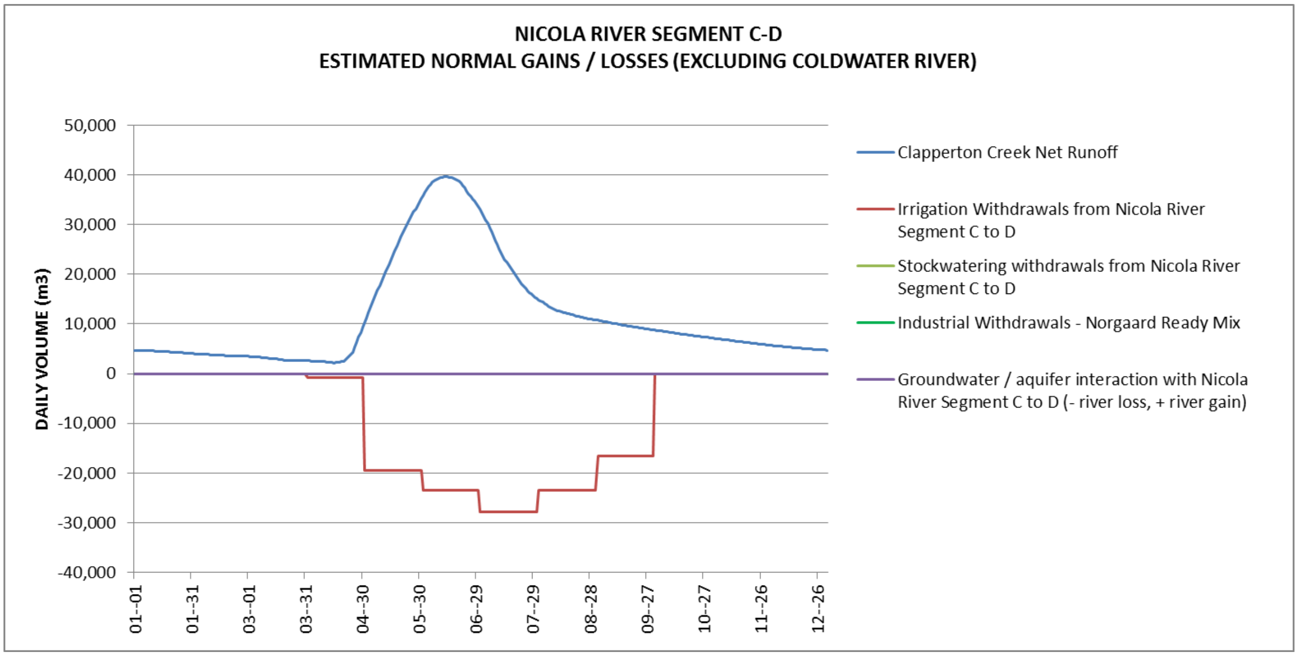
River Segment [1]	Water Budget Component		Gain (+) Loss (-)	Description of Estimation Method(s)
	20	Irrigation Withdrawals Nicola River Segment F to G	-	Since Golder (2016) did not present data downstream of Spius Creek), this estimate is based on total annual volume of water from Nicola River Segment F-G licenced for irrigation. The total licenced volume was however distributed according to the monthly average distribution for irrigation withdrawals from Nicola River Segment E-F (directly upstream), which was based on data in Appendix C of Golder (2016). Total annual water licences on Nicola River (segment E-F) for irrigation purposes are 4,743,594 m3.
	21	Domestic withdrawals from Nicola River Segment F to G	-	Based on domestic water licences for extraction from Nicola River Segment F-G.
	22	Groundwater / aquifer interaction with Nicola River Segment F to G (- river loss, + river gain)	+/-	Estimates are based on Appendix C of Golder (2016) report: Lower Nicola Valley Groundwater Budget.

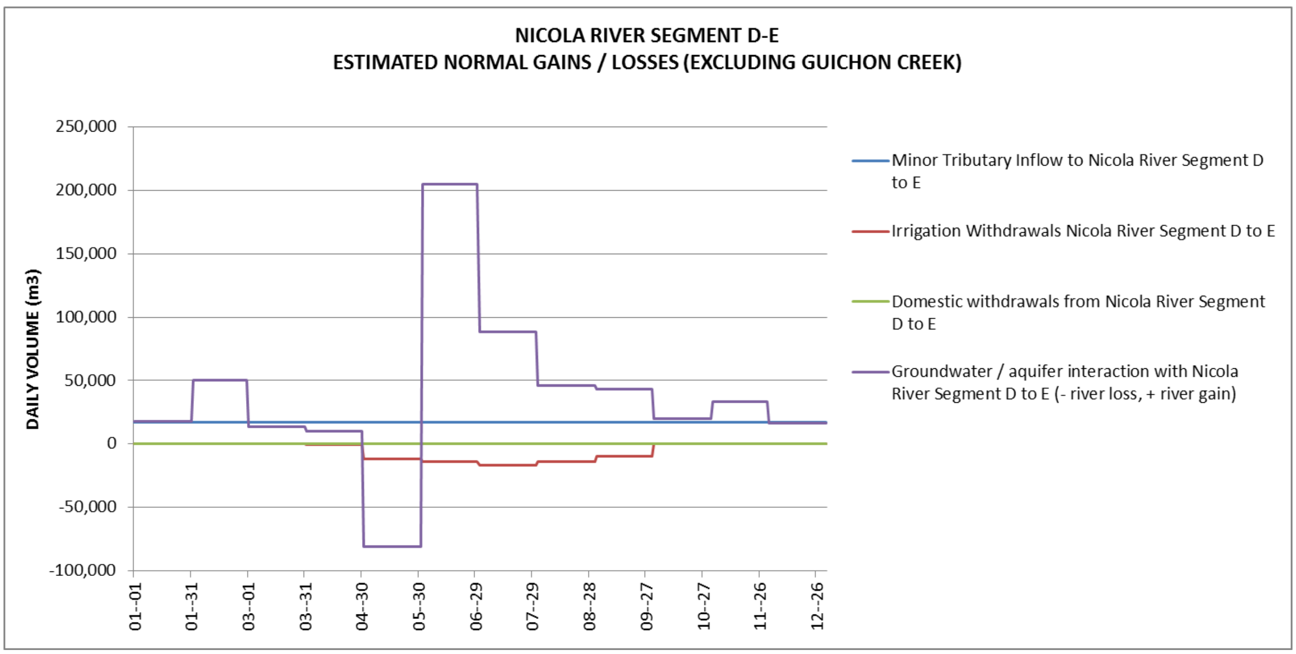
Notes:

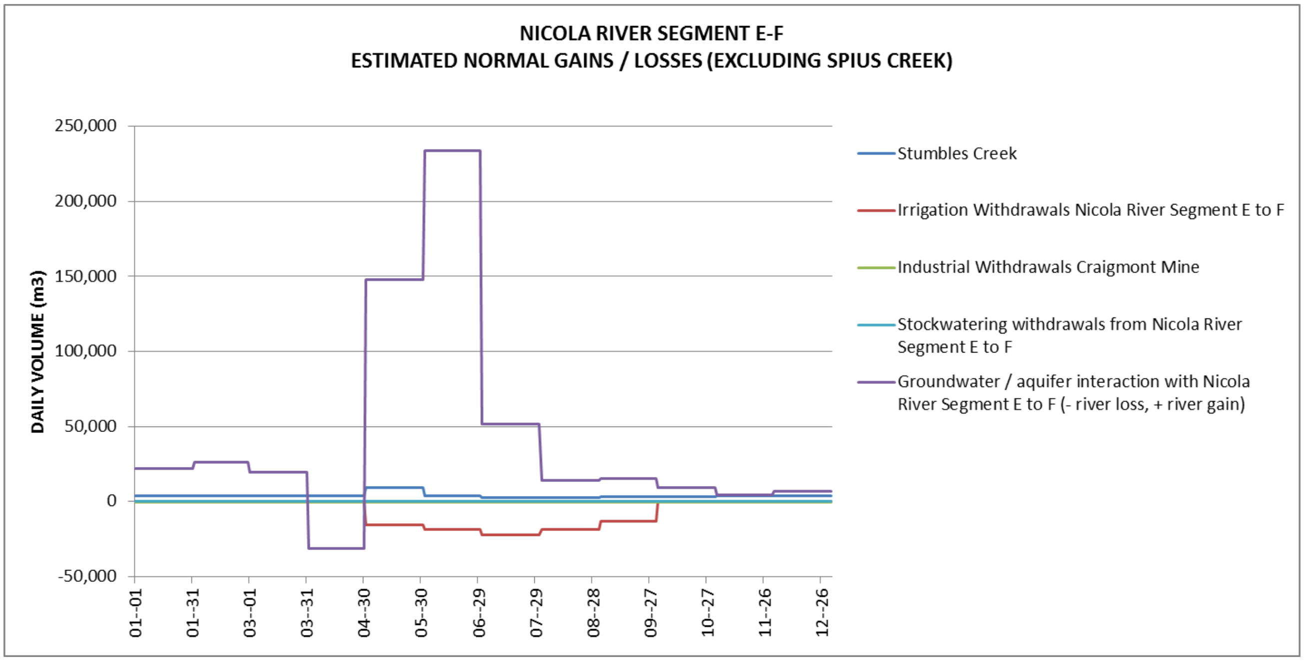
1. Description of river segments:

River segment	Reach	Description
Upstream of A	N4	Upper Nicola River at WSC Station 08LG049. Represents inflows from Upper Nicola River to Nicola Lake
Between C & D	N3	Nicola River between outlet of Nicola Lake and immediately downstream of Coldwater River confluence.
Between D & E	N2	Nicola River from immediately below Coldwater River confluence to immediately below Guichon Creek

		confluence.
Between E & F		Nicola River from immediately below Guichon Creek confluence to immediately below Spius Creek confluence.
Between F & G	N1	Nicola River from immediately below Spius Creek confluence to WSC station Nicola River near Spences Bridge.


NICOLA RIVER SEGMENT C-D
ESTIMATED NORMAL GAINS / LOSSES (EXCLUDING COLDWATER RIVER)
DAILY VOLUME (m3)
50,000
40,000
30,000
20,000
10,000
0
-10,000
-20,000
-30,000
-40,000
01--01
01--31
03--01
03--31
04--30
05--30
06--29
07--29
08--28
09--27
10--27
11--26
12--26
Clapperton Creek Net Runoff
Irrigation Withdrawals from Nicola River Segment C to D
Stockwatering withdrawals from Nicola River Segment C to D
Industrial Withdrawals - Norgaard Ready Mix
Groundwater / aquifer interaction with Nicola River Segment C to D (- river loss, + river gain)


NICOLA RIVER SEGMENT D-E
ESTIMATED NORMAL GAINS / LOSSES (EXCLUDING GUICHON CREEK)
DAILY VOLUME (m3)
250,000
200,000
150,000
100,000
50,000
0
-50,000
-100,000
01--01
01--31
03--01
03--31
04--30
05--30
06--29
07--29
08--28
09--27
10--27
11--26
12--26
Minor Tributary Inflow to Nicola River Segment D to E
Irrigation Withdrawals Nicola River Segment D to E
Domestic withdrawals from Nicola River Segment D to E
Groundwater / aquifer interaction with Nicola River Segment D to E (- river loss, + river gain)



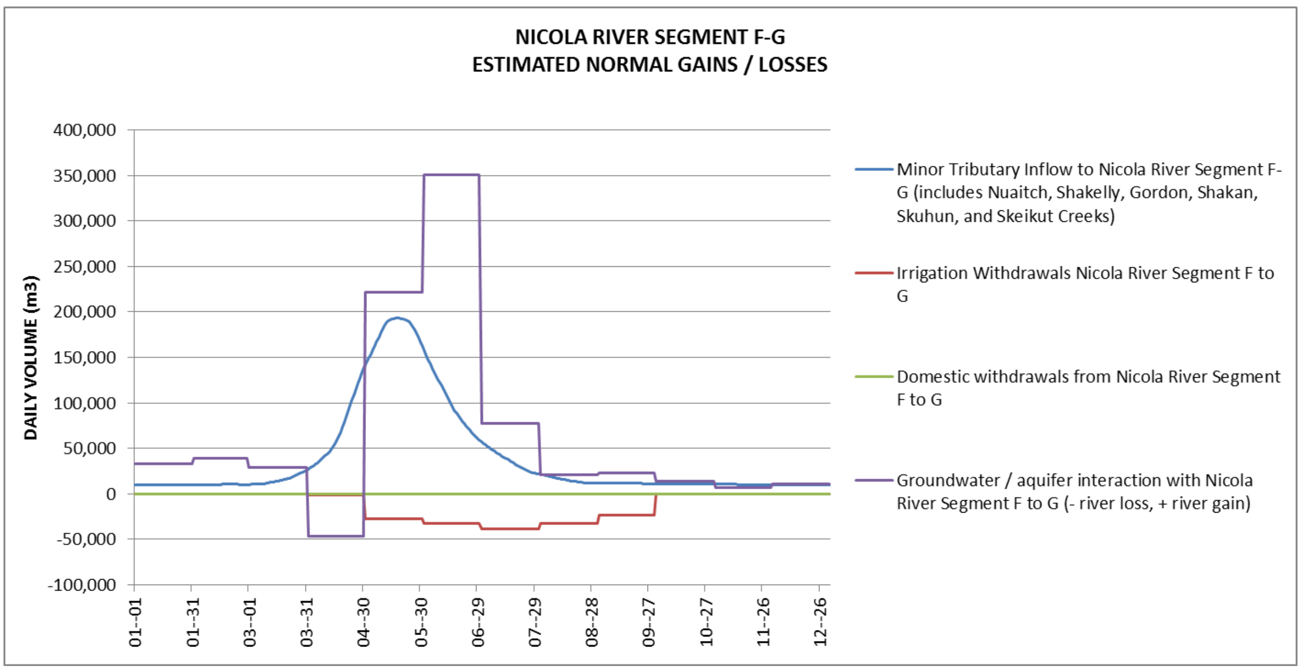


Figure 3-21. Estimated gains and losses from Nicola River, by river segment and water balance component.

3.3.7 Outputs & user interface

User Interface

The Hydrology & Water Balance submodel scenario tab has three major components (Figure 3-22): (Panel 1) forecasts water level in Nicola Lake and discharges in the Nicola River based on forecasted inflows to Nicola Lake, (Panel 2a,b) a schedule of releases from Nicola Lake Dam and (Panel 3a,b) assumed water use extractions. These inputs can be changed within the user interface of the NWMT (Figure 3-22).

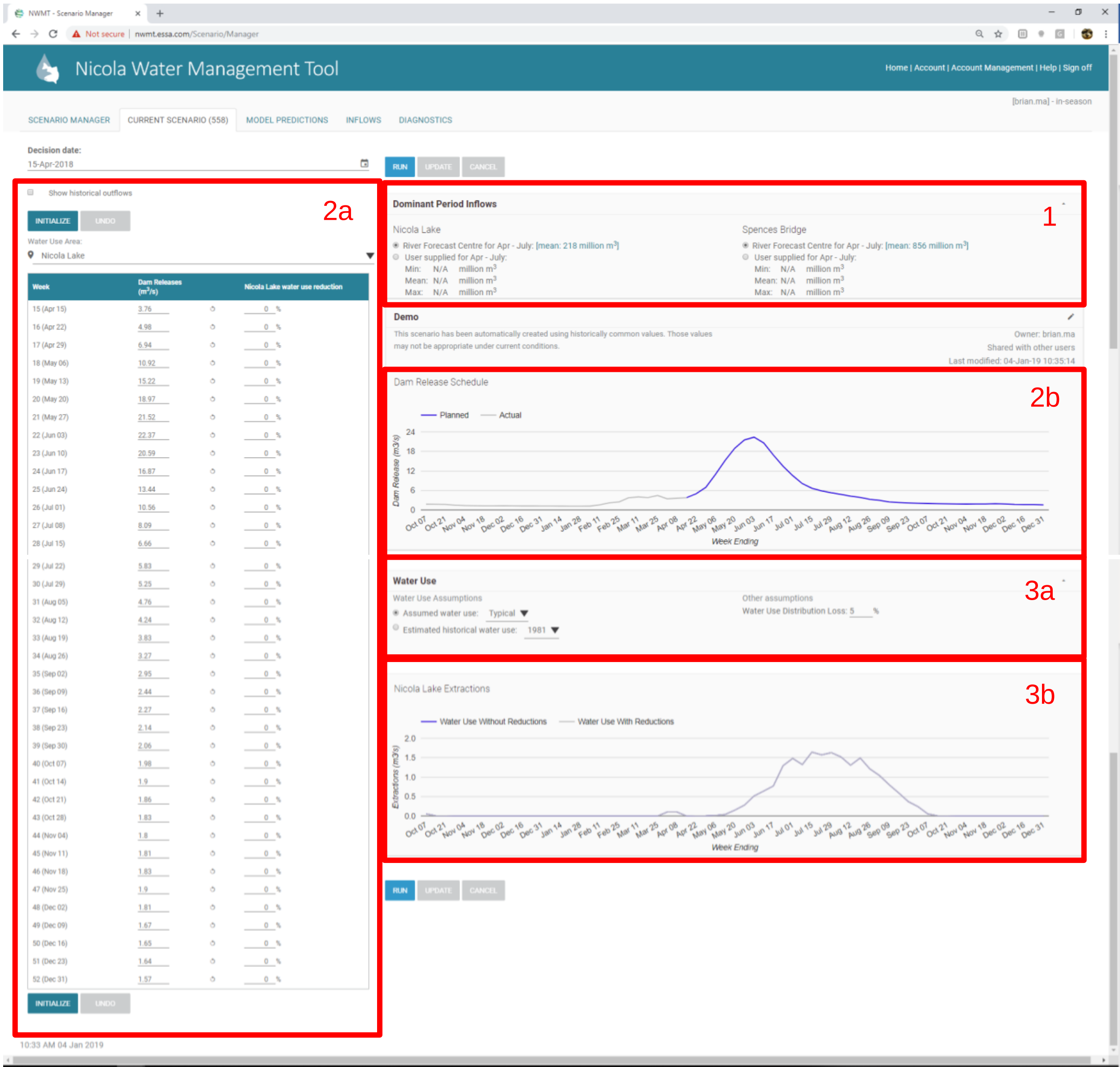


Figure 3-22. Example Current Scenario tab for the NWMT user interface.

Forecasted Inflows

Inflow forecasts can be updated in the box titled “Dominant Period Inflows”. As the name suggests, this is only relevant during the dominant period. The default setting is to use the River Forecast Centre’s inflow forecast, which will be stated along with the period of the forecast. In the above example (Figure 3-22, Panel 1), this period is from April 1 to July 31, with a mean value of 218 million m^3.

Users wishing to use an alternative inflow estimate they believe to be superior to the RFC estimate can enter values under the "User-Supplied" option. For the user-supplied option, select the "user supplied" radio button (in the "current scenario" tab) and enter your own minimum, mean, and maximum values.

Dam releases & water use

Changing the releases allows the user to understand the impacts of different release schedules on the with trade-offs between objectives and indicators under expected, high and low inflows. Similarly, users can change the assumed extractions, and evaluate the change in forecasted flows and performance indicators. For example, what would the forecasted flows be if agricultural water demand was 30% lower due to improved irrigation efficiency and good management as suggested by the Agricultural Water Demand Model (van der Gulik *et al.* 2013)?

The user-defined dam releases and extractions are specified in the left most panel for the current scenario (Figure 3-22, Panel 2a). To view the impact of these changes, press the "Update" button. This will update the displayed data in a chart (Figure 3-22, Panel 2b). Changes to the input are simultaneously updated on the charts.

The user can also specify water use assumptions, such as the estimated historical water use, or assumed water use (Figure 3-22, Panel 3a). To view the impact of these changes, press the "Update" button. This will update the figures for Nicola Lake Extractions (Figure 3-22, Panel 3b).

Output: Model Predictions

Model outputs are found on the Model Predictions tab (Figure 3-23).

Water elevation and Hazard Assessments

Model predictions are made for Nicola Lake (Figure 3-23), Upper Nicola River (N4), and Nicola River at Outlet Dam (N3), Spius to Coldwater (N2), and Spences to Spius (N1). These predictions are made for the average, minimum and maximum forecast assumptions, which can be viewed using the hyperlinked terms on the navigation pane.

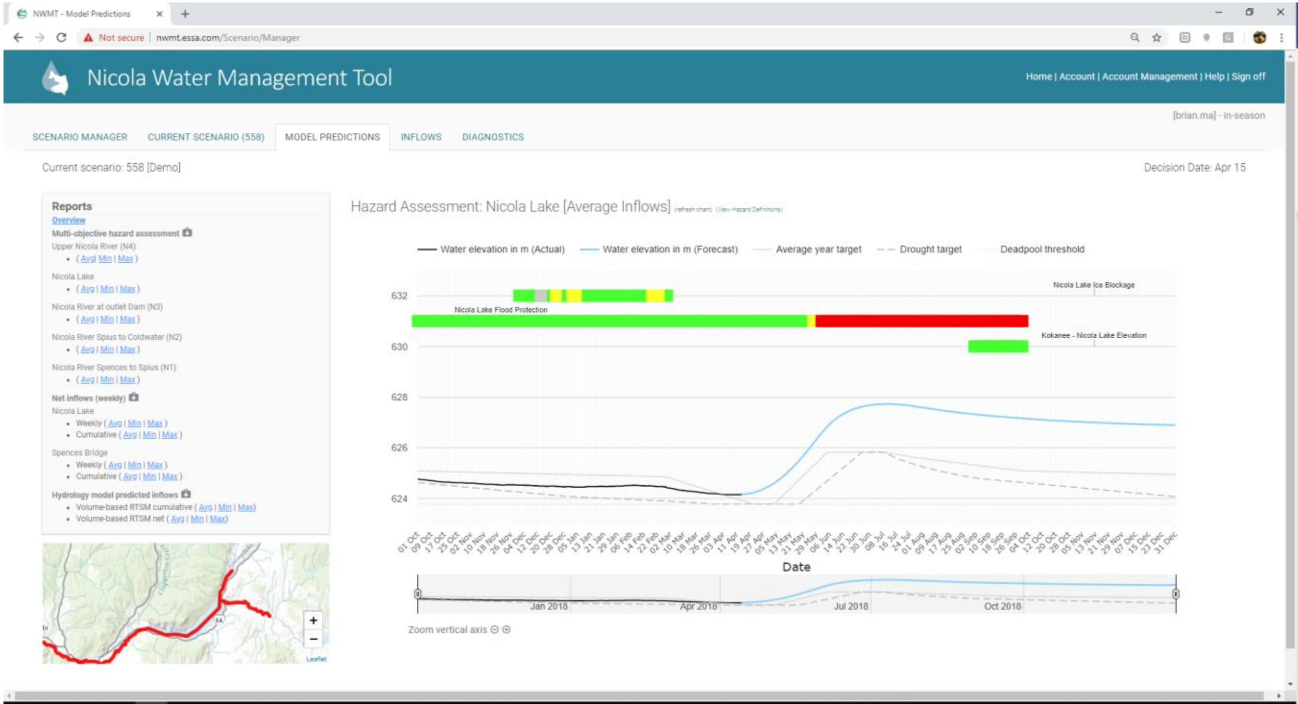


Figure 3-23. Predicted average water elevation in Nicola Lake and associated hazard assessment.

Net Inflows (weekly)

The net inflow screen (Figure 3-24) includes a chart of the actual net inflows up to the decision date of the current scenario (the chart displays historical data from real-time gauges before the decision date and forecast data afterwards), a map highlighting the selected inflow location and box where different reports can be selected. For all reports, average, minimum, and maximum flow assumptions can be viewed.

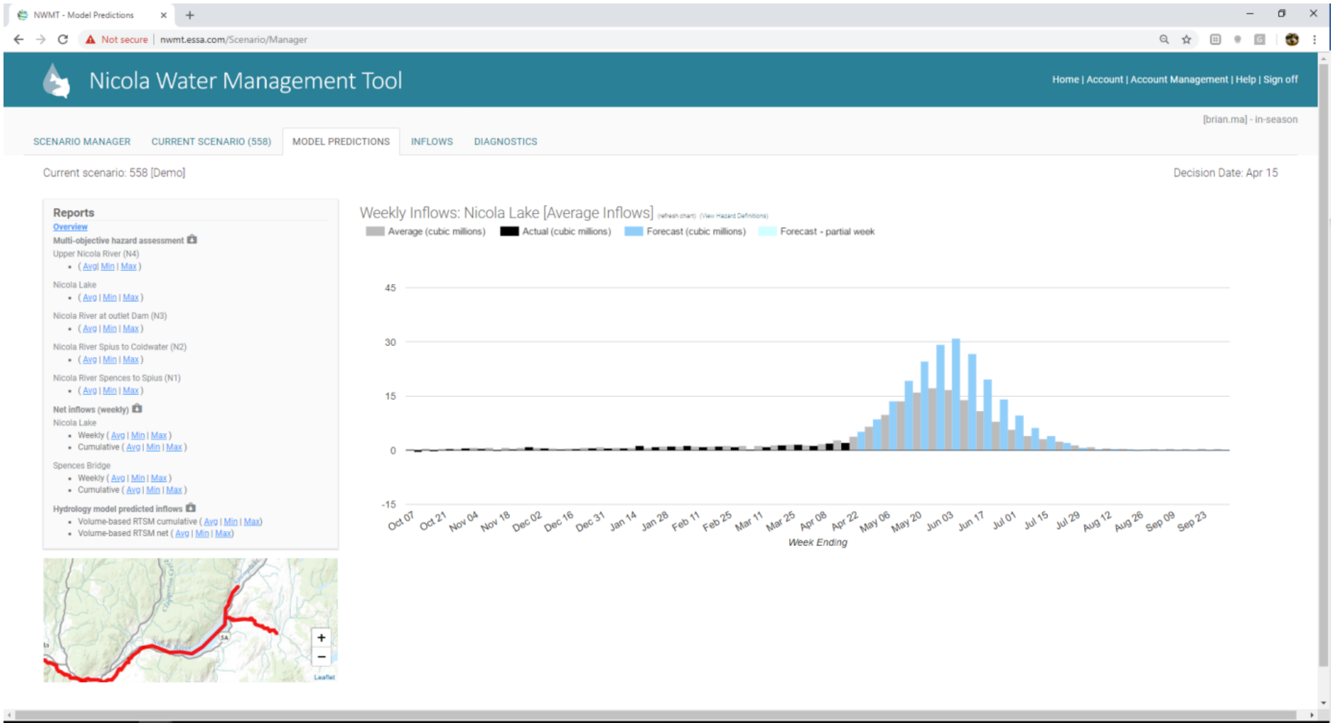


Figure 3-24. Net inflow report for N1 (average) in the NWMT. Weekly observed (black), forecast (blue), as well as historical average (grey) flow values are displayed in a chart. At the bottom left, a map displays the location being viewed.

Hydrology Model Predictions

The raw hydrology model predictions, which are used to determine the water elevation and resulting hazard assessments, are also shown by selecting “Hydrology model predicted inflows”, then selecting Volume-based RTSM cumulative, or net in the navigation pane on the left-hand-side. An example of this is shown in Figure 3-15.

Diagnostics

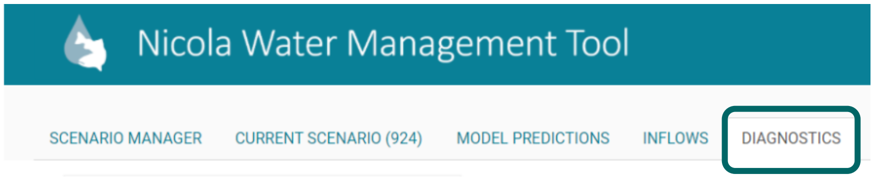
Hydrology model predicted inflows – Pattern-based RTSM curves

The Diagnostics tab provides the pattern-based RTSM model predictions. Unlike the volume-based predictions used in the “Model Predictions” tab, the pattern-based model prediction can differ in volume. If the volume predicted by the pattern-based RTSM is significantly different than the RFC- or user-supplied volumetric forecast, a warning message will appear (from April to July during the dominant period).

> The current pattern in this year's data compared with similar historical patterns suggests a 27.8% lower volume for Nicola Lake during the dominant period (Apr 1 - Jul 31) than the volumetric forecast (157.4 mil m3 vs. 218 mil m3). For comparison purposes, you may want to consider an analogous scenario with a user specified inflow forecast of 157.4 mil. m3. ×

This forecast can be considered an alternative hypothesis to the RFC forecast, and could be used to scale a user-supplied volumetric forecast.

Short-Term Conditions Dashboard



NWMT provides diagnostics information for its operators. Previous versions of NWMT included diagnostics for water supply and key Nicola Basin real-time gauging stations measuring river flows, water temperatures and lake levels. Managers use these data, along with other external sources, to assess trends in short term hydrologic conditions. This process also required logging into services separately and manually downloading data and reviewing disparate visualizations/charts. This is a tedious and time-consuming process.

NWMT now includes a dashboard that will allow water operators to inspect at a variety of real-time data sources *within the NWMT framework*. We worked with the FLNRORD dam operator to develop a list of commonly used data services, which include rain, air temperature and snow managed by Environment and Climate Change Canada, BC Ministry of Transportation, and BC Wildfire (Table 3-38).

Table 3-38. Metadata and key contacts for the real-time data used in the NWMT Short-term Conditions Dashboard.

Data Provider	Station / Location	Parameter(s)	Data service technical contacts
BC Ministry of Transportation (BC MoT), Road Weather Information System (RWIS)	Pennask Summit (29092)	Air temperature, snow, rain	Adam Todd (Adam.todd@gov.bc.ca)
BC MoT, RWIS	Pothole Lake (29093)	Air temperature, snow, rain	Adam Todd (Adam.todd@gov.bc.ca)
BC MoT, RWIS	Brenda Mine (29094)	Air temperature, snow, rain	Adam Todd (Adam.todd@gov.bc.ca)
BC Wildfire	Merritt Hub (291)	Rain	Matt MacDonald (BCWS.PredictiveServices@gov.bc.ca)
BC Wildfire	Aspen Grove (302)	Rain	Matt MacDonald (BCWS.PredictiveServices@gov.bc.ca)
Environment and Climate Change Canada (ECCC),	Nicola Lake (08LG046)	Water elevation	David Hutchinson (david.hutchinson@canada.ca) (Tel: 604-713-9548; Mobile: 604-240-

Data Provider	Station / Location	Parameter(s)	Data service technical contacts
Water Survey of Canada (WSC)			7640)
ECCC WSC	Nicola Lake at outlet Nicola Lake Dam (to Coldwater) (N3) (08LG065)	Flow, water temperature	David Hutchinson (david.hutchinson@canada.ca) (Tel: 604-713-9548; Mobile: 604-240-7640)

The short-term environmental metrics displayed (Table 3-38) include current conditions compared to historical daily minimum, maximum, 25th percentile, and 75th percentile data. Figure 3-25 provides a representative example of the new NWMT short-term conditions dashboard using air temperature data from Pennask Summit.

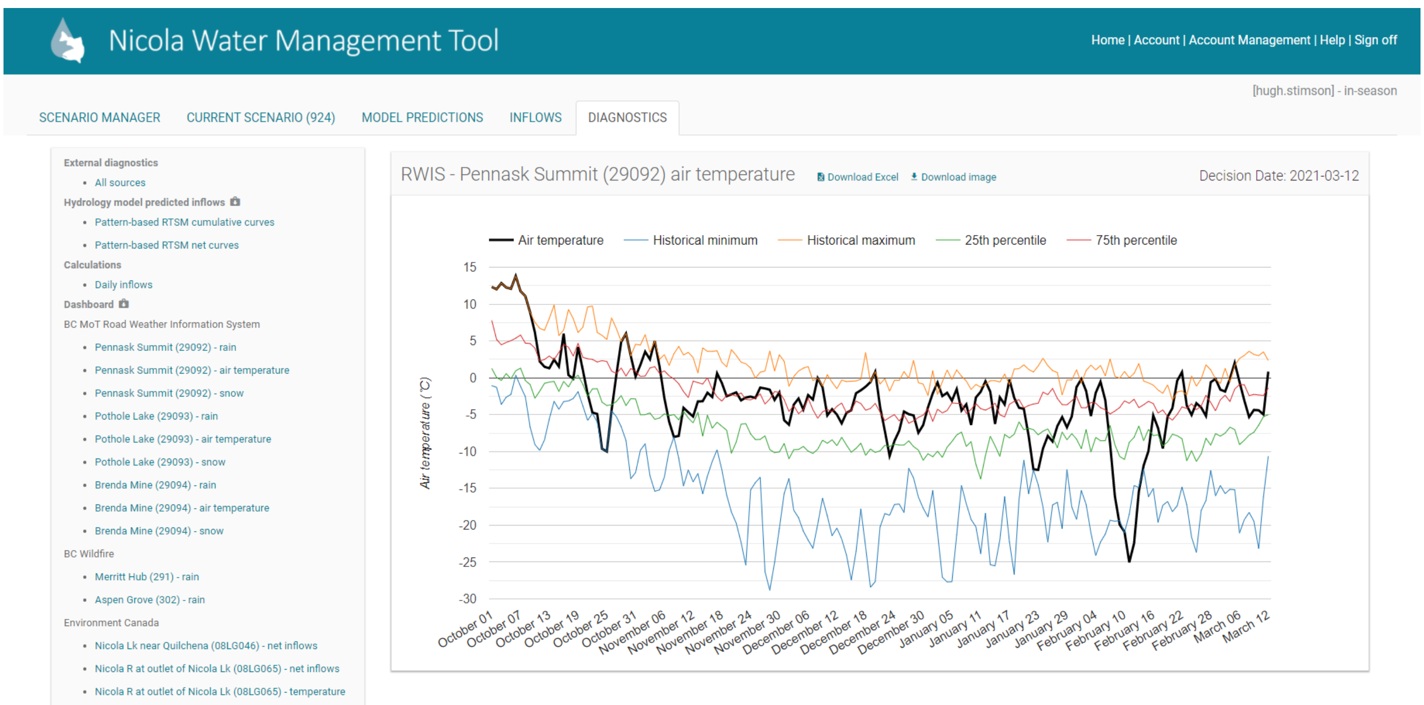
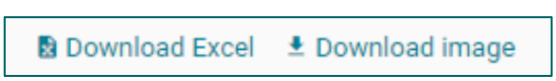


Figure 3-25. Screen capture of the short-term conditions dashboard, using the air temperature data at Pennask Summit as an example.

In addition, the short-term conditions dashboard also reports NWMT's daily net inflow calculations for the current date separate from running NWMT simulation. *Note: this inflow estimate is based on the user's latest scenario, so it is important to be aware of whether the user's last scenario used RFC or custom inflow forecast values.*



In all cases for all diagnostics, the results are available as separate images for ease of sharing and downloadable Excel files to access the raw data values. This provides a convenient way to access data needed to inform exploratory person-built Excel and HEC-DSS workflows for exploring short-term predicted inflows alongside NWMT's RTSM longer range inflow forecasts that are meant to power exploration of broader ranges of ecosystem and flood management objectives beyond Nicola Lake.

The dashboard data can also be batch downloaded using the briefcase icon, which provides a zip file for all of the charts and data.

Alert System

External data services frequently experience outages owing to physical instability/problems with field equipment (e.g., blown out stations) or problems with configuration of receiving servers, as well as other periodic changes to API protocols that stop external systems like NWMT from accessing the data without updates. When this happens, data becomes inaccessible. NWMT implements a simple email alert system and delivers these messages to NWMT Operators and the individuals listed in Table 3-38 so that technicians can be promptly engaged to rectify the problem and restore access to real-time data feeds. An example error alert message provided by NWMT:

"NWMT has detected an error with a real-time data feed for air temperature at Pennask Summit (29092). The appropriate administrators are notified, and we will follow up shortly with a solution."

3.3.8 Data needs, questions, caveats & next steps

Downstream water balance: representation of groundwater influence on mainstem channel

Groundwater is important but not well understood in the Nicola watershed. It is currently not feasible to include groundwater interaction in the NWMT but research on groundwater should continue in parallel with the development of the NWMT with a focus on future integration with the NWMT.

Groundwater and river interaction is an important process responsible for thermal refuges, summer base flows, and interaction with water extraction through wells. For example, McGrath and Walsh (2012) found that maximum daily temperatures were on average 11.5°C lower in groundwater upwelling areas in the Nicola River than adjacent areas. The surface and groundwater supply and interaction study (WMC 2008) concluded that any consumptive use within the Nicola Watershed, either from groundwater or surface water, will reduce downstream flows unless the consumptive use can be offset by reduced evapotranspiration. Furthermore, water extractions can directly influence groundwater upwelling locations if they are within the groundwater well cone of depression (Figure 3-26).

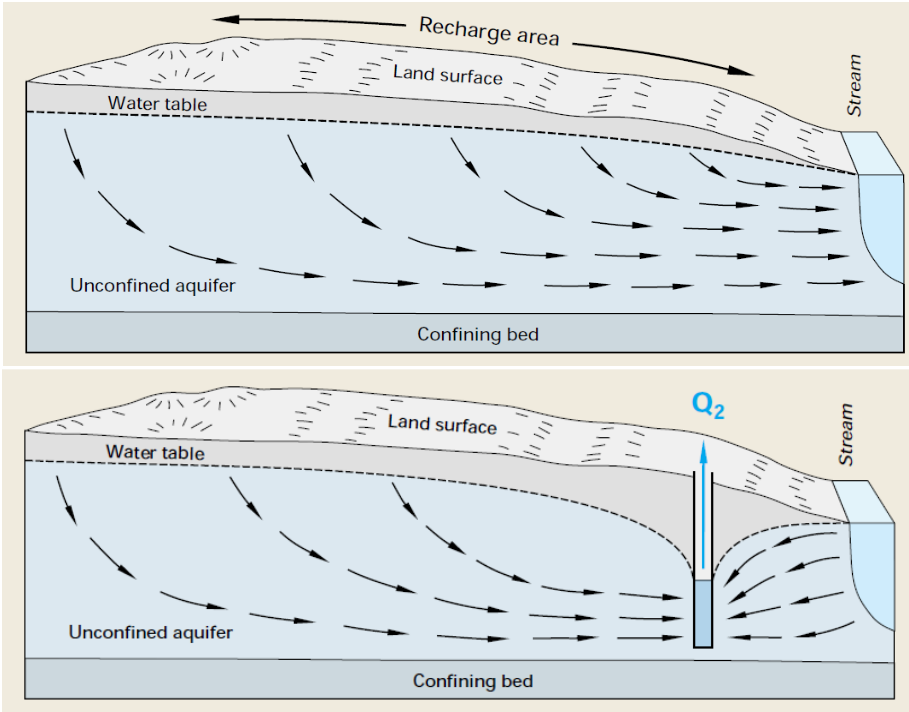


Figure 3-26. Groundwater discharges to a stream under natural conditions (top panel) and with groundwater extraction (bottom panel). If a well is pumped at a high enough rate or is close enough to a stream it can intercept additional water that would have discharged to the stream in the vicinity of the well and can draw water from the stream to the well. The cone of depression is a depression of water levels in an unconfined aquifer or a reduction in pressure head in confined aquifers. *Source*: Winter *et al.* 1998.

3.4 Water Use Submodel

The purpose of the water use submodel is to enable water managers to simulate the potential impact of voluntary water use reductions. The water use submodel provides a 30-year historical time-series of estimated weekly aggregate water extraction for agricultural (i.e., irrigation) purposes above key locations within the Nicola River watershed. The submodel leverages the results of the Agriculture Water Demand Model (AWDM) developed by the BC Ministry of Agriculture and Agriculture and Agri-Food Canada (Van der Gulik et al. 2013). A complete description of the water use submodel is found in **Appendix B**. In addition to the water use submodel described in **Appendix B**, we also describe water use at Nicola Ranch, and how the outputs from the submodel are used in the NWMT user interface.

3.4.1 Nicola Ranch water use

Flooding on Clapperton Creek in 2018 had major infrastructure impacts to storage dams and intakes. Due to these impacts, Nicola Ranch has changed their intake location from Clapperton Creek downstream of Nicola Lake to Nicola Lake itself. They are licensed to use this source, but it is a major daily loss from the lake (Figure 3-27) in addition to release and evaporation.

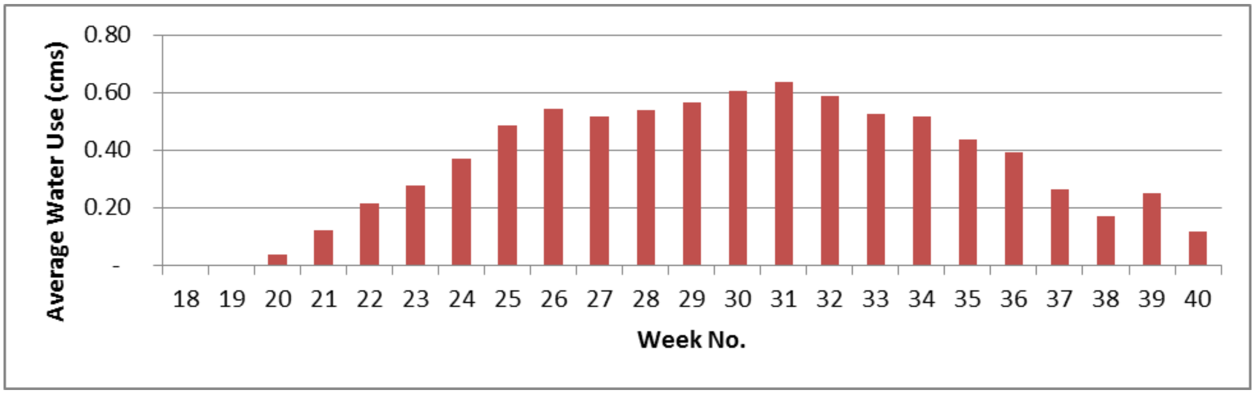


Figure 3-27. Average water use in Clapperton Creek

Nicola Ranch intake location can be specified in the current scenario tab under the water use section, see Figure 3-30. When the intake location is specified as Nicola Lake, a set of adjusted water balance equations are used instead, shown below with the change highlighted in bold. The water use reduction at N3 will no longer include water use reduction at Clapperton, which will be added to Nicola Lake

$$NicolaLakeInflow_{Adjusted} = NicolaLakeInflow + WaterUseReduction_{NicolaLake} - \boldsymbol{WaterUse_{Clapperton}}$$

$$N3_{Adjusted} = DamRelease + WaterUseReduction_{N3} + \boldsymbol{WaterUse_{Clapperton}}$$

$$\begin{aligned} WaterUseReduction_{NicolaLake} \\ &= WaterUseReduction_{MooreCreek} + WaterUseReduction_{QuilchenaCreek} \\ &+ WaterUseReduction_{StumpLake+} \boldsymbol{WaterUseReduction_{Clapperton}} \end{aligned}$$

$$WaterUseReduction_{N3,adjusted} = WaterUseReduction_{N3}$$

The additional water use for Nicola Ranch from Nicola Lake can have a significant impact on Nicola Lake water levels. For example, in an average year with average extractions, the difference between withdrawal from Clapperton Creek and Nicola Lake is 21 cm **(**Figure 3-28). The lake level is also affected by water reduction at N3 which historically includes Nicola Ranch. For example, a 50% water reduction for N3 when Nicola Ranch is withdrawing water from Nicola Ranch will result in a 10cm lower water level compared to withdrawal from Clapperton Creek. Naturally, water reductions in reach N3 will not impact water levels if Nicola Ranch is withdrawing water from Clapperton Creek.

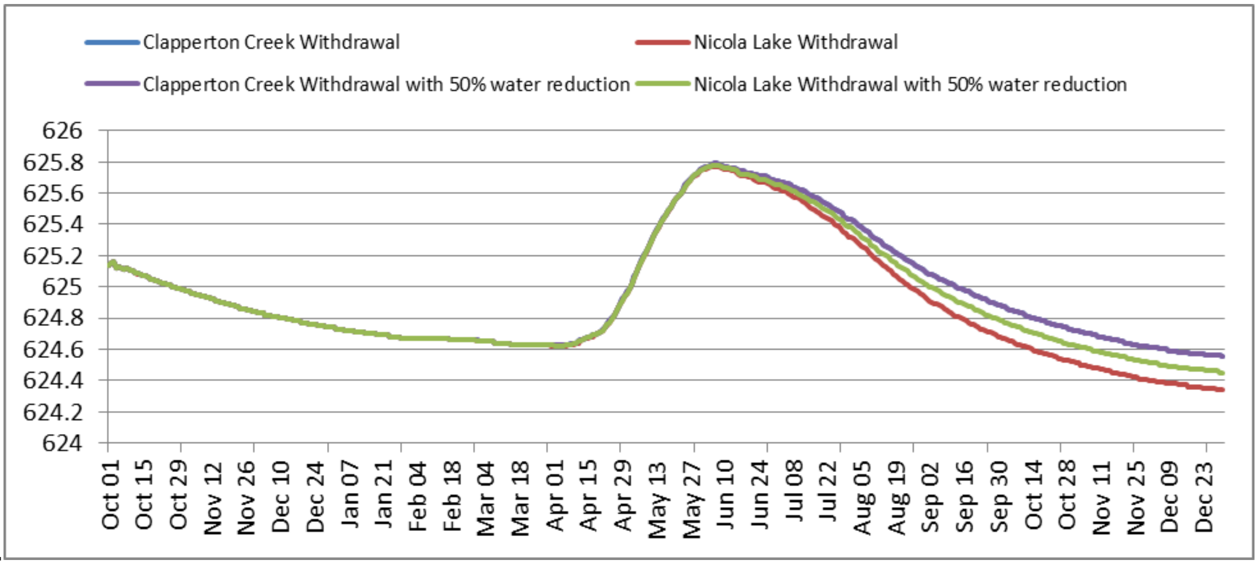


Figure 3-28. Example of different water intake for Nicola Ranch and water reduction

The source of water withdrawal for Nicola Ranch also has a significant impact on discharge for reach N3. For example, if we assume all years average dam releases of 6.66 cms during the week of July 10, the discharge at N3 increases to 7.25 cms if Nicola Ranch withdraws water from Nicola Lake instead of Clapperton Creek assuming a similar water use as 2006, a high water use year (Figure 3 30). Water reductions influence discharge in N3 both when Nicola Ranch uses Clapperton Creek and Nicola Lake as a water source. For example, during the week of July 10 discharge at N3 increases to 7.13 cms if withdrawal is from Clapperton Creek and 7.41 if withdrawal is from Nicola Lake.

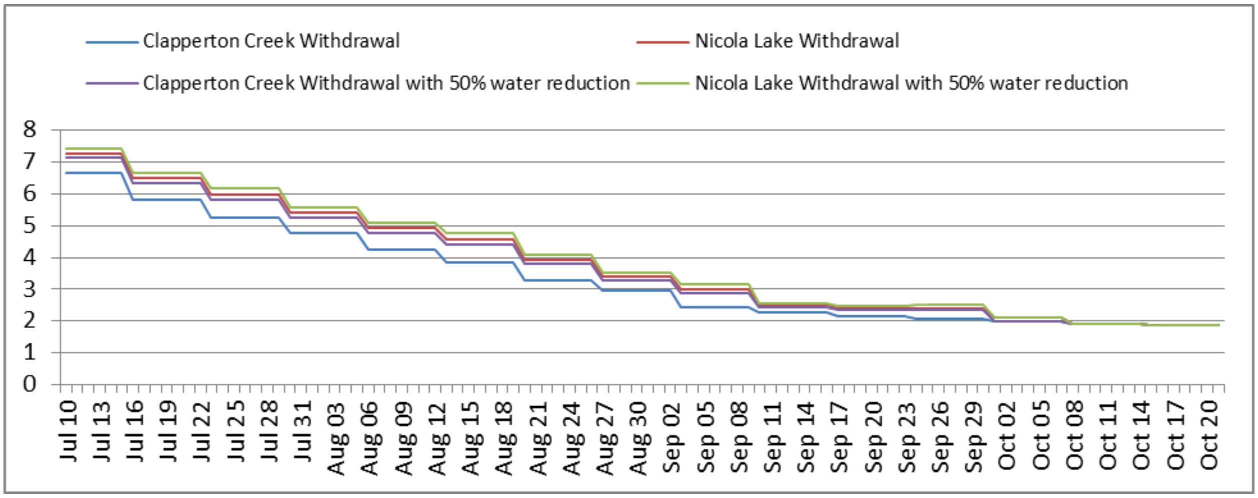


Figure 3-29. Examples of discharge at N3 with different water use assumption during the approximate maximum time period (approx. July 10 to October 21) that Nicola Lake Dam flow releases control flows in lower Nicola River (see Figure 3-1) assuming. Water use is assumed to be similar to 2006, a high water use year.

3.4.2 Outputs & user interface

The water use for each location of interest can be viewed and modified in the Current Scenario tab (Figure 3-30). This tab includes a chart of the water use for the current scenario, and a chart of the dam release schedule. The user can switch between water use areas, and modify the decision date. The water use for a river segment is reported at the next downstream location, e.g., water use between Spius Creek and Spences Bridge is reported at Spences Bridge.

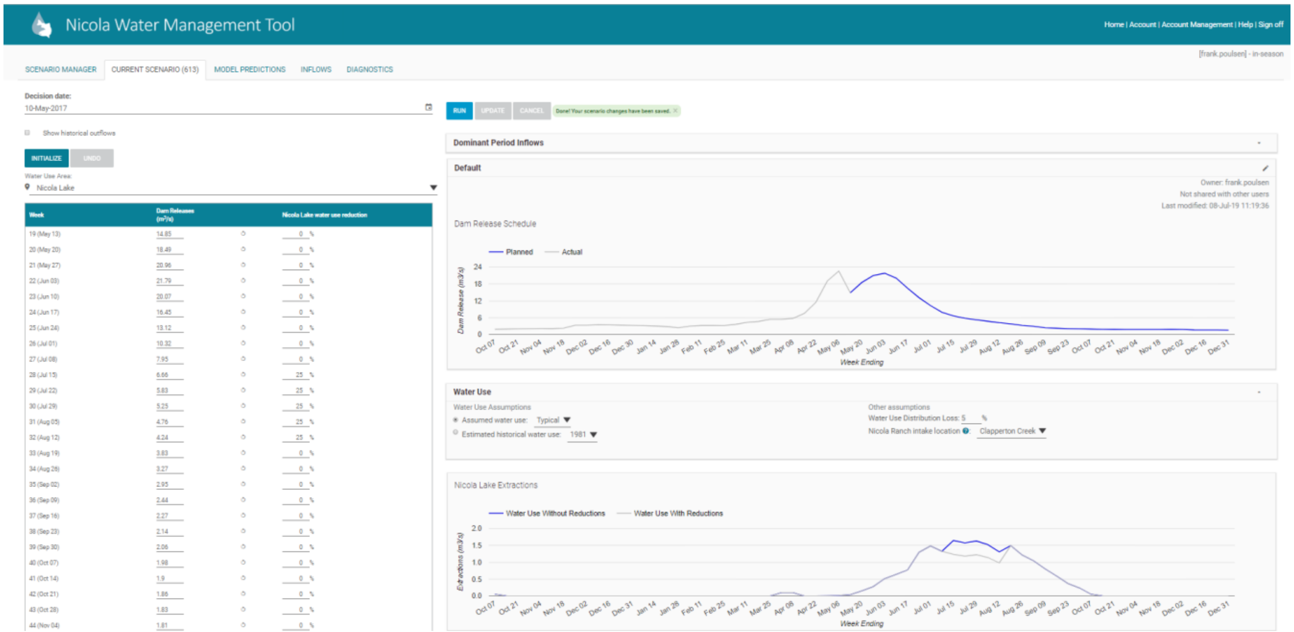


Figure 3-30. Current scenario tab for the NWMT, showing weekly water use in the bottom graph. The graph charts water use without (blue) and with water use reductions (grey) The user can input water use reduction values (%) in the table, which will update the graph in real time. The user can select between locations using the drop-down menu (Water Use Area) in the upper left. The user can also select the Nicola Ranch intake location.

3.5 Water Temperature Submodel

The water temperature submodel is designed as a diagnostics tool to forecast water temperatures that could lead to potential migration inhibition and lethal temperatures to salmonids. The model takes advantage of 2-week air temperature forecasts from Environment Canada to improve accuracy, i.e., the forecast is for the next 14 days after the decision date. The diagnostics tool only forecasts water temperatures, not potential impact on fish and ecosystems, and is most relevant for periods where water temperature issues can occur; i.e., the summer months. It is not designed to account for thermal refugia due to groundwater upwelling.

3.5.1 Locations of interest

The model only forecasts water temperatures for reach N1. N1 is likely to be representative of upstream temperatures; i.e., if fish experience water temperature related stressed at N1, they are likely to also be stressed at N2. Reach N3 is more influenced by dam releases but is less important to the effects of potentially lethal temperatures and temperatures inhibiting migration of salmonids.

3.5.2 Data sources

Temperature gauges have been added to the existing hydrometric stations at Nicola River at Spences Bridge (N1), Nicola River near Merritt (N3), Spius Creek, Guichon Creek and Coldwater River. Data for N1 and N3 is displayed as actual water temperatures in the NWMT user interface on their respective reports.

Air temperature forecasts are retrieved from Environment Canada's web service. The model uses the North American Ensemble Forecast System[10] (NAEFS) for the next 14 days. The ensemble produces a forecast at 6-hour intervals in GRIB2[11] format at a spatial resolution of 0.5x0.5 degrees. A point estimate is extracted using the coordinates for Merritt (50.4236N, 121.345W) and the average of all ensemble forecast is used as the best air temperature forecast. Finally, the daily average air temperature is calculated and used to forecast water temperatures. Note: The model is dependent on Environment Canada's web service and will require updates if Environment Canada changes their webservice.

3.5.3 Water temperature forecasting method

The statistical model is developed using air temperature to water temperature relationships. The relationship is developed using air temperature and actual water temperature from the previous day

$$WaterTemperature_i = a \cdot WaterTemperature_{i-1} + b \cdot AirTemperature_i + c \qquad \text{(Eq. 24)}$$

Where i is an index for the day,

$i - 1$ is the value from the previous day, and

a,b, and c are parameters.

The parameters were calculated using a linear regression in the R statistical computing environment. The parameter values can be found in Table 3-39.

Table 3-39. Parameters for the water temperature model

Parameter	Value
A	0.918915
B	0.059451
C	0.238789

The statistical model indicates that 91% (adjusted R^2 = 0.91) of water temperature variation in summer months (June, July and August) at Nicola River at Spences Bridge can be explained by air temperature and the previous day's water temperature based on 2016 data (Figure 3-31). The model results suggest that Nicola Lake dam releases, tributary flow and temperature and

[10] See https://weather.gc.ca/ensemble/naefs/index_e.html for details
[11] See https://weather.gc.ca/grib/what_is_GRIB_e.html for details

groundwater inflow all have a minor influence on water temperatures at Spences Bridge. The model also simulates periods of rapid cooling well *but does not* include a term for hyporheic web activation.

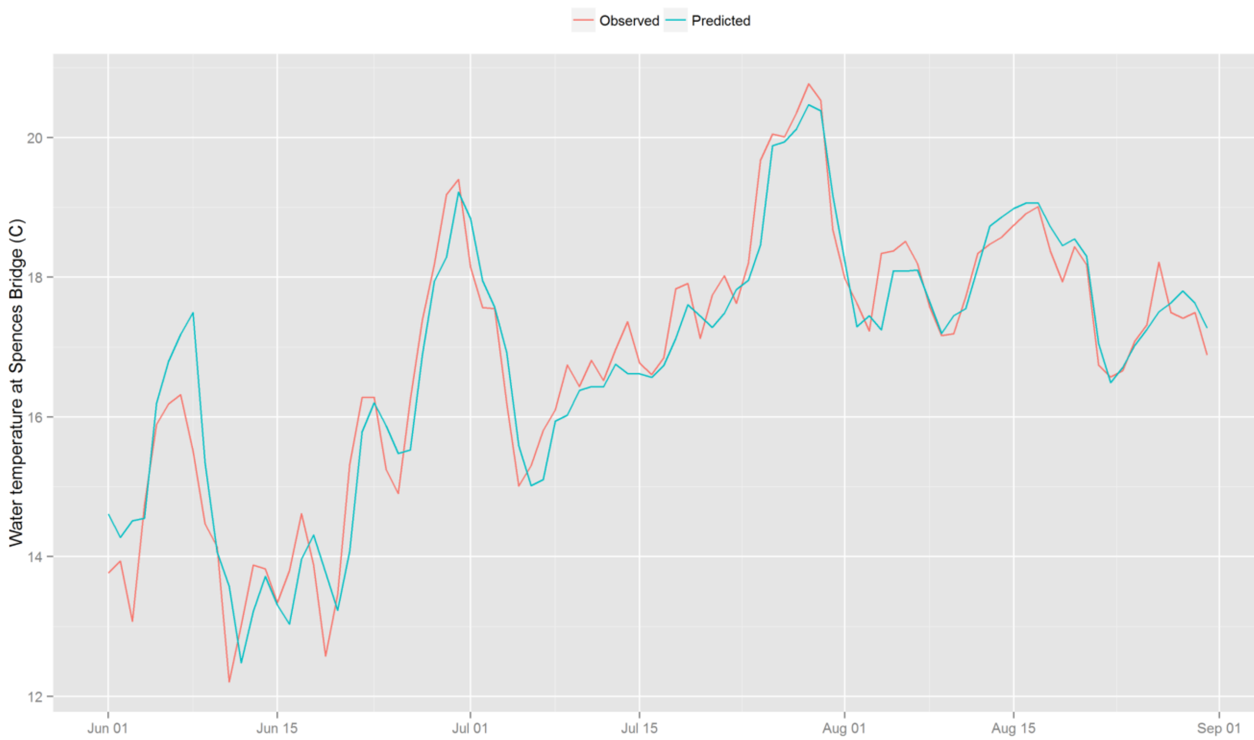


Figure 3-31: Result from preliminary water temperature model based on observed air temperature and the previous day's water temperature. Data is from 2016 for Nicola River near Spences Bridge. The model explains 91% of water temperature variation in summer months (June, July and August).

3.5.4 Outputs & user interface

The actual water temperatures can be found on the reports for N1 and N3, and the forecasted water temperature can be found on the report for N1, see Figure 3-5 for an example.

4 References and Further Reading

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Appendix A: Workshop Participants

Table A-1: Participants at the Design Workshop in Kamloops on February 17th and 18th 2015.

Participant	Affiliation	Expertise	Contact information
Alexander, Clint	ESSA Technologies Ltd	Facilitation, decision support systems, ecological flows, coupled modelling	calexander@essa.com
Bailey, Richard	DFO	Anadromous fisheries (salmon)	Richard.E.Bailey@dfo-mpo.gc.ca
Ball, Jep	MFLNRO	Hydrotechnical engineer, Dam operations	Jeptha.Ball@gov.bc.ca
Bison, Rob	MFLNRO	Steelhead	Robert.Bison@gov.bc.ca
Campbell, David	RFC - MFLNRO	Net inflow forecasting, tributary/river net flow forecasting	David.Campbell@gov.bc.ca
Caveryly, Al	Consultant	Resident/anadromous fisheries	alcaverly@shaw.ca
DeRose, Kim	MFLNRO (Cascades)	Water use/licensing	Kim.DeRose@gov.bc.ca
Edwards, Doug	DFO	Restoration	Doug.Edwards@dfo-mpo.gc.ca
Gardner, Tobi	RFC - MFLNRO	Net inflow forecasting, tributary/river net flow forecasting	Tobi.Gardner@gov.bc.ca
Lawrence, David	Nooaitch Indian Band	Traditional Land Use	David@nooaitch.com
McCleary, Rich	MFLNRO	Flows / hydrometric network opportunities	Rich.McCleary@gov.bc.ca
Morris, Andy	MFLNRO	Resident/anadromous fisheries	Andy.Morris@gov.bc.ca
Petersen, Andrew	MFLNRO	Extractive water use	Andrew.Petersen@gov.bc.ca
Poulsen, Frank	ESSA Technologies Ltd.	Decision support systems, computer programming	fpoulsen@essa.com
Thomas, Tracy	FBC	Stakeholder engagement, projecct governance, sponsorship	tthomas@fraserbasin.bc.ca

Table A-2: Participants at the Prototype Review Workshop in Kamloops on October 26th and 27th 2016.

Participant	Affiliation	Expertise	Contact information
Alexander, Clint	ESSA Technologies Ltd	Facilitation, decision support systems, ecological flows, coupled modelling	calexander@essa.com
Bailey, Richard	DFO	Anadromous fisheries (chinook salmon)	Richard.E.Bailey@dfo-mpo.gc.ca
Ball, Jeptha	MFLNRO	Hydrotechnical engineer, Dam operations	Jeptha.Ball@gov.bc.ca
Calverly, Al	<affiliation?>	Fisheries biologist (retired)	find
Crowe, Michael	DFO	Sr. Fisheries Management advisor	Michael.Crowe@dfo-mpo.gc.ca
Edwards, Doug	DFO	Restoration	Doug.Edwards@dfo-mpo.gc.ca
Farmer, Patrick	FLNRO	Water Stewardship Allocation	Patrick.Farmer@gov.bc.ca
Hyatt, Kim (by phone)	DFO	Anadramous fisheries, decision support systems	
Lawrence, David	Nooaitch Indian Band	Traditional ecological knowledge	David@nooaitch.com
Martin, Sara	Nicola Tribal Association	Fisheries biologist (recently hired)	smartin@nicolatribal.org
McCleary, Rich	MFLNRO	Flows / hydrometric network opportunities	Rich.McCleary@gov.bc.ca
Poulsen, Frank	ESSA Technologies Ltd	Decision support systems, computer programming	fpoulsen@essa.com
St- Pierre, Christian	FLNRO Ecosystems	Hydrology, water use	Christian.StPierre@gov.bc.ca
Petersen, Andrew	FLNRO Agriculture	Agricultural water use	
Thomas, Tracy	FBC	Project coordinator, governance, stakeholder engagement	tthomas@fraserbasin.bc.ca
Uunila, Lars	Polar Geoscience Ltd.		lars@pgeo.ca
West, David	Ecofish Research	Water temperature modelling	dwest@ecofishresearch.com
Whitehouse, Ryan	FLNRO Ecosystems		Ryan.Whitehouse@gov.bc.ca

Numerous other experts in the basin contributed beyond the key individuals listed in Tables A-1 and A-2.

Appendix B: Water Use Submodel

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