Plan of Study for Modernizing the Okanagan Lake Regulation System: Final Report

Okanagan Basin
WATER BOARD

Associated Environmental

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EXECUTIVE SUMMARY

This report describes the work required before significant changes are made to the Okanagan Lake Regulation System (OLRS) and the way it is managed. The required work is divided into 17 scientific and engineering studies and a final planning study, collectively known as the Plan of Study. During the final study, a plan for modernizing the OLRS and its Operating Plan will be developed. The OLRS modernization plan will reflect current knowledge and society's values, including the knowledge and values of the Syilx people, who sustainably managed the land and water of the Okanagan for thousands of years.

The ORLS consists of a series of dams and other structures located on major lakes and the Okanagan River between Penticton and Osoyoos in the southern Okanagan valley. It was constructed jointly by the federal and provincial governments in the 1950s, primarily to control flooding. A comprehensive water resources study in the early 1970s led to the Okanagan Basin Agreement, which provided recommendations for target lake levels and river flows to achieve several other benefits in addition to flood control. Those recommendations formed the basis for the OLRS Operating Plan that is still in use today. The recommendations were partly based on the results of an extensive public engagement program, so they generally reflect the societal values of the time. Operation of the system is becoming increasingly challenging because of the changing nature of the Okanagan hydrologic regime in response to ongoing climate change. In addition, the OLRS assets are approaching the end of their service life. The Province of B.C. therefore anticipates that changes to the OLRS infrastructure and to the way it is managed may be required to maintain or increase the benefits provided by the system. Society has evolved since the 1950s and 1970s, and a modernized OLRS will reflect modern priorities and values. In addition, it is now expected that Indigenous knowledge and values will be considered in both informing and planning the OLRS modernization project. The Plan of Study anticipates Indigenous participation in both the scientific studies and in the final step in this Plan of Study – developing a plan to modernize the OLRS. The OLRS modernization project could include re-naturalizing and restoring ecosystem function along the mainstem Okanagan River, expanding a program that has been underway since 2000.

This Plan of Study subdivides the required work into 18 discrete studies: 17 scientific and engineering studies leading to a final planning study during which a plan for modernizing the OLRS will be developed. The Plan of Study was developed through review of relevant historical and recent scientific and engineering work, and consultation with an advisory group comprising representatives of federal, Indigenous, provincial, and local governments with responsibility for Okanagan water. It is intended as a minimum list of studies that should be completed, based on current knowledge. As each of these studies is completed, additional knowledge gaps are likely to emerge, some of which may require additional investigation before decisions about modifying the OLRS can be made.

The study descriptions contained herein reflect knowledge as of March 2021. Knowledge will evolve as the studies are completed. Terms of Reference will be developed for each study that reflect the state of knowledge immediately prior to initiating work on the study. Also, as knowledge increases it may be necessary to re-examine previously completed studies. For example, improved climate data and models may emerge that suggest a need to re-examine the hydrologic and hydraulic models that provide the foundation for much of the work outlined herein.

Finally, there could be other ways to organize the required work than into the 18 specific studies described herein.

The Plan of Study is divided into five categories:

- Category One: Improved foundation to support OLRS operations (7 studies)

- Category Two: The past (2 studies)
- Category Three: The present and future (7 studies)
- Category Four: The path forward (2 studies)
- Category Five: Community engagement

Design and delivery of a broad-scale community engagement plan (Category Five) should begin before any of the other work described herein is undertaken, and continue for the entire period during which these studies are being performed.

Category One includes seven studies:

- Study 1: Create linked Okanagan-Similkameen hydrologic model
- Study 2: Improve OLRS Operating Plan documentation
- Study 3: Create integrated hydraulic model for Okanagan mainstem
- Study 4: Improve lake inflow forecasting models and account for uncertainty
- Study 5: Expand groundwater knowledge in support of OLRS management
- Study 6: Refine Fish Water Management Tool input data and model
- Study 7: Refine mainstem lake bathymetry

These studies will improve the information that underlies OLRS operational decision-making, thus both benefitting current operations and informing the need for and extent of future changes to the OLRS and its Operating Plan. Study 1 will extend work currently underway by the International Joint Commission. Study 2 seeks to clarify and strengthen the written documentation of operating procedures within the OLRS Operating Plan. Studies 1 and 2 will provide the foundation for an integrated hydraulic model for the entire Okanagan valley-bottom (Study 3). Studies 4, 5, 6, and 7 are supporting studies that will contribute useful information but are not essential to this Plan of Study.

Category Two includes two studies:

- Study 8: State of the Okanagan mainstem lakes and river before European settlement
- Study 9: OLRS history, benefits, and retrospective impact assessment

Study 8 will comprehensively describe the conditions that existed for centuries prior to the arrival of European settlers in the Okanagan valley. A greater understanding of the natural and Syilx-managed systems will promote informed communication and decision-making among alternative courses of action. This study will contribute essential background information for the retrospective OLRS impact assessment in Study 9. Study 9 will document the history of OLRS development, describe how it has changed the mainstem lake and river system, and identify its benefits (primarily flood control and drought mitigation). It will also describe the ecosystem impacts associated with the changes to the mainstem river and lake system due to OLRS construction and operation, and cultural and socio-economic impacts on Syilx society.

Category Three includes seven studies:

- Study 10: Flood level implications of not changing the OLRS Operating Plan
- Study 11: Okanagan mainstem flood risk assessment
- Study 12: Okanagan mainstem drought risk assessment
- Study 13: Impacts of climate change and Operating Plan changes
- Study 14: OLRS lifecycle analysis and replacement cost analysis
- Study 15: Opportunities to restore lost OLRS benefits

- Study 16: Feasibility of re-naturalizing and restoring the mainstem system

Study 10 will demonstrate that if the Operating Plan is not changed, design flood levels and Flood Construction Levels in Okanagan lakes will be substantially higher than reported and mapped by NHC (2020). Study 11 will evaluate the hazards and consequences related to water levels and flows that are above normal and will focus on constructed assets, including the OLRS infrastructure. Study 12 will recommend Operating Plan changes (if any) needed to maintain the drought management benefits provided by the OLRS into the future. It will also evaluate hazards and consequences related to water levels and flows that are below normal and will focus on constructed assets. Study 13 will focus on all other receptors, including natural aquatic and terrestrial ecosystems, socio-economic conditions, and international agreements, and will consider the full range of flows from drought to flood. Study 13 will therefore be analogous to a combination of Studies 11 and 12 for all non-constructed assets and receptors, and will follow from Study 9, in which the historical and present-day impacts of OLRS construction and operation on ecosystems and socio-economic conditions will have been assessed. Study 14 will identify the timing and costs required to replace each aspect of OLRS infrastructure as necessitated by its age and condition. Study 15 will build on previous studies to describe quantitatively how the benefits provided by the OLRS are diminishing over time due to climate change. Study 16 will examine the feasibility of significantly extending the ongoing work of the Okanagan River Restoration Initiative (ORRI) and other restoration programs to re-naturalize and restore the mainstem Okanagan River and other valley-bottom areas to pre-development conditions, while maintaining or enhancing the ability of the OLRS to provide flood control, drought management, and other benefits.

Category Four includes two studies:

- Study 17: Governing conditions for modernizing the OLRS
- Study 18: Develop a plan for modernizing the OLRS

Study 17 will describe the relevant legal, political, cultural, environmental, and social contexts governing the work of OLRS modernization and large-scale river restoration. Study 18 will integrate the outcomes of previous studies and develop a comprehensive and climate-resilient plan for OLRS modernization that reflects the values and priorities of all Okanagan society—Indigenous and non-Indigenous. The plan will likely include replacement and upgrades of OLRS infrastructure, changes to the OLRS Operating Plan, and a project to re-naturalize and restore lost aquatic habitat and ecosystem function throughout the mainstem Okanagan valley. The plan developed in Study 18 will provide the foundation for securing funding for subsequent detailed technical work and completion of the OLRS modernization project.

Category Five is a comprehensive community engagement program. It will be necessary to engage with the public and specific groups about the need to modernize the river and lake management system, and about the results of the studies described herein, as well as on OLRS modernization planning. Community contribution to an OLRS modernization program will provide the social capital necessary for the subsequent processes of decision-making and funding acquisition.

The studies are described in Section 3 of this report at a conceptual level. A detailed Terms of Reference (including workplan, budget, and schedule) needs to be developed for each study before it is initiated, which will reflect the then current state of knowledge. The linkages shown on Figure 3-1 in the main report illustrate the required order of the studies.

The report does not include cost estimates for the individual studies, or for the overall study program, since these costs depend significantly on the approach taken to deliver the study program, and on the distribution of the work between government, ONA, the private sector, and academia.

Figure 3-2 in the main report sets out a 7-year schedule to complete this Plan of Study. To optimize efficiency and continuity, the Plan of Study should be delivered as a single initiative, funding should be acquired for the entire Plan of Study in advance, and the studies should be managed by a central body using a dedicated Project Manager.

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LIST OF ABBREVIATIONS

AE	Associated Environmental Consultants Inc.
COBTWG	Canadian Okanagan Basin Technical Working Group
DRIPA	*Declaration on the Rights of Indigenous Peoples Act*
DWPA	*Drinking Water Protection Act*
EFN	Environmental Flow Need
EGBC	Engineers and Geoscientists BC
FCL	Flood Construction Level
FLNRORD	B.C. Ministry of Forests, Lands, Natural Resource Operations and Rural Development
FWMT	Fish Water Management Tool
IOLBC	International Osoyoos Lake Board of Control
IJC	International Joint Commission
LGA	*Local Government Act*
NHC	Northwest Hydraulic Consultants Ltd.
OBWB	Okanagan Basin Water Board
OHME	Okanagan Hydrologic Modelling Environment
OLRS	Okanagan Lake Regulation System
ONA	Okanagan Nation Alliance
ORRI	Okanagan River Restoration Initiative
RFC	B.C. River Forecast Centre
SARA	*Species at Risk Act*
UBCO	University of B.C. Okanagan
UNDRIP	United Nations Declaration on the Rights of Indigenous Peoples
WSA	*Water Sustainability Act*

1 INTRODUCTION AND PROJECT OBJECTIVES

This report describes a Plan of Study for developing the information required to inform a modernization of the Okanagan Lake Regulation System (OLRS) and the way it is managed. The Plan of Study comprises 17 scientific and engineering studies and a final study during which a plan for modernizing the OLRS and its Operating Plan will be developed. That plan will reflect current knowledge and society's values, including the knowledge and values of the Syilx people, who sustainably managed the land and water of the Okanagan for thousands of years.

The ORLS consists of a series of dams and other structures located on major lakes and the Okanagan River between Penticton and Osoyoos in the southern Okanagan valley. The OLRS, initially called the Okanagan Flood Control Project, was constructed jointly by the federal and provincial governments in the 1950s primarily to control flooding in the Okanagan valley. It was designed and constructed without Indigenous involvement, and significantly altered or destroyed valley-bottom habitat and ecosystems. The Okanagan Basin Agreement, finalized in 1974 (again, without Indigenous involvement), included recommendations for managing the mainstem lakes and the Okanagan River to achieve other economic, environmental, and social benefits in addition to flood control, and these recommendations remain the foundation of the current OLRS Operating Plan that prescribes lake elevation and river flow targets that vary throughout the year. Operation of the system is becoming increasingly challenging because of the changing nature of the Okanagan hydrologic regime in response to ongoing climate change, and in addition, the OLRS assets are approaching the end of their service life. Driven by these realities, the Province of B.C. anticipates that changes to the OLRS infrastructure and to the way it is managed will be required to maintain or improve the benefits provided by the system. Society has evolved since the 1950s and 1970s, and a modernized OLRS will reflect modern priorities and values. In addition, it is now expected that Indigenous knowledge and values will be considered in planning the OLRS modernization project. The Plan of Study anticipates Indigenous participation in both the scientific studies and in the final step in this Plan of Study—developing a plan to modernize the OLRS.

The Plan of Study was initiated by the B.C. Ministry of Forests, Lands, Natural Resource Operations, and Rural Development (FLNRORD), which issued a contract to the Okanagan Basin Water Board (OBWB), and OBWB engaged Associated Environmental Consultants Inc. (AE) to complete the work.

The objectives of this Plan of Study are to:

- Identify knowledge gaps that should be filled before the OLRS and its operations can be modernized to accommodate ongoing changes in climate and better reflect current environmental, cultural, and social governing conditions; and
- Recommend studies required to fill these identified knowledge gaps.

Since Kalamalka Lake is part of the mainstem Okanagan Lake and river system, the project includes consideration of Kalamalka Lake and its Operating Plan, even though at present Kalamalka Lake is not part of the OLRS. Kalamalka Lake is sometimes referred to in this report as Kalamalka-Wood Lake, because Kalamalka Lake and Wood Lake are hydraulically connected and at the same elevation.

The Plan of Study is not intended to halt the ongoing work of continuously refining the way the OLRS is managed under the current Operating Plan. Instead, it is intended to support a future major project to modernize the system and the way it is managed. The study descriptions contained herein reflect knowledge as of March 2021. Knowledge will evolve as the studies are completed. Terms of Reference will be developed for each study, which will reflect the state of knowledge immediately prior to initiating work on the study. Also, as knowledge increases, it may be necessary to re-examine previously completed studies. For example, improved climate data and models may emerge that suggest a need to re-examine the hydrologic and hydraulic models that provide the foundation for much of the work outlined herein.

To maximize efficiency and to promote continuity, the Plan of Study should be delivered as a single initiative, and managed by a leadership group with appropriate representation and a dedicated Project Manager, using funding obtained in advance for the entire suite of studies.

2 BACKGROUND

The OLRS was constructed between 1950 and 1958, and has been operated according to an Operating Plan developed in 1976 and updated periodically since then. The OLRS Operating Plan and guidelines are provided in Appendix A, as is the Operating Plan for Kalamalka Lake.

As described by AE (2017), the OLRS consists of three control dams (on Okanagan, Skaha, and Vaseux Lakes), multiple vertical drop structures and drainage structures, 68 km of diking, 32 km of engineered river channel, and three sediment basins. The Province of B.C., through FLNRORD, manages and 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 is not part of the OLRS, although it too is equipped with a control dam that is managed by the Province. Osoyoos Lake is regulated by Zosel Dam, located in Washington State. The dam is managed and operated by the Washington State Department of Ecology (with assistance from the Oroville-Tonasket Irrigation District) in accordance with operating rules provided in Orders of Approval issued by the International Joint Commission (IJC), and overseen by the International Osoyoos Lake Board of Control (IOLBC).

Symonds (2000) summarizes the water management history of Okanagan Lake and Okanagan River, and provides a historical account of the development of the OLRS. The primary purpose of the OLRS was to manage flooding, but its design also considered irrigation and navigation needs. The OLRS Operating Plan evolved from a comprehensive water resources evaluation in the early 1970s, leading to the Canada – British Columbia Okanagan Basin Agreement (Consultative Board, 1974), and it is now managed to mitigate both flooding and drought, as well as instream flow needs and recreational values. The Okanagan Basin Agreement studies included an extensive public engagement program (although neither the “list of study participants” nor the list of “Public Involvement Task Force members” provided in the report (Consultative Board, 1974) appear to include any Indigenous people). Thus, the recommendations of the report likely reflected the values of non-Indigenous Okanagan society at the time. It provided lake level and river flow targets that became the foundation for the OLRS Operating Plan that is still in use today – so the current Operating Plan likely reflects the values and priorities of non-Indigenous Okanagan society that existed about 50 years ago. Finally, the changes to the Okanagan River system associated with OLRS construction impacted aquatic and riparian habitat and natural ecosystem function, although in recent years anadromous salmon populations have begun to recover, and some lost habitat and ecological function has been restored.

OLRS operations are informed by a group that operates the Fish Water Management Tool (FWMT) decision support system. This group includes the Okanagan Nation Alliance (ONA) and Fisheries and Oceans Canada (DFO). The group provides fisheries and other information relevant to OLRS operations on an ongoing basis during the winter and spring.

NHC (2020) provided updated flood elevations and mapping for the entire Okanagan valley-bottom, with explicit consideration of the impacts of climate change during the 21st century. The result is a significant increase in design flood elevations in the main valley-bottom. These higher flood elevations assume that the OLRS Operating Plan can be changed to permit greater winter outflow from Okanagan Lake as well as a lower minimum lake level in winter than the current Operating Plan allows. If the Operating Plan can’t be changed to accommodate these assumptions, the design flood elevations will be even higher. If the Operating Plan was changed to permit greater winter outflow and a lower lake elevation, there could be impacts on a range of receptors (e.g., spawning fish and water supply intakes). These potential impacts have not yet been evaluated.

Recognizing the impacts the OLRS has had on river and riparian ecosystems, the Okanagan River Restoration Initiative (ORRI) has worked since 2000 to re-naturalize and restore ecosystem function in sections of the Okanagan River. Other river and habitat restoration work has been completed in significant tributaries to the mainstem system, including Mission and Trout Creeks. There is potential to extend this work and realize multiple and significant ecosystem benefits in the lower elevations of the Okanagan valley without reducing the flood or drought management benefits provided by the OLRS. The ORRI project has been conducted within a broader context of restoring salmon populations in the Okanagan valley led by ONA with many collaborators. Related work has included removing fish passage barriers at the McIntyre, Okanagan Falls, and Penticton dams, construction of a fish hatchery in Penticton, and improvements to flow management via the FWMT decision support system to benefit the riverine aquatic ecosystem.

Previous work has identified that the OLRS operating regime is not likely to be sufficiently robust to continue to provide flood control and drought management benefits in the face of ongoing climate change. In addition, Okanagan communities such as Peachland and Kelowna have identified concerns with the ability of the OLRS to manage water levels in Okanagan Lake. The OLRS infrastructure is nearing the end of its service life and will need replacement in the coming decades. The legal, political, cultural, environmental, and social environments have changed since the 1950s when the OLRS was constructed, and since the 1970s when the basis for the current Operating Plan was developed; and considering Indigenous knowledge, and inviting Indigenous participation in planning studies are now expected. Accordingly, there is now an opportunity to re-imagine the Okanagan mainstem valley through a modern lens during the process of conducting technical studies and planning the OLRS modernization project.

3 MODERNIZING THE OKANAGAN LAKE REGULATION SYSTEM

3.1 Introduction and Overview

Section 3 describes the work required to fill knowledge gaps and create a plan for modernizing the OLRS and the way it is managed, including investigating the feasibility of significantly expanding the program of ecological restoration that began along the Okanagan River about 20 years ago. This section divides the required work into several discrete studies. There could be other ways to organize and conduct the work than outlined herein.

The Plan of Study was developed through review of both historical and recent investigations related to the OLRS specifically, and to Okanagan water issues generally. The plan was developed through consultation with an advisory group comprising representatives of federal, Indigenous, provincial, and local governments with responsibility for Okanagan water.

It is intended as a minimum list of studies that should be completed. As each of these studies is completed, additional knowledge gaps are likely to emerge, some of which may require additional investigation before decisions about modifying the OLRS or its operating regime can be made. Over the course of completing the Plan of Study, new knowledge could emerge which suggests a need to re-examine some previously completed studies. The studies do not need to be completed in the order presented, but some studies must precede others, as discussed subsequently in this section. The Plan of Study is not intended to halt the ongoing work of continuously refining the way the OLRS is managed under the current Operating Plan. It is intended to support a major project focussed on addressing the challenges of ongoing climate change as the infrastructure approaches the end of its service life, during a modern era with new societal values, including the expectation of Indigenous participation.

The studies outlined in this Plan of Study will culminate in Study 18, which will integrate all the information generated in preceding studies and craft a well-informed and well-supported plan for modernizing the OLRS infrastructure and the valley-bottom Okanagan lake and river management system. Final pre-construction steps such as detailed engineering, land acquisition, cost estimation, and environmental permitting will follow Study 18, but are not included in this Plan of Study.

The Plan of Study is divided into five categories:

- Category One: Improved foundation to support OLRS operations (7 studies)
- Category Two: The past (2 studies)
- Category Three: The present and future (7 studies)
- Category Four: The path forward (2 studies)
- Category Five: Community engagement

Design and delivery of a broad-scale community engagement plan (Category 5) should begin before any of the other work described herein is undertaken and continue for the entire period during which these studies are being performed.

Most of the study descriptions outlined in Section 3 follow a consistent framework:

- Rationale – the knowledge gap that the study will fill and why it should it be done.
- Contribution – what the study will contribute to the overall Plan of Study.
- Background – context for the study (not included for all study descriptions).
- Overview – the scope of the study.

- Methods – how the study will be done (not included for all study descriptions).
- Deliverables – the products that will be produced by the study.

Most, but not all, of the studies are considered essential to the process of modernizing the OLRS. Studies 4, 5, 6, and 7 will support the modernization process but are not essential to the project. All studies are related to each other and each study will inform subsequent studies. However, based on the scope of each study described herein, some studies must be completed before others. Figure 3-1 describes the functional linkages between studies, indicating which studies must precede others, and which studies will be specifically informed by each one. Thus, the linkages shown on Figure 3-1 illustrate the required order of the studies. Studies 4, 5, 6, and 7 are grouped together on the right side of Figure 3-1 to indicate their role in supporting OLRS Operating Plan improvements, while not being essential to the process of OLRS modernization.

The studies are described at a conceptual level, and little effort has been directed towards study methods or workplans. A detailed workplan, budget, and schedule should be developed for each study before it is initiated.

The core OLRS modernization studies should be coordinated and managed by a central agency. It is anticipated that program delivery will require a combination of federal, provincial, and local government staff, the ONA, private consultants, and potentially academia. At minimum, provincial government staff will lead two studies (Studies 2 and 4) and will contribute to many other studies and to the community engagement program. It is expected that the provincial government will also provide program leadership. Given significant uncertainty over the approach that will be taken to lead, manage, and complete the Plan of Study, the present report does not include any cost information.

Figure 3-2 sets out a 7-year schedule to complete this Plan of Study. The schedule reflects the functional linkages shown in Figure 3-1 and the approximate time required for each study, based on its scope and complexity. Studies that do not depend on previous studies are arbitrarily shown as starting at the beginning of the Plan of Study, although they could begin later (providing they don't delay subsequent studies that depend on them).

Figure 3-1
Functional linkages within the Plan of Study for modernizing the OLRS

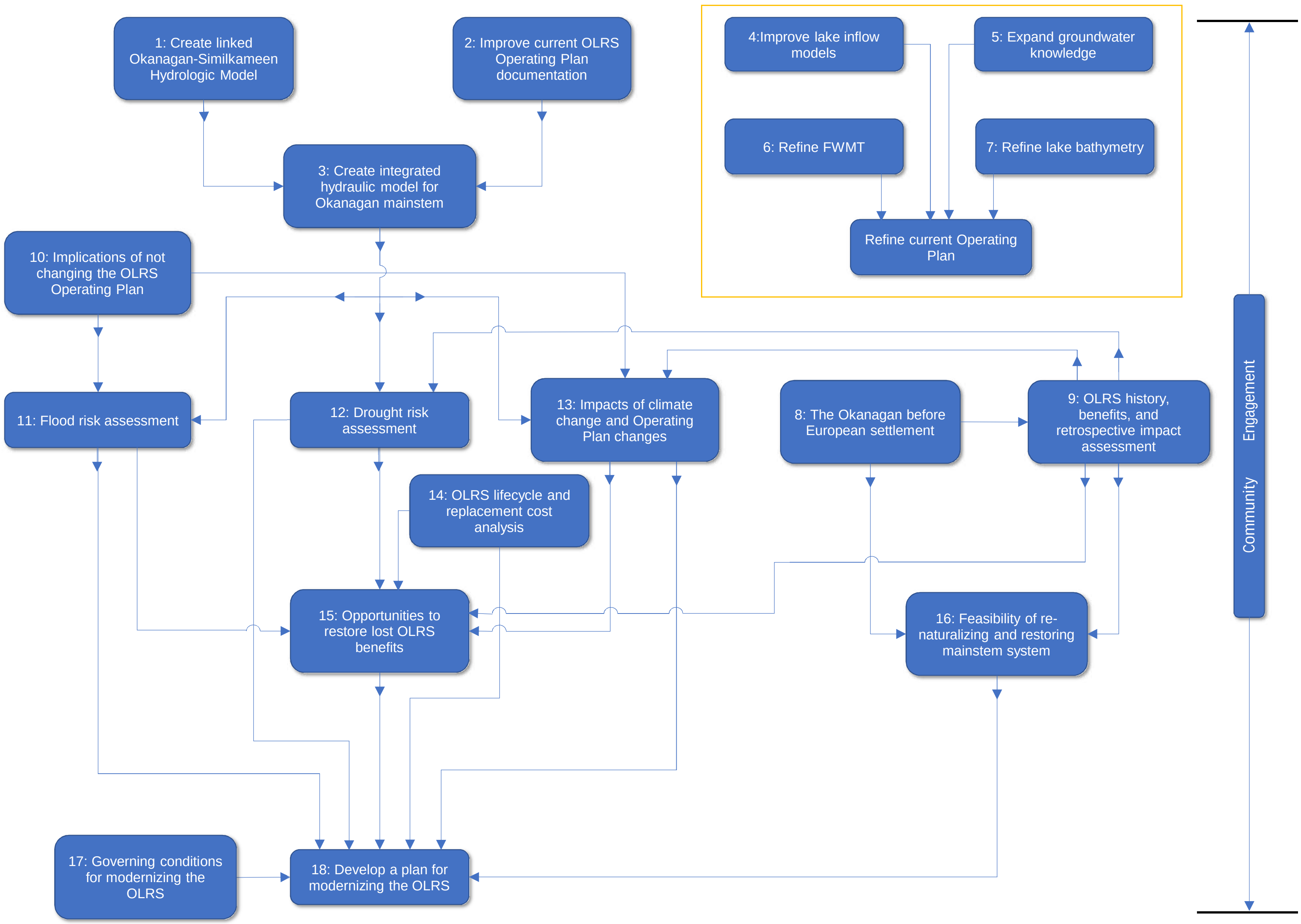

Figure 3-2
Suggested schedule for completing the Plan of Study

Category	Study	should be done after …	should be done before …	Schedule																											
				Year 1				Year 2				Year 3				Year 4				Year 5				Year 6				Year 7			
				Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Improved Foundation to Support OLRS Operations	1: Create linked Okanagan-Similkameen hydrologic model	n/a	3	X	X	X	X																								
	2: Improve current OLRS Operating Plan documentation	n/a	3	X	X	X	X																								
	3: Create integrated hydraulic model for Okanagan mainstem	1, 2	11, 12, 13					X	X	X																					
	4: Improve lake inflow forecasting models and account for uncertainty	n/a	n/a	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	5: Expand groundwater knowledge in support of OLRS management	n/a	n/a	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	6: Refine FWMT input data and model	n/a	n/a	X	X	X	X	X	X	X	X																				
	7: Refine mainstem lake bathymetry	n/a	n/a	X	X	X	X	X	X																						
The Past	8: State of the Okanagan mainstem lakes and river before European settlement	n/a	9, 16	X	X	X	X	X	X																						
	9: OLRS history, benefits, and retrospective impact assessment	8	12, 13, 15, 16							X	X	X	X																		
The Present and Future	10: Flood level implications of not changing the OLRS Operating Plan	n/a	11, 13	X	X																										
	11: Okanagan mainstem flood risk assessment	1, 2, 3, 10	15, 18								X	X	X	X	X	X	X														
	12: Okanagan mainstem drought risk assessment	1, 2, 3, 9	15, 18											X	X	X	X														
	13: Impacts of climate change and Operating Plan changes	1, 2, 3, 9, 10	15, 18											X	X	X	X	X													
	14: OLRS lifecycle and replacement cost analysis	n/a	15, 18	X	X																										
	15: Opportunities to restore lost OLRS benefits	9, 11, 12, 13, 14	18																X	X	X										
	16: Feasibility of re-naturalizing and restoring the mainstem system	8, 9	18											X	X	X	X	X	X	X											
The Path Forward	17: Governing conditions for modernizing the OLRS	n/a	18	X	X																										
	18: Develop a plan for modernizing the OLRS	all others	n/a																			X	X	X	X	X	X	X	X	X	X
Community Engagement	Design and deliver a community engagement program	n/a	all others	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Notes:

n/a = not applicable

Studies that do not need to follow other studies (4, 5, 6, 7, 8, 10, and 17) are arbitrarily shown as starting in Q1 of Year 1.

They can be started later, providing they don't delay studies that depend on them.

3.2 Improved Foundation to Support OLRS Operations

Category One includes seven studies. Individually and collectively they improve the information that underlies OLRS operational decision-making. Making these improvements will not only benefit current operations, it will help inform the need for and extent of future changes to the OLRS and its Operating Plan. Studies 1 and 2 are the first studies that should be completed in this Plan of Study. They both need to precede Study 3. Each of the other Category One studies (Studies 4, 5, 6, and 7) will lead to operational improvements, but each one can be initiated and completed independently of Studies 1, 2, and 3. Following completion of each of Studies 4 through 7, the OLRS Operating Plan should be refined accordingly.

Studies 4, 5, 6, and 7 are not essential to this Plan of Study. They will each contribute valuable information that will lead to improvements in system management and will support later studies with this Plan of Study, but the Plan could proceed without them. For this reason, they are grouped together within a defined area of Figure 3-1.

Study 1: Create linked Okanagan-Similkameen hydrologic model

Study 1 should be completed before any other studies within this Plan of Study. It directly supports Study 3, and together Studies 1 and 3 support several subsequent studies.

Rationale:
NHC and AE are currently building a hydrologic model of the Similkameen River system on behalf of the International Joint Commission (IJC). The model will be able to represent both high and low water conditions. Because high streamflows in the Similkameen River can create backwater conditions that influence water levels in Osoyoos Lake, the Okanagan and Similkameen River systems are linked. To comprehensively model streamflows and water levels for the entire Okanagan Basin under the influence of future climate, and to examine future scenarios related to land cover and other changes, a single comprehensive linked hydrologic model for the Okanagan and Similkameen River watersheds is needed.

Contribution:
A new Similkameen River hydrologic model that is linked to existing Okanagan hydrologic models (i.e., NHC [2020] and AE [2020] – Okanagan Hydrologic Modelling Environment) will enable comprehensive hydraulic investigations throughout the Okanagan mainstem system, including within Osoyoos Lake. This work will in turn provide a foundation for flood and drought risk analyses and impact assessments of future changes to the OLRS and its Operating Plan. This new model will also help with confirming and/or updating flood elevation and mapping results for Osoyoos Lake previously developed by NHC (2020). It is understood that the IJC plans to develop a linked hydrologic model as part of a future hydrologic and hydraulic modelling project.

In addition, this work will determine the potential significance of factors indirectly related or not related to climate change on the future hydrologic regime of the Okanagan, which will determine whether to include consideration of these other factors in Studies 11, 12, and 13.

Background:
In 2020, AE developed the OHME (Okanagan Hydrologic Modelling Environment), a complex Raven-based hydrologic modelling system, and applied it to 19 tributaries to the mainstem Okanagan Lake and river system (AE, 2020). These 19 tributaries together supply a substantial portion of the flow into the mainstem system.

In support of their flood mapping project, NHC (2020) also developed a Raven-based hydrologic model for the Okanagan. The NHC hydrologic model is focussed on accurately representing high flows since it was developed to support the hydraulic and flood mapping work. Contracted through the IJC, a Similkameen River hydrologic model is currently being developed by NHC and AE using the Raven hydrologic modelling framework.

The scope of the current IJC-led Similkameen River model development project is to produce a calibrated and verified hydrologic model at the sub-basin scale under naturalized and residual streamflow conditions. Once calibrated, the model will be used to assess future climate change impacts on the Similkameen River watershed up to 2100 and to assess predicted future drought conditions following the IJC's Order of Approvals drought criteria. This model development and supporting assessments are to be completed in March 2021.

Overview:
After the IJC's Similkameen River model has been developed, additional effort will be required to partner the model with Okanagan Basin models developed by NHC (2020) and AE (2020). In addition, more calibration may be required for the Similkameen River model to improve flood predictions. This new model will form the foundation for the hydraulic modelling work described in Study 3 below.

In addition, after developing the new linked hydrologic model, realistic scenarios based on future changes in forest cover; wildfire frequency, extent, and severity; and management strategies for upland reservoirs will be examined during Study 1. This work will determine the potential significance of factors indirectly related or not related to climate change, which will determine whether to include consideration of these other factors in Studies 11, 12, and 13.

Methods:
The process of linking the Okanagan and Similkameen hydrologic models will be performed by technical experts with previous experience in hydrologic modelling in the Okanagan and Similkameen watersheds, using state-of-the-art model conceptualization, calibration, and verification techniques used in modern hydrologic modelling practice.

Deliverables:
The study will produce a calibrated and validated Okanagan-Similkameen linked hydrologic model, the model source code, a user manual, an accompanying technical report, and likely presentations and user workshops. The report will provide recommendations for using the model to inform Study 3 and other studies in this Plan of Study.

Study 2: Improve current OLRS Operating Plan documentation

Study 2 is focused on bridging the gap between the documents that guide operational decision-making and the actual decision-making. It does not include refining the current Operating Plan with the results of other studies within Category One of this Plan of Study, although each of these will contribute subsequent refinements to the current Operating Plan. Study 2 will inform Study 3.

Rationale:
Despite the existence of an Operating Plan and water management guidelines, previous studies have had difficulty replicating actual OLRS operational decision-making in a model, suggesting that judgments are applied in real-time in response to changing circumstances and events, and system limitations that are not well documented in the plans and guidelines. It is particularly difficult to model operational decisions complicated by downstream constraints in the Okanagan River or Osoyoos Lake. Improved Operating Plan documentation is needed to facilitate the improvements in hydraulic modelling described in this Plan of Study, and to facilitate knowledge transfer between provincial OLRS operators and other parties.

Contribution:
This study will expand the documentation of the current Operating Plan and guidelines, such that these documents become sufficiently comprehensive that operational decisions can be accurately simulated in a computerized hydraulic model. The upgraded Operating Plan will:

- reduce uncertainty in the output of existing and future hydraulic models of the Okanagan mainstem system;
- contribute to consistency in operational OLRS decision-making; and
- contribute to succession planning in the OLRS Water Manager's office.

Background:
In 2010, the Phase 2 Water Supply and Demand project report (Summit 2010) identified several challenges in successfully modelling the operation of the OLRS, which indicated that the operators likely use other factors and judgment that are not documented in the written plans and guidelines. Similarly, NHC (2020) encountered difficulty in successfully modelling the operations of the OLRS based on the documented operating plans and guidelines. AE (2017) identified several issues with both the OLRS Operating Plan and the Kalamalka Lake Operating Plan, and recommended updating both plans. In addition, neither Kalamalka Lake nor Osoyoos Lake are referenced in the OLRS.

Overview:
The objective of this study is to expand the documentation of the current Operating Plan and guidelines, until these documents are sufficiently comprehensive that management decisions can be more successfully replicated by a hydraulic computer model. AE (2017) identified the potential for other related improvements, including documenting management decisions made during spring, and creating an Emergency Management Plan during times of very high expected or actual inflow. This study will address these recommendations. A decision-support matrix to guide the Water Manager in decision-making will also be considered, as it would create some present-day redundancy and continuity during a future succession process.

Ongoing work by the RFC (Study 4) will likely lead to a method of incorporating uncertainty into operational decision-making, which should be explicitly incorporated into the Operating Plan.

Finally, Kalamalka Lake levels and outflows are managed by FLNRORD as part of the Okanagan system, but it is not formally part of the OLRS. It has its own Operating Plan and is operated relatively independently of conditions on Okanagan Lake. Improved coordination between these two Operating Plans could simplify and improve operational decision-making on the entire mainstem system. This study will include incorporating the Kalamalka Lake Operating Plan into the OLRS, which will consolidate operational decision-making under a single Operating Plan. In addition, the Zosel Dam Orders of Approval should be referenced or appended to the OLRS Operating Plan since the forecast and real-time condition of Osoyoos Lake can influence OLRS management decisions.

Methods:
The work will be conducted by the OLRS Water Manager's office, in close collaboration with the operators of existing hydraulic models of the Okanagan mainstem system, who will test the contribution of the documentation upgrades to improving the accuracy and precision of existing hydraulic models. Other improvements will likely be done entirely internally by the Water Manager's office.

Deliverables:
The study will produce upgraded comprehensive documentation of the OLRS Operating Plan, which will contribute to improved models and operational decision-making.

Study 3: Create integrated hydraulic model for Okanagan mainstem

Study 3 will follow Studies 1 and 2, and will support Studies 11, 12, and 13.

Rationale:
A hydraulic model that includes the entire Okanagan valley-bottom system from Ellison Lake downstream to Osoyoos Lake and across the US border to the confluence of the Okanogan and Similkameen rivers is needed before flood and drought risk assessments for all Okanagan valley-bottom areas can be completed. This hydraulic model would be driven by the new linked Okanagan-Similkameen hydrologic model (Study 1), which will allow the impacts of climate change to be evaluated, and by the updated Operating Plan developed in Study 2.

Contribution:
The complete valley-bottom Okanagan hydraulic model resulting from Study 3 will provide the foundation for flood and drought risk analyses and impact assessments of future changes to the OLRS (including Kalamalka Lake) and its Operating Plan.

Overview:
Much of the required work has been completed or is currently planned. NHC (2020) developed a hydraulic model (using the US Army Corps of Engineers HEC-RAS model) for the Okanagan River between the outlet of Okanagan Lake at Penticton and the head of Osoyoos Lake. Specifically, the NHC hydraulic model includes the river and floodplain between Okanagan Lake and Skaha Lake, and the river and floodplain between the outlet of Skaha Lake and the head of Osoyoos Lake.

In a future project, the IJC plans to combine the Okanagan-Similkameen hydrologic model currently being developed with the Okanagan hydraulic model developed by NHC (2020) to examine potential improvements to the operation of Zosel Dam considering future climate change. The IJC project will expand the NHC (2020) Okanagan hydraulic model by adding Osoyoos Lake, the Okanogan River in the United States, and the operation of Zosel Dam. The IJC addition is referred to below as the Osoyoos/Zosel model.

The City of Vernon is currently completing a project to develop a hydraulic model for the portion of Vernon Creek between Kalamalka Lake and Okanagan Lake (commonly referred to as Lower Vernon Creek).

These three hydraulic models need to be linked and extended to include Vernon Creek between Ellison Lake and Kalamalka-Wood Lake, commonly referred to as Middle Vernon Creek.

The scope of Study 3 includes:

- Develop a hydraulic model to include Osoyoos Lake, Zosel Dam operations, and Okanogan River (the IJC is planning to complete this portion of the study);
- Develop a hydraulic model for Middle Vernon Creek (i.e. Vernon Creek between Ellison Lake and Kalamalka-Wood Lake); and,
- Link the mainstem hydraulic models (the NHC (2020) Okanagan River model, the Osoyoos/Zosel model, the City of Vernon model of Lower Vernon Creek, and the Middle Vernon Creek model).

Methods:
This work will be conducted by technical experts with Okanagan hydraulic modelling experience, using methods accepted in the industry. Most of the data needed to support development of the Study 3 hydraulic models exists, except cross-sectional data for Middle Vernon Creek. Acquisition of this information is included in the scope of the study. Although model accuracy would be improved if the some of the existing lake and channel bathymetric data were replaced with higher resolution data, the potential costs associated with acquisition of higher resolution data have not been included herein.

Deliverables:
If the planned IJC project proceeds, it will be reported separately from the Canadian portion of the work. Each of these two study components will produce a calibrated and validated hydraulic model, a user's manual, presentations, and a technical report with maps and figures as needed to explain the results. Results may be displayed on appropriate websites for public access. The reports will include recommendations for using the new hydraulic models to support other studies within this Plan of Study.

Study 4: Improve lake inflow forecasting models and account for uncertainty

Rationale:
The B.C. River Forecast Centre (RFC) operates a suite of models to forecast inflows to the mainstem lakes each spring. Recommendations for model improvement have been made in previous studies, and the RFC is engaged in progressively improving the existing models and developing new models. Although there is uncertainty associated with the forecast models, a method of accounting for uncertainty in model output has not yet been incorporated into OLRS operations. Doing so has the potential to improve OLRS operational decision-making.

Contribution:
Ongoing model improvements will progressively enable better OLRS management. Explicitly incorporating uncertainty will enable improved risk-based decision-making, which will also improve OLRS management.

Background:
AE (2017) provided many recommendations for reviewing and improving the seasonal lake inflow models used to forecast spring inflows to Okanagan mainstem lakes, including:

- Improvements to the climate, snow, and hydrometric networks that the models depend on;
- Improvements to the inflow forecast models;
- Increases in the forecast frequency; and
- Improvement in the weather forecast inputs to the inflow forecast models.

NHC (2020) also provided several recommendations relevant to improving seasonal inflow models.

Based on these and other sets of recommendations, and on ongoing experience, the RFC is continually improving the seasonal inflow models. Since 2017, the seasonal inflow forecast models have been improved as follows:

- The RFC has continued to operate the statistical seasonal forecast models for Okanagan Lake and Kalamalka Lake inflows. Operation includes annual evaluation of model performance, and the 2018-2020 period has included continued poorer than expected performance in some of those years.
- The RFC has been operationally forecasting inflows into Okanagan Lake using the “RFC RAVEN” hydrologic model. Models are now running on a weekly basis during freshet, but can be run more frequently if required. Models incorporate deterministic weather forecasts from Environment and Climate Change Canada (10-day) with historical weather scenarios used to create an ensemble projection for days 11+. Previous years’ data are added to the historical time series for ensemble projections each year, such that the model now includes weather scenarios from 2017 to 2020.
- In 2020, the RFC contracted an update to the statistical inflow forecast models (Okanagan Lake and Kalamalka Lake). These will be put into operation for the 2021 inflow season, in parallel with the previous statistical models. Some details of the update include:
    - Available historical data (particularly snow) are not of a sufficient temporal frequency (e.g., monthly sampling for most snow surveys) or of a sufficient record length to improve the frequency of forecasts;
    - Seasonal weather forecasting (temperature and precipitation) has been incorporated into models; and
    - Back-up models are employed in situations when input data is missing.

Increased sophistication, including a broader range of input variables, has led to overall improvements in forecast accuracy and precision. However, this has been offset by increased variability and unpredictability in the system over the past decade (i.e., the models are better, but the predictability of seasonal inflows is decreasing with a modest net benefit to 'improved' modelling; the new models significantly out-perform the currently used forecast models).

- The RFC is working on updates to the "RFC RAVEN" ensemble hydrologic models. The work should be complete by January 31, 2022, and is expected to be operational for the 2022 inflow season. Key requirements for the update include:
    - Integration/adjustment to a changing monitoring network (integration of new climate and snow monitoring sites and compensation for the deactivation of climate and snow monitoring sites);
    - Operationalization of the Kalamalka Lake model;
    - Analysis of model performance;
    - Update of models to the best state-of-knowledge regarding evapotranspiration, snowpack energy balance, and runoff response;
    - Improvement of the ability to calibrate models during the snow accumulation season;
    - Recalibration of models to 2020, accounting for extreme conditions in 2017, 2018, and 2020; and
    - Update of snowpack dynamics and energy balance.

Overview:
Study 4 will be led by the RFC and will focus on:

- Continuing the effort currently being directed at improving the Okanagan inflow forecasting models; and
- Developing a way to account for forecast model uncertainty.

Work to improve the models will continue the work underway since 2017 described above. That work could be informed by considering the adoption or incorporation of one of the two comprehensive RAVEN-based hydrologic models recently developed for the Okanagan basin in 2020 – i.e., the Okanagan Hydrologic Modelling Environment (OHME) (AE 2020) and the Okanagan flood model (NHC 2020). The OHME was developed to simulate hydrologic conditions throughout the year for 19 priority Okanagan watersheds, and the Okanagan flood model was developed to model high spring flows under current and future climate conditions. Significant effort has been expended to develop both models, and they both perform well in representing the physical processes of runoff generation. The RFC could likely benefit from examining their utility for seasonal inflow forecasting.

The Province of B.C. should allocate the resources needed to upgrade the climate, snowpack, and hydrometric networks that support the inflow forecasting models. At present, the responsibility for managing data networks (e.g., snow, climate, and hydrometric) is held by the B.C. Ministry of Environment and Climate Change Strategy. The RFC can influence but not control the allocation of resources to providing adequate monitoring to support the Okanagan seasonal inflow forecasting program. The RFC should continue to advocate for the necessary provincial resources, and to influence the federal government to improve seasonal weather forecasting accuracy and precision. The OBWB is committed to expanding data collection networks in the Okanagan, and in 2020 made a long-term commitment to funding an expanded Okanagan hydrometric network.

Finally, senior governments should develop a program to obtain significantly better over-lake wind data to support improved flood hazard mapping and support the upgraded lake bathymetry study described in this Plan of Study (Study 7). Collection of over-lake wind data should be combined with collection of over-lake meteorological data, which will support improved estimation of lake evaporation and future improvements to the current generation of Okanagan hydrologic models.

The study will address the following knowledge gaps with respect to model uncertainty:

- With two types of model (i.e., the statistical models and the ensemble RFC RAVEN model), and many forecast scenarios from the ensemble model, how should the "best" forecast be derived?
- Statistical models inherently forecast the "most likely" inflow given observed antecedent conditions (i.e., input variables) – an approach that does not provide good forecasts for extreme events. Is there a better way to forecast extreme events?
- Which is the best of the ensemble forecast to use: the median or some other percentile forecast?
- Given a changing climate, what is the best dataset to drive the ensemble models: the historical time series (e.g., 1950-2020) or an alternate synthetic timeseries (e.g., 2000-2050) that accounts for recent and future climate change?
- Should OLRS operators manage for an extreme but plausible scenario (e.g., one with a 20% chance of occurrence) rather than for the median or expected value of the forecast?

Methods:
The RFC will systematically examine these knowledge gaps for both Kalamalka Lake and Okanagan Lake inflow forecast models using a variety of approaches, such as:

- A game theory approach; and
- A forecast and management strategy versus stochastic inflow scenario, which examines scenarios of reservoir management given a particular forecast or particular distribution of forecasts versus what did or could have occurred and the resulting impacts on lake level.

The aim of these investigations will be to determine an optimized approach to lake level management that accounts for uncertainty in seasonal forecasts.

Deliverables:
The work will result in more robust data networks, better statistical inflow forecast models, an improved RAVEN model for forecasting seasonal inflows for Okanagan and Kalamalka Lakes, model documentation, and potentially improved seasonal weather forecasts. The improved seasonal lake inflow models will be used to revise the OLRS Operating Plan and thereby to improve management of the system.

Study 5: Expand groundwater knowledge in support of OLRS management

Study 5 will provide increased knowledge of the role of groundwater in the hydrologic regime of the mainstem lake and river system, leading to improvements in management.

Rationale:
The role of groundwater in the Okanagan hydrologic cycle is still relatively poorly understood. Knowledge improvements will promote better management of the OLRS. The Phase 2 Water Supply and Demand project (Summit, 2010) included development of a State-of-the-Basin report on groundwater resources that summarized the state of knowledge of groundwater in the Okanagan basin, and identified sources of information on groundwater. In the decade since completion of that project, a significant amount of monitoring and research focused on improving our understanding of Okanagan groundwater was completed. However, additional work is required to provide basic information and resolve ongoing uncertainties. In particular, the role of groundwater in influencing seasonal inflows to the major tributaries and the mainstem lakes is not yet well understood, nor is the influence of groundwater inflow to the Okanagan River downstream of Penticton, which influences tributary inflows and constrains the ability to release water from Okanagan Lake.

Contribution:
Improved knowledge of shallow and deep groundwater flow into and out of the lower reaches of the major Okanagan tributaries and the mainstem lakes and the Okanagan River would provide additional information and reduce the uncertainty associated with operational OLRS decision-making.

Background:
At the time of the State-of-the-Basin report, groundwater use was not regulated in B.C., and therefore limited information existed on the hydrogeology and groundwater resources of the Okanagan. During the Phase 2 project, a conceptual model of groundwater storage and flow was developed, which found that most of the groundwater activity occurs in 79 distinct shallow unconsolidated aquifers, located primarily along the lower elevation valley bottoms. Estimates of groundwater discharge to Okanagan Lake were found to vary over a wide range, which reflected the relative absence of information needed to make these estimates. The Phase 2 report recommended that additional hydrogeological characterization be completed, and more data on groundwater extraction and on surface/groundwater interactions should be obtained to better understand Okanagan groundwater resources. Specific investigations recommended in the Phase 2 report were:

- Assessing surface water-groundwater interaction, which involved collecting and mapping streamflow data in creeks crossing alluvial fans and monitoring water levels in aquifers near the creeks to identify and quantify areas where streams may be losing or gaining with respect to groundwater;
- Adding more provincial groundwater observation wells in aquifers currently not monitored;
- Conducting studies to confirm the conceptual model of groundwater flow in bedrock areas; and
- Refining evapotranspiration values as this affects upland aquifer recharge, which has a large influence on valley-bottom groundwater balances.

Examples of the significant monitoring and research completed in the decade since completion of the Phase 2 Water Supply and Demand project include:

- Research led by UBCO and Simon Fraser University faculty on surface/groundwater interactions, groundwater inflows to Okanagan Lake, groundwater susceptibility to drought, and other hydrogeology and groundwater topics;

- Installation of new monitoring wells;
- Mission Creek surface/groundwater interaction project;
- Groundwater water balance studies; and
- Geology mapping.

Additional work is required to provide basic information and resolve ongoing uncertainties. With particular relevance to operation of the OLRS, the role of groundwater in influencing seasonal inflows to the mainstem lakes is poorly understood, as is the influence of groundwater inflow to local of Penticton tributaries and the Okanagan River downstream of Penticton. Groundwater inflow downstream constrains the rate at which water can be released from Okanagan Lake at Penticton. Improved knowledge of shallow and deep groundwater flow into and out of the mainstem lakes and the Okanagan River, and improved knowledge of surface/groundwater interactions across tributary alluvial fans, will provide additional information and reduce uncertainty in making operational decisions for the OLRS.

Overview:
This study will continue the work recommended in the Phase 2 Water Supply and Demand project related to the role of groundwater in the hydrologic regime, with a more specific focus on relevance to OLRS management. This will require the following steps:

- Review the Phase 2 (Summit, 2010) recommendations related to groundwater;
- Review the Okanagan groundwater research, studies, and monitoring completed since 2010;
- Review the groundwater-related recommendations presented in AE (2020);
- Prioritize additional information needs, particularly those related to OLRS management;
- Develop a plan for completing the required future studies; and
- Access funding and complete the studies.

The required studies will likely include region-wide studies, as well as tributary-specific studies downstream of Penticton. This will be an ongoing project, expected to be led or coordinated by the Province. As each step is completed, the OLRS manager will consider the knowledge gained relevant to OLRS management and adjust the operating regime accordingly.

Methods:
Specific study methods will be developed for each of the component groundwater studies to be conducted within Study 5.

Deliverables:
Each groundwater contribution will be reported in a study report. Each report should provide recommendations for improving OLRS management.

Study 6: Refine Fish Water Management Tool input data and model

Study 6 will provide information to enable more refined OLRS operations, and background information to support some of the Category Three studies (e.g., studies 13 and 16).

Rationale:
The FWMT is a decision support system used to inform OLRS operations. It is a hydrological and fisheries process model that provides information on spawning, incubation, and emergence timing to the OLRS operator, who uses this information in operational decision-making to manage the impacts of OLRS operations on fish in the mainstem Okanagan lakes and the Okanagan River. The model works well; however, more refined fisheries information and a correspondingly refined FWMT model will enable more informed OLRS operations and reduced risk to fish and the aquatic environment.

Contribution:
This study will contribute to a better understanding of the benefits and impacts of a wide range of flows, and to refining the FWMT, which will better protect fish in Okanagan Lake, other mainstem lakes, and the Okanagan River.

Background:
As summarized by AE (2017), the OLRS Operating Plan identifies specific aquatic ecosystem objectives, but also identifies situations where these objectives can be overridden in favour of 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 – a group of Syilx Okanagan, 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. It also models fisheries lifecycle processes, and incorporates specific aquatic ecosystem constraints, such as minimum and maximum lake outflow rates while sockeye eggs are developing in redds in the Okanagan River, to avoid both desiccation and scour. It allows a model user to evaluate a range of possible future Okanagan Lake outflow scenarios to help select an optimal outflow scenario that meets aquatic ecosystem and other operational constraints.

The background to the FWMT, and a detailed description of the model, are provided by Hyatt et al. (2015). After 12 years of use, most of the internal sub-models were revised between 2014 and 2016, including the hydrology sub-model, for which:

- The former weekly time step was changed to daily; and
- A new statistical routine was introduced, 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. The statistical matching routine used in the upgraded model is a considerably more sophisticated non-parametric statistical method (known as Real-Time Statistical Matching) than the disaggregation method used in the original 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.

Overview:
This study will have two components:

- Obtaining additional fisheries information used to drive the FWMT model; and
- Refining the FWMT model with this and other information.

Additional information:
Management of the OLRS could better protect fish, if additional information was available, including:

- Expanded monitoring of spawning locations in the Okanagan River for Chinook salmon and other species each year, including providing more resilience to mitigate ongoing changes in climate and hydrology;
- Better knowledge of the timing of spawning for Chinook and other species each year;
- Better knowledge of the impacts of a wide range of high and low streamflows on egg stranding and redd scour (for multiple species);
- Improved methods of predicting the rate of maturation of fish eggs and timing of emergence for multiple species, including consideration of the ongoing effects of climate change and hydrologic change on incubation and emergence timing;
- Better information on the influence of dissolved oxygen and temperature on kokanee egg development; and
- Better information on minimum tributary streamflows needed to maintain connectivity to each mainstem lake and the Okanagan River.

Refined FWMT model:
AE (2017) summarized the history and status of the FWMT model, and provided several suggestions for improving the model. Study 6 will continue the ongoing model improvement process, considering experience gained by the FWMT modelling group, and the AE (2017) recommendations. In addition, the specific scientific information gained during Study 6 will be incorporated into model subroutines to improve their performance. The hydrology component of the model could likely be improved by incorporating elements of the new (2020) Okanagan Raven-based hydrologic models and/or upgraded lake inflow models being developed by the River Forecast Centre.

Methods:
The study will use accepted methods of experimental design, data collection, data analysis, and model development. For each of the above-noted study components, a detailed study plan will be developed and implemented.

Deliverables:
The study will be reported in a study report, or a series of reports providing results for study components. The information will be used to upgrade the FWMT model and the associated model documentation. Reporting will include recommendations for improving OLRS management.

Study 7: Refine mainstem lake bathymetry

Study 7 is a stand-alone study that will inform future upgrades to the NHC (2020) mainstem flood mapping project, and site-specific flood elevation analyses. Results will be useful to other studies within this Plan of Study, but none depend on its results. The following study description is more comprehensive and presented with a greater level of specificity than most others in this Plan of Study, because it was expanded during preparation of this report to support a funding application.

Rationale:
High resolution lake bathymetry information provides multiple benefits, including:

- Contributing to specification of design flood elevations and flood construction levels;
- Improving knowledge of lake water volumes at each water level;
- Improving predictions of nearshore sediment movement;
- Improving safety (e.g. related to navigation);
- Providing information relevant to water quality studies; and
- Improving inventory and understanding of nearshore aquatic habitat.

With reference to flood elevations and flood construction levels, wind and waves can make a significant contribution to lake levels. The effect of waves on the shoreline depends on wind speed and direction, fetch length, nearshore local lake bathymetry, and local shoreline characteristics. NHC (2020) indicated that their flood mapping results could be improved by obtaining more detailed lake bathymetry information around each of the Okanagan mainstem lakes, and the portion of Osoyoos Lake situated in the U.S. According to NHC (2020), the best available bathymetric information for most Okanagan mainstem lakes was obtained by the Province of B.C. between 1976 and 1981, and the best information for Okanagan Lake and Kalamalka-Wood Lake was obtained by the Canadian Hydrographic Service in 1994. NHC (2020) recommends updating the lake bathymetry data. Okanagan River bathymetry data were updated by the Okanagan Basin Water Board (OBWB) in 2019 and does not require updating.

Contribution:
The updated lake bathymetry data will tie into a recently upgraded bathymetry dataset for the Okanagan River (WSP 2019) and support a future updated flood hazard assessment for the Okanagan mainstem lakes. Improved bathymetry data would have other uses as well, for example for navigation, water quality, and fisheries habitat studies.

Specific Study Driver:
In March 2020, NHC identified flood construction levels (FCLs) around the shorelines of each of the Okanagan mainstem lakes: Ellison, Kalamalka-Wood, Okanagan, Skaha, Vaseux, and Osoyoos (NHC, 2020). Wind and waves exert a considerable influence on the FCL. Their effect varies with shoreline location and depends on wind speed and direction, fetch length, nearshore lake bathymetry, and shoreline conditions.

NHC (2020) identified the following limitations to their wind and wave analysis:

- The absence of sufficient measurements of wind speed taken directly over the surface of the lakes;
- Weaknesses in the currently available nearshore lake bathymetry data, largely due to low survey density; and
- Scale limitations: due to the large spatial extent of their project, NHC was not able to complete a wind and wave analysis at a sufficiently detailed scale to capture variations at the scale of an individual property.

NHC divided the shoreline of each mainstem lake into a relatively few zones (i.e., one zone each for Wood, Kalamalka, Vaseux, and Osoyoos Lakes, eight zones for Okanagan Lake, and four zones for Skaha Lake), within which shoreline characteristics relevant to shoreline wave runup were assumed to be uniform. The NHC wind and wave analysis was applied to each of these shoreline zones. However, the zones are too large to capture shoreline variability at the scale of an individual property. In addition, the available lake bathymetry information would not support an FCL analysis at the scale of an individual property.

To perform a wind and wave analysis at the scale of an individual property, NHC (2020) recommended that high resolution nearshore lake bathymetric data be acquired, and that more detailed shoreline data be compiled and used.

Overview:
The goal of this study is to obtain bathymetric data for nearshore areas of Ellison, Kalamalka-Wood, Okanagan, Skaha, Vaseux, and Osoyoos Lakes at sufficiently high resolution to facilitate a future wind and wave analysis and development of updated FCLs at the scale of individual shoreline properties. The study will focus on areas of the lakes adjacent to shorelines that are already developed or that could in future be developed. In addition to supporting future refinements to NHC's flood mapping and FCL analysis, the study will support many other areas of scientific enquiry, such as those listed under Rationale, above.

A need for improved over-lake wind data to support improved flood hazard mapping was identified in Study 4 in this Plan of Study. Better wind information will support the upgraded lake bathymetry study described here.

Methods:
The study will be accomplished primarily through multi-beam sonar surveys from a moving boat. The surveys will focus on the nearshore zone within which offshore waves begin to be influenced by the lake bottom as they approach the shore. The study will select particular widths for the lake survey zone, or alternatively a maximum water depth that must be captured by the survey will be identified. Other survey methods could also be used for areas that are difficult to reach by boat, such as using autonomous underwater vehicles. The lake surveys will be done at relatively high water levels, to create overlap with terrestrial LiDAR data obtained by OBWB at relatively low water levels in 2018. This overlap will promote stitching of bathymetry and LiDAR datasets together to a common datum and projection.

Existing data sources will be used to provide supplementary information. For example, the Navionics boating app provides interpolated bathymetric contours at 0.3 m intervals for all lakes. However, the resolution of the underlying data is generally much coarser, so this information may be of limited value to this project. Nonetheless, this app accepts "citizen science information" (e.g. contributions from recreational boaters), so it's possible that good quality high resolution information exists at some locations. In addition, utility companies and municipalities are likely to have detailed bathymetry at specific locations (e.g., along the paths of underwater cable crossings, and near water intakes.) Other supplementary information sources could include publications and maps arising from academic research. This supplementary information will be combined with the bathymetric data obtained in this study into a single combined bathymetric database for each lake.

The bathymetry surveys will tie into the 2018 LiDAR dataset and the 2019 Okanagan River bathymetry dataset. Detailed project specifications will be developed in consultation with GeoBC.

Deliverables:
The new bathymetric database will be used to create high resolution bathymetric maps and a bathymetric digital elevation model (DEM) for the nearshore areas of each lake. The study results will be presented in both map and report formats, and all datasets and associated metadata will be provided.

The report will include recommendations for using the outcomes in both site-specific and valley-wide flood hazard mapping, and the implications of the work for other studies within this Plan of Study.

3.3 The Past

Category Two of this Plan of Study includes two studies:

- State of the Okanagan mainstem lakes and river before European settlement; and
- OLRS history, benefits, and retrospective impact assessment

Study 8 will directly inform Studies 9 and 16, and Study 9 will directly inform Studies 12, 13, 15 and 16.

Study 8: State of the Okanagan mainstem lakes and river before European settlement

Study 8 does not depend on the outcomes of any other studies within this Plan of Study and will support several subsequent studies, in particular Studies 9 and 16, and will directly support the community engagement program.

Rationale:
Previous research and reports have referred to historical conditions in the Okanagan prior to the arrival of European settlers. However, this knowledge has not been assembled into a single location, nor has it been quantitatively documented or mapped at a sufficient level of detail to provide a sound basis for informing future decision-making related to the management of the Okanagan mainstem lakes and river system. This study will address that gap.

Contribution:
With wisdom, knowledge, and experience gained over thousands of years, the Syilx people sustainably managed the land and water of the Okanagan before the arrival of European settlers in the 19th century. This study will demonstrate to decision-makers and the public the state of the Okanagan prior to the arrival of Europeans. A greater understanding of the natural ecosystems of the Okanagan and Syilx values and approach to management will promote informed communication and decision-making among alternative courses of action. This study will contribute essential background information for the retrospective OLRS impact assessment in Study 9. It will also provide a clear historical picture to inform Study 16, which will examine the feasibility of significantly restoring the mainstem system to its historical condition.

Overview:
The Okanagan valley has been significantly changed since the arrival of European settlers. Many natural ecosystems have been significantly altered or destroyed. This study will serve both to educate the public and to provide quantitative historical information that will guide specific decisions about desired future conditions. It will require plain-language descriptions of form and function for a general audience. It will also require quantitative analysis to describe hydrologic regimes, fluvial morphology and processes, water quality, riparian and wetland ecosystems, and water management strategies.

The study will address:

- Natural Okanagan River, tributary stream, and floodplain morphology and function;
- Aquatic and riparian species, habitat, and ecosystem functioning;
- The natural hydrologic regime (i.e., the timing and ranges of lake levels, tributary streamflows, and Okanagan River flows, including probabilities associated with various flood and drought levels); and
- How Syilx people managed water, including a description of Syilx philosophies and relationship with water.

Methods:
Information sources will include but are not limited to:

- Indigenous Knowledge and Science;
- Aerial photos;
- Previous surveys;
- Academic research (including work by Syilx scholars and Dr. John Wagner of UBCO); and
- Existing technical reports (e.g., Summit 2002) which developed a natural hydrograph for Okanagan Lake based on river surveys completed prior to construction of a dam on the lake.

A key methodological component of the study will be interviews with Syilx Elders, community staff, and current staff of the Okanagan Nation Alliance (ONA) and individual Okanagan Bands. The design of this component of the study will need to be reviewed with and approved by local Syilx communities.

Deliverables:
Several deliverables will be developed in Study 8. The information will be presented in two technical reports: a shorter descriptive report written for a broad audience, and a longer more technical report containing the quantitative analyses of historical conditions. The reports will include a substantial component of visual information (e.g., photographs, aerial imagery, and maps). In addition, if approved by ONA, the reports could include call-out boxes containing quotes or key points provided by Syilx knowledge keepers. The study will produce GIS layers showing pre-contact aquatic features including the mainstem lakes, Okanagan River, tributary creeks, wetlands, riparian zones, and floodplains. Finally, the study will produce large format visual and text information for public display purposes to support the community engagement program.

Study 9: OLRS history, benefits, and retrospective impact assessment

Study 9 will follow and be directly informed by Study 8. In turn, it will support Studies 12, 13, 15, and 16 and provide information and materials to support the community engagement program.

Rationale:
The OLRS includes dams and control gates on the mainstem Okanagan lakes, vertical drop structures, dikes, sediment basins, and drainage works. It was constructed to control flooding, but it is now operated to manage drought, and to consider the needs of fish and other aquatic organisms, and recreation. The OLRS has provided significant benefits to society. However, its construction drastically altered the Okanagan River from its natural form to a mostly straight and narrow engineered channel constrained by dikes, with several drop structures to replace the natural river gradient. The meanders were cut off, significantly altering river and floodplain processes. Finally, the OLRS was designed and constructed without consultation with, or the approval of, the Syilx people, and its impacts on Syilx society have not been thoroughly documented. Neither the benefits nor the impacts of the OLRS have been comprehensively investigated or documented, yet this information is important as it will inform Study 18 – the plan to modernize the OLRS and its operating regime.

Contribution:
This study will describe both the benefits and the negative impacts of the OLRS. It will document the history of OLRS development, describe how it has changed the mainstem lake and river system, and identify its benefits (primarily flood control and drought mitigation). This information will be very useful in support of the community engagement program, as it will help the public understand why the OLRS was constructed and that it has provided significant benefits to society over the past several decades.

Study 9 will also comprehensively describe the negative ecosystem impacts associated with the changes to the mainstem river and lake system associated with OLRS construction and operation, and its cultural and socio-economic impacts on Syilx society. The impact assessment will help educate the public about the negative ecosystem and societal impacts of the OLRS, and provide essential background information for Studies 15 and 16.

Overview:
Study 9 will:

- Describe the purpose and history of OLRS development (beginning with some dams, weirs, and river channelization that preceded the OLRS);
- Describe the current physical and biological state of the mainstem lake and river system;
- Describe benefits provided by the OLRS; and
- Identify and assess the environmental and socio-economic impacts of OLRS construction and operation, and cultural impacts on Syilx communities.

Methods:
Several good sources exist for describing the reasons for development of the OLRS, and the story of its development, including Symonds (2000). In addition, past and present OLRS operators have personal knowledge that would be valuable in supplementing the documented record.

Descriptions and assessment of the current physical and biological state will use Study 8 as a reference point. Study 9 will describe in both text and visual forms and both qualitatively and quantitively how the OLRS changed the river, lakes, floodplains, wetlands, and riparian areas in the mainstem Okanagan valley.

Benefits provided by the OLRS include flood and drought management and socio-economic benefits. The study will identify and describe the benefits that the OLRS was originally designed to provide, as well as the additional benefits it now provides (e.g., for drought management, fisheries, and recreation). These benefits will be determined quantitatively. Modern ranges of lake levels and river flows will be compared against historical ranges derived in Study 8. Study 9 will include consideration of benefits to Osoyoos Lake management and international cross-border flows. It will also answer the following questions:

- Were the original objectives of the OLRS achieved?
- What are the limitations of the OLRS to manage flooding and drought?
- Has there been any reduction in the ability of the OLRS to provide benefits in recent times due to climate change or any other factors?

OLRS operators have compiled a significant experience-based understanding of the constraints on the OLRS to provide benefits, including:

- channel capacity issues in the Oliver reach of the Okanagan River, and in Lower Vernon Creek;
- constraints to releasing water from Kalamalka Lake due to the configuration of the lake outlet;
- constraints to managing water levels on Vaseux Lake;
- some locations lack sufficient erosion protection;
- high tributary inflows to the Okanagan River affect the ability to release flow from Okanagan Lake;
- river dikes can impound groundwater and cause flooding behind the dikes; and
- maintaining a flow regime that mitigates potential harm to the aquatic environment in the mainstem lakes and the Okanagan River constrains the ability to provide both flood control and drought management benefits.

Finally, a retrospective impact assessment will be completed. This part of the study will comprehensively identify and analyze negative impacts of the OLRS (both construction and operation) on the natural environment and on socio-economic and cultural conditions. This will require describing pre-European ecosystem values, and socio-economic and cultural conditions, and present-day values. The assessment will use accepted and commonly used methods for conducting environmental, socio-economic, and cultural impact assessments. The study by ECONorthwest (2013) that examined the value of an unchannelized section of the Okanagan River will be useful. The socio-economic and cultural impact assessments will include a program of interviews with Syilx knowledge keepers, and staff of the ONA and member Bands.

Deliverables:

Study 9 will require a comprehensive report that addresses each of the elements of the study identified in the Study Overview, above. Similar to Study 8, excellent visual presentations will be required in the report, and separately in large formats suitable for public display. The report will require a comprehensive but plain-language Executive Summary suitable for a general audience.

3.4 The Present and Future

Technical analyses completed during the Okanagan flood mapping project (NHC 2020) indicated that future design flood levels on Okanagan mainstem lakes will increase substantially. NHC sought ways to reduce these large predicted increases by simulating OLRS operations beyond the constraints imposed by the current Operating Plan. Two changes to OLRS operations were identified that, if implemented, would mitigate the very large predicted increases in design flood elevations. The design water levels would still increase from today's values, but they would not increase by as much as they would if the Operating Plan did not change. These changes are as follows:

- The season in which high outflows from Okanagan Lake are permitted can be expanded from the present season April through July, to a new longer season February through September; and
- Okanagan Lake can be lowered in winter by 0.2 m more than is permitted at present.

NHC (2020) assumed that these two changes could be made, and published flood mapping based on this assumption. The resulting design flood levels are higher than values in use today, but significantly lower than they would be if NHC had not assumed that these two changes could be made. However, the impacts of these assumed changes to the Operating Plan have not been identified or assessed.

Seven studies are described this section:

- Study 10: a report and mapping that describes the flood level implications of not changing the OLRS Operating Plan as assumed by NHC (2020);
- Study 11: a flood risk assessment considering risk to constructed assets;
- Study 12: a drought risk assessment considering risk to constructed assets;
- Study 13: an assessment of the impacts of future climate, with and without the Operating Plan changes assumed by NHC (2020) regarding high flows and those recommended in Study 12 regarding low flows, on natural assets, socio-economic conditions, and international agreements;
- Study 14: OLRS lifecycle analysis and replacement cost analysis;
- Study 15: Opportunities to restore lost OLRS benefits; and
- Study 16: Feasibility of re-naturalizing and restoring the mainstem system.

Study 10 will provide information to help inform the public and decision-makers about the need to modernize the OLRS and will provide information needed to complete the risk assessment in Study 11. Study 11 evaluates hazards and consequences related to water levels and flows that are above normal and is focussed on constructed assets. Study 12 evaluates hazards and consequences related to water levels and flows that are below normal and is similarly focussed on constructed assets. Study 13 will focus on all other receptors, including natural aquatic and terrestrial ecosystems, socio-economic conditions, and international agreements, and will consider the full range of flows from drought to flood. Study 13 will therefore be analogous to a combination of Studies 11 and 12 for all non-constructed assets and receptors, and will follow from Study 9, in which the historical and present-day impacts of OLRS construction and operation on ecosystems and socio-economic conditions will have been assessed. Study 14 will identify the timing and costs required to replace each aspect of OLRS infrastructure as necessitated by its age and condition. Study 15 will build on previous studies to describe quantitatively how the benefits provided by the OLRS are diminishing over time due to climate change. Study 16 will examine the feasibility of significantly extending the ongoing work of the ORRI and other restoration programs to re-naturalize and restore the mainstem Okanagan River and other valley-bottom areas to pre-development conditions, while maintaining the ability of the OLRS to provide flood control, drought management, and other benefits.

Study 10 can be performed independently of other studies described herein, as it relies only on NHC (2020). Studies 11, 12, and 13 will be directly informed by Studies 1, 2, and 3. In addition, Studies 11 and 13 will depend on Study 10, and Study 12 will depend on Study 9. Study 14 is a stand-alone study that can be conducted independently of any other studies within this Plan of Study. Study 15 will be directly informed by Studies 9, 11, 12, 13 and 14. Study 16 will be directly informed by Studies 8 and 9.

Study 10 will directly inform Studies 11 and 13. Studies 11, 12, 13, and 14 will each directly inform Studies 15 and 18. Studies 15 and 16 will directly support Study 18.

Study 10: Flood level implications of not changing the OLRS Operating Plan

Study 10 does not rely on the prior completion of any studies in this Plan of Study. It will directly support Studies 11 and 13 and other subsequent studies that depend on these studies.

Rationale:
The floodplain mapping presented in the Okanagan Mainstem Floodplain Mapping Project (NHC, 2020) was based on the assumption that modifications could be made to the OLRS Operating Plan and guidelines to mitigate the expectation for higher and more frequent floods in the future. The floodplain mapping is contingent on such modifications, and without them, the design flood levels for Okanagan mainstem lakes would be higher. For example the design flood elevation on Okanagan Lake would be 0.45 m higher. It is currently not known how much higher the design flood levels would be in the absence of these assumed Operating Plan modifications. This study is intended as a supplementary study to NHC (2020). It is needed to help the public understand the unmitigated impacts of climate change on design flood levels.

Contribution:
The intent of this supplementary report is to make the ongoing and future impact of climate change on flood levels and Okanagan Lake dam clear to the public and decision-makers. This information will help the public understand that some changes to OLRS infrastructure and/or operations are required.

Overview:
The report for this study will be written for a general audience and explain (i.e., through text, graphics, and maps) the Flood Construction Levels (FCLs) for Okanagan and Kalamalka Lakes[1] mid-century, assuming no changes to the current OLRS Operating Plan and guidelines (the operations). It will address the increased risk to Okanagan Lake dam and other OLRS infrastructure associated with higher flood levels than mapped in NHC (2020). The goal is to provide the public with an understanding of the flood-related impacts of mid-century climate change without adaptation (through changes to operations), with the outcome aiming to assist the public in understanding why some combination of changes to the operations and/or infrastructure are necessary. The study will also address, at a reduced level of effort, the changes to design flood elevations and OLRS infrastructure expected at the end of the 21st century. It is worth identifying potential changes at this long timeframe because any major OLRS infrastructure changes made in the next few decades will be required to provide flood control benefits to the end of this century and beyond.

Methods:
This study is expected to consist of the following components, which will contribute to an explanatory report written for a general audience:

- Hydrology – a description of flood level estimation for Okanagan and Kalamalka Lakes for the mid-century and end-of-century time periods without changes to operations.
- Lakeshore – an update to the estimation of wave effects on the Okanagan and Kalamalka Lake shorelines given the higher flood levels[2], and development of FCL zones for the mid-century time period, with description of approach.

[1] This study only evaluates Okanagan and Kalamalka Lakes, since an unregulated (gates open) mid-century climate change scenario was used as the design flood for the Okanagan River in NHC (2020). Thus, the impact of changes or no changes to operations cannot be compared downstream of Okanagan Lake Dam.
[2] Low elevation land to the west and east of Okanagan Lake Dam would be assumed to be raised for lakeshore component calculations and the floodplain mapping since the new water levels would be at a higher elevation.

- GIS – floodplain mapping for Okanagan Lake using new flood levels, wave estimates, addition of freeboard, and FCL zone extents (i.e. wave effects and flood inundation) for the mid-century time period. The CGVD2013 datum is proposed.

To ensure consistency with NHC (2020), the study will use the same bathymetric data used for that study, not the bathymetric data described in Study 7.

Deliverables:
The main deliverables of this project are an explanatory report written for a general audience, and updated floodplain mapping for Okanagan and Kalamalka Lakes mid-century, showing the change to FCLs from NHC (2020) given no modifications to the current OLRS Operating Plan.

Study 11: Okanagan mainstem flood risk assessment

Study 11 will depend on the prior completion of Studies 1, 2, 3 and 10. In turn, Study 11 will directly inform Studies 15 and 18.

Study 11 is a flood risk assessment of the Okanagan mainstem lakes and river system, focussed on constructed assets. It builds upon the floodplain mapping study completed by NHC (2020). It will evaluate hazards and consequences related to water levels and flows that are above normal, and the risk assessment will be based on three scenarios:

1. Current operations of the OLRS as guided by the OLRS Operating Plan and the Kalamalka Lake Operating Plan;
2. Mid-century climate change (as described by the NHC (2020) climate and hydrology model runs) without changing the Operating Plans; and
3. Mid-century climate change with the future alternative Operating Plan assumed by NHC (2020).

If determined potentially significant in Study 1, other factors that could affect hydrologic response (e.g. future land cover changes due to forest harvesting or wildfires, and changes to the management of upland reservoirs) will also be addressed in Study 11.

Hazards consider both frequency and magnitude, and both these elements will change based on the scenario chosen. The work based on scenario 1 above will provide a strong foundation for examining scenarios 2 and 3.

The OLRS infrastructure will be included as a receptor in the flood risk assessment.

Rationale:
To date, design flood levels and flood mapping have considered flood hazards (and the future influence of climate change), but not flood risk (except in specific locations). However, considering flood hazard alone does not provide insight into the combined likelihood and potential consequences of flood damage that can be derived from a risk-based approach, nor does it provide enough information to identify flood mitigation strategies or to choose amongst these strategies. The flood risk analysis will consider impacts on constructed assets, such as buildings, roads, and water supply infrastructure. Impacts on natural ecosystems and other receptors will be considered in Study 13.

In 2020, NHC completed the Okanagan Mainstem Lake Floodplain Mapping Study that developed floodplain mapping for the main Okanagan valley-bottom lakes including Ellison (Duck), Kalamalka-Wood, Okanagan, Skaha, Vaseux, and Osoyoos Lakes, and for the Okanagan River from Penticton to Osoyoos Lake. This floodplain mapping project and the consequent flood construction levels relies on a standards-based approach that facilitates policy development to reduce flood risk and allows regulation of floodplain areas. However, this approach does not provide insight into the combined likelihood and potential consequences of flood damage that can be derived from a risk-based approach. In its current form, the floodplain mapping identifies properties and infrastructure that are either “exposed” (below the FCL) or “protected” (above the FCL) in a binary fashion. In reality, a range of flood and storm events of various magnitudes, timing, and duration will impact the near shore areas to varying degrees resulting in varying levels of impact. A probabilistic flood risk assessment is needed to identify hazards, consequences, and risks over a range of high lake levels and river flows, and for the range of Operating Plan scenarios identified above.

Contribution:
A flood risk assessment will build on the flood hazard assessment completed by NHC (2020) to identify where future flood mitigation action is warranted, and to identify, evaluate, and recommend flood mitigation options based on quantitative analysis of costs and benefits. The work will facilitate future decision-making among options. Understanding the potential influences of future climate and potential OLRS operational changes will further inform flood mitigation strategies and policies.

Background:
Floodplain mapping identifies properties and infrastructure that are either “exposed” (below the FCL) or “protected” (above the FCL) in a binary fashion. The purpose of floodplain mapping is to improve understanding of the flood hazard and to allow governments (i.e., First Nations, local, and regional), organizations and individuals to plan for potential floods and reduce their risk. However, adhering to an established FCL may, in some cases be impractical, not economically viable, and/or result in other harmful impacts. In addition, a range of flood and storm events will impact the near shore areas to varying degrees resulting in varying impacts based on amount of development, cultural and historical values, and environmental sensitivities. For these reasons, floodplain mapping and the establishment of an FCL on their own may not be conducive to facilitating more integrated approaches to flood management that consider the value of flood hazard mitigation, including co-benefits of selected approaches.

A flood risk assessment is a methodology to quantify the combination of the likelihood of a hazard event occurring and the corresponding consequences of the event. This is done by analyzing potential hazards and understanding the exposure and vulnerability of the impacted area. A flood risk assessment can include a wide variety of receptors including both direct damages (e.g., building damage, content loss, vehicle damage, damage to docks or water supply infrastructure such as intakes, water treatment plants, and pump stations) and indirect damages (e.g., business interruption, loss of income, traffic interruption). While these types of losses can be measured in monetary terms, other losses cannot be easily quantified, including damage to cultural sites, contamination of ecosystems, or flood damage to ecosystems. Losses to these receptors can nonetheless be highly significant and will be considered in Study 13.

The risk-based approach to flood mitigation is particularly suited to addressing flood management in a changing climate. It requires an understanding of exposure and consequence under a range of small and large floods. This information is used to plan for a range of possible climate futures.

Compared to a single event damage estimate, a probabilistic assessment more accurately captures the total losses and averted damages associated with a full range of flood events. Damage can occur over a range of event probabilities, including those less than and more than the regulatory flood level. This approach relies on developing exceedance probability curves that relate the hazard likelihood with the associated consequences. Using a probabilistic risk assessment approach, the average annual loss can be calculated, which represents the long-term expected loss on an annualized basis.

Overview:
Using the NHC (2020) floodplain mapping as a starting point, the level of flood risk throughout the Okanagan mainstem system will be evaluated. Developing a baseline understanding of flood risk, based on a selected OLRS operating regime, is a necessary pre-condition to identifying preferred actions to reduce the risk. The flood risk

assessment will indicate which assets and locations are at highest risk of damage, and thus require priority in flood risk reduction measures.

After completing the flood risk assessment, specific flood-proofing actions will be identified to integrate multi-objective considerations. For example, various structural and/or non-structural risk reduction strategies will be evaluated to quantify avoided losses. These avoided losses will be compared against the cost of the flood mitigation strategy to evaluate the most beneficial solutions (i.e., benefit/cost, marginal cost analysis).

Based on the large geographic scope of the Okanagan mainstem system, the flood risk assessment will start with a high-level initial risk assessment to screen and identify higher risk areas based on flood depth/extent and a selected set of receptors. A subsequent phase will include a detailed flood risk assessment that will include additional flood hazard elements, a refined spatial definition, and possibly an expanded list of receptors. The spatial resolution should align with relatively consistent hazard exposure and potential flood mitigation measures. In this manner, any flood mitigation approach can be evaluated based on a common set of averted damages/losses. The comparison of averted damages against the cost of improvements will allow for economic evaluations of the overall value of any mitigation option considered.

Methods:
To complete a probabilistic flood risk assessment for the Okanagan mainstem lakes and river, a variety of flood levels/extents and corresponding likelihoods under future climate conditions is required. At present, these values exist for the 20-year, 100-year, 200-year and 500-year events; if warranted, additional intermediate event results could be produced.

Specific considerations for OLRS structural components:
Previous reports have identified the possible need for structural changes to the OLRS infrastructure to accommodate larger flows than the system was designed for. For example, NHC (2020) provided several recommendations related to upgrading OLRS infrastructure. However, the feasibility, costs, and benefits related to these recommendations have not yet been studied. Study 11 will include a thorough examination of risks to OLRS infrastructure, conducted at a higher level of detail than for other constructed assets.

Three areas of focus for considering risks to OLRS infrastructure are:

- Assessments of mainstem dams: NHC (2020) provided several recommendations related to the dams on the mainstem lakes, including improving rating curves for lake outflows, evaluating the risks of dam failure, developing formal high-water operating plans or emergency plans, and conducting dam safety reviews. These studies should be completed, and have been included within the scope of Study 11.
- Dike assessments: Although there is substantial existing knowledge of the condition of Okanagan River dikes, there are gaps in the information. NHC (2020) recommended completing dike surveys, including crest elevation surveys, vulnerability assessments, and dike breach analysis for the dikes along both sides of the Okanagan River. These studies should be completed, and have been included within the scope of Study 11.
- Assessment of risks relating to aquatic invasive species.

The study will be contracted to an engineering consultant with proven experience in flood risk assessment. The consultant will use all relevant B.C. guidelines for flood risk assessment, including those developed by Engineers and Geoscientists B.C. (EGBC). They will build on the information, modelling and digital materials developed in the

Okanagan Mainstem Floodplain Mapping Project (NHC, 2020), the Syilx Okanagan Flood and Debris Flow Risk Assessment (Ebbwater, 2019), and other flood maps and risk assessments developed since 2017 by Okanagan communities. Based on their initial review of these materials, the consultant will identify gaps, and develop a detailed work plan for the two-phase study described above. There will be extensive engagement with the Okanagan Collaborative Flood Planning Group (key community partners), as well as with regional and provincial experts, technical advisors, and key stakeholders.

Deliverables:
Study information will be delivered in a report, divided into two major headings:
- Flood Risk Assessment; and
- Recommendations for Flood Mitigation.

The analysis and recommendations will clearly address the influence of each of the three OLRS operational scenarios on the outcomes. The report will include map layers, to be linked to existing flood maps in local government, First Nation, and senior government GIS systems. Public-facing information will be developed to communicate flood risks through the Okanagan Flood Story website (https://okanagan-basin-flood-portal-rdco.hub.arcgis.com/).

Study 12: Okanagan mainstem drought risk assessment

Study 12 will require the prior completion of Studies 1, 2, 3 and 9. In turn Study 12 will inform Studies 15 and 18.

Study 12 is a two-part study:

1. Assessing the impacts of 21st century climate change on the drought management benefits provided by the OLRS, and recommending changes to the Operating Plan to maintain the drought management benefits into the future; and
2. A drought risk assessment.

The drought risk assessment of the Okanagan mainstem lake and river system will focus on constructed assets. It will evaluate hazards and consequences related to water levels and flows that are below normal, and the risk assessment will be based on three scenarios (analogous to those of Study 11):

1. The current operations of the OLRS as guided by the OLRS Operating Plan and the Kalamalka Lake Operating Plan;
2. Mid-century climate change (as described by the NHC (2020) climate and hydrology model runs, or NHC's climate combined with the new linked Okanagan-Similkameen hydrology model to be developed in Study 1) without changing the Operating Plans; and
3. Mid-century climate change with the future alternative Operating Plan recommended in the first part of Study 12.

If determined potentially significant in Study 1, other factors that could affect hydrologic response (e.g. future land cover changes due to forest harvesting or wildfires, and changes to the management of upland reservoirs) will also be addressed in Study 12.

Hazards consider frequency, magnitude, and duration, and each of these elements will change based on the scenario chosen. The work based on scenario 1 will provide a strong foundation for examining scenarios 2 and 3.

Rationale:
Although many water suppliers understand the risks related to low water levels and streamflows for their own water systems, no comprehensive valley-wide inventory of water supply assets exists, nor has there been a valley-wide analysis of the risks to water supply infrastructure and other assets susceptible to impacts associated with drought. The drought risk analysis will consider impacts on constructed assets, such as water supply infrastructure, marinas, and docks. Drought impacts on natural ecosystems and other receptors will be considered in Study 13. Although described separately in this Plan of Study, the drought risk analysis could be combined with the flood risk analysis described in Study 11.

Contribution:
A comprehensive drought risk analysis will assemble quantitative mapping and information on the impacts on water supply infrastructure and other infrastructure potentially affected by low lake levels and low river flows into a single map product and report for the entire Okanagan mainstem lake and river system. It will also provide a strong foundation for assessing the benefits and impacts of alternative OLRS operational guidelines and alternatives to the current OLRS infrastructure.

Overview:
NHC (2020) suggested two changes to the OLRS Operating Plan to mitigate the ongoing influences of climate change which are forecast to cause progressively higher flood levels (i.e., to mitigate progressively diminishing flood control benefits). The first part of Study 12 will examine this issue from a drought perspective. It will consider the climate modelling completed by NHC (2020), and potentially other sources of future climate information, and will recommend whether and how to change the OLRS Operating Plan such that the level of drought protection provided by the OLRS can be maintained in the face on ongoing climate change.

The scope of, and methods used in, the drought risk analysis (the second part of Study 12) will be consistent with those of the flood risk assessment described in Study 11. Water supply intakes, marinas, docks, and other relevant infrastructure will be mapped and the economic and social consequences associated with these intakes losing their functionality due to low lake levels and river flows will be assessed, based on the three above-noted operational scenarios. More specifically, by examining risks to water supply intakes, this study will assess risks to municipal, agricultural, and other water users with mainstem lake and river water intakes. Drought mitigation options will be identified, evaluated, and recommended.

Methods:
Relevant existing information will be assembled. Relevant information sources likely include municipalities and water suppliers, many of which have likely surveyed the locations and elevations of their water supply infrastructure, and have an understanding of the hazards and risks to that infrastructure related to low water. Other owners of water supply infrastructure, such as farms and wineries, may also have this knowledge. The FWMT considers the effects of low river flows on intakes installed in the Okanagan River, and the FWMT team and the OLRS manager likely have an understanding of the locations and impacts of low flows on these intakes. Information on marina, boat launch, and dock locations and possibly elevations is likely available from aerial imagery, municipalities and regional districts.

This and other relevant information on infrastructure subject to drought risk will be integrated into a single map product, which will form the foundation for the risk assessment. Existing knowledge held by municipalities and other infrastructure owners on hazards and risks will also be assembled and used to inform the risk assessment. The Okanagan Lake drought triggers report (OBWB, 2019) recommended specific lake levels intended to trigger drought level declarations by municipalities with water intakes in the lakes. Municipalities have begun to adopt these drought triggers, and their implications (and the implications for the drought triggers of changing the Operating Plan should be considered during this study. In addition, the Province is considering changes to the number of provincial "drought levels", which may have relevance for this study.

The risk assessment will follow accepted procedures for such analyses, and similar to the flood risk analysis, will consider a range of low lake levels and river flows, and will be conducted for three operational scenarios.

Deliverables:
Similar to the flood risk assessment, study information will be delivered in a report, divided into major headings:

- Recommendations to change the OLRS Operating Plan to maintain its drought benefits;
- A Drought Risk Assessment; and
- Recommendations for drought mitigation.

The analysis and recommendations will clearly address the influence of each of the three OLRS operational scenarios on the outcomes. The report will include map layers, which will be shared with local government, First Nation, and senior governments. Public-facing information will be developed to communicate drought risks to the public.

Study 13: Impacts of climate change and Operating Plan changes

Study 13 evaluates climate risks to non-constructed assets. It depends on prior completion of Studies 1, 2, 3, 9 and 10. In turn Study 13 will inform Studies 15 and 18. It is a large study with several components, which could be grouped into a single comprehensive study as described herein, or separated into smaller studies.

Rationale:
Progressive changes in climate are progressively changing the hydrologic regime that determines the rate, timing, and volume of water received by the mainstem lake and river system from higher elevation areas of the Okanagan Basin. These climate and hydrologic changes are predicted to continue for at least the next several decades, which means that the operational challenges experienced by the OLRS operators in some recent years will continue or worsen over time. Accordingly, the benefits provided by the OLRS (e.g., flood control, drought management, fisheries, and recreation) are expected to diminish over time. This study will examine the extent to which climate change (and other factors, if Study 1 identifies other factors that should be considered) will impact the ability of the OLRS to continue to provide the benefits described in Study 9.

Contribution:
This study will identify and assess impacts on a variety of receptors influenced by the OLRS that are expected to result from progressively increasing operational challenges due to ongoing climate change (and potentially other factors, as determined in Study 1).

Overview:
The risk assessments described in Studies 11 and 12 focus on constructed assets. Study 13 will focus on other assets, including natural aquatic and terrestrial ecosystems, socio-economic conditions, and international agreements. Impacts on municipal, agricultural, and other water users with intakes on the mainstem lakes and the Okanagan River will have been examined in Study 12. Consistent with the flood and drought risk assessments, the impact assessment in Study 13 will be driven by two future scenarios:

- Mid-century climate change (as described by NHC's climate and hydrology model runs, or NHC's climate combined with the new linked Okanagan-Similkameen hydrology model to be developed in Study 1 in this Plan of Study) without changing the OLRS or Kalamalka Lake Operating Plans; and
- Mid-century climate mitigated by the Operating Plan changes assumed by NHC (2020) related to flooding, and those recommended in Study 12 related to drought.

The <u>historical and present-day impacts</u> of OLRS construction and operation on ecosystems and socio-economic conditions will have been assessed in Study 9. Study 13 will examine the likely <u>future impacts</u> on a range of receptors resulting from ongoing climate change and of previously recommended changes to the Operating Plan to mitigate against climate change.

If determined potentially significant in Study 1, other factors that could affect hydrologic response (e.g. future land cover changes due to forest harvesting or wildfires, and changes to the management of upland reservoirs) will also be addressed in Study 13.

Methods:
Study 13 will consider impacts based on the full range of streamflows, rather than targeting either flood flows or drought flows. The study will:

- Identify all relevant receptors (e.g., aquatic and riparian ecosystems, socio-economic conditions, international agreements);
- Conduct a forward-looking impact assessment on each receptor, based on two future scenarios (and, if relevant, other scenarios related to land cover and upland reservoirs); and
- Identify opportunities to mitigate impacts, and the associated implications for future lake water levels and river flows.

Finally, Study 13 will contribute valuable information to Study 18, but it will not address the specific impacts related to the actions within the plan for OLRS modernization that will be developed in Study 18.

Potential hydrologic changes and receptors

The following is a partial list of documented hydrologic changes driven by climate change that are expected to continue over the next few decades. These changes could be responsible for future impacts on environmental and socio-economic receptors that are affected by OLRS operations.

- Advances in the timing of freshet and changes to the shape of the freshet inflow hydrograph;
- Increasing winter precipitation, and increasing proportion as rain;
- Increasing winter inflows and reduced late summer inflows; and
- Progressively reducing confidence in spring weather forecasts.

The following is an initial list of receptors that could be affected by future climate change and by changes to the Operating Plan to mitigate climate-driven changes:

- Aquatic ecosystems, fisheries, and water quality (including water temperature) in the mainstem lakes and the Okanagan River (including SARA-listed species such as Chinook salmon and Rocky Mountain ridged mussel, and the temperature/oxygen 'squeeze' in Osoyoos Lake);
- The natural terrestrial environments adjacent to the mainstem lakes and the Okanagan River;
- The structural integrity of the OLRS assets;
- The socio-economic environment, including Indigenous culture, values and ways of life; and
- International agreements (Zosel Dam operations and the informal cross-border flow agreement).

Potential impacts on aquatic ecosystems and fisheries

A great deal of work on aquatic ecosystems and fisheries in the Okanagan has been completed by the Okanagan Nation Alliance (ONA), Fisheries and Oceans Canada (DFO), provincial fisheries staff, OBWB and others. The FWMT was developed to provide fisheries-relevant input to the Water Manager during times of year most important to anadromous and non-anadromous fish in the Okanagan River and the mainstem lakes. The operators of the FWMT are progressively improving the model.

Examples of potential impacts caused by future climate change and Operating Plan changes include:

- If Okanagan Lake is managed at a lower level during fall, there could be impacts on kokanee spawning habitat quantity and quality due to less optimal substrate conditions;
- Higher or lower lake levels at particular times of the year could have implications for lake water quality;
- Lower summer outflows from Okanagan Lake could result in warmer river water, which could impact river spawning and rearing success and the temperature of Osoyoos Lake;
- Instream flow requirements could change in future with a warming climate; and

- Lower lake levels could impact tributary spawning, and drawdown below natural low levels could lead to channel instability, changes in the spawning beds, and/or perched deltas that are difficult for fish to access;

Potential impacts on socio-economic conditions
Changes to OLRS operations to buffer future climate-driven changes to the nature of floods and droughts will help to mitigate the effects of these changes. However, it may be necessary to accept higher or lower lake levels and river flows than are currently achieved through the operation of the OLRS.

The 1974 State of the Basin report (Consultative Board, 1974) included consideration of socio-economic issues of the time. The Orders of Approval for Osoyoos Lake consider socio-economic factors relevant to high and low lake levels. Socio-economic constraints inform the FWMT decision support system. However, socio-economic impacts associated with future changes to OLRS infrastructure or operations have not yet been identified or evaluated.

In addition to impacts on the public, businesses, and organizations, the study will address potential impacts on navigation and recreation, and on Indigenous peoples living along the mainstem lakes and the Okanagan River, and on Syilx culture, practices, and archaeology.

Potential impacts on international agreements
Osoyoos Lake is situated partly in Canada and partly in the U.S. Zosel Dam on Osoyoos Lake is situated in the U.S., and its operation is governed by the International Osoyoos Lake Board of Control (IOLBC). Osoyoos Lake is managed according to Orders of Approval within certain ranges of elevations. The Orders of Approval acknowledge the important influence of OLRS management on Osoyoos Lake level management. For example, when low inflows (i.e., "droughts") are expected, the authorized operating range for Osoyoos Lake is greater than in non-drought years. Each spring, three criteria specified in the Orders of Approval are used to determine the likelihood of a "drought" being declared that year. One of these criteria is the anticipated inflow to Okanagan Lake, and another is the anticipated June or July level of Okanagan Lake. Both criteria are relevant to the inflow to Osoyoos Lake from the Okanagan River. Any changes to OLRS operations could impact the level of Okanagan Lake and the flow of the Okanagan River, and affect the likelihood of a "drought" being declared on Osoyoos Lake.

The Osoyoos Lake Orders of Approval were updated in 2013, following completion of several studies. A great deal of information relevant to the influence of OLRS management on Osoyoos Lake was summarized and updated in these studies. Study 13 will include an assessment of the impacts of ongoing climate and hydrologic change in the Okanagan Basin, and of the changes to the OLRS Operating Plan assumed by NHC (2020) and recommended in Study 9, on the management of Osoyoos Lake, including the drought criteria.

Although no formal international agreement is in place to provide specific cross-border flows, the Province of B.C. has agreed informally to consider flow needs in Washington State in its OLRS decision-making. Study 13 will assess the implications of ongoing hydrologic change and changes to the OLRS Operating Plan on the informal transboundary flow agreement between B.C. and Washington State.

Deliverables:
This study has several components, and could be reported in a single comprehensive report, or in three reports, one for each major type of receptor:

- Impacts on aquatic and terrestrial environments;

- Socio-economic impacts; and
- Impacts on international agreements.

Study 14: OLRS lifecycle and replacement cost analysis

Study 14 does not rely on any previous study described herein. It will contribute directly to Studies 15 and 18.

Rationale:
The OLRS assets include dams, control structures, drop structures, dikes, and drainage works. These assets were first constructed in the 1950s and have been managed and maintained by the Province of B.C. The condition of each component of OLRS infrastructure is comprehensively evaluated at 10-year intervals, and necessary repair and maintenance work is then completed. Like all assets, however, each OLRS asset has an estimated lifespan, and inevitably each will reach the end of its useful service life over the next few decades. As the end of service life is approached, each asset will need to be replaced or comprehensively rehabilitated. However, the Province has not yet developed a present-day value for these assets, nor estimated the cost of replacing them, nor developed a schedule for asset replacement.

Contribution:
This study will provide the cost of replacement of each OLRS asset to today's structure standards but without enhancements, and the timeline over which this would occur. It will help the Province manage OLRS assets, and will help the public understand that replacing them is necessary in the relatively near future (with or without climate change).

Overview:
This study will provide a present-day valuation for each OLRS asset, a timeline for replacement, and an estimated replacement cost. The replacement cost will be estimated with the assumption that no changes are made to the OLRS or its operation, and provides the baseline against which other alternatives will be compared. The opportunities and costs to both replace and potentially improve the OLRS infrastructure to meet present-day requirements and provide more flexibility to account for future climate change will be examined in Study 15.

The study will:

- Identify each OLRS asset and its current condition;
- Estimate the present value of each OLRS asset;
- Determine the lifespan of each asset, and when it will need replacement;
- Estimate the capital investment required to replace each asset at the end of its service life, assuming the originally intended Level of Service is maintained through the replacement; and
- Propose a timeline for replacement of each asset.

Methods:
The present condition of each asset will be available from the most recent 10-year asset condition evaluation completed by the Province in 2018. Methods to determine present value, lifespan, replacement schedule and replacement cost will be based on standard engineering and economic analysis techniques used for asset management. The study will assume that each asset will be replaced without considering the potential for improvements.

Deliverables:
The deliverables are a draft report, presentation and final report to be supplemented by photographs, maps, figures, and graphs as needed to convey the information to a wide audience.

Study 15: Opportunities to restore lost OLRS benefits

Studies 13 and 14 will provide the foundation for Study 15. Other previous studies, including 9, 11, and 12, will also support Study 15. Study 15 will directly inform Study 18.

Rationale:
Recent operational experience indicates that the OLRS may no longer be fully capable of providing the benefits (flood control, drought management, fisheries, and recreational) that the system has been designed to deliver. This study will examine the infrastructure changes that could contribute to restoring those lost benefits, including incorporating greater flexibility to accommodate future hydrologic changes related to ongoing climate change. Accordingly, the analysis will make use of the mid-century climate and hydrologic information developed by NHC (2020), and potentially other climate and hydrology sources.

Contribution:
Study 15 will examine opportunities and capital costs required to restore any lost OLRS benefits, so that the OLRS can continue to provide its intended level of service into the future as the climate and hydrologic regimes that drive the system continue to change. It will also qualitatively identify challenges to implementing any of the potential changes.

Overview:
This study will investigate the feasibility of changing elements of the OLRS to restore any diminished level of service experienced in recent years. Specifically, it will investigate:

- Opportunities to expand channel capacity (see additional commentary below);
- Opportunities to pass higher flow through the river and across the vertical drop structures than the system is currently designed for;
- Opportunities to convey water from one lake to the next via means other than open channels;
- Opportunities to expand existing dams and change control gates;
- The potential to relieve the flow release constraint at Kalamalka Lake created by the configuration of the lake bottom at the dam;
- The potential to increase the discharge capacity at the outlet of Vaseux Lake; and
- Any other potential opportunities to regain flood control, drought management, fisheries, and recreational benefits, and provide the flexibility needed to accommodate the ongoing impacts of the changing climate.

The analysis will be done considering two scenarios:

1. The OLRS continues to be operated according to the current Operating Plan.
2. The OLRS is operated according to the changes recommended by NHC (2020) and the changes recommended in Study 9 (above).

For each opportunity identified above, and for each of these two scenarios, the study will:

- Describe the scope of the opportunity;
- Describe the potential benefit gained;
- Determine the approximate cost of the upgraded asset (ensuring any new dams meet or exceed the requirements of the Canadian Dam Safety Guidelines);
- Identify and describe potential land-related, environmental, and socio-economic issues (and any other potential constraints);
- Rank the identified options; and

- Provide recommendations for changes to the OLRS to restore lost benefits.

Additional detail with respect to increasing channel capacity:
Previous work has suggested that expanding channel capacity downstream of the Okanagan mainstem lakes would provide additional flexibility to manage the system and reduce the likelihood and severity of flooding. Attention has focussed on Vernon Creek downstream of Kalamalka Lake, for which the channel capacity is about 6 m^3/s, and on the Okanagan River downstream of Penticton, for which the design capacity is 75 m^3/s, although higher flows have been experienced. However, a comprehensive valley-wide assessment of these opportunities has not been conducted.

OLRS operators are aware of specific 'pinch points' that constrain channel capacity. This study will determine channel capacity along the entire Okanagan mainstem system, and identify specific opportunities to increase channel capacity, along with challenges and approximate capital costs for each opportunity. The work should include Osoyoos Lake and the Okanogan River in the U.S., since an expanded channel capacity and the potential to increase freshet discharges in Canada could impact flooding in the U.S. The potential for backwatering related to high flows on the Similkameen River is relevant to this work.

Methods:
The study will make extensive use of the operational experience of provincial OLRS operational personnel to create an initial list of opportunities and to prioritize the opportunities. Subsequent work will include conceptual engineering, environmental assessments, and socio-economic assessments for each option, leading to a ranked list of feasible options and a set of recommendations.

Beyond Study 15, further engineering design, environmental and socio-economic impact assessment, and community engagement will be required to select and evaluate preferred options before design and construction could occur. This work will take place within Study 18.

Deliverables:
Similar to Study 14, the results of this study will be presented in a report, supplemented by photographs, maps, figures, and graphs as needed to convey the information to a wide audience.

Study 16: Feasibility of re-naturalizing and restoring the mainstem system

Study 16 requires the prior completion of Studies 8 and 9. Other studies (e.g., Study 3) may help inform this study, but it can be completed independently of any other studies within this Plan of Study. Study 16 will directly inform Study 18.

Rationale:
The OLRS Operating Plan likely needs to be amended to minimize the anticipated impacts of climate change. In addition, because of its age, the OLRS infrastructure needs to be replaced over the next few decades. The OLRS and its Operating Plan have created substantial benefits to society since it was constructed nearly 70 years ago; however, it has also caused substantial ecosystem, cultural, and socio-economic impacts, and was built without the involvement of the Syilx people. The ORRI has begun the process of re-naturalizing and restoring ecosystem function along the Okanagan River, without impairing the benefits provided by the OLRS.

Social and environmental conditions have changed since the 1950s, and it may now be desirable and feasible to significantly expand the ORRI and other restoration work to encompass the entire Okanagan mainstem system, with the goal of maximizing re-naturalization and restoration potential, in conjunction with the process of replacing OLRS assets as necessitated by age and climate change drivers. In addition to ecosystem benefits, river restoration may provide multiple additional benefits, including flood and drought mitigation.

Contribution:
The study will develop a plan to re-naturalize and restore ecosystem function throughout the Okanagan mainstem system. The planning work will be performed recognizing the need to avoid impairing the flood control, drought management, and other benefits that the OLRS has provided.

Background on the ORRI Project:
The ORRI project is one of several inter-related initiatives underway to restore anadromous and resident fish populations and habitat in the Okanagan valley bottom lakes and Okanagan River. ORRI is a collaborative initiative among First Nations and federal, provincial, and local governments. It was initiated in 2000 with the goal of returning portions of the channelized Okanagan River to more natural conditions. Related fisheries restoration initiatives include construction of a fish hatchery at Penticton (opened in 2014), restoration of fish passage at the three OLRS dams (McIntyre (in 2009), Okanagan Falls (in 2013), and Penticton (in 2019)), and development of the FWMT decision support system to improve flow and lake level management. The ONA has been a champion and leader of each of these initiatives.

Between Okanagan and Skaha lakes, the Okanagan River is now entirely confined within an engineered channel. It is also channelized from Skaha Lake to Vaseux Lake. Between Vaseux Lake and Osoyoos Lake the river is partly natural, but mostly channelized and confined by dikes. As a result of the OLRS the river lost about half its original length in the section between Vaseux Lake and Osoyoos Lake, riparian and wetland areas were reduced by about 90%, and the average width of the river corridor is now 45 m, compared with 400 m before the OLRS was constructed.

About 30 km (84%) of the present-day modified Okanagan River is channelized, straightened, narrowed, and diked, and only 5 km (16%) remains in a natural or semi-natural state. ORRI projects completed or underway include:

- Re-connection of two isolated oxbows with the historical floodplain near Oliver (2009);
- Re-connection of a natural side channel near Oliver (2013);

- Modifying vertical drop structure #13 to enhance upstream spawning habitat (2013);
- Creation of floodplain ponds for amphibians near Oliver (2014);
- Creation of spawning beds for salmonids near Penticton (2014 and 2015); and
- Replacement (or backwatering) one of the four VDS between Skaha Lake and Vaseux Lake (VDS 14, 15, 16, or 17) with natural riffles (ongoing).

Overview:
The scope of Study 16 will include:

- Review of work completed to date (by ORRI and related projects) to restore portions of the mainstem Okanagan lakes and river system;
- Review of work done over recent decades to improve OLRS operations and replace infrastructure to increase benefits and mitigate negative impacts;
- Identification of further opportunities to improve OLRS operations and replace infrastructure to increase benefits and mitigate negative impacts;
- Examination of the feasibility of maximizing the restoration and re-naturalization of the mainstem system, including analysis of the costs, benefits, land and property issues, and other factors relevant to a whole system restoration project; and
- Development of recommendations for a comprehensive mainstem re-naturalization and restoration project.

This study will be comprehensive and will consider at least the following:

- Feasibility of re-activating meander bends cut off during construction of the OLRS by re-establishing flow through the dikes;
- Feasibility of replacing vertical drop structures with alternative methods of reducing channel gradient such as pool-riffle structures;
- Re-examination of the contribution of the Penticton spawning beds (since fine sediment is known to accumulate over time within these beds, reducing their effectiveness);
- Feasibility of setting back the dikes;
- Revegetation potential within setback dikes to provide shade and protection from predators, and cooler water for fish;
- The desire to re-establish lost habitat for Rocky Mountain ridged mussels;
- Feasibility of reactivating floodplains and wetlands;
- Examination of inundation levels and inundation timing for Chinook salmon and trout spawning (with the goal of making the system less desirable for invasive species such as carp and bass).
- Feasibility of restoring endangered cottonwood habitats, considering their inability to naturally regenerate under the current OLRS operational regime, and the current lack of connection of flood waters to cottonwood and birch areas.
- Changes in the dams for flood conveyance and improvements in fish passage for salmonids;
- Potential changes in the sediment basin approach to managing tributary sediment delivery to the mainstem Okanagan River;
- Identification and quantification of accessible alternative spawning habitat for anadromous salmon beyond the Okanagan River (see additional comments below); and
- Opportunities to achieve multiple benefits (e.g., restoration of lost habitat combined with increased channel capacity to pass high streamflows).

The new integrated Okanagan mainstem hydraulic model developed in Study 3 could be used to create a variety of hypothetical channel conditions to inform this study.

Considerations regarding anadromous spawning habitat beyond the Okanagan River:
Since current and future Operating Plans have had or may in future have impacts on salmon spawning in the Okanagan River, it may be necessary to consider locations beyond the Okanagan River where anadromous fish could spawn. The recently completed Phase 2 Okanagan EFN project (ONA Fisheries Department, 2020) identified and mapped spawning and rearing habitat in 18 tributaries of the Okanagan mainstem system. This work will inform this element of Study 16, which will seek alternative spawning locations and opportunities, and evaluate the feasibility of making use of this habitat for anadromous fish spawning.

Deliverables:
The study will produce a technical report, supplemented with substantial mapping and other visual resources. The visual resources will help to convey the potential for system restoration. The report and associated visual deliverables will support the community engagement program, and possibly inspire a common vision for whole system restoration.

This study will directly support Study 18. During Study 18, additional more detailed information will be required before any or the restoration work described in Study 16 can be designed or constructed.

3.5 The Path Forward

Study 17: Governing conditions for modernizing the OLRS

Study 17 does not rely on any previous studies within this Plan of Study. It will provide essential context for Study 18.

Rationale:
The work described in Study 18 will be conducted within a complex array of prevailing legal, political, cultural, environmental, and social contexts. These various contexts need to be identified and documented before Study 18 begins.

Contribution:
This study will describe the relevant legal, political, cultural, environmental, and social contexts governing the work to be completed in Study 18.

Overview:
The OLRS modernization project will be a complex project with many components that will be implemented over a period of several years or decades. The project could involve upgrading or replacing OLRS infrastructure, changing the lake level and river flow management regime, and re-naturalizing and restoring ecosystem function along the Okanagan valley bottom. The process of planning these changes must reflect a comprehensive understanding of the legal and other frameworks that will govern these activities. This study will identify and describe the current legal, political, cultural, environmental, and social contexts relevant to the process of OLRS modernization, and will anticipate future changes to these contexts, since they may evolve over a period of project implementation potentially spanning two or more decades.

The Syilx people are the original inhabitants of the Okanagan and have lived in the Okanagan for many thousands of years. Most of the OLRS modernization work will be conducted on land never ceded by the Syilx people. Accordingly, a foundational document governing the legal context for the project is the Canadian Constitution of 1982 (specifically Section 35), and subsequent Supreme Court of Canada decisions confirming the existence of rights and title for Indigenous peoples.

The United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP) was adopted by the United Nations in 2007. UNDRIP sets out 46 principles intended to enshrine the rights that constitute the minimum standards for the survival, dignity, and well-being of the Indigenous peoples of the world. Article 26 states that Indigenous peoples have the right to the lands, territories, and resources which they have traditionally owned, occupied, or otherwise used or acquired, and it directs states to give legal recognition to these territories.

Canada endorsed UNDRIP in 2016, and in December 2020 introduced legislation to fully implement the Declaration. In 2019, B.C. passed the *Declaration on the Rights of Indigenous Peoples Act* (DRIPA). Article 32 of DRIPA provides that states will consult with Indigenous peoples to obtain their free, prior, and informed consent before approving projects. DRIPA will apply to the OLRS modernization project, and Article 32 is quoted in its entirety here:

1. *Indigenous peoples have the right to determine and develop priorities and strategies for the development or use of their lands or territories and other resources.*
2. *States shall consult and cooperate in good faith with the indigenous peoples concerned through their own representative institutions in order to obtain their free and informed consent prior to the approval of any project*

affecting their lands or territories and other resources, particularly in connection with the development, utilization or exploitation of mineral, water or other resources.

3. States shall provide effective mechanisms for just and fair redress for any such activities, and appropriate measures shall be taken to mitigate adverse environmental, economic, social, cultural or spiritual impact.

Since 2019, there have been no significant changes in the Province's approach to decision-making with respect to Indigenous peoples. However, the Province has embarked on a long-term plan to align provincial legislation with the principles of the Declaration.

Four of the seven Syilx Bands are situated in the Okanagan. In addition, the Syilx people are represented by the Okanagan Nation Alliance (ONA). Through these Bands and the ONA, the Syilx people maintain working relationships with federal, provincial, and local governments throughout the Okanagan. They have a long history of leading or contributing to the restoration of fish populations and lost or damaged aquatic and terrestrial ecosystems in the Okanagan. The Syilx people have also led or contributed to scientific and planning studies leading to improved water and fisheries management, and the ONA makes an ongoing contribution to operational OLRS management through the FWMT. ONA staff contributed to development of this Plan of Study, and the Syilx people will expect to be full partners in the planning and implementation of the OLRS modernization project.

The project will be conducted across a wide range of political jurisdictions (federal, Indigenous, provincial, local, and regional), and there are many laws, regulations, policies, plans, and guidelines that will be relevant to the project.

Examples of relevant federal or provincial laws (including their enabling regulations) include:

- the federal *Fisheries Act*;
- the federal *Species at Risk Act* (SARA);
- the provincial *Water Sustainability Act* (WSA);
- the provincial *Drinking Water Protection Act* (DWPA); and
- the provincial *Local Government Act* (LGA).

Examples of other relevant documents that will influence the project include:

- the Syilx Water Declaration;
- municipal Official Community Plans;
- Regional Growth Strategies; and
- the Sustainable Water Strategy (developed by the Okanagan Water Stewardship Council).

With respect to social context, the study will describe the current and anticipated requirements and societal expectations related to participation in decision-making, particularly on projects involving public funds and public assets. In addition to all levels of government (from Indigenous to local), a broad range of local stakeholders will need to be engaged in the project. These stakeholders include individuals, property owners, private business and business organizations, institutions (including health and educational institutions), and environmental groups. This study will inform the community engagement program.

Deliverables:
The results of the study will be documented in the form of report. It is not expected that there will be significant visual component to the report. However, one or more graphics describing the various governing conditions and contexts for OLRS modernization will be produced to support the community engagement program.

Study 18: Develop a plan for modernizing the OLRS

Study 18 is the final study to be completed within this Plan of Study. It will integrate the outcomes of all previous studies and develop a plan for modernizing the OLRS that reflects the values and priorities of all Okanagan society (Indigenous and non-Indigenous).

Rationale:
A final planning study is needed that builds on the previous scientific and engineering studies, and develops a plan for modernizing the OLRS.

Contribution:
This study will develop a comprehensive, climate-resilient plan for OLRS modernization that reflects the values and desires of all Okanagan society (Indigenous and non-Indigenous). The plan will likely include replacement and upgrades of OLRS infrastructure, changes to the OLRS Operating Plan, and potentially a project to re-naturalize and restore lost aquatic habitat and ecosystem function throughout the mainstem Okanagan valley. The plan produced in Study 18 will also provide the foundation for securing funding to complete the OLRS modernization project.

Overview:
The integration of all previous studies in this final study will lead to an optimal approach to OLRS modernization and re-naturalization and restoration that realizes multiple societal and ecosystem benefits, while minimizing negative impacts and costs. The scope of Study 18 will include:

- Identifying desired future benefits and the changes needed to achieve those benefits;
- Developing criteria for ranking specific activities, and ranking them according to those criteria;
- Additional planning, engineering, and environmental work as needed to refine the work completed in previous studies, including estimating capital and lifecycle costs, assessing environmental and socio-economic impacts and benefits of the preferred activities;
- Assessing the costs of inaction, including OLRS system failure; and
- Developing a recommended OLRS modernization project, including a new Operating Plan, river restoration plan, and implementation strategy.

The outcome of Study 18 will be a final plan. However, other activities and costs will be incurred beyond completion of this plan and before construction takes place, including detailed engineering, land acquisition, detailed cost estimation, and environmental permitting. These costs cannot reliably be estimated at this time.

Methods:
Study 18 will require:

- Extensive involvement of the Syilx people throughout the study, given their history of involvement in the Plan of Study, their leadership on Okanagan environmental issues, and the legal and other contexts for the OLRS modernization project to be outlined in Study 17;
- Thorough integration of the outcomes of all previous studies within this Plan of Study;
- Integration of relevant information from other sources beyond this Plan of Study, such as the Okanagan Lake Responsibility Planning group;
- Extensive collaboration with all levels of government and Okanagan society throughout the study;
- An iterative approach to developing the final plan for OLRS modernization; and

- Possibly additional engineering, planning, and impact assessment work focussed on the preferred activities, beyond the work completed in previous studies within this Plan of Study.

The Syilx Enowkinwixw decision-making process could make a useful contribution to Study 18.

Deliverables:
There will likely be multiple deliverables associated with Study 18, including technical reports, summary reports, graphics, maps, and other visual material in support of the community engagement program.

3.6 Community Engagement

A comprehensive community engagement program will need to be developed and delivered before any significant changes to the OLRS (the Operating Plans, guidelines, or infrastructure) are made.

Rationale:
It will be necessary to engage with the public and specific groups about the need to modernize the river and lake management system, and about the results of the studies described herein, as well as on OLRS modernization planning. In the absence of societal acceptance, it will be difficult to make any significant changes to the system.

Contribution:
Community contribution to, and support of, an OLRS modernization program will provide the social capital necessary for funding and delivering the OLRS modernization project.

Overview:
Information provided by the studies outlined in this Plan of Study will provide a foundation for community acceptance of the need to make changes to the system and make informed discussion and public input possible. The engagement program will need to go beyond one-way information delivery to fully engage and solicit feedback from the community, as a legitimate contribution to the decision-making process. A comprehensive outreach and engagement program will be designed and delivered to all sectors of society that could be affected or that could have an interest in river and lake management. A detailed program should be designed as soon as the present document is complete, and program delivery should begin soon after, giving the public opportunity to be informed and give feedback on the individual studies outlined herein as they are produced.

The program will include a project website, provision of regular updates to the public via conventional media and social media, public and targeted events and open houses, and other elements. Outreach and engagement is an essential ongoing element of OLRS modernization, and will need to continue for the duration of the initiative. During the execution of this Plan of Study, there will be periodic need to engage different specific segments of the community (e.g., agricultural irrigators, or residents living along the Okanagan river channel, or residents living along the shorelines of specific lakes). As the OLRS modernization must be part of the ongoing public discourse of Okanagan water management, each study should include funding for outreach, as they roll out over time. These communication initiatives should be coordinated through a central agency and share their initiatives through the central 'landing spot' for information (the website). As this Plan of Study nears completion, a much broader effort will be launched in Study 18, bringing together information from all of the studies, and highlighting the trade-offs and synergies of different alternative management options. This should be funded separately, as a free-standing initiative. For each of the individual study communication efforts, and also for the final comprehensive outreach program, there should be many opportunities for stakeholder and direct public comment. This could include, but not be limited to, online and in-person facilitated workshops, focus groups, discussion forums, webinars and tabling events. There should be an ongoing investment in producing materials and communications about the OLRS modernization, including newsletters, social media posts, and traditional news media releases.

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APPENDIX A - OPERATING PLANS AND GUIDELINES

Table A-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 to April 30 not less than 50% of the September 15 to October 31 flow.

Table A-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	For 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	For 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	For 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	For 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 A-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. Prior to publication of NHC (2020), the estimated 200-year return period lake level was 343.05 m, and the Flood Construction Level (FCL) for the area around Okanagan Lake was 343.66 m.

Kalamalka Lake is at "full pool" at 391.82 m. Prior to publication of NHC (2020) the estimated 200-year return period lake level was 392.2 m; and the FCL for the area around the lake was 393.2 m. Citations for these key elevations on Okanagan Lake and Kalamalka Lake are provided in AE (2017).