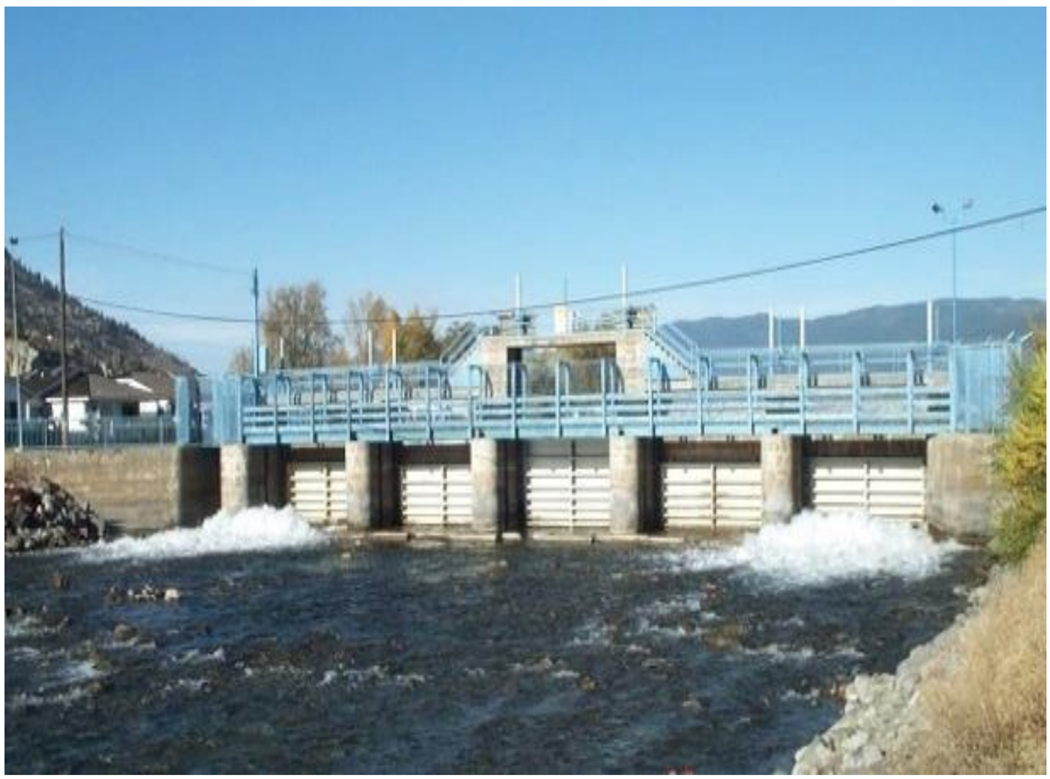
REPORT

Ministry of Forests, Lands, Natural Resource Operations & Rural Development

Review of 2017 Flood Response:
Okanagan Lake Regulation System
and Nicola Dam



December 2017

ISO 9001 and 14001 Certified | An Associated Engineering Company

Associated Environmental Consultants Inc.
Suite 200, 2800 29 Street
Vernon, B.C., Canada V1T 9P9

TEL: 250.545.3672
FAX: 250.545.3654
www.ae.ca | ISO 9001 & 14001 Certified

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Valerie Z. Cameron
Manager, Water Stewardship Program
Ministry of Forests, Lands, Natural Resource Operations and Rural Development
PO Box 9340 Stn. Prov. Govt.
Victoria, BC
V8W 9M1

EMail to: Valerie.Cameron@gov.bc.ca

Re: REVIEW OF 2017 FLOOD RESPONSE: OKANAGAN LAKE REGULATION SYSTEM AND NICOLA DAM

Dear Ms. Cameron:

Associated Environmental Consultants Inc. (Associated) is pleased to provide a report on the above-noted review. The report evaluates the actions taken by FLNRORD's Okanagan and Nicola Water Managers in spring 2017, and provides recommendations to improve delivery of the Province's water management responsibilities in the Okanagan and Nicola areas.

Yours truly,

PROFESSIONAL
PROVINCE
B. T. GUY
COLUMBIA
GEOSCIENTIST

Brian T. Guy, Ph.D., P.Geo.
Senior Geoscientist

BG

Executive Summary

BACKGROUND

The Ministry of Forests, Lands, Natural Resource Operations, and Rural Development (FLNRORD) owns and operates the Okanagan Lake Regulation System (OLRS) and Nicola Dam. The OLRS includes dams on Okanagan, Skaha, and Vaseux Lakes. Okanagan Lake is by far the largest of these lakes, and the focus of decision-making. Kalamalka Lake is also managed by FLNRORD, although it is not formally part of the OLRS. The Okanagan dams and the Nicola Dam are operated to achieve multiple objectives, including managing flood and drought and fulfilling the needs of aquatic ecosystems. Each winter and spring, the B.C. River Forecast Centre (RFC) develops and delivers forecasts of lake inflow to Okanagan, Kalamalka, and Nicola Lakes to regional Water Managers, who consider the inflow forecast, the management objectives for each lake, and other information, and make decisions that establish the rate of outflow from each lake. These decisions influence the flowrate in the channels downstream of the dams, and the level of the lakes behind the dams.

High inflows to Okanagan Lake, Kalamalka Lake, and Nicola Lake in spring 2017 were part of a general pattern of high flows in creeks and rivers in this area of B.C. that resulted in widespread flooding due to high lake levels, high groundwater tables, and high streamflows. The high flows resulted from melting of the upper elevation snowpack combined with above average rainfall. Localized flooding occurred around these three lakes, and high flows occurred in the Okanagan River downstream of Okanagan Lake, in Vernon Creek downstream of Kalamalka Lake, and in the Nicola River downstream of Nicola Lake. Nicola River overtopped its banks through the town of Merritt. All three lakes (Okanagan, Kalamalka, and Nicola) reached their highest levels since the dams were built. The peak lake elevations all exceeded the estimated 200-year return period elevations, but remained below the Flood Construction Levels (FCL) around the lakes. In fall 2017, FLNRORD retained Associated Environmental Consultants Inc. (Associated) to assess its management of the OLRS, Kalamalka Lake, and Nicola Dam in spring 2017.

OBJECTIVES

The general objectives of the work reported herein were to determine whether FLNRORD could have altered its management of the OLRS, Kalamalka Lake, and Nicola Lake during the period before and during spring 2017 to reduce flooding and other impacts of the high inflows to these lakes; and to identify opportunities for improvement. To achieve these objectives, Associated completed the following steps:

- summarized the process FLNRORD uses for managing the outflows from Okanagan, Kalamalka, and Nicola Lakes;
- described weather conditions in the Okanagan and Nicola regions from fall 2016 through summer 2017;
- documented the flooding that occurred in the Okanagan and Nicola regions in spring 2017;
- examined the models used to forecast inflows to these lakes, and the data that drives the models;

- documented and assessed decisions made by the Water Managers between fall 2016 and late spring 2017;
- identified organizational constraints to optimizing the value of RFCs inflow forecasts, and the process of water management decision-making; and
- developed recommendations to improve the inflow forecasts, to learn from the 2017 operational experience, and to overcome organizational barriers to more effective program delivery.

WEATHER CONDITIONS

In both the Okanagan and Nicola regions, weather conditions preceding and during spring 2017 were very unusual. Fall 2016 was substantially wetter than normal. Winter 2017 was drier and colder than usual, which combined to produce more than average snowfall in the populated low elevation areas, but less than average snowfall in upper elevation areas – the areas that typically produce the majority of the spring runoff. Accordingly, the first two inflow forecasts of the year, produced on February 1 and March 1, called for average or below average lake inflow during spring.

Spring 2017 was much wetter than average, producing rain in low elevation areas and snow in the uplands. By the end of April, the lakes were filling and the upper elevation snowpack had increased to between 10% (Nicola) and 50% (Okanagan) above average. In May, the wet weather continued, which combined with melting high elevation snow to produce very high inflows to the lakes. Both Okanagan and Nicola Lakes experienced their highest May inflows on record (FLNRORD does not compute Kalamalka Lake inflows). In mid-June however, the weather changed dramatically, and the subsequent summer was one of the driest on record.

ANALYSIS OF 2017 INFLOW FORECAST MODELS AND WATER MANAGEMENT DECISIONS

The RFC forecasts lake inflows with models developed using principal components analysis (PCA). The models rely on data representing four factors that determine lake inflow in spring: upper elevation snowpack (the water stored in the snow is usually the dominant source of spring inflow), rainfall during the previous fall (this influences the ability of soil to absorb rain and melting snow in the spring), low elevation precipitation during winter (this influences runoff in early spring), and current river flows (these are the baseflows that spring runoff builds from). The PCA-based models are run once per month from February 1 to May 1. The models use data available on the date the forecast is made; however, they do not look ahead to predict how future weather will influence lake inflows (instead they implicitly assume future weather will be average). The potential consequences of this well-known limitation were apparent in spring 2017, as the heavy spring rains and increasing, and subsequently melting, upper elevation snowpack strongly influenced the lake inflows. Every one of the inflow forecasts produced by the RFC using the PCA-based models underestimated actual inflows.

The Water Managers use the RFC-supplied forecasts to drive other models (i.e., the Fish Water Management Tool [FWMT] for the Okanagan and Nicola Water Management Tool [NWMT] for the Nicola) that help them consider the needs of aquatic ecosystems around and downstream of the lakes. These models distribute the volume inflow forecast into daily and weekly increments, which helps Water Managers predict the timing and magnitude of peak inflows, as well as peak outflows and lake levels that will be experienced under a range of hypothetical lake outflow decisions. However, these models are limited by the accuracy of the RFC-supplied volume inflow forecasts.

The RFC is experimenting with modelling approaches that incorporate a forecast of the upcoming weather, and that can be updated more frequently than monthly, but they are not yet sufficiently advanced that they can be relied upon.

Between fall 2016 and the end of April 2017 the OLRS Water Manager made decisions relating to the management of Okanagan Lake generally in accordance with the OLRS Operating Plan. He used the monthly inflow forecasts, the Operating Plan, his own observations, input from the FWMT model, and his experience and judgment to appropriately balance the effects of flooding around the lakes with the effects of high flows in the Okanagan River downstream of the lake. The Operating Plan specifies lake outflow decisions based on the volume inflow forecasts. Until April his decisions had all been in accordance with the Operating Plan. In April, recognizing the deficiencies in the inflow forecasts, he diverged from the plan to further mitigate the effects of the high lake inflows. However, by early May he had increased the lake outflow to nearly the maximum rate that the downstream channel can sustain without causing significant damage and flooding, and after that time he could no longer influence the level of Okanagan Lake. Subsequent inflows to the lake during May were the highest on record, which caused the lake to rise above its full pool elevation (342.48 m) to its highest level since the dam was built (343.25 m), which is 20 cm above the estimated 200-year return period elevation (343.05 m), and within 41 cm of the FCL (343.66 m). The return to dry weather in mid June helped to reduce the lake inflows and allowed Okanagan Lake to drop to normal levels relatively quickly, which helped keep the lake elevation from rising above 343.25 m, and helped minimize the duration of high water.

The Water Manager made decisions relating to the management of Kalamalka Lake in accordance with the Kalamalka Lake Operating Plan. While he could still control the level of Kalamalka Lake, he appropriately balanced the effects of flooding around the lake with the effects of high flows in Vernon Creek downstream of the lake. He had increased lake outflows and reached the flow capacity of Vernon Creek downstream of Kalamalka Lake by early May, and therefore had no ability to control the lake level after that. May inflows were very high, as they were for Okanagan Lake, and the lake rose to a peak of 392.45 m on June 4, 73 cm above its usual peak, 25 cm above the estimated 200-year return period elevation (392.2 m), and within 75 cm of the FCL (393.2 m).

Between fall 2016 and late spring 2017 the Nicola Water Manager made decisions relating to the management of Nicola Lake in accordance with the Nicola Dam Operating Plan. He considered the monthly forecast information made available to him, made personal observations of conditions on the ground, and ran the NWMT to help him interpret the forecast model outputs and make decisions. He appropriately balanced the effects of flooding around Nicola Lake with the effects of high flows in the Nicola River downstream of the lake. The level of Nicola Lake reached 626.97 m on May 18, 7 cm above the estimated 200-year return period lake level of 626.9 m, and 93 cm below the FCL of 627.9 m.

ORGANIZATIONAL CONSTRAINTS

A federal report currently in draft form indicates that the B.C. River Forecast Centre (RFC) is under-staffed relative to river forecast centres in comparable jurisdictions. A 2010 report on the operations of the B.C. RFC made 33 recommendations for improvement, but based on interviews conducted for the present study, some of those recommendations have not yet been fully implemented.

Staff numbers, experience, training, and succession planning are all issues that constrain the Province's ability to optimally deliver its flood forecasting and management responsibilities, but such issues did not negatively affect FLNRORD's management of the OLRS, Kalamalka Lake, or Nicola Lake in 2017. The three functions of data collection, forecasting, and water management are managed by two provincial Ministries, which may impair the Province's ability to optimally deliver these programs. Although evaluating FLNRORD's external communication was outside the scope of the work, we identified some opportunities to improve internal and external communication.

RECOMMENDATIONS

Recommendations can be classified into three groups:

- Recommended improvements to inflow forecasting models, and to the data needed to drive the models;
- Recommendations arising from 2017 experiences; and
- Recommendations to improve organizational performance.

A significant long-term commitment is needed to achieve sufficient, high quality, and consistent data needed to drive the forecasting models. A similarly significant commitment is needed to improve and regularly update the forecasting models, particularly recognizing that climate and hydrology have changed in B.C. in recent decades, and will continue to change.

Okanagan, Kalamalka, and Nicola Lakes were managed professionally and appropriately in 2017, and we have not identified any recommendations that would have resulted in improved outcomes. However, the 2017 experiences generated some recommendations related to reconsidering estimates of the 200-year return period lake elevations and vertical and horizontal setbacks for development, considering modifications to water management infrastructure, updating the Operating Plans and water management regimes, and consistently documenting water management decisions during the high flow season. We also recommend evaluating the external communication that occurred, and identifying opportunities for improvement.

Recommendations related to organizational performance are focussed on evaluating progress on implementing the recommendations of a previous comprehensive report, and on staffing levels, succession planning, training, mentoring, communication, and organizational responsibilities.

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Glossary and Acronyms

Term	Description
Basin Snow Water Index	Estimated water content in the high elevation snowpack in a basin (i.e. watershed), expressed as percent of average.
DFO	Fisheries and Oceans Canada
ESP	Ensemble Streamflow Prediction – a method being tested for suitability in forecasting lake inflows in the Okanagan.
FCL	Flood Construction Level – an elevation established to keep living spaces and areas used for storage of goods damageable by floodwaters above flood levels.
FLNRORD	B.C. Ministry of Forests, Lands, Natural Resource Operations and Rural Development – the Ministry responsible for management of the OLRS, Kalamalka Lake, and Nicola Dam.
FWMT	Okanagan Fish Water Management Tool – a model used for accounting for aquatic ecosystem requirements in and downstream of Okanagan Lake. The model distributes the forecasted volume inflows to Okanagan Lake into daily and weekly components, and a user can examine the effects of various lake outflow scenarios during the forecast period.
HRU	Hydrologic Response Unit – a homogeneous area used in the RAVEN Model
NWMT	Nicola Water Management Tool - a model used for accounting for aquatic ecosystem requirements downstream of Nicola Lake. The model distributes the forecasted volume inflows to Nicola Lake into daily and weekly components, and a user can examine the effects of various lake outflow scenarios during the forecast period.
OLRS	Okanagan Lake Regulation System - a set of dams, channels, and drop structures used to manage water in the large valley-bottom lakes and Okanagan River.
ONA	Okanagan Nation Alliance
PCA	Principal Components Analysis
PREOC	Provincial Regional Emergency Operations Centre
RAVEN	A hydrologic modelling framework used as part of the ESP modelling approach currently being tested for inflow forecasting in the Okanagan.
RFC	B.C. River Forecast Centre - the provincial agency responsible for providing forecasts of the inflows to Okanagan Lake, Kalamalka Lake, and Nicola Lake to the Water Managers. The RFC is part of FLNRORD.
RTSM	Real-Time Statistical Matching
Water Manager	The person responsible for operating the OLRS and the Nicola Lake Dam, referred to as the respective Water Manager.
SWE	Snow water equivalent - the water content of the snowpack, expressed as the depth of water that would be produced if the snowpack melted.
WSC	Water Survey of Canada – the federal agency responsible for monitoring water levels and streamflows.

1 Introduction

The Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD) owns and operates many water management structures in the province of British Columbia, including the Okanagan Lake Regulation System (OLRS) and Nicola Dam (Figures 1-1 and 1-2).

In the Okanagan, water flows from Kalamalka Lake into the north end of Okanagan Lake via Vernon Creek, then south through Okanagan, Skaha, Vaseux, and Osoyoos Lakes into the USA. The OLRS includes dams on each of these lakes. The dam on Kalamalka Lake is not formally part of the OLRS. The Nicola River flows into Nicola Lake from Douglas Lake, then downstream of Nicola Dam it flows through Merritt and into the Thompson River at Spences Bridge.

The spring freshet of 2017 in the southern interior of B.C. resulted in very high inflows to all the valley-bottom Okanagan lakes and Nicola Lake. Although FLNRORD staff were actively managing the outflows from these lakes during this time, widespread flooding resulted, with lake levels in some cases exceeding historic maximums. The flooding caused damage, including flooded homes and businesses, road washouts, and dock damage. Subsequently, FLNRORD has fielded questions about whether the OLRS and Nicola Dam could have been managed better to reduce the flooding and associated impacts.

Accordingly, FLNRORD initiated an assessment of it’s management of the OLRS and Nicola Dam in spring 2017. Whereas the assessment is referred to by the FLNRORD as an “internal” examination, it was conducted by Associated Environmental Consultants Inc. (Associated), an independent, external consultant with experience and expertise in water management.

This report presents the results of the assessment.

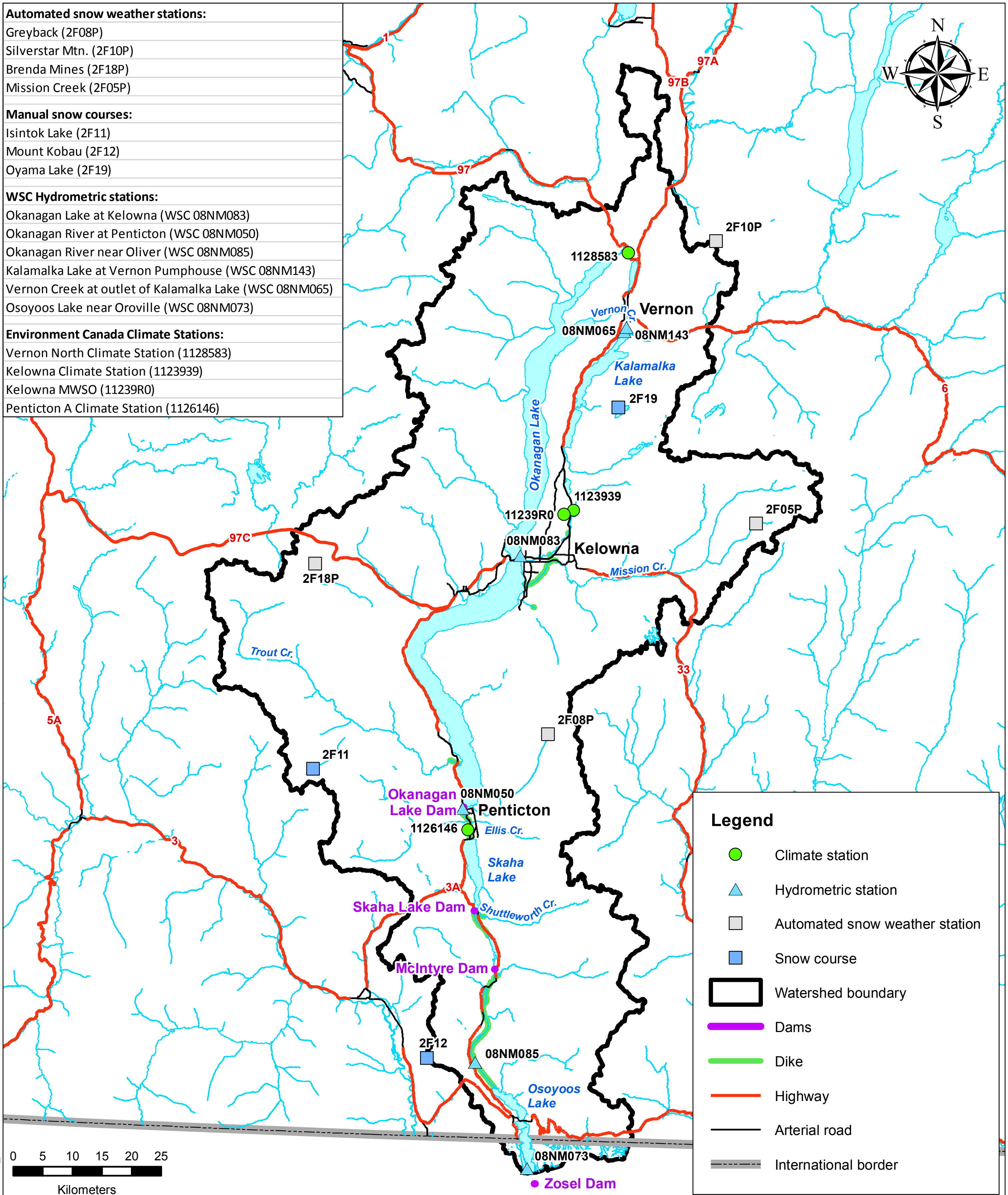

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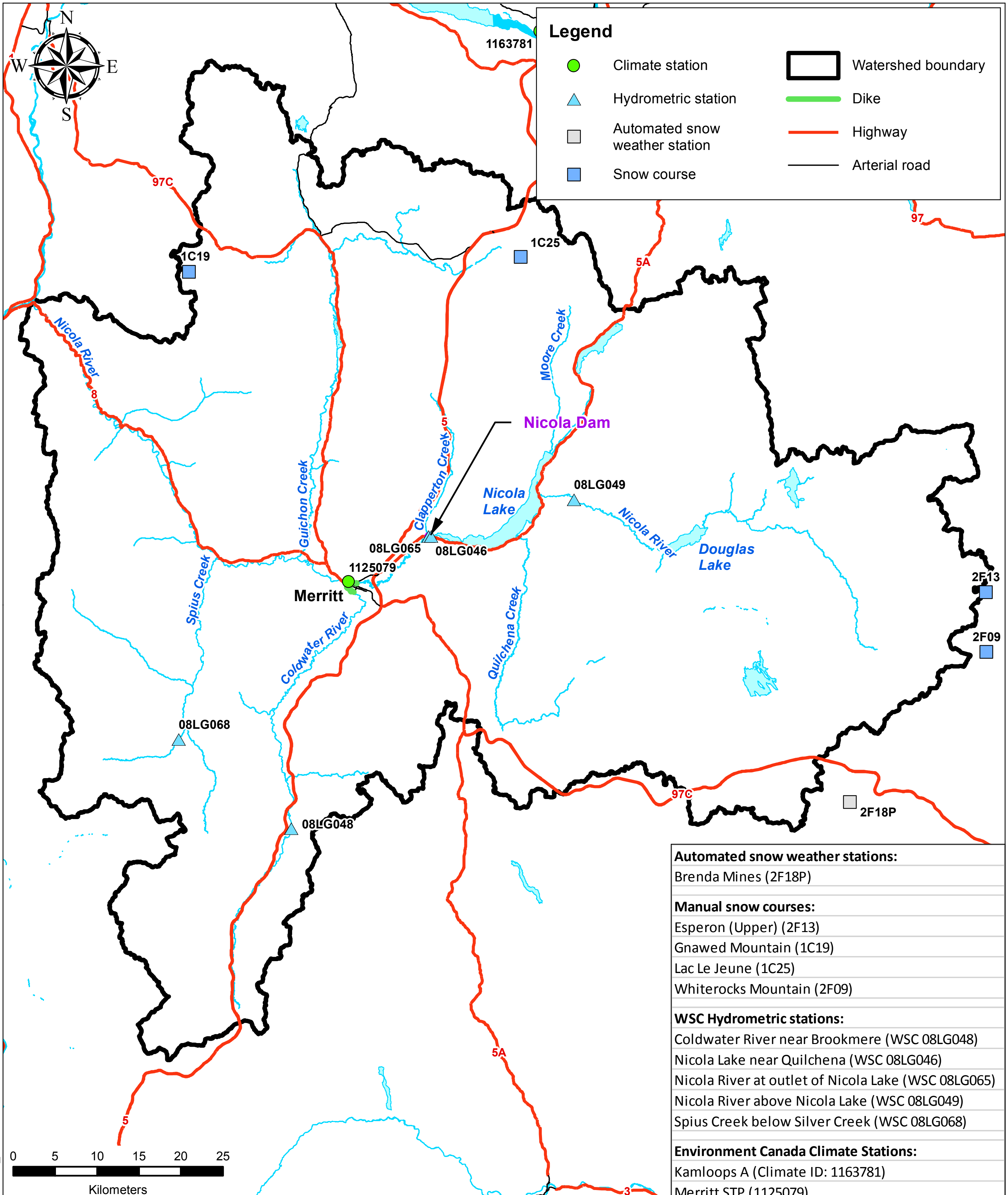
FIGURE 1-1: OKANAGAN WATERSHED AND OKANAGAN LAKE REGULATION SYSTEM

FLNRORD

Review of 2017 Flood Response: Okanagan Lake Regulation System and Nicola Dam



Automated snow weather stations:
Brenda Mines (2F18P)
Manual snow courses:
Esperon (Upper) (2F13)
Gnawed Mountain (1C19)
Lac Le Jeune (1C25)
Whiterocks Mountain (2F09)
WSC Hydrometric stations:
Coldwater River near Brookmere (WSC 08LG048)
Nicola Lake near Quilchena (WSC 08LG046)
Nicola River at outlet of Nicola Lake (WSC 08LG065)
Nicola River above Nicola Lake (WSC 08LG049)
Spius Creek below Silver Creek (WSC 08LG068)
Environment Canada Climate Stations:
Kamloops A (Climate ID: 1163781)
Merritt STP (1125079)

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FIGURE 1-2: NICOLA WATERSHED AND NICOLA DAM

FLNRORD

Review of 2017 Flood Response: Okanagan Lake Regulation System and Nicola Dam

2 Objectives and Tasks

As stated in the Terms of Reference for the assessment developed by FLNRORD, the purpose of the assessment was to evaluate the operation of the OLRS and Nicola Dam during freshet 2017, and identify opportunities for improvement during times of flooding.

The specific objectives of the assessment (taken from FLNRORD's Terms of Reference) were:

- To determine the effectiveness of the FLNRORD flood response in spring 2017, as it pertained to the operation of the Okanagan Lake Regulation System and Nicola Dam.
- To assess the models, information and data input that informed operational decisions, and identify any gaps or opportunities for improvement.
- To review decisions that were made in the operational management of the infrastructure during freshet 2017, assess their effectiveness, and make recommendations for improvement if required.
- To assess how information and operational decisions were communicated to response agencies and the public and make recommendations for improvement, if required.

Before work commenced, the fourth of these objectives was scaled back to "document the external communication that occurred during the period of high water".

Associated assumed that Kalamalka Lake was intended to be included within the scope of the assessment, although it is not formally part of the OLRS.

Front line flood response actions such as dike assessments carried out by FLNRORD were not part of this assessment, nor were flood response actions carried out by provincial agencies other than FLNRORD, or by other levels of government.

Associated completed the following tasks in support of the study objectives:

- Conducted interviews with key operational staff and others involved in the operations of the OLRS, Kalamalka Lake, and Nicola Dam in spring 2017;
- Reviewed the models and other information used to forecast inflows to the OLRS, Kalamalka Lake, and Nicola Lake;
- Described flooding impacts in the Okanagan and Nicola regions related to the operation of the OLRS, Kalamalka Lake, and Nicola Dam;
- Reviewed the decisions made by the FLNRORD managers who are responsible for the OLRS, Kalamalka Lake, and Nicola Dam operations;
- Evaluated operational practices and decisions against practices used in similar jurisdictions;
- Documented external communications by FLNRORD;
- Developed recommendations for improvement;
- Presented assessment results to FLNRORD key personnel during a meeting by teleconference on December 12, 2017; and
- Produced this report that describes our assessment of operations and our recommendations.

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3 Assessment Process

3.1 INTERVIEWS

Brian Guy and Rod MacLean of Associated interviewed the individuals listed in Table 3-1. Subsequently in this report, Shaun Reimer and Jeptha Ball are referred to as “Water Managers”.

Table 3-1
Interview Program

Name	Affiliation[1]	Role	Interviewee	Date	Method
Shaun Reimer, P.Eng.	FLNRORD	OLRS and Kalamalka Lake Water Manager	Rod MacLean	Sept. 12, 2017	Telephone
			Rod MacLean	Sept. 15, 2017	Meeting at his office
			Brian Guy	Oct. 26, 2017	Meeting at his office
Brian Symonds, P.Eng.	FLNRORD	Former OLRS and Kalamalka Lake Water Manager	Brian Guy	Oct. 31, 2017	Telephone
Jeptha Ball, P.Eng.	FLNRORD	Nicola Dam Water Manager	Brian Guy	Oct. 11, 2017	Meeting at his office
Kim Hyatt, Ph.D., R.P.Bio.	DFO	FWMT Okanagan Team Member	Brian Guy	Oct. 18, 2017	Telephone
David Campbell, P.Geo.	RFC	Head of the RFC	Brian Guy	Oct. 10, 2017	Skype
			Brian Guy	Oct. 31, 2017	Skype
Lars Uunila, P.Geo.	POLAR Geoscience	FWMT and NWMT Consultant	Brian Guy	Nov. 19 and 20, 2017	Email exchange

Note:
1. See Glossary

3.2 REVIEW OF INFLOW FORECASTING MODELS

The River Forecast Centre (RFC) uses several models and resources to provide the Water Managers with forecasts of the total spring inflow to the OLRS, Kalamalka Lake, and Nicola Lake at monthly intervals during winter and spring. These forecasts are then input into other models operated by the Water Managers and fisheries agencies, which subdivide the forecast of total inflow into daily and weekly increments, and allow users to run hypothetical scenarios to compare the implications of various potential lake release rates before a decision on release rates is made. The models, referred to as the Okanagan Fish Water Management Tool (FWMT) and the Nicola Water Management Tool (NWMT), allow the Water Managers to evaluate potential releases against fisheries and other objectives.

Associated obtained information on these models, and on their development and evolution, through two interviews with David Campbell, P.Geo., Head of the RFC, and an interview with Kim Hyatt, R.P.Bio., who helped develop the FWMT and the NWMT, and through review of documentation on the models. Mr. Campbell provided details on the data used to drive the inflow forecasting models and commented on their strengths and weaknesses. The Water Managers provided information on the volume inflow forecasting tools and on the FWMT and NWMT.

The strengths and weaknesses of the models and resources used to inform management of these systems were evaluated to assist in the development of recommendations.

3.3 DESCRIBE FLOOD IMPACTS

We obtained an understanding of the impacts of the 2017 spring flooding though the interviews noted above (Table 3-1) and through information obtained during two meetings (i.e., July 11, 2017 in Vernon and September 20, 2017 in Penticton) among local and provincial agencies, local consultants, and First Nation representatives to discuss the restoration of flood impacts in the Okanagan. These meetings were not directly related to the present study, but relevant information on flooding impacts was shared with Associated by the meeting attendees.

3.4 REVIEW OF OPERATIONAL DECISIONS

During and following the interviews with the Water Managers, summary information on the 2017 operations was provided to Associated. This information included details on:

- the volume inflow forecasts to Kalamalka, Okanagan, and Nicola Lakes received from the RFC;
- the actual inflows to Okanagan and Nicola Lakes;
- the Operating Plans for the facilities;
- consultations that occurred with fisheries representatives and other personnel during spring 2017; and
- water management decisions made by the Water Managers.

Operational decisions were assessed in light of this information.

3.5 EXAMINATION OF PRACTICES AGAINST BEST MANAGEMENT PRACTICES

We compared the resources of the RFC against those of other provincial River Forecast Centres. We briefly examined previous reviews of the operations of the RFC (WMC 2005, Mattison Enterprises 2010), which included recommendations for improvement, with a focus on how the 2017 events relate to those recommendations. Lastly, interviewees contacted during the present study provided comments on organizational challenges that constrain their abilities to deliver FLNRORD's flood forecasting and water management functions.

3.6 EXTERNAL COMMUNICATION

We learned about communication to internal agency personnel and external parties during the interviews with the Head of the RFC and the Water Managers.

3.7 REPORTING

Associated provided a summary of the assessment findings to senior FLNRORD staff in a meeting conducted via teleconference on December 12, 2017. This report summarizes our assessment of the 2017 flood response and provides recommendations to improve the delivery of water management services.

4 How the OLRS and Nicola Dam are Operated

4.1 OKANAGAN LAKE REGULATION SYSTEM

4.1.1 System Infrastructure

In the Okanagan, water flows from the high upland plateaux situated to the east and west of the major north-south aligned Okanagan valley downhill towards the valley bottom, where the major lakes of the region and the Okanagan River are located. Once in the valley bottom, water flows from north to south, crossing the Canada/USA border (which cuts across Osoyoos Lake) and into the USA. Each winter, snow accumulates on the high upland plateaux adjacent to the Okanagan valley, which melts and flows into the valley-bottom lakes in spring. This period of snowmelt runoff in spring is known as the "snowmelt freshet," or simply as the "freshet." On an annual basis, most of the annual inflow to the lakes arrives during the spring. Streamflows and lake levels decline through the summer and fall, and remain relatively steady over winter as the next spring's snowmelt accumulates again.

The OLRS (Figure 1-1) consists of three control dams (Okanagan Lake, Skaha Dam and McIntyre Dam), multiple vertical drop structures and drainage structures, 68 km of dike, 32 km of engineered river channel, and three sediment basins. The Province of B.C., represented by FLNRORD, operates the OLRS, which is used to manage lake levels in Okanagan, Skaha, and Vaseux Lakes, and the flow of the Okanagan River between Penticton and Osoyoos Lake.

Kalamalka Lake, situated in the north part of the Okanagan Basin (Figure 1-1), is not considered part of the OLRS, although it too is equipped with a control structure at its outlet, which is managed by FLNRORD. Osoyoos Lake at the southern extent of the Okanagan valley is controlled by Zosel Dam, located in Washington State. The dam is operated by the Oroville-Tonasket Irrigation District under operating rules provided by the International Joint Commission, and overseen by the International Osoyoos Lake Board of Control.

Symonds (2000) summarizes the water management history of Okanagan Lake and River, and provides a historical account of the development of the OLRS, which was constructed between 1950 and 1958. In 1976 the federal and provincial governments signed the Okanagan Basin Implementation Agreement, which includes an Operating Plan for the OLRS which is still followed today. The original purpose of the OLRS was to manage flooding, but water levels in Okanagan lakes today are managed to mitigate both flooding and drought, and operational decisions also consider instream flow needs and recreational values.

4.1.2 Forecasting Inflow to Kalamalka and Okanagan Lakes

4.1.2.1 RFC Models

<u>1984 Multiple Regression Models</u>
In the late 1970s the Province began developing methods to forecast the spring inflow to Okanagan lakes. These early tools were formalized in 1984, when the Province developed a set of multiple regression equations for forecasting the freshet inflow to Kalamalka Lake on four forecast dates, and another set of equations for forecasting the freshet inflow to Okanagan Lake on the same dates. The forecast periods in the 1984 equations extend from:

- February 1 to July 31;
- March 1 to July 31;
- April 1 to July 31; and
- May 1 to July 31.

The equations were generated using stepwise multiple linear regression, with the forecast-period inflow volume as the dependent variable; and hydrometric and meteorologic data (e.g., snowpack water equivalent, total precipitation, and streamflows) as the predictor variables.

<u>1999 Principal Components Analysis Models</u>
Because of operational difficulties associated with high uncertainty in the early season forecasts, and because nearly 15 years had elapsed since the models had been developed, in 1998 the Province commissioned a study (Summit 1999)[1] to review and improve these volume inflow forecasting models.

After considering the benefits and challenges of a forecasting method based on Ensemble Streamflow Prediction (ESP), which was in use at BC Hydro at the time, the Summit report authors adopted a regression approach based on principal components analysis (PCA) for improving the forecast equations. They compiled a new data set covering the full period of record up to and including 1997. In addition, they examined the potential usefulness of several predictor variables not included in the 1984 models (e.g., groundwater levels, plateau reservoir storage, a basin-wide index of snow water equivalent [derived using a trend surface approach and a digital elevation model of the Okanagan basin], and forecasts of future precipitation during the period covered by the inflow forecast published by the Canadian Institute of Climate Studies). They discovered that there was insufficient resolution in the data describing these variables to render them effective, so they were all subsequently discarded from the analysis. The remaining predictor variables implicitly account for the influences of these variables. In particular, the models implicitly assume that the spring precipitation (amount, type, and elevational distribution) will be the same as in an average year.

The 1999 volume inflow forecast equations use the following predictor variables:

- Water content of the upland snowpack (i.e., measured at manual snow courses or automated snow weather stations – melting snow is usually the main driver of the spring inflow);

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[1] Summit Environmental Consultants Ltd. is now known as Associated Environmental Consultants Inc.

- Fall precipitation (i.e., indicative of soil moisture status and storage in upland reservoirs);
- Winter precipitation in the valley bottom (i.e., indicative of early spring runoff potential); and
- Volume inflows to the lake in the preceding months (i.e., indicative of the current baseline rate of inflow).

Residual (unexplained) variation in the dependent variable is captured in a standard error value for each forecast equation.

For each of Kalamalka Lake and Okanagan Lake, and each of the four forecast dates (February 1, March 1, April 1, and May 1), the Summit (1999) report provided:

- the optimal volume inflow forecast equation covering the forecast period (i.e., the forecast date to July 31);
- a second equation in which the independent variables are the same for each forecast date (to facilitate data input);
- a user interface to facilitate operation of the models and storage of the results;
- a method of disaggregating each volume inflow forecast into monthly inflows, based on the average distribution of forecast-period inflows for the period of record;
- a method of estimating missing data for any of the forecast equations;
- the top 20 equations (each of the 160 equations [20 equations for four forecasts for each of two lakes] performed sufficiently well that any one of them could be used as a replacement for the optimal equation in case of missing data on any forecast date);
- a set of three back-up equations for each forecast date (24 in total), for use in case an entire class of data is missing (e.g., snow course data or fall precipitation data) on the forecast date; and
- An estimate of the standard error for each one of the 1999 forecast models.

These new models were significantly better than the 1984 models, and offered the RFC considerable power and flexibility.

<u>2011 Principal Components Analysis Models</u>

In 2010, Jim Mattison, a former senior member of the provincial water management staff, was commissioned to review the operations of the RFC. Following receipt of the report of that investigation (Mattison Enterprises 2010), the Province reviewed the 1999 inflow forecasting equations, which resulted in some updates to the equations, as reported by Jackson (2011). The Jackson (2011) report also created or modernized volume runoff forecast equations based on the PCA approach for many other river basins in B.C., and standardized the approach across the province.

The updated Kalamalka and Okanagan PCA equations make use of more current data, and now offer forecasts for two forecast periods on each forecast date: (1) from the forecast date to June 30; and (2) from the forecast date to July 31; but they do not offer the breadth of choice in case of missing data offered by the 1999 PCA equations. The wide range of potential 1999 PCA equations for each forecast date has been simplified to one equation for each date for each of the two forecast periods for Kalamalka Lake, and two equations for each date for each of the two forecast periods for Okanagan Lake.

The following predictor variables drive the 2011 PCA models (Figure 1-1):

- Precipitation data from Kelowna MWS0;
- Snow water equivalent data from automated snow weather stations at Greyback Reservoir (2F08P), Brenda Mine (2F18P), Mission Creek (2F05P), and Silver Star Mountain (2F10P);
- Snow water equivalent data from snow courses at Oyama Lake (2F19), Isintok Lake (2F11), and Mt. Kobau (2F12); and
- Antecedent inflows.

Finally, in using the 2011 PCA models, the RFC also relies on U.S. National Oceanic and Atmospheric Administration (NOAA) satellite data that indicate the spatial extent of snow cover. This helps the RFC interpret the model output and provides insight into medium and low elevation snow cover at the time of the forecast.

<u>2016 Ensemble Streamflow Prediction (ESP) Model</u>

In 2016 the Province initiated an internal study (Jackson 2011) to develop a new approach to volume inflow forecasting for Okanagan and Kalamalka Lakes. The main objective was to add a short-term weather forecast to the existing PCA models. Notwithstanding the challenges identified with the use of ESP in the Summit (1999) report, the Province has developed an ESP model for use in inflow forecasting for these two lakes. The model works as follows:

- It uses the RAVEN hydrologic modelling framework (RAVEN undated) to simulate the hydrologic state of the watershed on each forecast date;
- It then predicts lake inflows for 10 days using a combination of two short-term weather forecasts produced by Environment Canada (i.e., one for days 1 and 2, another for days 3 – 10);
- It then predicts lake inflows beyond 10 days using an ensemble of the past 37 years of observed weather during the forecast period to drive the RAVEN hydrologic model to the end of the forecast period (i.e., either June 30 or July 31).

To date there has been no formal documentation produced for the new ESP models.

RAVEN is a deterministic hydrologic process model. In the Okanagan application, the watershed was subdivided into 100 homogeneous "hydrologic response units" (within which all the factors that affect hydrology are assumed to be homogeneous), and it was calibrated using 37 years of data up to and including 2015. It was deemed ready for use in fall 2016, and was used on a trial basis during the 2017 snowmelt freshet period. In particular, it was run on a weekly basis during May 2017 after the final PCA forecast was produced on May 7.

Advantages of the RAVEN modelling framework include flexibility in terms of the complexity with which hydrologic processes are represented mathematically, and relatively fast run times. It can be updated each time a new weather forecast is produced (i.e., daily). In addition, a user can manually adjust the recent weather input to the model until a reasonable match is achieved between modelled and actual streamflows up to the forecast date. This newly "calibrated" model is then used to derive streamflow forecasts based on the current 10-day weather forecast.

Potential disadvantages of the Okanagan RAVEN application include a possible over-simplification resulting from the large size and small number of the "hydrologic response units," which may result in relatively poor ability to replicate the inherent variability of hydrologic response across the Okanagan landscape. By comparison, DHI's Mike SHE hydrology model, which was calibrated for the Okanagan in 2009, is driven by a network of over 30,000 grid cells, each only 500 m by 500 m in area, and each linked together to allow simulation of hydrologic response and flow routing throughout the basin. The same grid cell network is used by the Okanagan Water Demand Model used to estimate water demand by crops and other vegetated surfaces throughout the Okanagan.

Also, RAVEN does not explicitly represent groundwater, or groundwater/surface water interactions, nor include the option to estimate surface (or groundwater) withdrawals that remove water from the system. These limitations will restrict its ability to achieve a good calibration with observed streamflows in the Okanagan. The PCA models implicitly but crudely account for these processes through the regression approach.

<u>CLEVER Model</u>
The final model employed by the RFC is known as CLEVER. It was developed in-house by RFC staff for about 100 watercourses in B.C., including Mission Creek in the Okanagan and Nicola River. The CLEVER model provides a 10-day streamflow forecast based on the 10-day weather forecasts produced by Environment Canada (i.e., the same forecasts used by the 2016 Okanagan ESP models). Hydrologic conditions are estimated based on temperature and precipitation measured at climate stations and automated snow weather stations.

This model was run daily during spring 2017 to provide support to the other inflow forecasting methods, but not used directly to provide inflow forecasts to the regional Water Managers.

4.1.2.2 Okanagan Fish Water Management Tool (FWMT)

<u>"Legacy" FWMT Model</u>
The OLRS Operating Plan (Table 4.1) was developed primarily to balance flood and drought prevention objectives. FLNRORD draws the lake level down in early spring to allow for spring inflows, but not so low that there is insufficient water later in summer to meet water supply objectives downstream. The Operating Plan identifies specific aquatic ecosystem objectives (Table 1 and Figure 2 of Hyatt et. al. 2015; Symonds 2000), but also identifies situations where these objectives can be overridden in favour of the drought or flood prevention objectives.

Between 1997 and 2002, in response to concerns that aquatic ecosystem needs had not been clearly specified along the Okanagan River and lakes downstream of Penticton, and that water management decisions often did not give sufficient consideration to these needs, the Canadian Okanagan Basin Technical Working Group (COBTWG – an informal group of First Nation, federal, and provincial agencies) developed the Okanagan FWMT.

The FWMT is a computer model that disaggregates the volume inflow forecast produced by the RFC into weekly components based on an average historical weekly distribution of inflow during the forecast period. It incorporates specific aquatic ecosystem constraints, such as minimum and maximum lake outflow rates while sockeye eggs are developing in redds in the Okanagan River (i.e., to avoid desiccation and scour, respectively). It also allows a model user to evaluate a range of possible lake outflow scenarios to help select an optimal outflow scenario that meets as many of the operational constraints as possible, including constraints based on aquatic ecosystem needs. Finally, a model user can override the volume inflow forecast produced by the RFC, and specify a different value for scenario-running purposes (such as the expected value plus or minus one standard error, or the expected value plus or minus two standard errors).

The background leading to the development of the Okanagan FWMT, and a detailed description of the model, are provided by Hyatt et. al. (2015). Since the 2016 upgrade to the original FWMT model (described below), the original FWMT has become known as the "legacy" FWMT model.

<u>2016 upgraded FWMT Model</u>

The "legacy" FWMT model worked successfully for 12 years, and in 2014, work began on upgrading it. Most of the internal sub-models were revised, including the hydrology sub-model. The two improvements to the hydrology model were: (1) the former weekly time step was changed to daily, and (2) the revised model includes a statistical routine, which identifies previous years that are most likely to be a close match to the current year with respect to the total volume and temporal distribution of the inflow.

Using a daily time step in the upgraded model means not only that the volume inflow forecast provided by the RFC can be distributed into daily components, but that the model can be updated every day based on actual inflows without waiting for a new RFC volume forecast. However, in its current form, the daily inflow estimates are rolled up into weekly values for output to the user. The upgraded FWMT was ready for use in fall 2016, so none of the FWMT Team had experience with it in spring 2017, and it was run on a prototype basis in which results were interpreted with caution.

The statistical matching routine used in the upgraded model is a considerably more sophisticated non-parametric statistical method (known as Real-Time Statistical Matching [RTSM]) than the disaggregation method used in the "legacy" FWMT. It creates a forecast of daily future flows by finding a prior year that closely resembles the current year. This concept should work well in most years in a stationary climate, although it won't work as well in extreme years. In the current non-stationary climate, weather patterns and hydrologic response may be less well represented in the historical record. However, each year the model is run becomes part of the historical record, so the model is able to partially keep pace with a changing climate.

4.1.3 OLRS and Kalamalka Operating Plans

The OLRS Operating Plan is presented in Table 4-1. Guidelines to assist the Water Manager in implementing the plan are provided in Table 4-2. The Kalamalka Lake Operating Plan is presented in Table 4-3.

Table 4-1
Okanagan Lake Regulation System Operating Plan

Month	Volume Forecast (million m³)	Okanagan Lake Elevation (m)	Skaha Lake Elevation (m)	Vaseux Lake Elevation (m)	Flow at Oliver (m³/s)
January		341.74 by month end	337.80	327.40	5.0 - 28.3
February	< 430	As high as possible	337.80	327.40	5.0 - 28.3
	> 430	341.54 by month end (341.64 in FWMT)			
March	< 620	As high as possible	337.80	327.40	5.0 - 28.3
	> 620	341.49 by month end			
April	< 250	As high as possible	337.80	327.40	5.0 - 28.3
	370 - 500	341.44 by month end			5.0 - 28.3
	> 620	341.34 by month end (major flooding expected)			> 45.0
May	Lake Filling	342.48 by month end	337.85	327.50	> 6.5
June		342.44 by month end	337.90	327.60	> 6.6
July		342.24 by month end	337.90	327.60	> 8.2
August		342.04 by month end	337.90	327.60	10.6 - 28.3
September		324.04 on Sept. 1.	337.85	327.50	9.2 - 28.3
		341.94 by Sept. 15.			9.9 - 15.6
		341.89 by Sept. 30.			
October		341.84 by Oct. 15	337.80	327.40	9.9 - 15.6
November		341.84 by month end	337.80	327.40	5.0 - 28.3
December		341.84 by month end	337.80	327.40	5.0 - 8.3

Notes:
1. Okanagan Lake elevations are measured by Water Survey of Canada (WSC) and referenced to an assumed datum. A conversion factor of 340.236 m is used to convert to GSC datum. The conversion factor has changed over time; however, elevations included in the current Operating Plan have been updated to reflect the current conversion factor (i.e., 340.236 m).
2. Target lake elevations are based on the expected value of the inflow forecast, but do not explicitly consider the standard error of the forecast.
3. Lake elevations are targeted for the end of the month unless otherwise noted.
4. Flows at Oliver are targeted for the beginning of the month unless otherwise noted.
5. Maximum flows at Oliver may be exceeded in August and September due to extreme flood conditions.
6. Lake levels may be exceeded due to extreme flood conditions.
7. Okanagan Lake levels may not be attained due to extreme drought conditions.
8. Okanagan River flows at Penticton and Okanagan Falls are "as required to obtain lake levels."
9. Flows at Oliver from November 1 - April 30 not less than 50% of the September 15 - October 31 flow.

Table 4-2
Okanagan water management guidelines

Guideline Number	Guideline
1	Do **not** fill Okanagan Lake above 342.75 m.
2	Avoid drawing down Okanagan Lake below 341.5 m.
3	Minimize the drawdown of Okanagan Lake between the time of peak kokanee shore spawning and the date of 100% fry emergence (~March/April), i.e., minimize de-watering of kokanee eggs and fry subject to guidelines 1, 8 and 9.
4	Do not exceed 65 m^3/s releases at Okanagan River, Penticton, to minimize the number of buildings flooded at and downstream of Penticton. *Note: Okanagan Lake dam at Penticton is capable of water releases upwards of 78* m^3/s *under flood elevations. The 60* m^3/s *design level has been exceeded several times in the past.*
5	Provide summer flows for river recreation if possible (i.e., maintain flows of 20-30 m^3/s in July through August), subject to satisfying **ALL** other guidelines.
6	Adult sockeye migration - maintain flows at Oliver between 8.5 and 12.7 m^3/s from August 1 to September 15 to allow "easy" passage, subject to guidelines 1 and 2.
7	Adult sockeye spawning - maintain flows between 9.9 and 15.6 m^3/s from September 16 to October 31 to maximize "good" spawning habitat, subject to guidelines 1 and 2.
8	Sockeye egg and alevin incubation - keep flows between 5.0 and 28.3 m^3/s from November 1 to the anticipated date of 100% emergence (~April/May), i.e., incubation flows must be greater than or equal to 50% of spawning flows and must not exceed 28 m^3/s to avoid redd desiccation and scouring (respectively), subject to guidelines 1 and 2.
9	Sockeye fry emergence and migration - maintain flows between 5.0 and 28.3 m^3/s from February 16 to April 30, subject to guidelines 1 and 2.
10	Maintain adequate sockeye rearing habitat in Osoyoos Lake - under drought and early onset of temperature/oxygen "squeeze," provide average August or September inflows above 10 m^3/s to avoid high mortality of rearing fry, subject to guideline 2.

Table 4-3
Kalamalka Lake Operating Plan

Month	Month end Lake Level Target (m asl)	Discharge (Q) (m^3/s)
January	391.2	0.085 (minimum fishery flow)
February	391.2	FV[1] < 15 x 10^6: Q = 0.085
		FV > 15 x 10^6: Set Q to maintain lake level at 391.2
March	391.2	FV < 15 x 10^6: Q = 0.085
		FV > 15 x 10^6: Set Q to maintain lake level at 391.2
April	391.4	FV < 30 x 10^6: Set Q to achieve lake level of 391.5
		FV > 30 x 10^6: Set Q to achieve lake level of 391.4
May	391.6	Set Q to achieve lake level of 391.6
June	391.7	Set Q to achieve lake level of 391.7
July	391.6	Set Q to achieve lake level 391.6
August	391.5	Set Q to achieve lake level of 391.5
September	391.4	Set Q to achieve lake level of 391.4
October	391.35	Set Q to achieve lake level of 391.35
November	391.3	Set Q to achieve lake level of 391.3
December	391.25	Set Q to achieve lake level of 391.25

Note:
1. FV = Forecast Volume
2. As for Okanagan Lake, the lake elevation targets are determined by the expected value of the inflow forecasts - no direction is given on accounting for the forecast uncertainty.

Okanagan Lake is at “full pool” elevation at 342.48 m. The estimated 200-year return period lake level is 343.05 m, and the Flood Construction Level (FCL) for the area around Okanagan Lake is 343.66 m (B.C. Water Resources Service 1974).

Kalamalka Lake is at “full pool” at 391.82 m (WIB 1976); the estimated 200-year return period lake level is 392.2 m (McNeil 1997); and the FCL for the area around the lake is 393.2 m (Regional District of North Okanagan 2003, District of Lake Country 2016).

The 200-year lake level and the FCL for Kalamalka Lake are poorly documented. Several estimates of the 200-year elevation have been developed over the past several decades. For this report, we have chosen to adopt the most recent estimate (392.2 m), developed in 1997, even though that estimate appears to be an approximation.

4.1.4 Operational Procedures and Timing

4.1.4.1 Okanagan Lake

1. The RFC uses several tools to develop a volume inflow forecast for Okanagan Lake based on data collected on the first day of the following months: February, March, April, and May. The RFC forecasts cover two periods: (1) from the forecast date to June 30, and (2) from the forecast date to July 31. RFC provides these two forecasts to the OLRS Water Manager on or about the 7th of the month. The forecasts include a mean estimate and a standard error.
2. Upon receipt of each RFC forecast, the OLRS Water Manager inputs the volume inflow forecast for Okanagan Lake to the Okanagan FWMT, a desktop computer model that disaggregates the forecast volume inflow into weekly components (the “legacy” FWMT model), and into daily components (the 2016 revised FWMT model). However, the daily components are rolled up into weekly values for output to the user.
1. The FWMT Team members (FLNRORD, DFO, and Okanagan Nation Alliance [ONA]) independently examine potential flow release schedules, then meet to compare results. The non-FLNRORD members of the team provide advice to the OLRS Water Manager, but the Water Manager retains responsibility for managing the system.
3. The OLRS Water Manager considers the RFC forecasts, the input from the FWMT Team, the OLRS Operating Plan, and other relevant factors, and issues directions to set the gates on the Okanagan Lake dam to achieve a desired lake outflow.
4. Between this time and the date when the next volume inflow forecast is received from the RFC, the FWMT Team updates their estimated daily and weekly inflow distributions based on actual inflows subsequent to the forecast date, and the Water Manager may then update the flow release schedule.

4.1.4.2 Kalamalka Lake

1. Kalamalka Lake is about 10% of the size of Okanagan Lake, and it is not considered part of the OLRS. Instead, it is operated relatively independently of Okanagan Lake.
2. The RFC uses several tools to develop a lake inflow forecast for Kalamalka Lake based on data collected on the first day of the following four months: February, March, April, and May. The RFC forecasts cover two periods: (1) from the forecast date to June 30, and (2) from the forecast date to July 31. The RFC provides the forecast (mean and standard error) to the OLRS Water Manager on or about the 7th of the month.
3. Upon receipt of each RFC forecast, the Water Manager consults the Kalamalka Lake Operating Plan and sets the lake outflow in accordance with the lake inflow forecast and the Operating Plan targets.

4. The Water Manager can revise the lake outflow as needed to help achieve the month-end targets before the next RFC forecast is received.

4.1.4.3 Other Lakes and the Okanagan River

The OLRS includes target month-end elevations for Skaha and Vaseux Lakes, and for the flow of the Okanagan River at Oliver. The inflows to these lakes are primarily determined by the outflows from Okanagan Lake at Penticton. Similarly, the flow of the Okanagan River is largely set by the outflow at Penticton, although some influence is exerted by the management of Skaha and Vaseux Lakes, and tributaries contribute to the river (particularly in spring) between Penticton and Oliver.

Osoyoos Lake straddles the Canada/USA boundary, and is not part of the OLRS. Water flows through the lake and into the Okanogan River in Washington State, which is controlled at Zosel Dam at the southern limit of the lake. The dam is operated by the Oroville-Tonasket Irrigation District in accordance with an Operating Plan approved by the Osoyoos Lake Board of Control, a bilateral agency authorized by the International Joint Commission to manage Osoyoos Lake. Canada has no obligation to provide any particular flows across the border into the U.S., but the two countries have an informal cooperation agreement through which Canadian water managers help their American counterparts meet agricultural and aquatic ecosystem needs downstream of Osoyoos Lake to the extent possible.

The levels of Osoyoos Lake are determined by the inflows from Okanagan River, by the management of the lake levels at Zosel Dam, and by the flows of the Similkameen River, which enters the Okanogan River a short distance downstream of Zosel Dam. The Similkameen River watershed is about the same size as the Okanagan watershed, but because of the location of its headwaters, it produces spring freshet flows that can be a factor of ten higher than flows in the Okanagan River. These high flows can cause high water levels at the confluence of the Similkameen and Okanagan Rivers, and can create a significant backwater that extends up into Osoyoos Lake.

In 2017, due to high Okanagan River inflows and high Similkameen River flows, Osoyoos Lake reached unusually high (but not historic) levels.

4.2 NICOLA DAM

4.2.1 Dam Infrastructure

The Nicola Dam was built by the Nicola Ranch in the 1920s for irrigation and power generation. This ownership continued until 1986 when it was reconstructed with government funding. Since the 1990s, the Nicola Dam has been operated by the Province. The dam was upgraded in 2005 and is now operated to provide baseflows to meet environmental flow needs in the Nicola River downstream of the dam, and for flood control.

Major storage licenses are held by DFO and the Province. The dam includes two radial gates and one sluice gate. The combined maximum flow through the radial gates is 130 m^3/s when the lake is at the full supply level (626.83 m). The sluice gate is not used at high flows due to the potential for scour downstream of the dam. The spillway passes about 100 m^3/s. There are important salmon spawning areas in the Nicola River downstream of Nicola Lake, in particular about 2 km downstream of the lake.

The City of Merritt, located approximately 11 km downstream of the dam (11 km along the valley, not following the Nicola River), has built some dykes and reinforced river banks to help contain flooding of the Nicola River. The bankfull discharge of the Nicola River at Merritt is about 30 m^3/s, so the City experiences flooding when the river exceeds that flow.

The Coldwater River joins the Nicola River at the western side of Merritt, and Spius Creek joins about 17 km further downstream. These two sources provide larger flow contributions to the Nicola River than the flows released at the Nicola Dam (the mean annual flow released at the dam is 5.07 m^3/s[2], the mean annual flow of the Coldwater River is 8.10 m^3/s[3], and the mean annual flow of Spius Creek is 10.17 m^3/s[4]).

4.2.2 Forecasting Inflow to Nicola Lake

4.2.2.1 RFC Models

Inflow forecasting equations for Nicola Lake developed in 1984 were modernized in 2011, using the same Principal Components Analysis method first adopted for the Okanagan in 1999. The Nicola PCA models produce forecasts on the same dates and for the same forecast periods as the Okanagan models (i.e., February 1, March 1, April 1, and May 1) and for the same two forecast periods (i.e., forecast date to end of June, and forecast date to end of July).

The following predictor variables drive the 2011 Nicola PCA models (Figure 1-2):

- Precipitation data from Kamloops A and Merritt STP;
- Snow water equivalent data from the automated snow weather station at Brenda Mine (2F18P);
- Snow water equivalent data from snow courses at Whiterocks Mountain (2F09), Esperon Upper (2F13), Lac le Jeune (1C25), and Gnawed Mountain (1C19); and
- Antecedent inflows to Nicola Lake.

As for the Okanagan PCA models, the Nicola PCA models produce a standard error that can be used to estimate the uncertainty in the forecasts.

There is no ESP model in use for Nicola Lake. The CLEVER model has been calibrated for the Nicola River, and is used to support the PCA forecasts. The RFC staff make use of satellite-based snow cover imagery in the Nicola basin, as they do in the Okanagan basin, to support interpretation of the PCA forecasts.

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[2] Based on historic streamflow records from 1983-2014 recorded at WSC Station No. 08LG065 (Nicola River at Outlet of Nicola Lake.

[3] Based on historic streamflow records from 1913-2015 recorded at WSC Station No. 08LG010 (Coldwater River at Merritt.

[4] Based on historic streamflow records from 1911-2014 recorded at WSC Station No. 08LG008 (Spius Creek near Canford)

4.2.2.2 Nicola Water Management Tool (NWMT)

The NWMT was developed by the provincial government, the federal government (DFO), and the Nicola Tribal Association. The work proceeded in parallel with the modernizing of the Okanagan FWMT, and the NWMT shares many of the functions and features of the 2016 upgraded Okanagan FWMT. The NWMT includes the same real-time statistical matching (RTSM) routine used in the Okanagan FWMT, and includes an additional ability to model water withdrawals from the river downstream of the dam. The forecasted lake inflow volumes are disaggregated into daily values, which are rolled up into weekly values for output to the user.

The NWMT was first used operationally in spring 2017, and because it was new and the user team (Doug Edwards of DFO and Jeptha Ball of FLNRORD) lacked experience with it, its outputs were treated with caution by the user group. In addition, the users had some skepticism about some of the model outputs, and indicated that it needs improvement before it can be used with confidence.

4.2.3 Nicola Lake Operating Plan

Nicola Lake is operated in accordance with an Operating Plan developed in 1987 (MEP 1987). The lake is managed to provide sufficient flows to maintain aquatic ecosystem function, and to mitigate flood risks. The month-end target elevations for Nicola Lake are provided in Table 4-4. These targets are applicable to the "pre-dredging" condition described in the 1987 Operating Plan.

The full supply level for Nicola Lake is 625.83 m (MEP 1987). The estimated 200-year return period lake level is 626.9 m, and the FCL for the area around Nicola Lake is 627.9 m (MOE 1988).

**Table 4-4
Nicola Lake month-end target elevations**

Month	End of Month Target Elevation (m)
February	625.34 – 0.002 · February Inflow Forecast
March	625.54 – 0.004 · March Inflow Forecast
April	625.55 – 0.005 · April Inflow Forecast
May	625.83 – 0.5 (625.83 – May 1 Observed Lake Elevation)
June	625.83
July	625.83
August	625.69
September	625.54
October	Gradual drawdown aiming at elevation 625.0 on March 1
November	
December	
January	

Note:
The lake elevation targets are determined by the expected value of the inflow forecasts - no direction is given on accounting for the forecast uncertainty.

4.2.4 Operational Procedures and Timing

2. The RFC uses several tools to develop a volume inflow forecast for Nicola Lake based on data collected on the first day of the following four months: February, March, April, and May. The RFC forecasts cover two periods: (1) from the forecast date to June 30, and (2) from the forecast date to July 31. The RFC provides these two forecasts to the Water Manager on or about the 7th of the month. Each forecast includes an expected value and a standard error that describes the uncertainty in the forecast.
3. Upon receipt of each RFC forecast, the Water Manager inputs the volume inflow forecast for Nicola Lake to the NWMT, a computer model that disaggregates the forecast volume inflow into daily and weekly components, providing the weekly values to the user.
4. The NWMT Team members (DFO and the FLNRORD Water Manager) independently examine potential flow release schedules to achieve the various objectives, then meet to discuss results. The DFO input is considered advisory, as the Water Manager retains responsibility for managing the Dam.

5. The Nicola Water Manager considers the RFC forecasts, NWMT input, the Nicola Dam Operating Plan, and other relevant factors, and issues directions to set the gates on the dam to achieve a desired lake outflow.
6. Between this time and the date when the next volume inflow forecast is received from the RFC, both DFO and Water Manager update their estimated daily and weekly inflow distributions based on actual inflows subsequent to the forecast date, and the Water Manager may then update the flow release schedule.

5 Fall 2016 – Summer 2017 Weather Conditions

This section summarizes weather conditions between fall 2016 and summer 2017 to provide context for the subsequent analysis of high lake levels in the Okanagan and Nicola regions.

5.1 OKANAGAN

Valley bottom areas within the Okanagan experienced heavier than usual rains during October and November 2016, and upland areas likely did as well. At Penticton A and Vernon North climate stations, total rainfall was 190% and 230% of normal during October, and 121% and 165% of normal during November, respectively. As a result, soils throughout the watershed became saturated or nearly saturated at that time, thereby reducing the amount of storage available in the soil for rainfall and melting snow in spring 2017. In addition, upland reservoirs reached capacity by late fall / early winter, which eliminated their ability to store incoming rain and melting snow the following spring.

A long period of cold air temperatures in the valley bottom extended through the 2016/2017 winter period (i.e., December 2016 – February 2017). At Vernon North, Kelowna, and Penticton A climate stations, mean daily air temperatures for December 2016 and January 2017 were below the 1981-2010 climate normal daily minimum air temperature at each station. In addition, daily average temperatures recorded in February 2017 at the Vernon North climate station remained below the reported 1981-2010 climate normal daily minimum. Figures 5-1 to 5-3 display October 2016 – September 2017 mean daily temperatures recorded at Vernon North, Kelowna, and Penticton A climate stations, respectively, compared to 1981-2010 climate normal temperatures.

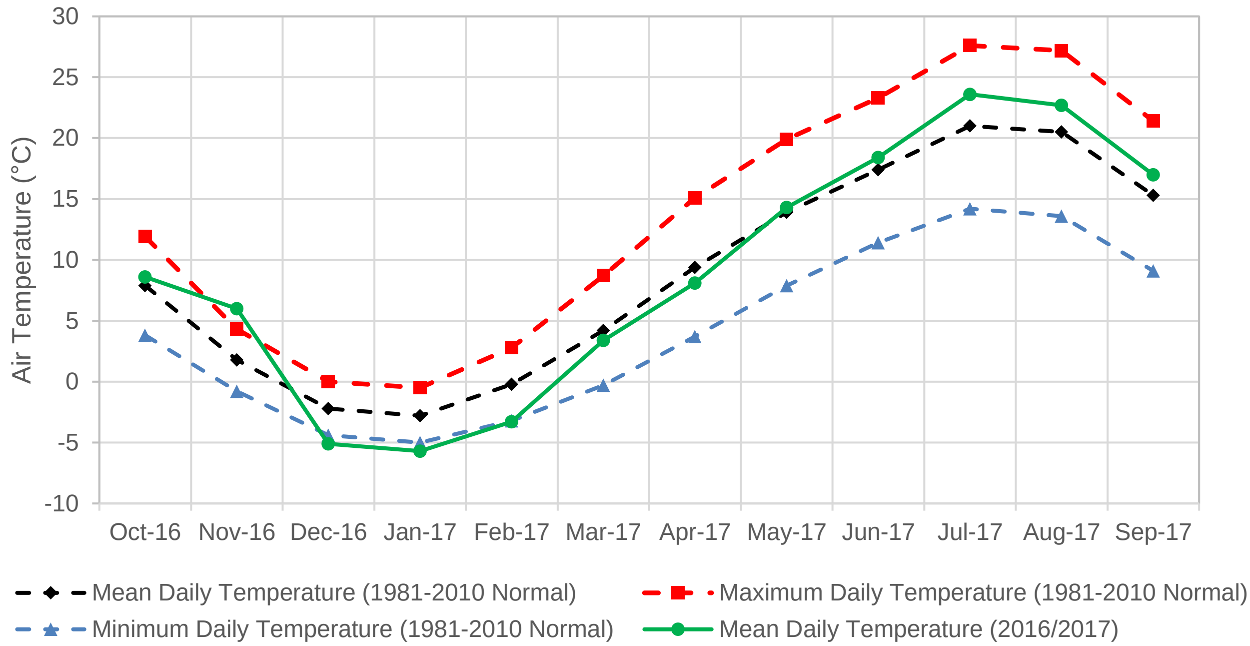

Figure 5-1
Air temperature measured at Vernon North Climate Station (Climate ID: 1128583)

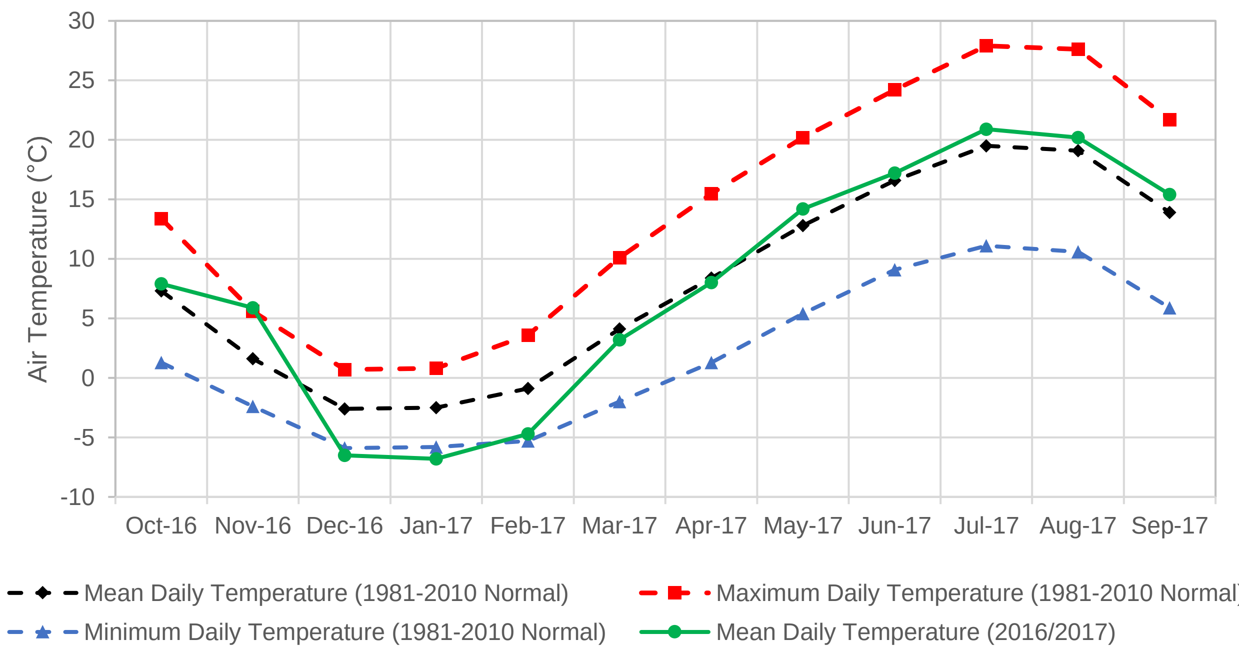

Figure 5-2
Air temperature measured at Kelowna Climate Station (Climate ID: 1123939)

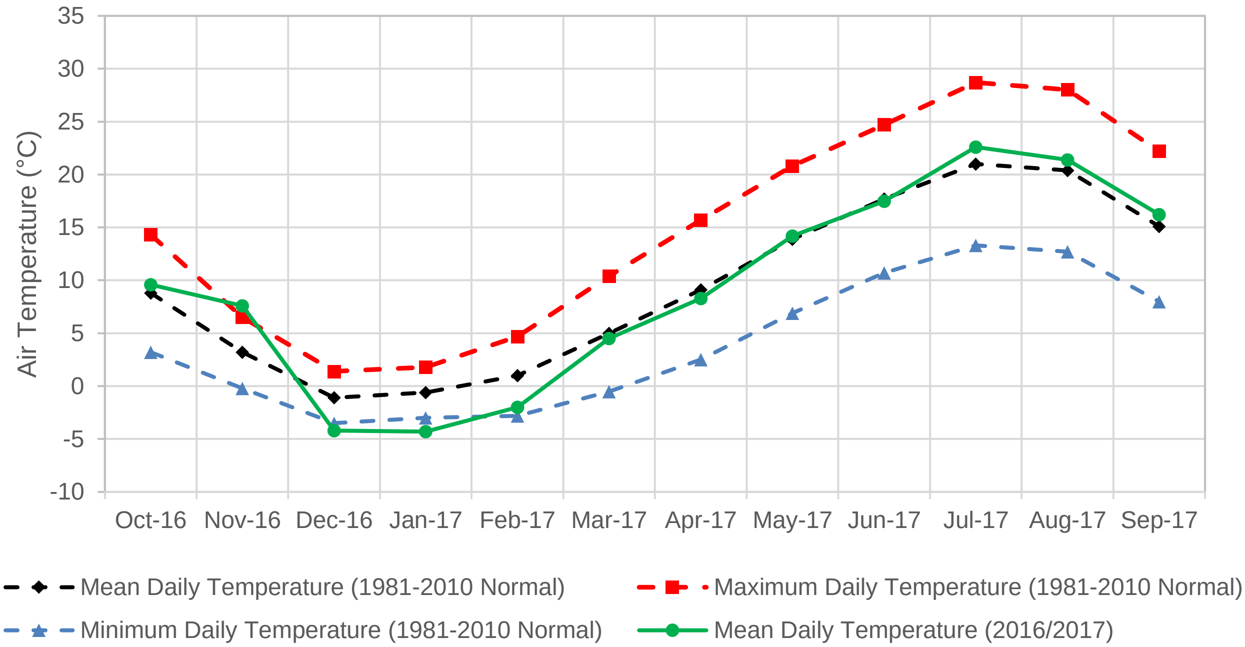

Figure 5-3
Air temperature measured at Penticton A Climate Station (Climate ID: 1126146)

Coupled with cold air temperatures, total snow recorded at Vernon North climate station was recorded to be 130% and 342% of normal for December 2016 and February 2017, respectively. At Penticton A climate station, December 2016 total snow was recorded to be 78% of normal, while total snow in February 2017 was 374% of normal. Despite heavy snowfall in the valley bottom, high elevation areas experienced considerably less snowpack than normal during the 2016/2017 winter period. Figures 5-4 and 5-5 present snow water equivalent measured at the Brenda Mine (Station ID: 2F18P) and Mission Creek (Station ID: 2F05P) automated snow weather station, respectively. Table 5-1 provides Basin Snow Water Index values for the Okanagan region from January 1, 2017 to June 15, 2017. The index value represents the high elevation snowpack that provides much of the inflow to the lakes in spring.

Tables 5-2 to 5-4 present the 1981-2010 climate normal data from three Environment Canada climate stations located in the valley bottom (i.e., Vernon North, Kelowna, and Penticton A). Included in these tables are climate data from October 2016 to September 2017 and the difference compared to the 1981-2010 climate normal for each location.

Table 5-1
Basin Snow Water Index values for the Okanagan Region

Date	Basin Snow Water Index (% of normal)
January 1, 2017	79
February 1, 2017	79
March 1, 2017	86
April 1, 2017	105
May 1, 2017	147
May 15, 2017	151
June 1, 2017	228
June 15, 2017	No Data

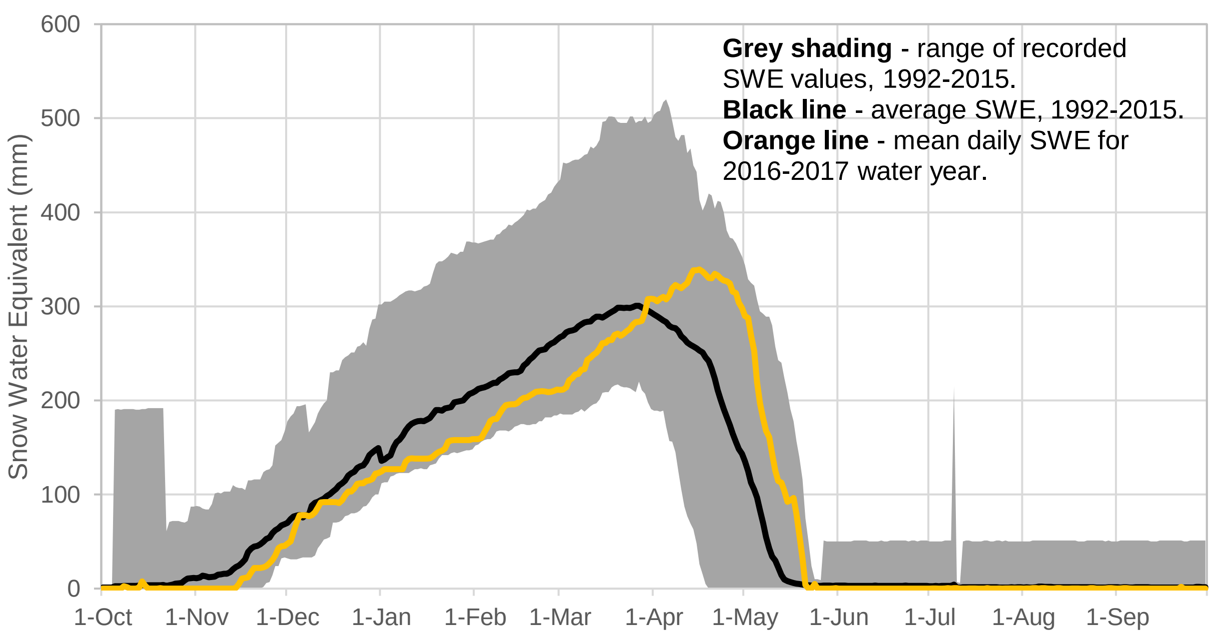

Figure 5-4
Snow water equivalent at Brenda Mines Automated Snow Weather Station (Station ID: 2F18P); Elevation: 1,453 m

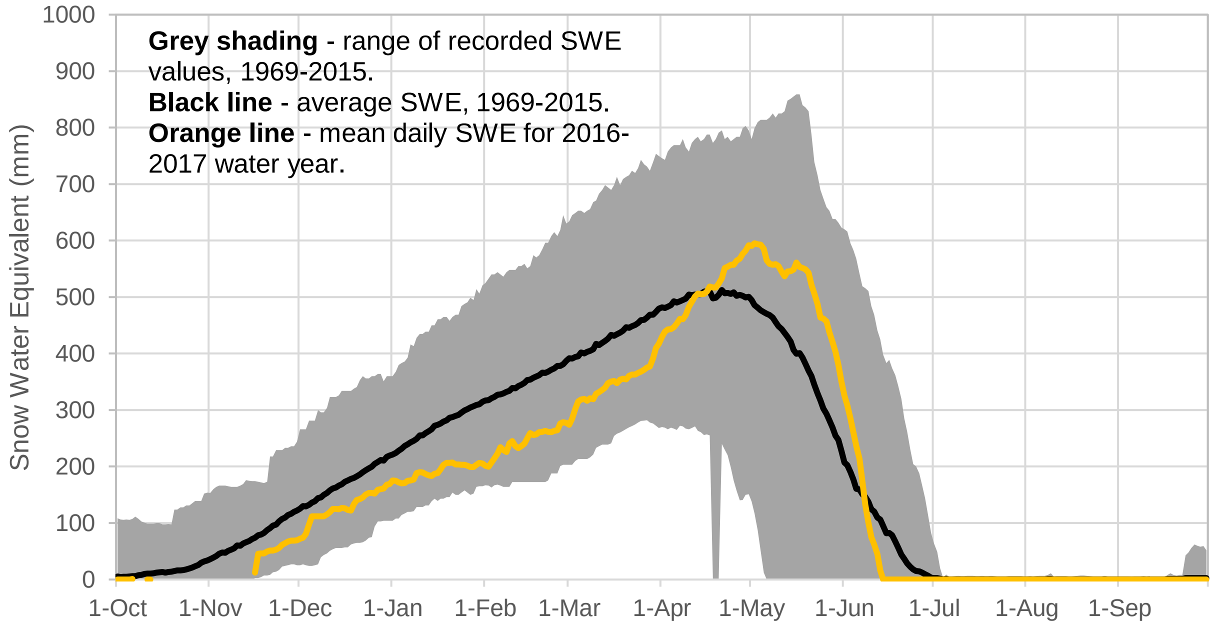

Figure 5-5
Snow water equivalent at Mission Creek Automated Snow Weather Station (Station ID: 2F05P); Elevation: 1,794 m

Table 5-2

Comparison of 1981-2010 Climate Normal Data and 2016/2017 Climate Data at Vernon North Climate Station (Climate ID: 1128583)

		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Precipitation													
Total Rain (mm)	1981-2010 Normal	40.7	31.1	9.7	11.6	11.7	17	27.2	46.3	49.6	35.4	31.9	32.7
	2016/2017	93.8	51.3	2.2	0.8	8.8	53.4	82	75.4	11.2	1	1	7
	% of Normal	230%	165%	23%	7%	75%	314%	301%	163%	23%	3%	3%	21%
Total Snow (cm)	1981-2010 Normal	0.9	26.5	47.3	40.5	13.5	11.7	1.8	0	0	0	0	0
	2016/2017	0	4	61.6	20.2	46.2	24.4	0	0	0	0	0	0
	% of Normal	0%	15%	130%	50%	342%	209%	0%	0%	0%	0%	0%	0%
Total Precipitation (mm)	1981-2010 Normal	41.5	57.5	57	52.2	25.2	28.7	29	46.3	49.6	35.4	31.9	32.7
	2016/2017	93.8	55.3	63.8	21	55	77.8	82	75.4	11.2	1	1	7
	% of Normal	226%	96%	112%	40%	218%	271%	283%	163%	23%	3%	3%	21%
Temperature													
Daily Average (°C)	1981-2010 Normal	7.9	1.8	-2.2	-2.8	-0.2	4.2	9.4	13.9	17.4	21	20.5	15.3
	2016/2017	8.6	6	-5.1	-5.7	-3.3	3.4	8.1	14.3	18.4	23.6	22.7	17
	Difference	0.7	4.2	-2.9	-2.9	-3.1	-0.8	-1.3	0.4	1	2.6	2.2	1.7

Table 5-3

Comparison of 1981-2010 Climate Normal Data and 2016/2017 Climate Data at Kelowna Climate Station (Climate ID: 1123939)[1]

		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Precipitation													
Total Rain (mm)	1981-2010 Normal	29.1	24.4	7.6	8.9	10	16.9	28.3	39.2	45.9	37.2	32.1	31.7
	2016/2017	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	% of Normal	-	-	-	-	-	-	-	-	-	-	-	-
Total Snow (cm)	1981-2010 Normal	0.1	13.6	32	26.9	10.8	4.8	0.8	0	0	0	0	0
	2016/2017	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	% of Normal	-	-	-	-	-	-	-	-	-	-	-	-
Total Precipitation (mm)	1981-2010 Normal	29.2	36.7	32.6	31	19	21.6	29.1	40.2	45.9	37.2	32.1	32.4
	2016/2017	60	28.3	8.3	2.8	16	36.9	32.1	31.1	9.3	0	0	3.6
	% of Normal	205%	77%	25%	9%	84%	171%	110%	77%	20%	0%	0%	11%
Temperature													
Daily Average (°C)	1981-2010 Normal	7.3	1.6	-2.6	-2.5	-0.9	4.1	8.4	12.8	16.6	19.5	19.1	13.9
	2016/2017	7.9	5.9	-6.5	-6.8	-4.7	3.2	8	14.2	17.2	20.9	20.2	15.4
	Difference	0.6	4.3	-3.9	-4.3	-3.8	-0.9	-0.4	1.4	0.6	1.4	1.1	1.5

Notes:

1. 1981-2010 Climate Normal Data are taken from Climate Station Kelowna A (Climate ID: 1123970) which was discontinued in 2005 and located approximately 130 m from the Kelowna Climate Station.
2. ND = No data available

Table 5-4

Comparison of 1981-2010 Climate Normal Data and 2016/2017 Climate Data at Penticton A Climate Station (Climate ID: 1126146)[1]

		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Precipitation													
Total Rain (mm)	1981-2010 Normal	26	21.8	11.4	12.6	14	20.3	25.4	39.3	46.3	28.7	28.3	24.6
	2016/2017	49.4	26.3	12.6	9.4	10.2	32.6	67.1	88.5	18.5	0	0	9.6
	% of Normal	190%	121%	111%	75%	73%	161%	264%	225%	40%	0%	0%	39%
Total Snow (cm)	1981-2010 Normal	0.1	7.5	21.1	18.3	7.6	3.5	0.6	0	0	0	0	0
	2016/2017	0	0	16.4	6.5	28.4	12	0	0	0	0	0	0
	% of Normal	0%	0%	78%	36%	374%	343%	0%	0%	0%	0%	0%	0%
Total Precipitation (mm)	1981-2010 Normal	26	28.1	28.6	26.9	19.8	23.6	26	39.3	46.3	28.7	28.3	24.6
	2016/2017	49.4	26.3	28.2	15.5	30.2	44	67.1	88.5	18.5	0	0	9.6
	% of Normal	190%	94%	99%	58%	153%	186%	258%	225%	40%	0%	0%	39%
Temperature													
Daily Average (°C)	1981-2010 Normal	8.8	3.2	-1.1	-0.6	1	5	9.1	13.9	17.7	21	20.4	15.1
	2016/2017	9.6	7.6	-4.2	-4.3	-2	4.5	8.3	14.2	17.5	22.6	21.4	16.2
	Difference	0.8	4.4	-3.1	-3.7	-3	-0.5	-0.8	0.3	-0.2	1.6	1	1.1

Notes:

1. 1981-2010 Climate Normal Data are taken from Climate Station Penticton A (Climate ID: 1126150) which was discontinued in 2012 and located approximately 500 m from the Penticton A (Climate ID: 1126146) climate station.

Following a cold winter in the valley bottom, spring precipitation recorded in the valley bottom was above normal, and upper elevation snowpack increased rapidly to above normal in late March / early April (Figures 5-4 and 5-5). Total precipitation recorded at Vernon North, Kelowna, and Penticton A climate stations ranged between 171% and 271% of normal in March 2017. Figures 5-6 to 5-8 present total precipitation recorded at Vernon North, Kelowna, and Penticton A climate stations between October 2016 and September 2017.

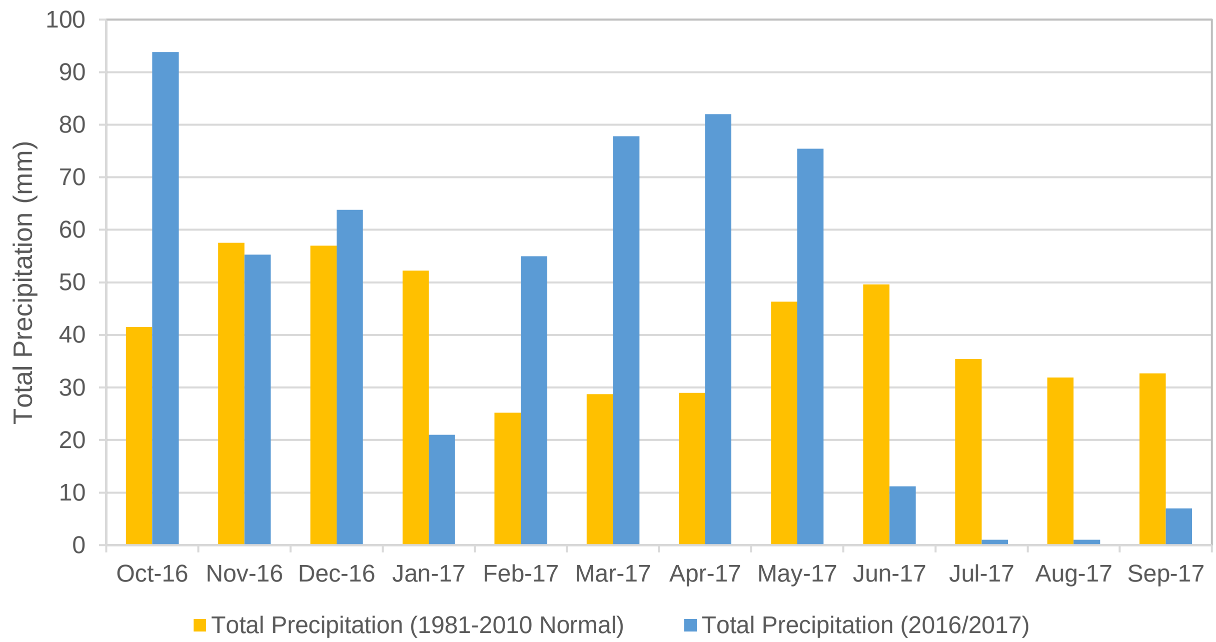

Figure 5-6
Total precipitation measured at Vernon North Climate Station (Climate ID: 1128583)

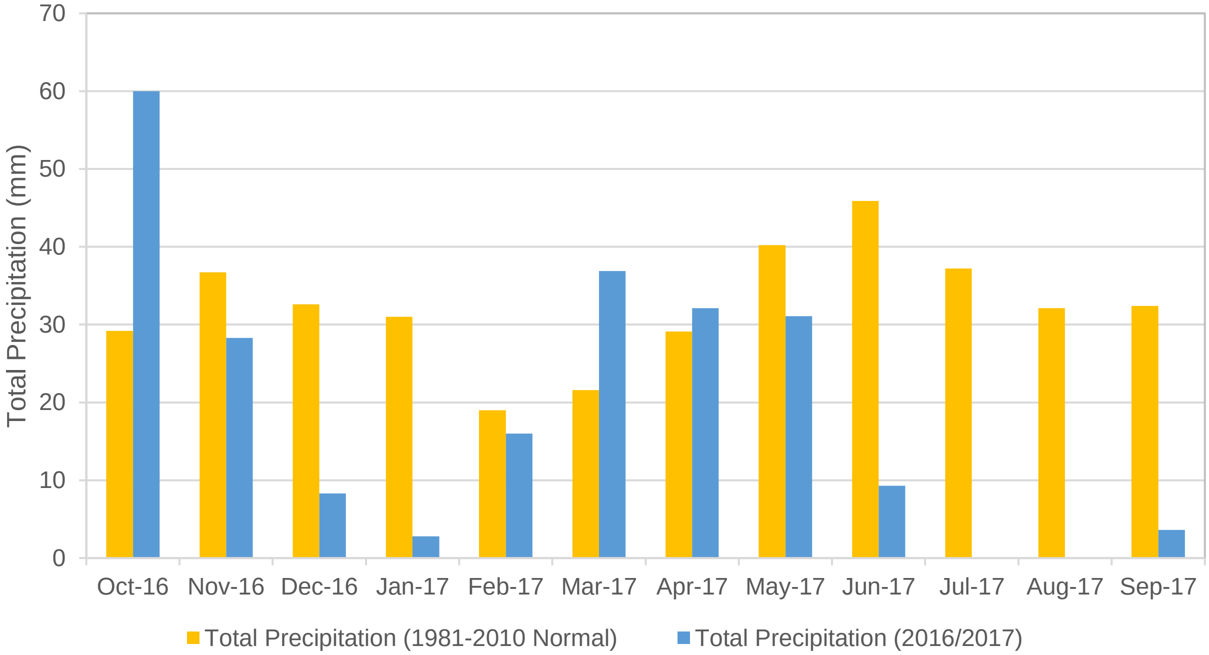

Figure 5-7
Total precipitation measured at Kelowna Climate Station (Climate ID: 1123939)

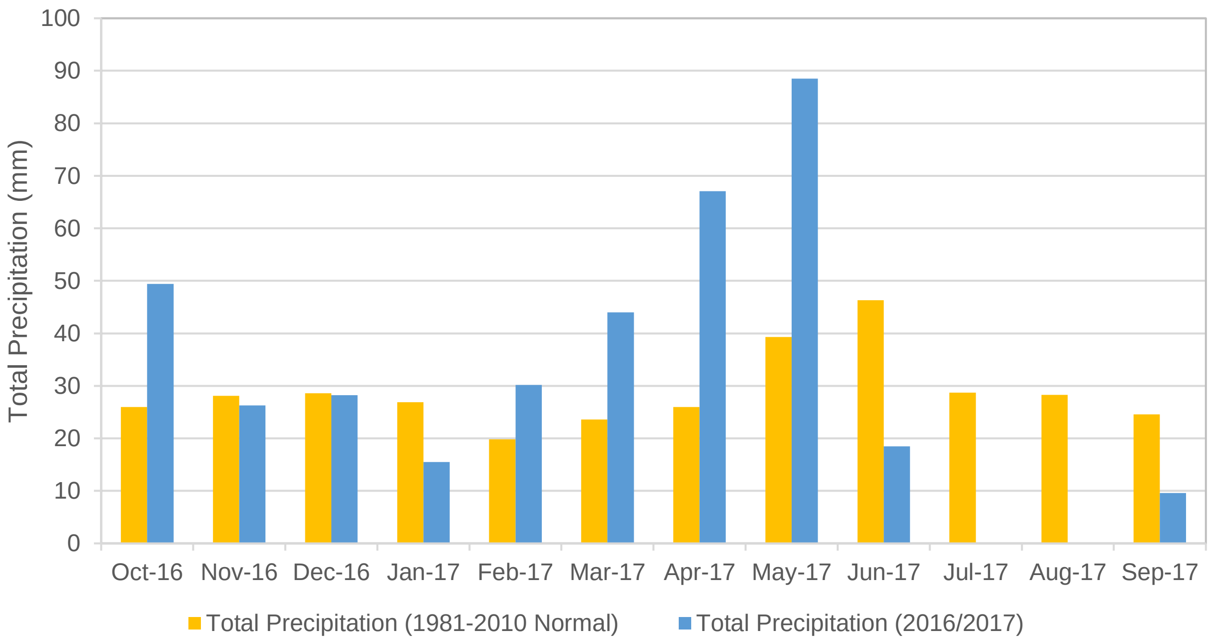

Figure 5-8
Total precipitation measured at Penticton A Climate Station (Climate ID: 1126146)

The combination of heavy fall rains, high spring snowfall in the uplands, and heavy spring rains in the valley bottom led to inflows to Okanagan Lake and Kalamalka Lake that were much higher than normal, and which were unusually concentrated in the month of May.

Following the unusually wet spring of 2017, summer 2017 was considerably drier than normal with June, July, and August precipitation at 23%, 3%, and 3% of normal, respectively, at the Vernon North climate station (Table 5-2). Similarly, at Kelowna and Penticton A climate stations, June was much drier than normal, and no precipitation was recorded during July and August (Tables 5-3 and 5-4). If summer conditions had not turned so quickly from wet to dry, flooding in the Okanagan region would likely have been worse.

5.2 NICOLA

Weather conditions in the Nicola region were very similar to those experienced in the Okanagan (Section 5.1). Fall rains recorded at the Merritt STP climate station were 239% and 106% of normal in October and November 2016, respectively. Winter mean daily air temperatures were at least 4°C below normal between December 2016 and February 2017. Mean daily air temperatures in December 2016 and January 2017 were below the 1981-2010 daily minimums (Figure 5-9). Cold air temperatures resulted in increased winter snowfall at Merritt, with 155%-549% of normal snowfall between December 2016 and February 2017. Table 5-5 provides Basin Snow Water Index values for the Nicola region (i.e., Middle Fraser Basin) from January 1, 2017 to June 15, 2017.

Table 5-5
Basin Snow Water Index values for the Nicola Region

Date	Basin Snow Water Index Value (% of normal)
January 1, 2017	82
February 1, 2017	81
March 1, 2017	84
April 1, 2017	97
May 1, 2017	110
May 15, 2017	122
June 1, 2017	107
June 15, 2017	162

In addition, as with the Okanagan, precipitation in the Nicola region during summer 2017 was below normal (Figure 5-10). Total precipitation measured at Merritt STP climate station in June, July, and August was 16%, 1%, and 10% of normal, respectively (Table 5-6).

Table 5-6
Comparison of 1981-2010 Climate Normal Data and 2016/2017 Climate Data at Merritt STP Climate Station (Climate ID: 1125079)

		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Precipitation													
Total Rain (mm)	1981-2010 Normal	26.2	23.4	13.3	13.7	11.0	11.8	14.2	29.8	36.6	29.1	20.6	24.6
	2016/2017	62.6	24.8	0	1.0	15.6	24.4	43.6	43.6	5.8	0.2	2.0	5.2
	% of Normal	239%	106%	0%	7%	142%	207%	307%	146%	16%	1%	10%	21%
Total Snow (cm)	1981-2010 Normal	1.3	12.0	22.7	16.8	8.3	4.4	0.9	0.3	0	0	0	0
	2016/2017	0	5	35.2	15.8	45.6	9.6	0	0	0	0	0	0
	% of Normal	0%	42%	155%	94%	549%	218%	0%	0%	0%	0%	0%	0%
Total Precipitation (mm)	1981-2010 Normal	27.6	35.4	36.0	30.5	19.4	16.2	15.1	30.1	36.6	29.1	20.6	24.6
	2016/2017	62.6	29.8	35.2	16.8	61.2	34	43.6	43.6	5.8	0.2	2.0	5.2
	% of Normal	227%	84%	98%	55%	315%	210%	289%	145%	16%	1%	10%	21%
Temperature													
Daily Average (°C)	1981-2010 Normal	7.6	1.2	-3.7	-3.0	-0.5	4.1	8.1	12.3	15.9	18.8	18.6	13.9
	2016/2017	7.7	5.5	-7.7	-7.5	-4.5	3.8	7.4	13.3	17.0	20.4	20.7	15.6
	Difference	0.1	4.3	-4.0	-4.5	-4.0	-0.3	-0.7	1.0	1.1	1.6	2.1	1.7

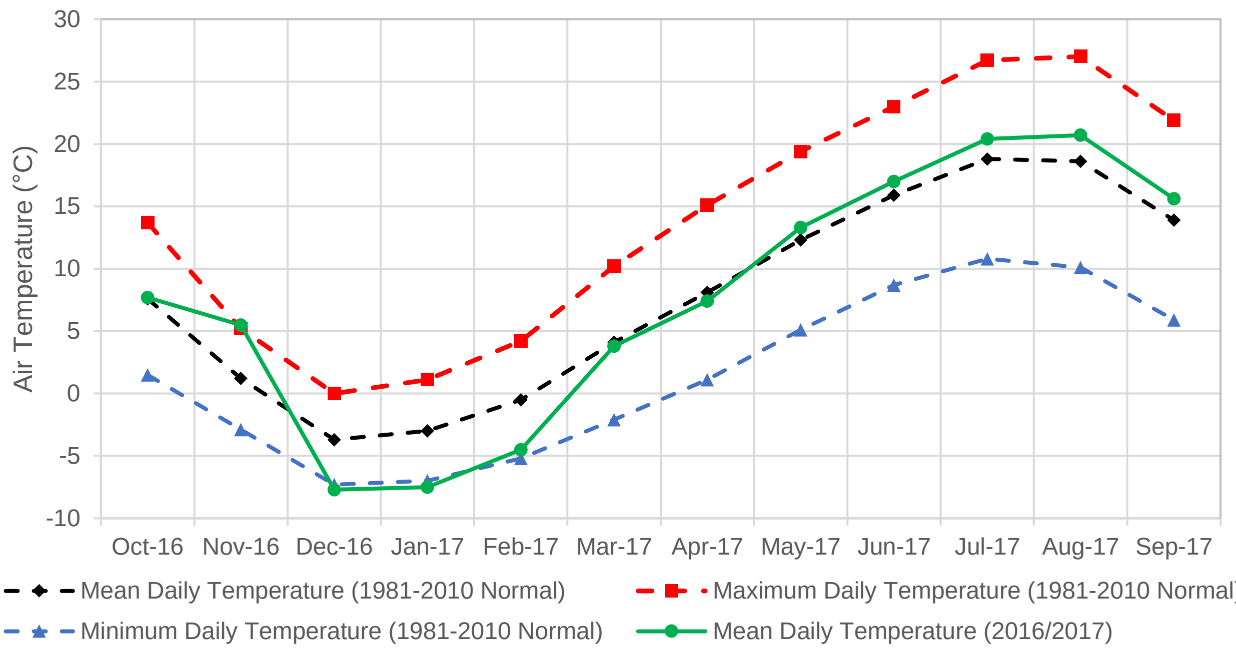

Figure 5-9
Air temperature measured at Merritt STP Climate Station (Climate ID: 1125079)

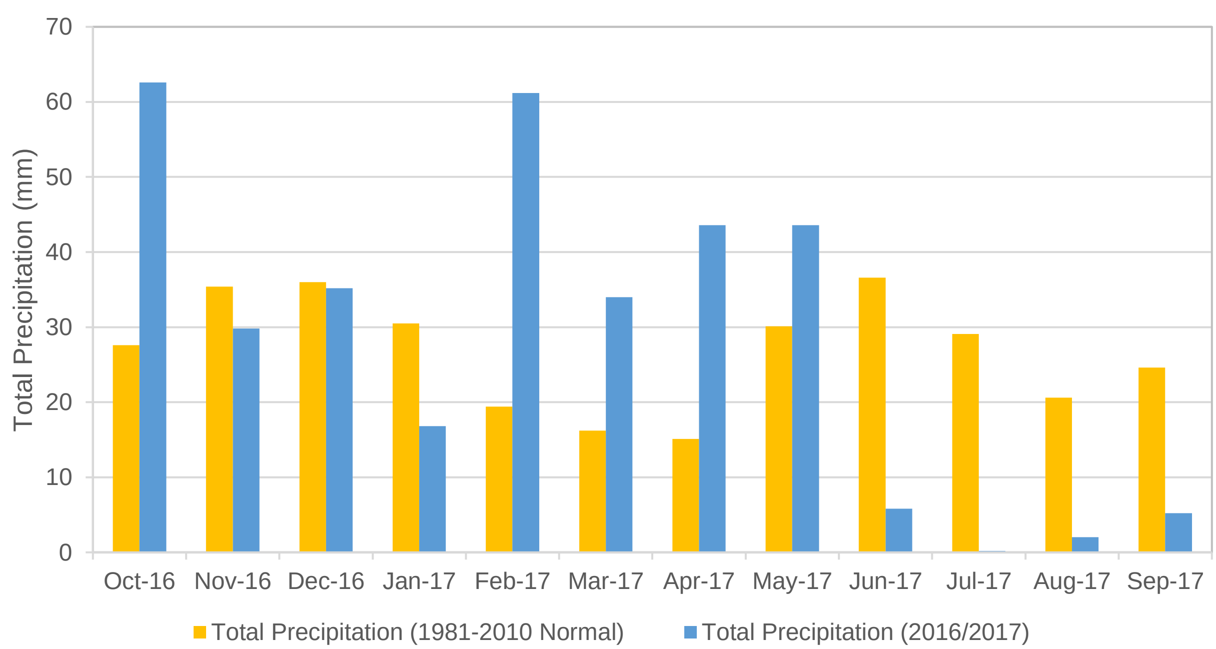

Figure 5-10
Total precipitation measured at Merritt STP Climate Station (Climate ID: 1125079)

6 Spring 2017 Flooding Impacts

The combination of weather conditions experienced in late 2016 and early 2017 lead to significant flooding along creeks and the Okanagan and Nicola Rivers, and high water levels on Okanagan Lake, other low elevation Okanagan lakes, and Nicola Lake. Okanagan Lake reached peak water levels not seen since before the OLRS was constructed (construction occurred between 1950 and 1958), resulting in impacts on infrastructure and properties.

Figures 6-1 and 6-2 plot the highest water level experienced on Okanagan Lake in 2017 along with the Flood Construction Level (FCL) for downtown Kelowna and the waterfront area of Penticton, respectively. Figure 6-3 shows the highest water level reached in 2017 around the north end of Nicola Lake, along with the FCL for the area around the lake.

On Okanagan and Kalamalka lakes, the maximum water levels reached in 2017 were 343.248 m and 392.453 m, respectively. On Nicola Lake, the maximum water level in 2017 was 626.968 m. The peaks on all three lakes exceeded the 200-year flood levels, but none reached the FCL elevations.

The 2017 lake level data used in this report was obtained from Water Survey of Canada. It is labelled preliminary and is provided to a precision of 3 decimal places (i.e. 1 mm). However, consistent with the precision assumed in the Operating Plans for the OLRS, Kalamalka Lake, and Nicola Lake, we have reported the 2017 data to 2 decimal places (i.e. 1 cm). Henceforth in this report we refer to the peak water levels as 343.25 m, 392.45 m, and 626.97 m, for Okanagan, Kalamalka, and Nicola lakes, respectively.

This section highlights some examples of the flood impacts experienced in the Okanagan and Nicola areas, and references several illustrative photographs in Appendices A and B. Subsequent sections of this report focus only on impacts on the mainstem lakes and rivers that are part of the OLRS and the Nicola system managed by FLNRORD.

6.1 OKANAGAN

Around Kalamalka Lake, high lake levels caused lakeshore property flooding, foreshore erosion, and damage to retaining walls and docks. Properties surrounding the Kalavista lagoon were flooded, and basements in this area required pumping for an extended period of time. Boat launches were shut down until mid-summer to mitigate damage from wave action. Lake access was restricted due to high water.

FLNRORD attempted to mitigate the high lake levels on Kalamalka Lake by releasing flow from the lake at as high a rate as possible without causing damage downstream. Flows were increased incrementally until several property owners notified FLNRORD about damage that was occurring, and then flows were scaled back. These owners included:

- Kalavida General Store;
- Dutch's Campground, which was flooded and shut down due to fallen trees caused by ground saturation;

- Vernon Golf Course, which sustained damage to the greens and fairways;
- The City of Vernon, which was concerned about bridge abutments being undermined by high flows;
- Polson Park, in which the ground became saturated adjacent to the creek, and the stability of retaining walls along the creek and nearby trees became a concern that persisted until late August; and
- Ministry of Transportation and Infrastructure, which reported that the culvert under Highway 97 at Polson Park was filled to capacity, and fill under the road eroded over time, until a large sink hole (the size of a car) developed in the northbound lanes.

In addition, the outlet of Swan Lake flooded and culverts on BX Creek washed out. Swan Lake empties into BX Creek, which flows into Vernon Creek downstream of Kalamalka Lake. The flow of BX Creek therefore influences the rate at which water can be released from Kalamalka Lake.

Associated Environmental

Peak water level - 343.25 m

Flood construction level - 343.66 m

Note: Flood construction level was derived from Okanagan Basin DEM (2017). Peak water level was interpolated from City of Kelowna shoreline data.

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DATE: December 2017
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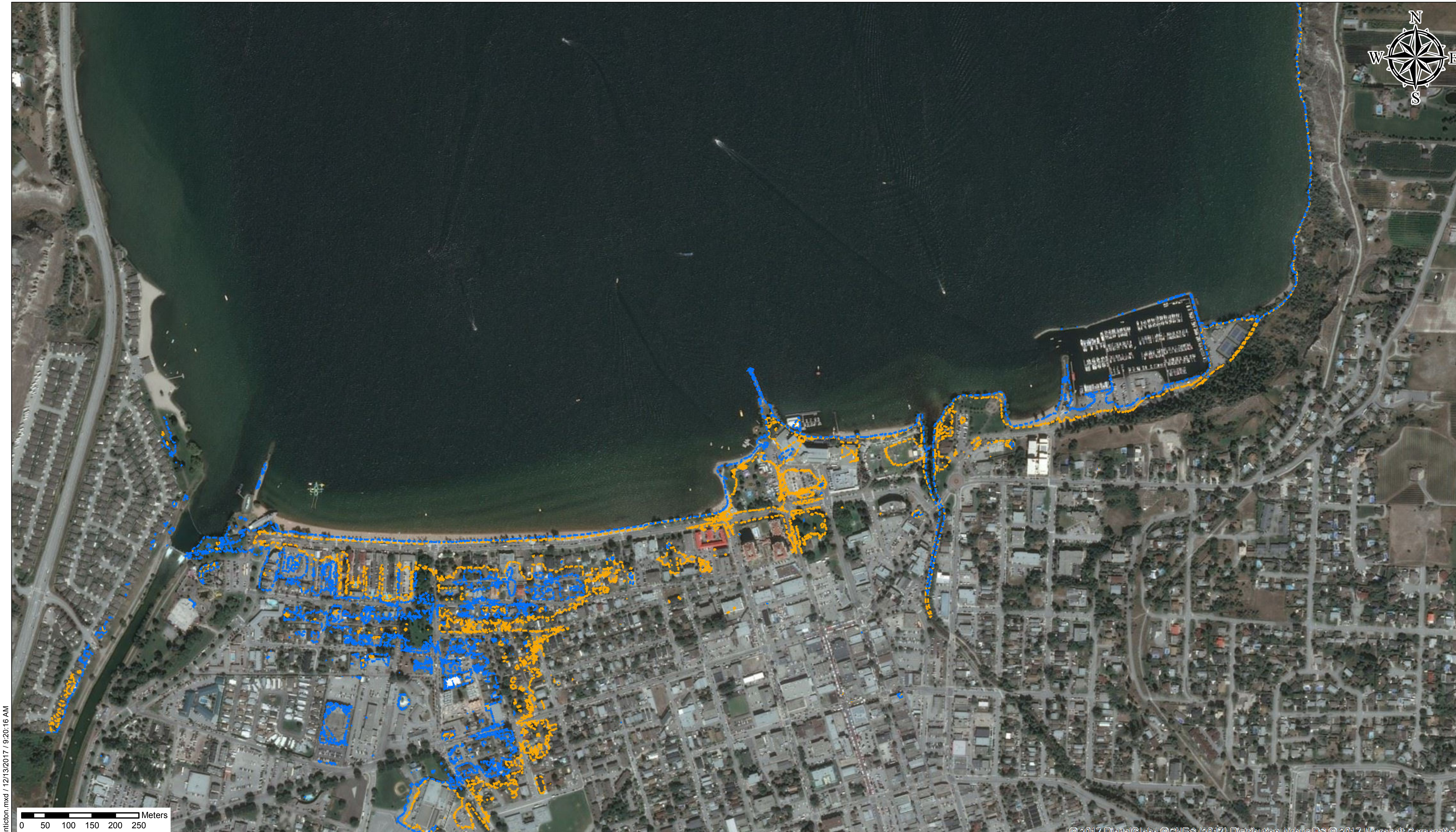
FIGURE 6-1: DOWNTOWN KELOWNA SHOWING HIGHEST WATER LEVEL REACHED IN 2017 ON OKANAGAN LAKE & FCL

FLNRORD

Review of 2017 Flood Response: Okanagan Lake Regulation System and Nicola Dam



Associated Environmental

Peak water level - 343.25 m

Flood construction level - 343.66 m

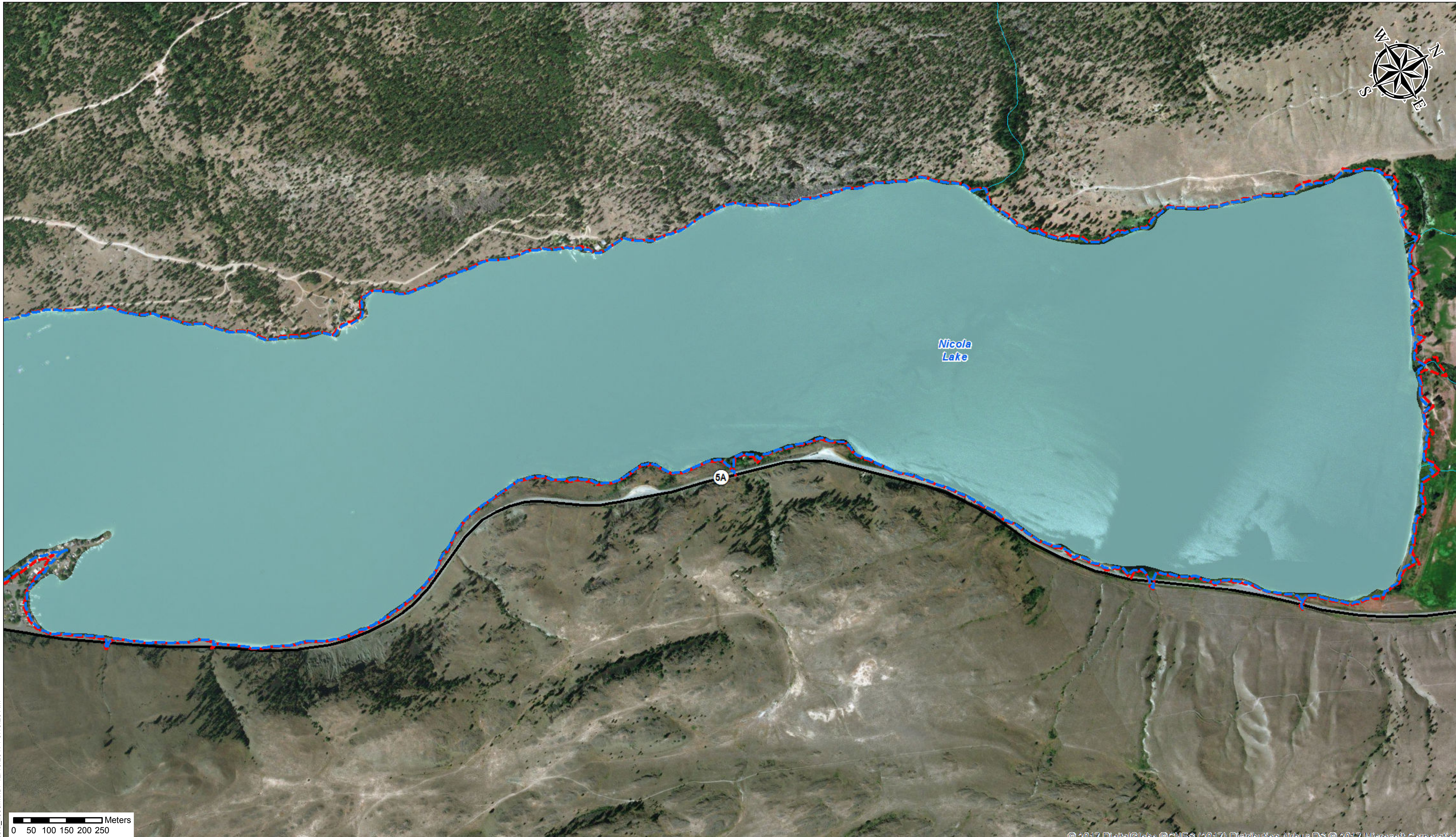
Note: Flood construction and peak water level derived from City of Penticton DEM (2013)

PROJECT NO.: 2017-8178
DATE: December 2017
DRAWN BY: BdJ

FIGURE 6-2: PENTICTON WATERFRONT SHOWING HIGHEST WATER LEVEL REACHED IN 2017 ON OKANAGAN LAKE & FCL

FLNRORD

Review of 2017 Flood Response: Okanagan Lake Regulation System and Nicola Dam



Associated Environmental

Peak water level - 626.97 m

Flood construction level - 627.9 m

PROJECT NO.: 2017-8178

DATE: December 2017

DRAWN BY: BdJ

FIGURE 6-3: NORTH END OF NICOLA LAKE SHOWING HIGHEST WATER LEVEL REACHED IN 2017 AND FCL

FLNRORD

Review of 2017 Flood Response: Okanagan Lake Regulation System and Nicola Dam

In addition, backwatering from Vernon Creek caused BX Creek to have higher sustained water levels than normal.

High lake levels on Okanagan Lake caused impacts similar to those noted above for Kalamalka Lake. Boat launches were shut down until mid-summer to mitigate damage from boat wakes. Beach and lake access was restricted due to high water, and in some places due to high *E.coli* counts from septic contamination. Several lakeside parks were closed. Portions of the Okanagan Indian Band were evacuated for several weeks.

Along Okanagan River downstream of the Okanagan Lake Dam at Penticton, FLNRORD intentionally pushed the lake outflow to beyond the design capacity of the channel, to the point where experience indicated that minor damage and other impacts could occur. Properties adjacent to the river experienced high water tables and basement flooding, and low-lying areas of golf courses and businesses were flooded in Penticton.

Access to some properties in Naramata was cut off due to bridge washouts on Chute Creek, and some other properties adjacent to creeks were evacuated due to flood risk. A boil water notice was issued for parts of Naramata after a watermain was exposed due to high flows. Many basements in Naramata were flooded.

6.2 NICOLA

Despite high inflows to Nicola Lake and high inflows to Nicola River downstream of the lake, there were few reports of notable flood-related impacts, with some exceptions as noted here:

- A senior’s residence in Merritt was evacuated due to high water.
- Harmon Estates along the north side of Nicola Lake experienced some flooding, although most houses in this area have been built since the current FCL was established and escaped significant damage.
- Some houses at Quilchena and recreational vehicle sites on the spit north of the Upper Nicola River were flooded.
- The lake elevation rose to within 0.5 m of Highway 5, and the Ministry of Transportation and Infrastructure responded by protecting and repairing sections of the highway along the lake.
- The Nicola River overtopped its banks along Upper Nicola Indian Band lands adjacent to the river. These lands also experienced a high groundwater table, which caused flooding, the spread of contamination from septic fields, and the evacuation of several homes.

Finally, it is noteworthy that Quilchena Estates on the east shore and Nicola Lakeshore Estates on the west shore were established after the FCL was set, and there were no reports of flooding in these areas. Similarly, houses at the north end of the lake escaped flooding.

7 Spring 2017 Inflows and Decisions

7.1 OKANAGAN

7.1.1 Inflow Forecasts Provided by RFC

The winter/spring volume inflow forecasts provided by the RFC to the OLRS Water Manager for Kalamalka and Okanagan Lakes are listed in Table 7.1. Two sets of forecasts are listed: those ending June 30 and those ending July 31. The table includes the date the forecasts were provided and the origin of the forecast (PCA or ESP model). Since the PCA models were the source relied upon by the RFC and the Water Manager, the table includes the PCA forecast and the actual inflow that was eventually recorded, in both absolute and relative terms (i.e., both in units of $kdam^3$ and % of normal). Only the expected values of the inflow forecasts are provided (not the standard errors) because the Operating Plans are driven by the expected values. However, it is noteworthy that for Okanagan Lake the actual inflow exceeded the upper limit of the range within which it would be expected to fall 95% of the time for all four of the end-June forecasts, and three of the four end-July forecasts (i.e., all but the May – July forecast). Actual inflows are not documented by FLNRORD for Kalamalka Lake.

The forecasts did not begin to exceed normal values until April 1, and grew to about 140% – 150% of normal by May 1. The actual inflows greatly exceeded each of the forecasts, even the May 1 forecast. The underestimation on all forecast dates occurred mostly because the PCA-derived forecasts do not attempt to predict the precipitation that will fall during the period covered by the forecast, and the spring 2017 precipitation was anomalously high.

Table 7-1

Volume inflow forecasts provided by the RFC to the OLRS Water Manager.

	Date forecast provided to Water Managers[1]	PCA Forecast Inflow ($kdam^3$)		Actual Inflow ($kdam^3$)	
		Okanagan Lake	Kalamalka-Wood Lake	Okanagan Lake	Kalamalka-Wood Lake[2]
February 1 - June 30	February 7 (PCA) February 8 (ESP)	492.9 (101% of normal)	18.04 (54% of normal)	940.6 (Week ending February 4 - July 1) (191 % of forecast)	NA[3]
March 1 - June 30	March 7 (PCA) March 8 (ESP)	456.94 (97% of normal)	18.54 (60% of normal)	918.2 (Week ending March 4 - July 1) (201% of forecast)	NA
April 1 - June 30	April 5 (PCA) April 19 (ESP)	529.66 (120% of normal)	22.97 (82% of normal)	849.6 (Week ending April 8 - July 1) (160% of forecast)	NA
May 1 - June 30	May 5 (preliminary PCA) May 8 (PCA) May 10 (ESP) May 16 (ESP) May 17 (revised ESP) May 30 (revised ESP)	501.73 (144% of normal)	23.59 (124% of normal)	691.3 (Week ending May 6 - July 1) (138% of forecast)	NA
February 1 - July 31	As above	518.2 (101% of normal)	17.23 (50% of normal)	943.5 (Week ending February 4 - July 29) (182% of forecast)	NA
March 1 - July 31		485.23 (98% of normal)	18.13 (56% of normal)	921.1 (Week ending March 4 - July 29) (190% of forecast)	NA
April 1 - July 31		569.57 (122% of normal)	25.1 (85% of normal)	852.5 (Week ending April 8 - July 29) (150% of forecast)	NA
May 1 - July 31		554.25 (147% of normal)	25.96 (127% of normal)	694.2 (Week ending May 6 - July 29) (125% of forecast)	NA

Notes:

1. Based on an information timeline summary provided by RFC.
2. Kalamalka-Wood Lakes refers to the combined surface of Kalamalka Lake and Wood Lake. These two lakes are actually one lake, as they are at the same elevation and joined by a short channel under a local road.
3. NA = Not Available. Kalamalka Inflows are not tracked by the RFC or the Water Manager.

7.1.2 Actions Taken by OLRS Water Manager for Okanagan Lake

The actual inflows and the actions taken by the OLRS Water Manager in winter/spring 2017 influenced the levels of Kalamalka and Okanagan Lakes and the flow of the Okanagan River. For Okanagan Lake, weekly inflows, lake levels, and outflows are shown on Figures 7-1, 7-2, and 7-3, respectively. Lake level targets are indicated on Figure 7-2. The flow of Okanagan River near Oliver is shown in Figure 7-4.

The Operating Plan (Tables 4-1 and 4-2), snow data (Table 5-1, Figures 5-4 and 5-5), the RFC supplied volume inflow forecasts (Table 7-1), and Figures 7-1 through 7-4 should be consulted while reviewing this section of the report.

7.1.2.1 Fall 2016 – January 2017

The October through December month-end targets for Okanagan Lake are all 341.84 m, and the end-January target is 341.74 m. Through fall 2016 the lake was slightly (about 10 cm) above its targets, but by the end of December had dropped to the target elevation, which held through January 2017 (Figure 7-2).

7.1.2.2 February 2017

The Okanagan Lake inflow forecasts received from the RFC on February 7 were very close to average. Consistent with the Operating Plan, the Water Manager was aiming to achieve a month end elevation of 341.64 m by the end of February. By month-end, the lake elevation was 341.75 m, 11 cm above the target. With input from the FWMT Team, the Water Manager indicated that the 11 cm difference would not create future problems since the snow conditions at the time were lower than average (Table 5-1, Figures 5-4 and 5-5), and he decided to make no changes to the outflow. Note that by June 30, the February through June inflow turned out to be nearly double the value forecast in early February (Table 7-1).

7.1.2.3 March 2017

In March, the RFC-supplied inflow forecasts were again very close to average for Okanagan Lake. The Basin Snow Water Index value was a little higher than it had been in February, but was still substantially below normal. However, the valley-bottom precipitation had been above normal for about a month and was continuing above normal as March progressed, and the Water Manager reported that he suspected the RFC forecast might be too low. Since the lake was already slightly on the high side and rising due to the valley-bottom rain and low elevation inflow, the Water Manager decided to ignore the Operating Plan (which called for the lake to rise as high as possible, expecting drought), and he began to release flow from the lake on about March 22 at a rate close to the fisheries egg scour criteria (28 m^3/s in Oliver). The results of this decision can be seen in Figure 7-2.

When inflows are expected to be above normal (which they weren't in March 2017), the end March target is 341.49 m, but the Water Manager reported that that that criteria is almost never achieved (and when it is achieved, it's only by moving up to the target by storing additional water, not by moving down to the target by releasing water), so as he released water from the lake contrary to the Operating Plan, he wasn't concerned when he failed to drop the lake to 341.49 m by March 31. By June 30, the March through June inflow turned out to be double the value forecasted in early March (Table 7-1).

7.1.2.4 April 2017

The April inflow forecasts were higher (as a percent of normal) than the previous forecasts—about 120% of normal for Okanagan Lake and 85% of normal for Kalamalka Lake—in the mid-range of the possible inflow forecasts for Okanagan Lake, and for which the month-end target is 341.44 m. The Basin Snow Water Index had risen again, and on April 1 it was now slightly above normal (105% of normal)

During April, inflows to the lake continued above average (Figure 7-1), due to continuing above average low elevation rainfall (Section 5). The Water Manager held outflows between about 19 m^3/s and 23 m^3/s, considering the RFC forecasts, ongoing inflows to the lake and tributary inflows to the Okanagan River downstream of the lake, and the fisheries scour criteria in the river near Oliver.

The FWMT Team began to run lake outflow scenarios during April. The FWMT was beginning to suggest that the lake might rise quickly and reach full pool (342.48 m). The Water Manager was continuing to use NOAA daily updates via Google Earth to get a picture of conditions on the ground, and other more direct observations of snow cover and runoff conditions. By mid-April, the Water Manager was becoming concerned that the inflow forecasts were low. On Wednesday April 19, the FWMT Team met in person, and the Water Manager stated his wish to release water at a rate significantly above the egg scour criterion (normally the egg scour criterion is in place up to or beyond April 24). Based on past operational experience he wanted to wait until the following Monday before he increased the outflows. On that day (April 24), he began to increase the outflow, and the channel design capacity of 60 m^3/s was reached by May 3[5] (Figure 7-3). This was despite receiving advice from FWMT Team biologists that the sockeye eggs in the Okanagan River needed protection beyond April 24. The month-end lake elevation was 342.12 m (0.68 m above the target elevation). The April through June inflow turned out to be 60% higher than the forecast made in early April (Table 7-1).

7.1.2.5 May 2017

The May inflow forecasts for Okanagan Lake were about 145% of normal. The Basin Snow Water Index had increased to 147% of normal by May 1, and it increased further to 151% of normal by May 15. The end-May target elevation for Okanagan Lake is full pool (342.48 m) only 36 cm above the May 1 lake elevation. However, by early May, the lake outflow was already at the channel design capacity (60 m^3/s), so the Water Manager would not normally increase it beyond this value. However, through experience (and consultation with Brian Symonds, P.Eng., a retired former OLRS Water Manager), he was confident that he could increase outflows to about 75 m^3/s before significant overbank flooding and notable riverbank erosion would occur downstream of the Okanagan Lake dam. Accordingly, he began to slowly increase the outflow, but not in a linear manner, as he periodically cut back the outflow in response to high tributary

[5] In consideration of downstream interests, the lake outflow must be increased gradually.

inputs to the river downstream of the dam. By the latter part of June, the outflow rate was 77 m^3/s (Figure 7-3).

During May, the Water Manager had almost no ability to control the lake level, as the lake outflow was already at or above the maximum rate. Okanagan Lake continued to rise, a result of heavy rainfall and melting upper elevation snow (see Section 5). The lake reached its ultimate elevation of 343.25 m on June 8, the highest level since the Okanagan Lake dam was built. The May inflow (Figure 7-1) was the highest on record, and arrived after the Water Manager had lost the ability to manage the lake levels.

Okanagan Lake rose to a peak of 343.25 m on June 8, 20 cm above the 200-year flood level, and within 41 cm of the FCL. The ultimate total 2017 lake inflow is expected to be about 900 million m^3, the fifth or sixth highest on record, consisting of about 180 million m^3 from February through April and about 720 million m^3 from May through July.

Throughout the spring, the Water Manager was communicating to internal agencies and external parties about inflow conditions, inflow forecasts, current and forecast lake levels, and the expected timing of peak levels. The May through June inflow turned out to be 38% above the forecast made in early May (Table 7-1), and this difference was mostly due to precipitation that occurred during this two-month period, after the inflow forecast was developed.

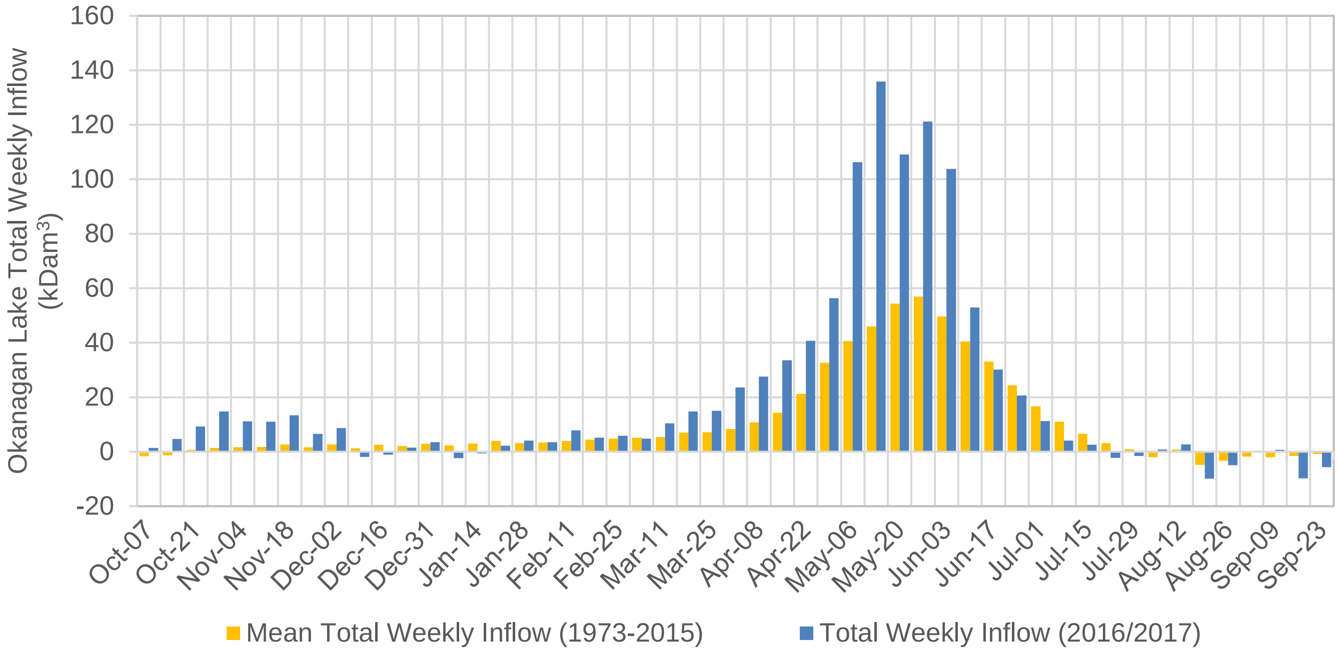


Figure 7-1
Weekly inflows to Okanagan Lake, October 2016 – September 2017

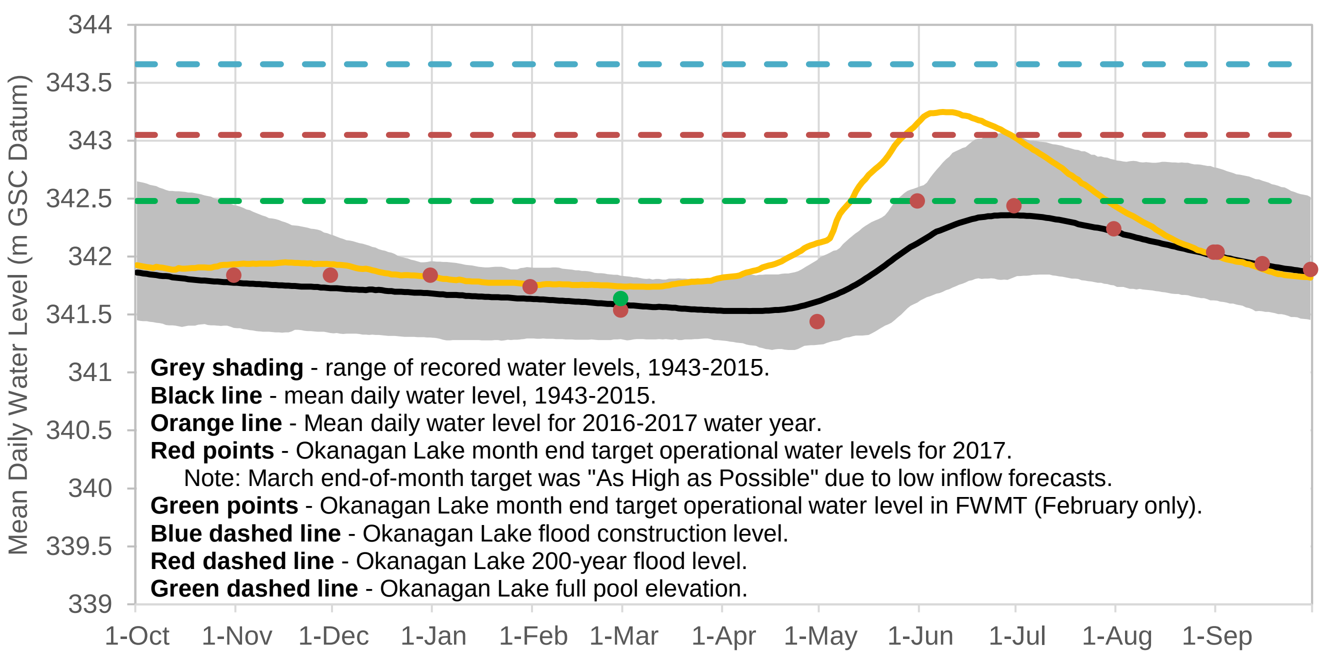


Figure 7-2
Okanagan Lake water level measured at Okanagan Lake at Kelowna (WSC 08NM083), October 2016 – September 2017

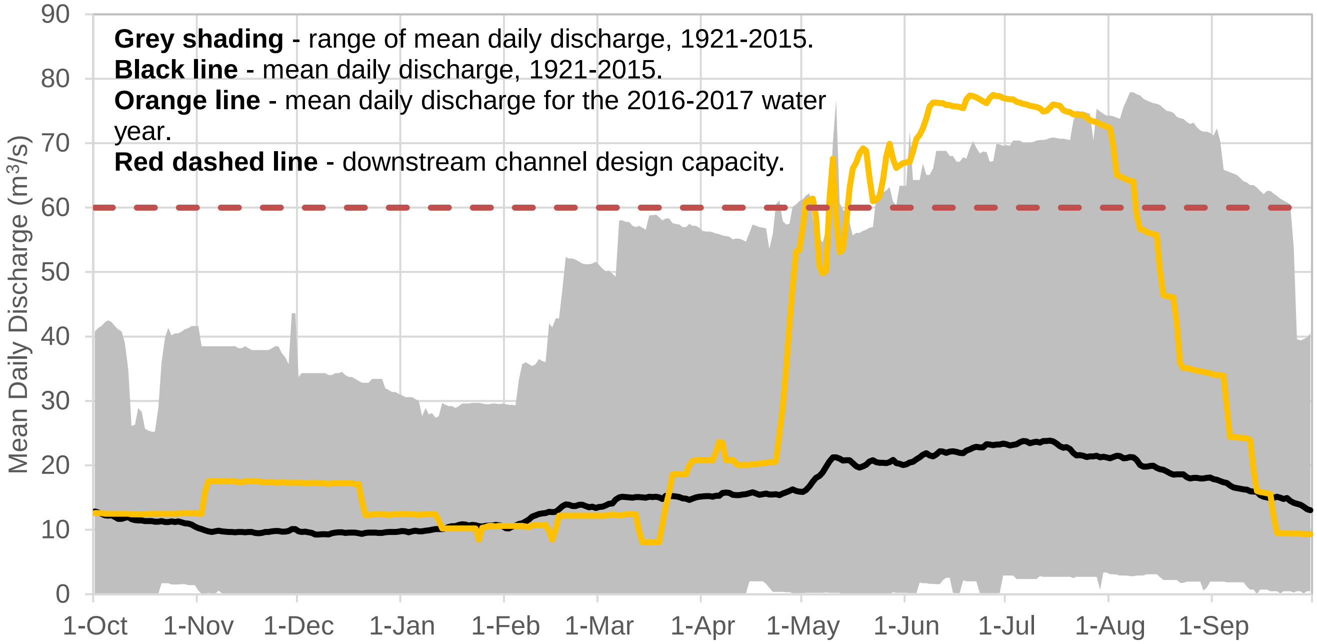


Figure 7-3
Okanagan River mean daily discharge measured at Okanagan River at Penticton (WSC 08NM050), October 2016 – September 2017

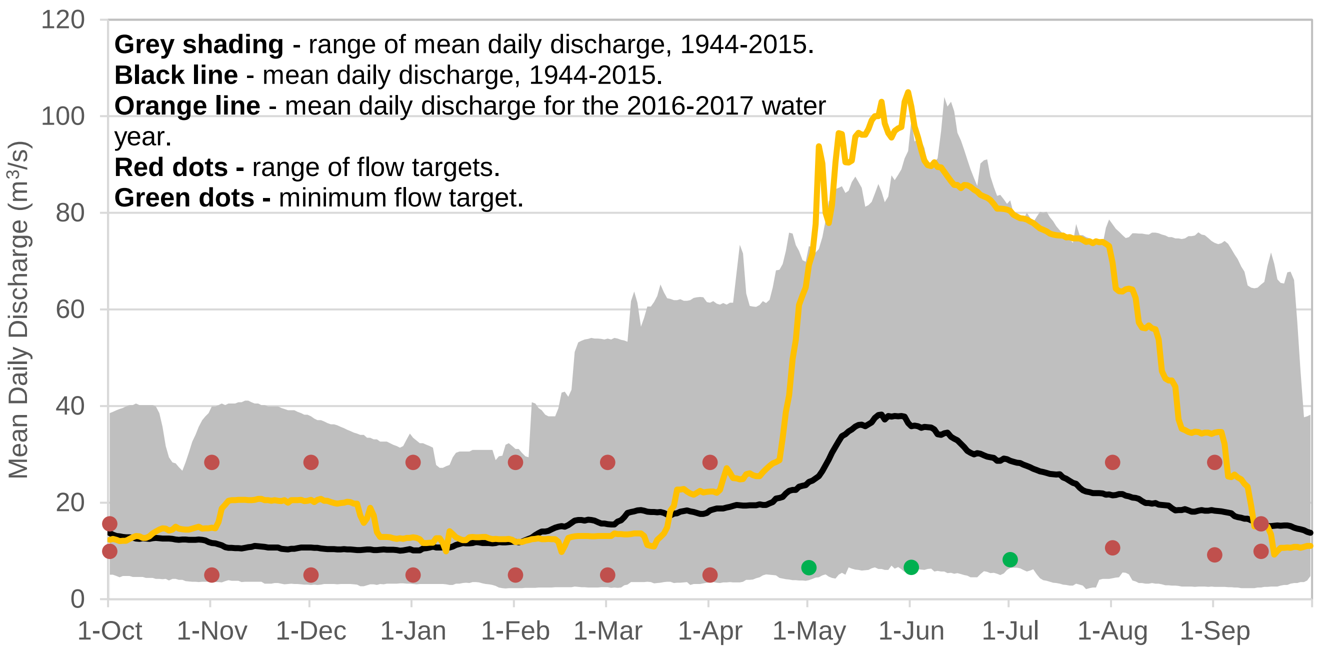


Figure 7-4
Okanagan River mean daily discharge measured at Okanagan River near Oliver (WSC 08NM085), October 2016 – September 2017

Associated Environmental

7.1.3 Actions Taken by OLRS Water Manager for Kalamalka Lake

The RFC-supplied inflow forecasts for Kalamalka Lake are provided in Table 7-1. Lake levels and outflows are shown on Figures 7-5 and 7-6, respectively. Target lake elevations are indicated on Figure 7-5. The Operating Plan (Table 4-3), snow data (Table 5-1, Figures 5-4 and 5-5), the RFC supplied volume inflow forecasts (Table 7-1), and Figures 7-5 and 7-6 should be consulted while reviewing this section of the report.

The elevation of Kalamalka Lake was very close to its target elevations from fall 2016 until the end of February 2017 (Figure 7-6). It began to exceed its target elevation in March 2017. As shown in Table 7-1, both the February and March volume inflow forecasts for Kalamalka Lake were about half of normal. The April forecasts had increased to about 80% of normal, but by May the forecasts had increased to about 125% of normal.

Notwithstanding the very low inflow forecasts, Kalamalka Lake rose in March and April (Figure 7-5) in response to higher than average low elevation rainfall (Section 5). The Water Manager maintained the lake outflow between about 0.5 m^3/s and 1.5 m^3/s during this time. However, by the end of April, the lake was continuing to rise and the Water Manager increased the outflow rate to a peak of 6.83 m^3/s on May 17 before scaling back to just below 6 m^3/s, which was maintained until nearly the end of June. The Water Manager anticipated (based on experience) that scour and damage could occur at outflow rates above 6 m^3/s, and as reported in Section 6, these high outflow rates did cause some damage downstream along Vernon Creek before the Water Manager reduced the outflow to just less than 6 m^3/s.

Because the Water Manager had increased the lake outflow rate to its maximum possible value, he lost the ability to control the lake level after about May 1. The lake reached its peak (392.45 m) on June 4, 73 cm above the usual peak, 25 cm above the estimated 200-year flood level (392.2 m), and within 75 cm of the Kalamalka Lake FCL (393.2 m).

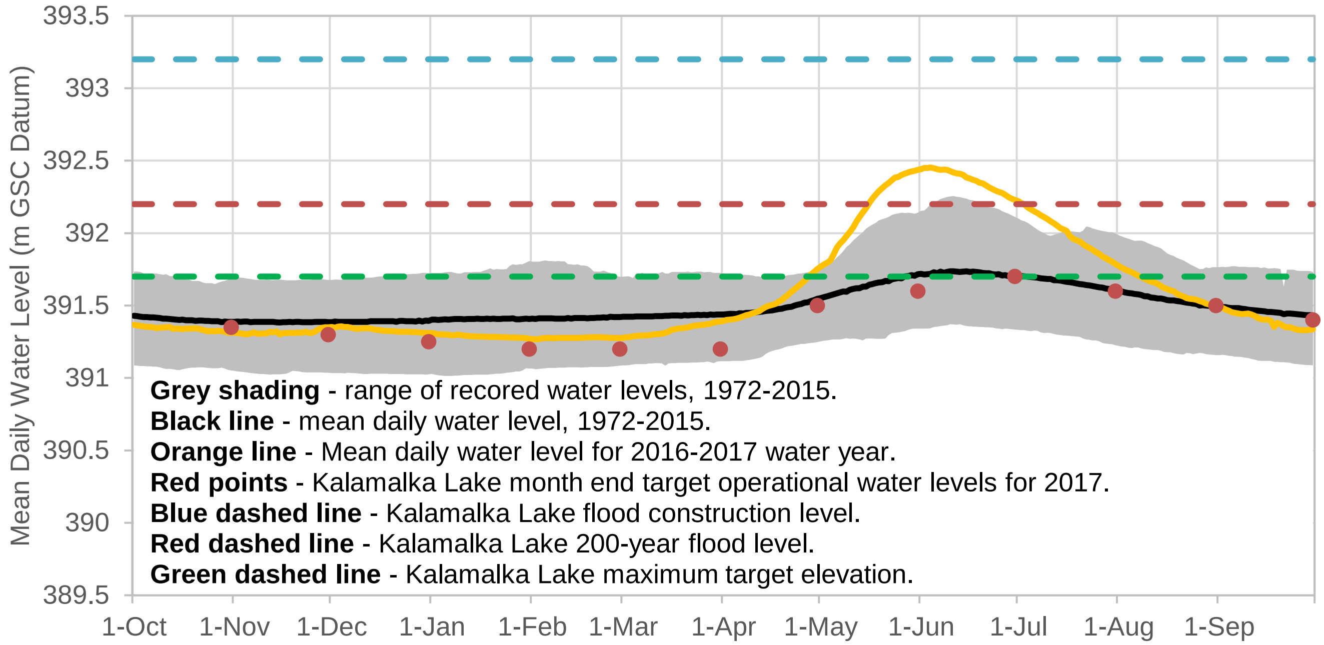


Figure 7-5
Kalamalka Lake water level measured at Kalamalka Lake at Vernon Pumphouse (WSC 08NM143), October 2016 – September 2017

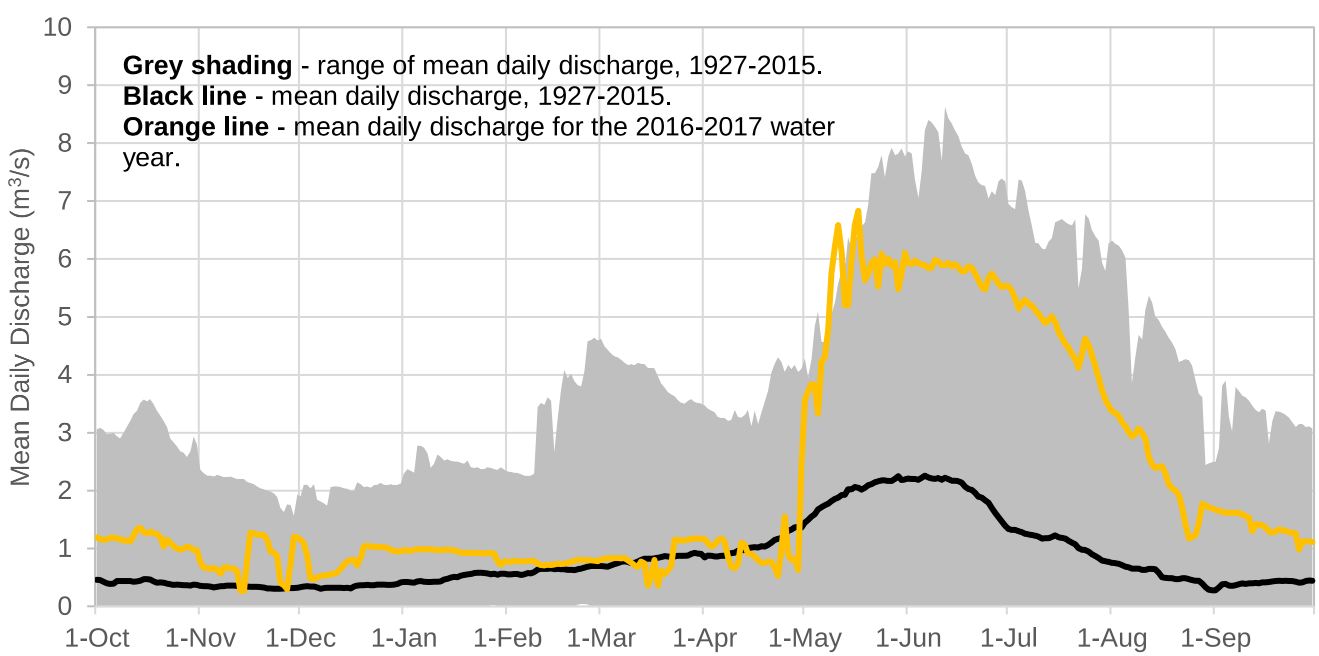


Figure 7-6
Vernon Creek mean daily discharge measured at Vernon Creek at outlet of Kalamalka Lake (WSC 08NM065), October 2016 – September 2017

Associated Environmental

7.1.4 Lakes Downstream of Penticton

Although the focus of this report was Okanagan Lake and Kalamalka Lake, this section briefly addresses 2017 conditions in Skaha, Vaseux, and Osoyoos Lakes, downstream of Okanagan Lake. Notwithstanding that the inflow to Skaha Lake and the outflows from the lake can be managed together to maintain control on the level of the lake, it rose to high levels in 2017. On Vaseux Lake, outflows above 45 m^3/s are constrained by the capacity of the channel leading to McIntyre Dam, about 1.4 km downstream of the lake. Vaseux Lake rose to historically high levels in 2017, and outflows were constrained by the channel capacity. Outflows from the lake during period of high flow could be increased by dredging the channel between the lake and McIntyre Dam.

Osoyoos Lake is not part of the OLRS, however we have plotted the levels of Osoyoos Lake in 2017 on Figure 7-7 to demonstrate that it also reached high (but not historic) levels. The high levels on Osoyoos Lake resulted from a combination of high inflow from the Okanagan River and backwater exerted by the Similkameen River.

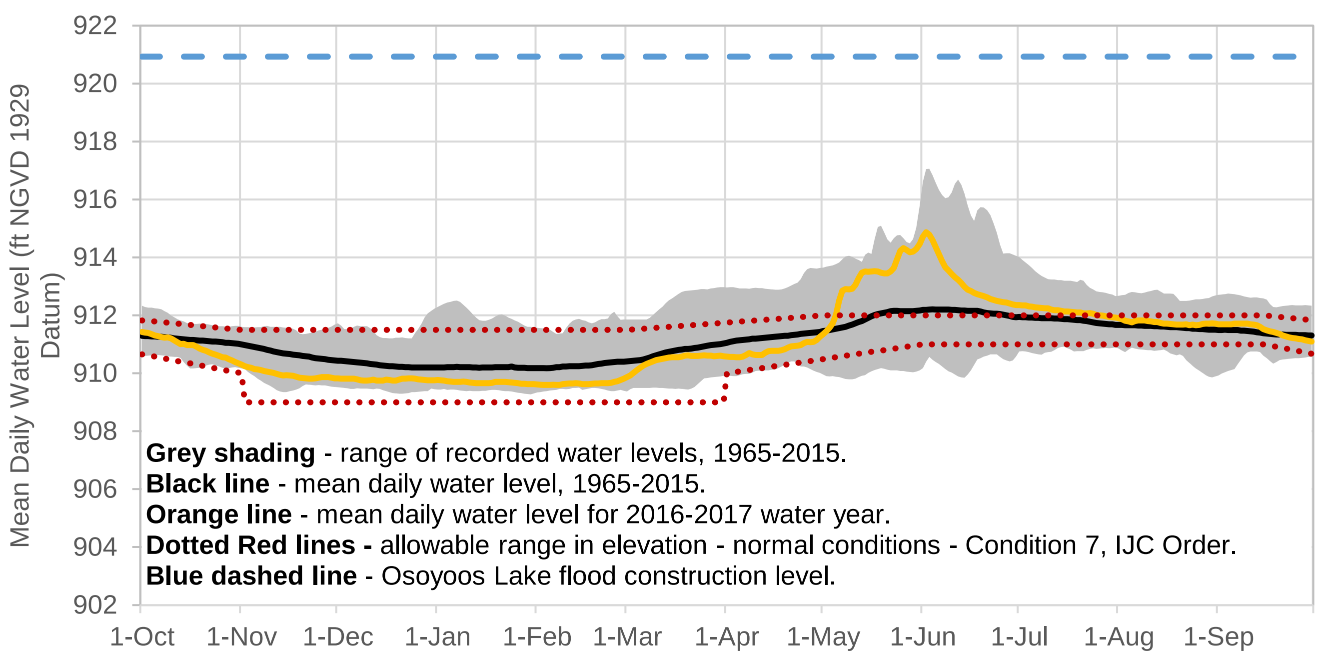


Figure 7-7
Osoyoos Lake water level measured at Osoyoos Lake near Oroville (USGS 12439000), October 2016 – September 2017

7.2 NICOLA

7.2.1 Inflow Forecasts Provided by RFC

The winter/spring volume inflow forecasts provided by the RFC to the Nicola Water Manager are provided in Table 7.3. Two sets of forecasts are listed: those ending June 30 and those ending July 31. The table includes the date the forecasts were provided, the forecast and the actual inflow that was eventually recorded, in both absolute and relative terms (i.e., both in units of $kdam^3$ and % of normal). Only the expected values of the inflow forecasts are provided (not the standard errors) because the Operating Plan is driven by the expected values. However, it is noteworthy that the actual inflow exceeded the upper limit of the range within which it would be expected to fall 95% of the time for the first two of the four end-June forecasts, and the first two of the four end-July forecasts. The other forecasts all underestimated the actual inflows too, but by smaller amounts. The widespread underestimation occurred mostly because the PCA-derived forecasts do not attempt to predict the precipitation that will fall during the period covered by the forecasts, which was unusually high in spring 2017.

The forecasts were similar to those provided to the OLRS Water Manager in terms of percent of normal. The February and March forecasts were near or below normal, and they grew to significantly above normal in April and May.

Table 7-2
Volume inflow forecasts provided by the RFC to the Nicola Water Manager

	Date forecast provided to Water Manager	Forecast Inflow (kdam^3)	Actual Inflow (kdam^3)
February 1 - June 30	February 7	100.3 (77% of normal)[1]	245.3 (Week ending February 7 - June 27) (245% of forecast)
March 1 - June 30	March 7	126.65 (101% of normal)	240 (Week ending March 7 - June 27) (194% of forecast)
April 1 - June 30	April 6	184 (153% of normal)	233.1 (Week ending April 4 - June 27) (127% of forecast)
May 1 - June 30	May 4 (preliminary) May 8 (final)	168.25 (161% of normal)	196.1 (Week ending May 9 - June 27) (117% of forecast)
February 1 - July 31	As above	156.19 (106% of normal)[1]	249.5 (Week ending February 7 - August 1) (160% of forecast)
March 1 - July 31		144.73 (101% of normal)	244.2 (Week ending March 7 - August 1) (169% of forecast)
April 1 - July 31		209.1 (152% of normal)	237.3 (Week ending April 4 - August 1) (113% of forecast)
May 1 - July 31		194.57 (160% of normal)	200.3 (Week ending May 9 - August 1) (103% of forecast)

Notes:
1. Analysis of the Excel spreadsheets used by the RFC to generate volume inflow forecasts for Nicola Lake suggests that there may have been a slight error either in the February to June forecast or in the February to July forecast. This potential error was not material however, and did not affect operations.

7.2.2 Actions Taken by Nicola Water Manager

The actual inflows to Nicola Lake and the actions taken by the Nicola Water Manager in winter/spring 2017 influenced the levels of the lake and the flow of the Nicola River. Weekly inflows to the lake, lake levels, and outflows are shown on Figures 7-8, 7-9, and 7-10, respectively. Lake level targets are indicated on Figure 7-9.

The Operating Plan (Table 4-4), snow data (Table 5-5, Figures 5-4 and 5-5), the RFC supplied volume inflow forecasts (Table 7-3), and Figures 7-8 through 7-10 should be consulted while reviewing this section of the report. The Operating Plan has been computerized (using the U.S. Army Corps of Engineers software package HEC Res-Sim) to help the Water Manager optimize lake management decisions, and this computerized optimization tool was used in 2017.

Finally, in fall 2017, the Nicola Water Manager prepared a memo (with supporting appendices) that reviews the weather conditions, lake inflows, and water management actions taken between fall 2016 and summer 2017. That document (Ball 2017) was used as a reference to help develop the text in this section of the report.

7.2.2.1 Fall 2016 – January 2017

Due to higher than normal precipitation in fall 2016, Nicola Lake rose to about 25 cm above its target elevation by November 30, but by the end of December had dropped to near the target elevation, which held through January 2017 (Figure 7-9). In cold winters, dam operations are affected by ice - both due to the gates freezing in place and due to an ice cover on the inlet channel that restrict lake outflows. Because of colder than normal conditions during the 2016/17 winter, the gates were affected by ice earlier than normal. The gate openings were set on December 1 and not adjusted again until March 2.

7.2.2.2 February 2017

The RFC provided their first forecasts of the season on February 7. The forecasts called for below average to average inflows. No adjustments to the gate settings were made in February, and at the end of the month the lake was within 5 cm of the end-month target.

7.2.2.3 March 2017

The March forecasts provided by the RFC on March 7 suggested normal inflows were to be expected. The Operating Plan suggested an end-month target elevation of near 625 m. The Water Manager began to use the new NWMT model to distribute the forecast March-July inflow into weekly values, and to test hypothetical flow release scenarios. Starting on March 1, the Water Manager began to increase the outflows, anticipating the spring freshet, and the lake dropped accordingly, to about 30 cm below the target elevation at month-end (Figure 7-9). Outflows were held to 5 m^3/s (Figure 7-10), based on the current understanding that the maximum flow that the downstream spawning beds can withstand is between 5 m^3/s and 8 m^3/s.

7.2.2.4 April 2017

The April forecasts provided on April 6 were predicting inflow about 50% higher than normal. The above average precipitation experienced in March continued into April. Early in the month, the Water Manager consulted the NWMT Team and FLNRORD fisheries staff to understand the consequences of exceeding the redd scour threshold. On April 12, he reduced the lake outflow temporarily to allow fisheries staff access to the river to examine the redds. The redds were determined to be free of both eggs and alevins, which meant that the scour constraint was no longer relevant. The Water Manager then stepped up the outflow between April 13 and April 30 to about 24 m^3/s, just below bankfull discharge in Merritt (Figure 7-10). Despite these efforts, the lake continued to rise to about 45 cm above the target elevation at month-end. The inflow to the lake in April was about 2.5 times the average for April. The Water Manager was examining options and determined that the lake could ultimately be kept to below 626 m (an average peak water level in spring) and the outflows could be kept to below 30 m^3/s (the overbank flooding threshold in Merritt), including the contribution from Clapperton Creek (which joins the Nicola River 300 m downstream of the lake – Figure 1-2), providing the inflow forecasts were correct, These conclusions were communicated to the City of Merritt and the Thompson-Nicola Regional District.

7.2.2.5 May 2017

The RFC provided preliminary inflow forecasts on May 4 and final forecasts on May 8. These forecasts called for lake inflows about 60% higher than normal for the forecast period. At the beginning of the month, the snowline was about 1600 m (based on personal observations by the Water Manager). Warm weather was followed by a major rainstorm on May 4 and 5 over the entire watershed. The flow of Clapperton Creek rose significantly to very high levels (estimated at 35 m^3/s), partly due to overtopping of some private storage structures. Because this flow adds directly to the flow of the Nicola River, the Water Manager reduced the outflows from the lake from 25 m^3/s to about 15 m^3/s (Figure 7-10). This action was taken to mitigate flooding downstream, including through Merritt, and to give the City of Merritt time to install emergency flood protection works. However, it allowed the lake level rise to accelerate.

During May, the Water Manager continued to run NWMT to estimate weekly inflows, and the optimization model to determine the optimum combination of lake level and lake outflow given the very high inflows that were occurring. The Water Manager obtained personal observations of snow and runoff conditions throughout the watershed to assist him in interpreting the results of the various forecasting models. He frequently communicated predictions of peak lake levels and downstream flooding potential to local and provincial agencies, including daily calls with the Provincial Regional Emergency Operations Centre (PREOC).

The lake outflows were increased steadily and rapidly between May 7 and 19. On May 13, Regional FLNRORD staff prepared an Emergency Operating Plan for Nicola Lake that laid out how the gates were to be operated for the remainder of the spring. The lake inflow peaked on May 8, but the lake continued to rise to a peak level of 626.97 m on May 18. The maximum lake level was about 1.00 m above the usual peak, 0.07 m above the 200-year flood level (626.9 m), and 0.93 m below the FCL elevation (627.9 m).

The lake level did not drop to the full supply level (625.83 m) until July 10. Lake outflows peaked at 52.4 m^3/s on May 19. Outflows remained above the flooding threshold in Merritt until the second week of June.

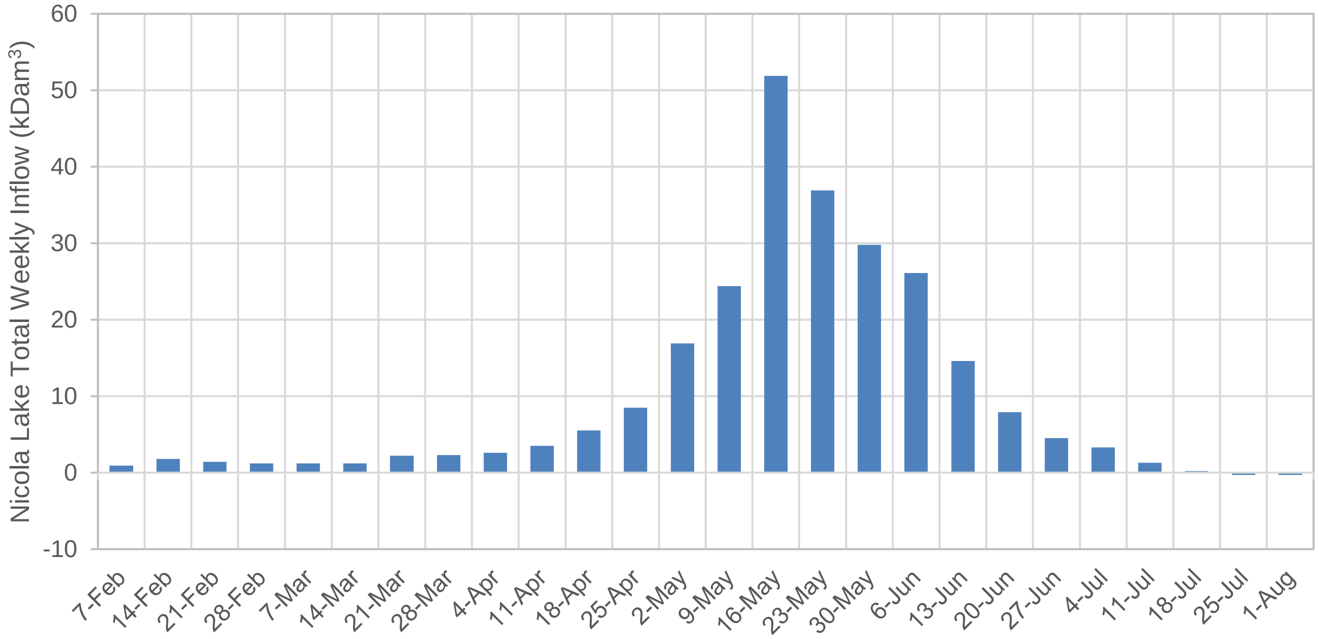


Figure 7-8
Weekly inflows to Nicola Lake, February – August 2017

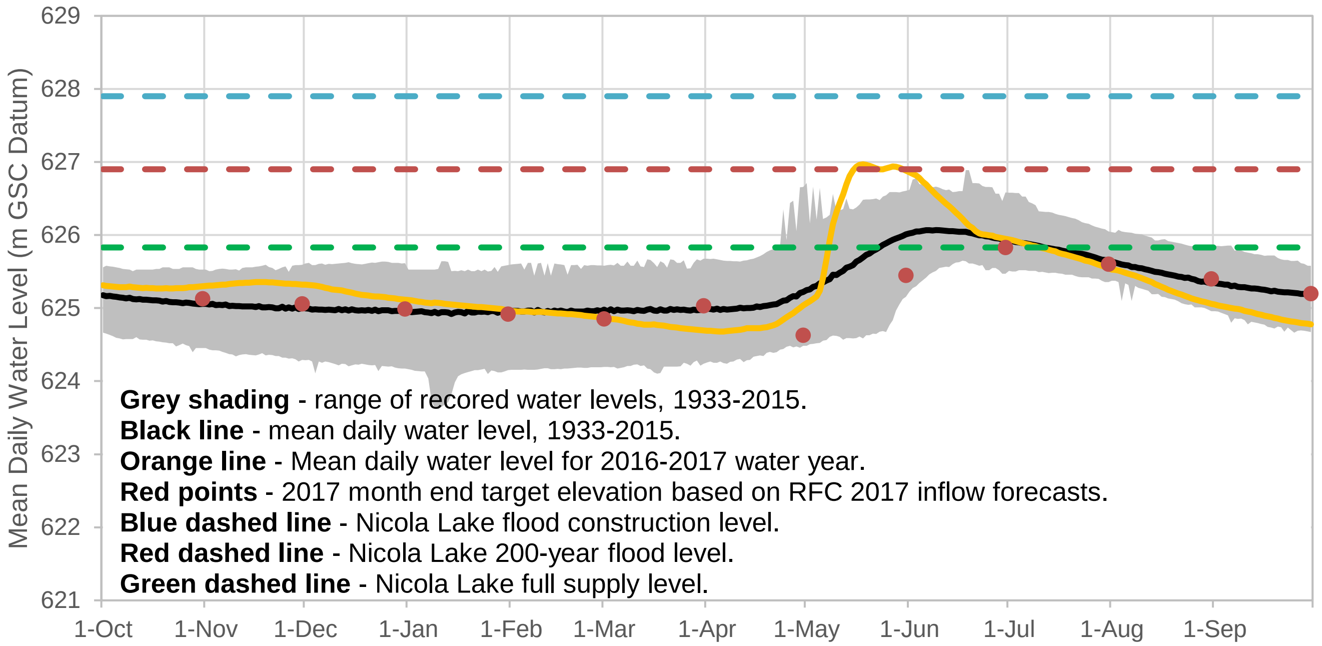


Figure 7-9
Nicola Lake water levels measured at Nicola Lake near Quilchena (WSC 08LG046), October 2016 – September 2017

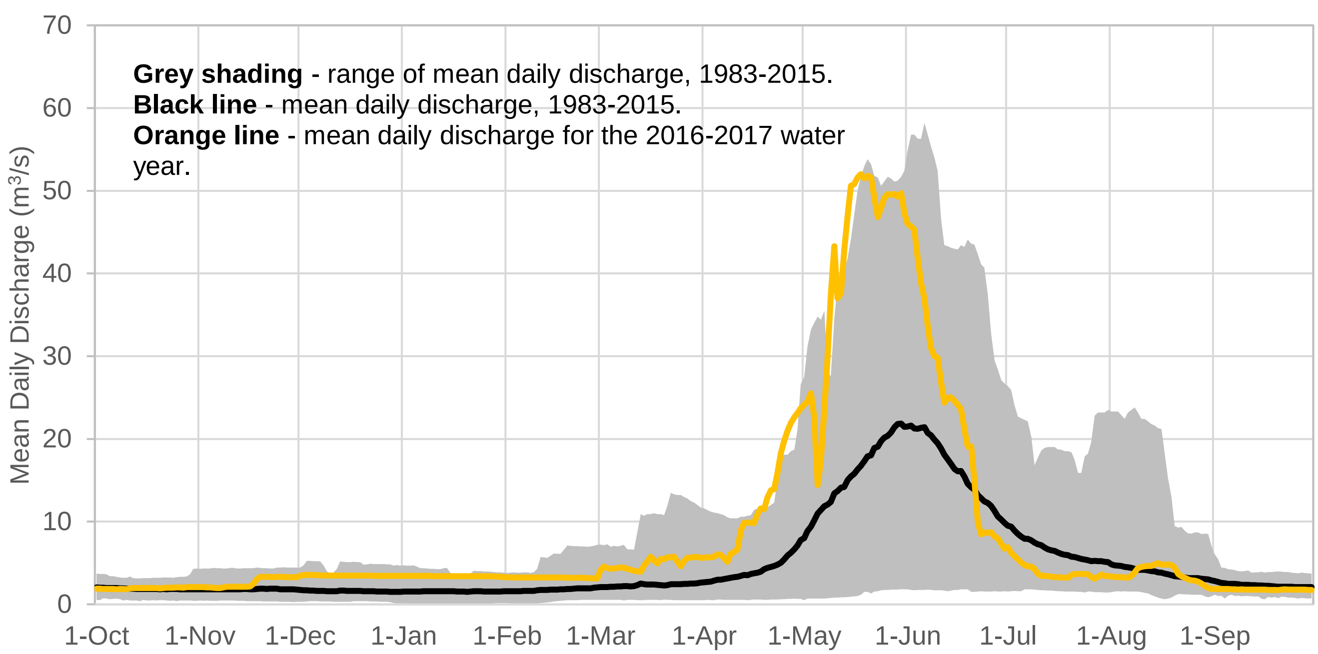


Figure 7-10
Nicola River mean daily discharge measured at Nicola River at outlet of Nicola Lake (WSC 08LG065), October 2016 – September 2017

8 Review of Models and 2017 Decisions

This section summarizes the assessment of the various models used to assist the Water Managers, and the decisions the Water Managers made in 2017 to manage lake levels and lake outflows. Recommendations are provided within the text. These recommendations are brought forward and listed in Section 10.

8.1 INFLOW FORECASTING MODELS

8.1.1 Model Input Data

8.1.1.1 Snow Data

The 2011 PCA inflow forecast equations rely on snow cover information provided by both automated snow weather stations (i.e., "automated stations") and snow courses. The automated stations provide real-time data, whereas snow courses are manually measured once per month on the first day of each of the forecast periods: February1, March 1, April 1, and May 1. Moving to greater use of automated stations could enable the RFC to develop revised PCA equations for different forecast start dates. However, there are some challenges in moving from snow courses to automated stations, as follows:

- An automated station includes a snow scale at a single point in a forest opening that measures the weight of the snow lying on it, whereas a snow course is a network of 10 or 20 individual measuring sites located over a sufficiently large area that they collectively represent the average snow cover in the area.
- Accordingly, a snow course does not produce the same estimate of snow water equivalent as an automated station.
- Two snow courses (Silver Star Mountain and Greyback Reservoir) have recently been converted to automated stations, under the assumption that data from the new automated station exactly replicates the former snow course, and the inflow forecast models assume they are equivalent.
- However, there has been insufficient documentation of the relationship between the former snow courses and the new automated stations (Silver Star Mountain [2F10P] and Greyback Reservoir [2F08P]) at these locations.
- The forecasting ability of the 2011 PCA forecast models is less than it was originally, since they are now using data from the new automated stations to develop forecasts with models calibrated using <u>snow course</u> data at the same locations.
- Knowledge of the relationship between data produced at a former snow course and at a new automated station is necessary for appropriately using the inflow forecasting equations.

The Silver Star snow course was converted to an automated station (number 2F10P) in summer 2016, so winter/spring 2017 was its first year of operation. However, the old snow course was not sampled in winter/spring 2017 (so there was no backup snow data from that location), and the data reported by the new automated station was suspect. The 2011 PCA volume inflow equations for both Kalamalka Lake and Okanagan Lake are heavily reliant on the snow data from Silver Star, and the RFC has lost its flexibility to use backup equations in cases of missing data, such as were provided in the 1999 report (Summit 1999).

However, even if this Silver Star snow data handicap had been mitigated, the PCA models would still not have been able to correctly forecast the spring inflow because they implicitly assume that the forecast period precipitation will be average, but it was significantly above average.

The Greyback snow course was also recently converted to an automated station, but at the same time the old Greyback snow course was discontinued. This switch from a snow course to an automated station was apparently triggered by Weyerhaeuser's decision to stop plowing the access road, FSR 201.

None of the automated stations or snow courses used to predict inflow to Nicola Lake are located in the watershed upstream of the lake, although most of them are located on high elevation plateau terrain close to the boundaries of the watershed.

Finally, we provide two general comments about the snow survey network. Climatic conditions are changing in southern B.C., resulting in potential increases in high elevation snowpack and reduced mid- and low elevation snowpack, but with increased variability. Accordingly, it is possible that the existing snow survey network is not optimal for representing snow conditions throughout the basins for which the snow data is used to support inflow forecasting.

The Basin Snow Water Index has been computed using a specific set of snow survey stations that has not changed since the 1970s, according to the Head of the RFC. Because of climate change, the index may be progressively becoming less representative of the upper elevation snow conditions it is intended to represent. Second, it may no longer be appropriate for this index to target only the upper elevation components of watersheds.

Recommendations:

- If the PCA models are to be revised to run more frequently than monthly, a sufficient number of snow courses will need to be converted to automated stations. However, these conversions must be done without losing the use of the record at the existing snow courses, consistent with the next recommendation.
- At automated snow weather stations, ensure that sufficient overlapping record is obtained at the old snow course and at the replacement automated station to determine the mathematical relation between them so that the snow course data is not lost.
- Ensure that the new Silver Star automated station is operational for winter/spring 2018 and future years.
- Maintain the old Silver Star snow course for several years and develop a mathematical relation between the data from the old snow course and data from the new automated station.
- Maintain the old Greyback snow course for several years and develop a mathematical relation between the data from the old snow course and data from the new automated station.
- Review the network of snow courses and automated stations in the Okanagan and Nicola regions (and potentially in other regions of B.C.), and add snow courses or automated stations where needed to ensure the snow survey network provides an accurate representation of snow conditions in these basins.

- Review the set of stations used to compute the Basin Snow Water Index for the Okanagan and Middle Fraser (and potentially other regions of B.C.); consider whether it remains appropriate for the Index to be focussed on representing upper elevation snowpack; and update the station lists as required.
- A recommendation relating to backup PCA equations is made in the next section.

8.1.1.2 Streamflow Data

The hydrometric station on the upper Nicola River provides a direct measure of the dominant source of inflow to Nicola Lake, so it is useful for both calibrating inflow forecasting models and for operational management. However, as reported by the Nicola Water Manager, the gauge is poorly situated.

Quilchena Creek and Moore Creek provide significant inflow to Nicola Lake, yet have no active hydrometric stations to record streamflows. Adding a hydrometric station to these creeks would facilitate further improvement of the inflow forecasts and assist with operational management of the lake.

Clapperton Creek joins the Nicola River 300 m downstream of Nicola Dam. During spring, this creek can add substantial flow to the Nicola River. For example, in 2017 it was contributing 30 – 35 m^3/s for several days. However, there is no active hydrometric station on Clapperton Creek to assist the Nicola Dam operators in setting the gate openings on the dam to manage the flow of the river and to mitigate flooding downstream, including in Merritt.

Recommendations:

- Relocate the station 08LG049 on the upper Nicola River to improve the quality (e.g., accuracy and reliability) of streamflow data from this location. We understand that the Nicola Water Manager has initiated steps to move the station to the outlet of Douglas Lake, which is likely a better location.
- Consider the benefits of installing new, or re-establishing former, hydrometric stations on Quilchena and Moore Creeks to permit further refinement of the inflow forecast models and to assist with operational management of Nicola Lake.
- Re-establish a hydrometric station on Clapperton Creek to provide the Nicola Water Manager with information needed to help set the gate openings to reduce the risk of flooding downstream.

8.1.1.3 Data Networks - General

One of the reasons that the Province undertook the 2011 forecast model upgrade was that many of the data sources (e.g., hydrometric, snow, and weather monitoring stations) used to drive the models had been discontinued at that time, and without input data, the models are useless. Notwithstanding the significant economic benefit of hydrometric data, reductions in network density have been occurring in B.C. and the Okanagan for several decades (Sellars et. al. 2003, Dobson and Letvak 2008). The inevitable and predictable result of reductions in the density of the streamflow, snow, and weather stations used to drive inflow forecasting models is a reduction in the Province's ability to provide high quality forecasts of seasonal inflows.

In addition, when stations are moved (or one is abandoned and a replacement is established elsewhere), the Province loses the accumulated benefit of the existing record at the abandoned station and replaces it with a new station with no historical data. Since better models can be developed from long data sets than shorter ones, this practice also erodes the Province's ability to develop and maintain high quality forecasting models.

Finally, the Province has been conducting theoretical and applied research on forest hydrology at the Upper Penticton Creek Research Station for many years. This research is supported by hydrometric and snow survey data networks. These data could be integrated into the provincial snow survey network and used to improve the inflow forecasting models, and to inform the Water Manager about upper elevation snow and runoff conditions on a real-time operational basis.

Recommendations:

- Evaluate the adequacy of existing data networks used to drive seasonal inflow forecasting models, and fill identified gaps to allow the Province to meet its mandate to deliver forecasts with sufficient accuracy and precision to appropriately manage flooding, drought, safety and other issues in the Okanagan and Nicola regions.
- Ensure that a sufficient number of its data sources with already long records continue to operate well into the future to allow the Province to continue to meet its forecast quality expectations.
- Make use of the snow and hydrometric data available from the Upper Penticton Creek Research Station to improve the inflow forecasting models, and to inform the OLRS Water Manager about upper elevation snow and runoff conditions on a real-time operational basis.

8.1.2 PCA Models

8.1.2.1 Alternative Equations

The failure of the newly installed Silver Star automated station to deliver any data in winter and spring 2017 contributed to poor quality inflow forecasts for both Kalamalka Lake and Okanagan Lake, and exposed a weakness in the current approach to using PCA models. Summit (1999) provided the RFC with significant flexibility to switch from the optimal model to alternative models when any of the required input data (such as snow data on the forecast date) were missing. However, the RFC lost this flexibility during its 2011 upgrade of these models.

Recommendation:

- For both the Okanagan and Kalamalka Lake PCA models, identify alternative models that can be adopted when needed input data is missing, similar to the approach used in Summit (1999).

8.1.2.2 Forecast Timing

The PCA Models used in the Okanagan and Nicola systems provide forecasts on four dates during winter and spring: February 1, March 1, April1, and May 1. A key weakness of these models is the one month delay between new updated forecasts. The input data used to drive the PCA models are obtained from weather stations, hydrometric stations and snow survey sites. All the required input data are available on a daily basis, except the data from snow courses (because snow courses are sampled manually on a monthly basis). If the snow courses were converted to automated snow weather stations (without losing the benefit of the snow course record at the site), it would be possible to develop PCA models that could be run significantly more frequently than monthly.

Recommendations:

- Develop PCA models that run on a weekly or bi-weekly basis.

8.1.2.3 Updating Frequency

All models used to forecast inflow are developed using historical data, then used to make inflow forecasts in future years. Models provide more accurate forecasts with less uncertainty when they have been calibrated using a long data record (i.e., a sample of the total population of historical weather and flow). Models also tend to provide better forecasts when the predictor variables are near average conditions than when they are near extreme conditions.

The OLRS Water Manager commented that spring snowmelt is occurring earlier than in the past. He also commented that the RFC forecasts have been less accurate in some recent anomalous years. This observation is potentially related to climate change, which is resulting in unusual weather patterns occurring with greater frequency than in the past. In other words, weather conditions that determined lake inflows during the historic period when the models were being developed are becoming increasingly less representative of current and future weather conditions. This implies that the accuracy and precision of forecasts will degrade over time, such that forecast models must be updated frequently to maintain the expected level of confidence in their output.

The persistence of the weather patterns that prevailed in each of the four seasons from fall 2016 through summer 2017 was unusual and contributed to the failure of the PCA models to provide accurate forecasts in 2017. The unusual persistence may also be related to climate change, as research in recent years has identified a link between changes in atmospheric circulation patterns, including their persistence, and climate change (Francis and Vavrus, 2015; Mann et. al. 2017).

Ultimately, the Province may need to move away from inflow forecasts that only incorporate past information (such as the PCA models), in favour of inflow forecasts that include an accurate weather forecast, but at present the ESP approach is still considered experimental in the Okanagan, and hasn’t been applied yet in the Nicola. In addition, the present accuracy of the weather forecasts used in the ESP approach is uncertain.

Recommendations:

- Update the PCA inflow forecast models every 5 years.
- Since 6 years have elapsed since the last model update, complete a comprehensive review and update of the 2011 PCA models within the next year.

8.1.2.4 Other Issues

Examination of the Excel-based spreadsheet used to compute the volume inflows for Nicola Lake identified a possible error in one of the forecast equations.

Although the Water Managers can make direct use of the standard errors provided with the PCA inflow forecasts using FWMT and NWMT, the guidance provided by the Operating Plans is based on the expected value of the forecasts (and not the standard error of the forecasts).

Finally, it should be noted that even the best models will be challenged to accurately predict inflows in extreme years such as 2017. Extreme years will continue to occur infrequently (though perhaps more frequently than in the past due to climate non-stationarity).

Recommendations:

- Modernize and upgrade the method used to run the inflow forecasting models from the current Excel-based platform, to improve security and reduce the possibility of error.
- Provide training to the Water Managers on how to interpret and use the standard error estimates that are provided with each forecast, and consider updating the Operating Plans to explicitly accommodate forecast uncertainty.

8.1.3 ESP Approach Used in the Okanagan

The first operational use of the recently developed ESP model was in spring 2017. It can be run on a daily basis, but suffers from some other challenges as noted in this section.

8.1.3.1 RAVEN Model

The RAVEN model used to represent hydrological processes for the first leg of the ESP approach subdivides the watershed into a small number of large hydrologic response units (HRUs) within which hydrologic conditions are assumed to be uniform. The Okanagan version of the model uses only 100 HRUs, which is a relatively small number compared with the approximately 30,000 HRUs used in DHIs Mike SHE model calibrated for the Okanagan in 2009. When used operationally for the first time in 2017, RAVEN did a relatively poor job of representing snow accumulation and melt, and provided inflow forecast that were even lower than the PCA forecasts (all of which were too low).

No PCA forecasts were possible after May 1, so the RFC ran the ESP Model on May 10, 16, and 22. It will be useful in future years to have the ability to run an inflow forecast model beyond May 1.

Recommendations:

- If the RAVEN model and the ESP approach will continue to be used, upgrade the RAVEN model until it provides reasonable calibrations to lake inflows without requiring substantial manual manipulations of the input weather data to achieve agreement between modelled and observed outcomes.

- Maintain the ability to run an inflow forecast model beyond May 1.

8.1.3.2 10 Day Weather Forecasts

It is likely that inclusion of high quality weather forecasts will improve the accuracy and precision of the volume inflow forecasts. However, the quality of the 10-day weather forecast currently used in the second leg of the ESP approach to drive predictions of lake inflow for the next 10-day period has not been evaluated, nor has the benefit of including a weather forecast in the model. The Summit report (1999) concluded that incorporating a one-month weather forecast did not improve the quality of the models. It seems likely that a 10-day forecast would be better than a one-month forecast, and it seems likely that Environment Canada's forecasting ability in 2017 would be better than it was in 1999, but these assumptions have not been checked.

Recommendations:

- Evaluate the capability of the current generation of 10-day weather forecasts to improve the accuracy and precision of the inflow forecasts. If this benefit is negligible, continue to focus on improving the PCA models, while providing Environment Canada with specific feedback on the need for improved short-term weather forecasts.
- Evaluate the potential benefit of including a weather forecast extending beyond 10 days, if such forecasts are sufficiently reliable.

8.1.3.3 Use of Historic Ensembles to Forecast Inflow and Pattern

The ESP approach uses historical weather data to derive an inflow forecast for each previous year, starting on the date 10 days from the forecast date out to the end of the forecast period. By considering weather data from many previous years, the ESP approach creates an ensemble of possible flows for this third leg of the forecast. It does not attempt to choose a "best estimate" of the expected flow pattern, so is less sophisticated than the RTSM used in FWMT and NWMT. However, like the RTSM routine, it incorporates new information every year, so it incorporates an element of climate resiliency.

Recommendation:

- If ESP will continue to be used by the RFC, develop a more sophisticated way to choose a likely inflow and inflow pattern for the third leg of the forecast (the period from 10 days from the forecast date to the end of the forecast period).

8.1.3.4 Other Issues

Recommendations:

- Ensure that sufficient effort has been expended to review the full spectrum of possible approaches to inflow modelling before committing to a preferred approach.
- If the PCA and ESP approaches will both continue to be used, the RFC should decide whether to focus on the ESP approach, the PCA approach, or continue to use both approaches. Each approach has strengths and weaknesses. It is likely that PCA models will continue to be valuable

for several years (due to limitations in current weather forecasting abilities), but ultimately the ESP approach may be needed due to ongoing climate non-stationarity and the value potentially gained by incorporating accurate weather forecasts.

- The value of any lake inflow forecast model is largely its ability to help the Water Manager avoid damages. The effort to be expended on model upgrading should be determined partly through consideration of the value of the property and infrastructure subject to flooding.
- If the ESP approach will continue to be improved and used in the Okanagan, upgrade it continuously.

8.1.4 FWMT and NWMT Models

The forecast period inflow provided by the RFC (or directly specified by a user) is the only input to an operational run of the FWMT and NWMT models. These models distribute that value into daily estimates for the forecast period using sophisticated RTSM routines. Their main weakness is that they cannot compensate for a poor RFC inflow forecast – they are limited to distributing the forecast into daily components over the forecast period. The year 2017 provided a good example of this limitation. The FWMT and NWMT models did keep up with actual inflows and the RTSM routines tried to choose an analogous year from the historical record, but no such year existed. However, the RTSM routines in both models will benefit in the future from having 2017 in the historical record now.

The FWMT and NWMT could be more effective if they provided the daily disaggregated inflows to the user, rather than rolling them up into weekly values.

The new FWMT model did a better job of anticipating anomalous conditions than the legacy FWMT. However, because it doesn't incorporate a weather forecast, it couldn't give advance warning of the coming inflows. It might be possible to add a crude method of forecasting future weather to FWMT by adapting an autoregressive technique already used in FWMT for modelling water temperature. Such a technique would allow a user to forecast future weather based on current and past weather. Alternatively, it might be possible to directly include a weather forecast into FWMT.

The FWMT Team creates a detailed "record of management strategy" several months following the end of the summer inflow period. This document could be simplified and used to educate and train other staff in the organizations represented on the FWMT Team.

As indicated in Section 4, the NWMT was first used in 2017, and so it was used with some trepidation and the results were viewed with skepticism by the user group. With time and with model improvements, this model will likely fulfill its intended function of assisting the Water Manager to establish a lake outflow regime that meets multiple constraints.

Finally, it appears that the commitment embedded in the 1987 Operating Plan to provide specified fisheries flow releases between December and March is not incorporated as an objective into the NWMT.

Recommendations to the FWMT and NWMT owners:

- Continue to improve FWMT and NWMT and the technical information that supports them, based on experience and as recommended by model operators.
- Allow a model user to view the daily inflows predicted by the models in addition to the rolled-up weekly values.
- Encourage the RFC to develop the ability to provide reliable volume inflow forecasts at intervals shorter than one month.
- Consider adding a method of forecasting future weather to FWMT by adapting an autoregressive technique already used in FWMT for modelling water temperature, or by directly including a weather forecast.
- The annual “record of management strategy” produced by the FWMT Team could be simplified and used to educate and train other staff in the organizations represented on the FWMT Team.
- Use the specific 2017 experience to continue to improve the FWMT and NWMT.
- Examine the fisheries-related flow objectives incorporated into the NWMT to ensure that the 1987 Operating Plan objectives are respected.

8.2 2017 WATER MANAGEMENT DECISIONS

8.2.1 Okanagan

The following list summarizes key observations related to weather and models used in the Okanagan; and assesses water management decisions made in 2017. Many of the following points are relevant to both Okanagan Lake and Kalamalka Lake. Additional comments specific to Kalamalka Lake are provided separately below.

- The Okanagan weather conditions preceding and during the spring freshet period were highly unusual.
- Each of the PCA-based inflow forecasts delivered by RFC significantly underestimated the actual inflow to Okanagan Lake because they cannot anticipate the precipitation that will occur during the period covered by the inflow forecast, which was significantly above normal.
- In addition, the early season inflow forecasts were below average to average because upland snow conditions are a key driver of the forecast, and snow conditions were below normal at that time.
- Following issuance of the March 1, April 1, and May 1 forecasts, heavier than normal precipitation occurred as rain in the valley bottom and as snow at higher elevations.
- Inflow to Okanagan Lake in May was 528 million m^3, the highest on record, and very close to the annual total inflow in an average year. Average May inflow is 231 million m^3. This resulted from high low elevation rainfall and high rates of upper elevation snowmelt during the month.
- If the PCA forecasts could have been updated more frequently than monthly, they would have been more accurate. However, as the PCA-based inflow forecast models do not include a weather forecast, they would still have failed to predict the total lake inflow accurately.
- The ESP model may have a useful ongoing role, since it can be updated daily, and includes a weather forecast. It was useful between the monthly PCA forecasts, in particular during May for flood response planning, but it needs to be improved before users have sufficient confidence in it.
- The FWMT tool can also be used for flood response planning, although it does not have the benefit of a 10-day weather forecast. This model received input from the PCA forecasts and distributed it

into daily amounts, which helped predict a rapid lake level rise even though the PCA forecasts were consistently too low. This model is useful for predicting the temporal distribution of the forecasted inflow, even though it does not include a weather forecast. The 2017 experience could be useful in updating the socio-economic and other constraints embedded within the FWMT.

- The OLRS Water Manager made decisions in fall 2016 and winter and spring 2017 in accordance with the OLRS Operating Plan.
- However, by mid-spring, recognizing that the continuing wet weather and higher than expected lake inflows would likely cause the total inflows to exceed the RFC-supplied forecast inflows, the Water Manager began to diverge from the Operating Plan for Okanagan Lake to reduce lakeshore impacts associated with high water.
- While the Water Manager still had the ability to control the lake level, he appropriately balanced flooding concerns around Okanagan Lake with flooding concerns downstream of Okanagan Lake.
- The Water Manager was constrained by the design capacity of the channel downstream of the Penticton Dam (60 m^3/s), which was reached in early May. After that time, he had no ability to control the lake level.
- Subsequent analysis showed that, to have prevented Okanagan Lake from rising above full pool (342.48 m), the Water Manager would have had to reach the channel design capacity (60 m^3/s) on February 17. However, at that time and for several weeks later, the upland snow conditions and inflow forecasts were pointing more towards below average inflow than above average inflow, so a decision to dramatically increase outflow on February 17 would not have been appropriate.
- The outflow would have had to increase to the channel design capacity on March 19 to prevent the lake from rising above the 1997 peak elevation (342.84 m), on March 23 to prevent the lake from rising above the 1990 level (342.89 m), and on April 10 to prevent the lake from rising above the 1948 level (343.065 m). These decisions would not have been appropriate with the information available at those times.
- Throughout May, the Water Manager did apply experience gained in prior years to knowingly exceed the design capacity to just below the point at which significant downstream impact would be expected, to mitigate flood impacts around the lake - he increased the lake outflow to 77 m^3/s.
- Although at a very detailed level, it might have been possible to have made slightly different decisions or decisions with slightly different timing. However, it would not have been possible for the OLRS Water Manager to have created a significantly different outcome than what was experienced in spring 2017.
- The switch to dry weather in mid-June prevented the flooding around Okanagan Lake (in terms of both lake elevation and duration), and downstream of the lake, from becoming worse. Normally the peak water level on the lake occurs in late June, but the dry weather that began in mid-June prevented the continued rise of the lake beyond its peak on June 8.

Other observations:

- From May 18 to 27 (after the ability to control the lake level had been lost), the OLRS was managed by a retired former OLRS Manager, due to a temporary absence of the OLRS Water Manager. This substitution did not negatively affect FLNRORD’s ability to manage the OLRS.
- The Operating Plan for April for Okanagan Lake (Table 4-1) has three month-end targets, each corresponding to a particular range of the inflow volume forecast. However, there are gaps

between the inflow forecast ranges used for the three targets. In addition, there are some minor inconsistencies between the Operating Plan (Table 4-1) and the Water Management Guidelines (Table 4-2). The OLRS Operating Plan has served the system well, but it has never been updated.
- The FCL for Okanagan Lake was established during the 1974 Okanagan Basin Study (B.C. Water Resources Service 1974) by estimating the 200-year flood level at 343.05 m and adding 0.61 m freeboard to reach 343.66 m. Estimating the 200-year flood level is difficult since it depends on both natural inflows and human control of the outflows, so this estimate is somewhat uncertain.
- In 2017, the level of Okanagan Lake reached 343.25 m, 20 cm above the 200-year flood level, and within 41 cm of the FCL.
- As described in Section 7.2, the Nicola Water Manager created a detailed record of the conditions and operations experienced in spring 2017 titled Nicola Dam: Fall 2016 – Spring 2017 Operation Review. This document provides more detail than reported in the present report. It would be useful for internal purposes for the OLRS Water Manager to create a similar document for the Okanagan region.
- Staff numbers, experience, training, and succession planning are all issues that constrain the Province’s ability to optimally deliver its flood forecasting and management responsibilities, but such issues did not negatively affect FLNRORD’s management of the OLRS in 2017.

The following additional observations are specific to Kalamalka Lake:
- Each of the PCA-based inflow forecasts delivered by RFC significantly underestimated the actual inflow to Kalamalka Lake.
- The OLRS Water Manager made decisions between fall 2016 and spring 2017 in accordance with the Kalamalka Lake Operating Plan.
- The Water Manager appropriately balanced flooding concerns around Kalamalka Lake with flooding and damage concerns downstream of the lake, while he still had the ability to control the lake elevation.
- The Water Manager lost the ability to control the level of Kalamalka Lake on about May 1.
- The level of Kalamalka Lake peaked at 392.45 m on June 4, 25 cm above the estimated 200-year flood level, and within 75 cm of the Kalamalka Lake FCL (393.2 m).
- There is some uncertainty in the estimated 200-year flood level on Kalamalka Lake. Several estimates have been developed over the past several decades, although documentation of these estimates has been inconsistent. We have adopted the most recent estimate (developed in 1997) for this report.
- Similarly, documentation of the Kalamalka Lake FCL is unclear, although it is referenced in at least two municipal bylaws.
- Unlike at Okanagan Lake Dam, the rate of outflow from Kalamalka Lake is controlled not only by the dam itself, but by the configuration of the lake bottom immediately upstream of the dam. This factor limits the rate of flow that the Water Manager can release in early spring.

Recommendations:
- It is not possible to provide recommendations that would have helped the OLRS Water Manager significantly improve his management of the OLRS or Kalamalka Lake in 2017.

- Identify options for increasing the flow capacity of the channel downstream of the Okanagan Lake Dam, and of all other components of the OLRS, and conduct a feasibility analysis that includes estimation of costs and benefits.
- Evaluate the costs and benefits of relieving the flow release constraint at Kalamalka Lake exerted by the configuration of the lake bottom at the dam.
- Even if the volume inflow forecast models are improved, the Water Managers should continue to use local, timely observations and other relevant supporting information such as NOAA satellite imagery, as well as their experience and judgment, to guide them in interpreting the inflow forecasts received from the RFC.
- FLNRORD should examine the OLRS and Kalamalka Lake Operating Plans with particular reference to past experience and to ongoing climate change, and update them as necessary to ensure they continues to meet their needs into the future. Consider incorporating uncertainty into the Operating Plans, as recommended above.
- Since both Okanagan Lake and Kalamalka Lake reached peak elevations in excess of the estimated 200-year flood elevations in 2017, and since the origin of both these estimates is somewhat uncertain, it is recommended that the 200-year water levels and FCL elevations be re-evaluated for both lakes. This recommendation should be extended to all the lakes regulated as part of the OLRS. Horizontal setback requirements should be re-evaluated at the same time, recognizing that establishing horizontal and vertical setbacks is the responsibility of local government.
- During the seasonal period of high inflow, the OLRS Water Manager should document the management decisions made in response to the weather conditions and inflow forecasts received from the RFC. This would be more detailed than the summary reported herein, and could be coordinated with the FWMT Team, which develops a “record of management strategy” several months following the period of seasonal high inflow.
- The OLRS Manager should consider the advantages of developing an Emergency Operating Plan (as the Nicola Water Manager did on May 13, 2017) for the OLRS and Kalamalka Lake during periods of extreme inflow that would provide clear direction to staff on operating the system in these situations, and add some resilience in case of unforeseen staff absences.
- Specific information on the impacts that occurred around the lakes due to high water levels and along the Okanagan River due to high outflows in spring 2017 should be assembled and used to improve the Okanagan water management regime (the Operating Plans and the FWMT model).

Recommendations regarding the use of the RFC and FWMT models have been provided earlier. Discussion and recommendations regarding operational issues are provided in Section 9.

8.2.2 Nicola

The following list summarizes key observations related to weather and models used in the Nicola region, and an assessment of water management decisions made in 2017. Many of the points are consistent with those made earlier concerning the management of the OLRS.

- Weather conditions in the Nicola watershed preceding and during the spring freshet period were highly unusual.

- Each of the PCA-based inflow forecasts delivered by RFC significantly underestimated the actual inflow to Nicola Lake because they cannot anticipate the precipitation that will occur during the period covered by the inflow forecast, which was significantly above normal in February, March, April, and May. Precipitation fell as snow in February throughout the watershed, then shifted to rain at low elevations while remaining as snow into May at high elevations.
- In addition, the early season inflow forecasts were below average to average because upland snow conditions are a key driver of the forecast, and snow conditions were below normal at that time.
- Inflow to Nicola Lake in May was 143 million m^3, the highest on record, significantly higher than the previous record of 80.1 million m^3. Average May inflow is 67.4 million m^3. This resulted from high low elevation rainfall and high rates of upper elevation snowmelt during the month.
- Total February – July inflow to the lake was 249.5 million m^3 (the highest on record), much higher than the average of 156.1 million m^3, and the previous maximum of 194.6 million m^3.
- If the PCA models could have been updated more frequently than monthly, they could have recognized the increased inflow potential sooner. However, as the PCA-based inflow forecast models do not include a weather forecast, they would still have failed to predict the total lake inflow accurately.
- The NWMT tool needs to be improved before it gains wide acceptance. It has a useful role in distributing the volume inflow forecasts into daily and weekly increments. However, it is limited to distributing the PCA inflow forecast as it cannot amend or update the volume inflow forecast. In addition, it does not have weather forecasting ability.
- The Nicola Water Manager made decisions in fall 2016 and winter and spring 2017 by considering the forecast information made available to him, and took initiative to gain personal observations of conditions on the ground to help him interpret the model outputs.
- The Water Manager operated the lake appropriately, in accordance with the Nicola Lake Operating Plan, and balanced flooding concerns around the lake with flooding concerns along the Nicola River downstream of the lake.
- The level of Nicola Lake reached 626.97 m, 7 cm above the 200-year flood level, and 93 cm below the FCL.
- Reported damage was minimal around Nicola Lake and downstream of the lake. However, the FLNRORD Water Manager has only qualitative knowledge of the damage to be expected at various water levels and outflow rates. Improving this knowledge may require mapping at increased horizontal and vertical accuracy than currently exists.
- The switch to dry weather in mid-June helped the lake return to normal levels relatively quickly.
- The detailed account of the conditions and operations experienced in spring 2017 prepared by Jeptha Ball (2017) provides not only a very useful record of events but also a valuable education and training tool.
- As outlined in Section 9, staff numbers, experience, training, and succession planning are all issues that constrain the Province’s ability to optimally deliver its flood forecasting and management responsibilities, but such issues did not negatively affect FLNRORD’s management of the Nicola Dam in 2017.

Recommendations:

- It is not possible to provide recommendations that would have helped the Nicola Water Manager significantly improve his management of the dam in 2017.
- Even if the volume inflow forecast models are improved, the Water Manager should continue to use local, timely observations and other relevant supporting information such as NOAA satellite imagery, as well as experience and judgment, to guide them in interpreting the inflow forecasts received from the RFC.
- FLNRORD should examine the Nicola Dam Operating Plan, with reference to past and likely future hydrologic changes related to climate change, and to experience gained since the 1987 plan was developed, and update it as necessary to ensure it continues to meet their meets into the future. Consider incorporating uncertainty into the Operating Plan, as recommended above.
- The peak level of Nicola Lake exceeded the estimated 200-year return period value, but remained 93 cm below the FCL. Nevertheless, the fact that it exceeded the 200-year estimate provides an opportunity to re-evaluate the estimate and the FCL, and either confirm their ongoing validity or adjust them as needed in consideration of the 2017 experience.
- Specific information on the impacts that occurred around the lakes due to high water levels and along the Nicola River due to high outflows in spring 2017 should be assembled and used to improve the Nicola Dam water management regime (the Operating Plan and the NWMT model).
- More generally, improve the understanding of the relation between water levels and damage around Nicola Lake, and the relation between flows in Nicola River and flooding and damage along the river. This may require the acquisition of better quality mapping than the TRIM mapping currently available for the area.
- Consider developing the ability to prevent lake ice from restricting gate operations at Nicola Dam during cold winters.
- As there is no RFC-supplied inflow forecast model for Nicola Lake that includes a forecast of the precipitation that will fall during the period covered by the forecast, FLNRORD should consider developing such a model for Nicola Lake.
- The detailed account of the spring 2017 operations prepared by Jeptha Ball (Ball, 2017) should become standard procedure each year, and should be completed during the spring period of high inflow, rather than afterwards.

9 FLNRORD Operations

This section compares the resources of the B.C. RFC against those in other jurisdictions. Previous reviews of the operations of the RFC in 2005 and 2010, which included recommendations for improvement, were also briefly examined with a focus on how the 2017 events relate to those recommendations. Finally, based on interviews conduced for the present review, this section assesses organizational issues that constrain provincial capabilities with respect to flood forecasting and management.

9.1 RESOURCES: B.C. RFC AND OTHER JURISDICTIONS

The assessment of the resources of the B.C. RFC against forecast centres in other jurisdictions was based on an ongoing study funded by the federal government referred to as the "FloodNet project," and on a 2010 review of the B.C. RFC.

FloodNet is an NSERC-funded network of researchers, which aims to mitigate the impacts of floods across Canada and improve the accuracy and timeliness of flood forecasts. The researchers are distributed among academia and government, and a key objective of the network is the involvement of end-users (i.e., operational flood forecaster) to improve the likelihood of success.

FloodNet activities are directed along four themes, one of which is the Development of a Canadian Adaptive Flood Forecasting and Early Warning System (CAFFEWS). The goal of activities under this theme is to advance our knowledge of flood forecasting systems and enhance flood forecasting capacity in Canada. There are five specific projects under Theme 3, the first of which is a review and evaluation of each of the flood forecasting centres in Canada, including the RFC in Victoria. The goals of the review were to:

- document basic information on the operations of each forecast centre;
- identify challenges faced by Canadian forecast centres;
- identify ways in which FloodNet might assist forecast centres in the development of tools, models, and methods for flood forecasting; and
- identify critical research needed to improve forecasting ability.

A confidential draft report on FloodNet Project 3.1 was prepared in May 2017 (Jha et.al. 2017), and information from that draft has been used to inform the present report. Table 9.1 compares the number of forecasting staff at each of the provincial forecasting centres that were the subject of FloodNet Project 3.1.

Table 9-1
Number of staff employed in forecasting at each flood forecasting centre in Canada in 2016

Forecast Centre	Number of Forecasting Staff
British Columbia	4
Alberta	8
Saskatchewan	3
Manitoba	10
Ontario (province) TRCA (Ontario) CVCA (Ontario)	8 15 10
Quebec	7
New Brunswick	5
Newfoundland and Labrador	4

Ontario appears to employ many more forecasters than any other province. In Ontario, flood forecasting is performed both by the Province and by Conservation Authorities. Table 9.1 provides information on the numbers of forecasting staff at the provincial headquarters and at two of the 36 Conservation Authorities.

Despite having higher climatic and hydrologic variability compared with the other provinces, B.C. has among the fewest numbers of forecasters on staff of any province. Only Saskatchewan has fewer forecasting staff.

Through interviews, Canadian flood forecasting staff provided information on their key challenges. Challenges noted by David Campbell, P.Geo., B.C. Head of the RFC, are summarized in Table 9-2.

Table 9-2
Forecasting challenges of the B.C. RFC

Data	Modelling	Forecast	Communication	Staff
Estimation of snow cover and snow water equivalent	Calibration of new models and comparison with existing models	Uncertainty in streamflow forecast due to unreliable weather forecasts	None	Limited funding and limited number of staff

Common challenges identified by many of the Canadian forecasters included:

- A need to develop better hydrologic process models;
- A need for better weather forecasts to drive the hydrologic models;
- Limited staff numbers due to limited funding;
- Lack of expertise and experience; and
- Increase in staff turnover.

In summary, the size and varied topography of B.C. suggests a level of variability in climate and hydrologic response that exceeds that in other provinces. However, the number of staff engaged in forecasting in B.C. is among the lowest of any of the eight provinces examined in the study. Finally, some of the challenges faced by the B.C. RFC are unique and some (particularly the challenges related to staffing) are common to other provinces.

In an earlier study (see Section 9.2) Mattison Enterprises (2010) compared the number of hydrometric stations and the number of RFC staff in B.C., Alberta, and the Northwest Region of the U.S. The results are summarized in Table 9.3. There are differences in the data used to create Tables 9-1 and 9-3 (e.g. 2016 vs 2010 information, and the staff numbers are RFC "forecasters" in Table 9-1 but "all RFC staff" in Table 9-3), so these two tables are not directly comparable. Nonetheless, Table 9-3 suggests that the level of input data in B.C. and the staff resources applied to forecasting in B.C. are notably smaller than in adjacent jurisdictions, supporting the findings of the more recent work of the FloodNet 3-1 project (Table 9-1).

Table 9-3
Number of hydrometric stations and river forecasting staff in B.C., Alberta, and the U.S. Northwest Region

	British Columbia	Alberta	U.S. Northwest Region
Land area (km^2)	944,735	661,848	740,182
Population (millions)	4.5 (2010)	3.7 (2009)	11.5 (2006)
# hydrometric stations	456	525	1079
# RFC staff	5.5	24	16

(adapted from Mattison Enterprises 2010)

9.2 PREVIOUS REVIEWS OF THE B.C. RFC

In 2005, the operations of the B.C. RFC were reviewed by Water Management Consultants Inc. (WMC 2005). That review assessed the ability of the RFC to deliver on its objectives, identified the elements required to sustain the operation, and examined the operations from a “systems” perspective. That review was somewhat limited in usefulness however, because the authors had been requested not to provide recommendations to address identified needs and weaknesses.

By 2010, some of the weaknesses identified in 2005 had been addressed. Other changes had also occurred, including separating the snow survey function from the RFC.

In 2010, Jim Mattison, a former Assistant Deputy Minister with the Ministry of Environment (with responsibility for the RFC) was contracted to “conduct a water supply and river forecast function business review and provide a risk assessment of the water supply and river forecast function” (Mattison 2010). Included in the scope of the review was an assessment of how the RFC would be optimally placed within the government structure.

Specifically, Mattison reviewed the operation of the RFC, and not the supporting functions, such as the snow survey or hydrometric programs. The scope was as follows:

- Identify the risk inherent in the current model of operation, qualitatively if not quantitively;
- Identify gaps in operations that may be exacerbating the risk;
- Identify opportunities and describe their benefits; and
- Recommend changes or improvements where appropriate.

The report (Mattison 2010) provides a thorough examination of the operation of the RFC. It acknowledged that climate, and in turn hydrologic responses, are changing. Also, it recognized that the characteristics of many B.C. watersheds are not static, but are changing in response to urbanization, industrial activity such as forest harvesting, forest fires, and insect infestations. The report concluded that the data and models used to develop streamflow forecasts, the technologies used, and the skills of the forecasting staff must also evolve in response to these non-stationarities.

The report provided 33 specific recommendations to improve the RFC. It is beyond the scope of the present study to assess the implementation status of each of these 33 recommendations. However, based on interviews with Water Managers and with the Head of the RFC concerning strengths and weakness of the forecasting system in use in 2017, it appears that some of the 2010 recommendations have not yet been fully implemented. Recommendations that appear to remain relevant today include the following:

- #1 – relating to provision of adequate staffing for briefings during emergency events;
- #8 – relating to cross-training of staff and a succession plan for the forecasters;
- #13 - relating to combining the RFC and snow survey program within one operational unit;
- #14 – relating to continuing the work of converting from periodic to real-time transmission of data to support the development of streamflow forecasts;
- #22 and #23 – relating to increasing the number of forecasters from 2 to 6 and adding at least 3 other staff members;
- #24 – relating to improvements in workplace culture to better foster an attitude of continuous improvement; and
- #27 – relating to conducting research to improve the accuracy and timeliness of the forecasts.

This list is not intended to be an exhaustive list of the Mattison recommendations that still may require attention. Instead, it is a selection of such recommendations that the 2017 flood response has shone a light on.

9.3 ORGANIZATIONAL CONSTRAINTS IDENTIFIED IN 2017

While interviewing key FLNRORD staff in support of this study, we enquired about organizational constraints to delivering an effective inflow forecasting and lake level and river flow management program in the Okanagan and Nicola regions. The results of these discussions are reported in this section. It is important to note that the organizational issues identified in this section did not negatively affect FLNRORD's management of the OLRS, Kalamalka Lake, or the Nicola Dam in 2017.

9.3.1 Succession Planning, Training, and Mentoring

In previous years, the Water Manager in Penticton would have had an "apprentice" training and becoming ready to assume the role of managing the OLRS when the Water Manager left the organization. For example, Des Anderson apprenticed in the role of Flood Safety Engineer with Brian Symonds when Brian was Water Manager, and Shaun Reimer apprenticed as Flood Safety Engineer with Des Anderson when Des was Water Manager.

Now however, the succession plan is weak, and there is no obvious successor to Shaun Reimer, the current Water Manager in Penticton. The current Flood Safety Engineer in Penticton has been in place only since June 2017 (i.e., after the key decision-making period during the spring 2017 flood season). The previous Flood Safety Engineer had transferred to another FLNRO office for personal reasons, exposing a lack of resilience to the kind of routine staff movements that can be expected to occur in any organization.

Similar issues are apparent in the Nicola Region, which led to FLNRORD asking a retired Nicola Dam Water Manager (Jeptha Ball, P.Eng.) to return from retirement to resume management of the Nicola Dam in 2017. While this solution provided FLNRORD with the benefit of Mr. Ball's extensive experience during a challenging year, reliance on retired employees is not a permanent solution to staffing a critical function.

In summer 2015, Mr. Ball gave his employer notice of his intent to retire in January 2016. Despite initiating a hiring process in September 2015, FLNRORD had not managed to identify a suitable replacement before Mr. Ball's retirement. To help the Ministry, in January 2016, he agreed to return to fulfill his pre-retirement duties until end-July 2016. FLNRORD filled his position in June 2016, but with only one month of overlap, there was insufficient time to train his replacement. In addition, within about two months of beginning her employment, the new Water Manager began a one-year maternity leave. Between August 2016 and March 2017, the dam was managed by the Regional Section Head in Kamloops. Meanwhile, in October 2016, Mr. Ball was again persuaded to return on a part-time basis to cover some aspects of the maternity leave. In March 2017, because Nicola Dam clearly needed active and experienced management, and because there were no other internal resources to draw from, Mr. Ball was asked to resume the role of Nicola Dam Water Manager. While this was a good outcome for 2017, it highlights a lack of resilience to normal and predictable staff movements (e.g. retirements and maternity leaves) that occur within organizations.

It is important to continually improve the inflow forecast models and automate management decisions using clear operational plans to the extent possible, even without the non-stationarities associated with climate change. Nevertheless, it would be impossible and undesirable to fully replace personal wisdom and experience with models or automated operational plans. FLNRORD has no formal mentoring program nor a sufficiently comprehensive training program to ensure that the current engineering staff in Penticton and Kamloops are fully prepared to execute their own roles, or prepared to assume more senior roles, such as that of Water Manager during temporary or permanent absences of the Water Manager.

Recommendations:

- Examine the internal approach to succession planning. Improve the approach to a level where the Province is prepared to keep the critical forecasting and management roles filled with qualified individuals on a continuous basis.
- Establish a formal mentoring program within the organization.
- Improve the internal training program to ensure that all staff are well trained for their current roles, and that a sufficient number of internal staff are capable of assuming more senior roles within the water management program.

9.3.2 Absences from the Office

Between May 18 and 27, 2017 the Water Manager (Shaun Reimer) was away from the office. Unable to identify a sufficiently experienced replacement from inside the organization, FLNRORD brought in Brian Symonds as a replacement. There is no more qualified replacement than Brian Symonds, so this substitution did not negatively affect the operation of the OLRS in spring 2017, particularly as it occurred after the ability to significantly change the rate of lake outflow was gone. Nonetheless, this situation highlights a potential weakness in the internal management system. Having to rely on a retired former OLRS Water Manager highlights a lack of adequate succession planning, experience, and training within the organization.

Recommendation:

- For critical regional water management functions, the Province should consider whether absences from the office at key times of the year can be permitted for key staff (except in emergencies) without a robust backup plan in place.

9.3.3 Federal/Provincial Communication

The OLRS Water Manager reported that communication between the federal government (Water Survey of Canada [WSC]), which manages hydrometric stations (lake level gauges and water level/streamflow stations), is strong and respectful. However, he also reported a possible communication issue between WSC and FLNRORD in spring that may have impacted operational decision-making. On May 2, WSC staff informed the Water Manager that they had identified a problem and applied a correction to the hydrometric gauge on Kalamalka Lake on that day. This meant that the lake was 7 cm higher than the Water Manager had thought it was. It's possible that there was no warning of a coming gauge correction. However, for the Water Manager, this was inopportune timing since by May 2 he no longer had the ability to control the lake level, and could not alter his decision-making to accommodate this new information.

Recommendation:

- Establish a formal communication protocol between WSC and the OLRS Water Manager specifying the scope of the information required to be communicated, acceptable methods of communicating, and timing expectations; and endeavour to identify and communicate gauge corrections before the spring freshet.

9.3.4 Managing Three Inter-related Functions (Data Collection, Forecasting, and Water Management)

In October 2010, the Ministry of Natural Resource Operations was formed, and operational water management was separated from science and information activities, which remained within the Ministry of Environment (MOE). The new ministry assumed responsibility for inflow forecasting and water management, but the collection of snow survey information remained the responsibility of MOE. In February 2011, the ministry was renamed the Ministry of Forests, Lands and Natural Resource Operations, and in fall 2017, it was renamed the Ministry of Forests, Lands, Natural Resource Operations, and Rural Development.

Although it has responsibility for snow surveys, MOE merely pays for the snow survey function, and uses regional or district-level FLNRORD technicians to complete the work. Since these technicians report to FLNRORD managers, their connection to the snow survey program is not as strong as it could be. The

RFC Head suggested that the quality and consistency of snow survey data has dropped since 2009. In addition, the OLRS Water Manager suggested that MOE budgets to not appear as strong as needed to deliver their programs.

Finally, discussions with the two Water Managers and with the Head of the RFC suggested that the Water Managers are not as familiar with the inflow forecasting models (including the data sources that drive the models) as they could be; nor is the Head of the RFC as familiar with the Operating Plans and constraints on lake level management as he could be. Brian Symonds, P.Eng., a retired former OLRS Water Manager reported that in past years, the RFC and the Water Managers were more familiar with each other's roles.

Recommendations:

- To improve service delivery, reconsider the 2010 separation of the function of snow data collection from forecasting and regional water management, with a view to bringing these functions together within a single well-funded organization.
- Provide sufficient time and resources to train the Water Managers on inflow forecasting data requirements and models, and advise the Head of the RFC on the management challenges faced by the Water Managers. This improved two-way understanding will improve communication and tend to increase the efficiency of information flow.

9.3.5 RFC Staffing Levels

In December 2016, one of the RFC forecasters resigned—the forecaster most familiar with the ESP model. The Head of the RFC was attempting to fill this gap during spring freshet in 2017, and has now replaced that individual. In addition, he has received approval to hire another forecaster, and as of November 2017, is advertising to fill this position. The second forecaster will provide research and development capability to continue the work of improving forecasting models. However, even with these two positions filled, the RFC will still be staffed at a level below that of comparable jurisdictions, and below the level recommended in Mattison (2010).

Recommendations:

- Review the WMC (2005) and Mattison (2010) reports and determine the status of each of the 33 Mattison recommendations (e.g., completed, started but not complete, or not started).
- For recommended actions that are not complete, confirm their continuing relevance or suggest alternative recommendations.
- Provide the staffing and resources needed to operate the RFC in compliance with its mandate, using the 2010 Mattison report and the 2016 draft FloodNet 3-1 report as guidance.

9.3.6 Challenges at Peak Times

In addition to leading the technical function of forecasting, during times of high flow and flooding, the Head of the RFC is called upon to communicate with external organizations (e.g., other provincial agencies and the public). This communication role reduces the forecasting power of the RFC when accurate forecasts are most needed, and when work intensity is higher than usual as new information is being received and new forecasts are being developed.

Similar challenges face the Water Managers in FLNRORD's Regional and District offices

Recommendations:

- Consider a method of flexible staffing levels within the RFC in which staff could be seconded from other agencies or Ministries at peak activity times of the year. These staff could likely be assigned to support roles such as data analysis, so they would not need to be familiar with the forecasting models themselves.
- Consider a similar approach to staffing key water management roles in the Regional and District offices.

9.3.7 External Communication

The original scope of the present study included evaluating FLNRORD's external communications during the 2017 period of high water. However, this scope was changed before the work began to simply document the type and frequency of external communications that occurred, based on discussions with FLNRORD staff.

The Head of the RFC reported some lack of clarity related to responsibilities for external communication between the various provincial groups (e.g., RFC, regional or District FLNRORD staff, the provincial emergency management program, and the public) with responsibility for managing aspects of flooding.

Recommendations:

- Fully examine the external communication that occurred in spring 2017 and develop recommendations for improvement.
- Clarify the roles and responsibilities for external communication among the various agencies that have responsibilities for inflow forecasting, water management, and emergency management.

10 Recommendations

The purpose of the assessment reported herein was to evaluate the operation of the OLRS, Kalamalka Lake, and Nicola Dam during freshet 2017, and identify opportunities for improvement during times of flooding. Although the spring 2017 flooding affected other parts of the B.C. southern interior, the scope of this report is limited to the OLRS, Kalamalka Lake, and Nicola Dam. The report qualitatively describes flood-related impacts, and reports (but does not assess) the external communication that occurred during the period of flooding.

Section 8 provided observations and analysis related to inflow forecasting models and 2017 water management decisions, and included recommendations flowing from the analysis. Those recommendations have been brought forward and are listed below.

Section 9 included assessment of organizational impediments to optimizing the delivery of the Province's responsibilities related to inflow forecasting and water management, and provided some recommendations. Those recommendations are also listed below.

Unless otherwise noted, the recommendations are directed at the Province.

Both climate and hydrology have changed in B.C. over the past century (MOE 2016), and are expected to continue to change. The non-stationarity of climate and hydrology will continue to increase the challenges faced by organizations responsible for water-related data collection, forecasting, and water management; which increases the importance and urgency of the recommendations presented herein.

10.1 INFLOW FORECASTING MODELS

10.1.1 Model Input Data

- If the PCA models are to be revised to run more frequently than monthly, a sufficient number of snow courses will need to be converted to automated stations. However, these conversions must be done without losing the use of the record at the existing snow courses, consistent with the next recommendation.
- At automated snow weather stations, ensure that sufficient overlapping record is obtained at the old snow course and at the replacement automated station to determine the mathematical relation between them so that the snow course data is not lost.
- Ensure that the new Silver Star automated station is operational for winter/spring 2018 and future years.
- Maintain the old Silver Star snow course for several years and develop a mathematical relation between the data from the old snow course and data from the new automated station.
- Maintain the old Greyback snow course for several years and develop a mathematical relation between the data from the old snow course and data from the new automated station.
- Review the network of snow courses and automated stations in the Okanagan and Nicola regions (and potentially in other regions of B.C.), and add snow courses or automated stations where

needed to ensure the snow survey network provides an accurate representation of snow conditions in these basins.

- Review the set of stations used to compute the Basin Snow Water Index for the Okanagan and Middle Fraser (and potentially other regions of B.C.); consider whether it remains appropriate for the Index to be focussed on representing upper elevation snowpack; and update the station lists as required.
- Relocate the Upper Nicola River hydrometric station 08LG049 to improve the quality (e.g. accuracy and reliability) of streamflow data from this location. We understand that the Nicola Water Manager has initiated steps to move the station to the outlet of Douglas Lake, which is likely a better location.
- Consider the benefits of installing new, or re-establishing former, hydrometric stations on Quilchena and Moore Creeks to permit further refinement of the inflow forecast models and to assist with operational management of Nicola Lake.
- Re-establish a hydrometric station on Clapperton Creek to provide the Nicola Water Manager with information needed to help set the gate openings to reduce the risk of flooding downstream.
- Evaluate the adequacy of existing data networks used to drive seasonal inflow forecasting models, and fill identified gaps to allow the Province to meet its mandate to deliver forecasts with sufficient accuracy and precision to appropriately manage flooding, drought, safety and other issues in the Okanagan and Nicola regions.
- Ensure that a sufficient number of its data sources with already long records continue to operate well into the future to allow the Province to continue to meet its forecast quality expectations.
- Make use of the snow and hydrometric data available from the Upper Penticton Creek Research Station to improve the inflow forecasting models, and to inform the OLRS Water Manager about upper elevation snow and runoff conditions on a real-time operational basis.

10.1.2 RFC Models

- For both the Okanagan and Kalamalka Lake PCA models, identify alternative models that can be adopted when needed input data is missing, similar to the approach used in Summit (1999).
- Develop PCA models that run on a weekly or bi-weekly basis.
- Update the PCA inflow forecast models every 5 years.
- Since 6 years have elapsed since the last model update, complete a comprehensive review and update of the 2011 PCA models within the next year.
- Modernize and upgrade the method used to run the inflow forecasting models from the current Excel-based platform, to improve security and reduce the possibility of error.
- Provide training to the Water Managers on how to interpret and use the standard error estimates that are provided with each forecast, and consider updating the Operating Plans to explicitly accommodate forecast uncertainty.
- If the RAVEN model and the ESP approach will continue to be used, upgrade the RAVEN model until it provides reasonable calibrations to lake inflows without requiring substantial manual manipulations of the input weather data to achieve agreement between modelled and observed outcomes.
- Maintain the ability to run an inflow forecast model beyond May 1.

- Evaluate the capability of the current generation of 10-day weather forecasts to improve the accuracy and precision of the inflow forecasts. If this benefit is negligible, continue to focus on improving the PCA models, while providing Environment Canada with specific feedback on the need for improved short-term weather forecasts.
- Evaluate the potential benefit of including a weather forecast extending beyond 10 days, if such forecasts are sufficiently reliable.
- If ESP will continue to be used by the RFC, develop a more sophisticated way to choose a likely inflow and inflow pattern for the third leg of the forecast (the period from 10 days from the forecast date to the end of the forecast period).
- Ensure that sufficient effort has been expended to review the full spectrum of possible approaches to inflow modelling before committing to a preferred approach.
- If the PCA and ESP approaches will both continue to be used, the RFC should decide whether to focus on the ESP approach, the PCA approach, or continue to use both approaches. Each approach has strengths and weaknesses. It is likely that PCA models will continue to be valuable for several years (due to limitations in current weather forecasting abilities), but ultimately the ESP approach may be needed due to ongoing climate non-stationarity and the value potentially gained by incorporating accurate weather forecasts.
- The value of any lake inflow forecast model is largely its ability to help the Water Manager avoid damages. The effort to be expended on model upgrading should be determined partly through consideration of the value of the property and infrastructure subject to flooding.
- If the ESP approach will continue to be improved and used in the Okanagan, upgrade it continuously.

10.1.3 FWMT and NWMT

Recommendations to the FWMT and NWMT owners:

- Continue to improve FWMT and NWMT and the technical information that supports them, based on experience and as recommended by model operators.
- Allow a model user to view the daily inflows predicted by the models in addition to the rolled-up weekly values.
- Encourage the RFC to develop the ability to provide reliable volume inflow forecasts at intervals shorter than one month.
- Consider adding a method of forecasting future weather to FWMT by adapting an autoregressive technique already used in FWMT for modelling water temperature, or by directly including a weather forecast.
- The annual “record of management strategy” produced by the FWMT Team could be simplified and used to educate and train other staff in the organizations represented on the FWMT Team.
- Use the specific 2017 experience to continue to improve the FWMT and NWMT.
- Examine the fisheries-related flow objectives included within the NWMT to ensure that the Operating Plan objectives are fully respected.

10.2 2017 DECISIONS

- It is not possible to provide recommendations that would have helped the OLRS Water Manager significantly improve his management of the OLRS or Kalamalka Lake in 2017.
- It is not possible to provide recommendations that would have helped the Nicola Dam Water Manager significantly improve his management of the dam in 2017.
- Identify options for increasing the flow capacity of the channel downstream of the Okanagan Lake Dam, and of all other components of the OLRS, and conduct a feasibility analysis that includes estimation of costs and benefits.
- Evaluate the costs and benefits of relieving the flow release constraint at Kalamalka Lake exerted by the configuration of the lake bottom at the dam.
- Even if the volume inflow forecast models are improved, the Water Managers should continue to use local, timely observations and other relevant supporting information such as NOAA satellite imagery, as well as their experience and judgment, to guide them in interpreting the inflow forecasts received from the RFC.
- FLNRORD should examine the OLRS and Kalamalka Lake Operating Plans with particular reference to past experience and to ongoing climate change, and update them as necessary to ensure they continues to meet their needs into the future. Consider incorporating uncertainty into the Operating Plans, as recommended above.
- Since both Okanagan Lake and Kalamalka Lake reached peak elevations in excess of the estimated 200-year flood elevations in 2017, and since the origin of both these estimates is somewhat uncertain, it is recommended that the 200-year water levels and FCL elevations be re-evaluated for both lakes. This recommendation should be extended to all the lakes regulated as part of the OLRS. Horizontal setback requirements should be re-evaluated at the same time, recognizing that establishing horizontal and vertical setbacks is the responsibility of local government.
- During the seasonal period of high inflow, The OLRS Manager should document the OLRS and Kalamalka Lake management decisions made in response to the weather conditions and inflow forecasts received from the RFC. This would be more detailed than the summary reported herein, and could be coordinated with the FWMT Team, which develops a “record of management strategy” several months following the end of the period of seasonal high inflow.
- The OLRS Manager should consider the advantages of developing an Emergency Operating Plan (as the Nicola Water Manager did on May 13, 2017) for the OLRS and Kalamalka Lake during periods of extreme inflow that would provide clear direction to staff on operating the system in these situations, and add some resilience in case of unforeseen staff absences.
- Specific information on the impacts that occurred around the lakes due to high water levels and downstream along the Okanagan and Nicola Rivers due to high outflows in spring 2017 should be assembled and used to improve the water management regimes (the Operating Plans and the FWMT and NWMT models).
- More generally for the Nicola area, improve the understanding of the relation between water levels and damage around Nicola Lake, and the relation between flows in Nicola River and flooding and damage along the river. This may require the acquisition of better quality mapping than the TRIM mapping currently available for the area.

- The detailed account of the spring 2017 operations prepared by Jeptha Ball (Ball, 2017) should become standard procedure each year, and should be completed during the spring period of high inflow, rather than afterwards.
- The peak level of Nicola Lake exceeded the estimated 200-year return period value, but remained 93 cm below the FCL. Nevertheless, the fact that it exceeded the 200-year estimate provides an opportunity to re-evaluate the estimate and the FCL, and either confirm their ongoing validity or adjust them as needed in consideration of the 2017 experience.
- FLNRORD should examine the Nicola Dam Operating Plan, with reference to past and likely future hydrologic changes related to climate change, and to experience gained since the 1987 plan was developed, and update it as necessary to ensure it continues to meet their meets into the future. Consider incorporating uncertainty into the Operating Plan, as recommended above.
- Consider developing the ability to prevent lake ice from restricting gate operation at Nicola Dam.
- As there is no RFC-supplied inflow forecast model for Nicola Lake that includes a forecast of the precipitation that will fall during the period covered by the forecast, FLNRORD should consider developing such a model for Nicola Lake.

10.3 FLNRORD OPERATIONS

The following recommendations are provided to assist FLNRORD improve its ability to continue to provide forecasting and water management services to the public at the expected level:

- Examine the internal approach to succession planning. Improve the approach to a level where the Province is prepared to keep the critical forecasting and management roles filled with qualified individuals on a continuous basis.
- Establish a formal mentoring program within the organization.
- Improve the internal training program to ensure that all staff are well trained for their current roles, and that a sufficient number of internal staff are capable of assuming more senior roles within the water management program.
- For critical regional water management functions, the Province should consider whether absences from the office at key times of the year can be permitted for key staff (except in emergencies) without a robust backup plan in place.
- Establish a formal communication protocol between WSC and the OLRS Water Manager specifying the scope of the information required to be communicated, acceptable methods of communicating, and the timing expectations; and endeavour to identify and communicate gauge corrections before the spring freshet.
- To improve service delivery, reconsider the 2010 separation of the function of snow data collection from forecasting and regional water management, with a view to bringing these functions together within a single well-funded organization.
- Provide sufficient time and resources to train the Water Managers on inflow forecasting data requirements and models, and advise the Head of the RFC on the management challenges faced by the Water Managers. This improved two-way understanding will improve communication and increase the efficiency of information flow.
- Review the WMC (2005) and Mattison (2010) reports and determine the status of each of the 33 Mattison recommendations (e.g., completed, started but not complete, or not started).

- For recommended actions that are not complete, confirm their continuing relevance or suggest alternative recommendations.
- Provide the staffing and resources needed to operate the RFC in compliance with its mandate, using the 2010 Mattison report and the 2016 draft FloodNet 3-1 report as guidance.
- Fully examine the external communication that occurred in spring 2017 and develop recommendations for improvement.
- Clarify the roles and responsibilities for external communication among the various agencies that have responsibilities for inflow forecasting, water management, and emergency management.
- Consider a method of flexible staffing levels within the RFC in which staff could be seconded from other agencies or Ministries at peak activity times of the year. These staff could likely be assigned to support roles such as data analysis, so they would not need to be familiar with the forecasting models.
- Consider a similar approach to staffing key water management roles in the Regional and District offices.

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Appendix A - Photo documentation of spring 2017 flooding in the Okanagan region

A) High winds and high water cause damage to highway adjacent to Okanagan Lake.

B) High streamflows in Naramata Creek result in sediment plume in Okanagan Lake.

Associated Environmental	PROJECT NO.:	2017-8178.000.000	**FIGURE A-1: Select photos of 2017 flooding within the Okanagan.**
	DATE:	December 2017	Ministry of Forests, Lands, Natural Resource Operations & Rural Development
	DRAWN BY:	LB	Review of 2017 Flood Response: Okanagan Lake Regulation System and Nicola Dam

A) High streamflows result in a culvert and road washout at Glen Fir Road, Naramata.

B) High streamflows at Okanagan Falls.

Associated Environmental	PROJECT NO.:	2017-8178.000.000	**FIGURE A-2: Select photos of 2017 flooding within the Okanagan.**
	DATE:	December 2017	Ministry of Forests, Lands, Natural Resource Operations & Rural Development
	DRAWN BY:	LB	Review of 2017 Flood Response: Okanagan Lake Regulation System and Nicola Dam

A) High water levels in Okanagan Lake result in localized flooding at Powell Beach, Summerland.

B) High water levels in Okanagan Lake result in localized flooding at Sun Oka Beach, Summerland.

Associated Environmental	PROJECT NO.:	2017-8178.000.000	**FIGURE A-3: Select photos of 2017 flooding within the Okanagan.**
	DATE:	December 2017	Ministry of Forests, Lands, Natural Resource Operations & Rural Development
	DRAWN BY:	LB	Review of 2017 Flood Response: Okanagan Lake Regulation System and Nicola Dam

A) High water levels in Okanagan Lake result in floating debris.

B) High water levels in Osoyoos Lake result in localized flooding around the lake.

Associated Environmental	PROJECT NO.:	2017-8178.000.000	**FIGURE A-4: Select photos of 2017 flooding within the Okanagan.**
	DATE:	December 2017	Ministry of Forests, Lands, Natural Resource Operations & Rural Development
	DRAWN BY:	LB	Review of 2017 Flood Response: Okanagan Lake Regulation System and Nicola Dam

Appendix B - Photo documentation of spring 2017 flooding in the Nicola region

A) Nicola River upstream of Highway 5.

B) Nicola River downstream of Highway 5.

Associated Environmental	PROJECT NO.:	2017-8178.000.000	**FIGURE B-1: Select photos of 2017 flooding within the Nicola Region.**
	DATE:	December 2017	Ministry of Forests, Lands, Natural Resource Operations & Rural Development
	DRAWN BY:	LB	Review of 2017 Flood Response: Okanagan Lake Regulation System and Nicola Dam

A) Nicola River at Burgess Avenue, Merritt.

B) Nicola River at Merritt, looking southwest.

Associated Environmental	PROJECT NO.: 2017-8178.000.000	**FIGURE B-2: Select photos of 2017 flooding within the Nicola Region.**
	DATE: December 2017	Ministry of Forests, Lands, Natural Resource Operations & Rural Development
	DRAWN BY: LB	Review of 2017 Flood Response: Okanagan Lake Regulation System and Nicola Dam

A) Nicola River at Merritt.

B) Nicola Lake at Harmon Estates.

Associated Environmental	PROJECT NO.: 2017-8178.000.000	**FIGURE B-3: Select photos of 2017 flooding within the Nicola Region.**
	DATE: December 2017	Ministry of Forests, Lands, Natural Resource Operations & Rural Development
	DRAWN BY: LB	Review of 2017 Flood Response: Okanagan Lake Regulation System and Nicola Dam

A) RV site adjacent to Upper Nicola River outlet and Highway 5A.

B) RV site on spit north of Upper Nicola River outlet.

Associated Environmental	PROJECT NO.: 2017-8178.000.000 DATE: December 2017 DRAWN BY: LB	**FIGURE B-4: Select photos of 2017 flooding within the Nicola Region.** Ministry of Forests, Lands, Natural Resource Operations & Rural Development Review of 2017 Flood Response: Okanagan Lake Regulation System and Nicola Dam