Design Document

Nicola Basin Fish/Water Management Tool

Phase 1: Conceptual Design (DRAFT)

Prepared for the Fraser Basin Council Society

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The Fraser Basin Council Society

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Nicola Lake Dam (Jep Ball 2011)

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Fundamental Terms and Concepts

Indicator

Performance indicator

Metric

Valued Ecosystem Component (VEC)

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 is an acceptable way 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" 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 Synopsis

A web-based Nicola Water Management Tool (**NWMT**) is proposed for in-season real time operations of weekly release schedules for Nicola Lake Dam. As demonstrated in the Okanagan (Hyatt *et al.* 2015), the use of such a tool will enable a sea change in transparency surrounding the operation of Nicola Lake Dam, catalyze cooperation and improved communication, and accelerate joint education of both water and fisheries managers regarding trade-offs amongst objectives and the science and values that underpin them. This worthwhile project has been under consideration for nine years. On October 16th 2006, ESSA Technologies facilitated a 1-day scoping and user requirements session at Fisheries and Oceans Canada in Kamloops. 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 18th 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 18th 2014, which led to preliminary design work and a scoping meeting on November 3rd 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. Subsequently, **a conceptual design workshop was held February 17-18th 2015** to consult with a broader range of technical experts on NWMT submodel components and decide on priorities for tool development. This draft design document reflects the information gathered at the February 2015 workshop. This document will be circulated to workshop participants for comment, and a final version will be generated that addresses comments (to the extent feasible given budget).

1.1 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, 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 will remove 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. 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.

1.2 Management Actions Implemented

The NWMT hydrology and water balance submodel will implement two (2) 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 — will illustrate 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 McLeary, pers. comm. 2015). Hence, in practice this action would be accompished 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 will merely be 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 would be voluntary and 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.

Other management actions discussed at the February 2015 design workshop included:

- Water releases from upland reservoirs above Nicola Lake
- Adding a coldwater siphon to Nicola Lake to access colder water

These later two actions are beyond the scope of the current NWMT.

1.3 What is NWMT?

The planned NWMT is a web-based DSS for in-season real time operations of weekly release schedules for Nicola Lake Dam. The DSS will automate 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 will determine 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 will be a powerful new communication aid for stakeholder learning and outreach purposes. For example, when additional water releases are needed for fish migration, the tool will be used to communicate these needs with downstream water users who would be encouraged to reduce withdrawals. The synthesis of data provided by the NWMT will also provide a simple method for these same water users to see the flow and ecosystem effects. The tool will also provide 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.

1.4 What NWMT is *Not*

The NWMT is a decison support system (DSS) project, not an overall governance or policy exercise. While NWMT is **not** a "water licence allocation tool", for certain it will raise visibility on current constraints associated wtih 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. However, the "purpose" of the tool should not be overstated. 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[1].

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

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

Several workshop participants identified the importance of a **groundwater monitoring network** that 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. <u>This research and source of data has multiple benefits that extend beyond the requirements of NWMT.</u> While having this data would *improve* the capability and spatial resolution of the NWMT (and fish population management generally, with or without NWMT), the presence of this monitoring network is **not** an essential pre-requisite. 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 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.

2 Model Scope and Bounding

Every decision support modelling exercise must include assumptions about what is included and excluded in order 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 our 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. With a list of fundamental objectives in mind, workshop participants are then asked to attribute consequences caused by various alternative actions 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 Performance Indicator Screening

An organizing tool to keep this effort tractable included defining and presenting indicator screening criteria to workshop participants (Table 2-1). This screening tool was communicated to participants February 17th 2015 prior to a series of structured exercises to define objectives, focal species and performance indicators for the initial version of NWMT. Workshop participants were reminded at several junctures to keep these criteria in mind, and to focus on ensuring that the performance measures would be responsive to the proposed management actions (Section 1.2). Therefore, socio-economic, focal habitat and species indicators that are not strongly governed by flow (and water temperature) actions during at least one critical life-history stage fall outside our sphere of consideration in NWMT version 1.

Table 2-1. Focal species and performance indicator screening criteria.

Label	Explanation	Levels
I **Importance**	The degree to which a linkage (functional relationship) controls the outcome relative to other drivers and linkages affecting that same outcome.	**4 = High:** Expected sustained major population level effect, e.g., the outcome addresses a key limiting factor, or contributes substantially to a species population’s natural productivity, abundance, spatial distribution and/or diversity (both genetic and life-history diversity) or has a landscape scale habitat effect, including habitat quality, spatial configuration and/or dynamics. **3 = Medium:** Expected sustained minor population effect or effect on large area or multiple patches of habitat. **2 = Low:** Expected sustained effect limited to small fraction of population, addresses productivity and diversity in a minor way, or limited spatial or temporal habitat effects. **1 = Minimal:** Conceptual model indicates little or no effect.
U **Understanding** (“Clarity”)	The degree to which the performance indicator can be predicted from the defined linkage (functional relationship) and its driver(s).	**4 = High:** Understanding is high and nature of outcome is largely unconstrained by variability in ecosystem dynamics, other confounding external factors. Is generally accepted, peer reviewed empirical evidence, strong predictive power and understanding, evidence not contested or confounded. Data in support of the functional relationship is derived from direct field observations. **3 = Medium:** Understanding is high but nature of outcome is moderately dependent on other variable ecosystem processes or uncertain external confounding factors. Strong evidence but not conclusive, only medium strength predictive power, some evidence for competing hypotheses and/or confounding factors. Data in support of the functional relationship is derived from direct field

Label	Explanation	Levels
		observations OR from field observations outside the study area. **2 = Low:** Understanding is moderate or low and/or nature of outcome is greatly dependent on highly variable ecosystem processes or other external confounding factors. Many important aspects are subject of active ongoing research. Theoretical support with some evidence, semi-quantitative relationships, several alternative hypotheses and/or confounding factors. Data in support of the functional relationship is derived from lab or theoretical studies without field evidence. **1 = Minimal:** Understanding is lacking. Mainly subject of active ongoing primary research. Hypothesized based on theory and/or professional judgment, purely qualitative predictions, many alternative hypotheses and/or confounding factors. Support for the functional relationship is largely hypothetical and based on first principles.
F **Feasibility**	The degree to which input data necessary to calculate the proposed performance measure can be delivered in a timely fashion (without external bottlenecks) and the amount of effort (relative to other possible indicators) needed to implement the cause-effect linkage in a computer model.	**4 = High:** Input data currently exists in a format easy to disseminate, can be delivered readily and the effort (time) associated with implementing the cause-effect linkage easily falls within project budget without sacrificing other indicators. **3 = Medium:** Input data currently exists (or can readily be generated by new model runs), and while it might need some additional formatting, can be delivered readily. The effort (time) associated with implementing the cause-effect linkage will fall within project budget subject to prioritization decisions elsewhere that remove some other indicators from consideration. **2 = Low:** Input data does not currently exist, but can be generated through additional analyses or external model runs. The time before this external work could be completed is or may be uncertain. The effort (time) associated with implementing the cause-effect linkage could be accommodated within the project budget, but a number of other indicators would need to be eliminated from consideration. **1 = Minimal:** Input data does not currently exist, and it is not clear if it can be generated through additional analyses or external model runs. The time before this external work could be completed is unacceptably long. The effort (time) associated with implementing the cause-effect linkage would take up a disproportionately high amount of the project budget, and the majority of other indicators would need to be eliminated.
P **Priority**		Overall priority ranking for including in DSS: **H**igh; **M**edium; **L**ow.

For anadromous and resident fish of the Nicola Basin, multiple cause-effect pathways modulate population level outcomes. In response, some researchers attempt to develop full life-cycle population representations that predict space-time abundance of a particular species or even the behavior and movement of individuals of a species as they are born, grow, develop into adults and reproduce. This significant additional detail, and the aim of predicting changes over time in adult abundance or population viability (or recovery potential), comes with a price; single-species models are typically “data hungry” and require intensive calibration procedures to tune life-cycle responses to the available historic datasets. Non-stationarity and equifinality[2] become particularly important challenges in parameter/calibration rich models often necessitating a leap of faith when applying them to future conditions. Further, these models are often sensitive to assumed initial starting conditions. Additionally, most population-level life-cycle models do not themselves integrate all of the factors that are influenced by a particular action. So while the target level of detail and end output metric may be more palatable with life-cycle models, the number of assumptions and sensitivity of the tools to these assumptions is generally very high, and in some cases may obscure the "true" accuracy of predictions.

Whenever possible, we encourage use of a functional flow approach that emphasizes specific cause-effect linkages between species responses and flow (and water temperature) (see Alexander *et al.* 2014). In this way, the formulation of NWMT's indicators is open to testing and adaptation through time as new data and understanding emerge. 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 Summary of Objectives & Performance Indicators

Management objectives and performance indicators identified at the February 2015 design workshop are summarized in Table 2-2. We are proposing that the initial version of the NWMT include a total of **nineteen (19) performance indicators** across fish, water supply and use, and flood management objectives. Details of these performance indicators are described in Section 3.

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[2] It is endemic to mechanistic modelling of complex open environmental systems that there are many different model structures and many different parameter sets within a chosen model structure that may be acceptable in reproducing historically observed behaviour of that system. This is called 'equifinality'. This is more than an academic concern if mechanistic models fit to historic data are relied upon to predict future trajectories of a variable of interest in detail. This is a significant concern when different (equally plausible in terms of fit to historical data) parameter sets produce different future trajectories.

Table 2-2. Summary of proposed 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 spring chinook salmon. Improve egg to smolt survival (spawning, incubation and rearing success) (2) Also manage flows with a view to improve water temperatures for in-migration, spawning and rearing for spring chinook salmon	▪ In-migration flows [CH1-MQ] ▪ Spawning flows [CH2-SQ] ▪ Egg scour flows [CH7-ScourQ] ▪ Rearing flows [CH3-RQ] ▪ In-migration temperatures [CH4-MT] ▪ Spawning temperatures [CH5-ST] ▪ Rearing temperatures [CH6-RT]
Steelhead trout (ST)	(1) Manage flows to improve parr rearing water quality for steelhead (2) Also manage flows with a view to improve water temperatures for rearing parr	▪ Parr rearing flows [ST1-RQ] ▪ Parr rearing water temperatures [ST2-RT]
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 spawning and incubation success	▪ Spawning passage flows [K1-SQ] ▪ Egg freezing risk [K2-Ice] ▪ Nicola Lake elevation [K3-LE]
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-Dessication Q] ▪ Nicola Lake ice & dock damage [NLI2-Dock Damage]
Nicola River flood protection	(2) Manage/minimize flood risk around Nicola River while allowing for a reasonable balance of achievement of other multi-objective targets	▪ Nicola River flood protection [NRF1-Merritt flooding]

2.3 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 most appropriate discrete spatial reporting unit for a performance indicator or physical variable (e.g., reach segment, cross-section, specific gauge location). Typically, this involves making decisions about suitable levels of aggregation for specific variables as well as choices about subsets of index locations to include in order to show representative trends and patterns of variation.

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 occuring. This level of spatial resolution may not be possible in the first version of NWMT (see: Section 3.3 Hydrology & Water Balance Submodel).

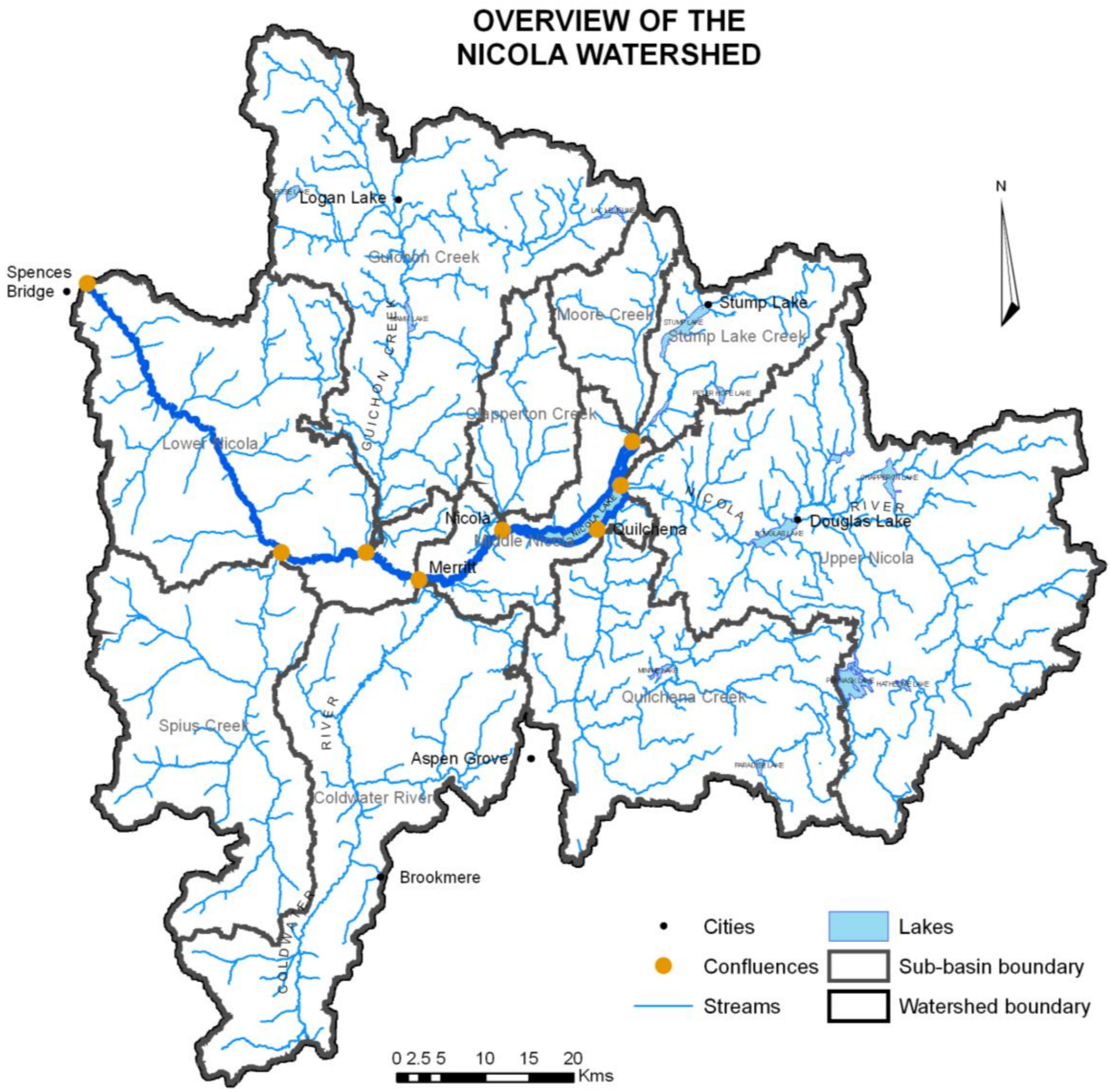


Figure 2-1. Overview of Nicola watershed.

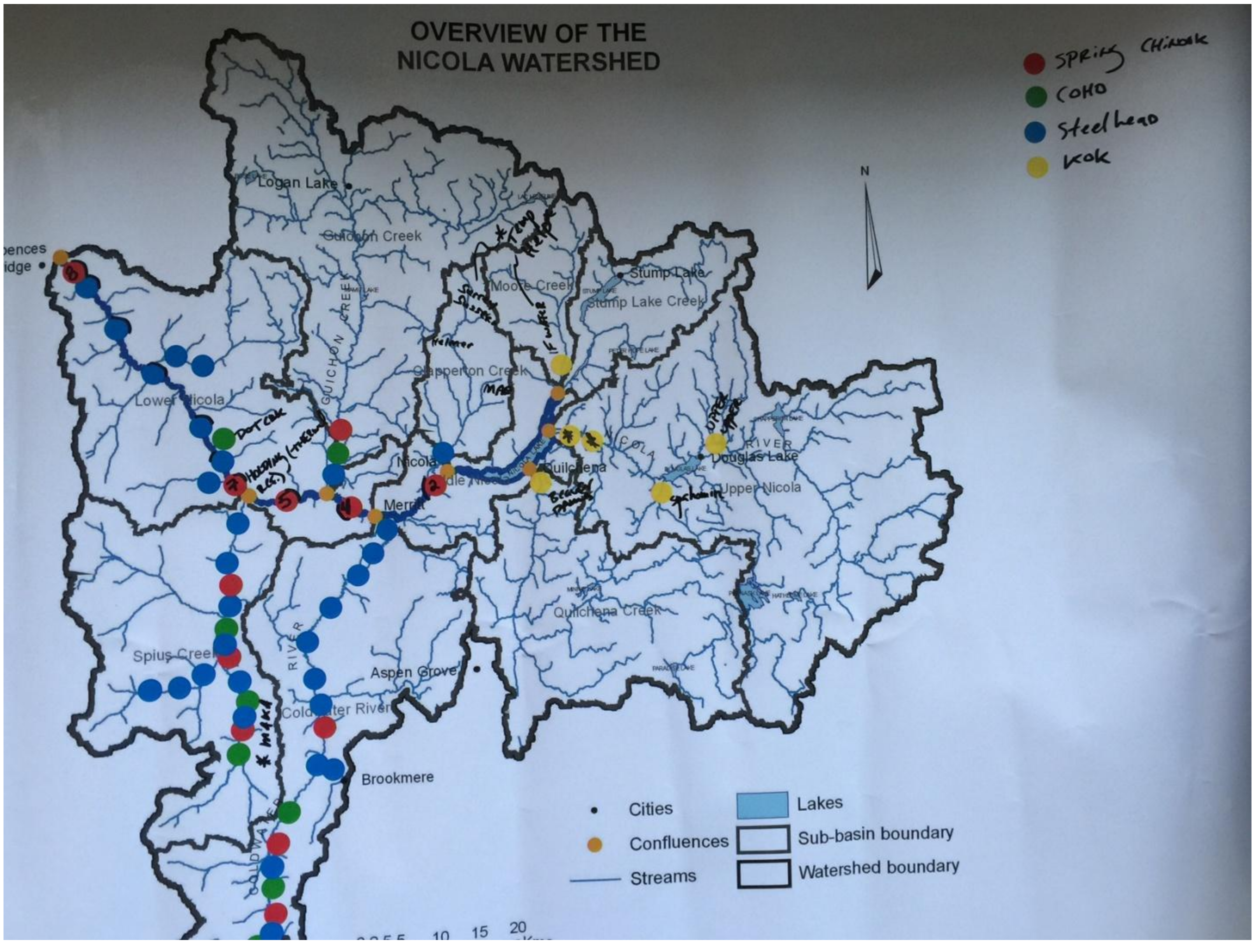


Figure 2-2. Locations of interest for the fish & ecosystem submodel. February 2015 workshop participants identified mixture of mainstem Nicola River and tributary habitats as being important to the priority fish species (spring chinook, steelhead, coho salmon and kokanee). For the initial version of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

2.4 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.

> *How long into the future do we need to run a model to understand the consequences of a particular management action?*

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).

> *Should we model various processes on an annual, monthly, weekly, or daily time step, given both the rates of change of system components, and the current state of knowledge?*

The temporal **horizon** NWMT is **October 1st** of year n to **September 30th** of year n+1 (12 months). 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 particular 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 release 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 will involve mixed weekly and daily time-steps. Prior to a given decision date (i.e., outcomes for actual historic observations), all submodels will operate on a daily time-step. When forecasting, the default temporal resolution of NWMT submodels will be weekly.

2.5 Submodel Coupling and Integration

A "looking outward matrix" is a proven and very useful technique for helping 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 formed by arraying subsystem components as follows:

To: / From:	**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. For example, the following question is asked of the members of the subgroup working on Component 1:

> *Given that you are a member of the subgroup working on Component 1, what information do you need about Components 2 and 3 to be able to draft an adaptive management plan for Component 1?*

Or

> *What do you need to know about all the other components to predict how yours will behave?*

This is quite different from an approach where specialists within subgroups are asked to predict how their own subsystem will behave. The "looking outward" approach steers participants away from over-elaboration of their own subsystem area and promotes attention to interdisciplinary links between subsystems. For this reason, the diagonal cells of the looking outward matrix are crossed out and shaded – subsystem details are left to subgroup discussions. The process defines the responsibility of each participant. For example, if part of your subgroup responsibility is to assess the status of aquatic biota in various streams, what information do you need from a water quality subgroup in order to accomplish this task? It is helpful to define the spatial and temporal resolution of information transfers, as well as units of measurement.

It is also sometimes helpful to place driving variables within the looking outward matrix. Driving variables are things typically outside the control of the humans managing the system of interest. Examples of driving variables include interannual variation in precipitation and economic demand. Placing driving variables within the looking outward matrix provides a helpful reminder of important external factors.

The looking outward exercise thus serves several important functions. First, it begins the process of promoting interdisciplinary communication by forcing subgroups to “look outward” at both the kinds of information they need to receive from other subgroups, as well as the kinds of information they need to provide to other subgroups. Requests for information can and should be challenged (e.g., “It’s a lot of work to generate that information. How are you going to use it?”). Second, the looking outward exercise forces the realization that not all parts of a system can be considered, and that not all parts are of equal importance in the decision making process.

Unfortunately, during the NWMT model design workshop, too many participants were unavailable on day 2 to complete this important exercise. For now, the transfers between submodels can be inferred from review of subsystem models in Section 3 (Table 2-3). Reviewers of this report are asked to identify any "failed handshakes" between subsystem models. This is an important "nexts step".

Table 2-3. Reversed engineered Looking Outward Matrix based on draft design document.

To / From	Fish and ecosystem	Socio-economic rules	Hydrology & Water Balance	Water use	Water temperature
Fish and ecosystem					
Socio-economic rules					
Hydrology & Water Balance	Weekly 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 from gauges in mainstem Nicola River and preferably major tributaries. Scheduled weekly releases from Nicola Lake.	Expected water year type (average, dry or wet). Real-time daily average flows from gauges in Nicola River donstream of Nicola Lake and preferably major tributaries. Assumed changes in extractions.	Real-time daily water and air temperature from gauges.

3 NWMT Submodel Functional Details

3.1 Fish & Ecosystem Submodel

During the February 17-18th 2015 design workshop, fish and ecosystem subgroup participants were tasked with prioritizing species for inclusion in the first version of the NWMT (including considering the screening criteria in Table 2-1). Workshop discussions were launched by a keynote presentation by Richard Bailey (Fisheries and Oceans Canada) on the status and trends of anadromous fish in the Nicola Basin.

For Nicola Basin salmon, seasonal variations in water conditions pose a variety of challenges during the period of freshwater residence. By season, Richard Bailey summarized these as:

- **Winter**: Threat of freezing both for eggs in gravel and for off-channel rearing juveniles. Also, anchor ice formation and "rain-on-snow" events often have a profound negative influence.
- **Spring**: Freshet activity can lead to scour of incubating eggs, displacement of rearing fish, and stranding if freshets recede rapidly.
- **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). 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.
- **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.

Richard Bailey strongly emphasized the importance of groundwater upwelling/infiltration zones that create thermally stabilized local habitats. **Groundwater** is important to salmon survival throughout year, except during the freshet. Groundwater-based thermal refugia are critical to salmon survival in high water temperature conditions. 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 meant 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 was 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).

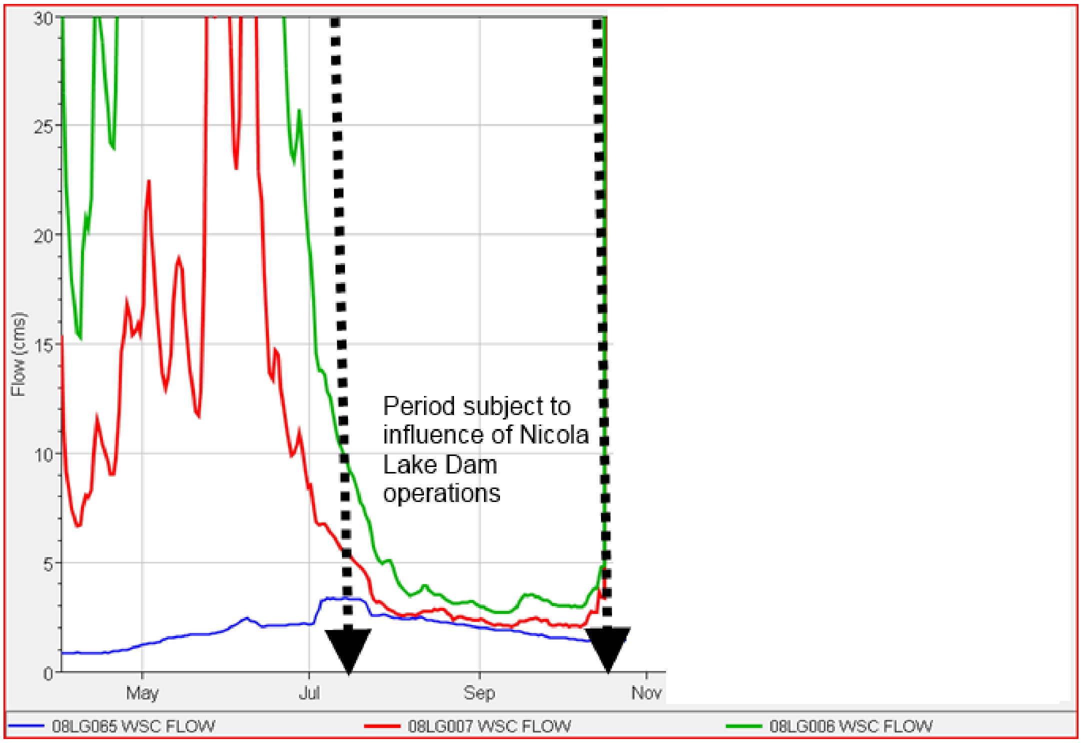


Figure 3-1. Approximate maximum time period (approx. **July 10 to October 21**) that Nicola Lake Dam flow releases control flows in lower Nicola River near confluence with the Thompson River. Blue line is the release from Nicola Lake Dam. Green line is the downstream flow at Spences Bridge. (Example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

Fish and ecosystem subgroup participants were guided through an exercise of prioritizing anadromous salmon (chinook, coho, steelhead, pink, sockeye) and resident fish species (burbot, kokanee, rainbow trout, bull trout, mountain whitefish) at the February 2015 workshop. Participants were given four "voting dots" each and asked, based on both screening criteria (Table 2-1) and consideration of the importance to these species of Nicola Lake Dam flow releases (Figure 3-1), to provide their opinion on priorities. In order of priority, the resultant top four priority species for the initial version of NWMT were:

1. **Spring chinook** 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)

Spring-run chinook salmon were identified as being very vulnerable to summer flow and temperature stress issues. Spring chinook likely survive as adults only because of the thermal refugia created by influent groundwater. This run of chinook enters the Nicola River in the 2nd or 3rd week of April, arrival peaks in the 3rd 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). 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) and usually 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 two major tributaries to Nicola Lake: the Nicola River and Moore Creek (Lorz and Northcote 1965; Kosakoski and Hamilton 1982). 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 (sic) was identified as an important First Nation fishing site for kokanee and chinook. Fish subgroup participants commented that **releases from Douglas and Chapperon Lake** can have impacts on kokanee survival (details were not provided).

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 by fish subgroup experts to be closely linked to flow management decisions at Nicola Lake Dam. 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

Workshop participants focused on the time period of approximately the **first week of July to the last week of October** during which time Nicola Lake Dam releases have the largest influence on downstream flows. For the priority focal species (spring-run chinook, steelhead, kokanee and coho), this generated the periodicity charts 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. Spring-run chinook 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.

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

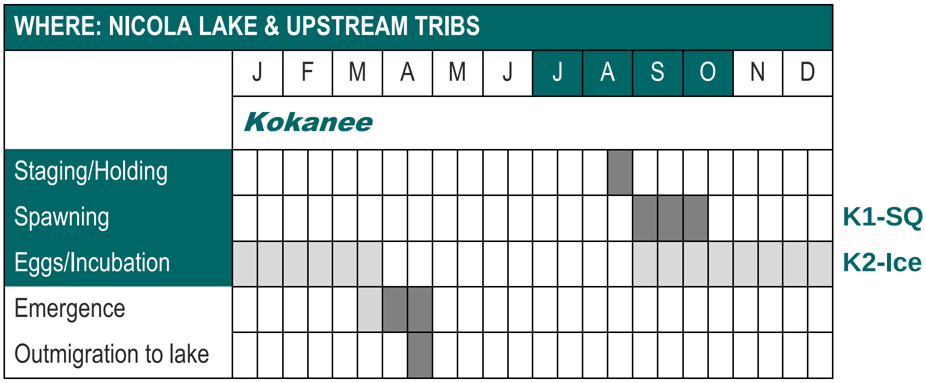
Table 3-2. Steelhead life-history events that overlap July-October period when Nicola Lake Dam releases have influence on downstream flows. Relevant performance indicator codes are listed in last column.

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.



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 Kosakoski and Hamilton (1982) and MOE (1983).

	Fisheries maintenance flows (not species specific) {Generally analagous to "minimum" instream flow requriements}		
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**	**5.66 m^3/s**	**5.66 m^3/s**
Nicola River Spius to confluence Coldwater River (N2)	**3.12 m^3/s**	**3.12 m^3/s**	**3.12 m^3/s**
Nicola River Coldwater to Nicola Lake Dam (N3)	**1.69 m^3/s**	**1.13 m^3/s**	**1.7 m^3/s**
Upper Nicola River above Nicola Lake to Douglas Lake (N4)	**0.78 m^3/s**	**0.78 m^3/s**	**0.80 m^3/s**

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 (1982) and Ptolemy (1984)[3] are generally in good alignment with the recent transect data collected by MOE (2004-2007). 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

[3] As cited by Lewis et al. (2009).

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.

Table 3-6. Optimal instream flows for spring chinook, 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	Spring chinook	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 spring chinook, 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	Spring chinook	Steelhead	Coho
In-migration	**Use spawning flows?**	**Use spawning flows?**	**Use spawning flows?**
Spawning	**Optimal: 11 m^3/s (Lewis *et al.* 2009)[4]** **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).

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

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

	Nicola River Coldwater to Nicola Lake Dam (N3)	Nicola River Coldwater to Nicola Lake Dam (N3)	Nicola River Coldwater to Nicola Lake Dam (N3)
Life-history stage	Spring chinook	Steelhead	Coho
In-migration	**Use spawning flows?**	**Use spawning flows?**	**Use spawning flows?**
Spawning	**Optimal: ?? m³/s (Lewis *et al.* 2009)** **Optimal: 3.4 m³/s (Bruce and Hatfield 2003)*** Optimal: 1.7 m³/s (Kosakoski and Hamilton 1982)*	**Optimal: 4.3 m³/s (Lewis *et al.* 2009)**	**Optimal: 3.4 m³/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 m³/s (Lewis *et al.* 2009)**	**Optimal: 1.1 m³/s (Lewis *et al.* 2009)**
Rearing (1+) (parr)	**Optimal: 1.4 m³/s (Lewis *et al.* 2009)**	**Optimal: 3.2 m³/s (Lewis *et al.* 2009)**	**Optimal: 2.1 m³/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 manitained, 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."

3.1.4 Not just flow – water temperatures

In addition to emphasizing the importance of **groundwater**, workshop discussions also emphasized the importance of tracking and factoring in water temperature effects on fish. Richard Bailey strongly emphasized the importance of groundwater upwelling/infiltration zones that create **thermally stabilized local habitats**. 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. 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 Dam is too warm.

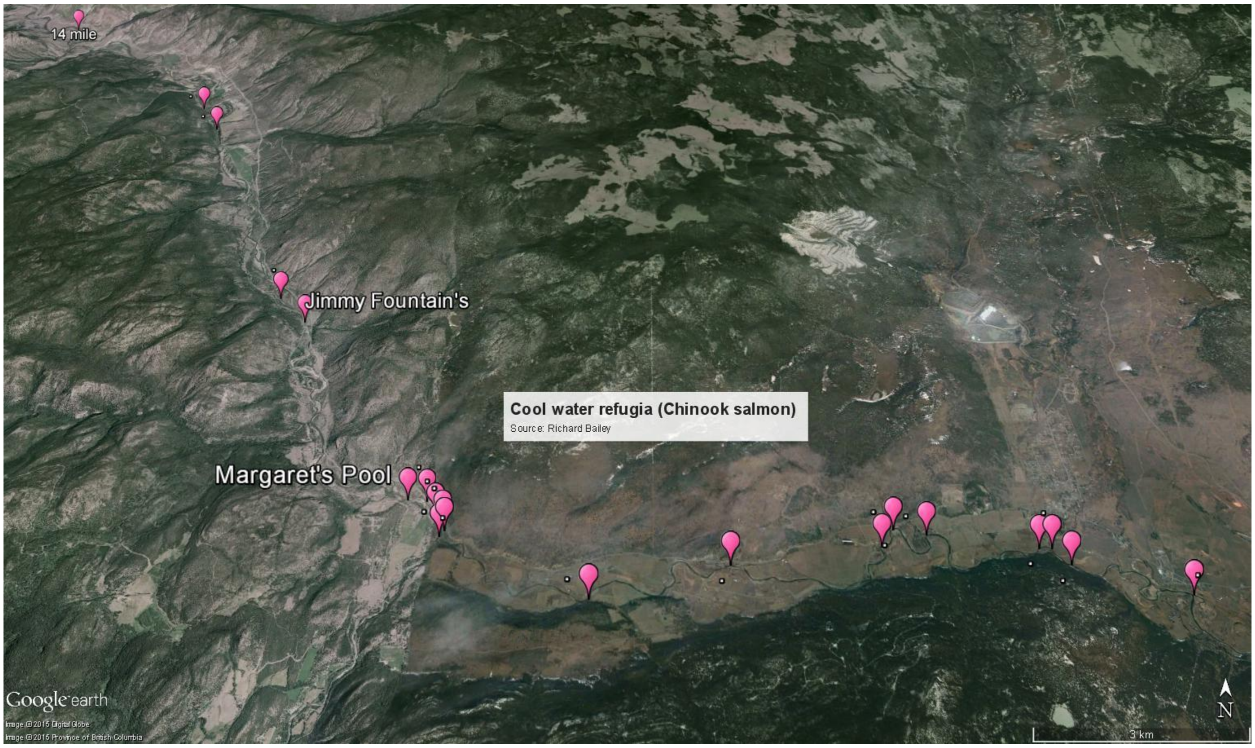


Figure 3-2. Cool water refugia locations used by chinook salmon during high water temperature periods. *Source*: Richard Bailey and Richard McCleary (pers. comm. 2015).

An important challenge for the **water temperature submodel** is to factor in the potential for localized cooling due to areas where groundwater gains are occuring.

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).

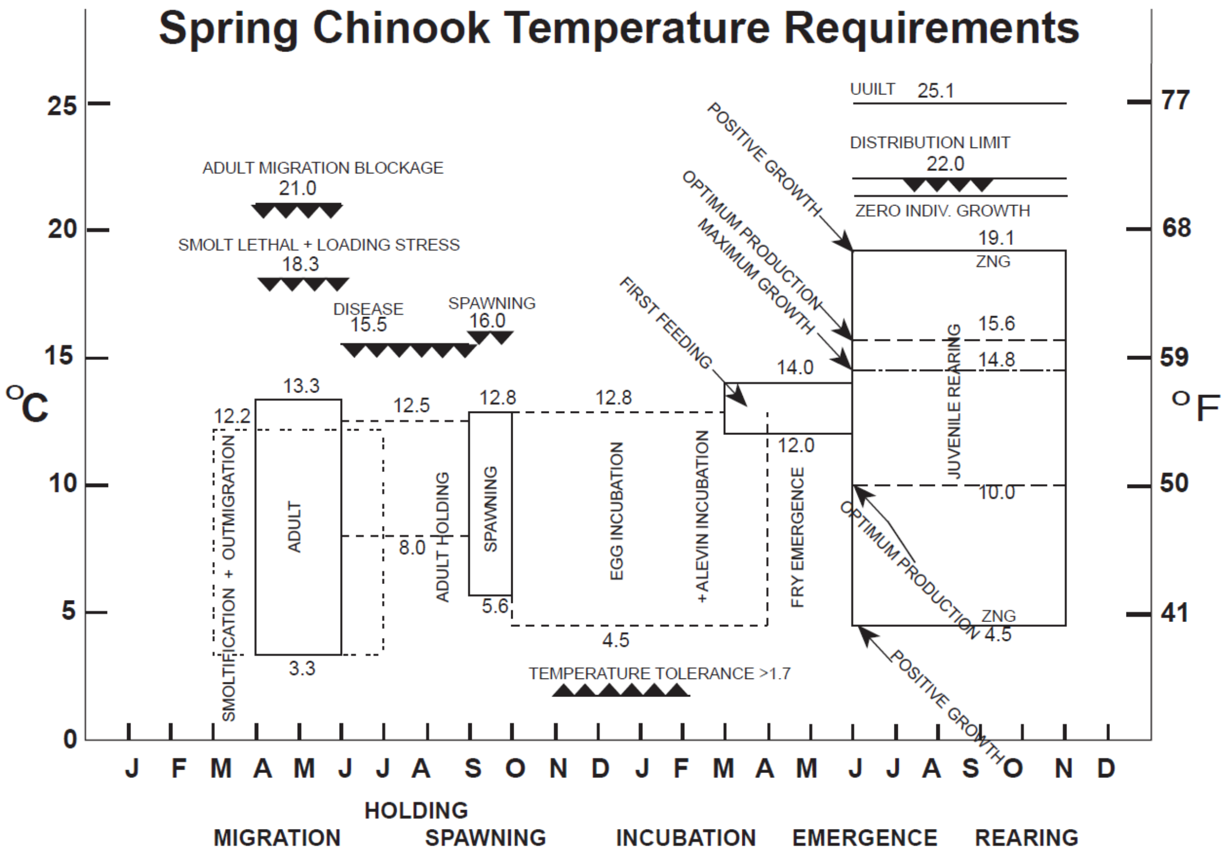


Figure 3-3. Example of temperature range tolerances, optima and limits for spring chinook salmon. *Source*: McCullough 1999.

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

Table 3-9. Maximum temperature limits for salmon proposed for the Nicola Fish/Water Management Tool.

Threshold	Limit	Range	Evidence and/or Comment
Migration limit, migration delays	**≥ 21.7°C**	**21°C to 23.9°C**	Richter and Kolmes (2005) and references therein. 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	**≥ 16°C**		Richter and Kolmes (2005) and references therein. Temperature should be below this threshold.
Juvenile Rearing and Growth	**≥ 16.5°C**	**10°C to 19°C**	Richter and Kolmes (2005) and references therein. Temperature should be below this threshold.
Extreme stress	**≥ 22.75°C**	**22°C to 24°C**	Richter and Kolmes (2005) and references therein. Nicola Lake can frequently hit temperatures in this range in August. Temperature should be below this threshold.
Lethal	**≥ 25°C**		Richter and Kolmes (2005) and references therein. Gills cannot extract oxygen (Richard Bailey, pers. comm. 2015). Temperature should be below this threshold.

As a **diagnostic measure**, workshop participants also suggested accessing local air temperature measurements, with a focus on **overnight air temperatures (D2-AirT)**. This can be an important proxy indicator of the degree of thermal stress in the river.

3.1.5 Flow and temperature related performance indicators

Fish subgroup particpants recommended a total of twelve (12) performance indicators for the four (4) priority focal species: spring chinook salmon, steelhead, kokanee and coho (Table 3-10; Table 3-11). The locations that these performance measures are relevant, and the time-periods of relevance are cross-referenced in Table 3-10 and Table 3-11. Additionally, two (2) "diagnostic" indicators were identified related to thermal stress (Table 3-11). For flow-related performance indicators (Table 3-10), 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). Likewise, for thermal stress related performance indicators (Table 3-11), the approach recommended was to define two threshold water temperatures based on established values given in Table 3-9.

Table 3-10. Flow-related performance measures identified by fish subgroup participants for the priority focal species.

Focal species or Diagnostic	Flow related performance indicator	Code	Location	Relevant time-period
Diagnostic	**None identified; see Table 3-11.**			
Spring chinook	**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
	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
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

Table 3-11. Temperature-related performance measures identified by fish subgroup participants for the priority focal species.

Focal species or Diagnostic	Temperature related performance indicator	Code	Location	Relevant time-period
Diagnostic	**Cooling flows from Coldwater River**	**D1-ColdQ**	Coldwater River	Last two weeks July
		Coldwater flow at end of July (% Mean Annual Discharge (MAD) sets relative level of concern related to water temperatures in downstream Nicola River related to migration and pre-spawn thermal stress and mortality. Specification: %15MAD (yellow); %5MAD (red).		
	Overnight air temperatures	**D2-AirT**	To do: identify appropriate climate station	To do: specify (likely Aug-Sep); evening temperatures, not day-time.
Spring chinook	**In-migration temperatures**	**CH4-MT**	Nicola River Thompson River to confluence Spius Creek (N1)	See: Table 3-1
	Spawning temperatures	**CH5-ST**	Nicola River Spius to confluence Coldwater River (N2)	See: Table 3-1
	Rearing temperatures	**CH6-RT**	Nicola River Spius to confluence Coldwater River (N2)	See: Table 3-1
Steelhead	**Parr rearing temperatures**	**ST2-RT**	Nicola River Thompson River to confluence Spius Creek (N1)	See: Table 3-2
Kokanee	**Egg freezing risk**	**K2-Ice**	Upper Nicola River above Nicola Lake to Douglas Lake (N4)	See: Table 3-4

Richard McLeary 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 on Nicola River fall below approximately 6 m^3/s.

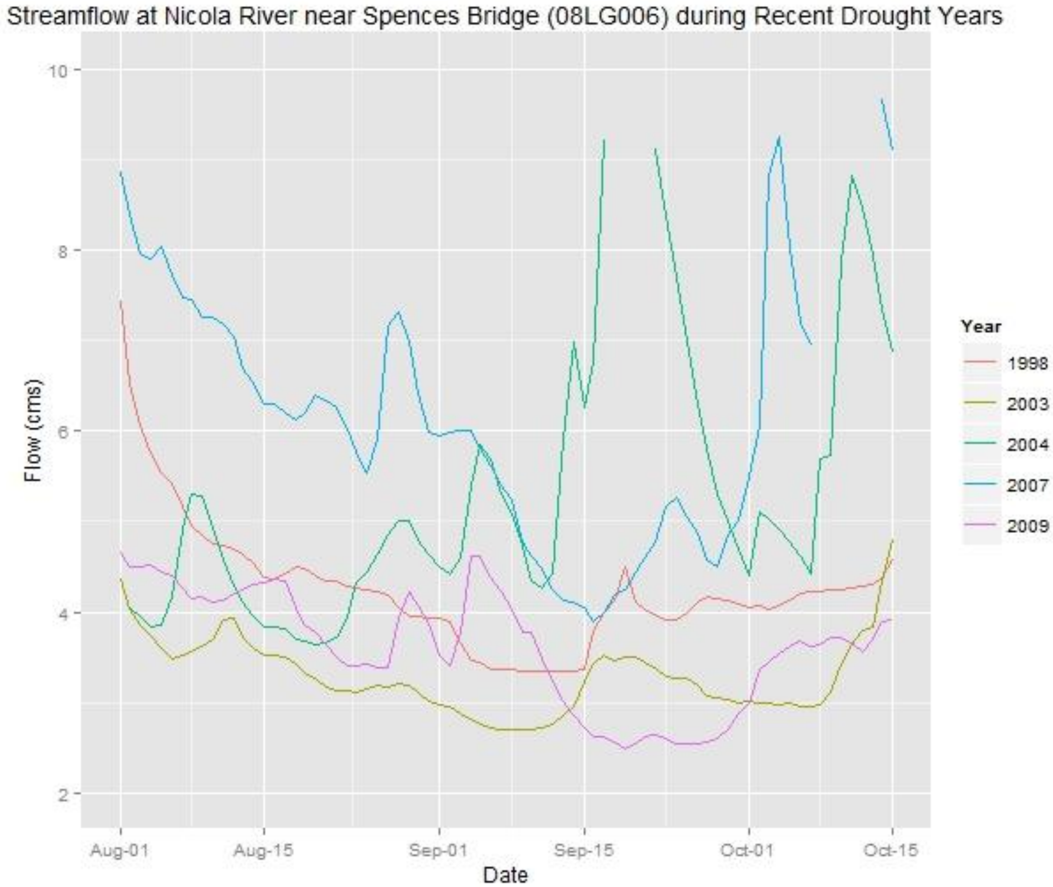


Figure 3-4. Flows during summer low flow periods in "bad years" years known to have generated significant stress and mortality on fish.

Diagnostic - Cooling flow from Coldwater River [D1-ColdQ]

Fish subgroup paticipants identified Coldwater River flow at the end of July as an important diagnostic for the magnitude of cooling flows and subsequent thermal stress risk for fish. This diagnostic indicator establishes the relative level of concern related to August-September pre-spawn thermal stress for all brands of fish downstream of Merritt (Table 3-12).

Table 3-12. Definition for cooling flow from Coldwater River [D1-ColdQ].

D1-ColdQ	Good	Fair	Poor	Key Evidence or Comments
Values:	≥?? MAD	15%MAD	≤5%MAD	Expert opinion. Review To Do.
Location:	Coldwater River			
Time period relevant:	Late July			

Diagnostic - Overnight air temperatures [D2-AirT]

In addition to late July Coldwater River flows, fish subgroup participants recommended evaluation of evening air temperatures in August as an additional diagnostic indicator of thermal stress risk for fish. This diagnostic indicator establishes the relative level of concern related to August-September pre-spawn thermal stress for all species of fish downstream of Merritt. Specific air temperature values and "hazardous" diurnal fluctuations were not discussed. To do.

Spring chinook - In-migration flows [CH1-MQ]

Draft presumptive standards for spring chinook salmon in-migration attraction flows are provided in Table 3-13.

Table 3-13. Definition for spring chinook in-migration flows [CH1-MQ], reach N1.

CH2-SQ	Good	Fair	Poor	Key Evidence or Comments
Values:	**≥8.9m³/s**	**between**	**≤5.66 m³/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)			N1 flows indicative of flows experienced at confluence with Thompson River
Time period relevant:	See "In-migration" Table 3-1			

Spring chinook - Spawning flows [CH2-SQ]

Draft presumptive standards for spring chinook salmon spawning flows are provided in Table 3-14 and Table 3-15. 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 as 4.25 m^3/s (31% Mean Annual Discharge (MAD), whereas the the relationships in Bruce and Hatfield (2003) suggest an optimal flow of 6.8 m^3/s (49% MAD); both of these values contrast with optimum flows from more recent empirical data of 11 m^3/s (80% MAD) (Lewis *et al.* 2009). Kosakoski and Hamilton (1982) recommended a minimum instream flow of 3.12 m^3/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 m^3/s for the months of October through December, which are suitable for the rearing life-history stages of chinook, steelhead and coho. An issue to review with these recommendations is the habitat suitability profile for chinook, which appears to have been based on larger bodied chinook of coastal British Columbia and Vancouver Island.

Table 3-14. Definition for spring chinook spawning flows [CH2-SQ] indicator, reach N2. Month of **August and September** only.

CH2-SQ	Good	Fair	Poor	Key Evidence or Comments
Values:	**≥8.9m³/s**	**between**	**≤5.5 m³/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 Spius to confluence Coldwater River (N2)			N2 the critical reach
Time period relevant:	**August and September only** See "Spawning" Table 3-1			Lewis *et al.* (2009). Higher min. flow recommended in months of August and September (only).

Table 3-15. Definition for spring chinook spawning flows [CH2-SQ] indicator, reach N2. **October**.

CH2-SQ	Good	Fair	Poor	Key Evidence or Comments
Values:	**≥8.9m³/s**	**between**	**≤3.12 m³/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 Spius to confluence Coldwater River (N2)			N2 the critical reach
Time period relevant:	**October+** See "Spawning" Table 3-1			

Spring chinook - 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 (for review).

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

CH7-Scour	Good	Fair	Poor	Key Evidence or Comments
Values:	**<Q m³/s**	**…**	**≥Q m³/s**	Periodically high flushing flows can improve gravel; ideally these flows would be outside egg incubation period.
Location:	Nicola River Coldwater to Nicola Lake Dam (N3)			Spawning beds downstream of dam.
Time period relevant:	See "Eggs/Incubation" Table 3-1			

Spring chinook - Rearing flows [CH3-RQ]

Draft presumptive standards for spring chinook 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.

Table 3-17. Definition for spring chinook rearing flows [CH3-RQ], reach N2.

CH3-RQ	Good	Fair	Poor	Key Evidence or Comments
Values:	**≥2.3m³/s**	**between**	**≤1.13 m³/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 Spius to confluence Coldwater River (N2)			A standard for N1, N2 and N3 can be defined if desired, or one representative reach chosen.
Time period relevant:	See "Rearing" Table 3-1			

Table 3-18. Definition for spring chinook rearing flows [CH3-RQ], reach N1.

CH3-RQ	Good	Fair	Poor	Key Evidence or Comments
Values:	**≥2.45m³/s**	**between**	**≤1.13 m³/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)			A standard for N1, N2 and N3 can be defined if desired, or one representative reach chosen.
Time period relevant:	See "Rearing" Table 3-1			

Spring chinook - In-migration temperatures [CH4-MT]

Based on workshop discussions and review of the literature, we recommend the maximum temperature limits in Table 3-9 for salmon using the mainstem Nicola River. In general, the "limit" values identified in Table 3-9 can be considered the de facto threshold for "poor" performance. Values of water temperatures that represent the threshold between "good" and "fair" conditions require additional input from salmon biologists (to do). Hence, for all temperature related thresholds in NWMT, workshop participants need to review the "limit" values identified in Table 3-9 and recommend appropriate cut-off thresholds. This will lead to a specification resembling Table 3-19.

Table 3-19. Definition for chinook in-migration temperature thresholds, reach N1 [CH4-MT].

CH4-MT	Good	Fair	Poor	Key Evidence or Comments
Values:	<?? T °C	...	≥21.7°C	Based on workshop discussions and review of the literature, we recommend the maximum temperature limits in Table 3-9 for salmon using the mainstem Nicola River. Richter and Kolmes (2005); and references therein. 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.
Location:	Nicola River Thompson River to confluence Spius Creek (N1)			
Time period relevant:	See "In-migration" Table 3-1			

Spring chinook - Spawning temperatures [CH5-ST]

Based on workshop discussions and review of the literature, we recommend the maximum temperature limits in Table 3-9 for salmon using the mainstem Nicola River. In general, the "limit" values identified in Table 3-9 can be considered the de facto threshold for "poor" performance. Values of water temperatures that represent the threshold between "good" and "fair" conditions require additional input from salmon biologists (to do). Hence, for all temperature related thresholds in NWMT, workshop participants need to review the "limit" values identified in Table 3-9 and recommend appropriate cut-off thresholds. This will lead to a specification resembling Table 3-19 (recognizing the appropriate life-history stage, and time period).

Spring chinook - Rearing temperatures [CH6-RT]

Based on workshop discussions and review of the literature, we recommend the maximum temperature limits in Table 3-9 for salmon using the mainstem Nicola River. In general, the "limit" values identified in Table 3-9 can be considered the de facto threshold for "poor" performance. Values of water temperatures that represent the threshold between "good" and "fair" conditions require additional input from salmon biologists (to do). Hence, for all temperature related thresholds in NWMT, workshop participants need to review the "limit" values identified in Table 3-9 and recommend appropriate cut-off thresholds. This will lead to a specification resembling Table 3-19 (recognizing the appropriate life-history stage, and time period).

Steelhead - Parr rearing flows [ST1-RQ]

Draft presumptive standards for steelhead par rearing flows are provided in Table 3-20.

Table 3-20. Definition for steelhead rearing flows [ST1-RQ], reach N1.

ST1-RQ	Good	Fair	Poor	Key Evidence or Comments
Values:	**≥8.2 m³/s**	**between**	**≤5.66 m³/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 3-2			

Steelhead - Parr rearing temperatures [ST2-RT]

Based on workshop discussions and review of the literature, we recommend the maximum temperature limits in Table 3-9 for salmon using the mainstem Nicola River. In general, the "limit" values identified in Table 3-9 can be considered the de facto threshold for "poor" performance. Values of water temperatures that represent the threshold between "good" and "fair" conditions require additional input from salmon biologists (to do). Hence, for all temperature related thresholds in NWMT, workshop participants need to review the "limit" values identified in Table 3-9 and recommend appropriate cut-off thresholds. This will lead to a specification resembling Table 3-19 (recognizing the appropriate life-history stage, and time period).

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

Draft presumptive standards for coho off-channel habitat connectivity flows are provided in Table 3-21. Fish subgroup participants commented that if off-channels are groundwater fed, coho will want to access them. The remaining homework is to map out side-channel areas, and the associated elevation versus surface flows required to connect them with the manistem (to do).

Table 3-21. Definition for coho habitat connectivity flows [CO1-CQ], reach N1.

CO1-CQ	Good	Fair	Poor	Key Evidence or Comments
Values:	**≥xxx m³/s**	**between**	**≤xxx m³/s**	Fish subgroup participants commented that if off-channels are groundwater fed, coho will want to access them. The remaining homework is to map out side-channel areas, and the associated elevation vs. surface flows required to connect them with the manistem.
Location:	Nicola River Thompson River to confluence Spius Creek (N1)			
Time period relevant:	See "Rearing" Table 3-3			

Kokanee - Spawning passage flows [K1-SQ]

Draft presumptive standards for kokanee spawning passage flows are provided in Table 3-22. 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. Flows were reportedly very low (below 50 L/s). When irrigation was shut off, kokanee suddenly came in to spawn.

Table 3-22. Definition for kokanee spawning passage flows [K1-SQ], reach N4.

K1-SQ	Good	Fair	Poor	Key Evidence or Comments
Values	**≥xxx m³/s**	**??**	**15%MAD ≤xxx m³/s**	Participants recommended reviewing flows in 2009 (poor year), 2010 (poor year) and 2007 (good year). To do.
Location:	Upper Nicola River above Nicola Lake to Douglas Lake to Chapperon Lake (N4)			
Time period relevant:	See "spawning" Table 3-4			

Kokanee - Egg freezing risk [K2-Ice]

Draft presumptive standards for kokanee egg freezing risk are provided in Table 3-23. Fish subgroup participants identified the risk to incubating kokanee eggs of freezing in the upper Nicola River associated with cold air temperatures, low flows, and limited groundwater pressure. Participants commented that as long as there was positive groundwater pressure, incubating eggs would not freeze. Participants recommended reivewing flows and air temperatures when gauge 08LG046 had ice anomalies. This would be an indication of risk to incubating kokanee eggs of freezing mortality. This is also an example of where actions to reduce the risk would be associated with non-Nicola Lake Dam actions, namely, increasing releases from Chapperon Lake.

Table 3-23. Definition for kokanee egg freezing risk [K2-Ice], reach N4.

K2-Ice	Good	Fair	Poor	Key Evidence or Comments
Air temperature	???	<-15C ?? x days out of y	<-20C for x days out of y	Identify an appropriate real-time climate station
Values flow:	≥xxx m³/s	between	≤xxx m³/s	Participants recommended reivewing flows and air temperatures when gauge 08LG046 had ice anomalies. This would be an indication of risk to incubating kokanee eggs of freezing mortality. To do.
Location:	Upper Nicola River above Nicola Lake to Douglas Lake to Chapperon Lake (N4)			
Time period relevant:	See "incubation" Table 3-4			

Kokanee - Nicola Lake elevation [K3-LE]

Draft presumptive standards for Nicola Lake target elevations during kokanee spawning are provided in Table 3-24. Below a certain lake elevation, kokanee spawners will have difficulty accessing the Upper Nicola River above Nicola Lake (N4). However, specific lake elevations were not identified at the workshop (to do). Hence, 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 3-24. Definition of target elevation for kokanee, Nicola Lake [K3-LE].

K3-LE	Good	Fair	Poor	Key Evidence or Comments
Values	≥xxx m		≤xx m	Participants recommended reviewing flows in 2009 (poor year), 2010 (poor year) and 2007 (good year). To do.
Location:	Nicola Lake			
Time period relevant:	See "spawning" Table 3-4			

3.1.6 Draft outputs & user interface mock-up

We envision that results of calculations for the four focal species and various performance indicators could be displayed in a manner resembling Figure 3-5. As with all mockups in this conceptual design document, these are merely for illustration purposes, and are not intended to be viewed as the final design. At this stage, they are intended to inspire comments and feedback. The precise implementation of this information in the "as-built" NWMT will vary from this early draft mockup.

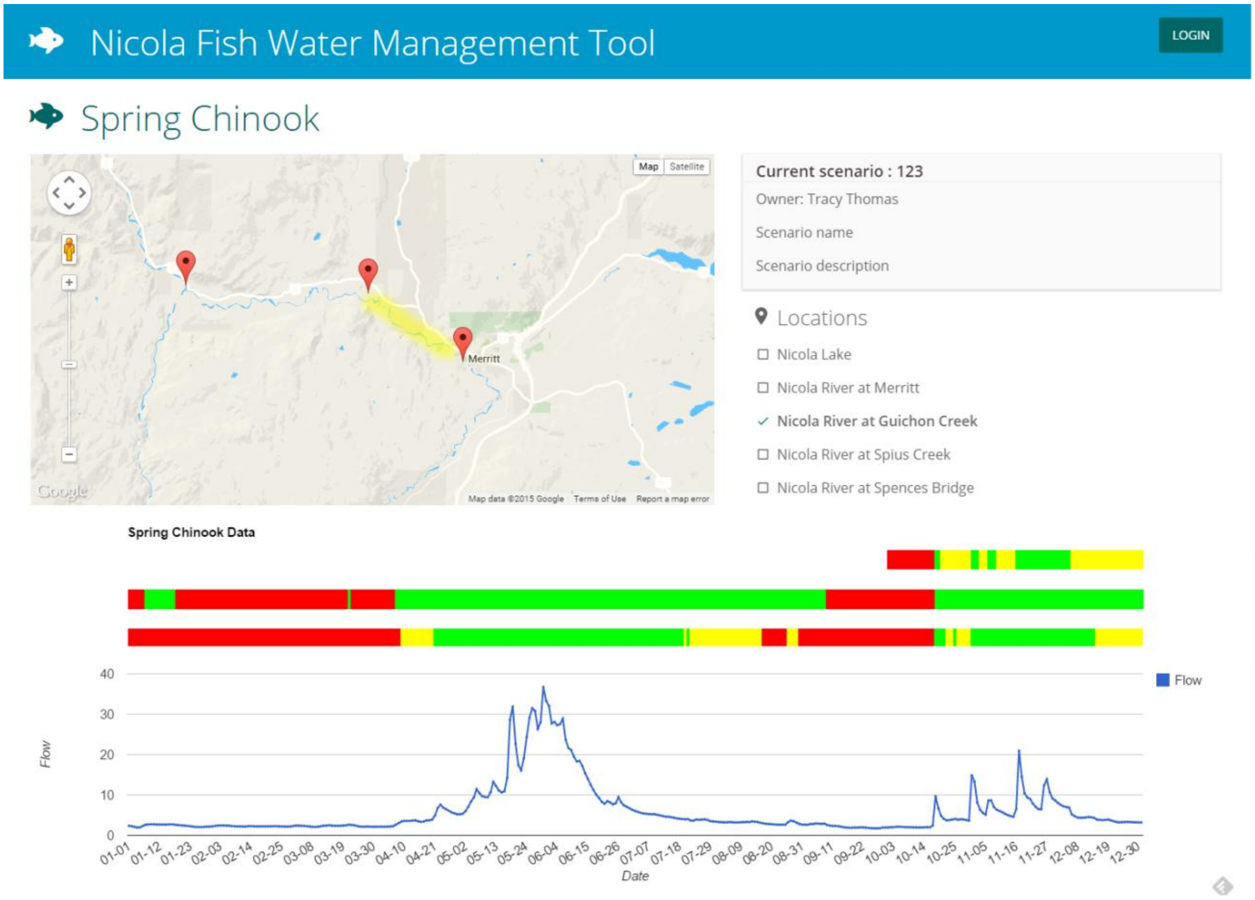


Figure 3-5. Hypothetical mockup of results displayed by the NWMT for spring chinook salmon. Depending on the performance indicators selected (not indicated in this rough example), the relative suitability and hazard risk of flows and water temperatures would be shown vs. realized and forecast flows and water temperatures. These indicators would be displayed alongside the relevant time series data for the relevant locations. The output screen will also display a map, showing the index location associated with the species and selected performance indicators.

3.1.7 Data needs, questions, caveats & next steps

There are a variety of details in the information listed in this submodel description that require review. This includes obtaining consensus (from fisheries biologists) on the appropriate flow and water temperature thresholds for the twelve performance indicators. We also need to review the mapping of the most suitable climate and hydrometric stations to the locations of interest for these species and life-history performance indicators. These needs are identified with "to do" and other yellow higlight text above.

Other data needs include completing mapping of important groundwater exchange locations (thermal refugia). In particular, an important challenge for the water temperature submodel is to factor in the potential for localized cooling due to areas where groundwater gains are occuring. To aid in this task, it was suggested that we ask Scott Decker and John Hagen (spelling unsure) to map groundwater exchange locations identified during their night time snorkel observations. However, it is likely that the level of spatial and process resolution that is possible with respect to water temperature modelling will require simplifying assumptions in the first version of NWMT.

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 about 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).

3.2.1 Nicola Lake water supply

Jep Ball provided a very informative presentation on Nicola Lake Dam operations ("Nicola Feb 2015 Jep Ball v5 (final).pptx"). 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. Top of fishway
4. Crest of spillway

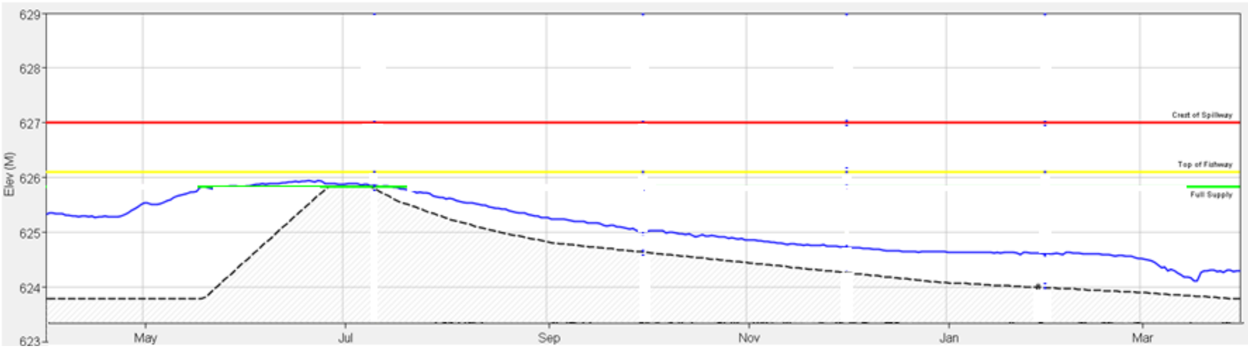


Figure 3-6. Key Nicola Lake water surface elevations by time of year.

The lower dotted black line in Figure 3-6 refers to the minimum target lake elevation 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 FSL is the target to **supply water** for all existing water licence holders. 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 peformance indicator; however, we recommend not defining a range that overlaps with surface elevations that are to be avoided for flood management purposes).

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 appropraite "**yellow**" **flood warning level** for Nicola Lake (Jep Ball, pers. comm 2015). Jep Ball noted that at this level, issues around the lake are mostly landscaping problems, i.e., gardens, etc. rather than wet basements.

A truly hazardous and "**red**" (poor) performance level occurs at the crest of the spillway. At this elevation, the overflow spillway begins to have flow through the riprap cap, and all Nicola Lake Dam gates should be fully open (although they don't have to be). **This is the "red alert" level**. When the gates are fully open at this lake elevation, discharge approximates 100 m^3/s . At this level of flow, the **City of Merritt will definitely experience flood related damage** (Jep Ball, pers. comm. 2015).

Additional downstream locations and flood related risks should be reviewed.

3.2.3 Nicola Lake ice management

Nicola Lake ice blockage & zero flows [NLI1-Dessication Q]

During long cold snaps between December and February (e.g., 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.

Implementation of this indicator therefore requires climate station monitoring for cold weather (air temperatures) and tracking of Nicola Lake elevations.

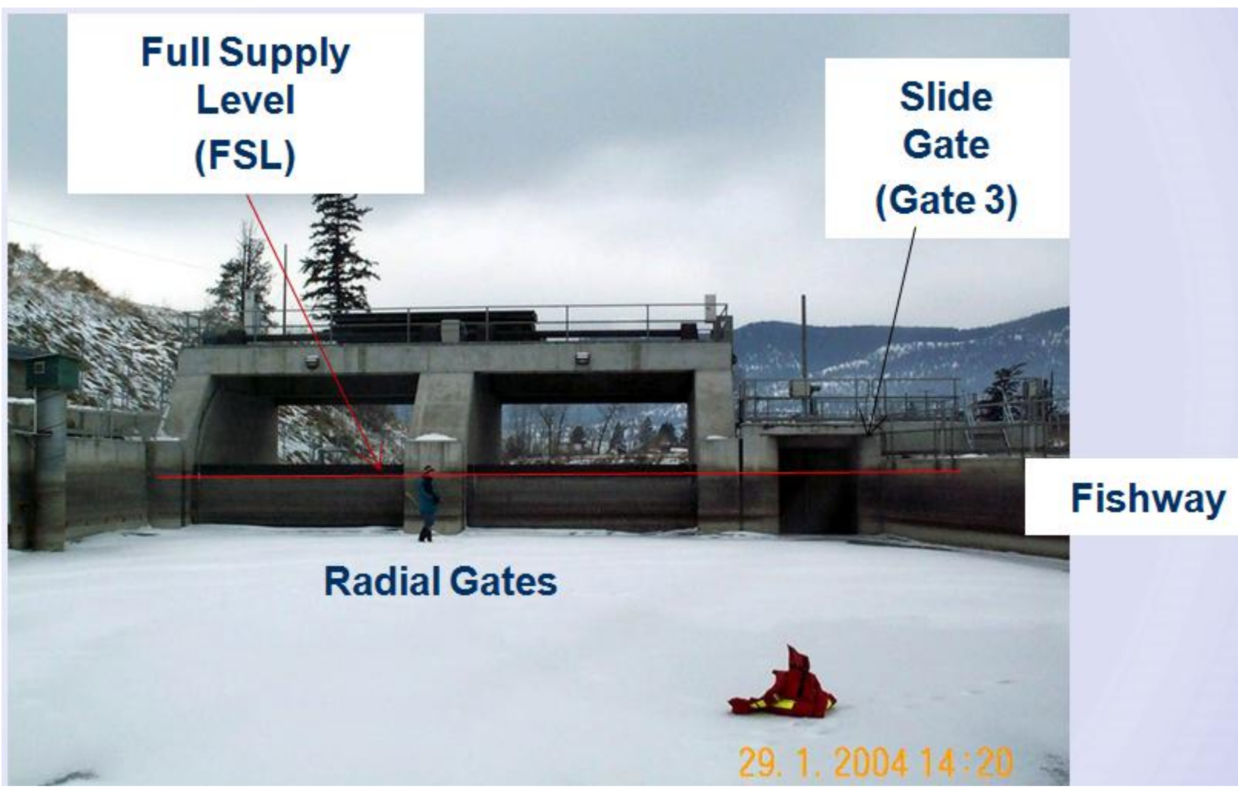


Figure 3-7. Example of icing condition, Nicola River immediately below Dam (January 1 2004).

Nicola Lake ice & dock damage [NLI2-Dock Damage]

During long cold snaps between December and February (e.g., more than one week at -20°C or colder), ice can damage boat docks if Nicola Lake elevation is too high when freeze-up occurs (Jep Ball, pers. comm. 2015) (Figure 3-8). The elevation at which this is a concern requires definition.

Implementation of this indicator also requires climate station monitoring for cold weather (air temperatures) and tracking of Nicola Lake elevations.

Figure 3-8. Example of icing condition, Nicola Lake (January 1 2004).

3.2.4 Nicola River flood flows (city of Merritt)

Nicola River flood protection [NRF1-Merritt flooding]

Draft flood flow standards for the City of Merritt are provided in Table 3-25. 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).

Table 3-25. Definition for Nicola River flood flows, City of Merritt.

Merritt flood flows	Good	Fair	Poor	Key Evidence or Comments
Values:	**<24 m³/s**	**between**	**≥35 m³/s**	Experience indicates that 25 m³/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 m³/s, sandbagging and other emergency protection is required. 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).			

3.2.5 Draft outputs & user interface mock-up

Mockups for this submodel were not generated. However, they will be analagous to Table 3-5, but focused on these socio-economic indicators:

- Water supply availability [WS1-Availability]
- Nicola Lake flood protection [NLF1-Shoreline flooding]
- Nicola Lake ice blockage & zero flows [NLI1-Dessication Q]
- Nicola Lake ice & dock damage [NLI2-Dock Damage]
- Nicola River flood protection [NRF1-Merritt flooding]

3.2.6 Data needs, questions, caveats & next steps

The threshold details for the five (5) performance indicators associated with this submodel require review. This includes obtaining consensus (from Nicola Dam operators and other stakeholers) on the appropriate flow and water temperature thresholds for the performance indicators. Some of these needs are identified with "to do" and other yellow higlight text above.

3.3 Hydrology & Water Balance Submodel

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

Every year, the Government of British Columbia's River Forecast Centre (RFC) independently forecast inflows 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)).

In this report, we describe a draft approach to:

- estimate seasonal inflow for the Nicola Watershed;
- disaggregate the total seasonal inflow forecasts provided by the RFC into weekly estimates;
- predict future weekly changes in the elevation of Nicola Lake, based on the forecasts of weekly lake inflow and a series of weekly 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.

These methods form the backbone of the Hydrology & Water Balance Submodel in the NWMT. Weekly values in each case are calculated in terms of an expected value, a high estimate corresponding to the mean +1 SE and a low estimate corresponding to the mean -1 SE.

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 (Figure 3-9). 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 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:

- Nicola Lake

- ☐ Upper Nicola River (incld. 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

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

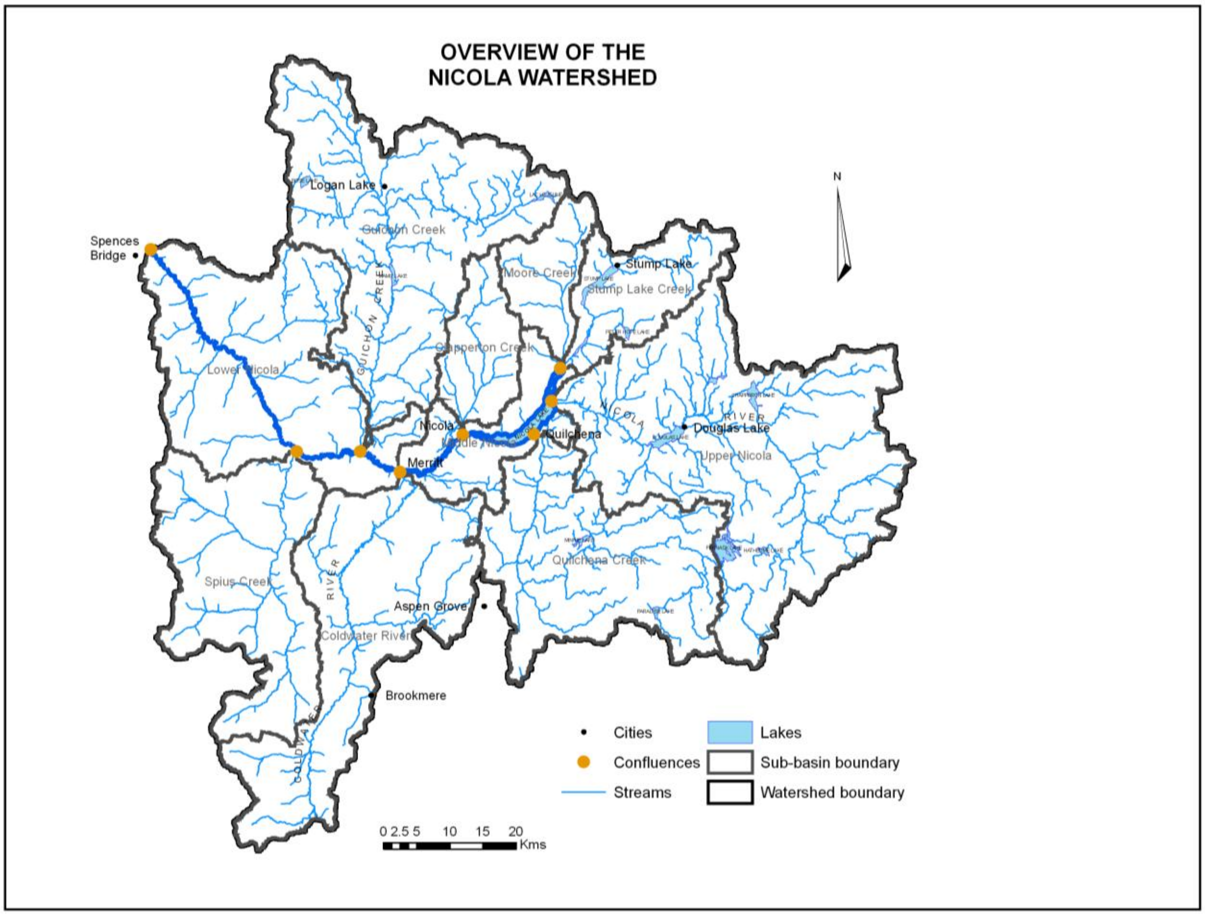


Figure 3-9. Overview of Nicola Watershed.

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 3-26, Figure 3-10) 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 3-26. 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
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

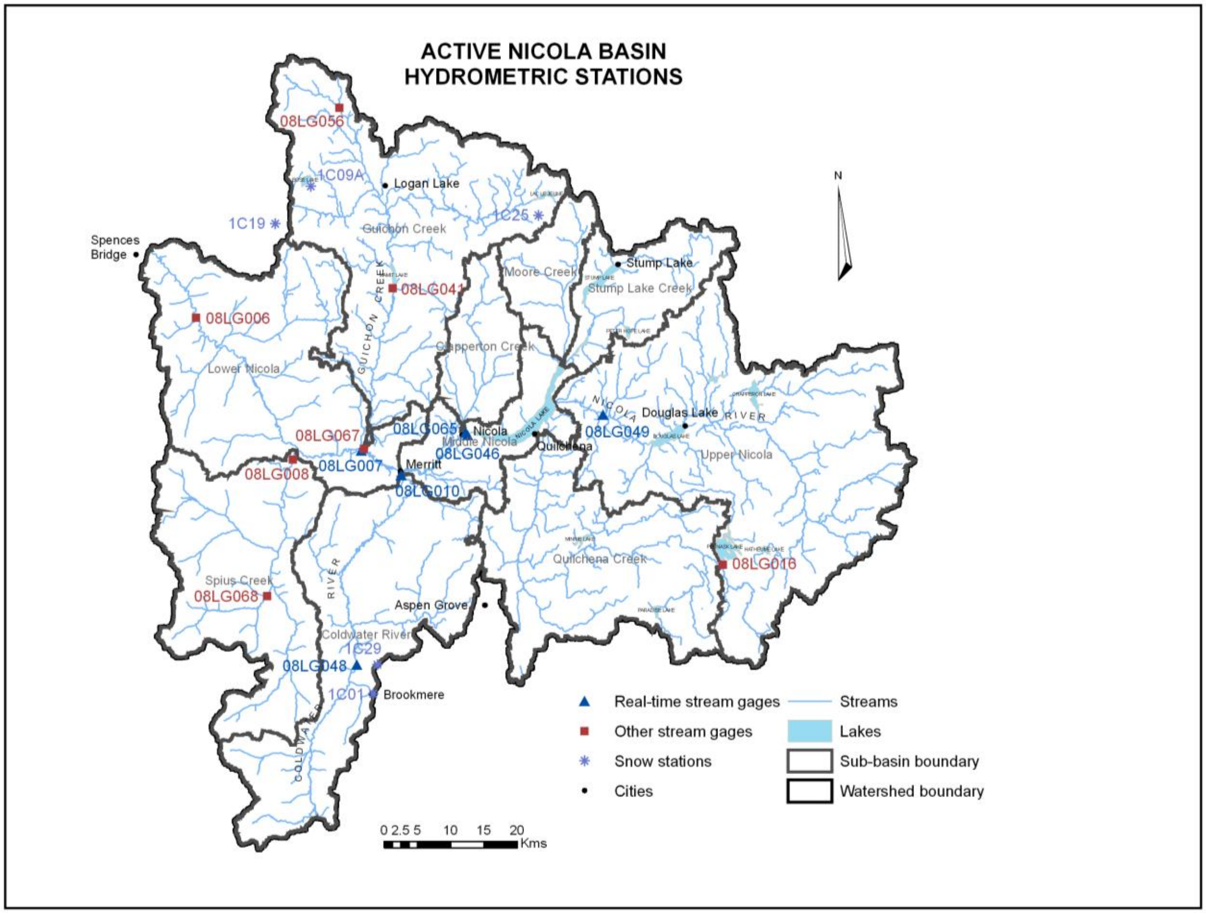


Figure 3-10. Map of Nicola basin hydrometric stations.

3.3.3 Inflow forecasting methods

A conceptual design workshop was convened on February 17th and 18th 2015 in Kamloops to consult with technical experts on NWMT submodel components and decide on priorities for the tool. During breakout sessions in the afternoon, the Hydrology & Water Temperature Subgroup discussed Inflow forecasting methods. Specifically, two models were discussed: The seasonal forecast model and the Channel Links Evolution Explicit Routing (CLEVER) model, both maintained by the RFC. Both of these models are described briefly below, followed by a model recommendation by the subgroup.

The 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 (Figure 3-11). The forecast is updated monthly from February to May and spans the time from the date produced (e.g., March 1st) to both June and July (e.g., for the March 1st forecast, the duration is from March 1st to June 1st and March 1st to July 1st). 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. The timeline for this enhancement would most likely be fall/winter of 2015.

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 (kdam³)	Normal (1981-2010) (kdam³)	% of Normal	Std. Error (kdam³)	Forecast (kdam³)	Normal (1981-2010) (kdam³)	% of Normal	Std. Error (kdam³)	Forecast (kdam³)	Normal (1981-2010) (kdam³)	% of Normal	Std. Error (kdam³)
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 kdam³=1,000,000 m³
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 3-11. 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.

The CLEVER model is a process-based basin runoff model. Currently there are 32 basins delineated in the model (with the Nicola system a sub-basin within the model). Because the model scope is regional, it takes significant staff time to produce forecasts. The model divides each major basin into several sub-basins, which are routed in lump-sum by using the unit hydrograph method. The sub-basins are connected with channel links which are distributed by using the Kinetic Wave model equations and the numerical scheme is semi-explicit. Snowmelt is simulated by the temperature index method. The model has an hourly resolution and explicit channel routing. Inputs to the model include antecedent streamflow and groundwater conditions, historical and forecast precipitation, temperature and snowpack conditions. The model is intended for streamflow predictions, particularly during the spring flood season and for large precipitation events that affect large areas of the province. The CLEVER model is still under development and testing.

The Hydrology & Water Temperature Subgroup recommended the use of the seasonal forecast model because the current spatial coverage for the CLEVER model does not include inflows to Nicola Lake, which is essential for the Nicola Water Management Tool. It is important to note that the seasonal forecast model needs to be enhanced to run the entire water year to make the NWMT operational. Furthermore, additional locations are highly desirable. These enhancements are likely to be implemented in fall/winter of 2015.

3.3.4 Disaggregating net inflows to weekly flow

The NWMT is designed to work with weekly discharges; however, the inflow forecasts period for the seasonal forecast model ranges from six month in February to three month in May. This period will be disaggregated to weekly flows based on the historical flow pattern.

First, the timing of the flows for each year is determined by calculating the percentage of total flows by week by dividing the total weekly volume by the total volume for the time period, e.g., February 1st to July 30th (Figure 3-12).

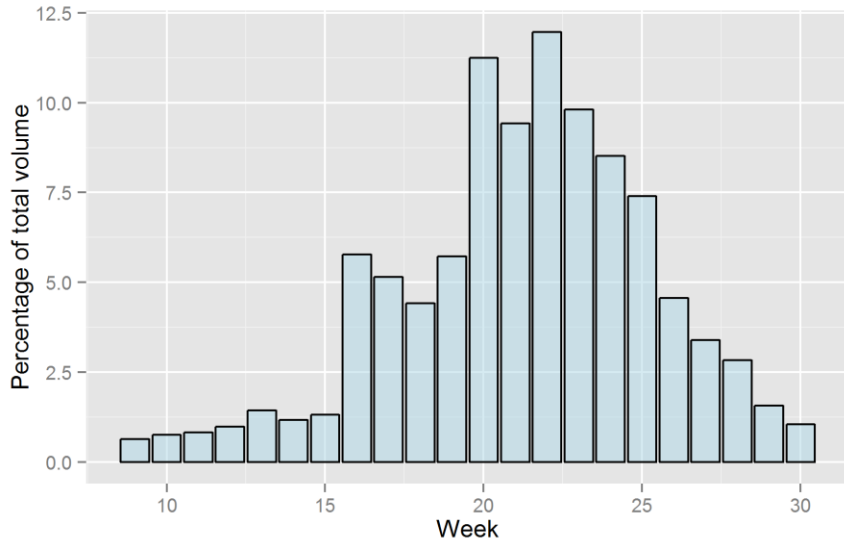


Figure 3-12. Example of weekly disaggregation of flows for a single year. The percentage of total flows by week is calculated by dividing the total weekly volume by the total volume for the time period.

This procedure is then repeated for all available years to develop a unique pattern for each year (Figure 3-13), at which point overall patterns begin to emerge across years. A “typical” annual pattern can now be developed by averaging the weekly percentage of total volume across year, making sure to normalize to 100%.

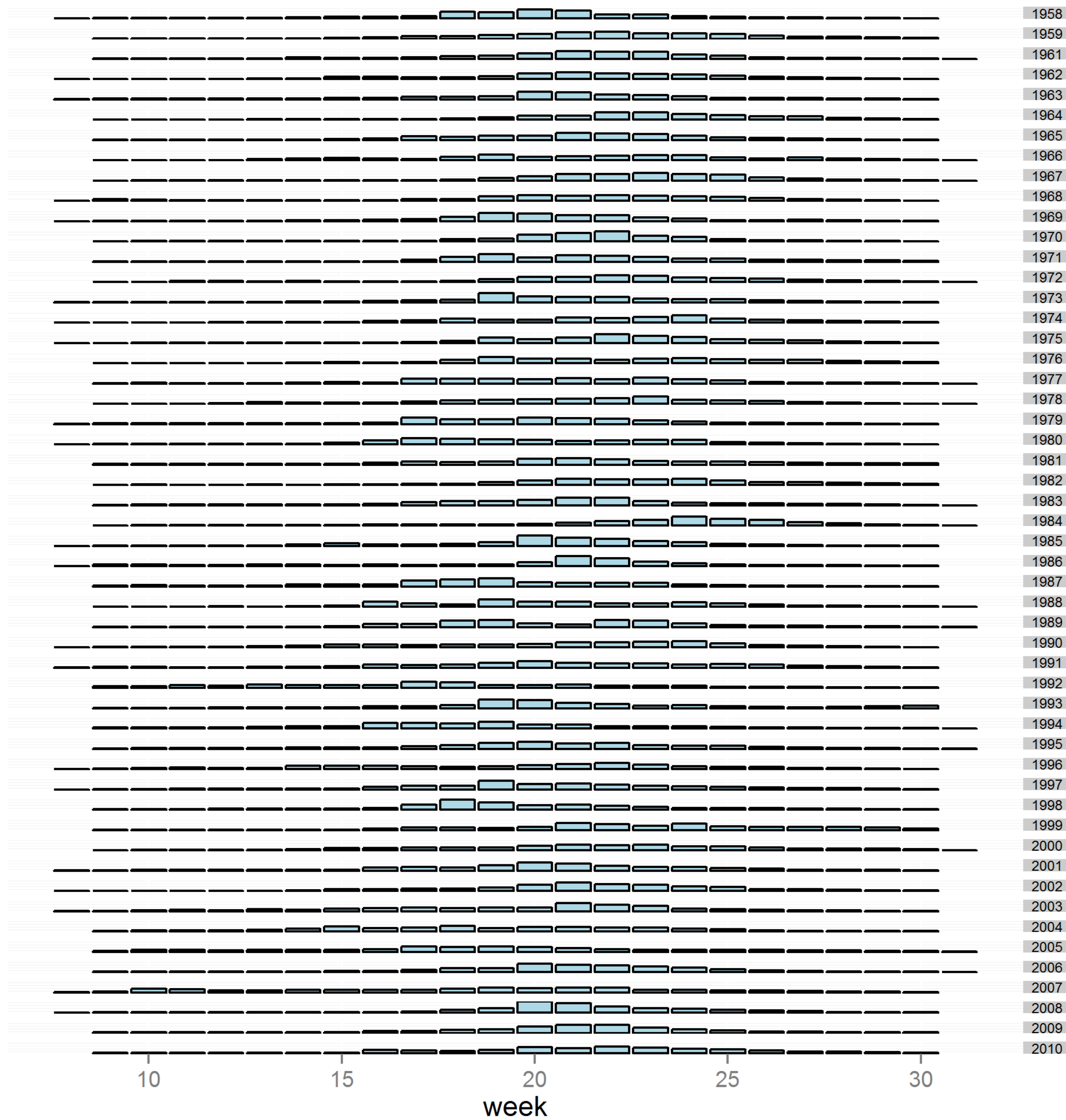


Figure 3-13. Example of weekly disaggregation of flows across years. When looking across all available years, a "typical" annual pattern begins to emerge with higher inflow volumes from week 17 to 25.

Since the timing of flows is known to change with water year type (e.g., peak flows tend to occur earlier in drier years), the weekly proportion will be derived for different water year types. Statistically, "low" inflow years are defined as those years when total seasonal inflow is less than the long-term average inflow - 1 SE. "High" inflow years are those years which have total seasonal inflows greater than the long-term average inflow + 1 SE and "Average" inflow years are those years that have total seasonal inflows between (and including) the long-term average ± 1 SE. Finally, the analysis is repeated for each type period produced by the seasonal inflow forecast model.

3.3.5 Water balance equations

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 is assumed 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. 1).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.

$$Q_{Upper\ Nicola\ River} = I_{Nicola\ Lake} * \alpha_{Upper\ Nicola\ River} \qquad \text{(Eq. 1)}$$

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).

The water volume in Nicola Lake is calculated using (Eq. 2). The volume is then converted to a water level elevation using the relationship in Figure 3-14.

$$V_{Nicola\ Lake,t=i+1} = V_{Nicola\ Lake,t=i} + I_{Nicola\ Lake} - Q_{Nicola\ Lake} \qquad \text{(Eq. 2)}$$

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.

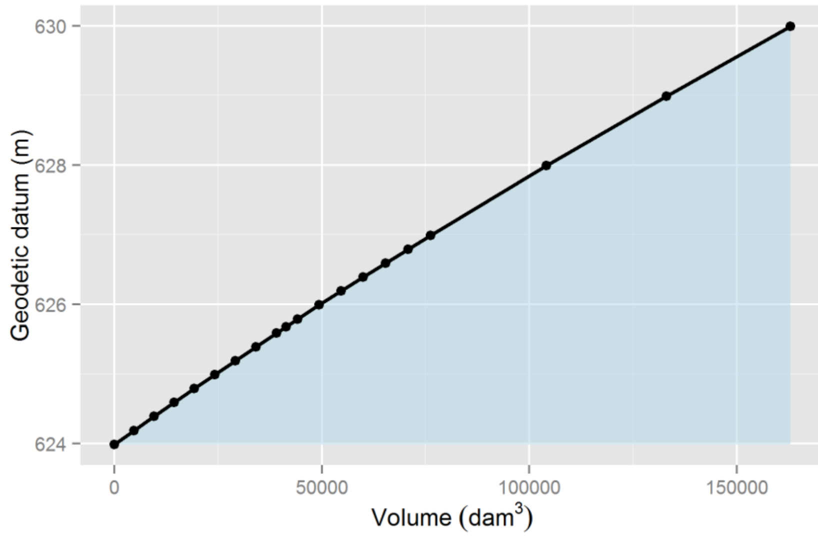


Figure 3-14. Storage-capacity curve for Nicola Lake. This relationship is used to convert the weekly forecasted volume to an elevation for Nicola Lake.

The downstream flows are calculated using (Eq. 3) to (Eq. 6). For each location represented by a confluence of the mainstem and a tributary, a simple water balance is assumed. 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 Chapter 3.4.

$$Q_{Merritt} = Q_{Nicola\,Lake} + I_{Coldwater} - E_{Merritt} \quad \text{(Eq. 3)}$$

$$Q_{Guichon} = Q_{Merritt} + I_{Guichon} - E_{Guichon} \quad \text{(Eq. 4)}$$

$$Q_{Spius} = Q_{Guichon} + I_{Spius} - E_{Spius} \quad \text{(Eq. 5)}$$

$$Q_{Spences\,Bridge} = Q_{Spius} - E_{Spences\,Bridge} \quad \text{(Eq. 6)}$$

Where $Q_{Location\,of\,interest}$ is weekly flow at a location of interest,
$I_{Tributaru}$ 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 Downstream water balance: representation of groundwater influence on mainstem channel

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 3-15).

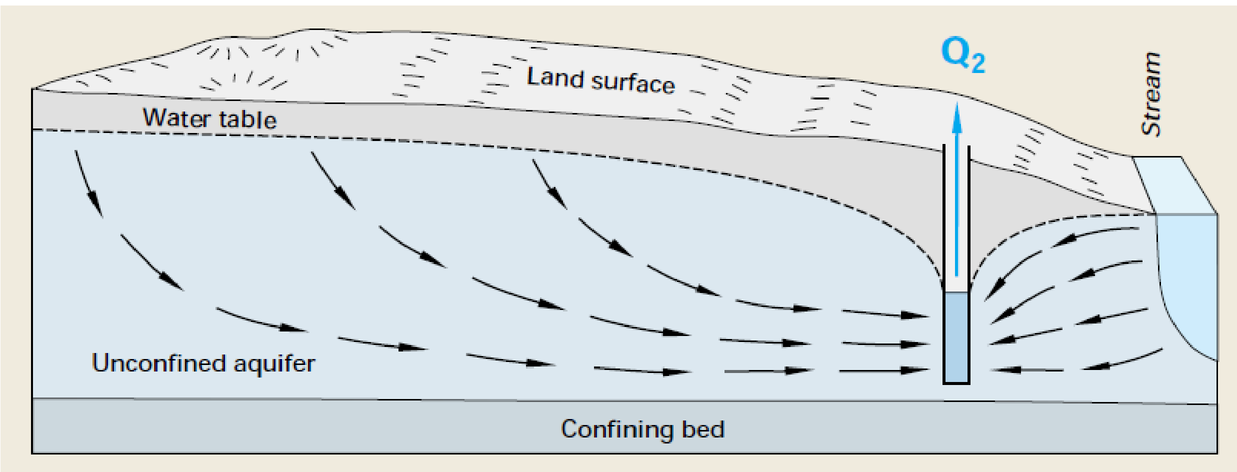


Figure 3-15. Groundwater wells cone of depression. If a well is pumped at a high enough rate or is close enough to a stream it can intercept additional water that would have discharged to the stream in the vicinity of the well and can draw water from the stream to the well. The cone of depression is a depression of water levels in an unconfined aquifer or a reduction in pressure head in confined aquifers. *Source*: Winter *et al.* 1998.

Workshop participants agreed that groundwater is extremely important in the Nicola watershed, but not necessarily well understood. 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.

3.3.7 Application of real-time data to inflow forecasts

Real-time data will be used to adjust the forecasted flows using a “self-correcting” inflow algorithm based on deviations of the weekly observed flows from the predicted inflows. Forecast periods affected are: Mar1-Jul31, Apr1-Jul31 and May1-Jul31. The approach does not apply in February, which is deemed too early for any consistent high/low trends in inflows. The correction is implemented by adding the fraction of the total computed difference (∆I) to the last three weeks in the four week forecast period. This limits the adjustment to the short term, weighting the immediate next week highest, the second week lower and the final week in the forecast period lowest.

Currently, a correction factor can only be calculated for inflows to Nicola Lake because required real-time data is not available elsewhere, but the algorithm can be applied to the major tributaries when real-time data becomes available. Initially, the self-correction factor calculated for Nicola Lake will be applied to all forecasts until more data is available, assuming that the deviation is due to an over- or underestimation of net inflow applicable to the entire region.

The difference between the forecasted inflow and the observed inflow is calculated using (Eq. 7). For example, if the observed inflow was 80% of the predicted inflows, ∆I would be -0.2, or 20% lower.

$$\Delta I = \frac{I_{obs}}{I_{forecast}} - 1 \qquad \text{(Eq. 7)}$$

Where I_{obs} is the observed inflow,

$I_{forecast}$ is the forecasted flow, and

∆I is the deviation from predicted flow.

The forecasted inflow for the next week is then adjusted based on the deviation from the previous week, using a coefficient specific to the week (Eq. 8).

$$I_{adj,week=i} = (1 + \alpha_i * \Delta I) * I_{week=i} \qquad \text{(Eq. 8)}$$

Where ∆I is the deviation from predicted flow,

$I_{adj,week=i}$ is adjusted inflow prediction for week i,

$I_{week=i}$ is adjusted inflow prediction for week I, and

α_i is a week specific adjustment coefficient.

For example, if the deviation (∆I) in week 1 was -0.2, a week specific coefficient (α_i) of 0.3575 would yield a downwards adjusted inflow prediction for week 2 of 93% of forecasted inflows. The week specific coefficient (α_i) accounts for a potential issue with this type of automated correction or adjustment in the forecast net inflows where “by the time you see it, it may be over.” In other words, at weekly increments, large differences between actual and forecast inflows will not continue indefinitely. Typically, large ∆I deviations will reflect rapid snow melt during a temporary warming or a rain on snow event. Our approach assumes inflow forecast errors owing to these kinds of processes will have a finite life-span. Therefore, based on experience in the Okanagan, only 55% of the total ΔI deviation will be applied to the future periods. This is tantamount to assuming that by the time our ΔI deviation is observed, 45% of it has already exercised itself and that the remaining 55% of this expected trend will fall out in the next three weeks. The coefficients used are:

- Week 2: 0.3575
- Week 3: 0.15125
- Week 4: 0.04125

The model design still allows any systematic changes in snow accumulations or precipitation to be naturally captured through standard revisions to the RFC estimates themselves. The design used ensures that only the raw RFC estimate is used during the first week of any new inflow forecast period (i.e., on Mar1, Apr1 and May1; during the first week, the self-adjusting algorithm has no effect). Thus, this adjustment procedure only applies after the first full week (Mar7, Apr7, May7), up to the next forecast period, when the process is re-set, and the calculations re-done for the new forecast period. This keeps the internal workings consistent in terms of the model's reliance on RFC estimates, forecast periods, and associated disaggregations.

A similar self-correction algorithm will be calculated for Upper Nicola River based on (Eq. 1) and real-time data from the Nicola River above Nicola Lake gauge.

3.3.8 Draft outputs & user interface mock-up

The Hydrology & Water Balance submodel forecasts water level in Nicola Lake and discharges in the Nicola River based on forecasted inflows to Nicola Lake, a schedule of releases from Nicola Lake Dam and assumed extractions. Changing the releases allows the user to game with trade-offs between different objectives and performance 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 for the current scenario are specified on the input screen (Figure 3-16). The input is specified on a weekly basis in a table and displayed in two charts. Changes to the input are simultaneously updated on the charts so users can compare initial and changed values. The input screen also displays a map, a description of the current scenario and the locations of interest.

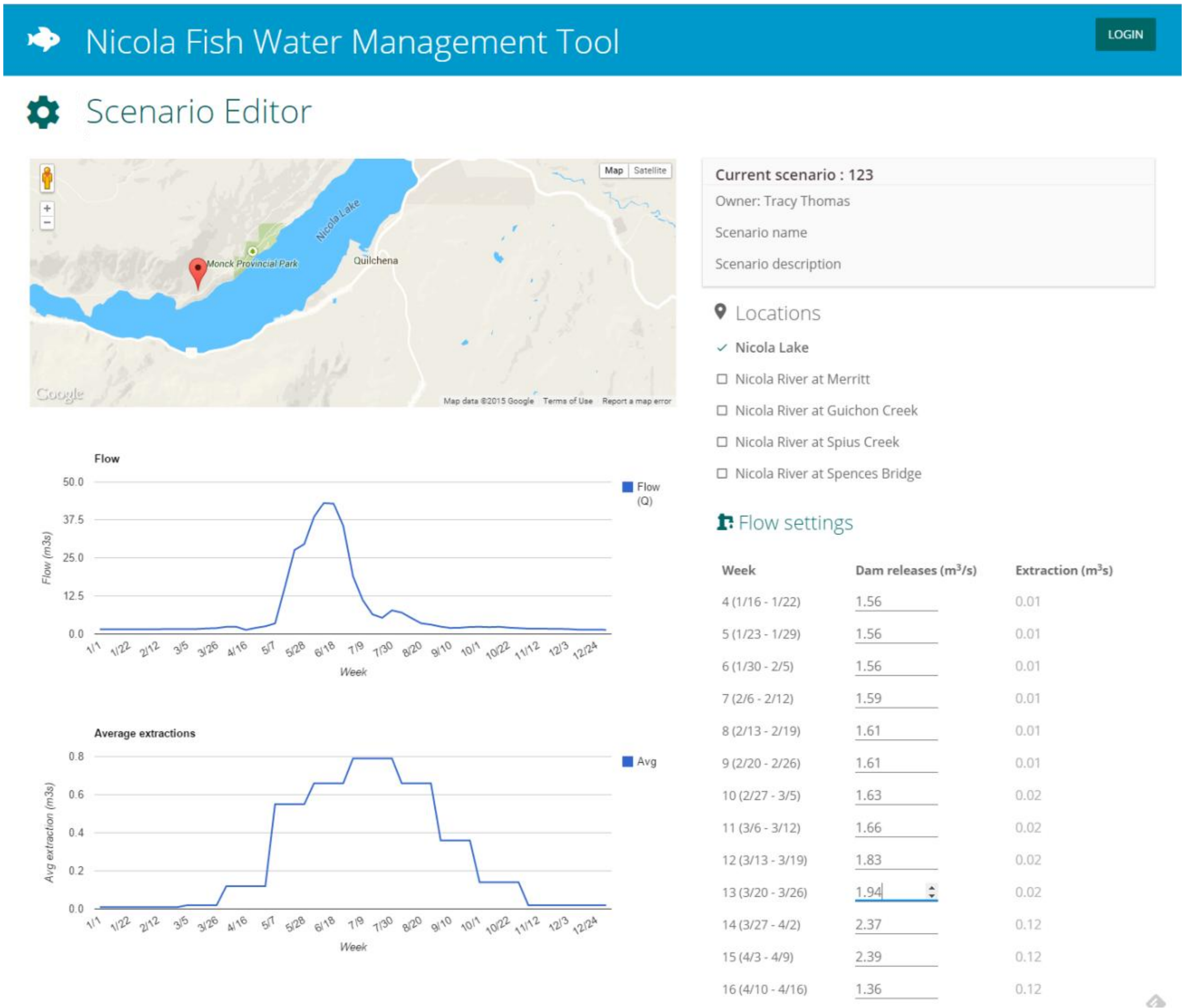


Figure 3-16. Hypothetical mockup of input screen from the NWMT. Weekly dam releases and extractions are specified by the user in a table and simultaneously displayed in to charts. The input screen also displays a map, a description of the current scenario and the locations of interest.

The forecasted flows based on the scheduled dam releases and assumed extractions can be view on the flow output screen (Figure 3-17). The output screen includes a chart of the flows for the current scenario, a map highlighting the selected output locations and a description of the current scenario. Output for locations can be turned on and off using checkboxes. This output screen can also be used to compare flows under expected, high and low inflow assumptions. The chart displays historical data from real-time gauges before the decision date and forecast data afterwards.

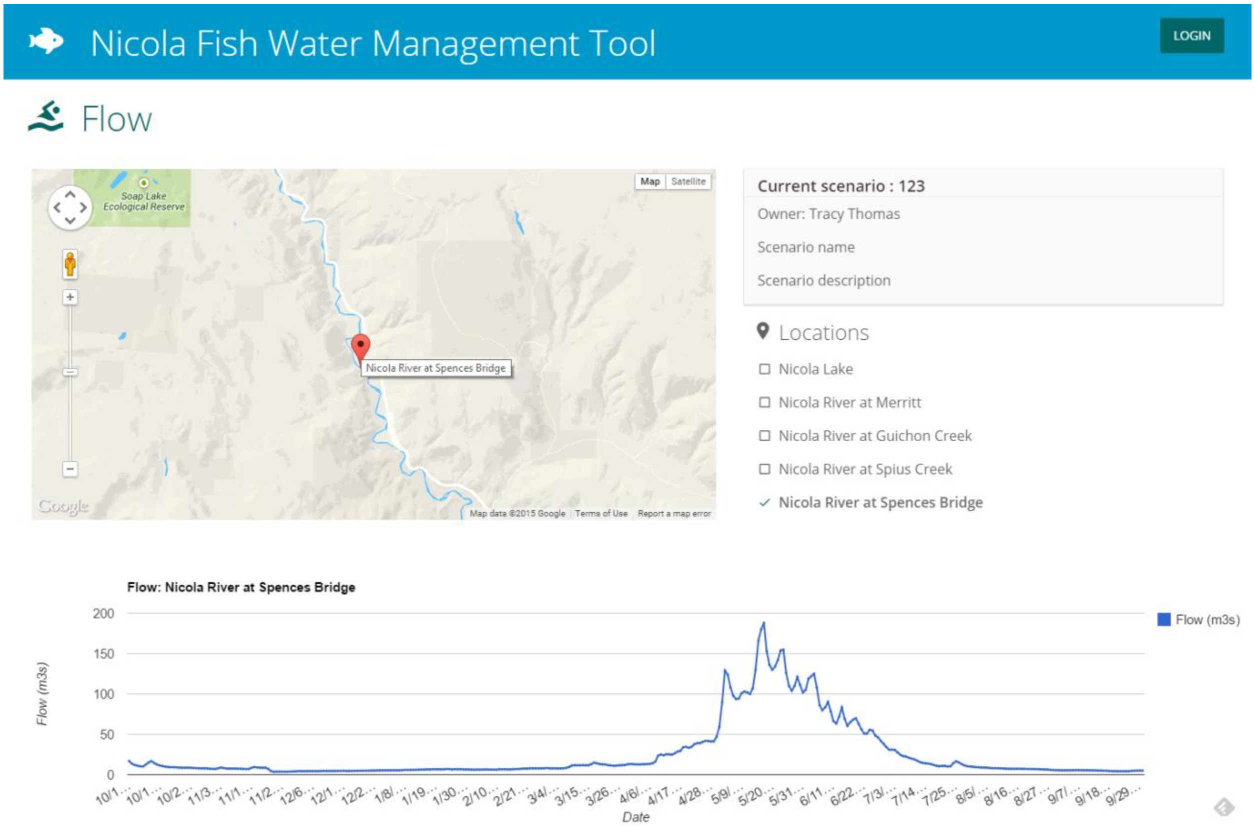


Figure 3-17. Hypothetical mockup of flow output screen for the NWMT. Daily flow values are displayed in a chart at the bottom of the screen, a map displays selected output locations and output for locations of interests can be turned on and off.

3.3.9 Data needs, questions, caveats & next steps

An important next step is to enhance the seasonal forecast model to predict inflows for the entire water year, as well as for the major tributaries. This work is likely to happen in fall/winter 2015. The current design of the NWMT is dependent on these enhanced inflow forecasts and new algorithms will have to be developed if this data is not available.

Currently, only Nicola Lake, Nicola mainstem and Coldwater Creek have real-time data available. It is important in the future to have real-time data available for the remaining two major tributaries (Guichon Creek and Spius Creek). Furthermore, real-time stations downstream of confluence would be desirable to better evaluate gains and losses due to, for example, groundwater and water extractions.

Workshop participants agreed that groundwater is extremely important in the Nicola watershed, but not necessarily well understood. 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.

The current NWMT is designed to forecast average flows on a weekly basis. For some objectives, e.g., minimizing redd scour, maximum daily flows may be more important. The NWMT can potentially be enhanced to provide daily minimum and maximum flows in the future.

Due to the non-stationarity of the hydrologic regime related to natural and anthropogenic influences on water supply, demand and climatic regime, it is possible that the future inflow and lake level regimes may shift from those represented by the historical base period. Therefore, it is recommended that the analyses presented here be repeated approximately every 10 years to ensure they remain valid.

Finally, we note that the likely future effects of regional climate change on the Nicola watershed were not considered in this study.

3.4 Water Use Submodel

The overall objective of the water use submodel is to forecast weekly estimates of water use as input to the water balance submodel. The primary water use in the Nicola watershed is agriculture, which is estimated to account for 76% of total annual water use (Summit 2007). By comparison, the industrial and domestic sectors represent about 11% and 8% of total annual demand while business/commercial, institutional, and recreation resort sectors represent the remaining 5%. Because of the seasonal variation of water use demand for agriculture, 75% of water use occurs from May to August (Summit 2007).

In this report, we describe a draft approach to:

- estimate weekly water use for Nicola Lake and the mainstem Nicola River; and
- adjust predictions based on real-time data.

3.4.1 Locations of interest

The spatial scope of the submodel includes the mainstem Nicola River from the Nicola Lake Dam to the confluence with the Thompson River at Spences Bridge. Water use from Nicola Lake and upstream of the lake is not included because it is already accounted for in the predicted net inflows. Water use is divided into major segment of the Nicola River mainstem between the major tributaries (Coldwater Creek, Guichon Creek and Spius Creek). 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. The locations of interest for the water use submodel are:

- ☐ Upper Nicola River (incld. Douglas Lake to Chapperon Lake)

- Nicola River at Merritt
- Nicola River at Guichon Creek
- Nicola River at Spius Creek
- Nicola River at Spences Bridge

3.4.2 Water use estimation methods

A conceptual design workshop was convened on February 17th and 18th 2015 in Kamloops to consult with technical experts on NWMT submodel components and decide on priorities for the tool. During breakout sessions in the afternoon, the Hydrology & Water Temperature Subgroup discussed water use estimation methods. The method would be required to provide weekly estimates of water use for reaches of the Nicola River stratified by water year type (dry, wet or average). Specifically, five methods were discussed:

- Nicola river watershed present and future water demand study
- Agricultural Water Demand Model
- Water Licenses database analysis
- FarmWest evapotranspiration relationship
- Water use reporting

Each of these methods is described briefly below, followed by a comparison and selection of a preferred model by the subgroup.

Nicola River watershed present and future water demand study

The Nicola River watershed present and future water demand study (Summit 2007) estimates current and future water demands for 10 subbasins (Figure 3-18).

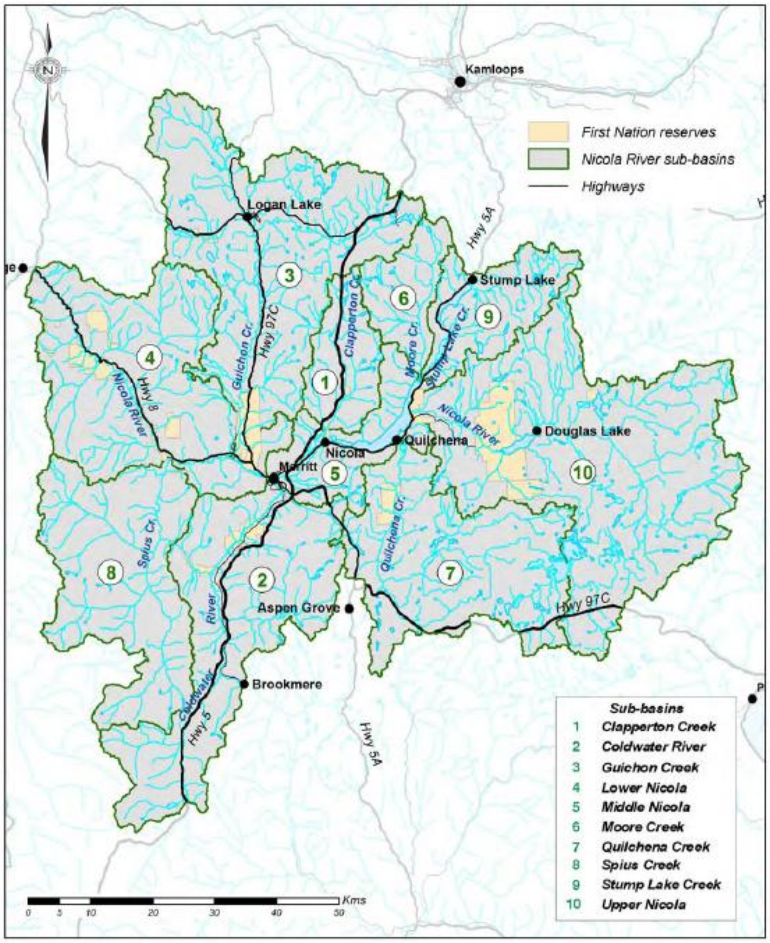


Figure 3-18. Map of subbasins used in the Nicola river watershed present and future water demand study. *Source*: Summit (2007).

Irrigation demands were estimated in each sub-basin according to the procedure outlined in the BC Irrigation Management Guide (MAFF 2005). Industrial water use was estimated by a combination of interviews and by approximating the water use using an assumed water use rate per employee. To calculate water demand in the business and commercial sector, in institutions and for recreation and resorts, the number of relevant “units” (e.g., seats for a restaurant) that characterize each business was multiplied by an assumed water use rate per unit. Total domestic water demand was based on estimating the population of each sub-basin and identifying a representative per capita domestic water demand (Summit 2007). The estimated water demand was summarized by subbasin and month, with weekly estimates for August and September (Figure 3-19).

LOWER NICOLA													
	Estimated volumetric water demand for offstream use (m^3)												
Sector	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Agricultural	0	0	0	236,988	1,258,814	1,522,445	1,794,090	1,495,157	794,811	267,441	0	0	7,369,746
Industrial	39	3,517	18,088	17,976	14,904	8,186	17,135	18,020	18,992	24,664	21,097	27,791	190,407
Business/Commercial	133	133	133	133	133	133	133	133	133	133	133	133	1,598
Domestic	26,034	22,037	25,421	41,929	55,047	57,852	84,278	78,260	48,996	33,192	25,484	25,895	524,425
Institutional	1,459	2,612	2,950	3,011	3,274	2,945	19,617	16,584	9,119	3,349	716	716	66,351
Recreation/Resorts	0	0	0	0	442	442	442	442	442	164	0	0	2,373
Total Demand (all sectors)	**27,665**	**28,299**	**46,592**	**300,037**	**1,332,613**	**1,592,002**	**1,915,695**	**1,608,596**	**872,492**	**328,944**	**47,430**	**54,535**	**8,154,901**

Figure 3-19. Example of estimated water demand for the Lower Nicola subbasin. *Source*: Summit (2007).

The Nicola River watershed present and future water demand study would be able to provide monthly and limited weekly estimates of water demand for each subbasin but would not be able to provide estimates based on water year type (i.e., results are for average conditions, not for wet or dry years).

Agricultural Water Demand model

The Agricultural Water Demand model (AWDM) was originally developed in the Okanagan Watershed and applied to the Nicola Watershed in 2013 (van der Gulik *et al.* 2013). The model calculates water use on a property-by-property basis, and sums each property to obtain a total water demand for the entire basin or each sub-basin. Crop, irrigation system type, soil texture and climate data are used to calculate the water demand. Climate data from 2003 was used to present information on one of the hottest and driest years on record, and 1997 data was used to represent a wet year. The model is based on a Geographic Information System (GIS) database that contains information on cropping, irrigation system type, soil texture and climate. The water use is calculated on a daily basis and typically reported as water use for the water year for each subbasin. It can run for any time period chosen but an annual demand is the normal request (MOA 2011).

The AWDM has also been integrated into a real-time web-based system called the Okanagan Irrigation Management (OKIM). The tool has been developed for agricultural users in water districts to aid smart water use in agricultural irrigation. The AWDM calculates the theoretical water use of each property based on a real-time reference evapotranspiration rate (ETo) from **farmwest.com**. OKIM then generates a monthly report for each property to compare the AWDM theoretical value with the actual water use from the water metre databases of the water purveyors. Through the monthly reports, producers are able to see how much water is used and how much should be used every month (MOA 2011).

The ADWM could be used to estimate water use for each subbasin by week for dry, wet and average years to drive the NWMT model, but would not include non-agriultural demands.

Water licenses database analysis

The water license database could be used to derive estimates for each subbasin, but it would be a high estimate since water use is generally significantly lower than licensed amount. Furthermore, simplifying assumptions would have to be applied to generate monthly or weekly licensed amount. The water license database could however be used to develop a maximum water use estimate.

FarmWest evapotranspiration relationship

The FarmWest website (http://farmwest.com/) forecasts evaporation based on the short-term weather forecast (Figure 3-20 and Figure 3-21). The estimates of evapotranspiration could potentially be used for refinement of short-term water demand. This is already being used in the Okanagan for the Okanagan Irrigation Management (OKIM) tool combined with the AWDM.

EVAPOTRANSPIRATION
Lower Nicola (Sunshine Valley) for Jan 01 - Mar 31, 2015

	Jan 01 - Mar 31		Forecast				
	Total	Daily Average	Thu Mar 19	Fri Mar 20	Sat Mar 21	Sun Mar 22	Mon Mar 23
Evapotranspiration(mm):	32	0.4	1.91	1.79	1.58	2.25	1.86
Effective Precipitation (mm):	7	0.1					
Moisture Deficit (mm):	25	0.3					
Total Precipitation (mm):	-16603	-186.6					
Historical Avg Moisture Deficit (mm):	-7	-0.1					
Previous Year Moisture Deficit (mm):	0	0					

Figure 3-20. Example output from FarmWest estimate of evapotranspiration created on March 19 2015 for the period March 19 to March 23.

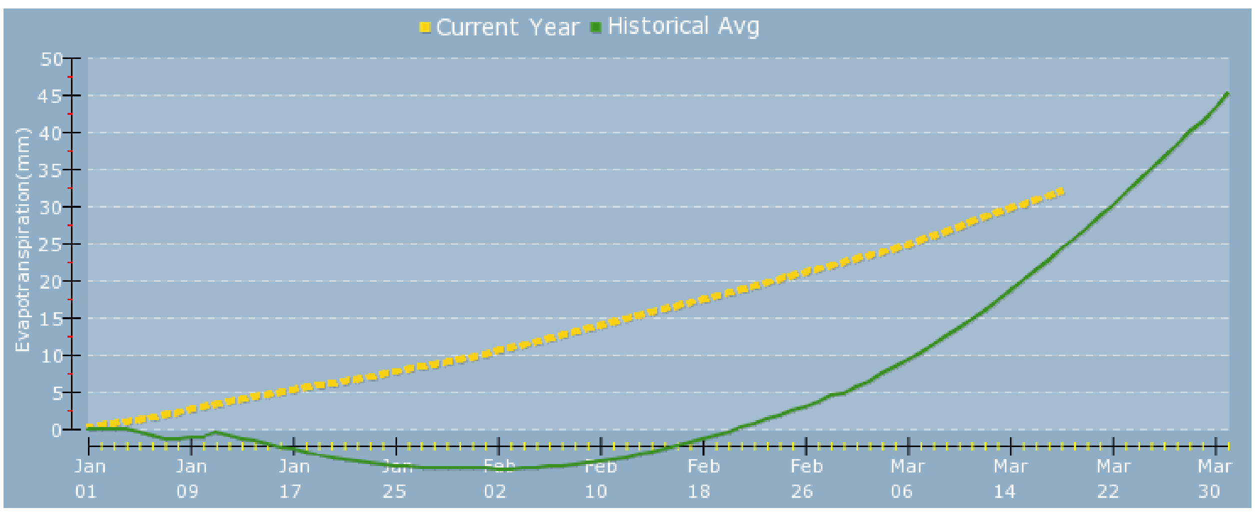


Figure 3-21. Example output from FarmWest estimate of evapotranspiration created on March 19 2015 for the period March 19 to March 23.

The FarmWest application could be used together with the AWDM to create a highly detailed five day forecast of water demand but would not be able to forecast long-term water use.

Recommendation

The Hydrology & Water Temperature Subgroup recommended using the Agricultural Water Demand Model because it has more recent data than the Nicola River watershed present and future water demand study and can provide water demand estimates for different water year types. The water demand estimates from the AWDM may have to be augmented with estimates for non-agricultural use from the Nicola River watershed present and future water demand study. The subgroup suggested that the water license database analysis could potentially be used to create a worst-case water use estimate in parallel with the AWDM estimates. The FarmWest evapotranspiration relationship was considered too complex and complicated for the current NWMT.

3.4.3 Application of real-time data to update lake and downstream forecasts

Actual extractions are commonly different from estimated extractions based on water demand, e.g., grasses are often irrigated to a lesser degree than their full theoretical requirement for optimal growth (van der Gulik *et al.* 2013). To account for this, the NWMT applies a self-correction algorithm based on real-time data (Eq. 9). The correction coefficient is calculated using (Eq. 10) based on total forecasted inflows and extractions from Nicola Lake to Spences Bridge ((Eq. 11) and (Eq. 12)). The self-correcting algorithm can be refined as more real-time gauges become available but will currently have to be calculated and applied based on total inflows and extractions because the only real-time location available is at Spences Bridge.

$$E_{adj} = \alpha * E_{forecasted} \qquad \text{(Eq. 9)}$$

Where α is a correction coefficient for all extractions and
$E_{forecasted}$ is the total forecasted extractions from the AWDM.

$$\alpha = \frac{\sum I + Q_{Nicola\ Lake} - \sum E}{Q_{Spences\ Bridge,Obs}} \qquad \text{(Eq.}$$

Where α is a correction coefficient for all extractions,
$\sum I$ is the total forecasted inflow, adjusted by realtime data,
$Q_{Nicola\ Lake}$ is the weekly scheduled release from Nicola Lake Dam,
$\sum I$ is the total forecasted extractions, and
$Q_{Spences\ Bridge,Obs}$ is observed flow at Spences Bridge.

$$\sum I = I_{Coldwater} + I_{Guichon} + I_{Spius} \qquad \text{(Eq. 11)}$$

$$\sum E = E_{Merrit} + E_{Coldwater} + E_{Guichon} + E_{Spius} + E_{Spences\ Bridge} \quad \text{(Eq. 12)}$$

3.4.4 Draft outputs & user interface mock-up

The water use for each location of interest can be found on the water use output screen (Figure 3-22). The output screen includes a chart of the water use for the current scenario, a map highlighting the selected output locations and a description of the current scenario. Output for locations can be turned on and off using checkboxes. 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.

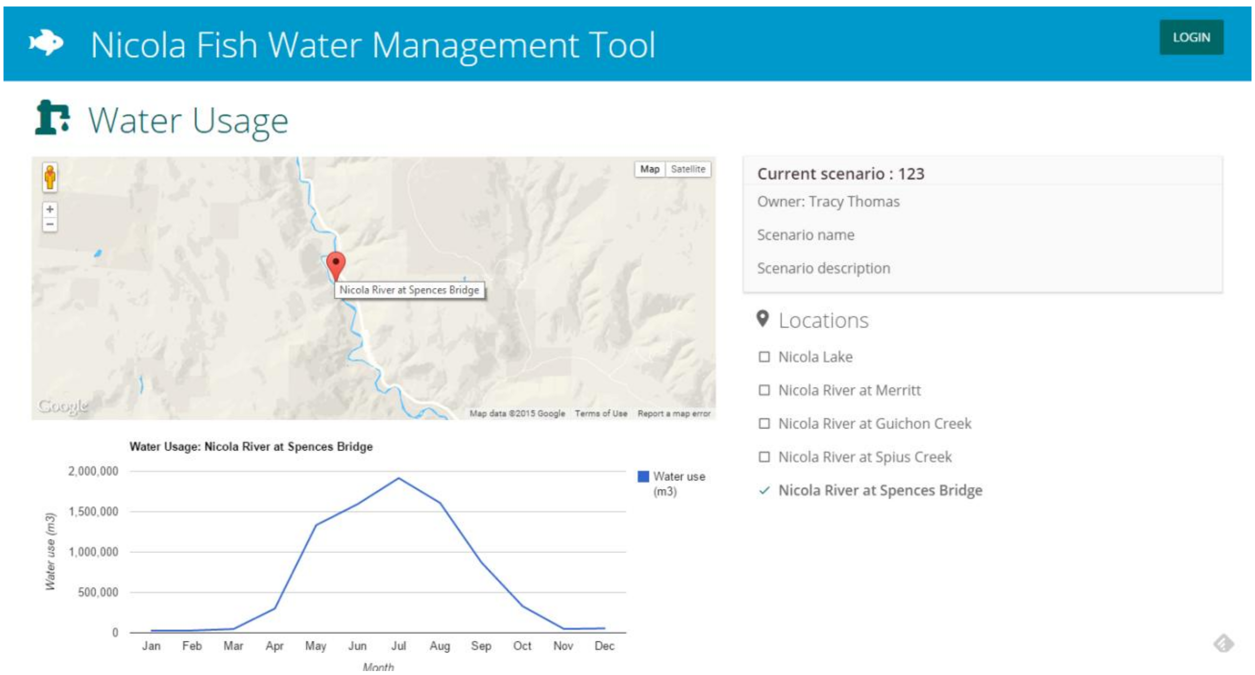


Figure 3-22. Hypothetical mockup of water use output screen for the NWMT. Weekly water use values are displayed in a chart at the bottom of the screen, a map displays selected output locations and output for locations of interests can be turned on and off.

3.4.5 Data needs, questions, caveats & next steps

The data from the AWDM is not currently in a form that can be readily used by the NWMT. An important next step is to extract a dataset from the AWMD that contains weekly values of water demand for the locations of interest in the mainstem Nicola River. Extractions from tributaries need to be excluded from this dataset as they are already accounted for in the net inflow predictions from the seasonal forecast model. The weekly water demand would be calculated for average, wet and dry conditions using representative years, e.g., in the AWDM study (van der Gulik *et al.* 2013), 1997 and 2003 were used to represent a wet and a dry year respectively.

Furthermore, the actual extractions may vary from estimated water demand, e.g., grass and alfalfa often received less irrigation that the calculated need. This is accounted for using real-time data, where available, but further refinements should be incorporated into the NWMT.

The current design for the water use component of the NWMT focusses on agricultural water demand. Agriculture accounts for 76% of total annual water use, but industrial and domestic sectors are also significant (approximately 11% and 8% respectively). The AWDM was recommended by workshop participants for modelling water use, but further research on how to integrated water use estimates for industrial and domestic sectors, e.g., from the Nicola River watershed present and future water demand study (Summit 2007), would be desirable.

Finally, more real-time stream gauges between confluences on the Nicola River would significantly improve the estimates of actual extractions and be very useful for refining the self-correction algorithm.

3.5 Water Temperature Submodel

Fish submodels in NWMT require time-series of daily water temperature data for selected locations to determine annual incubation, egg hatching and fry emergence dates. Long-term continuous records of daily water temperature are not available for the Nicola Valley. To compensate, long-term air temperature records can be used as a foundation to reconstruct historic water temperature regimes. The analyses in this chapter document the data and approach used to construct daily water temperatures.

The overall objective of the water temperature submodel is to develop the framework for forecasting weekly estimates of the water temperature at Nicola Lake and the Nicola River at Merritt, Guichon Creek, Spius Creek, and Spences Bridge. In this report, we describe a draft approach to:

- recreate historical water temperature records for Nicola Lake, Coldwater Creek, Guichon Creek and Spius Creek;
- forecast weekly water temperatures; and
- adjust water temperature forecast based in real-time temperature measurements.

These methods form the backbone of water temperature forecast assumptions in the NWMT. Weekly values in each case are calculated based on expected, high, and low inflow values from the hydrological model.

3.5.1 Locations of interest

The spatial scope of the submodel includes Nicola Lake and the mainstem Nicola River from the Nicola Lake Dam to the confluence with the Thompson River at Spences Bridge. Submodel calculations are performed only at Nicola Lake, the major tributaries (Coldwater Creek, Guichon Creek and Spius Creek), and below major confluences in the mainstem Nicola River. The specific points of interest within the watershed are:

- Nicola Lake
- Coldwater creek
- Guichon Creek
- Spius Creek
- Nicola Lake River at Merritt
- Nicola Lake River at Guichon Creek
- Nicola Lake River at Spius Creek
- Nicola Lake River at Spences Bridge

3.5.2 Data sources

Long-term water temperature datasest are not generally available for the Nicola watershed. There is currently only one real-time temperature gauge in the watershed, located in Coldwater Creek. A review of existing stream temperature data in BC (including the Nicola) from researchers, consultants and government agencies compiled by Nelitz *et al.* (2008) revealed two other water temperature gauges with time period extending beyond one year. The available long-term datasets are summarized in Table 3-27.

Table 3-27. Known stations with more than one year of water temperature data from WSC and work by Nelitz *et al.* 2008).

Station Name	River	Start	End	Days available	Source
Nicola River	Nicola	1994-06-29	2003-10-24	3404	Nelitz *et al.* (2008)
TJT3	Coldwater	2000-07-01	2001-08-30	425	Nelitz *et al.* (2008)
Coldwater River at Merritt	Coldwater	2006-01-22	Current	2983 (on 2015-03-23)	WSC

There are many shorted duration water temperature datasets available. The dataset compiled by Nelitz *et al.* (2008) contained 91 other temperature records ranging in duration from 24 to 262 days, typically sampled in the summer months. McGrath and Walsh (2012) sampled water temperature at six locations in the summer to evaluate the impact of groundwater for three years, plus some sampling in the winter. Water temperature is also collected during annual chinook stock assessment field work using a standard procedure whereby water temperature is recorded whenever fish tagging is done (Richard Bailey, unpublished). These records go back at least to 1998 and are almost always for the morning periods. Short-term records might not be long enough to calibrate a water temperature model but can be used for validation instead.

According to a study by Water Management Consultants (WMC 2008), there are 13 active or inactive climate stations throughout the Nicola watershed available through the National Climate Data and Information Archive compiled by Environment Canada (Table 3-28, Figure 3-23). Climate stations are important because water temperature records can be created or extended based on climate data using a variety of models.

Table 3-28. Climate stations within the Nicola Watershed. *Source*: WMC 2008.

Station	Station ID	Elevation (m)	Latitude		Longitude		Active dates	
			Degrees	Minutes	Degrees	Minutes	Start	End
Brookmere	1121090	972	49	49	120	52	1986	1994
Douglas Lake	1122541	808	50	9	120	12	1979	2006
Elkhart Lodge	112K653	1615	49	55	120	21	1992	1995
Highland Valley BCCL	1123468	1470	50	30	121	0	1966	1989
Highland Valley Lornex	1123469	1268	50	28	121	1	1967	2006
Lac Le Jeune	1124460	1305	50	28	120	31	1984	1988
Logan Lake	1124668	1101	50	30	120	49	1971	2004
Meadowgreen	1125060	1207	50	28	120	40	1980	1986
Craigmont	1125075	732	50	12	120	52	1962	1976
Merritt STP	1125079	609	50	6	120	48	1968	2006
Nicola Lake	1125586	633	50	15	120	27	1979	1985
Nicola Lake West End	1125590	642	50	10	120	37	1984	1992
Spences Bridge	1167637	235	50	25	121	19	1980	2002

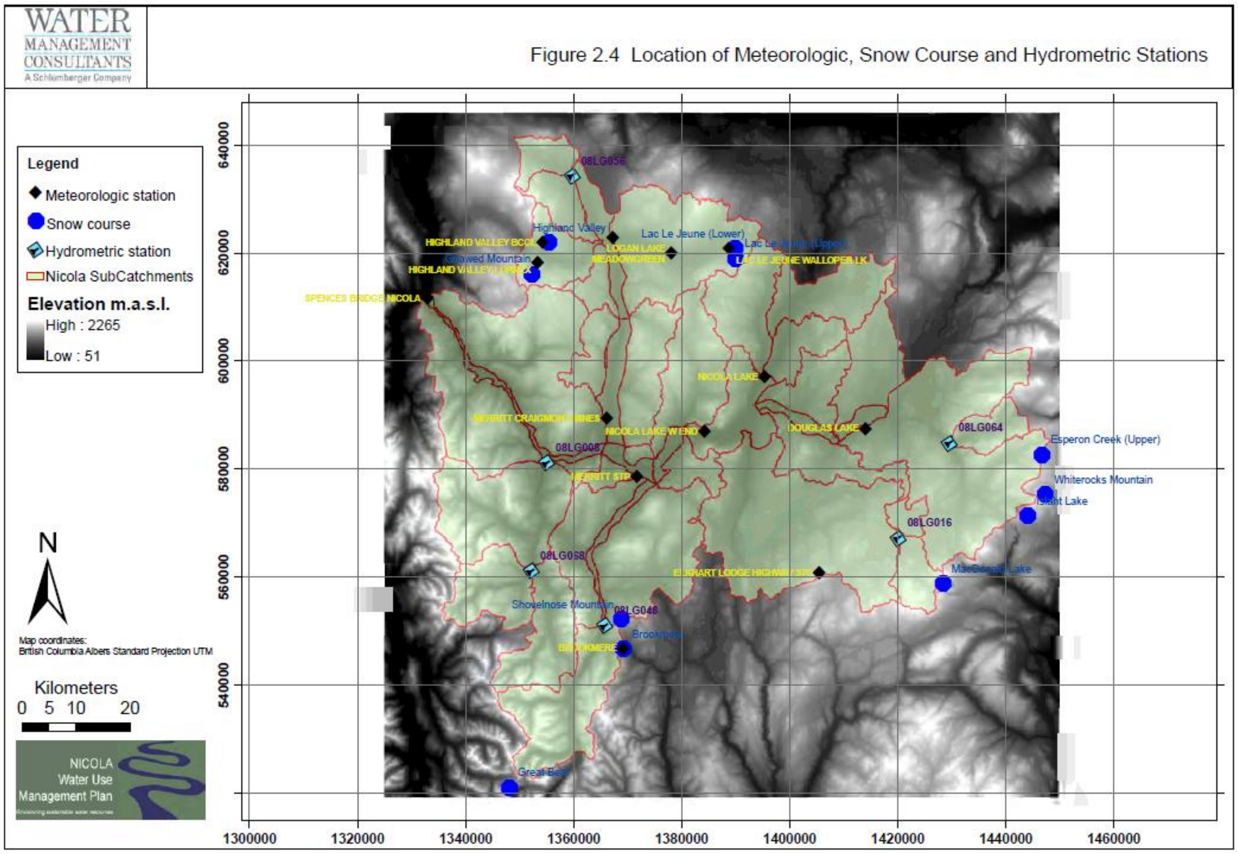


Figure 3-23. Location of meteorologic, snow course and hydrometric stations. *Source*: WMC 2008.

3.5.3 Historical water temperature modelling approaches

Historical water temperatures are important because they form the empirical basis for water temperature forecasting. Unfortunately, historical water temperature time-series are limited in the Nicola Valley, with time-series longer than one year only available at three locations. Fortunately long-term air temperature time-series are readily available in the Nicola Valley and can be used to re-create or extend historical water temperature time-series in combination with other variables. This chapter provides a brief summary of modelling approaches derived from the literature (no water temperature experts were available at the conceptual design workshop).

Models for predicting stream temperatures fall along a spectrum between deterministic models based on physical principles including energy and water balances, and statistical models based on empirical relationships.

Deterministic or physical-process models are based on energy budget equations and use inputs such as solar radiation, evaporation, and conduction to calculate thermal exchange between the atmosphere and streams. Deterministic models are typically developed for individual stream reaches, require extensive data inputs, and can provide very accurate estimates of stream temperature (e.g., Horne *et al.* 2004; Caissie *et al.* 2007; Herbert *et al.* 2011). However, the fine scale (e.g., reach-specific) data inputs and predictions of deterministic models typically make them impractical for use at regional scales (Mohseni *et al.* 1998; Moore *et al.* 2013), but see van Vliet *et al.* (2012) for a deterministic modelling approach applied at a global scale.

In contrast to deterministic models, statistical models do not directly account for sources of heat flux but instead are entirely based on data and rely on variables that are correlated with stream temperature and can incorporate geomorphic, riparian and catchment characteristics (Nelitz *et al.* 2007; Daigle *et al.* 2010; Hrachowitz *et al.* 2010; Mayer 2012; Moore *et al.* 2013). The types of statistical models used to generate prediction of stream temperatures are numerous. The most common type of statistical model used is multiple linear regression (reviewed in Caissie 2006 and Webb *et al.* 2008). Other modelling approaches include generalized least squares, generalized additive and mixed-effects models (e.g., Wehrly *et al.* 2009), autoregressive moving average models (ARIMA; Cole *et al.* 2014) and neural networks (Chenard and Cassie 2008). Studies comparing the performance of these statistical models in predicting stream temperatures from a common dataset have found that while linear mixed-effects and ARIMA models performed the best, differences among methods were marginal (Wehrly *et al.* 2009; Cole *et al.* 2014).

To account for network topology and non-independence of observations that are characteristic of data from watersheds, predictive models can be built as spatial statistical network models (e.g., Peterson et al. 2013; Isaak *et al.* 2014). These geospatial models can generate improved predictive ability and parameter estimates relative to non-spatial models. However, when the distribution of data is sparse, network-based geostatistical models do not perform any better than non-spatial statistical models from a predictive perspective.

A statistical model is preferred for the NWMT because it is able handle large spatial scales and has lower data requirements than deterministic models. A network topology model is considered too complex for the purpose of the NWMT.

3.5.4 Recommended starting model

Simple regression statistical models of air-to-water temperature associations are often adequate for prediction of seasonal or annual water temperature regimes of aquatic habitats (Brown 1969; Johnson 1971; Crisp and Howson 1982; Sinokrot and Stefan 1993; Stefan and Preud'homme 1993; Pilgrim *et al.* 1998). Linear regression models of air-to-water temperature relations are easy to develop but have some limitations. Application of air-to-water relationships implicitly assumes that there have been no significant changes in the geology, hydrology or biology of the subject ecosystems capable of significantly altering the key processes of air-to-water heat exchanges (e.g., removal of forest canopy; major alterations in seasonal exchanges between surface and groundwater sources etc.). Furthermore, in lacustrine and lake-fed, riverine habitats, seasonal changes in daily water temperature often exhibit pronounced patterns of hysteresis where aquatic temperatures lag both in spring-to-summer warming and in summer-to-winter cooling with air temperature (Mohseni *et al.* 1999; Kyle and Brabets 2001).

Hysteresis owes to the complex physics controlling air-water heat exchanges (Wetzel 1975). Thus, at both very high and low temperatures, air-to-water temperature relations are non-linear. For instance, evaporative cooling experienced with high air temperatures allows aquatic habitats to increase their rate of heat loss. By contrast, the rate of heat loss may be slowed at low air temperatures by the release of latent heat from ice formation (Webb and Nobilis 1997) or by changes in the volume of the stored heat "reservoir" when lake habitats undergo thermal destratification in the fall and winter (Wetzel 1975). Hence, the complex physics that determine seasonal, air-water heat exchanges at such sites often necessitates either: (1) the development of season-specific sets of linear regressions; or (2) identification of one or more forms of non-linear regression to predict water temperature (Mohseni *et al.* 1998).

Adapted from Mohseni *et al.* (1998), the air-to-water temperature relationship for stream data can be reasonably described by a continuous nonlinear four-parameter logistic function of the general form:

$$t_W = \mu + \frac{(\alpha - \mu)}{1 + e^{\gamma(\beta - t_a)}} \qquad \text{(Eq. 13)}$$

Where: t_w = estimated water temperature,
t_a = measured water temperature,
α = estimated maximum water temperature,
β= air temperature at the inflection point of the S-shaped function,
γ= maximum slope of the function, and
μ= minimum water temperature.

The linear coefficients α and μ can be estimated directly. In the Nicola Watershed, μ can be assumed to be zero. Experience from the Okanagan River near Oliver demonstrated that season-specific equations generally can achieve a good model fit (Figure 3-24).

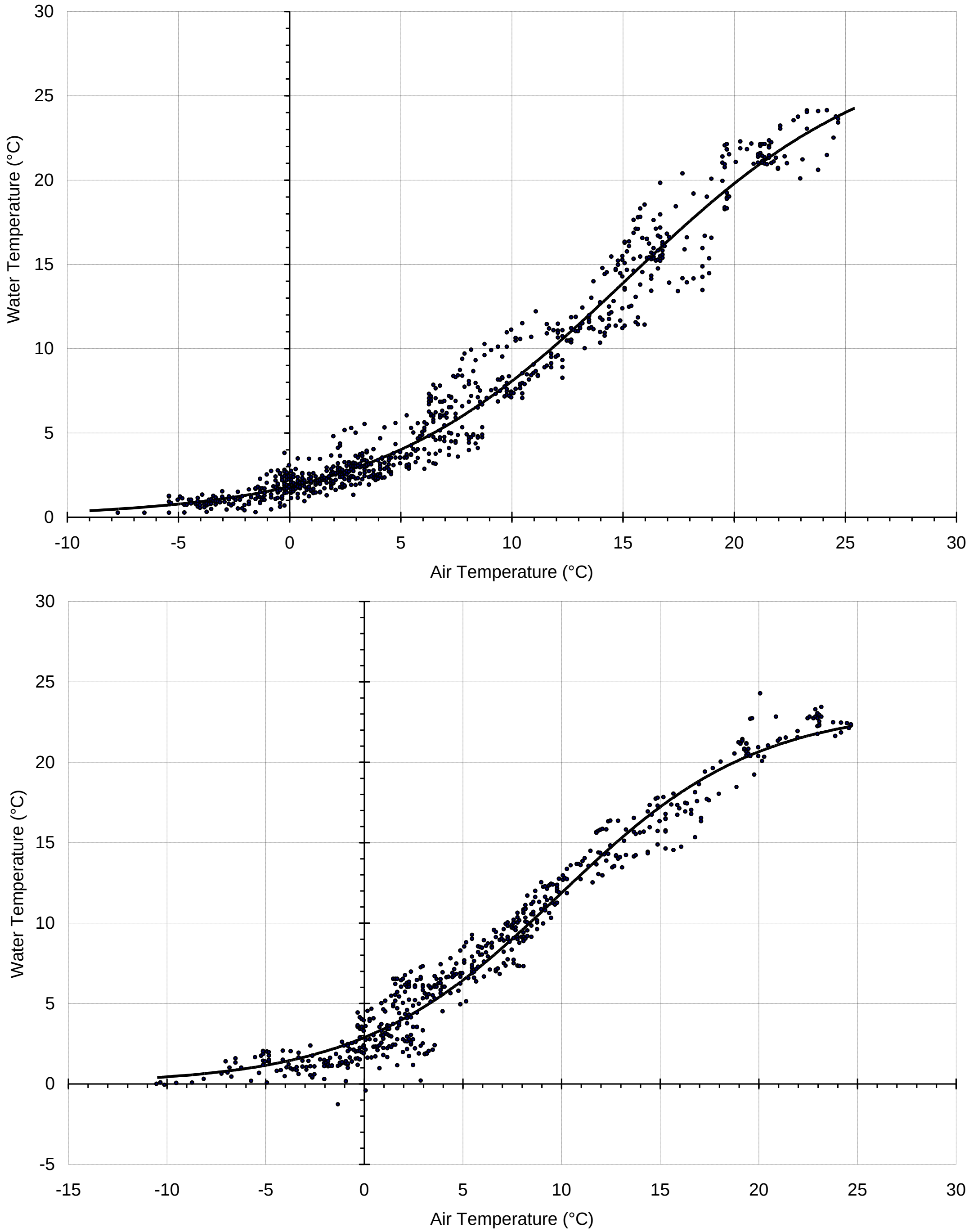


Figure 3-24. Example of a logistic regression fits for the Okanagan River near Oliver. Top panel: spring-summer warming limb; bottom panel: fall-winter cooling limb. Both regressions had a Nash-Sutcliffe coefficient (NSC) of Goodness of Fit of 0.96. *Source*: Alexander and Hyatt 2013.

3.5.5 Water temperature forecasting

To forecast ahead of a given decision date, the temperature submodel's all year average daily water temperature values for a particular location are adjusted according to the trajectory suggested by the trend in the real-time data in the last 30 days. The 30-day lookback and mean error adjustment is repeated throughout a water year every time the decision-date is changed and the model is run, resulting in a new temperature trajectory. Thus, the process is partially "self correcting" since real time data are provided daily as the season progresses.

The difference between the observed and historical average temperature is calculated using (Eq. 14). The forecasted inflow for the next week is then adjusted based on the deviation from the previous week (Eq. 15).

$$\Delta T = \frac{T_{30,obs}}{T_{30,historical}} \quad \text{(Eq. 14)}$$

Where $T_{30,obs}$ is the observed average temperature in the last 30 days,
$T_{30,historical}$ is historical average temperature in the last 30 days, and
ΔT is the observed deviation from average temperature flow in the last 30 days.

$$T_{forecast,day=i} = \Delta T * T_{historical,day=i} \quad \text{(Eq. 15)}$$

Where ΔT is the observed deviation from average temperature flow in the last 30 days,
$T_{forecast,day=i}$ is the forecast temperature for day i, and
$T_{historical,day=i}$ is the average historical temperature for day i.

To ensure a smooth transition from observed to forecast temperatures, a linear interpolation between last observed temperature and forecasted temperature is applied for 10 days (Figure 3-25).

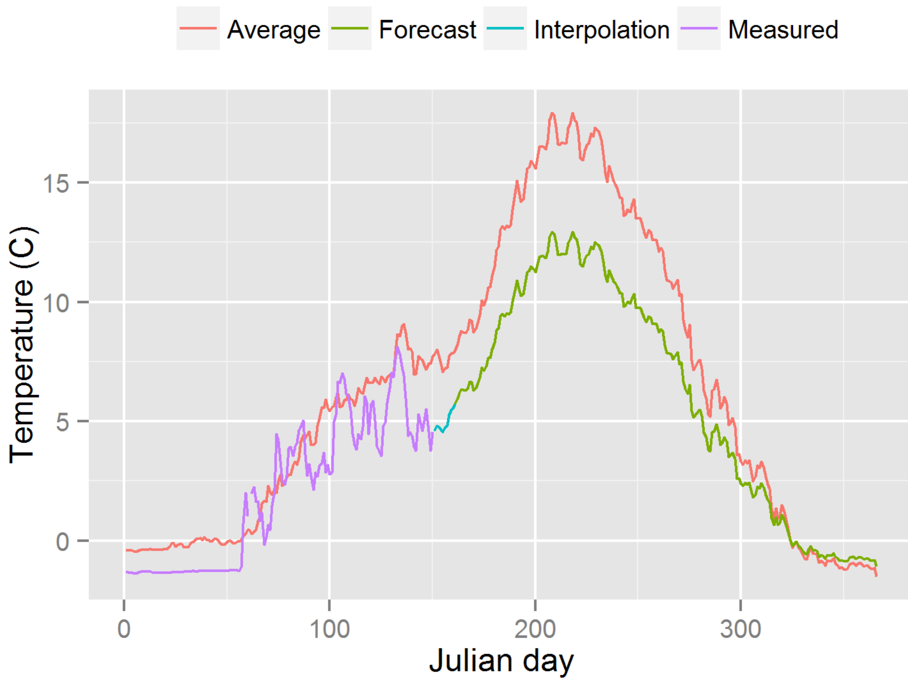


Figure 3-25. Example for water temperature forecast. In this example, the measured temperature for the last 30 days was 28% lower than the average temperature. The forecast for the remainder of the rest is reduced by 28% for the rest of the year and the first 10 days is interpolated between the last measured temperature and the average temperature reduced by 28%.

Of course, this process assumes the current month's level of water temperature deviation from the all-year mean is informative about what the rest of the year will be like. Although this is unlikely to be true (i.e., it might apply to the next few weeks but seldom over intervals as long as several months), we are unaware of a better forecasting algorithm. The simple approach used adequately reflects the type of "what if" thinking and gaming that is central to NWMT. In practice, the self-correcting nature of the approach (especially at the one to two week intervals for which NWMT is typically used in winter and early spring), coupled with the provision of external advisory information on egg and fry incubation rates to real-world water managers, provides a useful balance of economy and rigor.

As the real-time network of stream temperature gauges gets expanded, they will be used in the NWMT.

3.5.6 Downstream water temperature: incorporation of unregulated tributaries

The NWMT forecasts weekly estimates of the water temperature and discharge in the Nicola River at Merritt, Guichon Creek, Spius Creek and Spences Bridge. The water temperature is assumed unchanged between confluences.

The downstream temperature is calculated using (Eq. 16) to (Eq. 19). For each location represented by a confluence of the mainstem and a tributary, a simple water temperature equation is applied. There are no major tributaries between Spius Creek and Spences Bridge, so temperature is assumed unchanged.

$$T_{Merritt} = \frac{Q_{Nicola\ Lake} * T_{Nicola\ Lake} + I_{Coldwater} * T_{Coldwater}}{Q_{Nicola\ Lake} + I_{Coldwater}} \quad \text{(Eq. 16)}$$

$$T_{Guichon} = \frac{Q_{Merritt} * T_{Merritt} + I_{Guichon} * T_{Guichon}}{Q_{Merritt} + I_{Guichon}} \quad \text{(Eq. 17)}$$

$$T_{Spius} = \frac{Q_{Guichon} * T_{Guichon} + I_{Spius} * T_{Spius}}{Q_{Guichon} + I_{Spius}} \quad \text{(Eq. 18)}$$

$$T_{Spences\ Bridge} = T_{Spius} \quad \text{(Eq. 19)}$$

Where $T_{Location\ of\ interest}$ is weekly temperature at a location of interest,
$Q_{Location\ of\ interest}$ is weekly flow at a location of interest, and
$I_{Tributary}$ is weekly forecasted inflow for a tributary.

3.5.7 Draft outputs & user interface mock-up

The water temperature for each location of interest can be found on the water temperature output screen (Figure 3-26). The output screen includes a chart of the water temperature for the current scenario, a map highlighting the selected output locations and a description of the current scenario. Output for locations can be turned on and off using checkboxes. The chart displays historical data from real-time gauges before the decision date, if available, and forecast data afterwards.

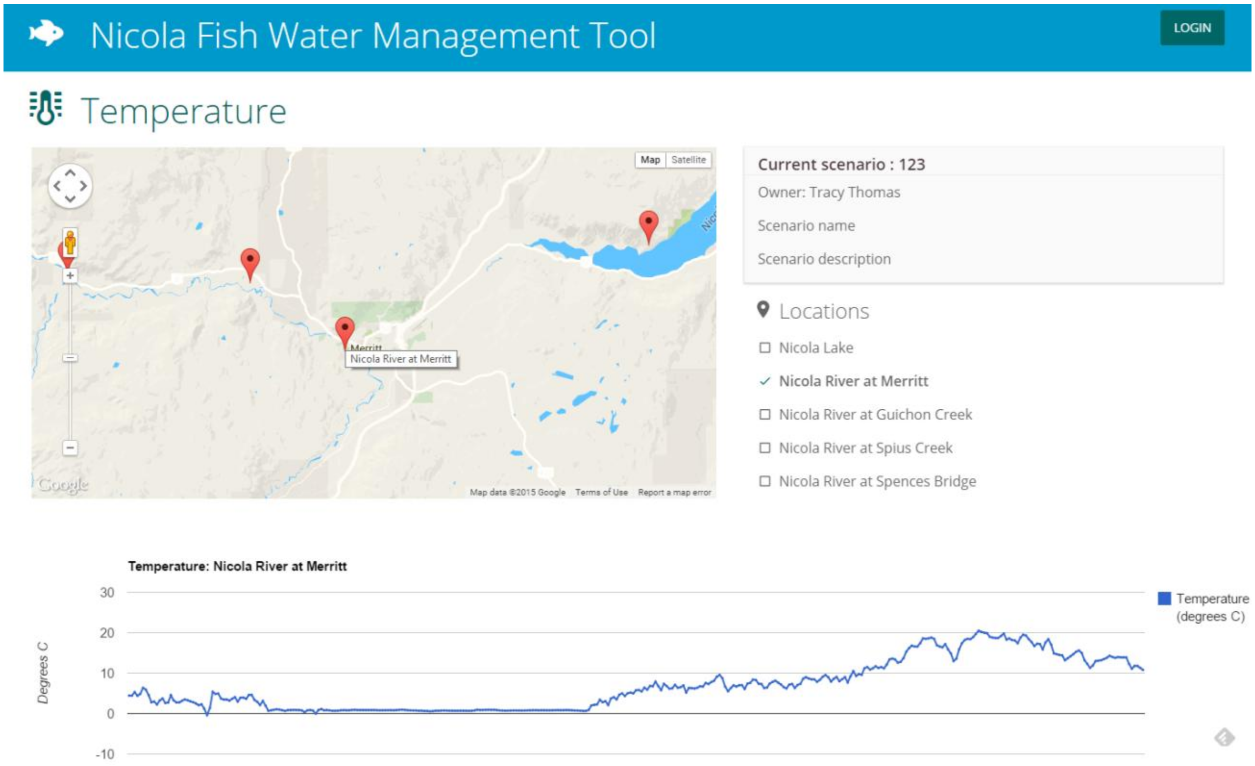


Figure 3-26. Hypothetical mockup of temperature output screen for the NWMT. Daily water temperature values are displayed in a chart at the bottom of the screen, a map displays selected output locations and output for locations of interests can be turned on and off.

3.5.8 Data needs, questions, caveats & next steps

Long-term water temperature datasets are not generally available in the Nicola watershed and most short-term records are focused on the summer period. More real-time gauges, particularly in the major tributaries and on Nicola Lake, are required to refine the water temperature forecasting. The quality of the water temperature model will depend on the data available. If temperature data is not available for some tributaries to appropriately calibrate a water temperature model, it is possible that simplifying assumptions, e.g., Guichon and Spius water temperature relates to temperatures in Coldwater, will be required. Alternatively, a dedicated study to create a deterministic model for selected subbasins could be explored. Real-time data will also be very useful for refining the self-correction algorithm.

Water temperature also depends greatly on groundwater upwelling, particularly in temperature refugia locations for fish, e.g., McGrath and Walsh (2012) found that maximum daily temperatures were on average 11.5°C lower in the groundwater upwelling area in the Nicola River. Workshop participants agreed that groundwater is extremely important in the Nicola watershed, but not necessarily well understood. 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.

The current NWMT is designed to forecast average temperature on a weekly basis. For some objectives, e.g., thermal stress, maximum daily temperature may be more important. The NWMT can potentially be enhanced to provide daily maximum temperatures in the future.

Due to the changes in the watershed, e.g., from Mountain Pine Beetle infestations, it is possible that the future temperatures may shift from those represented by the historical base period. Therefore, it is recommended that the analyses presented here be repeated approximately every 10 years to ensure they remain valid.

Finally, we note that the likely future effects of regional climate change on the Nicola watershed were not considered in this study.

4 References and Further Reading

Alexander, C.A.D. and K. Wieckowski. 2008. Technical Feasibility and Design Options for an Integrated Decision Support Tool for Water Use Management in the Nicola Basin. Prepared for the Nicola Watershed Community Round Table Steering Committee, Merritt, BC. 66 pp.

Alexander, C.A.D. and K. Hyatt (eds.). 2013. The Okanagan Fish/Water Management Tool (FWMT): Record of Design (v.2.4.000). Prepared for Canadian Okanagan Basin Technical Working Group, Kamloops, BC. 173 pp.

Alexander, C.A.D., D.C.E. Robinson, and F. Poulsen. 2014. Application of the Ecological Flows Tool to Complement Water Planning Efforts in the Delta and Sacramento River: Multi-Species effects analysis and Ecological Flow Criteria. Final Report to The Nature Conservancy. Chico, California. 228 pp. + appendices.

Arthington, A.H., J.M. King, J.H. O'Keefe, S.E. Bunn, J.A. Day, B.J. Pusey, D.R. Bluhdorn, and R. Tharme. 1991. Development of a holistic approach for assessing environmental flow requirements of riverine ecosystems. In Water Allocation for the Environment: Proceedings of an International Seminar and Workshop, J.J. Pigram and B.A. Hooper (eds). The Centre for Water Policy Research, University of New England Armidale, Australia: 69-76.

Arthington A.H., S.E. Bunn, N.L. Poff, and R.J. Naiman. 2006. The challenge of providing environmental flow rules to sustain river ecosystems. Ecological Applications 16: 1311-1318.

Bovee, K. 1982. A Guide to Stream Habitat Analysis Using Instream Flow Incremental Methodology. U.S. Fish and Wildlife Service, Instream flow information paper 12, FWS/OBS-82/26, 248 pp.

Brown, G.W. 1969. Predicting temperatures of small streams. Water Resources Research. 5: 68 -75.

Bruce, J. and T. Hatfield. 2003. Predicting salmonid habitat-flow relationships for streams from western North America. II. Prediction of whole curves. Draft manuscript.

Caissie, D. (2006). The thermal regime of rivers: a review. Freshwater Biology, 51(8), 1389-1406.

Caissie, D., M.G. Satish, and N. El-Jabi, 2007. Predicting water temperatures using a deterministic model: application on Miramichi River catchments (New Brunswick, Canada). Journal of Hydrology 336: 303-315.

Carlisle D., D. Wolock, and M. Meador. 2010. Alteration of stream flow magnitudes and potential ecological consequences: a multiregional assessment. Frontiers in Ecology and the Environment. doi: 10.1890/100053.

Chenard, J.F. and D. Caissie. 2008. Stream temperature modelling using artificial neural networks: application on Catamaran Brook, New Brunswick, Canada. Hydrological Processes 22(17): 3361-3372.

Cole, J., K.O. Maloney, M. Schmid, and J.E. McKenna, Jr. 2014. Developing and testing temperature models for regulated systems: A case study on the Upper Delaware River. Journal of Hydrology 519 (Part A): 588-598.

Crisp, D.T. and G. Howson. 1982. Effect of air temperature upon mean water temperature in streams in the North Pennines and English Lake District. Freshwater Biology. 12: 359-367.

CRM (Compass Resource Management Ltd.). 2010. Nicola Water Use Management Plan.

Daigle, A., A. St-Hilaire, D. Peters, and D. Baird. 2010. Multivariate Modelling of Water Temperature in the Okanagan Watershed. Canadian Water Resources Journal 35: 237-258. doi: 10.4296/cwrj3503237.

Elliott, J.M. 1981. Some aspects of thermal stress on freshwater teleosts. pp. 209-245. In: Stress and fish. A.D. Pickering (ed.). Academic Press.

ESSA (ESSA Technologies Ltd.). 2008. Technical feasibility and design options for an integrated decision support tool for water use management in the Nicola Basin: FINAL Report. Prepared for the Nicola Watershed Community Round Table Steering Committee.

Fleenor, W., W. Bennett, P. Moyle, and J. Lund. 2010. On developing prescriptions for freshwater flows to sustain desirable fishes in the Sacramento-San Joaquin Delta. Submitted to the State Water Resources Control Board regarding flow criteria for the Delta necessary to protect public trust resources. Center for Watershed Sciences, University of California, Davis. 46pp.

Gardner, B., P.J. Sullivan, and A.J. Lembo, Jr. 2003. Predicting stream temperatures: geostatistical model comparison using alternative distance metrics. Canadian Journal of Fisheries and Aquatic Science 60: 344-351.

Hatfield, T. 2009. Nicola watershed and Water Use Management Plan. Overview of Instream Flow Requirements. Report by Solander Ecological Research Ltd., Victoria BC, for Fraser Basin Council, Vancouver and Kamloops BC and Nicola Water Use Management Plan, Merritt BC.

Hatfield, T., A. Lewis, D. Ohlson, and M. Bradford. 2003. Development of instream flow thresholds as guidelines for reviewing proposed water uses. BC Ministry of Sustainable Resource Management and BC Ministry of Water, Land and Air Protection. Victoria, BC.

Hatfield, T. and J. Bruce. 2000. Predicting salmonid habitat-flow relationships for streams from western North America. North American Journal of Fisheries Management 20: 1005-1015.

Hebert, C., D. Caissie, M.G. Satish, and N. El-Jabi. 2011. Study of stream temperature dynamics and corresponding heat fluxes within Miramichi River catchments (New Brunswick, Canada). Hydrological Processes 25(15): 2439-2455.

Horne, B.D., E.S. Rutherford, and K.E. Wehrly. 2004. Simulating effects of hydro-dam alteration on thermal regime and wild steelhead recruitment in a stable-flow Lake Michigan tributary. River Research and Applications 20: 185-203.

Hrachowitz, M., C. Soulsby, C. Imholt, I.A. Malcolm, and D. Tetzlaff. 2010. Thermal regimes in a large upland salmon river: a simple model to identify the influence of landscape controls and climate change on maximum temperatures. Hydrological Processes 24: 3374-3391.

Hyatt, K.D., C.A. Alexander, and M.M. Stockwell. 2015. A decision support system for improving “fish friendly” flow compliance in the regulated Okanagan Lake and River System of British Columbia. Canadian Water Resources Journal 40(1): 87-110.

Instream Flow Council (IFC). 2002. Instream Flows for Riverine Resource Stewardship. 410 pp.

Isaak, D.J., E.E. Peterson, J.M. Ver Hoef, S.J. Wenger, J.A. Falke, C.E. Torgersen, C. Sowder, E.A. Steel, M.-J. Fortin, C.E. Jordan, A.S. Ruesch, S. Som, and P. Monestiez. 2014. Applications of spatial statistical network models to stream data. Wiley Interdisciplinary Reviews: Water 1(3): 277-294.

Jowett, I.G. 1997. Instream flow methods: a comparison of approaches. Regulated Rivers: Research and Management 13: 115-127.

Johnson, F.A. 1971. Stream temperatures in an alpine area. J. Hydrol. 14: 322-336.

Kosakoski, G.T., and R.E. Hamilton. 1982. Water requirements for the fisheries resource of the Nicola River, BC. Can. MS. Rep. Fish. Aquat. Sci. 1680: 127p.

Kyle, R.E. and T.P. Brabets. 2001. Water temperature of streams in the Cook Inlet Basin, Alaska, and implications of climate change. Water Resources Investigation Report 01-4109. 24 p. United States Department of the Interior and Unites States Geological Service. Anchorage, Alaska.

Lewis, A., D. Lacroix, A.J. Harwood, K. Healey, and T. Kasabuchi. 2009. Nicola Water Use Management Plan: Instream flow requirements for anadromous and resident fish. Preliminary Environmental Impact Assessment. Consultant's report prepared by Ecofish Research Ltd. DRAFT V1.

Lewis, A., T. Hatfield, B. Chilibeck, and C. Robert. 2004. Assessment methods for fish, fish habitat, and in-stream flow characteristics in support of applications to dm, divert, or extract water from streams in British Columbia. Prepared for Ministry of Water, Land, and Air Protection and Ministry of Sustainable Resource Development. Victoria, BC.

Lorz, H.W. and T.G. Northcote. 1965. Factors affecting stream location, and timing and intensity of entry by spawning Kokanee (*Oncorhynchus nerka*) into an Inlet of Nicola Lake, Brithish Columbia. J.Fish.Res.Bd. Canada. 22(3). 1965.

Matthews, M., G. Glova, and T. Sampson. 2007. Nicola River watershed stream temperatures, July-October 2006. Prepared for Pacific Salmon Foundation.

Mayer, T.D. 2012. Controls of summer stream temperature in the Pacific northwest. Journal of Hydrology 475: 323-335. doi: http://dx.doi.org/10.1016/j.jhydrol.2012.10.012.

McCullough, D.A. 1999. A review and synthesis of effects of alterations to the water temperature regime on freshwater life stages of salmonids, with special reference to Chinook salmon.

McGrath, E. and M. Walsh. 2012. The Use of Groundwater Upwelling Areas by Interior Fraser Coho. Prepared for the Fraser Salmon and Watersheds Program.

MAFF (Ministry of Agriculture, Food and Fisheries). 2005. BC Irrigation Management Guide. Resource Management Branch.

MOA (Ministry of Agriculture). 2011. Agriculture water demand model. Order No. 500.320-2. May 2011.

Mohseni, A., H.G. Stefan, and T.R. Erickson. 1998. A nonlinear regression model for weekly stream temperatures. Water Resources Research 34: 2685-2692.

Moore, R.D., M. Nelitz, and E. Parkinson. 2013. Empirical modelling of maximum weekly average stream temperature in British Columbia, Canada, to support assessment of fish habitat suitability. Canadian Water Resources Journal 38(2): 135-147.

Nelitz, M.A., E.A. MacIsaac, and R.M. Peterman. 2007. A science-based approach for identifying temperature sensitive streams for rainbow trout. North American Journal of Fisheries Management 27: 405-424.

Nelitz, M.A., R.D. Moore, and E. Parkinson. 2008. Developing a Framework to Designate 'Temperature Sensitive Streams' in the BC Interior. Final Report Prepared by ESSA Technologies Ltd., University of British Columbia, and BC Ministry of Environment for BC Forest Science Program. Vancouver, BC.

Nelson, T., R. Bocking, and M. Gaboury. 2001. Coldwater River Watershed Recovery Plan. Prepared for Pacific Salmon Endowment Fund by LGL Limited, Sidney, BC.

Peterson, E.E, J.M. Ver Hoef, D.J. Isaak, J.A. Falke, M.J. Fortin, C.E. Jordan, K. McNyset, P. Monestiez, A.S. Ruesch, A. Sengupta, N. Som, E.A. Steel, D.M. Theobald, C.E. Torgersen, and S.J. Wenger. 2013. Modelling dendritic ecological networks in space: an integrated network perspective. Ecology Letters 2013 (16): 707-719. doi: 10.1111/Ele.12084.

Petts, G.E. 2009. Instream Flow Science for Sustainable River Management. Journal of the American Water Resources Association (JAWRA) 45(5): 1071-1086. doi: 10.1111 ⁄ j.1752-1688.2009.00360.x.

Pilgrim, J. M., X. Fang and H.G. Stefan. 1998. Stream temperature correlations with air temperatures in Minnesota: implications for climate change. J. Am. Wat. Res. Assoc. 34: 1109-1121.

Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. 1997. The natural flow regime: a paradigm for river conservation and restoration. Bioscience 47: 769-784.

Poff, N.L. and J.Z.H. Zimmerman. 2010. Ecological responses to altered flow regimes: a literature review to inform the science and management of environmental flows. Freshwater Biology 55: 194-205. doi: 10.1111/j.1365– 2427.2009.02272.x.

Poff, N.L., B.D. Richter, A.H. Arthington, S.E. Bunn, R.J. Naiman, E. Kendy, M. Acreman, C. Apse, B.P. Bledsoe, M.C. Freeman, J. Henriksen, R.B. Jacobson, J.G. Kennen, D.M. Merritt, J.H. O'Keeffe, J.D. Olden, K. Rogers, R.E. Tharme, and A. Warner. 2010. The ecological limits of hydrologic alteration (ELOHA): a new framework for developing regional environmental flow standards. Freshwater Biology 55: 147-170.

Postel, S. and B. Richter. 2003. Rivers for life: managing water for people and nature. Island Press.

Ptolemy, R. and A. Lewis. 2002. Rationale for Multiple British Columbia Instream Flow Standards to Maintain Ecosystem Function and Biodiversity. Draft for Agency Review. Prepared for BC Ministry of Water, Land and Air Protection and BC Ministry of Sustainable Resource Management.

Richter, B.D., J.V. Baumgartner, J. Powell, and D.P. Braun. 1996. A method for assessing hydrologic alteration within ecosystems. Conservation Biology 10: 1163-1174.

Richter, B.D, J.V. Baumgartner, R. Wigington, and D.P. Braun. 1997. How much water does a river need? Freshwater Biology 39: 231-249.

Richter, A. and S.A. Kolmes. 2005. Maximum temperature limits for chinook, coho, and chum salmon, and steelhead trout in the Pacific Northwest. Reviews in Fisheries Science 13: 23-49.

Richter, B.D., M.M. Davis, C. Apse, and C. Konrad. 2012. A presumptive standard for environmental flow protection. River Research and Applications 28(8): 1312-1321.

Rosenau, M.L. and M. Angelo. 2003. Conflicts between people and fish for water: two British Columbia salmon and steelhead rearing streams in need of flows. Vancouver, BC. Pacific Fisheries Resource Conservation Council.

Sinokrot, B.A. and H.G. Stefan. 1993. Stream temperature dynamics. Wat. Res. Res. 29: 2299-2312.

Stanford J.A., J.V. Ward, W.J. Liss, C.A. Frissell, R.N. Williams, J.A. Lichatowich, and C.C. Coutant. 1996. A general protocol for restoration of regulated rivers. Regulated Rivers: Research and Management 12: 391-413.

Stefan, H.G. and E.B. Preud'homme. 1993. Stream temperature estimation from air temperature. Wat. Res. Bull. 29: 27-45.

Summit (Summit Environmental Consultants Ltd.). 2007. Nicola River watershed present and future water demand study. Prepared for the Nicola Watershed Community Round Table.

Tennant, D.L. 1976. Instream Flow Regimes for Fish, Wildlife, Recreation and Related Environmental Resources. Fisheries 1(4): 6-10.

Tharme, R.E. 2003. A global perspective on environmental flow assessment: emerging trends in the development and application of environmental flow methodologies for rivers. River Research and Applications 19(5-6): 397-441.

Triton Environmental Consultants. 2014. Nicola Lake Eurasian watermilfoil management planning – fisheries utilization assessment. Prepared for the Fraser Basin Council.

van der Gulik, T., D. Neilsen, R. Fretwell, A. Petersen, and S. Tam. 2013. Agriculture water demand model: Report for the Nicola Watershed.

Van Vliet, M.T.H., J.R. Yearsley, W.H.P. Franssen, F. Ludwig, I. Haddeland, D.P. Lettenmaier, and P. Kabat. 2012. Coupled daily streamflow and water temperature modelling in large river basins. Hydrology and Earth System Sciences 16: 4303-4321.

Wetzel, R.G. 1975. Limnology. W.B. Saunders Company, London.

WMC (Water Management Consultants). 2008. Surface and groundwater supply and Interaction study – Phase 1 and 2.

Webb, B.W., D.M. Hannah, R.D. Moore, L.E. Brown, and F. Nobilis, 2008. Recent advances in stream and river temperature research. Hydrological Processes 22: 202-918.

Webb, B.W. and F. Nobilis. 1997. Long term perspective on the nature of the air-water temperature relationship; a case study. Hydrol. Proc. 11: 137-147.

Wehrly, K.E., T.O. Brenden, and L. Wang. 2009. A comparison of statistical approaches for predicting stream temperatures across heterogeneous landscapes. Journal of the American Water Resources Association 45: 986-997.

Winter, T.C., J.W. Harvey, O.L. Franke, and W.M. Alley. 1998. Ground Water and Surface Water. A Single Resource. U.S. Geological Survey Circular 1139.

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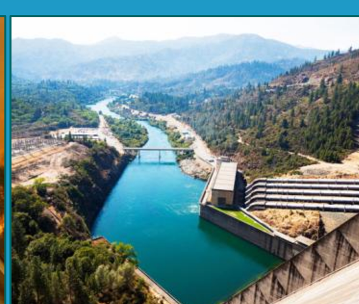
Design Document

Environmental & Cumulative Effects Assessment

Climate Change Adaptation & Risk Reduction



Aquatic Species at Risk & Water Resource Management

Terrestrial Ecology & Forest Resource Management