

Arrow Lakes Reservoir Mid-Elevation Scenarios: Scoping Evaluation

March 2018



Prepared for:

Kathy Eichenberger

Ministry of Energy and Mines, Province of British Columbia

and

Heather Matthews

BC Hydro and Power Authority

Co-authored by:

Alan Thomson, Mountain Station Consultants Inc., Nelson, BC.

Greg Utzig, Kutenai Nature Investigations Ltd., Nelson, BC.

Bill Green, Canadian Columbia River Inter-tribal Fisheries Commission, Cranbrook, BC.

Nicole Kapell, Ktunaxa Nation Council, Cranbrook, BC.

Revision 3.1

Disclaimer

This report was prepared by the authors exclusively for the Ministry of Energy and Mines of the Province of British Columbia and BC Hydro and Power Authority. The material in it reflects the authors' best judgment in light of the information available to them at the time of preparation. Any use which a third party makes of this report, or any reliance on or decisions to be made based on it, are the sole responsibility of such third parties. The authors accept no responsibility for damages of any kind, if any, suffered by any third party as a result of decisions made or actions based on this report.

All conclusions, views and opinions expressed in this report are those of the authors unless specifically attributed to others.

Report Revisions

<u>Revision</u>	<u>Date</u>	<u>Description</u>
1.0	Jan. 29 2016	Draft for client review
2.0	May 18, 2016	Draft for CBRAC review
3.0	April 13, 2017	Draft. Includes responses to public comments and Draft Scenario 3
3.1	March 28, 2018	Final Draft. Includes responses to comments received from Okanagan Nation Alliance.

Recommended Citation: Thomson, A., G. Utzig, B. Green and N. Kapell. 2018. Arrow Lakes Reservoir Mid-Elevation Scenarios: Scoping Evaluation. Prepared for the Province of British Columbia and BC Hydro and Power Authority. 109 pgs. plus appendices.

Executive Summary

The Arrow Lakes Reservoir (ALR) is a vital part of the hydroelectricity generation and flood control dam complex on the Columbia River. The reservoir was created when the Hugh L. Keenleyside Dam was commissioned in 1968 as part of the Columbia River Treaty that was ratified and came into effect in 1964. Fifty years later, both Canada and the United States are assessing the Treaty, Treaty dams and examining alternatives to adjust facility operations to reflect current and projected economic, social and environmental values.

This report examines one possible operational alternative for the ALR. The concept in its base form involves changing the ALR from a storage reservoir - where spring runoff is stored and released slowly over the fall and winter months - into a run-of-river operation where flows are passed through the reservoir largely unimpeded during years where the forecasted risk of flood damage is low. The reservoir water elevation would remain at a constant and stable elevation as opposed to the pre-dam hydrograph which fluctuated with the spring freshet. During forecasted high water years, the reservoir would be used to store excess water to reduce flood risk and the reservoir water elevation would rise and fall over a defined period. This report explores on a conceptual level how various key social, environmental and economic interests may be affected if this stable elevation concept becomes operational. The terms of reference for the report did not include an examination of the implications of a stable elevation concept on values or infrastructure above (i.e. Revelstoke and Kinbasket reservoirs) or below (i.e. lower Columbia R.) the ALR.

The report scopes the implications of implementing an ALR constant elevation operational regime by analyzing existing data and reports, and interviewing stakeholders. Two similar stable elevation Scenarios were examined: Scenario 1 holds the ALR water elevation at a constant 1,425 ft. (434.3 m) year round with a small drawdown in the spring and fall periods, and a flood event to full pool once in five years; Scenario 2 holds the ALR water elevation slightly lower at 1,420 ft. (432.8 m) year round with a flood event to full pool once in seven years.

In order to derive the greatest benefit for the most issues from a constant elevation concept, the report authors hypothesize that the constant elevation concept must allow the development and maintenance of a permanent, diverse and vigorous vegetated zone (including trees, shrubs and herbs, as upland, riparian and wetland ecosystems) above a defined elevation of the reservoir. It is further hypothesized that the frequency and duration of vegetation inundation determines vegetation species composition and diversity and survival probability. Based upon analysis of pre-regulation vegetation species spatial and elevation patterns along the Arrow Lakes along with water elevations and flood frequency, it is unlikely that Scenario 1 would allow mature vegetation to establish in the current drawdown zone. Scenario 2, which further limits the current drawdown zone inundation frequency and duration, will more likely encourage mature vegetation establishment and permanence, although mature forest development will take a number of decades. Other ALR values, such as fish access into tributaries, wildlife, dust abatement and other values would then benefit as a result from vegetation establishment.

Most of the assessed value results are either positive or mixed/uncertain when compared to the current ALR operational regime. There are also some neutral and negative aspects of the Scenarios. The successful establishment of riparian vegetation is seen to heavily influence several values in a positive direction, such as erosion, wildlife (ungulates and birds), dust generation, archaeological sites, and fish access into tributaries. Scenario 2 encourages a more robust and permanent mature riparian vegetation community when compared to Scenario 1. Vegetated

reservoir banks and shorelines are less prone to wind and wave erosion, and dust generation above the constant elevation would be reduced, more so with Scenario 2. Terrestrial wildlife habitats would increase, notably ungulate winter range because of improved riparian vegetation. Archaeological sites above the base elevation would be better protected from wind and wave erosion and conceal artifacts from pothunters due to establishment of riparian vegetation, more so for Scenario 2. However, since vegetation would not establish within a few feet of the constant elevation, archaeological sites within this zone would be severely degraded or completely lost without mitigation measures. Tributary stream banks are expected to stabilize with mature vegetation establishment under Scenario 2, which would aid fish access to upstream spawning habitats.

Some other values not directly associated with riparian vegetation establishment also move in a positive direction. Commercial navigation is improved equally under both Scenarios, and annual power generation at Arrow Lakes Generating Station is expected to be slightly higher under Scenario 1 than annual power generated under the current operational regime. Agricultural opportunities are expected to increase under both Scenarios, more so for Scenario 2. Bird nest flooding, a concern in the Revelstoke Reach and other parts of the reservoir, will decrease for nests above the base constant elevation in non-flood years in both Scenarios. Scenario 2 offers better nest flooding protection over Scenario 1. Herptiles, shorebirds and waterbirds should have better access to wetlands and ponds above the base constant elevation for both Scenarios in non-flood years.

Although there are positive attributes to the scenarios, and in particular Scenario 2, analysis of some values found mixed or uncertain outcomes when compared to the existing ALR operational regime. At the scoping level it is very difficult to evaluate the combined effects of multiple potential changes on fish related values. For both scenarios, most fish related values are uncertain (could be either positive or negative) or mixed, in particular pelagic primary and secondary productivity, kokanee biomass, aquatic productivity values in the Revelstoke Reach, and fish migration conditions in the lower reaches of tributaries for Scenario 1. Additional research that includes ALR ecosystem modelling, seasonal analysis of fish population life history requirements in the Revelstoke Reach for current operations and two Scenarios, and a comprehensive assessment of risks to current fish stocks and aquatic ecosystems associated with the two Scenarios is required.

Other values that are mixed include shoreline owners' use of waterfront properties. Both Scenarios offer more certainty and consistency over access to the water since it is not fluctuating as under current conditions. However the water's edge would be farther during summer months and closer during winter months than under current conditions. Under both Scenarios, the frequency and magnitude of mass wasting events are also mixed.

Burbot spawning and incubation success will unlikely be affected by both Scenarios, and ALGS annual power generation is roughly equal to current annual generation under Scenario 2.

The Scenarios also pose challenges to some values. Flood water storage capacity would be reduced almost equally in both Scenarios when compared to current operations, and invasive vegetation species may become established without aggressive revegetation. Shoreline property owners and marina operators would prefer a higher constant elevation than evaluated in this report.

Although this is the most comprehensive report to date on the ALR constant elevation concept, the report only scoped the issues using existing data collected and reports written for other purposes. As such, the report outcomes are directional only and not refined enough to determine magnitude of change. More research and data analysis that is specific to understanding the outcomes of a constant elevation are required before uncertainties can be significantly reduced, starting with a more detailed analysis of historical vegetation patterns and flood events, and vegetation inundation and duration tolerance experiments to determine native riparian vegetation survival requirements and successional rates in the drawdown zone. Understanding mature vegetation tolerances and limitations would inform operational parameters of other values such as flood control.

Lastly, the report analysis is restricted to the ALR footprint and does not analyse upstream or downstream values that would be clearly affected if a constant elevation concept were enacted in the ALR. Recommended future analysis of an ALR constant elevation concept should evaluate additional stable elevations, mimic the pre-regulation natural hydrograph, and examine affected resources and values initially in all sections of the Columbia River upstream of the international border, and later in mid and lower Columbia River sections.

Acknowledgements

The project team owes special thanks to Kathy Eichenberger of the BC Ministry of Energy and Mines and Heather Matthews of BC Hydro for continued guidance and feedback received throughout the project.

The authors would like to acknowledge and thank the following individuals who provided advice and thoughtful feedback concerning the two Scenarios:

Lars Hulstein	Interfor
Dave Kew	Interfor
Debbie and Lorne Imeson	Scotties Marina
Mike Lynn	Zellstoff Celgar
Hugh Watt	NACFOR
Karen Hamling	Mayor of Nakusp
Sue Dyer	Columbia Power Corporation
David de Git	Columbia Power Corporation
Audrey Repin	Columbia Power Corporation
Johnny Strilaeff	Columbia Basin Trust
Francis Maltby	Resident of Revelstoke
Crystal Spicer	Resident of Edgewood
Janet Spicer	Resident of Nakusp
Ed McGuinness	Resident of Burton
Eileen Parkes	Resident of Nelson
Misun Kang	CCRIFC
Will Warnock	CCRIFC
Okanagan Nation Alliance	Okanagan Nation Alliance
Jim Graham	Resident of Revelstoke
Howard May	Resident of Burton
Evan McKenzie	Plant Ecologist
Loni Parker	CSRD Director
Virgil Hawkes	LGL Ltd Environmental Research Associates
Katherine Enns	Delphinium Holdings Inc.
Irene Manley	Ministry of Forests, Lands and Natural Resource Operations
Eva Schindler	Ministry of Forests, Lands and Natural Resource Operations
Steve Arndt	Ministry of Forests, Lands and Natural Resource Operations
Harry van Oort	Cooper Beauchesne and Associates Ltd.
Erik Lees	LEES+Associates
Karen Bray	BC Hydro
Wayne Choquette	Independent consulting archaeologist

Table of Contents

DISCLAIMER	I
EXECUTIVE SUMMARY	II
ACKNOWLEDGEMENTS	V
TABLE OF CONTENTS	VI
TABLE OF FIGURES AND TABLES	VII
ACRONYMS AND TERMINOLOGY	VIII
1. INTRODUCTION	1
1.1 REPORT CONTEXT.....	1
2 HISTORICAL AND CURRENT HYDROLOGICAL REGIME	3
2.1 HISTORICAL HYDROLOGICAL REGIME.....	3
2.2 CURRENT HYDROLOGICAL REGIME.....	3
3 CONSTANT MID-ELEVATION SCENARIOS	4
3.1 DEVELOPMENT OF TWO SCENARIOS.....	5
3.2 DEVELOPMENT OF SCENARIO 2.....	7
3.3 BC HYDRO ALTERNATIVES 7TT AND 8TT	9
4 SCENARIOS ANALYSIS AND DISCUSSION.....	11
4.1 INTRODUCTION	11
4.2 VEGETATION AND WILDLIFE	11
4.3 EROSION	28
4.4 FISHERIES AND AQUATIC RESOURCES	34
4.5 ARCHAEOLOGY	58
4.6 RECREATION.....	62
4.7 COMMERCIAL NAVIGATION AND OPERATIONS	67
4.8 AGRICULTURE.....	70
4.9 POWER GENERATION - ARROW LAKES GENERATING STATION	73
4.10 FLOOD CONTROL.....	78
5 SCENARIO 1 AND 2 ASSESSMENT SUMMARY AND TRADEOFFS	95
6 RECOMMENDED ARROW LAKES RESERVOIR OPERATIONS EVALUATION CRITERIA FOR FUTURE OPERATIONS MODELLING	99
7 REFERENCES	101
APPENDIX 1: NUMBER OF DAYS UPPER ARROW LAKE WAS ABOVE WATER ELEVATIONS FOR PRE-REGULATION PERIOD 1922- 1967	110
APPENDIX 2: TABLE OF LISTED BIRD SPECIES OF POTENTIAL RELEVANCE TO CHANGES IN THE OPERATION OF THE ARROW LAKES RESERVOIR AS OF JANUARY 2017 (INFORMATION SUPPLIED BY ENVIRONMENT AND CLIMATE CHANGE CANADA). 111	
APPENDIX 3: RESPONSES TO COMMENTS RECEIVED BY THE PROVINCE ON THE ARROW LAKES RESERVOIR MID ELEVATION SCENARIOS – SCOPING EVALUATION REPORT – MARCH 2018.....	114
APPENDIX 4: ARROW LAKES RESERVOIR MID-ELEVATION SCENARIOS: SCOPING EVALUATION - SCENARIO 3 DRAFT	148

Table of Figures and Tables

FIGURE 1: MAP OF ARROW LAKES RESERVOIR	2
FIGURE 2: REVELSTOKE REACH PRE-REGULATION LOOKING SOUTH TOWARDS UPPER ARROW LAKES.	3
FIGURE 3: PRE AND POST-REGULATION HYDROGRAPH OF THE ARROW LAKES.	4
FIGURE 4: HYDROGRAPHS OF TWO SCENARIOS WITH PRE AND POST ALR REGULATION AVERAGE WATER ELEVATIONS	7
FIGURE 5: COLUMBIA RIVER TOPOGRAPHICAL MAP SURVEYED IN LATE 1940S SHOWING NORTH END OF UPPER ARROW LAKE VEGETATION TYPES AND EXTENT PRE-REGULATION (CDMTS 1946-1957).	8
FIGURE 6: VEGETATION CROSS SECTION IN DRAWDOWN ZONE, LOWER REVELSTOKE REACH. JULY 13, 2015. ALR ELEVATION 1,422 FT. (433.4 M.) NOTE THAT SPORADIC OCCURRENCES SHRUBS AND SMALL TREES ARE LIMITED TO THE HIGHEST ELEVATION JUST BELOW FULL POOL.	15
FIGURE 7: HERON IN CARTIER BAY, REVELSTOKE REACH. JULY 13, 2015.	23
FIGURE 8: BANK EROSION, REVELSTOKE REACH. JULY 13, 2015.	29
FIGURE 9: BANK SLUMPING AND LOSS OF AGRICULTURAL LAND IN THE NARROWS (PHOTO CREDIT: C. SPICER)	32
FIGURE 10: CARIBOO CREEK AT CONFLUENCE WITH ALR; JULY 14, 2015.	38
FIGURE 11: MEAN, MAXIMUM AND MINIMUM MONTHLY DISCHARGES FOR DEER CREEK (LOWER ARROW RESERVOIR TRIBUTARY) AND KUSKANUX CREEK (UPPER ARROW RESERVOIR TRIBUTARY)	39
FIGURE 12: SHORE BASED RECREATIONIST AT McDONALD PROVINCIAL PARK, ALR. JULY 14, 2016. ALR WATER ELEVATION 1,422 FT. (433.6 M.)	64
FIGURE 13: SCOTTIES MARINA, ALR. JULY 21, 2015. ALR WATER LEVEL 1,420 FT. (432.8 M.)	65
FIGURE 14: INTERFOR LOG SORT AND DUMP AT HALFWAY CREEK, ALR. JULY 13, 2015.	68
FIGURE 15: INTERFOR TUG BOAT IN THE NARROWS. JULY 14, 2015.	69
FIGURE 16: AREA WITH AGRICULTURAL POTENTIAL IN THE REVELSTOKE REACH. JULY 13, 2015. ALR WATER ELEVATION 1,422 FT. (433.4 M.)	70
FIGURE 17: REVELSTOKE REACH LOCATIONS OF PRE-DAM AGRICULTURAL ACTIVITIES ABOVE 1,417 FT. (432 M) PRIOR TO DAM CONSTRUCTION (RED INFILL).	72
FIGURE 18: ARROW LAKES GENERATING STATION (LEFT) AND HUGH KEENLEYSIDE DAM (RIGHT). MAY 8, 2015.	74
FIGURE 19: ACTUAL AND PROJECTED AVERAGE ALGS GENERATION – YEARS 2002-2013 AND SCENARIOS 1 & 2	76
FIGURE 20: ARROW MINIMUM DRAFT ELEVATION AND STORAGE CAPACITY 1995-2013	80
FIGURE 21: MAXIMUM MONTHLY ALR DRAWDOWN RATE FOR SCENARIOS AND HIGH DRAWDOWN RATE YEARS.....	81
TABLE 1: COMPARISON OF TWO SCENARIOS.....	6
TABLE 2: INUNDATION LEVELS, DURATION (DAYS) AND DEPTHS (M) FOR THE 20-YEAR PERIOD FROM 1995 TO 2014; MEAN, MIN, MAX OF DAYS ARE OF THE YEARS WITH INUNDATION.	13
TABLE 3: OBSERVATIONS OF AQUATIC AND FISHERIES PRODUCTIVITY CONSEQUENCES OF RIVERINE VS. RESERVOIR HABITAT CONDITIONS.	46
TABLE 4: SUMMARY OF POTENTIAL EFFECTS OF STABLE ARROW SCENARIOS ON FISH AND AQUATIC ECOSYSTEMS	56
TABLE 5: COMPARISON OF EXISTING VERSUS PROJECTED ALGS DAILY GENERATION FOR 1,420 AND 1,425 FT.....	77
TABLE 6: SUMMARY OF CURRENT ALR OPERATIONS AND SCENARIO OPERATIONAL PARAMETERS.....	83
TABLE 7: SUMMARY OF CURRENT ALR OPERATIONS AND SCENARIO ASSESSMENT ON ISSUES AND VALUES	84
TABLE 8: SUMMARY EVALUATION OF SCENARIO IMPACTS COMPARED WITH CURRENT ALR OPERATIONS.	97

Acronyms and Terminology

ALGS	Arrow Lakes Generating Station
ALR	Arrow Lakes Reservoir
AOP	Annual Operating Plan
CBT	Columbia Basin Trust
cms	cubic metres per second
CPC	Columbia Power Corporation
DDZ	Drawdown Zone
DOP	Detailed Operating Plan
ft	feet
Ha	hectares
HLK	Hugh L. Keenleyside dam
Maf	Million acre-ft
m ³ /s	cubic metres per second
S1	Scenario 1
S2	Scenario 2
VCT	Vegetation Community Types
WUP	Water Use Plan

Terminology

Significant – used in the colloquial sense, meaning “noteworthy, of considerable amount or effect or importance”; where “statistical” significance is indicated it is specifically stated as such.

1. Introduction

1.1 Report Context

The Arrow Lakes Reservoir was created when the Hugh L. Keenleyside (HLK) dam construction was completed in October 1968. The dam is located on the Columbia River mainstem immediately upstream of the City of Castlegar in British Columbia (see Figure 1). The HLK dam is one of three Canadian Columbia River Treaty dams that impound water primarily for enhanced flood control and power generation purposes. The dam raised the water level in the Arrow Lakes valley upwards of 38 feet (11.6 m.) (pre – dam peak to post- dam peak) and created one water body that extends, at high water, from the HLK dam 232 km north to Revelstoke BC. Before the dam was installed, the footprint occupied by the reservoir was comprised of 2 lakes - Lower Arrow and Upper Arrow Lakes - separated by a 30 km long riverine section known as the Narrows. A second riverine section, known as the Revelstoke Reach or Flats extended approximately 42 km from Revelstoke downstream to the Arrowhead area (about 4 km north of the Shelter Bay ferry terminal). A third riverine section extended about 7 km in the Lower Arrow Lake from the Syringa Creek fan to the location of the HLK dam.

Numerous studies and reports document and describe the change in social, ecological and economic environments that resulted from the Arrow valley being flooded and subjected to annual fluctuations of the reservoir water levels (e.g. Utzig and Schmidt 2011; Penfold 2012). The impacts were and remain significant as documented in Penfold (2012). BC Hydro, the entity that operates and manages the reservoir in accordance with the terms of the Columbia River Treaty and in cooperation with the CRT U.S. entity, has initiated and participates in numerous compensation and mitigation programs to address the community and environmental impacts with mixed success and acceptance by valley residents (Local Governments Committee 2013). Many Arrow valley residents have long noted the numerous problems that are directly attributed to the fluctuating reservoir water level (British Columbia 2014) and some residents and First Nations have advocated for a more stable reservoir water regime as a method to resolve these problems and to revitalize the valley's ecological, social, cultural and economic conditions.

A more stable ALR operational regime has been studied and/or modelled several times over the last 5 years with varying degrees of sophistication. Earlier studies modeled the entire Columbia River hydroelectric system assuming an ALR stable full or near full pool (Canadian and United States Entities 2010; Bonneville Power Administration 2012). The most comprehensive study to date was conducted by BC Hydro (BC Hydro 2013, 2013b) that examined multiple scenarios for the Canadian sections of the Columbia River that included a range of mid and high constant elevation scenarios for the ALR. The BC Hydro study is described in more detail in Section 3.3 below. The study found that the various constant elevation scenarios were somewhat beneficial in some areas evaluated, especially for a constant mid elevation scenario that was identified and scoped by Thomson (2013).

This report expands on previous studies that examined a stabilized ALR, particularly the BC Hydro study, and discusses the main issues associated with two distinct constant elevation scenarios in more detail while making recommendations as to further study.

This report only examines potential effects of stabilized, mid-elevation Arrow reservoir between the Revelstoke and Hugh Keenleyside dams. The authors recognize that restricting the analysis to the ALR footprint is a considerable study limitation and that upstream (Kinbasket reservoir) and downstream (transboundary, mid and lower Columbia reaches) effects of these scenarios will

occur. Scoping of upstream and downstream effects were determined to be out of scope for this initial study phase but will be considered in future research and reporting phases.

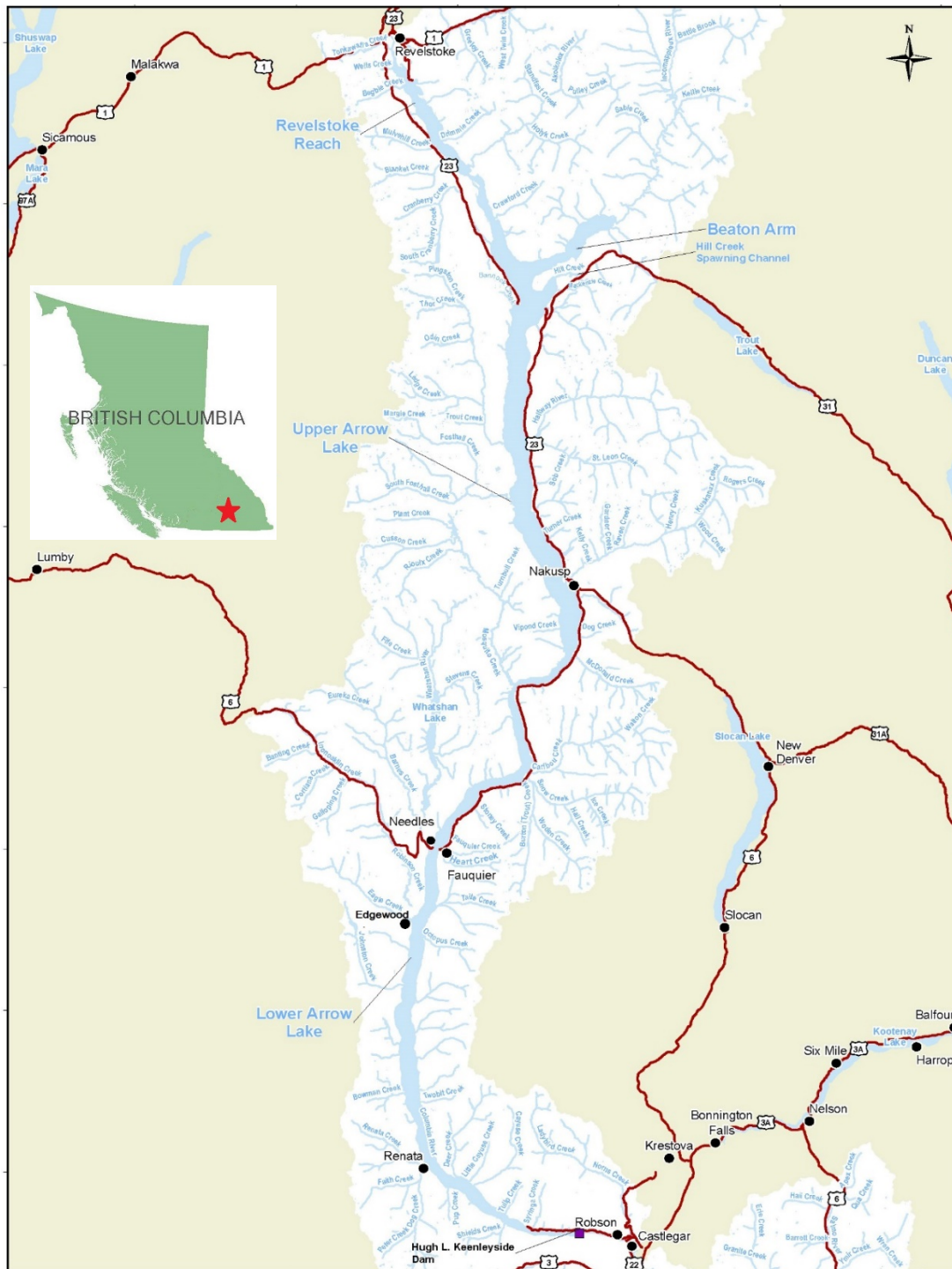


Figure 1: Map of Arrow Lakes Reservoir



Photo courtesy of Arrow Lakes Historical Society.

Figure 2: Revelstoke Reach pre-regulation looking south towards Upper Arrow Lakes.

2 Historical and Current Hydrological Regime

2.1 Historical hydrological regime

As described in Section 1, two lakes and three riverine sections that existed pre-regulation are now occupied by the Arrow reservoir footprint. Before the CRT, the Canadian section of the Columbia River was free flowing and unimpeded from the headwaters in the Canal Flats area to the international border south of Trail, BC. Since the Arrow Lakes hydrograph is snow and glacier-melt driven, high freshet flows and water levels occurred in the spring with a rapid rise of upwards of 22 feet on average over 2 months, typically May 1 – June 30, with a slow decline back to the low stable elevation by late fall or early winter (see Figure 3). Although the maximum and minimum water levels changed year over year due to snow pack depth, spring melt timing and rainfall intensity, the seasonal pattern was very consistent year over year. The base lake elevation was approximately 1,377 feet (420 m) and early summer peaks ranged between 1,393 ft. (424.5 m) and 1,409 ft. (429.5 m). Flooding of private property and riparian areas around the Arrow Lakes and in the Narrows was not uncommon.

2.2 Current hydrological regime

After the 1968 commissioning of Hugh L. Keenleyside dam, the ALR hydrograph changed dramatically (see Figure 3). Spring freshet water that once passed on downstream of the Arrow

Lakes now remains impounded behind the dam and in most years water is slowly released over the fall and winter months to a minimum elevation in the early spring. The maximum annual reservoir elevation is typically reached in July or August, slightly later than the pre-impoundment condition. The decline in reservoir elevation is much slower than occurred historically, although the lowest reservoir/lake elevation typically occurs in mid- to late April both pre- and post-impoundment. Overall, reservoir elevations are higher at all times of year and have a greater average range than that which occurred in the pre-impoundment era: 1,377 ft. (420 m) to 1,398 ft. (426.1 m) pre-impoundment versus 1,396 ft. (425.5 m) to 1,437 ft. (438.0 m) post-impoundment. Year over year this pattern is repeated, however with much more variation than the pre-dam water elevations as is evident in Figure 3. The terms of the CRT and sub agreements between Canadian and American Entities largely dictate this general pattern that is optimal for downstream flood control and power generation. Many of the issues and impacts associated with the ALR are a result of this transformed hydrological regime, and are discussed throughout this report.

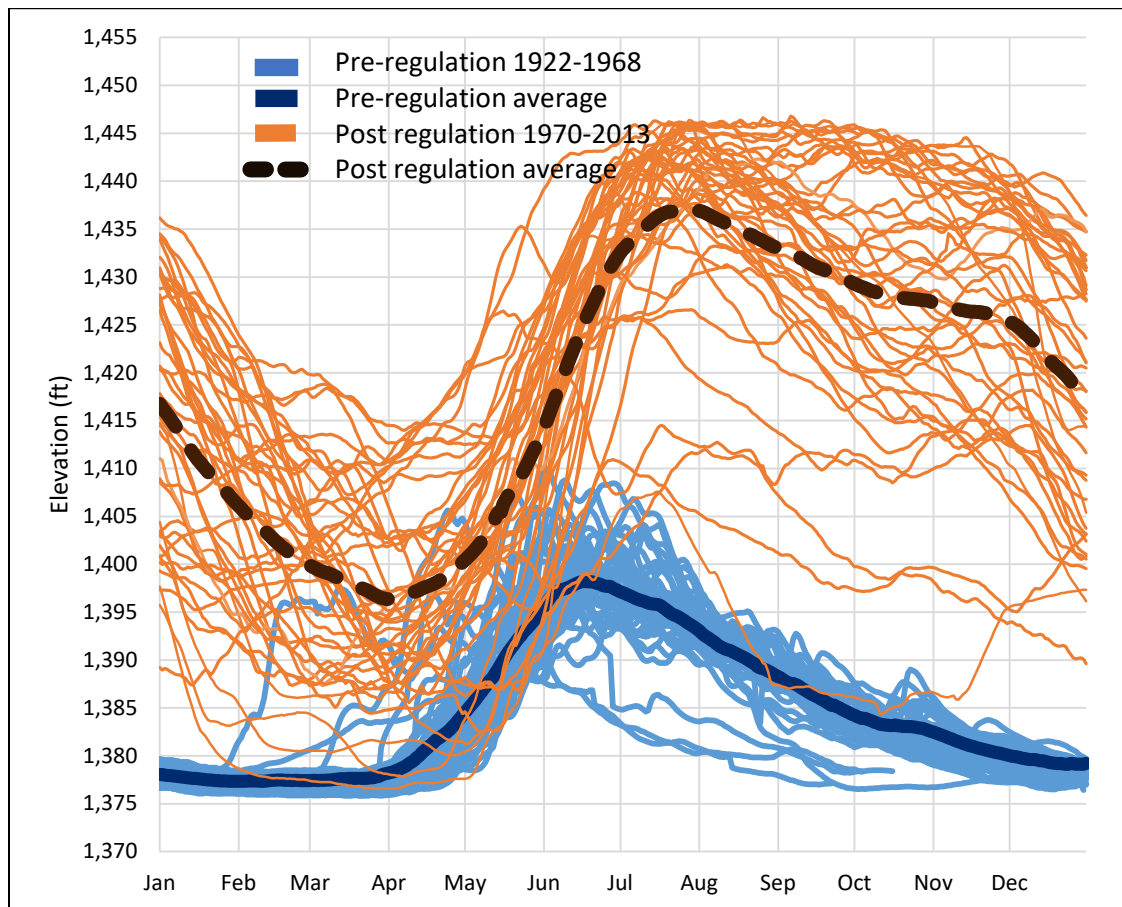


Figure 3: Pre and post-regulation hydrograph of the Arrow Lakes.

3 Constant Mid-Elevation Scenarios

All of the initial scoping exercises on various stabilized ALR Scenarios indicate the concept is worthy of additional detailed analysis, in particular a mid-elevation stable elevation concept. In

order to maximize the benefit of the concept to multiple values (wildlife, fisheries, etc.), the study team concluded that the scenario's hydrological regime must initially encourage re-vegetation of a diversity of communities, including both wetland and perennial woody species in the upper part of the current drawdown zone, and once the vegetation is established, reservoir operations must not kill the vegetation by frequent and prolonged inundation. Multiple vegetation studies have noted that the duration and timing of vegetation inundation is one of the primary limitations to vegetation establishment and continued growth in the drawdown zone, especially for trees and shrubs (see Section 4.2). A reservoir operational regime that allows for establishment and persistence of a variety of riparian zone vegetation communities potentially contributes to numerous other related benefits.

3.1 Development of Two Scenarios

Two Scenarios are evaluated in this report (see Table 1 and Figure 4). Scenario 1 requires that the reservoir is held at a constant elevation of 1,425 ft. (434.3 m) throughout the year 4 out of 5 years on average. The reservoir is drawn down to 1,421 ft. (433.1 m) for a short period in the spring and fall. To allow for high inflow years – typically flows in the top 10-20th percentile - that would result in downstream flooding if not contained, for 1 in 5 years the reservoir will fill to full pool 1,444 ft. (440.1 m) during freshet. Water is later released over 2 months over the summer and early fall periods. Scenario 1 is identical to BC Hydro's Alternative 8TT (BC Hydro 2013b) for the Arrow Lakes section of the alternative¹. It is also similar to BC Hydro's Alternative 7TT but with the added 1 in 5 year flood event.

Scenario 2 requires that the reservoir is held at a constant elevation of 1,420 ft. (432.8 m) throughout the year 6 out of 7 years on average. To allow for high inflow years that would result in downstream flooding if not contained, for 1 year in 7 the reservoir can fill up to full pool 1,444 ft. (440.1 m) during freshet. The water is released quickly from full pool to 1,430 ft. (435.9 m) and then more slowly from 1,430 ft. to 1,420 ft. (435.9 m to 432.8 m). A defining aspect of Scenario 2 is that the drawdown zone above 1,430 ft. (435.9 m) is never inundated for greater than 35 days for reasons outlined below.

For both Scenarios, maintaining a constant elevation – one that does not vary or fluctuate at all over the short term – is not considered operationally realistic. Minor fluctuations of a few feet over the short term (i.e. days) are considered reasonable and do not significantly alter the outcome of this analysis as long as the constant elevation value is maintained over the longer term.

¹ Alternative 8TT examined both Kinbasket and Arrow Lakes Reservoirs.

Table 1: Comparison of Two Scenarios.

Description	Scenario 1	Scenario 2
Base constant elevation	1,425 ft. (434.3 m)	1,420 ft. (432.8 m)
Maximum flood elevation	1,444 ft. (440.1 m)	1,444 ft. (440.1 m)
Flood frequency ¹	1 in 5 years	1 in 7 years
Flood water inundation period	5 months above base elevation	5.5 months above base elevation
Estimated area between base elevation and 1,444 ft. (440.1 m)	Approx. 4,100 ha (10,000 acres) ²	Approx. 5,000 ha (12,000 acres) ²
Comment	Same as BC Hydro Alternative 8TT for the ALR part of the analysis	Drawdown zone above 1,430 ft. (435.9 m) never inundated for greater than 35 days; between 1430 ft. (435.9 m) and 1444 ft. (440.1) approx. area is 2,400 ha (6,000 acres) ²

For both Scenarios, the evaluation assumes that the reservoir will fill completely to full pool (1,444 ft.) once every 5 years (Scenario 1) or 7 years (Scenario 2), and that these years would be high inflow/flood years. This does not mean that it will flood every 5 or 7 years exactly, but that it will average 1 in 5 or 1 in 7 over the long term (e.g. - a century). Depending on annual precipitation and snowmelt conditions, the reservoir could fill 2 out of 3 years, and then not fill for 10 or 15 years, and still average 1 in 5 or 1 in 7 years.

² Area estimates are based on available bathymetry/ topography of the drawdown zone and have low reliability; data from elevation/ water storage relationships suggest all the areas could be as much as 50% greater than those from the bathymetry/ topography data.

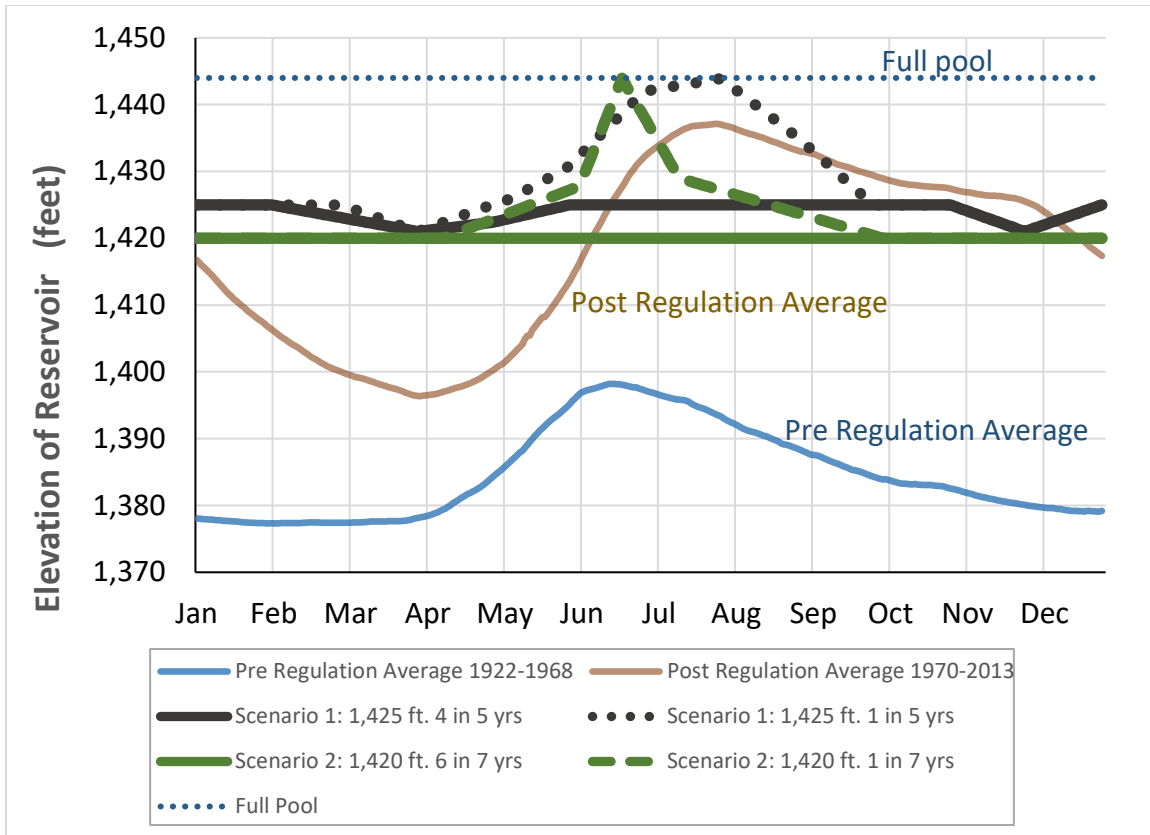


Figure 4: Hydrographs of Two Scenarios with Pre and Post ALR Regulation Average Water Elevations

3.2 Development of Scenario 2

In order to assess the potential benefits of modifying the management regime for Arrow Reservoir, it is necessary to estimate which areas have the potential to re-vegetate following a modification in the reservoir management regime. Two of the key factors that affect re-vegetation within the reservoir footprint are frequency and duration of flooding. One way to assess the potential impacts of those factors on vegetation is to examine the historic presence of vegetation around Upper Arrow Lake in relation to flooding frequency and duration. Two main sources of data for such an analysis are:

- 1/ Upper Arrow Lake and Arrow Reservoir elevation data from Nakusp (Water Survey of Canada 2015) – before and after the Hugh Keenleyside Dam flooding (1922 to 1967, 46 years of pre-dam, and 1970 to 2012, 43 years of post-dam); and
- 2/ Pre-dam vegetation mapping that shows the distribution of vegetation in relation to those elevations (Canada Department of Mines and Technical Surveys 1946-57).

Pre-dam vegetation mapping (CDMTS 1946-1957) shows fully developed coniferous and deciduous forests down to an elevation of 1,400 ft. (426.7 m) around Upper Arrow Lake under natural conditions (see Figure 5). In some areas of relatively flat shoreline (<~5% slope; e.g. between Cranberry Creek and Columbia River confluence with Upper Arrow Lake), “scrub”, marshes and grasslands extend down to approx. 1390 ft. (423.7 m), indicating their greater flood

tolerance. Below those elevations, the mapping shows unvegetated shorelines and gravel bars all around the lake. In areas of steep shoreline (>~80% slope) the mapping shows unvegetated eroding slopes above 1,400 ft. (426.7 m.)

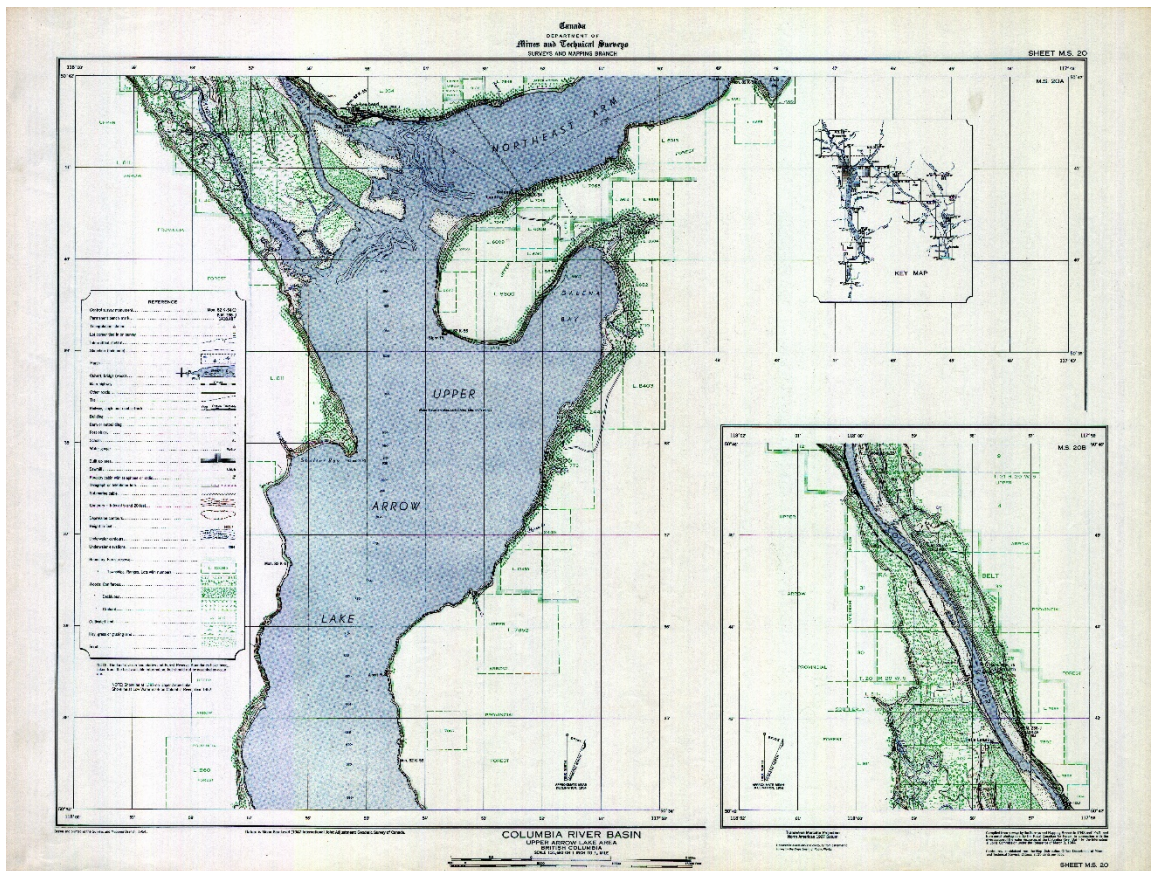


Figure 5: Columbia River topographical map surveyed in late 1940s showing north end of Upper Arrow Lake vegetation types and extent pre-regulation (CDMTS 1946-1957).

The elevation data shows that some flooding occurred above 1,400 ft. (426.7 m.) in 26 of the 46 years of data. The duration of flooding ranged from 1 day to 43 days. Depth of flooding ranged from a few inches to almost 10 feet (0.05 – 3 m.).

Initiation date of flooding (above 1,400 ft. or 426.7 m.) ranged from May 22 to July 2, with most years falling between May 30 and June 17. The end of flooding ranged from June 5 to July 26, with most years falling between June 17 and July 7. The peaks ranged from early June to late July, but generally occurred in mid to late June. Of the 26 flood years, the duration of flooding above 1,400 ft. (426.7 m.) was up to 43 days one year, between 30 and 35 days in 6 years, and more than 20 days in 11 years.

Based on an examination of vegetation occurrence and the frequency and duration of flooding on Upper Arrow Lake prior to 1968, it appears that the following flooding regimes may be compatible with development of natural floodplain vegetation communities, including forests, wetlands and shrubs:

- flooding of up to 35 days in 1 out of 7 years; and/or

- flooding of up to 20 days in 1 out of 5 years.

These conclusions form the basis for the formulation of Scenario 2. The rates of lake pre-dam and reservoir post-dam storage and evacuation were also examined to ensure that it was feasible to fill the reservoir and evacuate it above 1,430 ft. (435.9 m) within the 35 days proposed in Scenario 2. Based on an assessment³ of post-dam storage and evacuation rates it appears to be possible to meet those requirements, although it would require infilling and evacuation at rates close to the maximum achieved in the past. This will likely result in high flows downstream of HLK dam during post-peak evacuation in the 1 in 7 year flood years, however in some years there may be opportunities to moderate these to some extent with changes in the operations of Mica and/or the Revelstoke dams.

A similar analysis of Kootenay Lake elevations at Queens Bay from 1932 to 1966 (Water Survey of Canada 2015) – before the Duncan and Libby Dams (1967, 1975), but subsequent to construction the Corra Linn Dam (1932) – combined with coincident vegetation mapping of the floodplains at the north and south ends of Kootenay Lake (CDMTS 1945, 1946) was also undertaken. The Kootenay Lake analysis results were less decisive, but indicated a similar range of riparian forest flooding tolerance. Only a few scattered cottonwoods were mapped below 1,755 ft. (534.9 m), the average high water level during that period. Cottonwood forest stands occurred sporadically between 1,755 and 1,765 ft., (538.0 m) and were more widespread above that elevation. Marshes and “scrub” vegetation (i.e. shrubs) were mapped extensively between 1,745 and 1,760 ft. (530.4 and 535.0 m). During the 35 years of record, flooding above 1,755 ft. only exceeded 30 days 8 times (1 in 4-5 years) and 35 days 4 times (1 in 9 years), above 1,756 ft. (535.2 m) for 35 days twice (1 in 18 years), and above 1,757 ft. (535.5 m) never for 35 days. Therefore, the distribution of cottonwood stands surrounding historic Kootenay Lake confirms that limiting flooding to a maximum of 35 days once in seven years under Scenario 2 should allow cottonwood stands to develop between 1,430 ft. (435.9 m) and 1,444 ft. (440.1 m).

3.3 BC Hydro Alternatives 7TT and 8TT

In the fall of 2013 BC Hydro completed a modelling exercise of the BC section of the Columbia River to evaluate how environmental and social interests would be affected in various hypothetical CRT scenarios (BC Hydro 2013a). The model predictions, including for power generation and revenues, were compared with existing facility operations and interests.

Two scenarios – Alternative 7TT (Arrow Reservoir stabilized at mid elevation) and Alternative 8TT (Ecosystem Function) - modelled by BC Hydro (BC Hydro 2013b) are similar in several respects to the two scenarios examined in this report such that the results warrant discussion.

Alternative 7TT modelled the ALR held at constant elevations of 1,420 ft. (432.8 m) and 1,425 ft. (434.3 m) throughout the year, with a small water level variation allowance of 5 ft. (1.5 m) but no allowance for a flood storage operation up to full pool. The following is a summary of the modelling outcomes in the 2013 BC Hydro report that used existing Performance Measures developed during the WUP process, and later adapted for evaluation of the NTSA and CRT Technical review for a reservoir that fluctuates throughout the drawdown zone. The Performance

³ Although of less relevance to reservoir conditions, an assessment of upper Arrow Lake post-freshet water levels indicates that lake levels occasionally dropped equally rapidly under natural conditions.

Measures are acknowledged by BC Hydro as not necessarily capturing the changes in interests over time for a stabilized reservoir:

- Vegetation and wildlife (nesting and migratory birds) benefitted from lower constant water elevations in the Revelstoke Reach. An additional 1,373 ha and 481 ha of area that supports vegetation becomes available for constant elevations of 1,420 ft. (432.8 m) and 1,425 ft. (434.3 m) respectively when compared to existing ALR operations and typical average water level.
- Lower ALR water levels translates into greater length of functional large riverine habitat available throughout the year in the Revelstoke Reach. Approximately 2 and 4 additional kilometers of large riverine habitat are gained on average over the Treaty Continue reference for 1,425 ft. (434.3 m.) and 1,420 ft. (432.8 m.) constant elevations respectively and are considered insignificant or marginal gains. Under current operations, the river length fluctuates from 0 km long during high water to approximately 50 km long during drawdown as the ALR water level fluctuates seasonally.
- Results for recreational users are mixed. Shore based recreational users prefer water elevations in the 1,425 – 1,435 ft. (434.3 – 437.4 m) range, whereas boaters prefer water elevations in the 1,435 – 1,444 ft. (437.4 – 440.1 m) range. The 1,425 ft. (434.3 m) constant elevation Scenario just meets the shore based recreational users' requirements; the 1,420 ft. (432.8 m) constant elevation Scenario misses the requirement completely. Neither Scenario meets the recreational boaters' requirements. However, boaters may find a stable reservoir operation more aesthetically pleasing as vegetation would likely establish on the foreshore where sand, mud or cobble currently exists.
- Worse tributary access for spawning kokanee although the assessment acknowledges that tributary access would improve over time under a constant elevation scenario as tributary sediment blockages eroded or were physically removed.
- Reduced protection of archaeological sites due to increased site erosion, although the analysis did recognize this outcome is questionable.
- Reduced (worse) aquatic productivity as lower water elevation results in a reduced water residence time in the epilimnion (surface water layer, warmer in summer). This is anticipated to result in reduced nutrient retention and utilization. However, the analysis recognized that a more stable water elevation may result in increased littoral productivity and aquatic vegetation growth in shallow areas around the reservoir perimeter. This may only partially counter balance lower retention of nutrients.
- Commercial navigation would be better at a stable elevation of 1,425 ft. (434.3 m.) versus 1,420 ft. (432.8 m.) which is considered the minimum elevation for unimpeded log towing through the Narrows.

Alternative 8TT – the Ecosystem Function Scenario – models both Arrow Lakes and Kinbasket reservoirs and considers a more complex operational regime than taken for Alternative 7TT. However, the Arrow reservoir component of Alternative 8TT is very similar to scenario 1 that is evaluated here. In Alternative 8TT the ALR is held at a constant elevation of 1,425 ft. (434.3 m.) with provision to flood in 1 in 5 years to full pool. For most issues within the Arrow reservoir the response is very similar to Alternative 7TT.

4 Scenarios Analysis and Discussion

4.1 Introduction

Issues that were considered in the analysis of the two Scenarios are analyzed and discussed below. For each issue, relevant literature and data taken from studies of the ALR are reviewed, assessed and discussed as to how they inform possible outcomes of both constant elevation Scenarios. Interviews were conducted with individuals who are knowledgeable with ALR operations and how a constant elevation Scenario may impact the issues familiar to them or their business. Lastly, recommendations to increase understanding of Scenarios consequences and areas of additional research for each issue are made.

It was beyond the scope of this project to consider the potential impacts of climate change on the scenarios themselves, or effects on the potential scenario benefits or impacts. With regard to local species and ecosystem adaptation to climate change, anything that reduces stress on those species and ecosystems will increase their resilience to climate change, but it was beyond the scope of this project to directly address changes in resilience for individual species or ecosystems. Due to the complexity of potential responses within the overall Columbia River system of dams to the anticipated increase in occurrences of climatic extremes (e.g. flooding, drought), exploration of how these scenarios would interact with those occurrences can only be addressed in the context of future system wide modeling.

4.2 Vegetation and Wildlife⁴

4.2.1 Vegetation and Wildlife Habitat Losses due to Reservoir Inundation

To better understand the significance of vegetation and wildlife habitat benefits of the Scenarios it is useful to understand what vegetation types and habitats are most impacted by present reservoir operations. Prior to construction of the Hugh Keenleyside dam, and the subsequent flooding of the Arrow Lakes Valley, limited information on the vegetation and wildlife habitat was collected (Utzig and Schmidt 2011). In 2005 the Columbia Basin Fish and Wildlife Compensation program undertook to update the understanding of the footprint impacts on the Canadian Columbia River dams and reservoirs. As a part of the project, pre-dam aerial photographs and broad forest cover maps were analyzed to create a map of aquatic and terrestrial habitats that existed prior to the flooding of the Arrow Lakes reservoir, and further analyses evaluated the impacts of losses of those habitats on relevant fish and wildlife species. Information from those studies are summarized in the report *Dam Footprint Impact Summary: BC Hydro Dams in the Columbia Basin* (Utzig and Schmidt 2011).

Taking into account the proportion of area flooded and rarity, forested wetlands/ very wet forests and gravel bars were all identified as having a very high habitat loss risk rating due to the reservoir footprint. Open wetlands, cottonwood stands, other wet forests, shallow water ponds

⁴ Primary author: Greg Utzig

and lake/ river shoreline habitats were assigned a high habitat loss risk rating (Manley and Krebs 2010).

The dam impacts study also identified a number of wildlife species that have been negatively impacted due to loss of key habitats, mainly species associated with wetland, riparian and shoreline habitats. Very high and high species impact ratings were assigned to numerous bird species, including a number of waterbirds (including migratory waterfowl), waders, shorebirds, aerial insectivores and a few songbirds. A few species of herptiles, including frogs, toads and turtles, were also given high to very high ratings. Mammals receiving high to very high impact ratings included various species of bats, fisher and moose.

Losses of aquatic habitats were also summarized in the dam impacts study. Large low elevation low gradient rivers (stream order 8-9, <650 m elevation, <7% gradients) were assigned very high and high habitat loss ratings. These types of habitats have suffered 50% or more losses due to the dams and reservoirs on the Columbia system in BC, and 92% loss in the Arrow Reservoir reference area. As well, flooding of the Arrow Reservoir resulted in the loss of 36% of the small low elevation low gradient streams, along with 1.02 km² of shallow ponds (Thorley 2008).

The dam impacts study also examined alterations to gross primary productivity (GPP) due to the change from complex upland terrestrial, riparian, wetland and river/ stream aquatic ecosystems to a reservoir-dominated lotic ecosystem, with minor simplified drawdown vegetation types. The Arrow Lakes reservoir footprint is estimated to have suffered a loss of about 90% in GPP (a loss of approx. 125,000 tons of carbon per year). Although the widespread occurrence of reed canary grass in the Revelstoke Reach appears to provide extensive vegetative inputs, when examined in detail by Moody et.al (2007), it was found to have significantly reduced productivity and habitat values when compared to the natural riparian/ floodplain, wetland and littoral habitats that it replaced.

The current littoral zone of the major reservoirs owing to wide water level fluctuations is basically non-functional; desiccation and/or inundation keeps communities in a perpetual state of early succession. The biofilm, periphyton, or wetland plant communities that become established within the reservoir wetted littoral are removed annually or sometimes semi-annually by the cycle of flooding and/or drawdown. It comes as no surprise that heterotrophic production is much lower in the present post-dam setting, since the drawdown zones (shorelines, littoral slopes, and flats) of most reservoirs in the basin are mostly bare and devoid of soil or vegetation, (i.e. no carbon).(Moody et al. 2007, p.99).

4.2.2 Vegetation

4.2.2.1 Literature Review

The broad forest cover maps published in the 1957 (CDMTS 1946-57), when combined with the daily Upper Arrow Lake and reservoir elevation data at Nakusp from the Water Survey of Canada (WSC 2015) provide a record of flooding in relation to natural vegetation establishment for historical Upper Arrow Lake. This data provides information on the potential tolerance of natural vegetation to frequency, duration and depth of inundation under the natural flooding cycles of Upper Arrow Lake. That information was used to assess whether conditions that would result from the proposed operational Scenarios may be tolerated by natural ecosystems, and whether those ecosystems may re-establish in the drawdown zone (see Section 3.2).

Analysis was also undertaken to investigate whether any portion of the drawdown zone under the present operational regime over the past 20 years met the inundation criteria limits required for natural ecosystem establishment that were estimated from examination of pre-dam flooding (see Table 2). The data illustrated in Gantt chart format in Appendix 1 indicate that only the extreme upper portion of the drawdown zone meet the criteria under present operations – above approximately 1,442 ft. (439.5 m). Even at an elevation of 1,440 ft. (439 m) inundation exceeded the maximum 35 days of the growing season in 4 years out of 20. As the following sections will show, this is consistent with the general lack of fully developed tree and shrub communities below that elevation.

Table 2: Inundation levels, duration (days) and depths (m) for the 20-year period from 1995 to 2014; Mean, min, max of days are of the years with inundation.

Criteria	Elevation							
	>430 m (1,411 ft.)	>433 m (1,421 ft.)	>434 m (1,424 ft.)	>436 m (1,430 ft.)	>437 m (1,434 ft.)	>438 m (1,437 ft.)	>439 m (1,440 ft.)	>440 m (1,444 ft.)
# of years inundation (of 20)	20	19	19	18	17	16	14	2
# Days-mean	251	180	152	112	84	57	30	21
# Days-min	173	56	26	15	19	28	2	14
# Days-max	365	267	239	209	192	133	53	28
Depth(m)-mean	5.2	3.7	3.3	2.2	1.7	1.3	1.0	0.2
Depth(m)-min	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Depth(m)-max	10.5	7.5	6.5	4.5	3.5	2.5	1.5	0.5
# of years >35 days (of 20)	20	19	18	17	16	13	4	0

Vegetation within the Arrow Lakes reservoir drawdown zone, including the Revelstoke Reach has been the subject of numerous studies dating back to the 1990s. The early studies were primarily associated with the dust control program in the Revelstoke Reach (e.g. Carr et al. 1993; Moody 2002). Following the recommendations of the consultative process for BC Hydro's mainstem Columbia River facilities in 2004 and the completion of the Columbia River Project Water Use Plan in 2007, a series of projects were initiated to inventory, monitor and further establish vegetation within the drawdown zone of the ALR. The numerous interim progress and final reports of the projects constitute the bulk of the literature related to vegetation associated with the ALR.

Although the various studies provide significant information on the existing vegetation within and numerous initiatives to further revegetate the reservoir drawdown zone, they provide little direct information on how that vegetation may change with adjustments to the present operating regime. However, the existing information can be used to infer trends that may result from pursuing the two Scenarios being investigated here.

Vegetation Distribution

Following construction of the Hugh Keenleyside Dam in 1968 vegetation cover in the Revelstoke Reach declined steadily to the late 1970s, and then remained relatively steady until the early 1990s (Moody 2002). The majority of vegetation decline occurred in areas of natural forest, forest harvesting areas and agricultural lands. During the 1990s vegetation cover increased significantly in the Revelstoke Reach, although the types of vegetation changed dramatically to species that tolerated repeated inundation (e.g. reed canary grass, sedges and horsetails). The increase in the new vegetation types was mainly due to gradual spread of the species suited to the periodic inundation regime, and in some cases was aided by annual seeding of grasses to combat dust storms. The Arrow Lakes portion of the reservoir likely had the same decline in vegetation, however the 1990s increase was limited to a few stable areas with gentle slopes and conducive substrates.

Recent vegetation surveys have defined 16 Vegetation Community Types (VCTs) in the drawdown zone (Enns and Overholt 2013; Enns et al. 2007). The occurrence and distribution of individual species and VCTs throughout the reservoir are controlled by various environmental factors and species tolerance to those factors, including:

- substrate (texture - related to nutrients, drought, erodibility and stability);
- stability (slope, texture, moisture);
- moisture availability (related to upslope seepage and local water tables);
- physical abrasion (wave action/ scouring, debris pounding);
- disturbance from off-road vehicle use; and
- reservoir inundation (duration, frequency, depth).

Due to significantly more variability in substrates, VCT diversity in the Arrow Lakes portion of the reservoir is greater than the Revelstoke reach. A number of the VCTs are sparsely- or non-vegetated, or controlled by human disturbance (e.g. gravel beaches, rock outcrops, slope failures, etc.). Two VCTs occur primarily where streams or rivers enter the reservoir, and are likely more influenced by stream action, rather than the reservoir (RS – willow stream entry, WR – silverberry river entry). One includes mostly permanent small ponds and wetlands (PO – ponds). The remaining 5 VCTs have significant vegetation cover, and are more directly influenced by reservoir operations.

The most prominent VCT, especially in the Revelstoke Reach, is the reed canary grass⁵ mesic (PC). It is dominated by reed canary grass, but can include minor components of other species,

⁵ Reed canary grass (*Phalaris arundinacea*) is a perennial rhizomatous grass native to North America, with widespread occurrences at lower elevations throughout Southern BC (Anonymous 2013). It was first recorded in B.C. in 1897 and is generally found in wet meadows and along stream banks and lake shores. Introduced cultivars from Europe have likely cross-bred with the native varieties, and these more vigorous hybrids are sometimes classed as invasive (GISD 2017). It prefers fine textured soils and is highly flood tolerant, which likely explains its widespread occurrence in the Revelstoke Reach. It is generally considered of little value for wildlife, and can out-compete other more desirable species, given the right conditions.

occurring mainly on silty sandy gentle terrain. The reed-rill (RR) VCT generally occurs in moist areas and is dominated by wetland species including grasses, mosses, sedges, rushes and reeds. The horsetail lowland (PE) generally occurs on moist silty soils and is dominated by wetland species such as sedges, rushes and reeds. The redtop upland (PA) is dominated by shrubs and several species of grasses and other drought tolerant species, and occurs on gravelly to sandy beaches, often on former forested or farmed soils. The only VCT with significant fully developed trees and shrubs is the cottonwood riparian (CR). It generally occurs on relatively deep and occasionally boulder soils.



Figure 6: Vegetation cross section in drawdown zone, lower Revelstoke Reach. July 13, 2015. ALR elevation 1,422 ft. (433.4 m.) Note that sporadic occurrences shrubs and small trees are limited to the highest elevation just below full pool.

The vegetated VCTs, and many individual species, are generally distributed by elevation band within the drawdown zone (Enns and Overholt 2012, pp.35). Of the VCTs with sufficient occurrence for comparison, the Cottonwood riparian (CR) primarily occurs between 1,442 and 1,444 ft. (439.5 and 440 m), the Reed canary grass mesic (PC) between 1,427 and 1,437 ft. (435 and 438 m), the Reed-rill (RR) between 1,429 and 1,437 ft. (435.5 and 438 m), and the Horsetail lowland (PE) between 1,429 and 1,430 ft. (435.5 and 436 m). The poorly vegetated gravelly and sandy beach VCTs are most common between 1,425 and 1,437 ft. (434.5 and 438 m). These VCTs occasionally occur at higher and lower elevations, but only in isolated areas.

Although vegetation cover varies with substrate and exposure, vegetation cover, vigor, and height, as well as species diversity and biomass (especially when shrubs are included) all decrease with increasing duration of inundation and decreasing elevation. “Plots that have been inundated for longer than 100 days tended to have lower vegetation cover, height, distribution, biomass and abundance than plots that have a longer exposure period.” (Enns and Overholt 2013, pp.9). Increased exposure time above inundation levels, especially during the growing season, is

positively correlated with both height and cover of vegetation, while occurrence of wave scouring is negatively correlated (Enns and Overholt 2012, pp.41-42).

Vegetation in the Revelstoke Reach has been generally summarized by van Oort et al. (2011):

Today, the flats are vegetated extensively by reed canary grass (Phalaris arundinacea) and sedges (Carex spp.), and to a lesser degree by horsetail (Equisetum spp.) above 432 m [1,417 ft.] elevation. Willow shrubs (typically Salix sitchensis) and sapling cottonwood (P. balsamifera) become increasingly established above 437 m [1,434 ft.] in the upper elevations of the drawdown zone. Mature cottonwood riparian forest habitat can be found in a few locations above 439 m [1,440 ft.] elevation. (p.6)

Revegetation Projects

Since the late 1980s, various revegetation projects have been implemented throughout the reservoir. Initially fall rye was planted on an annual basis for wind erosion control and dust abatement, mainly in the Revelstoke reach (Moody 2002). Fertilizer treatments occasionally accompanied the fall rye plantings.

Over a four year period spanning 2008 to 2011, various vegetation trials were established throughout the reservoir from Renata in the south to McKay Creek near Revelstoke. These trials included three species of sedge plugs, plugs of woolgrass, small-fruited bulrush and bluejoint reedgrass, live stakes and seedlings of black cottonwood, willow and red-osier dogwood, and seedlings of choke cherry (Keefer 2011). A total of 108 ha were planted, and 50 ha were fertilized. Unstable areas (especially sand) and lower elevations within the reservoir had the poorest survival, while stable substrates with sufficient coarse fragments to resist wave action, especially at upper elevations, showed the greatest success. Some plantings were lost to off-road vehicle disturbance, and some live stakes were pulled out by the public. Cottonwood live stake treatments were most successful above 1,434 ft. (437 m) on moist sands and gravels (Enns and Overholt 2013, pp.10). Voles and other pests also attacked some cottonwood stake plantings.

Vegetation and Inundation Patterns

During the period of monitoring (2008-2011), although there was not significant enough variation in the operating regime to correlate differences in vegetation due to the operating regime, longer duration of higher water levels was reported to have a negative influence on both the cover and height of vegetation in the lower drawdown zone (1,424 – 1,430 ft., 434 – 436 m). Drought-prone substrates and scouring by wave action are also important factors in vegetation survival. Wave scouring could also be considered as partially a reflection of operating regime, as it is more likely to occur when the reservoir remains at a single elevation for an extended period.

Over the period of monitoring a number of upland species have established in the upper portions of the drawdown zone (>1,434 ft., >437 m), persisted for a period of time, but then died (Enns and Overholt 2013, p.72). Although the loss of these species was not tied to any particular event or factor, based on the evidence and interviews, it is presumed these species simply could not tolerate the repeated inundations.

4.2.2.2 Summary of Interview and On-Site Visit Results

To further investigate vegetation in the reservoir, portions of three days were spent reviewing vegetation at various elevations and locations within the drawdown zone. The field visits and interviews with technical experts involved in drawdown zone vegetation monitoring confirmed vegetation distribution described above, and the limited success of recent revegetation efforts.

All experts interviewed agreed that either of the two Scenarios had potential to significantly increase the cover, diversity and structural complexity in vegetation above the proposed base level elevation. They also recognized that the reduced frequency and shorter duration of inundation in Scenario 2 would have significantly greater benefits to vegetation development, although it will likely take a few years for revegetation to establish, and decades for forested mature vegetation to fully develop.

Some experts expressed concern for the spread of invasive species, and noted that some vegetation types present today would likely decrease in abundance (e.g. reed canary grass and sedges). The occurrence of the listed species moss grass (*Coleanthus subtilis*) may also be negatively affected.

4.2.2.3 Conclusions

Current vegetation composition and distribution is in part determined by the various substrate and moisture factors listed above, but probably the most important factors are those associated with the operational regime of inundation (i.e., duration, frequency, depth and exposure to wave action and floating debris), as reflected in the elevational distribution of vegetation types (Enns and Overholt 2012, 2013).

At present there are no parts of the reservoir that regularly simulate the conditions that would exist under the proposed Scenarios, hence the impacts of the proposed Scenarios on vegetation have to be inferred. At present, all of the reservoir drawdown zone, with the exception of a few isolated areas above 1,440 ft. (439 m) elevation, is lacking well-developed terrestrial ecosystems that include trees and shrubs or fully functioning wetland communities. It appears that the frequency and duration of annual inundation precludes the development of forest and shrub communities or fully functioning wetland communities (physical abrasion by floating debris, wave action and sedimentation may also be significant factors). Off-road vehicle activity and intensive geese grazing has also resulted in some drawdown vegetation losses.

Many of the vegetation monitoring reports indicate that the best way to increase vegetation cover, diversity, and vigor in the drawdown zone is to decrease the duration of inundation during the growing season – generally from April to October (e.g. Enns and Overholt 2013; 2014).

The other main factor in vegetation success is wave scouring. Wave scouring mainly occurs on steeper sites in topographic positions and aspects exposed to wave action. However, it is also likely associated with times where the reservoir level is held constant for a period of time, where a particular elevation is exposed to a number of storm cycles and repeated intense wave action. Long duration full pool levels can also result in increased debris scouring where shoreline debris is floated by reservoir waters. Based on these observations, it is concluded that Scenario 2, with a rapid inundation and rapid return to the baseline elevation, offers reduced risk to vegetation loss due to wave scour and debris abrasion than Scenario 1, and in comparison to current operations.

The periodic establishment and subsequent loss of native species in the upper elevations of the drawdown zone indicate that there are seed sources and suitable substrates for re-establishment of upland ecosystems in many locations. Some areas in the DDZ with steeper or unstable slopes, or shallow, extremely coarse-textured or severely degraded soils may take significantly longer to revegetate, or not revegetate at all without remediation.

Due to the lack of inundation above 1,425 and 1,420 ft. (434.3 and 432.8 m) during 4 in 5 and 6 in 7 years in the respective Scenarios, it is projected that the cover and vigor of herbaceous vegetation will likely increase under both Scenarios above the baseline elevations. Due to the long duration of inundation above the 1,425 ft. (434.3 m) elevation associated with Scenario 1 in 1 in 5 year flood years (>40 days), it is projected that there will not be significant change in the development of tree and shrub dominated ecosystems above those existing under the present operating regime. In contrast Scenario 2, with inundation limited to less than 35 days above an elevation of 1,430 ft. (435.9 m), 1 in 7 years, should result in vegetation succession to more natural ecosystems in that zone, including ecosystems with trees and shrubs above an elevation of 1,430 ft. (435.9 m). See Section 3.2 for further discussion of forests and inundation. Between 1,422 and 1,430 ft. (433.4 and 435.9 m), herbaceous vegetation similar to that presently occurring in the drawdown zone today should persist under Scenario 2, but with increased cover and vigor. Below 1,418 ft. (432.2 m) vegetation will generally disappear, or transition into aquatic vegetation where substrates and depth are suitable. Under both Scenarios, a persistent beach will likely develop at the baseline elevation, likely extending a few feet or a meter above and below that elevation due to wave action.

Under Scenario 2, above 1,430 ft. (435.9 m), the rate of ecosystem succession will vary across the reservoir. Periodic establishment of trees, shrubs and other herbaceous species under existing conditions in low water years, demonstrates that revegetation can begin quickly (likely in 1 to 5 years, depending on species and weather conditions), especially in the fringe adjacent to seed sources (potentially up to 100m+). Parts of the reservoir above 1,430 ft. (435.9 m), but areas further from seed sources will likely take longer. The rate and trajectories of succession will vary depending on substrate, moisture availability, as well as seed source. Moist areas with finer textured soils at the upper elevations will likely revegetate more quickly. In general substrate conditions within the Revelstoke Reach, and areas on alluvial fans in the Arrow Lakes portion of the reservoir are more favourable to rapid succession although competition with dense communities of reed canary grass and other sedges may slow initial transition in some areas. Coarse textured soils and exposed bedrock sites will be the slowest to revegetate. Under favourable conditions succession to shrub communities will likely take at least 5 years, while development of full forest structure will likely take at least 30 years. Development on less favourable substrates will take longer, and would potentially benefit from soil enhancement and planting. Un-managed off-road vehicle disturbance may slow revegetation in some areas.

The growing season weather of the initial non-flood years will also affect the speed of revegetation by determining seed production and seedling survival. The periodicity of the 1 in 7 flood years will also impact the speed of revegetation, the longer the initial non-flood interval, the faster revegetation will proceed.

Given the apparent association of reed canary grass with prolonged annual flooding cycles, it is likely to decrease in cover and vigour as the flooding periodicity changes. To date there are no indications that reed canary grass is major local threat to areas outside the reservoir. As conditions become more favourable for native species in the Revelstoke Reach, those species should be in a position to more successfully compete with reed canary grass above 1430 ft. (435.9

m). Under Scenario 2, wildfire danger in the reed canary grass areas would be no greater than it is presently in low water years, and should decrease as productivity decreases. It is possible that reed canary grass will become established at lower elevations than it presently occurs due to reduced water depths.

Effective implementation of Scenario 2 will require an adaptive management strategy complete with on-going monitoring and the potential for responses to identified issues. Where appropriate, the responses may include actions such as: planting of trees and shrubs, control of invasive species, re-establishment of stream channels on alluvial fans, fertilization, management of off-road motorized access to minimize disturbance of establishing vegetation, wildfire management and others.

4.2.2.4 Information Needs

- consultation with relevant First Nations to ensure inclusion of Traditional Ecological Knowledge (TEK) in the assessment of past and potential vegetation communities in and surrounding the Draw Down Zone (DDZ);
- topographic/ bathymetric mapping of the DDZ to accurately determine the area at various elevations (including the requirement for an accurate Digital Elevation Model – DEM);
- investigation of the inundation tolerance (frequency, duration and depth) of local shrub and tree species;
- investigation of vegetation communities on floodplains or in other reservoir drawdown zones to further understand vegetation community development under flood regimes of relevant frequencies and durations;
- investigation of the likely successional rates and trends and on various substrates and moisture regimes under an altered operational regime;
- terrain and soil mapping of the DDZ areas above 1,415 ft. (431.3m) to better understand soil chemistry, the distribution of substrates, and their suitability for revegetation (including interpretations for potential vegetation community types and stability/erodibility);
- investigation of the impacts and benefits of rapid inundation and drawdown associated with Scenario 2; and,
- investigation of various risks, including but not limited to invasive species, wildfire, and increasing damage due to un-managed off-road vehicles.

See Table 8 at the end of Section 5 for a summary of all issues.

4.2.3 Wildlife and Wildlife Habitats

4.2.3.1 Literature Review

Information related to wildlife and wildlife habitats includes anecdotal observations during vegetation studies, habitat ratings based on vegetation interpretations, site-specific inventory data and modeling. None of the studies directly assess potential changes in wildlife use or wildlife habitats that may result from changes in reservoir operations such as those proposed in the study Scenarios. What some of the studies do provide however, are indications of what species are

using the various habitat niches created within the reservoir footprint, often by elevation band (especially the bird habitat studies). When combined with projected changes in reservoir levels due to the Scenarios, these habitat relationships can contribute to an estimate of the potential benefits or negative impacts of vegetation changes resulting from the proposed scenarios.

Early wildlife habitat assessments based on expert opinion (Enns et al. 2007) generally rated the poorly vegetated VCTs (BB, BE, BG, IN, SS) as poor to nil suitability for all species groups (see Section 4.2.2.1 for descriptions of the VCTs). Herbaceous VCTs (PC, PA, RR, PE, and RH) were generally rated poor to moderate for a variety of species, and occasionally high for large mammals and shorebirds/waterfowl. Rock cliffs (CL) were rated high for reptiles and songbirds and moderate to low for other species groups. Silverberry river entrance VCTs were rated moderate for shorebirds/ waterfowl and butterflies, but low to nil for other species groups. Cottonwood riparian, willow stream entry, ponds and log debris zone VCTs (CR, RS, PO, LO) were generally rated moderate to high for most species groups.

Over the past few years there have been a number of studies initiated to monitor the wildlife effectiveness of vegetation treatments and other completed and proposed physical works. Many of the studies are focused on specific habitats in the Revelstoke Reach, while a few are more widespread throughout the reservoir. The various sections below summarize relevant findings for various habitats and species groups, as well as some of the implemented and proposed works.

Wetland and Riparian Habitats

The loss and degradation of wetland and riparian habitats are some of the most important wildlife effects of the Arrow Reservoir flooding, affecting not only local resident populations, but also migratory waterfowl who use them as important food and cover during annual migrations, especially in the Revelstoke Reach (Manley and Krebs 2009, van Oort et al. 2011). Although wetland species are more tolerant of flooding than upland species, and tend to persist in the drawdown zone, they are also affected by reservoir operations, especially long duration inundation during the growing season.

Some wetland and riparian habitats that occur near or above 1,444 ft. (440 m) in elevation (e.g. parts of Airport Marsh, Beaton Beaver ponds) continue to function within the drawdown zone and have minimal effects of reservoir inundation (Miller and Hawkes 2013). Other wetlands such as Montana Slough, Cartier Marsh, lower Beaton ponds, and Lower Inonoaklin pond are significantly impacted by reservoir operations. Wetland and riparian habitats below 1,427 ft. (435 m) have generally been lost. The impacts are summarized as follows:

The ecology of these sites [Montana Slough and Cartier Bay] is influenced by reservoir inundation on an annual basis and the combination of low species richness and relative abundance compared to more stable wetland complexes (i.e., Airport Marsh and Beaton Arm) suggests that reservoir operations are having a negative impact on the secondary productivity of wetlands situated in the drawdown zone of Arrow Lakes Reservoir.... However, those sites not typically affected by reservoir operations (Beaton Arm and Airport Marsh) had one to seven times as many taxa in June and between 1 and 3.5 times more taxa in August as wetlands inundated by Arrow Lakes Reservoir (i.e., Montana Slough and Cartier Bay). This suggests that the aquatic macroinvertebrate fauna of wetlands inundated by Arrow Lakes Reservoir is limited in terms of species richness. (Miller and Hawkes 2013, pp. 43 & 45).

Amphibians and Reptiles

Four amphibian and five reptile species⁶ have been detected in the reservoir drawdown zone – Long-toed Salamander, Western Toad, Pacific Chorus Frog and Columbia Spotted Frog; Western Painted Turtle, Northern Alligator Lizard, Western Skink, Western Terrestrial Garter Snake and Common Garter Snake. Western Toads, Columbia Spotted Frogs and Common Garter Snakes are the most common species (Hawkes et al. 2015b). All are generally found above 1,427 ft. (435 m). Amphibians are mainly tied to wetlands and pond habitats in the drawdown zone for breeding – while reptiles are generally using terrestrial and pond habitats for foraging.

The dam impacts study on wildlife and wildlife habitats (Manley and Krebs 2010) and the BC Conservation Data Center (BC CDC 2017) identify a number of listed herptile species that have potentially been impacted by the Arrow Reservoir, and could be potential beneficiaries of habitat changes resulting from Scenario 2. These include the Western Painted Turtle, Western Toad and Western Skink (all BC Blue-listed; COSEWIC – Species of Special Concern), and the Northern Rubber Boa (COSEWIC – Species of Special Concern).

The reservoir operational regime significantly impacts habitat availability for herptiles – higher water levels mean less habitat is available. Keeping reservoir levels as low as possible for as long as possible into the summer benefits these species. Following the prolonged period of high reservoir levels in 2012, few individuals were found in the drawdown zone in the late summer and fall, even after water levels had dropped (Hawkes and Tuttle 2013). Early inundation may impact toad reproduction in some wetlands by flooding ponds where tadpoles have not yet undergone metamorphosis.

Researchers have indicated that revegetation could be of benefit, but that it must be focused on habitats adjacent to wetlands and include expansion of dense shrub habitats. This has not been an objective of revegetation to date, and based on analysis from this study, is unlikely to succeed without an alteration of the operating regime.

Western Painted Turtles have been studied at three sites in the Revelstoke Reach area of the drawdown zone: Airport Marsh, Montana Slough and Cartier Bay (Hawkes et al. 2013; Wood and Hawkes 2014). Turtles have been observed to overwinter in mud on the bottom of shallow ponds at Airport Marsh and Montana Slough. Nesting sites have not been located in the drawdown zone, although they may exist in the vicinity of Montana Slough. Inundation and loss of turtle habitat during summer and fall flooding by cooler reservoir water reduces availability of basking and foraging habitat, and can increase energy expenditure, predation risk and road mortality as the turtles are forced to temporarily seek suitable habitat elsewhere. Winter inundation and/or drawdown may affect hibernation success.

Songbirds

Ongoing monitoring of neotropical migrant songbirds in the drawdown zone of the Revelstoke Reach has shown that species diversity and abundance is greatest in the forested habitats above 1,440 ft. (439 m), with wetland and shrub habitats having the second highest densities (CBA 2015). Very few songbirds are recorded in the lower elevation (1,419 – 1,427 ft., 431 – 435 m)

⁶ Rubber boa has subsequently been added to the reptile list

and un-vegetated plots. Grass and sedge habitats generally have a third to half the densities recorded in shrub and wetland habitats.

The dam impacts study on wildlife and wildlife habitats (Manley and Krebs 2010) and the BC Conservation Data Center (BC CDC 2017) identify a number of listed songbird species that have potentially been impacted by the Arrow Reservoir, and could be potential beneficiaries of habitat changes resulting from Scenario 2. Appendix 2 summarizes listed bird species associated with the Arrow Reservoir DDZ, with other relevant information including their relationship to the Migratory Bird Convention Act (MBCA⁷).

Revegetation treatments with grasses and sedges have had marginal impacts on songbird diversity and abundance (van Oort and Cooper 2011). Planting with cottonwood stakes has had mixed results, increasing utilization of treatment areas by migrant songbirds on some sites, but not on others (CBA 2015). The cottonwood stakes provide temporary perching and foraging habitat, even when the trees themselves have not survived.

Recent studies of nest mortality of migratory songbirds in the drawdown zone due to reservoir inundation (van Oort, H. and J.M. Cooper. 2015a) show there are recorded losses in all of the seven years that monitoring has been carried out (161 nests, affecting 32 species, from approximately 4 to 20% of nests monitored each year). Monitoring of two species of shrub-nesting species indicated that shallow flooding of nesting habitat below the level of a nest in the shrubs may have some mixed effects, such as a reduction in nest predation and a potential increase in drownings during fledging. Further monitoring is needed to fully understand the net effects of partial flooding. Protecting Airport Marsh alone from inundation would reduce nest inundation significantly, especially in high impact years (potentially protecting up to 175 to 275 nests/ year in high impact years).

Additional multi-year monitoring of songbirds in the Arrow Lakes reaches has identified differences in relative abundance and species richness between the DDZ and adjacent upland habitats (Hawkes et al. 2014). The DDZ (both control and planted habitats) had reduced relative abundance and species richness compared to upland areas in all years of sampling.

Shoreline and Waterbirds

Shoreline and waterbirds have been studied for a number of years during the spring and fall migrations, and the nesting season in the Revelstoke Reach – with over 30 species of water birds and over 15 species of shoreline birds commonly present (van Oort and Cooper 2015b). The productivity of four wetland raptor species has also been monitored. Waterbird surveys are concentrated on Downie Marsh, Airport Marsh, Locks Creek Outflow, Montana Slough and Cartier Bay; shoreline bird surveys are throughout the Revelstoke Reach; while raptor surveys include Revelstoke Reach and Beaton Arm.

The dam impacts study on wildlife and wildlife habitats (Manley and Krebs 2010) and the BC Conservation Data Center (BC CDC 2017) identify a number of listed shoreline and waterbird species that have potentially been impacted by the Arrow Reservoir, and could be potential beneficiaries of habitat changes resulting from Scenario 2. Appendix 2 summarizes listed bird

⁷ There are approximately another 50 MBCA bird species relevant to the reservoir habitat, for further information see: <https://www.ec.gc.ca/nature/default.asp?lang=En&n=7CEBB77D-1>

species associated with the Arrow Reservoir DDZ, with other relevant information including their relationship to the Migratory Bird Convention Act (MBCA).

A summary of dabbling and diving duck fall migration numbers shows that the migrants generally peak in April (typically low water) and October (typically higher water), with significant numbers in months on both sides of the peak months. Reservoir operations affect the availability and quality of wetland habitats used by water and shoreline birds through exposure or inundation of important vegetation types, and by affecting the depths of submerged foraging substrates. During the fall migration, the presence of dabbling ducks appears to be negatively impacted by reservoir inundation depth and frequency at Cartier Bay, but Montana Slough and Airport Marsh are less effected due to their higher elevations 1,430 and 1,437 ft. vs. 1,423 ft. / (436.0 and 438.0 m vs. 433.8 m), floating bog habitat at Montana Slough, portions of Airport Marsh extending beyond the reservoir, and more extensive vegetation in shoreline areas. The full impacts of reservoir operations on shoreline and waterbirds are not completely understood at this time.



Figure 7: Heron in Cartier Bay, Revelstoke Reach. July 13, 2015.

Mammals

There are numerous anecdotal reports of large mammals using the reservoir (e.g. deer, elk, coyotes, cougars, beaver, etc.; Hawkes et al. 2011), but their sporadic occurrence has made study of large mammal use challenging. One study attempted to evaluate whether the vegetation treatment areas had increased use by ungulates in the drawdown zone, but the small treatment areas and the scarcity of ungulate use resulted in a recommendation to abandon the study (Adama and Hawkes 2015).

Twelve species of bats have been detected in the reservoir, including two blue-listed species (Hawkes et al. 2014, Hawkes pers. com. 2016). Based on available information, bats appear to be fairly well distributed throughout the reservoir, and dominated by *Myotis* species.

The dam impacts study on wildlife and wildlife habitats (Manley and Krebs 2010) and the BC Conservation Data Center (BC CDC 2017) identify a number of listed mammal species that have potentially been impacted by the Arrow Reservoir, and could be potential beneficiaries of habitat changes resulting from Scenario 2. These include Northern Myotis Bat (BC – Blue-listed), Grizzly Bear (BC – Blue-listed) and Caribou (BC – Red-listed, COSEWIC – Endangered, herd connectivity).

Arthropods

Studies to inventory and monitor selected arthropods have been undertaken in a number of sites in the Arrow Lakes reaches to better understand the lower levels of the food chain for some songbirds and bats (Hawkes et al. 2014). To date, monitoring has not consistently detected differences between the vegetation treatment areas and control areas within the drawdown zone, however there were detectable differences between arthropods associated with DDZ habitats and upland habitats. Future monitoring will assess the potential for spiders and beetles to be used as potential indicators of habitat change and revegetation impacts.

As part of the BC Hydro's water use planning studies, mosquito populations were inventoried in the Revelstoke Reach during the spring and summer of 2009 (Jackson et al. 2010). Unfortunately the studies were only undertaken for a single year, and that year was a hot dry year with lower reservoir levels, extensive larvicide treatments, and generally lower levels of mosquito populations. Although even with low population numbers, 11 species of mosquito were detected in the study area, including some species that are vectors for the West Nile virus.

Using 2009 sampling results and other data, Jackson et al. (2009) identify four main factors as potentially influencing the level of mosquito populations: spring and summer precipitation, spring and summer temperatures as they affect snowmelt rates and degree of flooding in local tributaries (e.g., the Illecillewaet River), reservoir levels, and efficacy of mosquito abatement activities (larvicide treatments). Jackson (2009) found that hot dry springs and summers, especially when combined with low reservoir levels tended to coincide with fewer mosquitoes, and cool wet years combined with extended periods with reservoir levels above 1,419 ft. (432.5 m) tended to increase mosquito populations. Most of the mosquito breeding areas were located on sites dominated by reed canary grass, although some natural wetlands and seepage sites were also contributors. Pond habitat was not considered a major source of mosquitoes due to the presence of natural predators.

Revegetation Wildlife Effectiveness

Monitoring of revegetation treatment areas has included the collection of information on songbirds, arthropods, bats and ungulates (Hawkes et al. 2014), and some of the results are described above. In general, three to four years of monitoring has shown that wildlife are using the revegetation areas, but there is no significant difference between use in the treatment areas and use in the untreated control areas. In fact there may be more use in the control areas by some species (Adama and Hawkes 2015). However, distinct communities of songbirds and arthropods were identified in the drawdown zone in comparison to the upland reference sites surrounding the

reservoir. There is significant uncertainty in the effectiveness monitoring results, due to small treatment plots, limited samples, short timeframe and lack of appropriate baseline sampling.

Physical Works Projects

A series of physical works projects have been identified as potential candidates for improving wildlife habitat (e.g. Golder 2009; Hawkes and Howard 2012). Many of them involve creating or increasing the area of existing wetlands and/or ponds by construction of dykes, water control structures and/or modification of existing structures. Three of these projects involving wetland enhancement have been selected for development of detailed plans: Burton Creek, Lower Inonoaklin Road and Edgewood South (Hawkes and Howard 2012). The created wetlands would be at approximately 1,434 to 1,440 ft. (437 to 439 m) in elevation. A couple further projects involve potential modifications of the Cartier Bay wetlands, however, recent analysis has indicated that the benefits of the proposed projects at Cartier Bay do not necessarily outweigh the risks to existing wetland values (Hawkes et al. 2015a).

4.2.3.2 Summary of Interview and On-Site Visit Results

Interviews with technical specialists and local stakeholders confirmed information summarized above. Some interviewees indicated that proposed or modified physical works could improve wetland and pond habitat availability to a limited extent, but most suggested that a change in operating regime that limited inundation would provide significantly greater benefits.

When asked for their opinions regarding the potential benefits or detrimental impacts to wildlife habitat from the two proposed Scenarios, all responded that the benefits would be significant. Most specialists stressed that benefits would be greatest if a scenario allowed for development of forest and shrub communities within the drawdown zone. This was especially important for songbirds. It was specifically noted that reduced inundation during the spring/fall seasons would greatly improve access to pond and wetland habitat for migratory waterfowl, and that reductions in the summer season would improve habitat access for reptile and amphibian breeding and foraging. A more stabilized shoreline would also likely benefit shoreline birds.

Interviewees familiar with the elevation of the various wetlands in the Revelstoke Reach expressed preference for keeping the baseline elevation low enough to ensure that all key wetlands are free of inundation. Technical specialists familiar with the proposed wildlife enhancement projects indicated that due to decreases in inundation, the proposed Scenarios would increase the effectiveness of those works, and potentially decrease their construction and maintenance costs. A couple of specialists indicated that some of the wetland projects may require annual reservoir flooding above the scenario elevations to maintain sufficient water levels. These projects may require inclusion of an external water source under the proposed scenarios to be fully effective.

One technical specialist emphasized the importance of restoring terrestrial primary productivity in the drawdown zone that has been lost under the present operating regime (see Utzig and Schmidt 2011 for further information).

4.2.3.3 Conclusions

The general conclusions are that Scenario 1 would likely provide some benefits to some wildlife species, but that Scenario 2 would likely provide significantly more benefits to almost all of the

species groups due to an increase in forest and shrub habitats. In addition, if proposed works to enhance wetland and habitat were implemented the benefits would be even greater.

Wetland habitat would be enhanced under both Scenarios by making the existing habitats above 1,420 or 1,425 ft. (432.8 or 434.3 m) available for the complete growing season in 4 in 5 or 6 in 7 years. Under Scenario 2, they would be available in more years, and even for a portion of the growing season in flood years. Scenario 2 will expose more wetland habitats simply because it has a lower base elevation (e.g. Cartier Bay).

There have been some concerns raised that limiting inundation may result in desiccation of some wetlands and ponds. This may be true of some minor wetlands/ponds, such the old Downie gravel pit near Revelstoke or Lower Inonoaklin Road, however it is not a concern in the primary wetlands described above (Airport Marsh, Beaton Beaver Ponds, Montana Slough and Cartier Bay). To varying extents all of the primary wetlands existed prior to inundation (Ketcheson et al. 2005), and continue to be supplied by surface and groundwater sources not associated with reservoir inundation. Further evidence of independent water sources for the wetlands was confirmed by the continued persistence of standing water during field visits in 2015, an extremely low water year where the reservoir failed to inundate most of the wetlands.

Riparian ecosystems and habitats along tributary streams would likely develop more complexity and cover under Scenario 1, and may even develop significant shrub cover. However they would likely not develop stands of trees, and therefore stream channel stability may not improve significantly. In contrast under Scenario 2, streamside riparian communities should develop into floodplain forest and shrub communities that will provide bank and channel stabilization, instream cover, shading and food for lotic habitat enhancement, as well as important riparian habitats. Due to the lower baseline elevation, Scenario 2 will expose more riparian habitats and stabilize longer stream segments. Many seepage sites now dominated by sedges and horsetails would likely transition to cottonwood and shrub communities.

Most amphibians and reptiles would benefit from increased seasonal access to wetland and pond habitats under both Scenarios. Toads would benefit from longer availability of pond habitat for tadpole maturation, and turtles from increased habitat availability for basking and foraging. Scenario 2 has greater benefits due to reduced flood frequency and duration, and the potential for development of shrub habitats adjacent to wetland habitat.

Under Scenario 2, arthropod communities are likely to shift closer to those found in natural habitat outside the dam footprint where corresponding habitats develop within the footprint. Under both scenarios, mosquito populations are likely to be reduced in areas above the baseline elevations in non-flooding years, especially in years where the reservoir would have filled under the present operating regime. In flood years (i.e. 1 in 5 and 1 in 7), mosquito populations are likely to be unchanged from what they are under the present regime. However, cool wet years will continue to have increased mosquito populations due to non-reservoir factors, especially due to flooding in local rivers and streams.

Songbirds will benefit from reduced nest flooding under both Scenarios, and more so under Scenario 2 due to the less frequent flooding. However, Scenario 2 offers significantly more benefits for songbirds due to the potential development of forested and shrub ecosystems which studies have shown to support the greatest abundance and diversity of songbirds.

Shoreline birds would likely benefit from both Scenarios, with the development of a more permanent shoreline at the baseline elevations, and a likely reduction in nest flooding frequency, particularly with Scenario 2. The potential development of a littoral zone in both scenarios would also benefit shoreline birds.

Waterbirds would benefit due to the improved access to wetlands and shallow pond habitats, as well as a more developed littoral zone. With the reservoir being more stable, the availability of those habitats would also be more consistent and dependable during migration periods. In the Revelstoke Reach, species that depend on grassland habitats for nesting, or flooded grasslands for feeding may see a reduction in habitat availability over time.

Many large mammals, especially those who utilize browse and/or require adjacent cover to utilize grassland habitat would benefit from the increased shrub and tree cover that would likely result from Scenario 2. Given that most if not all of the drawdown zone is located in areas that would provide low elevation ungulate winter range, a major limiting factor for ungulates, the habitat increase would be very significant. Any increase in ungulate use would also likely then indirectly benefit predators such as cougars, wolves and grizzly bears.

As described above various listed-species that were impacted by the reservoir flooding would likely benefit from both Scenarios, with more significant benefits accruing from Scenario 2. This is particularly important where rehabilitated habitat may contribute to Critical Habitat identified in Recovery Strategies under the Federal Species At Risk Act (SARA).

Physical works, such as those proposed for enhancement of wetland and pond habitats, could multiply the benefits of both Scenarios in those habitat types. If there is a decision to further investigate either of the Scenarios, it could be useful to include consideration of the proposed operating regime in the ongoing effectiveness assessments for the physical works projects, including any potential effects on water sources. Where lack of reservoir-related inundation would limit the effectiveness of the proposed works, development of external water sources should be investigated.

Under both Scenarios, herbaceous vegetation plantings may increase the rate and effectiveness of revegetation, and may be useful to increase diversity and/or enhance targeted habitats. Under Scenario 2, planting of trees and shrubs could likely speed up the development of some of the most valuable habitats, and would likely have far greater success than past plantings under the present operating regime. Management of motorized recreation to minimize damage during the revegetation phase will necessary, especially in areas with fragile and/or wet soils and areas where access-sensitive species may be expected to occur.

4.2.3.4 Information Needs

- more detailed review of potential habitat benefits (and losses) associated with an altered operating regime (including terrestrial, wetland, shoreline and shallow water habitats) – could include habitat interpretations associated with terrain and soil mapping combined with an accurate DEM as recommended in Section 4.2.3.4.
- further assessment of the impacts of inundation on wetlands and associated species throughout the Arrow Reservoir.
- further assessment of the impacts of inundation on songbirds, shoreline birds and waterfowl in mid and southern portions of the Arrow Reservoir.

- re-assessment of potential wildlife enhancement works projects with reference to an altered operating regime – with an emphasis on compensation for habitats suffering the greatest impacts from inundation.
- assessment of water sources feeding existing or proposed wetlands above 1,420 ft. (432.8 m), and potential augmentation options where reservoir recharge is found to be a significant source.
- further evaluation of Provincially- and Federally-Listed species at risk that may potentially occur in the DDZ, and how the Scenarios may affect those species and their habitats.
- assessment of how the Scenarios may contribute to federal Recovery Strategies and Identification of Critical Habitat (CH ID) and Recovery Strategies under SARA.

See Table 8 at the end of Section 5 for a summary of all issues.

4.3 Erosion⁸

4.3.1 Introduction

It is well established that current Arrow Lake Reservoir operations exacerbate soil erosion processes in both the main reservoir body and in the Revelstoke Reach river section. Soil erosion by water reduces or inhibits shoreline vegetation establishment, exposes cultural sites, degrades stream access for spawning fish, degrades recreational sites and devalues waterfront private property. It affects commercial activity and transportation infrastructure. Erosion by wind causes dust storms originating from unvegetated drawdown areas and periodically reduces quality of life for residents in ALR communities.

Soil erosion mechanisms in the Revelstoke Reach section that extends from Revelstoke to Shelter Bay differ somewhat than those in the main reservoir body. Revelstoke Reach river sections switch between riverine and lacustrine environments due to seasonal ALR water level fluctuations. In addition, daily water level fluctuations result from peaking operations of the Revelstoke Dam (REV) that is located at the upper end of the Revelstoke Reach. The following discussion and analysis addresses soil erosion in the Revelstoke Reach and in the main ALR body separately.

Soil erosion caused by water and wind is discussed in several sections throughout this report as it affects a number of valued resources. It is discussed below to provide context and background as it relates to the two constant elevation Scenarios.

⁸ Primary author: Alan Thomson



Figure 8: Bank erosion, Revelstoke Reach. July 13, 2015.

4.3.2 Literature Review - Revelstoke Reach.

Under the present ALR operating regime, during most periods of the year the Revelstoke Reach is a combination of riverine and lacustrine environments. During late winter/early spring when the ALR is drafted down, most of the Revelstoke Reach is riverine, and lacustrine environments are restricted to the extreme southern end of the reach. During the typical high water period of mid-summer, the lacustrine environment approaches the base of the Revelstoke Dam.

When the reservoir is at full pool and flows are low from the REV dam, lacustrine environments extends to the base of the dam. With full pool and high flows from the REV dam riverine habitats extend to about 8 km downstream from the dam (Plant et al. 2013). As the ALR levels decrease, the interface between riverine and lacustrine habitats moves downstream. At low reservoir levels the interface is about 45 km below the REV dam just upstream of Shelter Bay (Golder 2012).

The location of the interface zone between riverine and lacustrine environments is also contingent on the discharge from REV. Since REV is a peaking plant – the plant generation and discharge responds to hourly fluctuating power demand– water discharge can fluctuate between 142 m³/s (mandated minimum flow) to 2,124 m³/s with all five turbines in operation. As a result, in Revelstoke Reach sections closer to REV, the water elevation can rise and recede upwards of 3.5 m. over a 24 hour period. If a 6th generator is added to REV in 2021 as contemplated by BC Hydro, daily Revelstoke Reach water level fluctuations due to peaking operations will increase further.

Soil erosion and shoreline stability in the Revelstoke Reach has been studied numerous times, more recently during the 2006 environmental assessment certificate application regarding the expansion of the REV plant capacity from 4 to 5 turbines (BC Hydro 2006). Although the application assessed bank and bed erosion issues in the Revelstoke Reach under current reservoir operations and proposed operation of the 5th generation unit, some assessment information is useful in projecting erosion issues under a constant elevation scenario.

Erosion studies indicate that under current reservoir and REV operations, bank and channel erosion is minimal in most Revelstoke Reach sections. Some sections are actively eroding or aggrading, but the bank erosion rates are low and in the order of 1-2 m per year where fine-grained banks are over-steepened and unstable. Erosion rates generally correlate negatively with increasing distance downstream from the dam. Sites evaluated close to the dam have higher bank erosion rates than sites further downstream (KWL 2012). Conversely, study sites downstream have greater deposition than sites closer to the dam. Surface erosion and slumping rates can be further increased where saturated banks are exposed to repeated water level fluctuation due to peaking. However, in sections where exposure to waves is high, soil erosion by wave action during reservoir inundation is the dominant bank erosion mechanism (KWL 2012).

4.3.3 Evaluation of Effects of Scenarios on Erosion in the Revelstoke Reach

Under both constant elevation Scenarios, the interface zone between the lacustrine and riverine environments will likely sustain the most bank erosion. This area will be subjected to erosion from wave action, as well as local water level fluctuations due to peaking discharges from REV. Based on analysis of physical habitat modelling results reported in the CLBMON-15a study (Golder 2012) this zone will extend from about 9 km to 23 km downstream of REV dependent upon REV discharge and the ALR constant elevation.

In Scenario 1, in 4 of 5 years, the transition zone between riverine and lacustrine environments ranges from approximately 9 km to 20 km downstream for minimum and maximum REV discharge respectively. In river sections downstream of the transition zone, and below elevation 1,425 ft. (434.3 m.), bank erosion will be limited to the reservoir shoreline. Upstream of approximately 9 km section, bank erosion will occur at similar rates and locations as under current operations since current riparian vegetation species composition and spatial location are expected to remain unchanged. Within the transition zone bank erosion will increase over current rates, although to what degree is unknown.

In Scenario 1, under a one in five year flood event up to 1,444 ft. (440.1 m.), slack water can extend close to the base of the Revelstoke dam. Bank erosion patterns and rates between 1,444 ft. (440.1 m.) and 1,425 ft. (434.3 m.) should remain similar to current rates and patterns as the main deterrent to bank erosion – riparian vegetation – will remain unchanged as discussed in detail in Section 3.2. The impacts of less frequent flooding on bank erosion are not well understood.

In Scenario 2, in 6 out of 7 years bank erosion will occur in the transition zone which is approximately between 13 and 23.5 km downstream of REV. Upstream of the transition zone bank erosion may decrease as mature riparian vegetation is expected to establish along the banks and wave action erosion is eliminated during those years. However, fluctuating water levels due to peaking of REV will continue in this area, and this will contribute to continued bank erosion in some areas. Within the transition zone, a non-vegetated beach area may develop in areas exposed to repetitive wave action. In other areas current riparian vegetation species composition may

remain since the daily water fluctuations caused by the daily peaking nature of the Revelstoke generating station may prevent mature vegetation establishing within this zone.

In Scenario 2 in one in seven years the reservoir will fill to full pool and most sections downstream of the Revelstoke dam will be inundated. At bank elevations above 1,430 ft. (435.9m.) (north of Montana Slough) mature riparian vegetation is expected to establish and withstand a temporary inundation of upwards of 35 days. Bank erosion rates and patterns upstream of the transition zone will be the same as in non-flood (in 6 of 7) years.

4.3.4 Literature Review - Arrow Lakes Reservoir Main Body

Soils present in the drawdown zone in the main reservoir body are exposed to wave action and susceptible to erosive forces. Erosion rates vary greatly throughout the perimeter and are affected by:

- aspect (wave action can be more severe on reservoir banks facing north or south);
- parent material (e.g. rock, cobble, sand or clay/silt);
- slope angle (steep banks can be undermined thus allowing the whole bank to slide);
- the presence of logs and debris (rolling logs and debris along the shoreline disturbs soils and increases shoreline erosion rates), and;
- the presence of established vegetation.

Three main erosion processes occur within the main ALR: beaching, mass wasting and wind erosion.

Beaching

Beaching is a term that describes the erosion of sands and gravels at higher reservoir elevations, and subsequent deposition at lower elevations through wave action and small scale slumping. Eroded finer sediments (silts and clays) remain suspended in water for extended periods and are removed from the immediate site, transported by water currents and deposited in other areas of the reservoir. The result is a shoreline transformation from a steeper slope to a shallower long term stable slope. The final long term beach slope of sediments other than silts takes many years to achieve and generally does not occur during the lifespan of a reservoir project (Thurber 1978). In the Narrows area which becomes riverine during low water periods, the redeposited material lower in the water column may be eroded further.

Under current ALR operations, shorelines formed with cobbles, boulders or bedrock will experience very little additional erosion due to wave action. Shorelines comprised of sands and gravels will generally erode more rapidly, with silts and clay eroding the most quickly. It can be assumed that the long term beach slopes will be reached at all reservoir levels for finer sediments during the life of the reservoir.

In a few locations (e.g. Nakusp) banks have been reinforced with riprap or other forms of erosion protection works, and groins are used to maintain public beaches. Since the reservoir was first commissioned in 1968, organic soil layers have been completely removed by wave and wind action from the drawdown zone sections. North facing banks are particularly wave eroded due to

the predominance of northwesterly winds during high water periods of summer and fall. This is particularly evident in the West Demars area where reservoir banks are dominated by silts.

Mass Wasting

Mass wasting of shorelines in the ALR mostly occurred in the first three years of ALR operation as is typical in new reservoirs (Thurber 1978). Landslides typically occur where pre-existing weaknesses in slopes exist and are exacerbated by high water events which flood the toe of the slope and reduce shear resistance within the soil. Rapid drawdown is also known to trigger slides (BC Hydro 2014b). Although mass wasting events do not occur as frequently now as when the reservoir was first commissioned, slumping of hill sides particularly in the Narrows area that affects Highway 6 and agricultural land still occurs (C. Spicer, per. comm.).



Figure 9: Bank slumping and loss of agricultural land in the Narrows (photo credit: C. Spicer)

Wind erosion

Historically soil erosion due to wind in the ALR was a significant issue between Revelstoke and Shelter Bay. Dust storms were common during the 1970-1980's in Revelstoke during the late winter and early spring periods when large areas of dry unvegetated silts and fine sands were exposed to strong southerly winds. BC Hydro commenced a dust abatement program in 1987 and seeded large sections of the Revelstoke Reach with fall rye until the program was terminated in 2008 (BC Hydro 2010a). The revegetation program succeeded in abating dust storms as the vegetation is regenerating naturally and native species are encroaching into control areas (BC Hydro 2010a). However soil erosion due to wind that generates dust storms remains an issue in

other areas of the ALR (CRT Local Governments Committee 2014) that affects health and welfare of nearby communities.

Maintaining vegetation is widely considered the most effective method of reducing and controlling soil erosion. Vegetation binds soils together, reduces erosive wind energy near the soil surface and traps moving soil particles. Although vegetation establishment has been fairly successful in the Revelstoke Reach, it has met with mixed results in other parts of the reservoir (see Section 0 for further discussion of vegetation).

4.3.5 Evaluation of Effects of Scenarios on Erosion in the ALR Main Body

Under a constant elevation scenario, shoreline erosion will continue until a long term stable slope is achieved, where the rate of soil erosion equals soil deposition. The difference between both Scenarios and the current operation is the rate and location of shoreline erosion. Thurber (1978) estimated that 70% of the shoreline at elevation 1,444 ft. (440.1 m.) is surface or shallow depth bedrock. In these locations substrates are coarse enough and the bank angle sufficiently shallow to resist further significant erosion. The most rapid and aggressive erosion of the finer surface soils has already occurred over the 45 years of reservoir operations. In many sections, and over time, vegetation of varying species and maturity are expected to establish under Scenario 2 above 1,430 ft. (435.9m.), but not under Scenario 1 (see Section 3.2). Once firmly established the vegetation is expected to slow or halt soil erosion that may still be occurring. Soil erosion will continue under Scenario 1 above 1,425 ft. (434.3 m.) albeit at a slower rate than under current operations due to less frequent inundation. Minor slumping will likely continue as soft banks are undercut and beaches slowly attain the long term stable slope.

In ALR shoreline sections that continue to be susceptible to erosion (i.e. sections that are comprised of sands, gravels and silts) active short term erosion that is aggravated by wave action will continue to occur, and may increase, within approximately a few feet of the stable elevation for each Scenario (1,420 ft./432.8 m. in the case of Scenario 2 and 1,425 ft./434.3 m. in the case of Scenario 1). In the longer term, under Scenario 2, vegetation in sections that are protected from aggressive wave action will see vegetation establish closer to the water line. Beaching from wave action can also result in building up of banks through deposition, typically of sands and gravels. Sediments can be pushed up the beach and deposited if the bank is shallower than the long term beach slope. Under a constant elevation scenario, there may be some limited areas where beach deposition and aggradation could occur although it is likely the dominant regime will continue to be shoreline erosion until a long term stable beach slope is achieved.

Vegetation establishment in the current drawdown zone is the preferred method for abating soil erosion due to wind. Both Scenarios will allow for herbaceous vegetation similar to that which exists today to establish above the constant reservoir elevation but with increased cover and vigor. In addition, since there will be no significant drawdown below the baseline elevations, exposure of non-vegetated deeper parts of the reservoir will be eliminated. In Scenario 2 additional protection of shrubs and tree species will establish above 1,430 ft. (435.9 m.) thus providing additional ground level soil protection from erosive winds. In both Scenarios beaches within a few feet of the water elevation will be present from which silts and clays can be eroded by wind. However, the unvegetated surficial area from which dust is generated will be substantially reduced in both Scenarios when compared to current ALR landscape.

It is unclear how the Scenarios will affect the frequency and magnitude of mass wasting events when compared to current operations. Under both Scenarios the frequency of large drawdown

events will be reduced from annually to 1 in 5 years and 1 in 7 years for Scenarios 1 and 2 respectively. This should help reduce soil saturation in unstable soils above the constant elevation value and thus reduce the probability of a mass wasting event. However, during the high water years, the drawdown rate of Scenario 1 is higher than the average current drawdown rate, and much higher for Scenario 2. Rapid drawdown rates are linked to occurrences of mass wasting events in some types of soils and profiles. Thus, Scenario 1 would likely result in fewer and/or smaller magnitude mass wasting events than Scenario 2. However, whether either Scenario would increase or decrease the frequency or magnitude of mass wasting events when compared to current operations is unclear.

See Table 8 at the end of Section 5 for a summary of all issues.

4.3.6 Information Needs

- Erosion mechanisms that affect other values in the ALR under the two Scenarios (i.e. archaeological sites, tributaries and fish access, vegetation, etc.) along with specific information needs are discussed in their respective report sections.
- Determination of whether mass wasting events would increase or decrease in magnitude and frequency over current operations.
- A terrain map based on an accurate digital elevation map that identifies areas within the ALR of existing and potential low, medium and high erosion sites.

4.4 Fisheries and Aquatic Resources⁹

4.4.1 Introduction

The Arrow Lakes historically supported very valuable and culturally important First Nations fisheries. Anadromous chinook and sockeye salmon, kokanee salmon (land locked sockeye), rainbow trout, bull trout, westslope cutthroat trout, white sturgeon and burbot were all prized food fish (Green, 1997), and with the exception of chinook and sockeye salmon (extirpated) and white sturgeon (endangered), continue to be harvested today.

The reservoir also continues to support populations of chiselmouth, lake chub, carp (introduced), longnose dace, speckled dace, pygmy whitefish, mountain whitefish, peamouth, northern pikeminnow, tench (introduced), redbelt shiner, longnose sucker, bridgelip sucker, brown bullhead, prickly sculpin, slimy sculpin, shorthead sculpin and torrent sculpin. With the exception of limited First Nations harvest of mountain whitefish, northern pikeminnow and redbelt shiner, there is negligible harvest of these species.

Dam and reservoir operations, forest harvesting in tributary watersheds and riparian (shoreline) developments and alteration all are likely to have an impact on aquatic ecosystems, fish communities and fish harvest. The Fish and Wildlife Compensation Program (FWCP) supports annual fertilization (nutrient restoration) of the upper Arrow reservoir with considerable year-to-year variability in effectiveness as measured in kokanee biomass (there are a wide range of factors which influence kokanee abundance and biomass). The FWCP also supports the

⁹ Primary author: Bill Green

operation of the Hill Creek spawning channel which is operated to partially mitigate for the loss of kokanee spawning and incubation habitat caused by the construction of the Revelstoke dam. Hill Creek Spawning Channel is intended to support and in turn, increase size and abundance of bull trout and piscivorous rainbow trout. Arrow fisheries management objectives are under review and Hill Creek operations may be modified as a result of this review (see Parkinson and Arndt, 2014).

There are a wide variety of potential effects of a more stable Arrow reservoir operating regime. In this section of the report, we examine eight of the most obvious and potentially significant effects. Our analysis attempts to estimate effects in comparison to the current reservoir operating regime (as directed by the Columbia River Treaty and Non-Treaty Storage Agreement operations) that defines the ‘baseline’ case. This section of the report is based principally on a review of: (i) literature specifically relevant to the Arrow reservoir; and (ii) literature from investigations in other storage reservoirs. However, none of the literature reviewed pertains to the types of operational Scenarios considered in this report. As a result, we are limited to drawing inferences from studies that are not directly applicable.

4.4.2 Literature and data review

4.4.2.1 Effects on pelagic primary and secondary productivity and kokanee biomass

A key concern with the stabilized, mid-elevation reservoir operation concept is how it would affect primary and secondary productivity and kokanee production. The general proposition that reduced epilimnetic concentrations of nitrogen (e.g. total dissolved nitrogen) and phosphorus (e.g. measured as soluble reactive phosphorus) in temperate oligotrophic systems result in reduced pelagic and kokanee productivity is well established (e.g. Pieters et al. 2000). The details of this relationship are very complex with effects from relative concentrations of N and P, seasonal timing of nutrient availability, settling of organic particles out of the epilimnion and other factors. This relationship has been studied extensively in recent years in both the ALR and Kootenay Lake by the Province. In both bodies of water the declines have been attributed to upstream reservoir uptake of nutrients that resulted in ultra-oligotrophic conditions which significantly impacted kokanee as well as other fish species (e.g. Daley et al. 1981; Pieters et al. 1999; Ashley et al. 1999).

Schindler et al. (2011b) have also described the response – up to 2008 - of each trophic level to fertilization (additions of N and P) noting that in reference to ALR kokanee, their numbers have increased in response to fertilization along with improved growth, higher fecundity, higher fry-to-adult survival rates, greater biomass and spawner-recruit ratios greater than 1. Results since 2008 have been considerably more variable.

It is also important to consider the relationship between water residence time in the reservoir (flushing rate) and nutrient availability. Matzinger et al. (2007) modelled the effects of impoundment on nutrient availability and productivity in lakes and reservoirs using ALR as a model. Specifically, the authors attempted to partition the effects of: (i) water level increase; (ii) impoundment/storage; and (iii) subsurface (deep) release of water from the dam on nutrient retention and primary productivity. They characterized the complicated effects of ‘impoundment’ (leveling of the outflow; component ii) as:

- an increase in water residence time leads to a reduced nutrient supply to the productive surface layer due to less supply and more settling of organic particles;

- increased time for algae to grow in early June;
- from mid-June until early August, a reduction in primary productivity due to the reduced nutrient supply; and
- from early August until early September increased flow and reduced flushing (in comparison to earlier in the season, and with upwelling comparable to the pre-reservoir period) result in late growth that partly compensates for the lost productivity earlier.

They concluded that the inter-seasonal leveling of the flow through Upper Arrow resulted in a “slightly reduced” primary productivity in comparison to the pre-dam condition (Matzinger et al. 2007; pg. 2637).

Matzinger et al.’s (2007) modelling analysis also considered the effects of the raising of the average level of the ALR and the consequent deepening of the narrows between the upper and lower Arrow basins. Under current operations, the narrows are now on average 52.5 ft. (16 m.) deeper than prior to impoundment. A consequence of this is that the outflow from the upper basin into the lower basin is now denser, incorporating cooler, denser hypolimnetic water. This water incorporates more of the inflow from the upper Columbia River which plunges below the thermocline of the upper Arrow basin during the growing season. The following summary of this aspect of their analysis is provided:

Nutrients, bypassing the productive layer in the Upper Arrow, become available in Lower Arrow. Through upwelling, this additional soluble reactive phosphorus enters the productive layer, despite the deeper intrusion of the denser Narrows water into Lower Arrow. As a result, productivity in the Lower Arrow increases by 12% as a result of higher water level in the Narrows. Still, the overall productivity of the entire ALR decreases by 9% as a result of submerging the Narrows. (Matzinger et al. 2007; pg. 2636).

Stable Arrow Scenario 1 would reduce the average depth of the narrows during the growing season by 5.8 m, thereby reducing the productivity impact arising from the impoundment-induced deepening of the narrows.

“Impoundment” as modelled by Matzinger et al. is essentially the opposite of the two ‘stable Arrow’ Scenarios being examined. Impoundment in the Keenleyside context implies inflows greatly exceeding outflows (i.e. ‘storage’) from April through early July. The seasonal flow management component, according to Matzinger et al., has only a minor effect on primary productivity. Based *only* on Matzinger’s modelling, we would conclude that the stable Arrow Scenario would not likely significantly affect primary productivity in comparison to the current (Treaty Continues) operational Scenarios.

On the other hand, Schindler et al. (2010) offered the following speculation based on Arrow Lakes fertilization program monitoring through year 9 of the program: “However the most recent data on ALR points to in-lake productivity problems such as effective transfer of nutrients from one trophic level to another and or suspected changed physical conditions due to increased discharge during the growing season which may increase entrainment of both zooplankton and kokanee.” This speculation implicates entrainment of zooplankton and kokanee, at least in high inflow years, rather than direct nutrient loss, arising from increased spring-summer discharge. However, the report also notes another possible nutrient flushing-related mechanism, as follows:

“Daphnia spp. biomass significantly decreased in Arrow in 2007 compared to 2006. The flushing rate of the Arrow narrows in 2007 was the highest since 1999, the year when nutrient additions commenced (R. Pieters, pers. comm.). The high flushing rate is a possible explanation for decreased Daphnia spp. biomass.”¹⁰ Overall, Schindler et al. (2010) provides the following recommendation with respect to reservoir flow through/nutrient flushing: “More attention needs to be directed to the question of reservoir flow through to determine if this is a causative factor in the recent decline in the ALR productivity as reflected in the recent decline in the kokanee population.”

A Scenario 2 operation would, in comparison to the current treaty operation and Scenario 1, possibly reduce the productivity impact arising from the deepening of the narrows. Scenario 1 results in a 19 ft. (5.8 m.) reduction in the average growing season depth of the narrows; Scenario 2 in a 23.9 ft. (7.3 m.) reduction, with a larger reduction estimated to be more beneficial for Arrow reservoir pelagic productivity.

Another potential effect of Scenarios 1 and 2 relates to turbidity, which in turn effects light penetration through the surface waters of the reservoir and thus primary productivity. The more stable Arrow Scenarios should generally have reduced turbidity in comparison to the current operation because sediments around the reservoir will not be re-suspended during the annual reservoir filling and drafting regime. Reduced turbidity should result in increased primary productivity, to benefit kokanee and piscivorous fish.

In summary and based on a review of available literature, we cannot draw any firm conclusions about the relationship between increased spring and early summer discharge associated with ‘Stable Arrow’ Scenarios 1 and 2, primary and secondary productivity within the Arrow reservoir and kokanee biomass and abundance. It is, however, a significant area of concern which will need to be addressed if serious consideration is given to a stable type of Arrow reservoir operation.

4.4.2.2 Effects on lower reaches of tributaries

As described in Section 4.2.2, Scenario 1 is estimated to have the following effects on revegetation within the upper drawdown zone:

- Revegetation of reeds and grass species above 1,425 ft. (434.3 m.);
- No recruitment of shrubs or trees below 1,440 ft. (438.9 m.);
- Unlikely to establish natural vegetation communities.

This means that under Scenario 1 tributary reaches across the drawdown zone will not be stabilized as a result of revegetation of reed and grass species, and these reaches will likely remain unconfined, over-widened, braided and shallow and lacking mature riparian cover. In 4 out of 5 years reservoir wave action will not disturb and exacerbate tributary channel instability in alluvial fan sections above 1,425 ft (434.3 m). During those years with stream downcutting into the old fan/delta deposits some channelization may occur and result in moderate improvement of stream access. Revegetation of reed and grass species above 1,425 ft (434.3 m) may also add some degree of tributary bank and channel stability over current conditions. These geomorphic

¹⁰ In 2007, water residence time overall was low thus the nutrient flushing rate was high.

and revegetation processes will vary from stream to stream depending on sediment load and sedimentation (deposition of sediment in the channel), stream gradient, bank soils, exposure to wave action and other factors. Under the present reservoir management scheme, there is strong evidence that spawning migrations of kokanee are impeded in some tributaries in the drawdown zone when the reservoir level is at or below 1,430 ft. (435.9 m.), however these are significantly different conditions than those in either proposed Scenario. Hawes and Drieschner (2012) summarized observations of spawning access to Arrow tributaries from the fifth year of a monitoring program under present operations as follows:

- High fluctuations of the reservoir contribute to channel instability, aggrading and braiding in some tributary fans;
- Upstream fish migration can be blocked when stream flows are low to very low (e.g. late summer and early fall). In lower Arrow reservoir tributaries (e.g. Eagle Creek), low stream flows can impair upstream fish migration in late summer and early fall even upstream of the reservoir drawdown zone (K. Bray, pers. comm.);
- Passage conditions are generally good during higher tributary flows in the spring;
- Kokanee migration access has been observed to be reduced in some years even with reservoir levels at or above the 1,424 ft. (434 m.) level.



Figure 10: Cariboo Creek at confluence with ALR; July 14, 2015.

Figure 11 provides mean monthly streamflow data for two Arrow reservoir tributaries: Deer Creek and Kuskanux Creek. For adult bull trout migration purposes and without considering channel configuration through the reservoir drawdown zone, Kuskanux Creek does not appear to be streamflow impaired through late summer, with mean and minimum monthly average flows at 31% and 19% respectively of mean annual discharge (MAD) in August and September. On the other hand, streamflow conditions in late summer in Deer Creek (a much smaller creek) may

impair bull trout migration, with mean and minimum monthly average flows of 17% and 13% respectively of mean annual discharge (MAD) in August and September.

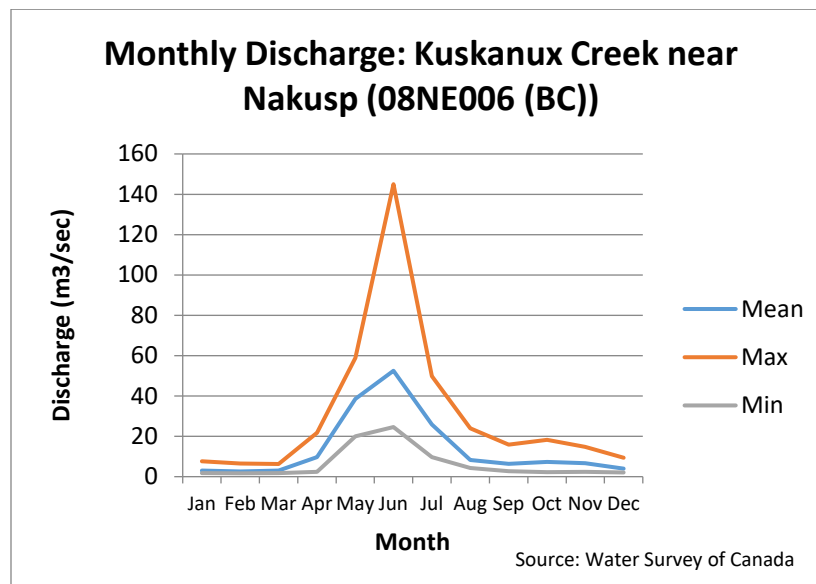
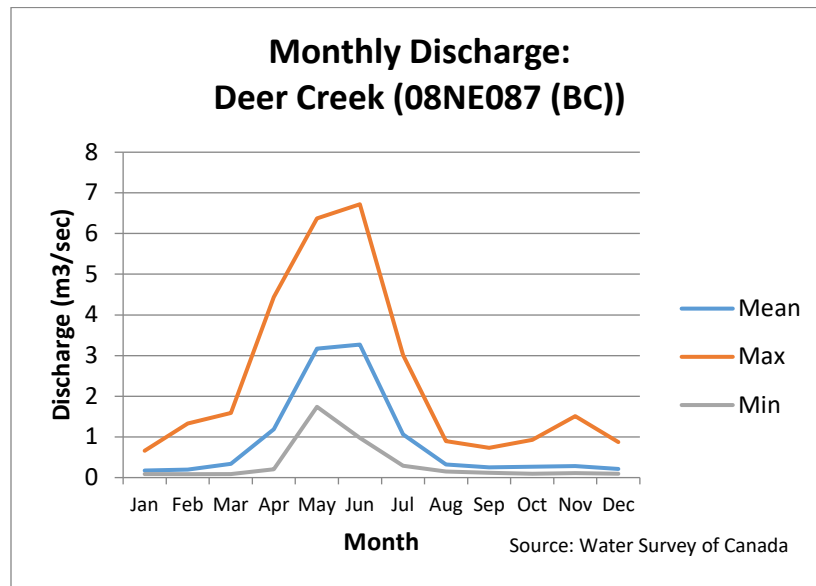


Figure 11: Mean, maximum and minimum monthly discharges for Deer Creek (lower Arrow reservoir tributary) and Kuskanux Creek (Upper Arrow reservoir tributary)

Spawning migrations of spring spawners is unlikely to be impaired by either Scenario one or Scenario two because of high spring (freshet) discharge (see Figure 11). On the other hand, spawning migrations of fall spawners (e.g. kokanee and esp. bull trout due to larger body size) would likely be impaired due to low streamflow conditions combined with the longer stream length within the drawdown zone.

Hawes and Drieschner (2012) also provided observations regarding tributary spawning habitat conditions in the drawdown zone, summarized as follows:

- Spawning in the lower (drawdown zone) reaches of tributaries is highly variable from year to year;
- In some streams, high spring/early summer stream flows result in the deposition of large volumes of gravel near the full pool reservoir level. Kokanee spawners were observed to use these gravel deposits in Burton Creek in 2012. The benefits of these fresh gravel deposits may be reduced if they occur outside of the channel thalweg and are subsequently de-watered during low winter and early spring streamflow conditions;
- The braided nature and subsequent shallow water depths experienced in the majority of the tributary fans may also contribute to potential for mortality from egg freezing or lack of oxygen if flows are insufficient.

Hawes and Drieschner (2012) also provide useful information about habitat attributes that support effective migration through the drawdown zone as well as instream habitat conditions:

Tributaries containing rooted stumps and other anchored structures through the drawdown zone fan (e.g. Cranberry, Payne, and Mackenzie Creeks) tended to have improved channel scour as a result of these features, thereby maintaining a more defined and passable channel, and at the same time contributing to fish habitat values. Consistent with the recommendations by Gebhart (1999), debris providing fish habitat values should not be removed unless they become unstable. The design and placement/anchoring of structures through the unstable drawdown zone may function to reduce channel braiding and help to maintain a more defined thalweg. Emulating the function of rooted tree stumps and rootwads may be a viable option with the use of untreated timber piles placed/driven strategically to influence fluvial morphology. (Hawes and Drieschner 2012, pg. 40.)

Based on the Hawes and Drieschner (2012) report, we can therefore conclude that the stable Arrow Scenario 1: (i) is unlikely to significantly improve fish passage conditions in the drawdown zone of tributaries; (ii) will, on a multi-year average basis, result in similar length of drawdown zone reaches in tributaries and thus equal spawner migration success as under current conditions; and (iii) is likely to improve spawning and incubation habitat (as opposed to fish passage) conditions within the drawdown zone reaches of tributaries as a result of:

- (i) In some streams (depending on gradient) deposition and maintenance of clean gravels above the 1,425 ft. (434.3 m) stabilized reservoir elevation combined with
- (ii) reduced reservoir inundation of redds during the incubation and emergence periods with the reservoir held at 1,425 ft. (434.3 m) in most years.

In summary, the likely consequence of a stable Arrow Scenario 1 operation, in comparison to the current operational regime, is no or little improvement of fish passage in tributaries that is offset, at least in part, by improved spawning and incubation success within the uppermost reservoir elevation band, above 1,425 ft. (434.3 m.). The overall net effect is uncertain. An additional area of concern is bird predation on kokanee spawners in the drawdown zone reaches of tributaries. With similar (on average) drawdown zone reaches, predation impacts may remain the same as under current conditions.

As described in Section 4.2.2 with respect to the potential effects on mature vegetation of a Scenario 2 operation, moderate to low gradient areas between ~1,430 ft. (435.9 m) and full pool potentially can be revegetated with flood tolerant vegetation (i.e. similar to floodplain vegetation; e.g. cottonwood, willows, dogwood, sedges). The development of mature vegetation on the alluvial fan and channel banks will, over time, help stabilize the channel banks and streambed and increase channel roughness, create hydraulic diversity and thus create more fish passage opportunities upstream of 1,430 ft. over a wide range of discharges. Large woody debris within the channel will also store sediment, form pools used by rearing juveniles, and encourage hydraulic diversity that sorts and cleans gravels and creates spawning sites for kokanee and rainbow trout resulting in increased abundance of these species. Therefore under Scenario 2, the establishment of mature riparian vegetation species above 1,430 ft (435.9 m) will provide more fish upstream migration and utilization of channel habitats for all life stages for both spring and fall migration species when compared to current conditions and Scenario 1.

4.4.2.3 Effects on littoral productivity

The littoral zone is that portion of the reservoir, generally around the reservoir margins, which is shallow enough to allow sufficient light to penetrate to the bottom to support growth of plants. In the Arrow reservoir (and many other reservoirs) the annual variation in reservoir surface elevation prevents the development of a stable littoral zone, the littoral zone moving up and down over the course of one year. This significantly reduces the productivity of the littoral zone in comparison to a lake or more stable reservoir.

Differences in littoral productivity at the secondary (macro-invertebrate) level are, not surprisingly, more complex. Furey, Nordin and Mazumder (2006) compared densities, biomass and species composition in littoral zones in a reservoir with a significant drawdown zone (Sooke Lake Reservoir, SLR) with the same parameters for the littoral zone in a nearby natural lake (Shawnigan Lake, SHL). Contrary to their predictions, "...macroinvertebrate density and biomass usually were greater in SLR than in SHL. In SLR, densities and biomasses of macroinvertebrates, especially chironomids, were higher below the drawdown exposure zone than in the upper littoral area. Chironomids with r-selected survival strategies (i.e., smaller size) or desiccant-resistant stages appeared well suited to the fluctuating environment of littoral zones in reservoirs. Orthocladiinae, Chironomini, Tanytarsini, and Tanypodinae dominated at sampling sites immediately below the drawdown exposure zone in SLR, whereas only Orthocladiinae dominated at deeper sites. These contrasting benthic macroinvertebrate communities indicate that variable drawdown regimes could have significant impacts on benthic food webs and the transfer of energy and nutrients to the pelagic area."

Evtimova and Donohue (2014) examined the effects of water level fluctuations on littoral zone ecological indicators in experimental mesocosms (lotic conditions.) They found that "Water level fluctuations reduced benthic algal biomass and the density and taxonomic distinctness of benthic invertebrate assemblages. Both the taxonomic and trophic structure of benthic assemblages were altered significantly in ponds with water level fluctuations and homogenised along the depth gradient."

Hunt and Jones (1972) summarized investigations of littoral fauna changes in Llyn Tegid, a regulated lake in Wales, over 18 years, from a period with low fluctuations, through amplified fluctuations and returning to reduced fluctuations. The period with amplified fluctuations resulted in big reductions in numbers and variety of invertebrates living in the littoral zone. The

reduced water level fluctuations in subsequent years resulted in re-establishment of some of the littoral fauna.

The importance of littoral environments in lakes and reservoirs for a variety of fish species and life stages is relatively well known. Particularly for juvenile life stages and smaller fish species, littoral environments provide a combination of both pelagic (open water) and benthic food sources, including benthic invertebrates. They also provide shelter (predator avoidance) habitat in coarse substrates and around large rocks and submerged woody debris. See, for example, Tabor and Wurtsbaugh (1991) and Rosenau (2014) concerning juvenile rainbow trout and Plate (2014) concerning juvenile mountain whitefish, juvenile to adult sculpin spp., adult bull trout in the spring and juvenile to adult kokanee in the upper part of the Revelstoke reservoir (which does not have a significant drawdown zone).

In summary, considering the direct effects of annually fluctuating reservoir levels on littoral zones and littoral fish communities, it is likely that a more stable Arrow reservoir operating regime (either Scenario 1 or 2) should result in increased productivity of littoral-associated fish species including mountain whitefish, rainbow trout, sculpin species and, possibly in the spring period, bull trout. There is no information available to suggest that either Scenario 1 or 2 is better with respect to littoral zone productivity.

4.4.2.4 Effects on aquatic plants and invasive species

Truelson and Warrington (1994) investigated how reservoir operations affected aquatic plants in a reservoir in Florida and noted the following:

- Prevailing water levels during the growing season, and not the duration of inundation, determined the distribution of aquatic plants in the reservoir;
- Very low water levels during the growing season determined the maximum limit of emergent vegetation;
- Water level control can be an effective tool for controlling excessive growth of submerged aquatic plants.

There are, of course, a range of other factors including reservoir bottom slope, water velocity and substrate which can affect the growth of aquatic macrophytes.

Northern pike are not native to the Columbia River system but have been introduced within the U.S. parts of the basin. As a result, they are now present in the Columbia River downstream of the Keenleyside dam and small numbers may be present in the ALR. Northern pike are aggressive predators and are likely to affect the abundance and distribution of native fish species in the ALR, for example kokanee, rainbow trout and bull trout.

Casselman and Lewis (1996) provide a comprehensive description of the life stage associations between northern pike and large aquatic plants. These plants are important to all life stages of northern pike. For spawning, macrophytes are of less spawning habitat value than submerged grasses and sedges. Young fish are dependent on vegetated nursery habitat: “As they disperse into deeper water, they are usually found in moderately dense vegetation. Presumably, this increased activity makes them more vulnerable to predation, so dense vegetative cover is important in providing them shelter, enhancing survival. The catches of juvenile and adult

northern pike were low at low macrophyte densities, highest at intermediate densities (35–80%) and low in very dense, virtually continuous vegetative mats. The larger pike were caught at low vegetation densities, and the smallest were taken in the densest vegetation.”

With respect to northern pike, Mills et al (2004), conducted an experiment in the Experimental Lakes Area in northwestern Ontario with a Before-After-Control-Impact (BACI) design in which the treatment was the harvesting of aquatic macrophytes. The following conclusions were reached about the effects of macrophyte harvesting on northern pike: no change in growth, 50% decrease in abundance, shift to larger individuals, 50% reduction in young-of-year recruitment, and overall a 60% reduction in biomass and production.

A similar experimental design was applied in a macrophyte removal experiment in lakes in Minnesota. With respect to largemouth bass, Cross et al (1992) reported that “Macrophyte harvesting did not affect, density, age or size structure, condition or diet, but could have affected first-year growth of largemouth bass in Mary and Ida Lakes. With respect to northern pike, macrophyte removal did not affect density, size structure, age structure, growth or diet of northern pike. Gill net CPUE (catch per unit effort) and length distribution of the catch before and after mechanical harvesting were similar.”

In summary, it appears likely that large aquatic plant communities would increase in the Arrow reservoir with the proposed Scenarios 1 and 2 operating regimes. There are a wide range of potential interactions between aquatic macrophyte communities and native fish species and especially salmonids (e.g., Pandit (1984)). Aquatic macrophyte communities support invertebrate communities which in turn are consumed by fish. They also provide hiding/shelter habitat for both predator and prey species. It is therefore difficult to determine how increased macrophyte communities would affect native fish populations.

While the literature evidence is mixed, based on the known association between northern pike and aquatic macrophytes, it is reasonable to conclude that it is more probable than not that at least northern pike (an invasive species) and possibly other invasive species would benefit from more abundant macrophyte communities.

4.4.2.5 Effects on the Revelstoke Reach

The Revelstoke Reach is between the Revelstoke dam and Arrowhead, the historic head of the Arrow Lake. During very low Arrow reservoir elevations, this reach is free-flowing in its entirety; at full pool (1,444 ft./440.1 m), and the Columbia River is backwatered by the reservoir to the base of the Revelstoke dam. Thus some or all of this reach (depending on the year) fluctuates between a flowing large river condition and a more lacustrine/lower velocity reservoir condition. Year round, large river habitat is thought to be limited in the complex of aquatic ecosystem types within the Canadian Columbia River basin because most of it has been lost due to inundation behind the Hugh Keenleyside, Revelstoke and Mica dams. The only remaining functioning¹¹ large river habitats within the Canadian portion of the Columbia River are: (i)

¹¹ “Functioning” large river habitat is lotic (flowing) in nature and does not have extreme variability in flows due to hydro-peaking operations.

upstream of the Kinbasket reservoir to the headwaters at Columbia Lake; and (ii) downstream of the Hugh Keenleyside dam to the international border.

The Columbia River Treaty Technical Report Addendum (BC Hydro 2013b) compared the effects of two more stable Arrow reservoir regimes (similar but not identical to Scenarios 1 and 2) on the average annual linear kilometres of functional large river habitat upstream between the Arrow reservoir and the Revelstoke dam. Their 'Alt 7TT – 1,425' Scenario (similar to Scenario 1) was projected to result in 33 average annual river kilometres of functional large river habitat compared to 31 average annual river kilometres in the reference 'treaty continue' scenario, similar to the current operating regime. This difference is not estimated to be significant. Their 'Alt 7TT – 1,420' Scenario (similar to Scenario 2) was projected to result in 35 average annual river kilometres of functional large river habitat, a 13% increase over the reference 'treaty continue' Scenario.

The Technical Report Addendum has a significant limitation in that it does not report on the average minimum length of large river habitat in the Revelstoke Reach; that is, the length of river that is riverine in nature/flowing for the entire year. Instead the 'large river' performance measures reports on the average annual length of large river habitat, thereby including portions of the river which are flowing for part of the year and slack/reservoir-like for part of the year. Variable areas are unlikely to provide all of the values of year round riverine reaches.

Scenario 1 would result, in 4 out of 5 years, in year-round riverine conditions for the 10 km. reach of the river from the Revelstoke dam to the confluence of the Illecillewaet River. This lower boundary is affected by Revelstoke dam discharge, extending to 13 km. downstream of the dam during peak discharge. Scenario 2 extends the year-round riverine conditions, in 6 out of 7 years, to downstream of the Revelstoke airport (15 river km. from the Revelstoke dam) with less variability caused by peaking operations at the dam.

Comparing the effects of year-round riverine (lotic) vs. year round reservoir (lentic) and variable conditions is made much more complex in the Revelstoke Reach by the peaking operation of the Revelstoke generating station (REV). The operational discharge range for the generating station is between the regulated minimum flow of 142 cubic metres per second (cms) and a maximum of 2,124 cms. Flows can vary on a daily basis between these minimum and maximum levels. As a result, wetted habitat area, velocity, depth and other parameters can vary considerably on a daily basis. In particular, this means that the wetted area of the Columbia River can vary a great deal on a daily basis as a result of the peaking operation of the Revelstoke dam. This greatly reduces the value of any continually flowing large river habitat downstream of the dam.

There is little information to draw on about the aquatic and fisheries productivity consequences of riverine (lotic) vs. reservoir (lentic) habitat conditions. The Columbia Water Use Plan includes a Revelstoke Flow Management Program (RFMP) which is designed to determine the effectiveness of the regulated 142 cms minimum flow in improving fish habitat conditions. The RFMP includes physical habitat, primary and secondary productivity, adult fish use and juvenile fish use study components. These studies do not directly address the fish habitat and population effects of riverine (lotic) vs. reservoir (lentic) conditions, but inferences can be drawn from the results of these studies. Table 3 below summarizes these inferences, including whether the effect or observation is likely to be negative or positive, in comparison to current conditions, for Scenarios 1 and 2, in upstream (riverine) and downstream (backwatered/reservoir) areas. Table 3 was developed by reviewing the three reports cited (Schleppe et al, 2014; Okanagan Nation Alliance 2014; Slivinski and Sykes, 2014) and extracting all observations relevant to the productivity

consequences of riverine versus reservoir habitat conditions. We only examined productivity consequences for benthic communities (periphyton and invertebrates), and adult and juvenile fish because of data availability considerations. Data is not readily available that would allow a comparison of pelagic (phytoplankton and zooplankton) productivity between reservoir and riverine conditions.

Table 3: Observations of aquatic and fisheries productivity consequences of riverine vs. reservoir habitat conditions.

Key: + :effect positive when compared to current ALR operations.

- : effect negative when compared to current ALR operations.

Aquatic and Fisheries Productivity Observations	Inferred Effect <u>Upstream</u> (river-like) of 1,420 ft. and 1,425 ft. backwater elevation	Inferred Effect <u>Downstream</u> (reservoir) of 1,420 ft. and 1,425 ft. backwater elevation
Benthic productivity observations (Schleppe et al. 2014).		
1. Abundance of bacteria and fungi are reduced by repeated desiccation (drying out due to variable flows) and high flows (in the high varial zone). Bacteria and fungi on substrates are valuable components of the benthic food web.	-	+
2. Reach 3 (downstream, Jordan to Illecillewaet River confluences) had more biofilm than reach 4 (upstream, Revelstoke dam to Jordan River confluence) possibly because of scour	-	+
3. Drift of reservoir algae during backwatering increases biofilm. Biofilm is the thin film of living matter that grows on substrates (e.g. cobbles, boulders, gravel) and is eaten by ‘grazing’ invertebrates.	-	+
4. Depth increases light attenuation (reduction of available light) and reduces primary productivity.	+	-

Aquatic and Fisheries Productivity Observations	Inferred Effect <u>Upstream</u> (river-like) of 1,420 ft. and 1,425 ft. backwater elevation	Inferred Effect <u>Downstream</u> (reservoir) of 1,420 ft. and 1,425 ft. backwater elevation
5. Increased flow leads to reduced periphyton growth, particularly in high flow conditions: High flows river conditions result in reduced periphyton abundance and biovolume, on the order of 50% or more, higher decline in upstream reach 4 (dam to Jordan River confluence). Fall data suggest that abundance and biovolume decreased with increasing velocity.	-	+
6. Backwatering increases periphyton abundance and biovolume.	-	+
7. Periphyton production increased with total incubation time (wetted during daylight hours). Submergence was a consistent and vital predictor of benthic production and diversity (number of species)	-	+
8. Substrate exposure increases periphyton mortality.	-	+
9. Greater abundance of EPT ¹² taxa corresponded with years of higher average flow and associated increased submergence of substrates within varial zones. The quantity of food for fish (i.e., EPT taxa and Chironomids) increased with increasing relative abundance of cobble boulder, and increasing velocity, as shown by both the fish food index and Hilsenhoff Index.	+	-

¹² EPT: Ephemoptera, Plecoptera, Tricoptera. Mayflies, stoneflies and caddis flies. The relative abundance and diversity of these orders of invertebrates is frequently used as an indicator of water quality, with higher abundances and diversities indicative of higher water quality. These are also important food items for insectivorous trout.

Aquatic and Fisheries Productivity Observations	Inferred Effect <u>Upstream</u> (river-like) of 1,420 ft. and 1,425 ft. backwater elevation	Inferred Effect <u>Downstream</u> (reservoir) of 1,420 ft. and 1,425 ft. backwater elevation
10. Extreme events (flows in excess of 1,800 cms that extend for more than 48 hr.) or minimum flows of 142 cms occur regularly and can result in large scale die-off of benthic communities. Extreme events, coupled with routine BC Hydro operations, ultimately determine the aquatic benthic community structure and productivity within MCR.	-	+
11. Revelstoke reach River periphyton communities may be more dependent upon the overall operating regime (daily, monthly, and annual patterns of flow release, ALR backwatering, etc.) than the specific effects of minimum flow because the normal operating regime determined the wetted edge of the channel during daytime periods, a key explanatory variable in modelling data.	-	+
12. Generally, any increase in wetted (submerged) productive habitat should cause a subsequent increase in fish food availability. Reservoir inundation increases the wetted area.	-	+
Adult fish population observations (Okanagan Nation Alliance 2014).		
1. Species richness is higher in reach 3 (downstream, Jordan River to Illecillewaet River) which is more frequently backwatered. Overall, species richness generally increased with distance downstream from the dam. Higher species richness downstream is likely a reflection of this portion of the study area serving as a transition zone between the flowing section of the Columbia River and ALR. If this transition zone provides diverse habitat types, including more riverine and lacustrine areas, then it could explain the higher richness compared to other reaches.	-	+

Aquatic and Fisheries Productivity Observations	Inferred Effect <u>Upstream</u> (river-like) of 1,420 ft. and 1,425 ft. backwater elevation	Inferred Effect <u>Downstream</u> (reservoir) of 1,420 ft. and 1,425 ft. backwater elevation
2. Higher densities of rainbow trout and northern pikeminnow in reach 3 (Jordan River to Illecillewaet River), compared to reach 4 (upstream, Revelstoke dam to Jordan R.). Reach 3 is more frequently backwatered by the Arrow Lakes reservoir.	-	+
3. Higher reservoir elevations are positively correlated with rainbow trout and sucker spp. abundance.	-	+
4. Higher reservoir elevations are negatively correlated with mountain whitefish body condition.	+	-
5. Reach 3 (Jordan R. to Illecillewaet R.) represents a transition zone between lacustrine (lake like) and riverine habitats, particularly during the fall study period when ALR water elevations levels are higher. The complex species assemblage (higher species richness and evenness) in that portion of the study area reflects the greater habitat diversity in the transition zone.	-	+
6. Overall, Northern Pikeminnow densities were low compared to other species, although they were slightly higher in Reach 3 than in Reach 4. Fish indexing reports confirm that northern pikeminnow densities are consistently higher in downstream reaches. (K. Bray, pers. comm.).	-	+

Aquatic and Fisheries Productivity Observations	Inferred Effect <u>Upstream</u> (river-like) of 1,420 ft. and 1,425 ft. backwater elevation	Inferred Effect <u>Downstream</u> (reservoir) of 1,420 ft. and 1,425 ft. backwater elevation
<p>7. Bull trout and mountain whitefish located closer to REV showed increased muscle activity and energy expenditure compared to fish located at stations further downstream (Taylor and Lewis 2011).</p> <p>Bull trout and mountain whitefish in more riverine, higher velocity conditions used more energy to maintain position and forage in the river than in more downstream (lower average velocity) locations.</p>	-	+
Juvenile fish population observations (Slivinski and Sykes 2014).		
<p>1. Fish usage both before and after minimum flow/REV5 tended to be higher and more consistent in the lower reaches (Reaches 1 and 2, downstream of the Illecillewaet R.) than the higher reaches (Reaches 3 and 4, upstream of the Illecillewaet R.). (NB: lower reaches more frequently inundated by Arrow reservoir).</p>	-	+
<p>2. Inundated reaches are always warmer (spring, summer and fall).</p>	-	+
<p>3. Spring: higher overall abundance reaches 3 and 4 (upstream of Illecillewaet R., less frequently reservoir inundated) v. reaches 1 and 2 (downstream of Illecillewaet R.)</p>	+	-
<p>4. Summer: higher overall abundances in reach 1 (most downstream/most inundated) v. reaches 2, 3 and 4.</p>	-	+
<p>5. Fall: higher overall abundance reaches 1 and 2 (downstream of Illecillewaet R., more frequently inundated) v. reaches 3 & 4.</p>	-	+

Aquatic and Fisheries Productivity Observations	Inferred Effect <u>Upstream</u> (river-like) of 1,420 ft. and 1,425 ft. backwater elevation	Inferred Effect <u>Downstream</u> (reservoir) of 1,420 ft. and 1,425 ft. backwater elevation
6. Similar to previous years of the study, condition factors of juvenile bull trout tended to be somewhat higher with closer proximity to the dam. This suggests higher value rearing habitat for juvenile Bull Trout in the riverine reaches than the reservoir reaches. (This observation can also be explained, at least in part, by the availability of zooplankton or other food items entrained through the Revelstoke dam.)	+	-
7. Similar to previous sampling years, condition factors of juvenile mountain whitefish tended to be somewhat higher with closer proximity to the dam. This may suggest higher value rearing habitat for juvenile mountain whitefish in the riverine reaches and tributaries than the reservoir reaches.	+	-
8. Growing conditions for juvenile reidside shiner appear to be more suitable in lower velocity flow that characterizes the reaches downstream of the Illecillewaet River.	-	+

As described earlier in this section, the average availability (kilometres) of large river habitat in the Revelstoke Reach area is not significantly different between the current operational regime and the 'Scenario 1' type of operation: 31 vs. 33 km. While Scenario 1 would provide additional large river habitat in the late spring through early fall period, in comparison to the current operational regime, the potential fish and aquatic ecosystem benefits of more large river habitat are greatly reduced by the hydro-peaking operation of the Revelstoke generating station. Scenario 2 does provide a small increase in the average annual availability of large river habitat in comparison to the current operational regime (35 vs. 31 km.), and obviously considerably more large river habitat in the late spring through early fall period. However, based on a qualitative comparison of the benefits of riverine vs. reservoir conditions in a situation of extreme daily flow variability, it is uncertain whether Scenarios 1 or 2 provide a net benefit for aquatic ecosystems and fish populations in the Revelstoke Reach in comparison to current operations.

4.4.2.6 Potential effects on burbot

Adult burbot tend to favour deep, cool areas of lakes and reservoirs. Young burbot can be found along rocky lake shores and in weedy areas, or hiding between the rocks in tributary streams. Spawning habitat selection is highly variable, with some burbot spawning in shallow, groundwater fed tributaries and others spawning on gravel and cobble reefs in lakes and reservoirs at a variety of depths. The susceptibility of Arrow reservoir burbot to exposure (due to drawdown) and desiccation of spawning redds has been investigated in a BC Hydro funded (Water Use Planning) study. Robichaud, Glova and Kingshott (2013) have reported on the fifth year of these studies, with the following key conclusions:

1. Tracking during the assumed spawning period over four consecutive winters (February/March) has shown that there are consistent locations of elevated Burbot concentration. Sampling in Years 4 and 5 confirmed that Burbot in the aggregation areas were in spawning condition, and some (27% in Year 5) were spawned out.
2. Winter tracking has shown that Burbot move out of the parts of the Revelstoke Arrowhead Reach that are most affected by the reservoir drawdown. Burbot do not appear to be spawning in the areas most affected by drawdown.
3. From a substantial body of evidence gathered during the 5-year study, the primary spawning in this reservoir probably occurs in relatively deep (>20 m), near bottom areas in the Beaton complex (Beaton Arm and Beaton Flats).

Therefore, it seems reasonable to conclude that Scenario 1 and Scenario 2 are neutral, in comparison to the current operating regime, with respect to effects on burbot spawning and incubation.

4.4.2.7 Potential effects on white sturgeon

White sturgeon are identified as an endangered species under schedule 1 of the federal *Species at Risk Act*¹³. A recovery strategy for the species has been developed and formally approved. Three areas within the Revelstoke Reach have been identified by regulation as ‘Critical Habitat’ under SARA in support of the Arrow – mid-Columbia component of the Canadian Columbia River white sturgeon population:

- Adjacent to the Revelstoke Golf Course/confluence of the Jordan River (spawning, larval rearing and adult feeding);
- Big Eddy (adult feeding and staging, possibly larval rearing); and
- Salmon Rocks (adult feeding and staging, possibly larval rearing).

All of these areas are inundated by the ALR at a variety of reservoir elevations, with Salmon Rocks the first inundated with reservoir elevations exceeding 1,425 ft. (434.3 m.).

Spawning has been documented in many years in the area adjacent to the Revelstoke Golf Course but no juvenile sturgeon produced from wild spawning have been detected, suggesting that some component of early life stage survival is likely to be critically-limiting to the Arrow white sturgeon population component.

Hildebrand et al (2014) investigated the combined effects of reservoir inundation and Revelstoke dam discharges on spawning, incubation and larval rearing habitat conditions in the Revelstoke Golf Course and Big Eddy areas. This study showed generally that the area of suitable white sturgeon spawning and incubation habitat increases at lower reservoir elevation levels. However, the study also noted that:

- flow/velocity conditions during the larval dispersal period may be more important for white sturgeon recruitment than during the spawning and egg incubation period, as successful spawning and egg development has been observed at both high and low Arrow reservoir levels;
- maximum depth in the Revelstoke sturgeon spawning/egg incubation area during periods of maximum discharge from Revelstoke Dam typically ranges from 5 to 6 m in the channel thalweg although at the minimum 120 m³/s Revelstoke Dam discharge, maximum depths can be reduced to 2 or 3 m. These values are within the reported depth range for spawning by this species at other locations;
- depths do not appear to be a critical factor influencing spawning site selection;
- depths in the study area appear sufficient to stimulate white sturgeon spawning activity under all present flow regimes and ALR levels.

¹³ http://www.sararegistry.gc.ca/document/default_e.cfm?documentID=414

- white sturgeon spawners appear to prefer near-bottom velocities of 0.8 to 2.0 m/s., at least based on the distribution of eggs recovered from egg mats in a variety of velocity conditions;
- in 2008, with very high Arrow reservoir elevations during the spawning period, velocities were generally reduced in the overall spawning area and eggs were found further upstream in comparison to more normal reservoir elevation years. Conversely, 2009 had the lowest Arrow reservoir elevations during the sturgeon spawning period of any year in which successful spawning has been observed, and the highest number of eggs was collected;
- the greatest area with near bottom velocities exceeding 1.0 m./sec. occurs at lowest Arrow reservoir elevations; and
- there appears to be a higher risk of entrainment of drifting larvae into the less suitable Big Eddy area with low Arrow reservoir elevations and flows between 850 and 1,700 cms.

As Scenarios 1 and 2 provide significantly lower reservoir elevations in most years in the known spawning and egg incubation area in comparison to current operations, we can conclude that these Scenarios are likely to benefit white sturgeon spawning and egg incubation, with less certain consequences for larval dispersal.

4.4.2.8 Potential effects on anadromous salmon

Anadromous salmon (sockeye and chinook salmon and possibly steelhead) historically used the Arrow Lakes and tributaries for migration, spawning, egg incubation and juvenile rearing. It is estimated that the Arrow Lakes produced about 85% of the total Columbia River system sockeye production prior to 1939 (Fulton, 1970). Sockeye spawning occurred in Kuskanux Creek (Fulton, 1939) and probably many other tributaries. Summer-run chinook salmon spawned between the Arrow Lakes, upstream from the Arrow Lakes (Fulton, 1968) and likely in the larger Arrow Lakes and Columbia River tributaries.

The completion of the Grand Coulee dam in the early 1940's caused the extirpation of all upstream anadromous salmon populations. Consideration is currently being given, through the Columbia River Treaty renewal and other processes, to the possibility of restoring anadromous salmon populations upstream of Grand Coulee Dam. Columbia Power Corporation (CPC), prior to constructing the Arrow Lakes Generating Station (ALGS), investigated fish passage options in relation to the proposed power plant. Results were encouraging and CPC is legally required as a condition of the Environmental Assessment Certificate for the ALGS to construct and operate fish passage facilities at their facility IF anadromous salmon become established in the transboundary reach of the Columbia River and federal, First Nations and the provincial governments support fish passage. Thus, restoration of sockeye and chinook salmon populations into the Arrow Lakes is a significant possibility in the medium term (5 – 10 years) future.

For the reasons described in Section 4.4.2.2, the effects of Scenario 1 on tributary passage and habitat conditions for upstream migrating sockeye salmon are uncertain, with a positive effect anticipated for Scenario 2. The more stable Arrow scenarios will likely limit stranding, redd dewatering and egg desiccation/freezing in comparison to current operational scenarios where reservoir levels generally decline through the fall and winter post-spawning period. For Scenario

1, we do not have information on the relative magnitude of the effects described in Section 4.4.2.2 in comparison to stranding, dewatering, etc. effects. Changes in Arrow reservoir pelagic productivity will also affect juvenile sockeye which will likely spend from 1 to 2 years rearing in the reservoir. However, the effects will be less significant for sockeye than for kokanee (as described in Section 4.4.2.1) because more than 95% of the growth of sockeye salmon occurs in the ocean, whereas all of the growth of kokanee occurs in the freshwater environment. This will at least partially offset possible detrimental effects of Scenarios 1 and 2 on aquatic productivity. Increased littoral zone productivity and habitat value (see Sections 4.4.2.3 and 4.4.2.4) predicted for Scenarios 1 and 2 will also likely benefit rearing anadromous salmon in comparison to the reference condition.

Chinook salmon are likely to be less affected by either Scenario 1 or 2, in comparison to sockeye salmon and kokanee because chinook salmon will likely spawn in the mainstem of the Columbia River upstream from the Arrow reservoir or in larger tributaries (e.g. Incommapleux, Illecillewaet, Jordan, Caribou) less susceptible to passage impairment in their drawdown zone reaches. Pelagic productivity conditions may affect chinook salmon, but only if they adopt life history strategies involving reservoir rearing, which does occur in the Snake River.

4.4.3 Summary of Interview Results

With respect to potential effects of Scenarios 1 and 2 on nutrient availability and primary productivity, one reviewer noted the problems inherent in assessments based on averages. Of course there is great inter-annual variation in Arrow Lakes inflows. In dry years, stable Arrow Scenario 1 and 2 will likely result in increased water residence time and nutrient retention and possibly primary productivity, in comparison to normal or high inflow years. However, in dry years, both Scenario 1 and Scenario 2 will likely result in reduced nutrient retention in comparison to current operations. On the other hand, inflows are the source of natural (non-anthropogenic) nutrient inputs so low inflows may also result in reduced nutrient availability.

Another reviewer noted that the question of effects on primary and secondary productivity (and kokanee production) need to be carefully considered, in part by careful modelling of Arrow reservoir discharge during the growing season with particular attention to inter-annual variability.

One reviewer noted the possibility of a trade-off, with nutrient limitation, between littoral and pelagic productivity. That is, nutrients are required for primary production in littoral benthic habitats (periphyton and larger aquatic plants) as well as for pelagic (mid-reservoir, open water) productivity. In an acutely nutrient limited ecosystem, uptake of nutrients by littoral communities will likely reduce the availability of nutrients for pelagic, kokanee-supporting productivity. This idea warrants further assessment.

Another reviewer commented on the importance of considering downstream impacts because of the higher recreational fishery value of the Columbia River downstream of the Hugh Keenleyside dam, and noted that fisheries management objectives for the Arrow reservoir are currently under review and may result in changes to the nutrient augmentation program and/or to the operation of the Hill Creek Spawning Channel. This general comment is well-taken and, indeed, can be expanded to include the entire Columbia system, at least within Canada. Recommendations in section 6 of this report speak to this need.

A number of reviewers commented on the tremendous challenges associated with attempting to understand nutrient dynamics, pelagic productivity and kokanee abundance and biomass in the

Arrow reservoir, considering variable reservoir levels, inflows and reservoir thermal regimes and hydrodynamics. Hydro-dynamic modeling is a potential tool to understand the effects of the more stable Arrow scenarios on nutrient dynamics; in particular, the Matzinger et al (2007) might be extended for this purpose.

One reviewer noted other potential consequences of more stable Arrow reservoir scenarios: (i) increased probability of establishment of zebra/quagga mussels; (ii) reduced impacts to native mussels; and (iii) theoretically, development of suitable habitat for shore spawning sockeye/kokanee, especially with Scenario 2.

4.4.4 Conclusions

The following Table 4 summarizes the potential effects of Scenario 1 and Scenario 2 operations in comparison to the current operating regime:

Table 4: Summary of potential effects of stable Arrow Scenarios on fish and aquatic ecosystems

Type of effect	Scenario One	Scenario Two
Effects on pelagic primary and secondary productivity and kokanee biomass	?	?
Effects on lower reaches of tributaries	0/+	+
Effects on littoral productivity	+	+
Effects on aquatic macrophytes and aquatic invasive species	+/-?	+/-?
Effects on the Revelstoke Reach section	?	?
Effects on burbot	0	0
Effects on white sturgeon spawning and incubation habitat conditions	+	+
Effects on anadromous salmon (if restored to the Arrow reservoir)	?	+/?

Key: ? Uncertain - Negative + Positive 0 Neutral

Given the wide range of uncertainties indicated, it is very difficult to evaluate the combined effects of multiple potential changes. As outlined in Section 4.4.2.1 the effects of the stable Arrow Scenario 1 on pelagic productivity generally and on kokanee productivity and biomass specifically are uncertain and could be either positive or negative. They may also differ between the upper and lower reservoir areas. The net effects of Scenario 1 on tributary fish passage, spawning and incubation habitat conditions are also uncertain in both direction and magnitude. Thus, combining these two uncertain effects we are faced with a degree of uncertainty with

respect to net effects of a Scenario 1 operation on kokanee abundance and on kokanee predators, for example bull trout and piscivorous rainbow trout.

As described in Section 4.4.2.2 with respect to Scenario 2, the abundance of kokanee as affected by tributary habitat conditions may be increased. The possibility of improved tributary passage and habitat conditions through the upper part of the drawdown zone, combined with reduced red stranding and desiccation/freezing, is likely (but not certain) to increase egg/fry deposition and survival with Scenario 2 in comparison to the reference condition. There is great uncertainty about the effect of Scenario 2 on reservoir pelagic productivity and thus on kokanee biomass. Thus, the most probable effect of Scenario 2 on kokanee is reduced spawner (and in reservoir) sizes and fecundity with uncertain effects on overall kokanee biomass and abundance.

For piscivorous (fish eating) rainbow trout, lower reaches of tributaries are generally not impaired during the spring runoff (and spawning migration) period and thus the effects of Scenario 2 should be neutral in comparison to the current operational regime. This leaves the uncertainty associated with the effects of Scenario 2 on pelagic (including kokanee) productivity to impair our ability to predict effects on this species. Arrow reservoir creel survey data suggests that the availability of adequate kokanee forage is the most important factor governing piscivorous rainbow trout abundance and biomass (S. Arndt, pers. comm.)

For fall-spawning bull trout, Scenario 2 should improve migration habitat conditions in the lower reaches of many tributaries. However, accessibility of most Arrow reservoir bull trout spawning streams is not considered to be impaired under the current operational regime by conditions within the drawdown zone. A large degree of uncertainty remains, however, as a result of our inability to predict the effects of Scenario 2 on pelagic productivity.

The potential effects of either Scenario 1 or 2 on ecological productivity and habitat conditions in the Revelstoke reach (from the Revelstoke dam to Arrowhead) are complex and, in many cases, conflicting. Anticipated benefits of a longer 'riverine' reach are reduced by the Revelstoke dam peaking/minimum flow operation. Short of an adaptive management experiment, it is likely impossible to predict either net benefit or net impact from the more stable Arrow scenarios on Revelstoke reach aquatic productivity and habitat conditions.

4.4.5 Information Needs

As described throughout Section 4.4 and in the conclusions section, there is a high degree of uncertainty about both the direction (positive/beneficial vs. negative/harmful) and magnitude of many of the potential effects of either of the proposed Scenarios on aquatic ecosystems and fisheries. What is reasonably certain, however, is that at least some of the potential effects of the proposed Scenarios on fish and aquatic ecosystems are likely to be important. Thus, further fisheries and aquatic ecosystem investigations are of fundamental importance in making decisions about a potential stabilized Arrow reservoir operation, along the following lines:

- Research within the affected indigenous nations to acquire, compile and understand Traditional Ecological Knowledge pertaining to historic Arrow Lakes fish and aquatic ecosystems;
- Ecosystem modelling of the ALR, focusing on reservoir hydrodynamics, water residence time patterns, turbidity, water temperature, nutrient dynamics and primary and secondary pelagic, littoral and kokanee productivity;

- Comprehensive seasonal analyses of fish population life history requirements vs. availability in the Revelstoke Reach under the current operating regime and Scenario 1 and/or 2;
- Analysis of the effects of a stabilized Arrow operation on vegetated communities (and associated fish communities) in the lower portion of the Revelstoke Reach;
- Comprehensive assessment of the potential benefits and impacts associated with development of aquatic macrophyte communities, including invasive aquatic macrophytes, introduced fish species including northern pike and other invasive aquatic species such as zebra/quagga mussels;
- A thorough assessment of fisheries and aquatic ecosystem effects, of the proposed stabilized, mid-elevation Arrow reservoir scenarios on the transboundary reach of the Columbia River (downstream of the Hugh Keenleyside dam) including any changes to Total Gas Pressure as a result of operational changes at ALGS and HLK dam is essential.
- Assessment of fish stranding under the current operating regime versus under the more stable reservoir scenarios;
- Quantitative assessments to augment the largely qualitative assessments outlined in these sections, either from existing data and literature or from field studies;
- Modeling of the effective littoral zone and nearshore rearing habitat conditions under the current regime versus Scenarios 1 and 2. This modeling will need to include information from detailed updated topographic and bathymetric surveys of the drawdown zone;

It is possible that research and monitoring program to address some of these data gaps could possibly be funded through a Fish and Wildlife Compensation Program “Directed Study”.

See Table 8 at the end of Section 5 for a summary of all issues.

4.5 Archaeology¹⁴

4.5.1 Introduction

Archaeological work has been conducted in many forms within the Arrow Lakes Reservoir for the past fifty years. This work has been driven by different objectives and projects and has resulted in a rich depiction of the archaeological record, but has also shown the impact of development that has occurred within the region, including the building of hydro-electric dams. Prior to the construction of the Hugh Keenleyside Dam, many of the archaeological sites recorded were still relatively intact, and provided information about the past human life ways within the region.

The following information is based on the reporting of the full suite of work within the ALR, including the Revelstoke Reach, for the past fifty years, which has many limitations. Since the flooding of the ALR, there has never been a true accounting of the nature or condition of the

¹⁴ Primary author: Nicole Kapell

more than 100 archaeological sites known in the ALR drawdown zone. It is difficult to assess the impacts of different operating scenarios on these archaeological sites as an accurate representation of the physical characteristics of those sites does not yet exist. However, this section discusses possible impacts of different operating scenarios on the current condition of the archaeological sites within the Arrow Lakes Reservoir.

Archaeological surveys and impact assessments are currently occurring within the draw down zone (DDZ) of the ALR on an annual basis as a part of BC Hydro's Reservoir Archaeology Program. The current survey just completed year 5 of 10 of this program in the spring of 2015. New archaeological sites are recorded within the DDZ on an average of 10 sites per year. Recorded archaeological sites range in elevations from 1,407.5 ft. (429 m) to 1,502.6 ft. (458 m) and are impacted in various ways by the operation of both the Revelstoke and Hugh Keenleyside dams.

Archaeological sites can be impacted directly through wind and wave action, which can cause deposition or erosion of sediments within a site boundary. This wind and wave activity not only moves artifacts that were left *in situ*, but also destroys any intact soils which provide the context for the archaeological site (i.e. date, pre-historic ecology, environmental events over time, etc.). In some cases, entire landforms containing archaeological information have been seen to be washed away from one year to the next, causing entire sites to be lost (Choquette & Thompson, 2014).

Through the rising and falling of water levels within the reservoir any contextual information used to assess an archaeological site is lost. All that is left are artifacts randomly deposited either on the surface of a landform or just below the surface. These artifacts have been recorded to be moved around on an annual basis (Parker et al, 2012), and therefore tell a very small fraction of the story behind the archaeological site.

A second, indirect impact, of the operations of the ALR also occurs through erosion; that is the exposure of artifacts to the public. As mentioned above, artifacts are moved around by wind and wave action both while inundated and while reservoir levels are rising and falling. These artifacts are often left exposed on public beaches and every year many people walk these beaches looking specifically for artifacts to take (Brown & Oakes, 2014). This "pot-hunting" is illegal in British Columbia under the Heritage Conservation Act. In many cases, when an archaeological field crew begins their annual survey in the spring, the public have already combed the beaches within the ALR and have taken the artifacts. As mentioned, these artifacts are the only surviving remnants of an archaeological site, and once removed all evidence of a vibrant culture at that location is lost.

Finally, given the elevation of the recorded archaeological sites extends outside of the DDZ, activities that occur adjacent to the DDZ should also be taken into account when analyzing these scenarios. Any activity that disturbs the ground has the potential to impact an archaeological site. These activities include, but are not limited to, recreational use, including the use of off-road vehicles (ORV), revegetation projects, and development associated with residential properties including beach creation and grooming, road building, boat launch creation and upkeep, etc. The creation of a reservoir along the Arrow Lakes and Columbia River attracts residents and increases human use of the area, which can increase the potential for impacts to archaeological sites.

4.5.2 Evaluation of Scenarios

Scenario 1

Based on current data, approximately 30% of recorded archaeological sites are below 1,425 ft. (434.3 m.) within the ALR (Cameron et al, 2013, 2013a, 2014, 2014a & BC Hydro 2010b, c.) Under Scenario 1 reservoir water levels fluctuate 1,421 – 1,425 ft. (433.1 - 434.3 m.) during the spring and fall for short periods, and are held at 1,425 ft. (434.3 m.) for the remaining period for 4 out of 5 years. This annual fluctuation could be detrimental to the sites located between 1,421 and 1,425 ft. (433.1 - 434.3 m.) as there could be continual wave/current action occurring throughout the year. If wave height of 1 ft. is taken into consideration, landforms containing archaeological artifacts between 1,420-1,426 ft. (432.8-434.6 m.) would be subject to erosive wave action. In some reservoir shoreline areas subject to high waves from storm events, wave erosion may affect sites up to 1,430 ft. (435.9 m.). Approximately 2% of recorded sites are at 1,425 ft. (434.3 m.), and would be impacted severely by the wind and wave action under this scenario, not only through erosion but through movement of sediment along the surface of a landform. This type of movement through wave action has been documented in the Duncan Reservoir (Golder Associates 2011) to be the cause of the displacement of smaller lithic material or “flakes”. In some cases, the flakes have moved several meters from their original location; in others they disappear from the site area altogether.

Approximately 70% of recorded sites are located above 1,425 feet (434.3 m.) (Cameron et al. 2013, 2013a, 2014, 2014a & BC Hydro 2010b, c). Under Scenario 1, these sites would be exposed year round in four out of five years (sites above 1,425 ft. are now exposed for 170 days or 47% of the year on average). Exposure could lead to pot hunting, but there are many ways to prevent this from occurring, and the benefits could outweigh the impacts. For example, an archaeological field crew could re-visit exposed sites and systematically collect artifacts in order to collect any remnant data, and store those artifacts in a centrally located museum. Crews could also establish an extensive re-vegetation program within site areas. Vegetation has the ability to hide artifacts lying on the surface, and also creates landform stability which would further prevent erosion. Revegetation success however would vary as discussed in Section 4.2.2 and would likely be limited to herbaceous species below 1,440 ft. (438.91 m.). In terms of adjacent activities impacting these sites, holding the reservoir below 1,425 ft. for four years may encourage development activities within the upper limits of the DDZ, increasing the potential for those activities to impact sites. Again, establishing vegetation may discourage the use of ORV and other recreational activities.

In one in five years, reservoir levels will rise and fall 23 ft. (7 m.) to a maximum elevation of 1,444 ft. (440.1 m.) over a period of six months. Archaeological sites located at elevations up to full pool would be subject to wave and wind erosion in that year. Overall archaeological site degradation would be marginally better to that experienced under current reservoir operations since the established herbaceous vegetation would be compromised immediately following a 6 month inundation at some lower elevation locations.

Sites below 1,420 ft. (432.8 m.) would be submerged year round and not subject to wave erosion. However, sediments eroded from higher elevations would settle and aggrade in shallow areas below 1,420 ft. (432.8 m.). Full inundation of archaeological sites has been seen by some to be beneficial, as it is in essence preserving those sites from disturbance. Others do not feel that inundation is a preservation method, and therefore this scenario could be considered by some as detrimental to sites below 1,420 ft. (432.8 m.).

Scenario 2

Under Scenario 2, the reservoir levels would remain at 1,420 ft. for 6 out of 7 years. Reservoir banks in the elevation band of 1,419 – 1,421 ft. would be exposed to constant wave action and resulting erosion. In some reservoir areas exposed to long reservoir fetches elevations up to 1,425 ft. (434.3 m.) would be exposed to and eroded by waves during storm conditions. As a result, archaeological sites located between 1,419 – 1,421 ft. (432.5 - 433.1 m.) and up to 1,425 ft. (434.3 m.) in some exposed locations would likely be severely degraded or completely lost under Scenario 2 without mitigation measures. Archaeological sites located at elevations below 1,420 ft. (432.8 m.) would be submerged and subjected to deposition from erosion originating from higher elevation areas, and water current erosion depending on the site location.

Most archaeological sites above 1,421 ft. (433.1 m.) - an estimated 80% of recorded archaeological sites within the draw down zone - would be protected from wave and wind erosion in 6 of 7 years if mitigation measures were effective. Establishment of mature shrub and tree riparian vegetation (as discussed in Section 4.2.2) would greatly reduce wind erosion and conceal archaeological sites from pot hunters above 1,430 ft. (435.9 m.). Archaeological sites in the elevation range 1,421 - 1,430 ft. (433.1 – 435.9 m.) would likely be protected, to a lesser degree, from pot hunters and wind erosion with the establishment of dense herbaceous vegetation. In terms of residential and recreational impacts, again the amount of development at or just above full pool may increase as developers have more assurance of water level stability. This increase in use would increase the negative impacts to archaeological sites. Establishing vegetation in site locations could discourage development and use, but may have the opposite effect of attracting people to the locations.

In the 7th year reservoir levels would rise and fall 24 ft. between 1,420 ft. and 1,444 ft. (432.8 m. and 440.1 m.) over a period of six months. Minor erosion of archaeological sites from wave action would occur but herbaceous vegetation (1,421-1,430 ft.; 433.1 – 435.9 m.) and mature vegetation (above 1,430 ft.; 435.9 m.), if successfully established, could greatly reduce potential artifact displacement from wind and wave erosion, or loss of artifacts due to pot hunting.

4.5.3 Conclusions

The impacts to archaeological sites within the ALR are greatly dependent on mitigation strategies, as well as how well erosion control would work (i.e. establishment of vegetation). Based on initial review of the variables, it would seem that both scenarios would have less of a negative impact on archaeological sites than the current reservoir operations, even absent mitigation. With mitigation, there would be less of a chance that archaeological sites would be negatively impacted or destroyed. Under Scenario 1, archaeological sites within the elevation 1,420-1,426 ft. (432.8 – 434.6 m.), and possibly up to 1,430 ft. (435.9 m.) in some locations, would be severely degraded or lost absent mitigation efforts. Protection of sites from 1,426-1,444 ft. (434.6 – 440.1 m.) would be marginally better than under current operations due to reduction in wave damage and increased herbaceous cover.

Scenario 2 would allow for the greatest benefit to the stabilization and protection of the remaining archaeological sites and material. Archaeological sites located between 1,419 – 1,421 ft. (432.5 – 433.1 m.) and up to 1,425 ft. (434.3 m.) in some locations would likely be severely degraded or completely lost under Scenario 2 without mitigation measures. However, most sites between

1,421 and 1430 ft. (433.1 – 435.9 m.) would be better protected from wave and wind erosion if the establishment of herbaceous vegetation were successful and because of reduced inundation. Sites above 1,430 ft. (435.9 m.) would be largely protected under successful establishment of shrub and tree vegetation and because of greatly reduced inundation. Pot hunting would also be more difficult with improved vegetation establishment above 1,421 ft. (433.1 m).

Archaeological sites below 1,420-1,421 ft. (432.8 – 433.1 m.) will be submerged year round in both Scenarios. Opinion varies as to whether complete inundation is a positive or negative outcome of a constant reservoir elevation scenario.

See Table 8 at the end of Section 5 for a summary of all issues.

4.5.4 Information Needs

The following additional data analysis is required to further understand the implications of both Scenarios on archaeological sites:

- Further exploration of concerns and benefits of archaeological site continuous inundation as a preservation strategy;
- Further understanding of the current condition of archaeological sites in the ALR (ongoing as a part of the Reservoir Archaeology Program) specifically more detailed information on the affected sites, size, content, condition, stratigraphy, surficial geology, aspect, and sedimentology;
- Further understanding of mitigation options (i.e. perceived benefits are based on assumption of the successful establishment of vegetation and accurate modeling of erosion under different operating scenarios).

4.6 Recreation¹⁵

4.6.1 Introduction

Over the decades since the Hugh Keenleyside dam was constructed, there have been a number of studies regarding recreation use of the reservoir, as well as various consultations regarding BC Hydro operations that included input by recreational users. The potential for benefits or negative impacts of moving to a constant mid-elevation operating regime, with an occasional full pool, vary somewhat depending on the recreation activity examined and point-of-view of the stakeholder group responding.

¹⁵ Primary author: Greg Utzig

4.6.2 Boat-based Recreational Users/ Stakeholders

4.6.2.1 Literature Review

The largest and most comprehensive survey of recreational users collected data from recreational boaters over a period of 5 years at 11 public boat launch sites and 2 day-use areas widely distributed around the reservoir (Lees + Assoc. 2015b). Results of this study indicated that boaters showed little preference for specific water levels, other than a weak aversion to very low and very high levels. Overall use was found to be positively correlated with higher water levels; however, this was confounded by the fact that higher levels coincided with the summer months when most people had holidays.

Some survey comments suggest that the main issues with very high water levels were the lack of beaches and the increase in floating debris. Issues associated with very low water levels were the emergence of boating hazards, lack of access to some areas by boat, and unsightliness of the shoreline.

Boaters were also surveyed with respect to their satisfaction with boat launching facilities (Lees + Assoc. 2015a). Survey responses indicated that one of the most important issues was the availability of boat launching opportunities on a year-round basis, regardless of the water elevation.

4.6.2.2 Summary of Interview and On-Site Visit Results

Interviews with recreational consultants confirmed that in general the boating public showed little preference for specific reservoir elevations. The consultants also confirmed that they had not used any survey questions that would indicate users' preferences with regard to the two Scenarios. On-site visits confirmed the recent installation and upgrading of boat launch facilities that were accessible at all or most reservoir elevations. Limited discussions with boaters generally confirmed the survey results, but also demonstrated they generally had a very limited knowledge of reservoir operations.

4.6.3 Shoreline-linked Recreational Users/ Stakeholders

4.6.3.1 Literature Review

There is limited literature that specifically identifies issues related to shoreline-linked recreational users – mainly shoreline property owners, shoreline business owners and campers (surveys to date have mostly focused on boating recreational users). Given our discussions with shoreline property owners and businesses, it is likely that many of the comments that are summarized from the Soft Constraints Review (BC Hydro 2014a) that call for a lengthened summer season of full pool or elevations above 1,435 ft., (437.4 m), likely are comments from waterfront landowners and/ businesses. These stakeholders are also among those who are calling for better communication and reliability of predictions of short term and seasonal water levels.



Figure 12: Shore based recreationalist at McDonald Provincial Park, ALR. July 14, 2016. ALR water elevation 1,422 ft. (433.6 m.)

4.6.3.2 Summary of Interview and On-Site Visit Results

Based on a limited set of interviews, it appears that shoreline property owners prefer constant higher water levels (likely around 1,430 – 1,435 ft., 435.9 – 437.4 m). They prefer levels at which shoreline docks, wharves and personal boat launch facilities operate most efficiently, and yet a moderate amount of beach is exposed. However when property owners were questioned about a constant level of 1,420-1,425 ft. (432.8 – 434.3 m), some agreed that they could adapt to that elevation if necessary, especially if the water level was more constant and more predictable. Their level of support for a new regime would also significantly increase if some form of assistance (financial and/or appropriate works) was provided for adapting to the new regime. Some property owners commented that minimizing or avoiding full-pool elevations would have the benefit of decreased flood risk for lakeshore properties.

Entities that operate large public recreational facilities, such as the beach in Nakusp, would also prefer to see higher constant water elevations. However when questioned regarding adaptation to lower levels, they also indicated they could adapt, and could see advantages if the levels had reduced fluctuations, and were more predictable.

There are three marinas on the reservoir. The commercial marina operator near the lower end of the reservoir would prefer a more constant elevation operating regime, preferable at 1,428-1,430 ft. (435.2 – 435.9 m). Fluctuating elevations (up to 16 ft. per month) create maintenance and safety issues for the marina. At low reservoir elevations, ramps leading out to the floating marina structure are dropped onto the uneven reservoir bottom that shifts and erodes each season, resulting in dangerous tilts. The boat launch ramp is inoperable below an elevation of 1,408 ft. (429.2 m). Local clientele generally avoid using the marina during low levels.

The marina operators could adapt to a constant reservoir elevation at 1,420-1,425 ft. (432.8 – 434.3 m), and would be more open to that elevation range should there be funding available to assist with adapting to that elevation. The 1 in 5 or 1 in 7 full pool frequency is not an issue, as they already have infrastructure in place to cope with those elevations. However, there may be some issues with fast flowing water currents in front of the marina during times of peak flow, especially during rapid drawdown events.



Figure 13: Scotties Marina, ALR. July 21, 2015. ALR water level 1,420 ft. (432.8 m.)

Terrestrial recreation users interviewed who recreate in the drawdown zone (hikers, bird watchers, bicyclists, etc.) show a strong preference for more constant lower water levels, as there would be more recreation sites available for longer periods of the year (e.g. the old rail bed in the Revelstoke Reach for biking and walking, trails near Revelstoke). Some non-motorized boat users complained about having to carry their water-craft long distances to the water when the reservoir was at lower elevations or when water levels are unexpectedly low. Some shoreline recreational users expressed concern that many beaches are unavailable due to flooding when reservoir levels are at full- or near full-pool levels during peak summer swimming season under the present operating regime. People in Revelstoke have stressed that recreational use in the drawdown zone should be managed to prevent damage to habitat values.

The lack of predictability of water level fluctuations was repeatedly raised as a major concern, especially by shoreline property owners. There seemed to be a general concern that the water level predictions by BC Hydro were not reliable, and were often inaccurate (even on a daily and weekly basis). This lack of faith in BC Hydro reliably adhering to specific patterns of reservoir management tempered their support for a new operating regime, because they didn't have faith that it would be reliably implemented. However, virtually all of those interviewed support a constant elevation scenario over the current reservoir operating regime.

4.6.3.3 Conclusions

In general the proposed Scenarios would be moderately positive for boat-based users, as there would be no occurrences of extreme low water, and only occasional occurrences of extreme high water levels (1 in 5 or 1 in 7 years). Under both Scenarios it should require less capital investment and maintenance effort to achieve year-round access to boat launch facilities due to the reduction in water elevation range that the facilities operate within. Where substrates are suitable, beaches would likely form at the baseline elevation, and be available in most years for much of the summer. Terrestrial users of the drawdown zone would benefit significantly with increased access to trails on a year-round basis in most years. Bird watching and animal viewing opportunities would increase with increased habitat availability (see Section 4.2.3 for discussion of wildlife). Beach access and extent would be significantly improved in both scenarios when compared to full pool water levels.

The proposed Scenarios are not the preferred option for shoreline landowners and marina operators (preferring a constant elevation in the range of 1,428 to 1,435 ft. (435.2 – 437.4 m), although they are also unhappy about the present annual fluctuating operational regime. Under the proposed Scenarios they would benefit from increased certainty and predictability of reservoir elevation, and some would gain aesthetically as the now bare DDZ would be revegetated, while others may have their views obstructed from the eventual establishment of mature forest vegetation. Debris deposition would likely be reduced, except in flood years. Depending on the specifics of their shoreline topography and their pattern of reservoir use, some landowners may consider the Scenarios a net benefit over present operation patterns, while others may not.

The exact baseline constant water level, and pattern of annual fluctuation that would be most advantageous for recreational users will require further study, and will likely vary depending on the focus of individual users and the specific property or recreational use location on the reservoir.

Fishers as a recreational user group are assumed to be primarily concerned with changes to fisheries productivity although it is well known that the fishing experience itself is of considerable importance to recreational fishers. The uncertainty regarding impacts on fish populations makes it difficult to assess potential impact on recreational fishers. Off-road recreational users will likely lose area available for their activities as revegetation occurs under both Scenarios and low gradient areas currently exposed under lower water conditions remain inundated. However off-road recreational use may increase in the early years, creating a need for access management where it conflicts with revegetation objectives. Conflicts between off-road use and other values (e.g. wildlife habitat, agriculture, archaeological sites) may also increase.

4.6.4 Information Needs

- more surveys that specifically target potential scenarios and their impacts, as well as differentiation between user groups and geographic areas;
- necessary fluctuation and seasonality in reservoir levels to maintain beaches;
- fishers as a recreation group, and their potential responses to the scenarios;
- investigation of potential recreation sites and beach formation associated with various baseline elevations;
- investigation of shoreline owner impacts and possible mitigation strategies;

- modelling (or measurement) of water currents in recreational areas that may pose a safety hazard during rapid drawdown, and investigation of mitigation strategies where appropriate;
- potential interactions with off-road vehicle use, and investigation of mitigation strategies where appropriate (e.g. archaeological sites).

See Table 8 at the end of Section 5 for a summary of all issues.

4.7 Commercial Navigation and Operations¹⁶

4.7.1 Introduction

Several companies around the Arrow Lakes - Interfor Forest Products, Zellstoff Celgar and NacFor and other smaller logging contractors - rely either directly or indirectly on log tow transportation in the ALR between the upper reservoir and the Castlegar area. Water levels in the reservoir have a direct impact on both log raft transport through the Narrows and the efficiency of the operation.

Interfor Forest Products Ltd. operates a large sawmill in Castlegar adjacent to the Zellstoff Celgar pulp mill. Interfor has multiple operating areas around the Arrow Lakes and supplies approximately 70% of its Castlegar mill with wood that originates above the Arrow Lakes Narrows. Zellstoff Celgar has no wood tenure in the Arrow Lakes but instead purchases wood from various forestry contractors at log dumps and contracts Interfor to transport the logs to the Castlegar pulp mill. Approximately 15% or 400,000 m³ of Celgar's wood supply originates above the Narrows. Nakusp and Area Community Forest (NacFor) is a small logging contractor and community forest tenure holder owned by the village of Nakusp and provides seasonal employment ranging from 3 to 20 employees. NacFor sells wood to Interfor and Celgar at the log dumps but does not operate log tows on the lake.

4.7.2 Literature review

There are no studies other than the BC Hydro Technical Review that describe impacts on commercial Navigation under a constant elevation Scenario. The Technical Review found that commercial navigation would improve significantly in Scenarios that maintained ALR water elevations above 1,420 ft. (432.8 m.) for long as possible over the year.

4.7.3 Operational Overview and Interview Summary

Harvested wood is brought by logging truck to eleven log dumps around the reservoir. While still on the truck, logs are bundled with cable wrap and then pushed onto a skidway by a front end loader at the water's edge. Log bundles roll down the skidway and are corralled into a raft approximately equal to 50 logging truck loads. Log rafts are secured in pens until approximately 18 rafts are assembled and combined to equal one "tow" equal to 900 logging truck loads. A large

¹⁶ Primary author: Alan Thomson

tug transports a tow down the lake through the Narrows towards Castlegar over a 10-12 day period.



Figure 14: Interfor log sort and dump at Halfway Creek, ALR. July 13, 2015.

Log dump operators and supervisors interviewed stated that fluctuating reservoir levels reduce operational efficiency at log dump sites and during the tow down towards Castlegar. At log dumps fluctuating water levels require that dump site operators frequently reposition skidways in response to changing water elevations. In addition, wave action erodes bank materials and can undermine skidway foundations. Operators then have to reposition or reinstall skidways notably in the spring period resulting in lost time and work place inefficiencies. Under a constant elevation scenario, Interfor would consider replacing the log dump skids with an “A-frame” crane where logs would be lifted off the trucks and lowered into the water, a much safer procedure over current procedures. Since the reservoir’s edge under current operations is constantly moving, an “A-frame” setup is not possible.



Figure 15: Interfor tug boat in the Narrows. July 14, 2015.

An additional and significant source of operational inefficiency results from log tows being restricted in the Narrows due to low water typically during January to mid-April. Large tows of 18 rafts are unable to navigate the Narrows below 1,420 ft. (432.8 m.). Between 1,410 (429.8 m.) and 1,420 ft. (432.8 m.) the 18 raft tows have to be broken down into smaller 8 raft tows and reassembled. Below 1,410 feet, tows are further reduced in size to 5 rafts. Below 1,400 ft. (426.7 m.), navigation through the Narrows becomes extremely difficult and the tug must follow the narrow and winding Burton channel. When log transport is compromised as described above, the cascading economic impact is felt by upstream suppliers and downstream buyers and users of the wood fiber. Logs are difficult to unload under low water conditions, and this affects logging and trucking contractor employment and scheduling. Downstream, Celgar and Interfor may be required to source alternative supplies of fiber, and/or incur higher costs to bring the tows down the ALR and through the Narrows under sub-optimal conditions.

4.7.4 Conclusions

Stabilizing the ALR at or above 1,420 ft. (432.8 m.) is considered optimum for commercial operations on ALR. Operations would be much more predictable as operators at the various log dumps would know weeks in advance whether the ALR would remain stable or rise to contain floodwaters, and could plan operations accordingly. Occasional flooding up to 1,444 ft. (440.1 m.) is not considered problematic as the infrastructure to operate under these conditions already exists. Hence from a commercial navigation perspective there is practically no difference between the two Scenarios. According to Interfor interviewees, both Scenarios are much preferred over existing reservoir operations.

4.7.5 Information Needs

Reservoir operations that affect log sort facilities and log transport on the ALR are well understood and documented. No further data requirements or information gaps were identified during this study.

See Table 8 at the end of Section 5 for a summary of all issues.

4.8 Agriculture¹⁷

4.8.1 Literature Review

With the exception of information on agricultural areas prior to dam construction, no literature was found regarding agricultural potential in the drawdown zone.

The dam impacts study completed by the Fish and Wildlife Compensation Program – Columbia Basin (Utzig and Schmidt 2011) reported that approximately 2,200 ha of the DDZ were in orchards, under cultivation, or had been cleared for pasture prior to dam construction.

In a recent report for the Columbia River Treaty discussions, Penfold (2012) summarizes agricultural activity prior to inundation, noting various types of agricultural production. Penfold quotes reports from the 1960s indicating there were approximately 260 farmsteads in the area, with the majority of them under 12 ha in size, and the remainder between 12 and 70 ha. According to those reports approximately 2,400 ha of agricultural land use included orchards, hay, cereal grains, vegetables and pasture. It was also estimated at the time that there was an additional 5,200 to 9,500 ha in the area that had agricultural potential.



Figure 16: Area with agricultural potential in the Revelstoke Reach. July 13, 2015. ALR water elevation 1,422 ft. (433.4 m).

A recent report on agricultural potential in the West Kootenays has indicated that the potential for agricultural production may increase with climate change, given the projected increases in frost free period and degree days during the growing season (Roussin 2014).

¹⁷ Primary author: Greg Utzig

4.8.2 Summary of Interview and On-Site Visit Results

Interviews with agricultural practitioners adjacent to and within the drawdown zone confirmed that there is potential for expansion of agricultural production within the drawdown zone.

Presently there are agricultural operations in the Revelstoke Reach that utilize approximately 400 ha of the drawdown zone for grazing and hay production. They operate on private land and land leased from BC Hydro, the Crown and other owners. The operations make use of reed canary grass and other grasses, as well as some improved pasture areas. The main limitations are the length of season when the farmlands are not inundated, as well as having to occasionally clear in-washed debris.

In response to the proposed Scenarios, an agricultural operator said that both Scenarios would definitely improve his operations, and would allow for expansion of both grazing and hay production areas. It would also likely increase productivity of existing use areas due to longer seasons.

The possibility for growing other crops was also discussed with a number of agricultural stakeholders. There are likely possibilities for cereal production in some areas (primarily the Revelstoke Reach), and a variety of vegetable crops at various sites throughout the reservoir. Use of the drawdown zone for annual crops would be greatly enhanced with a reliable spring warning system regarding the likelihood of that year being the 1 in 5 or 1 in 7 full pool operating year. Agricultural use would generally be limited to sites with suitable soils and topography, access to irrigation water, and likely require investments in soil amendments. Dust control may be a limitation for annual crops in some areas.

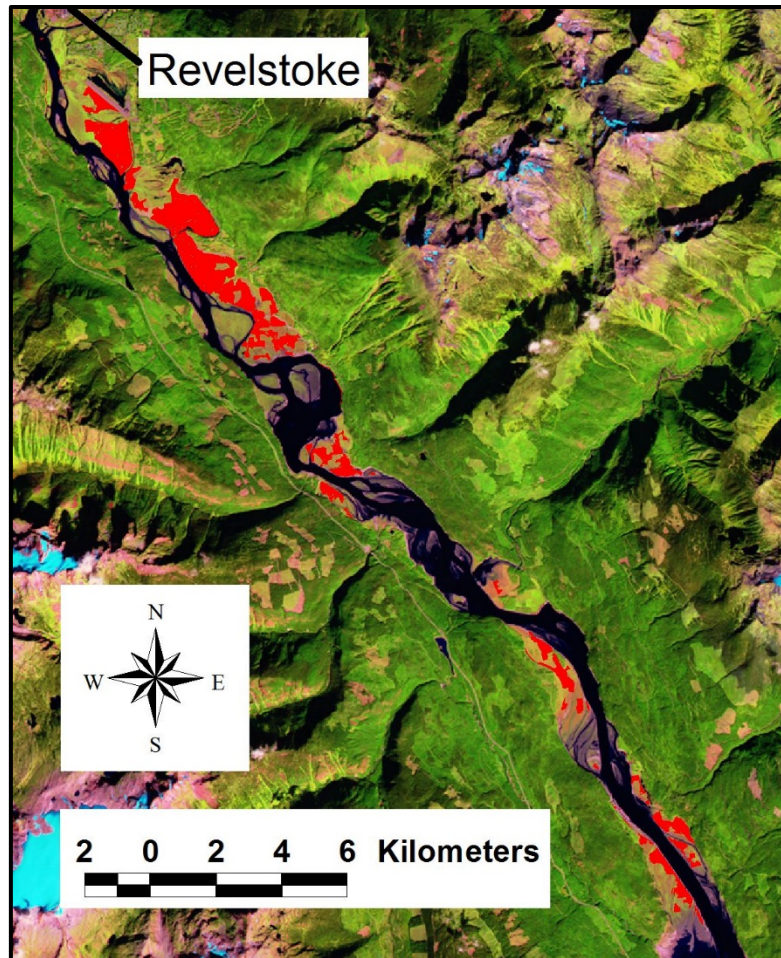


Figure 17: Revelstoke Reach locations of pre-dam agricultural activities above 1,417 ft. (432 m) prior to dam construction (red infill).

4.8.3 Conclusions

Both Scenarios will provide significant opportunities for the expansion of agriculture in the drawdown zone, including both increased area and increased diversity of crops. Scenario 2 will provide greater opportunities due to the lower water levels exposing more potential agricultural lands with less frequent inundation. Development of seasonal inundation risk projections and effective communication of those risks to the agricultural operators in the drawdown zone would increase production potential in the drawdown zone.

Based on the location of agricultural activities above 1,417 ft. (432 m) prior to 1967 (see Figure 16), it is estimated that Scenario 2 would likely provide access to at least 1,000 ha of lands with significant agricultural capability. Most of these lands would be in the Revelstoke Reach, however other small areas with potential would also be available near Shelter Bay, Nakusp, East Arrow Park, Burton, Needles, Applegate and Renata.

4.8.4 Information Needs

- an inventory of agricultural potential within the drawdown zone above the selected baseline elevation (including limitations due to climate, topography, soil texture and nutrient status)
- an assessment of the potential range of crops suitable for the drawdown zone
- research to aid in the development of an effective agricultural land tenure system for the drawdown zone that encourages and supports agricultural operations, while taking into account the unique risks associated with periodic inundation

See Table 8 at the end of Section 5 for a summary of all issues.

4.9 Power Generation - Arrow Lakes Generating Station¹⁸

4.9.1 Overview and Literature Review

Arrow Lakes Generating Station (ALGS) is a 185 MW hydroelectricity generation plant located approximately 400 m downstream of the BC Hydro-owned Hugh L. Keenleyside dam near Castlegar, BC. The facility was built between 1999 – 2002 at a cost of approximately \$270 million to generate electricity from water that was previously spilled. The facility is equally owned by the Columbia Basin Trust (CBT) and Columbia Power Corporation (CPC). Facility day-to-day operation is coordinated by BC Hydro which receives all of the resulting power and remunerates the partnership under a long-term, fixed-price power sales agreement (Columbia Power Corp., n.d.). The current electricity purchase agreement between BC Hydro and CPC/CBT expires in 2045.

ALGS was designed and is operated on the assumption of an annually fluctuating ALR hydrograph that can vary up to 66 ft. (20.1 m) from 1,378-1,444 ft. (420.12 – 440.1 m.) with the ability to surcharge an additional 2 ft. to 1,446 ft. (440.7 m.) The CRT and to a lesser degree the NTSA dictate the ALR hydrograph profile for any given year given forecasted and actual hydrologic runoff (see Figure 3 in Section 2.2). Numerous sub agreements and negotiated short term adjustments between the entities allow for additional minor seasonal variations of ALR discharge and water elevation. However, year over year the hydrograph follows the same pattern of high water elevations post spring freshet and a deep draft in the pre-freshet early spring period¹⁹.

ALGS power generation output typically follows the hydrograph, with maximum generation output during high water and discharge months of July and August, and minimum output during April as the ALR starts to fill and hydraulic head and discharge is low. Annual plant maintenance

¹⁸ Primary author: Alan Thomson

¹⁹ During exceptionally dry years with lower runoff (e.g. during the summer of 2015), a “Dry Year Strategy” is invoked (CRT ‘Proportional Draft’) that requires the ALR to be drafted in the summer months much earlier and deeper than is typical.

– and ALGS shutdown - is typically scheduled in the spring period when power generation potential and wholesale electricity prices are low. Because of intake channel restrictions, the plant typically commences generation at reservoir elevations above 1,398- 1,400 ft. (426.11 – 426.7 m.), although minimal power can be generated at water elevations as low as 1,395 ft. (425.20 m.).



Figure 18: Arrow Lakes Generating Station (left) and Hugh Keenleyside Dam (right). May 8, 2015.

There is little literature on the operation of ALGS under a constant elevation Scenario other than what was modelled and reported by BC Hydro for the CRT technical review (BC Hydro 2013a,b), and some studies conducted by U.S. interests (Canadian and United States Entities 2010). The BC Hydro studies do not detail specific ALGS operational inputs or outcomes but only summarize financial outcomes of four constant elevation Scenarios on a BC system-wide basis. The U.S. studies attempt to analyze system wide impacts under various Treaty outcomes and in most models assume that ALR will operate at or near full pool to maximize power production within Canada (Canadian and United States Entities 2010). Otherwise, there are no known publicly available studies that evaluate ALGS in an ALR constant elevation scenario.

4.9.2 Discussion

At 185MW generating capacity, ALGS is the smallest generating station on the Columbia River mainstem, and the smallest owned by CPC/CBT. The relatively small capacity is primarily due to the low hydraulic head available to the turbines.

In order to gain an approximate indication of the power generation potential for the two Scenarios under consideration, historical ALGS generation data was used to build a basic model for the two Scenarios. For this high level of analysis and reporting a simple model is considered appropriate

to indicate approximate generation values for the Scenarios. More accurate generation figures will be determined upon further detailed plant generation modelling. Turbine discharges were approximated using simulated data from BC Hydro's CRT technical studies and augmented with theoretical flowrates and water elevation profiles for high water years. Modeled generation values were then compared with actual generation values in order to compare current ALGS generation to Scenario generation values.

ALGS has been operational and generating power since 2003 (see Figure 18). Power generation ramped up for the first 4 years, and has become more consistent in later years. Since the startup period - 2003 to 2006 - is not indicative of current plant generation this period is not included in the following analysis and discussion.

Over the six year period between 2007 and 2012, ALGS annual generation ranged from approximately 800 GWhr to 1,060 GWhr or 906 GWhr on average. In two of the six years (2008, 2011) annual generation was on average 1,060 GWhr and the remaining four years annual generation was on average 827 GWhr (see Figure 18). The two years of higher annual generation can be partially attributed to relatively high reservoir water elevations in the spring and fall periods that produced greater hydraulic head than typical for these periods.

Power generation outcome modelling of the two Scenarios found that average ALGS annual generation at a constant reservoir water elevation in both Scenarios is approximately equal for Scenario 2 (1,420 ft./432.8 m.) or slightly greater for Scenario 1 (1,425 ft./434.3 m.) than historical average annual generation under the current reservoir and plant operational regime. Projected annual generation figures for both Scenarios are based on assumptions concerning discharge and a theoretical hydrograph and should be interpreted with caution. Scenario 1 average generation for 4 of the 5 years is very similar to the two highest generation years (2008, 2011), and the 1 in 5 year value exceeds the high generation years by 12%. As expected, Scenario 2 average generation values are lower than Scenario 1 due to the 5 ft. (1.5 m.) difference in hydraulic head. Scenario 2 average generation values are more similar to existing generation values than Scenario 1, suggesting that a constant elevation value of approximately 1,420 ft. (432.8 m.) is neutral in impact on ALGS average power generation.

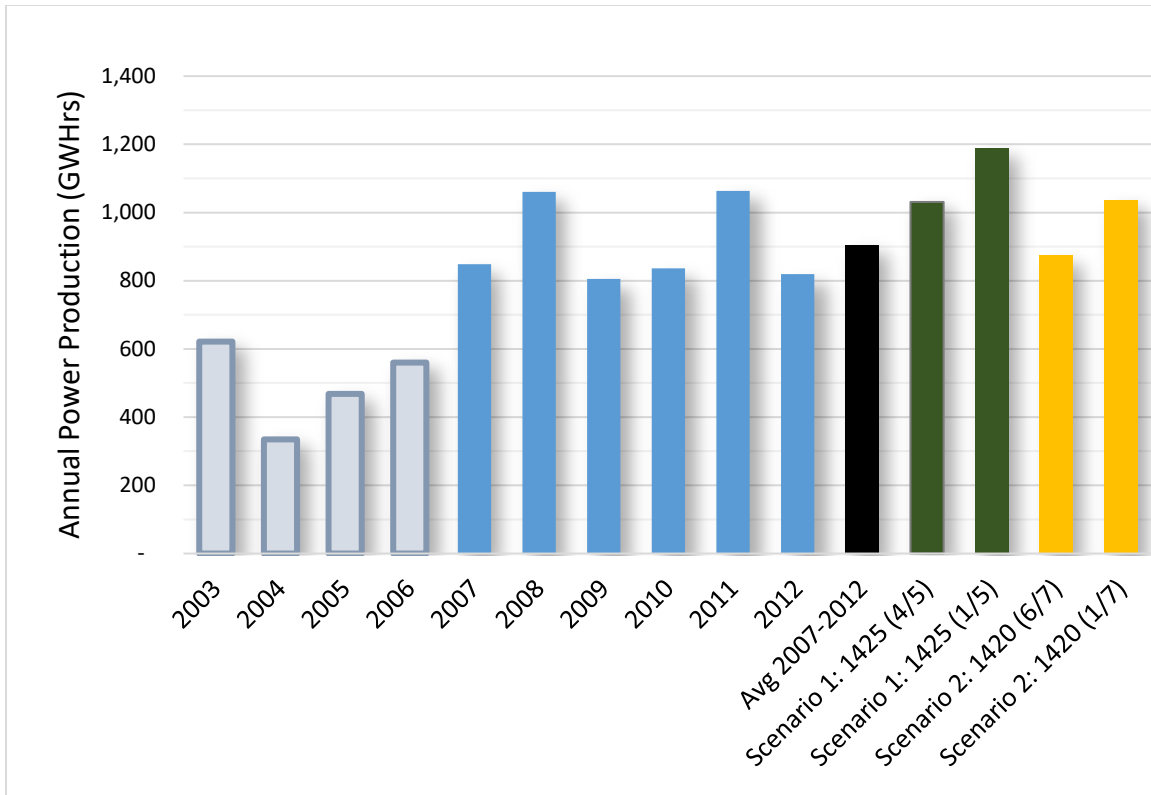


Figure 19: Actual and Projected Average ALGS Generation – Years 2002-2013 and Scenarios 1 & 2

A second analysis of the ALGS projected Scenario average annual generation found similar results. Daily ALGS generation values in the 1,420 ft. (432.8 m.) and 1,425 ft. (434.3 m.) range for 2007-2012 were tabulated and compared to projected daily generation values for the same elevations (see Table 5). As with the previous analysis, the results should be interpreted with caution as differences in turbine discharge between the actual and projected generation exist. However, the sample size of actual generation values in the narrow elevation range is sufficient to capture actual generation values over a range of turbine discharges. On average, both modelled Scenarios exceeded average ALGS generation values for each reservoir elevation range. Both Scenarios were also compared to the average ALGS generation for the entire ALGS operational range from 2007-2012. Scenario 2 generated the same amount of daily power on average, and Scenario 1 generated 17% more daily power.

Table 5: Comparison of Existing versus Projected ALGS Daily Generation for 1,420 and 1,425 ft.

Reservoir elevation Range (ft.)	ALGS Average Daily Generation 2007-2012 (MWhr)	Projected Average Daily Generation (MWhr) (weighted)		Percentage Increase of Projected over 2007-2012 Daily Average (%)
		Scenario 1	Scenario 2	
1,420 +/-0.5 ft.	2,379 (n=95)		2,523	6.4
1,425 +/- 0.5 ft.	2,761 (n=106)	2,985		8.1
Reservoir Range ¹ 1,394.7-1,445.4 ft.	2,542		2, 523	-0.8
Reservoir Range ¹ 1,394.7-1,445.4 ft.	2,542	2,985		17.4

1. Reservoir elevation range over which ALGS has generated power 2007-2012.

The results from both analyses broadly indicate that ALGS operating with a constant ALR elevation of 1,420 -1,425 ft. (432.8 – 434.3 m.) will generate roughly equal or slightly more power on an annual basis than under current reservoir operations. Scenario 1 with a higher constant elevation is projected to consistently generate more power than Scenario 2, and Scenario 2 appears to be more similar in terms of current annual ALGS generation than Scenario 1. A more detailed and robust analysis of ALGS data, as well as more detailed modelling of inflows and tail water conditions is required to further assess implications of both constant elevation Scenarios on ALGS power generation.

4.9.3 Interviews and site visits

Representatives from both CPC and CBT were interviewed and consulted on the constant elevation concept and possible implications for ALGS operations and corporate mandates. Both organizations declined formal comment until more detailed information is available. The ALGS site was toured with CPC personnel during 2015 spring freshet.

4.9.4 Information Needs

The following information needs and additional analysis are recommended:

- ALGS daily and annual average generation be modelled for the two Scenarios using a complete series of hydrometric data and simulated flowrates similar to the process followed for the BC Hydro CRT Technical Review. Results should also be compared/contrasted with plant generation data from 2007 to present.

See Table 8 at the end of Section 5 for a summary of all issues.

4.10 Flood Control²⁰

4.10.1 Introduction

Arrow Lakes Reservoir's two prime roles as defined by the CRT are to store water for power production and to reduce the risk of downstream flooding. With an active storage capacity of 7.1 million acre-ft. or 8.76 cubic kilometers, it is second only to the Kinbasket reservoir in flood water storage capacity in the entire Columbia River watershed. It attenuates extreme water events that may otherwise cause flood damage in downstream areas, namely in the Castlegar – Trail, Portland OR and Tri-Cities WA areas.

This report's focus is restricted to the ALR footprint and thus does not include an analysis of the impact of either Scenario on controlling flood waters or managing flood risk in downstream environments. Such an analysis involves extensive and detailed system-wide hydraulic modelling that will be conducted by BC Hydro and USACE. However, discussion of ALR future flood control options requires context.

The CRT splits the broad term “flood control” into *Assured Annual Flood Control* and *On-Call Flood Control*. Assured Annual Flood Control requires Canada to provide 8.45 million acre-ft. of annual draft at the three treaty reservoirs for 60 years, of which 7.1 million acre-ft. was initially allocated to ALR. In 1995, the Entities agreed to transfer 3.5 Maf of Assured Annual Flood Control storage from Arrow to Kinbasket, if the total Annual Assured Flood Control capacity in Canadian CRT reservoirs was increased from 8.45 to 8.95 Maf. (USACE 2003). In order to draft the remaining 3.6 Maf pre-freshet, ALR must draft to 1,414.1 ft. (431.1 m.) each spring to meet Treaty obligations²¹. The Assured Annual Flood Control aspect of the CRT as currently defined automatically expires in 2024. On-Call Flood Control requires Canada to provide additional storage than provided under Assured Annual Flood Control when an extreme flood event is forecast and certain conditions apply (i.e. the U.S. uses all effective U.S. storage first, and forecast flows must have the potential to exceed specified flow targets below the Dalles Dam).

In 2024, On-Call is renamed Called-Upon Flood Control and remains in effect as long as treaty dams exist (BC Hydro 2013a). Upon a Called-Upon request by the USACE, the ALR may have to draft empty (to 1,378 ft./420.1 m) and then fill to full pool (to 1,444 ft./440.1 m.). The Scenarios assume that the requirement for Called-Upon will fit with in the one in five year event (Scenario 1) and a one in seven year event (Scenario 2) using only storage between 1,420-1,444 ft. (432.8-440.1 m.) This aspect of the Scenarios differentiate them from earlier U.S. studies on the constant elevation concept.

4.10.2 Literature Review

The subject of a constant elevation ALR and flood control has been examined in a few reports, most notably by BC Hydro as discussed in Section 3.3. Some earlier CRT review studies also examined the Arrow Reservoir being held at a constant elevation (Canadian and United States

²⁰ Primary author: Alan Thomson

²¹ The Entities agree annually whether to reallocate up to 3.5 Maf flood storage from Arrow to Kinbasket each year at BC Hydro's request. The reallocation has occurred each year in the last decade, and BC Hydro assumes in their system wide modelling that the reallocation will continue.

Entities 2010; Bonneville Power Administration 2012). A U.S. study by the Bonneville Power Administration study (BPA 2012) modelled numerous options for BC Hydro Columbia River facilities assuming a Treaty Terminate scenario. Several of the scenarios minimized ALR water level fluctuations. The scenario recommended by the U.S. authors for BC Hydro operations involved maintaining the ALR at a constant elevation of 1,442 ft. (439.5 m.) with a two month spring draft to 1,431 ft. (436.2 m.) to maximize turbine outflow and to minimize spill. The second most recommended BC Hydro facility operations was similar to the first only that Arrow was managed for recreation and wildlife values by reducing the summer and fall elevations to 1,439 ft. (438.6 m.) with summer levels at 1,442 ft. (439.5 m.) and a power draft similar to the first recommended operation. The report authors also noted that ALR has a range of non-power benefits that could result in lower reservoir levels “down to 1,425 ft. (434.3 m.) or so” (BPA 2012, pg. 77).

The study conducted by both Entities (Canadian and United States Entities 2010) reported that in a Treaty Terminate scenario (where the operation of Canadian reservoirs do not follow CRT operational rules) Canada would be motivated to operate Arrow elevations higher resulting in reduced flood storage capability. ALR is also deemed more effective at providing U.S. flood control protection than either Kinbasket or Duncan reservoirs, thus most of the Called Upon flood control draft is assumed to be in ALR (Canadian and United States Entities 2010).

4.10.3 Evaluation of Scenarios

For each of the Scenarios, a key issue is how much flood water storage each Scenario will provide. It is possible to compare Scenario storage to existing storage patterns based on reservoir operations. Although not definitive, this provides an indication of current versus Scenario storage volumes, and operations required to maintain them.

Over the winter and early spring period, the ALR is drafted in anticipation of storing the predicted spring freshet. The total volume that the reservoir can store is the difference in volume at the lowest elevation pre-freshet that typically occurs late March to early May and maximum pool height (1,444 ft. / 440.1 m.) that typically occurs mid-July. Since 1995 the minimum pre-freshet reservoir elevation range has increased from 1,385 – 1,395 ft. (422.5 – 425.2 m.) to 1,402-1,413 ft. (427.3-430.7 m.). The increase is due to a number of more recent water reallocation agreements between the entities (see Figure 19).

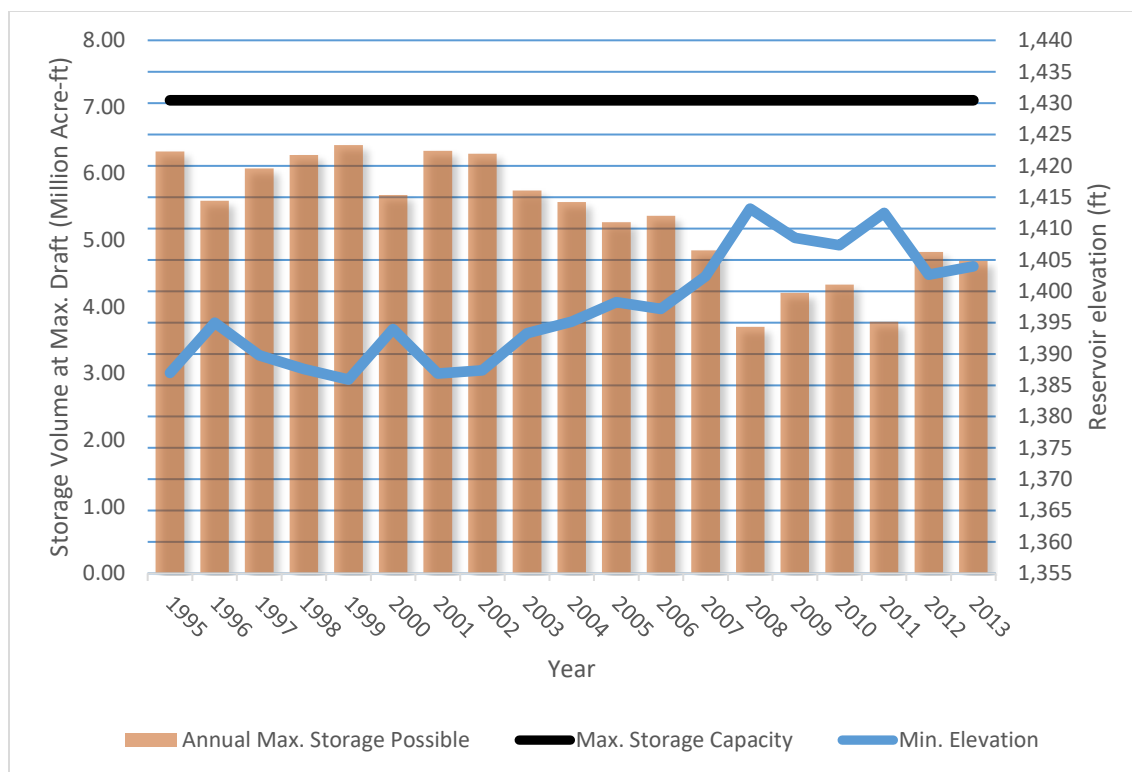


Figure 20: Arrow Minimum Draft Elevation and Storage Capacity 1995-2013

Given a known relationship between the ALR water elevation and storage volume, it is possible to determine the flood water storage capacity in the reservoir. Between 2008 and 2013, the annual flood storage capacity was 3.7 – 4.8 million acre-ft. Scenario 1 base elevation is 1,425 ft. (434.3 m.) but is slightly drawn down pre-freshet to 1,421 ft. (433.1 m.). The flood water storage capacity in the reservoir is 2.8 million acre-ft., and thus less than the flood storage capacity of current storage operations. For Scenario 2, the base elevation is 1,420 ft. (432.8 m.) with no small pre-freshet drawdown. The flood water storage capacity in the reservoir is 2.9 million acre-ft., again less than the flood storage capacity of current storage operations. As is evident there is little difference between flood storage capacity between the two Scenarios, and both are approximately 0.9-2.0 million acre-ft. less than ALR storage capacity in recent years.

In order to maintain current flood risk management objectives, reallocation of additional storage capacity to other treaty storage facilities would be required. If maintaining the constant elevation feature of both Scenarios is considered a permanent reallocation of assured annual flood storage to other Canadian storage facilities (e.g. to Kinbasket reservoir), then an additional annual reallocation of 0.78 Maf and 0.66 Maf for Scenarios 1 and 2 respectively would be required²².

²² Supplemental upstream storage capacity in addition to these amounts may be required to ensure an equal degree of flood risk reduction at critical downstream locations.

Reservoir Drawdown Rate under Scenarios

Both proposed Scenarios have a higher drawdown rate from full pool back to the constant elevation value than current operations. One of the key differences between the Scenarios is the more rapid drawdown rate in Scenario 2. Under current operations, the reservoir is typically drawn down from full or near-full pool to the minimum draft (varies annually but more recently in the 1,395 – 1,405 ft. (425.2 – 428.2 m.) range over a period of several months. In Scenario 1, the drawdown from 1,444 ft. to 1,435 ft. (440.1 – 437.4 m.) takes place over approximately 1 month at an average rate of 0.30 ft./day (0.09 m/day). Discharge at HLK/ALGS of approximately 19,300 cfs (546 cms) in addition to reservoir inflows would result. For Scenario 2, the drawdown from 1,444 ft. to 1,429 ft. takes place over approximately 24 days at an average rate of 0.62 ft./day (0.19 m/day) that would result in reservoir discharge at HLK/ALGS of approximately 39,500 cfs (1,118 cms) in addition to reservoir inflows. In order to compare Scenario drawdown rates to current operations, maximum ALR drawdown rates in the summer/fall period for each year since 1970 were examined²³ (see Figure 20). The highest drawdown rates in the top 20% of years for the summer/fall period range from 0.33 - 0.64 ft./day (0.1-0.2 m./day). The highest rate of 0.64 ft./day (0.2 m./day) was sustained for 24 days in 1992, followed by 0.49 ft./day (0.15 m./day) that was sustained for 10 days in 1984.

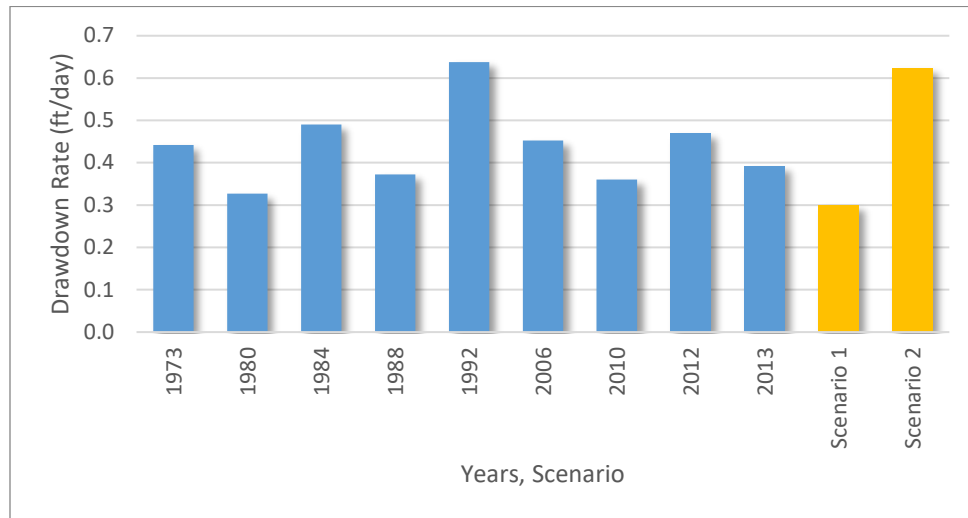


Figure 21: Maximum Monthly ALR Drawdown Rate for Scenarios and High Drawdown Rate Years

As Figure 20 illustrates, the drawdown rate for Scenario 1 is within the range of current ALR drawdown rates. The Scenario 2 drawdown rate is higher than typical under current operations but has been surpassed once – in 1992 – since commissioning of HLK dam and start of ALR operations. Under the CRT, the maximum ALR draft rate allowed as specified by the Columbia River Treaty Operating Committee (2010) and set out in the Assured Operating Plan (AOP) is 1.0 ft./day (0.3 m./day) and exceeds current and Scenario drawdown rates. The AOP specifies that the

²³ Although not directly comparable, it should be noted that in some years natural drawdown rates experienced on Upper Arrow Lake prior to dam construction were also in this range.

facility outflow and thus drawdown rate is limited to physical capacity (i.e. – no CRT limitation) except for 80 kcfs and 70 kcfs in January and February respectively.

Other issues associated with a rapid ALR drawdowns include:

- Depending on the effectiveness of revegetation, potential for increased reservoir shoreline slumping and mass wasting events, as discussed in the Erosion section (Section 4.3)
- Strong currents in the HLK dam area that are considered dangerous by boaters as discussed in the Recreation section (Section 4.6);
- Strong currents in the Narrows area that may make commercial log transport more difficult;
- Possible concerns with flooding downstream at Trail and/or Castlegar, fish impacts in the lower Columbia River due to larger spill events at HLK dam, higher discharge etc. and other concerns. These issues, although significant, are outside of this report's scope.

In terms of flooding within the reservoir footprint, there are no direct concerns about either Scenario causing flooding within the ALR as all non-flood proofed infrastructure is located well above the maximum surcharged pool elevation of 1,446 ft. (440.7 m.). The risk of flooding infrastructure within the ALR footprint in either Scenario is no different than is the case under current ALR operations. However, with the reduced flooding frequency of the Scenarios, foreshore private property owners may be tempted to build within the drawdown zone. To ensure that private developments remain out of the drawdown zone existing setbacks (safelines and/or impact lines as defined by BC Hydro) and flowage easements should remain in place.

4.10.4 Information Needs

Modelling is required to determine whether the Scenario drawdown rates would cause issues (as noted above) within the Arrow footprint and downstream flooding, in conjunction with Kootenay River discharge, in the Castlegar and Trail BC areas.

See Table 8 at the end of Section 5 for a summary of all issues.

Table 6: Summary of Current ALR Operations and Scenario Operational Parameters

	Current Operations (1995 to 2013)	Scenario 1	Scenario 2
Reservoir Levels	Licensed to operate between 1,378 – 1,444 ft. (420 – 440.1 m.) (66 ft./20.1 m.) with surcharge to 1,446 ft. (440.7 m.) upon approval by the provincial Water Comptroller. Typical operational range is 40-50 ft. (12.1-15.2 m.) annually.	1,425 ft. (434.3 m.) with short drafts to 1,421 ft. (433.1 m.) in the spring and fall in 4 in 5 years	1,420 ft. (432.8 m.) in 6 of 7 years
Frequency of inundation to full pool (1,440+ ft.)	13 out of 19 years.	On average, 1 in 5 years, based on flood risk.	On average, 1 in 7 years, based on flood risk.
Duration of inundation above 1,430 ft.	Average 112 days (15-209), most years.	Approximately 100 days, no limit, 1 in 5 years.	Maximum of 35 days, 1 in 7 years.

Table 7: Summary of Current ALR Operations and Scenario Assessment on Issues and Values

	Current Operations (1995 to 2013)	Scenario 1	Scenario 2	Comment
Fisheries and Aquatic Resources Pelagic nutrients/ lower food chain	The effects of current operations on nutrient dynamics and primary and secondary pelagic productivity are complex and highly variable from year to year.	Nutrient dynamics and primary and secondary productivity in Arrow reservoir are highly complicated with a wide variety of potential effects, both positive and negative, from a Scenario 1 operational regime. The net effect of a Scenario 1 operation is highly uncertain and requires further research and analysis.	Nutrient dynamics and primary and secondary productivity in Arrow reservoir are highly complicated with a wide variety of potential effects, both positive and negative, from a Scenario 2 operational regime. The net effect of a Scenario 2 operation is highly uncertain and requires further research and analysis.	
Pelagic fish productivity and habitat	The abundance of kokanee in the Arrow reservoir is highly variable from year to year and this is due in large part to the variability in pelagic primary and secondary productivity.	A Scenario 1 operation will have highly uncertain effects on kokanee abundance because of the uncertain effects of Scenario 1 on primary and secondary productivity. There will be a net reduction in pelagic habitat area during the most productive late spring – summer period. Effects on piscivores (e.g. bull trout and piscivorous rainbow trout) are equally or more uncertain.	A Scenario 2 operation will have highly uncertain effects on kokanee abundance because of the uncertain effects of Scenario 1 on primary and secondary productivity. In comparison to current operations and Scenario 1, there will be a net reduction in pelagic habitat area during the most productive late spring – summer period. Effects on piscivores (e.g. bull trout and piscivorous rainbow trout) are equally or more uncertain.	
Stream access for fish	Depending on late summer and fall reservoir elevations, current operations impair fall spawner (e.g. kokanee, bull trout) access to tributaries to varying and in some years significant degrees.	A Scenario 1 operation would likely result in no to slightly positive change for fall spawners access to some tributaries in comparison to current operations.	The effects of Scenario 2 operation on access by fall spawners to tributaries in comparison to current operations and Scenario 1 is positive.	

	Current Operations (1995 to 2013)	Scenario 1	Scenario 2	Comment
Stream spawning and rearing habitats	In general, current operations significantly impair spawning, incubation and rearing habitat conditions within the drawdown zone reaches of tributaries.	Under Scenario 1, there is potential for modest improvement in spawning and incubation habitat conditions within the reservoir drawdown reaches of tributaries.	Scenario 2 is likely to lead to significant improvement in spawning and incubation habitat conditions within the reservoir drawdown reaches of tributaries, in comparison to both current operations and Scenario 1.	
Littoral habitats and productivity	Current operations do not provide for stable littoral habitats and thus significantly impair littoral habitat conditions and productivity.	Scenario 1 would likely significantly improve littoral habitat conditions and productivity in comparison to current operations.	Scenario 2 would also likely significantly improve littoral habitat conditions and productivity in comparison to current operations and Scenario 1, in part because of the less frequent flood storage operation (and deep inundation) with Scenario 2.	
Aquatic macrophytes (large plants) and invasive species	Current operations significantly compromise the development of aquatic macrophyte communities.	Scenario 1 would likely result in the expansion of aquatic macrophyte communities, which are likely to support both the native fish community as well as invasive fish species like northern pike.	Scenario 2 would likely result in the expansion of aquatic macrophyte communities, which are likely to support both the native fish community as well as invasive fish species like northern pike, in comparison to current operations.	

	Current Operations (1995 to 2013)	Scenario 1	Scenario 2	Comment
Riverine productivity and habitats	Current reservoir operations combined with daily peaking operations at the Revelstoke generating station significantly impair the productivity of and habitat conditions for some fish species within the mid-Columbia river reach.	A Scenario 1 operation will result in a longer length of riverine habitat between the Arrow reservoir and the Revelstoke generating station during the productive late spring – early fall months, in comparison to current conditions. However, the benefits of this to aquatic ecosystem productivity and fish populations are highly uncertain because of the complex and overall negative effects of highly variable flows resulting from the daily peaking operations.	A Scenario 2 operation will result in a longer length of riverine habitat between the Arrow reservoir and the Revelstoke generating station during the productive late spring – early fall months, in comparison to current conditions and Scenario 1. However, the benefits of this to aquatic ecosystem productivity and fish populations are highly uncertain because of the complex and overall negative effects of highly variable flows resulting from the daily peaking operations.	
Burbot	Current operations are unlikely to significantly effect burbot spawning and incubation habitat.	A Scenario 1 operation will likely be neutral (neither beneficial or harmful) for burbot spawning and incubation in comparison to current conditions	A Scenario 2 operation will likely be neutral (neither beneficial or harmful) for burbot spawning and incubation in comparison to current conditions	
White sturgeon	Current operations significantly effect, as a result of reservoir inundation, sturgeon spawning and incubation habitat conditions in the known spawning area adjacent to the Revelstoke Golf Course.	A Scenario 1 operation will likely improve white sturgeon spawning and incubation habitat conditions, and possibly larval dispersal, in comparison to current conditions. This conclusion has a high degree of uncertainty.	A Scenario 2 operation will likely improve white sturgeon spawning and incubation habitat conditions, and possibly larval dispersal, in comparison to current conditions. This conclusion has a high degree of uncertainty.	

	Current Operations (1995 to 2013)	Scenario 1	Scenario 2	Comment
Anadromous salmon	Anadromous salmon (sockeye and chinook) do not currently inhabit the Arrow Lakes Reservoir. If they did occur, there would be significant effects on them from: (i) passage and habitat conditions in the drawdown zone reaches of tributaries (for sockeye salmon adults in particular); (ii) highly variable pelagic productivity...more so for sockeye than chinook salmon	The potential effects of Scenario 1 operation on passage, spawning and incubation habitat conditions in tributaries is uncertain or slightly positive. The potential effects on reservoir productivity and thus food availability for juvenile sockeye and chinook salmon is highly uncertain.	<p>The potential effects of Scenario 2 operation on passage, spawning and incubation habitat conditions for sockeye and chinook salmon in the lower (drawdown zone) reaches of tributaries is likely positive.</p> <p>The potential effects on reservoir productivity and thus food availability for juvenile sockeye and chinook salmon is highly uncertain.</p>	
Archaeology	Current operations have significant impacts to archaeological resources (sites and materials) through wave and wind erosion and deposition of sediments.	Under Scenario 1, archaeological sites within the elevation 1,420-1,426 ft. (432.8 – 434.6 m.), and possibly up to 1,430 ft. (435.9 m.) in some locations, would be severely degraded or lost due to water/wave erosion absent mitigation efforts. Protection of sites from 1,426-1,444 ft. (434.6 – 440.1 m.) would be marginally better than under current operations due to reduction in wave damage and increased herbaceous cover.	<p>Scenario 2 would allow for the greatest benefit to the stabilization and protection of the remaining archaeological sites and material. Sites at 1,419 – 1,421 ft. (432.5 – 433.1 m.) and up to 1,425 ft. (434.3 m.) in some locations would be severely degraded or lost due to water/wave erosion absent mitigation efforts. Sites above the constant water elevation would be protected from wind and water erosion by vigorous herbaceous cover and mature vegetation and shrubs at higher elevations.</p> <p>Illegal pot hunting would also be more difficult with improved vegetation establishment above 1,421 ft. (433.1 m).</p>	

	Current Operations (1995 to 2013)	Scenario 1	Scenario 2	Comment
Recreation				
Boat-based	Main concern is boat ramps that are accessible at all elevations; some launches now not available at extreme low water; no strong preference for specific elevation; slight aversion to very low and very high elevations.	Increased certainty in 4 of 5 years; boat ramps available all year; likely improved beach development; potentially decreased boat launch maintenance costs.	Increased certainty in 6 of 7 years; boat ramps available all year; likely improved beach development; potentially decreased boat launch maintenance costs.	Both scenarios create improved certainty around boat ramp access and likely improvements in beach development.
Shoreline-based	Shoreline land owners are unhappy with current regime; most would prefer constant elevation at 1,430-1,435 ft. (435.9 – 437.4 m.); Shoreline-based marinas unhappy with current regime – especially extreme low water.	Not shoreline land owners’ preferred regime, but they could adapt; preferable to present regime; would be more agreeable with some mitigation assistance; Shoreline-based marinas would benefit from certainty in 4 of 5 years; concern regarding flow rates in narrows and near dam.	Not shoreline land owners’ preferred regime, but they could adapt; preferable to present regime; would be more agreeable with some mitigation assistance; Shoreline-based marinas would benefit from certainty in 6 of 7 years; concern regarding flow rates in narrows and near dam.	Shoreline owners would prefer higher elevations than Scenario 1 or 2, but shoreline owners and marinas like the increased certainty; all stated they could adapt to a constant water elevation in the 1,420-1,425 ft. (432.8 – 434.3 m.) range.
Terrestrial	Limited access to drawdown area due to annual inundations, especially during summer and fall; more area available when water very low.	Year-round access for activities 4 of 5 years; increase in available area except winter/early spring; likely decreased maintenance costs to trails and other facilities.	Year-round access for activities 6 of 7 years; increased summer/ fall access in 1 of 7 years; larger increase in available area except winter/early spring; likely decreased maintenance costs to trails and other facilities.	Terrestrial recreational activities would benefit from both Scenarios, with the greatest benefits from Scenario 2.

	Current Operations (1995 to 2013)	Scenario 1	Scenario 2	Comment
Vegetation	Vegetation mostly limited to herbaceous grass and sedges below 1,440 ft. due to inundation and wave scour; trees and shrubs only occur sporadically above approximately 1,440 ft. (438.9 m.).	Herbaceous vegetation increases cover and vigour above 1,425 ft. (434.3 m.); species diversity increases during non-flood years and then decreases immediately after flood years; somewhat reduced vegetation loss due to wave/debris scour; tree/shrub communities do not develop below 1,440 ft. (438.9 m.); potential risks due to invasive spp. and off-road vehicle use.	Herbaceous vegetation increases in diversity, cover and vigour above 1,420 ft. (432.8 m.); diverse tree/shrub, wetland and riparian communities develop above 1,430 ft. (435.9m.); species diversity decreases slightly after flood years; significantly reduced vegetation loss due to wave/debris scour; potential risks due to invasive spp. and off-road vehicle use.	Scenario 1 provides some improvement in herbaceous cover above 1,425 ft. (434.3 m.), while Scenario 2 provides for the development of wetland, riparian and upland tree and shrub communities above 1,430 ft. (435.9 m.) creating significant improvements in habitat diversity and availability.
Wildlife Herptiles	Limited use by frogs, toads, turtles and snakes; mainly in areas where wetlands have persisted in upper elevations of Revelstoke Reach drawdown zone; habitat access limited by spring/ summer/ fall inundation (mostly studied in Revelstoke Reach, but other areas such as Beaton Arm, Burton Flats and Inonoaklin Road have received some attention).	During non-flood years, increased year-round habitat access for all species above 1,425 ft. (434.3 m.); during flood years access limited by spring/ summer/ fall inundation.	During non-flood years, increased year-round habitat access for all species above 1,420 ft. (432.8 m.); during flood years access slightly limited by spring/ early summer short duration inundation (above 1,430 ft./435.9 m.); shorter access window between 1,420 ft. (432.8 m.) and 1,430 ft. (435.9 m.); increased riparian and other tree/ shrub habitats; likely decrease of grassland habitat for some snakes.	Scenario 1 provides some improvement in habitat availability for herptiles, while Scenario 2 provides significantly more improvements in habitat diversity and availability.

	Current Operations (1995 to 2013)	Scenario 1	Scenario 2	Comment
Waterbirds and Shoreline birds	Limited access to shoreline, wetland and pond habitats due to periodic spring, summer and fall inundation in most years; nesting failures due to nest flooding (mostly studied in Revelstoke Reach).	Complete year-round access to wetland, pond and shoreline habitats above 1,425 ft. (434.3 m.) in 4 of 5 years; establishment of semi-permanent shoreline habitats at approx. 1,425 ft. (434.3 m.); reduced nesting losses due to inundations in non-flood years.	Complete year-round access to wetland, pond and shoreline habitats above 1,420 ft. (432.8 m.) in 6 of 7 years; increased duration access to habitats above 1,430 ft. (435.9 m) in flood years due to short duration flooding; establishment of semi-permanent shoreline habitats at approx. 1,420 ft. (432.8 m.); reduced nesting losses due to inundations in non-flood years; development of riparian habitats above 1,430 ft. (435.9 m.).	Scenario 1 provides some improvement in habitat availability for waterbirds and shoreline birds, while Scenario 2 provides significantly more improvements in habitat diversity and availability.
Songbirds	Songbird diversity and abundance significantly limited due to the lack of tree/shrub habitats; significant mortality due to nest flooding (mostly studied in Revelstoke Reach).	Minor increase in grassland songbird species due to increase in herbaceous cover above 1,425 ft. (434.3 m.); decrease in nesting losses in non-flood years.	Significant increase in songbird species diversity and abundance due to increase in tree/ shrub communities and increased availability of wetland and riparian habitats above 1,430 ft. (435.9m.); decrease in nesting losses in non-flood years.	Scenario 1 provides minor habitat improvement for songbirds, while Scenario 2 provides significant habitat improvement for songbirds.
Mammals	Small mammals and bats frequently use the drawdown zone; use by large mammals is limited and sporadic, mainly due to lack of cover.	Mammal use may increase slightly in non-flood years due to increased herbaceous vegetation cover; use by large mammals will still be limited by lack of cover.	Potentially significant increase in mammal use due to development of riparian habitats and tree/ shrub communities; availability of browse and cover will contribute to increased large mammal use; likely will contribute to ungulate winter range – a key limiting factor.	Scenario 1 provides minor habitat improvement for small mammals, while Scenario 2 provides significant habitat improvement for small and large mammals.

	Current Operations (1995 to 2013)	Scenario 1	Scenario 2	Comment
Navigation	<p>1,420 ft. (432.8 m.) and above: optimal for log tow operations</p> <p>1,410 – 1,420 ft. (429.8 – 432.8 m.): minor reduced log tow capacity through Narrows</p> <p>1,410 ft. (429.8 m.) and below: major reduced log tow capacity through Narrows</p>	<p>Considered minimum elevation for optimal log tow capacity through the Narrows.</p> <p>Log sort will function unimpeded. Stable reservoir elevation will allow Interfor to upgrade log sort and use safer and more efficient “A” frame to unload trucks and swing loads into the water.</p>	<p>Exceeds minimum elevation for optimal log tow capacity through the Narrows.</p> <p>Log sort will function unimpeded. Stable reservoir elevation will allow Interfor to upgrade log sort and use safer and more efficient “A” frame to unload trucks and swing loads into the water.</p>	<p>Both Scenarios will allow for unimpeded log tow operations through the Narrows. Both Scenarios are better than current operations that allow for reservoir levels to drop below 1,420 ft. (432.8 m.).</p> <p>Log sort operations would benefit from both Scenarios.</p>
Agriculture	<p>Agricultural production limited to grazing and hay production on approx. 400 ha in the Revelstoke reach; limitations due to inundation during the growing season and occasional in-washed debris.</p>	<p>Agricultural production potential would increase in areas above 1,425 ft. (434.3 m.), principally in the Revelstoke reach, but also in small local areas in other parts of the reservoir; potential for annual crops in 4 of 5 years; productivity would increase significantly in 4 of 5 years due to lack of inundation; frequency of in-washed debris would decrease somewhat.</p>	<p>Agricultural production potential would increase in areas above 1,420 ft. (432.8 m.), principally in the Revelstoke reach, but also in small local areas in other parts of the reservoir; potential for annual crops in 6 of 7 years; productivity would increase significantly in 6 of 7 years due to lack of inundation; some potential for grazing and hay production above 1,430 ft. (435.9m.) even in flood years due to short duration inundation; frequency of in-washed debris would decrease significantly.</p>	<p>Agricultural activities would benefit from both Scenarios, with the greatest benefits from Scenario 2.</p>

	Current Operations (1995 to 2013)	Scenario 1	Scenario 2	Comment
Power Generation	Generation variable throughout year at ALGS; power production follows hydrograph, with max. generation during high water periods early summer to early fall. Average annual production 2007-2012 was 906 GWh and ranged from 806-1,063 GWh.	Modelling completed using existing data projects that in 4 of 5 years, ALGS will generate 1,031 GWh, and in 1 in 5 years ALGS will generate 1,190 GWh. Annual generation for Scenario 1 is projected to exceed current annual generation. Analysis does not account for power generation gains/losses at upstream or downstream plants to maintain Scenario 1 constant water elevations.	Modelling completed using existing data projects that in 6 of 7 years, ALGS will generate 875 GWh, and in 1 in 7 years ALGS will generate 1,038 GWh. Annual generation for Scenario 2 is projected to roughly equal current annual generation. Analysis does not account for power generation gains/losses at upstream or downstream plants to maintain Scenario 2 constant water elevations.	Scenario 1 will generate more power than Scenario 1. Both Scenarios will generate roughly the equivalent or greater power than under current operations.
Erosion	Minor bank erosion occurs in the Revelstoke Reach, primarily in reaches closer to REV. Wave action from the ALR is the dominant cause of bank erosion in the Revelstoke Reach. Shore erosion in main ALR body is ongoing, and varies considerably due to size of substrates (e.g. whether silts or cobble) material, aspect, beach angle of repose, presence of logs, and vegetation cover. Shoreline erosion occurs over the entire ALR drawdown range with lessor	Bank erosion in the Revelstoke Reach will occur in reaches where riverine and lacustrine environments meet. Upstream of the interface, erosion rates will remain similar to current rates; downstream banks will be inundated year round. REV peaking function and daily discharge will cause the interface zone to vary in length and location. Shoreline erosion will be focused in a narrow elevation range from 1,425 ft. (434.3 m.) to about 1,430 ft. (435.9m.) primarily due to wave action. Shoreline erosion will continue above 1,430 ft. (435.9m.) albeit at a lower rate than under current ALR operations due to	Bank erosion in the Revelstoke Reach will occur in reaches where riverine and lacustrine environments meet. Upstream of the interface, erosion rates will remain similar to current rates; downstream banks will be inundated year round. REV peaking function and daily discharge will cause the interface zone to vary in length and location. Shoreline erosion will be focused in a narrow elevation range from 1,420 ft. (432.8 m.) to about 1,425 ft. (434.3 m.) primarily due to wave action. Shoreline erosion will be partially reduced above 1,425 ft. (434.3 m.) due to established herbaceous vegetation, and reduced further above 1,430 ft. (435.9m.) where mature vegetation will establish. Minor slumping will likely continue as soft banks	Scenario 1 would likely result in fewer and/or smaller magnitude mass wasting events than Scenario 2 due to the higher drawdown rate of Scenario 2.

	Current Operations (1995 to 2013)	Scenario 1	Scenario 2	Comment
	<p>erosion at elevation extremes than in the middle of the range.</p> <p>Wind erosion causing dust storms will continue in areas that remain devoid of vegetation cover throughout the drawdown zone. Revelstoke Reach dust storms have largely been abated due to successful planting program.</p>	<p>less frequent inundation and limited herbaceous vegetation establishment. Minor slumping will likely continue as soft banks are undercut and the beach slowly attains the long term stable slope.</p> <p>Wind erosion causing dust storms will continue in areas that remain devoid of vegetation cover above 1,425 ft. (434.3 m.) Areas below 1,425 ft. (434.3 m.) that contributed to dust generation under current operations will no longer be exposed. Dust generation severity and magnitude is expected to decrease over current events.</p> <p>Whether Scenario 1 would increase or decrease the frequency and magnitude of mass wasting events when compared to current operations is unclear.</p>	<p>are undercut and the beach slowly attains the long term stable slope.</p> <p>Wind erosion causing dust storm may increase in some areas in the short-term, but will significantly subside in severity and magnitude greater than current events and that predicted under Scenario 1 as mature vegetation establishes above 1,430 ft. (435.9m.) Dust will continue to be generated from exposed beach areas closer to the water's edge. Areas below 1,420 ft. (432.8 m.) that contributed to dust generation under current operations will no longer be exposed.</p> <p>Whether Scenario 2 would increase or decrease the frequency and magnitude of mass wasting events when compared to current operations is unclear.</p>	

	Current Operations (1995 to 2013)	Scenario 1	Scenario 2	Comment
Flood Risk Management	ALR is drafted each spring to ensure adequate freshet storage to minimise downstream flood risk. Since 2008, the reservoir minimum draft elevation ranges from 1,402-1,413 ft. (427.3 – 430.7 m.). Minimum draft elevation is 1,378 ft. (420.1 m.). In the same period, max. freshet storage ranges 3.7-4.8 million acre-ft. out of a max. storage capacity of 7.1 million acre-ft.	<p>The base elevation for Scenario 1 is 1,425 ft. (434.3 m.) but just before onset of freshet, ALR is drafted to 1,421 ft. (433.1 m.). Storage capacity from 1,421 ft. (433.1 m.) to maximum licensed elevation of 1,444 ft. (440.1 m.) is 2.8 million acre-ft. More recent operations – since 2008 - provide for an additional 0.9-2.0 million acre-ft. of flood water storage over Scenario 1.</p> <p>Current Assured Annual Flood Control procedure requires drafting Arrow to 1,414.1 ft. (431.1 m). An additional 0.78 Maf of flood storage will have to be allocated to other Canadian treaty reservoirs to maintain current total annual flood storage capacity as defined by the CRT.</p>	<p>The base elevation for Scenario 2 is 1,420 ft. (432.8 m.). Storage capacity from 1,420 ft. (432.8 m.) to maximum licensed elevation of 1,444 ft. (438.9 m.) is 2.9 million acre-ft. More recent operations – since 2008 - provide for an additional 0.9-2.0 million acre-ft. of flood water storage over Scenario 2.</p> <p>Current Assured Annual Flood Control procedures require drafting Arrow to 1,414.1 ft. (431.1 m.). An additional 0.66 Maf of flood storage will have to be allocated to other Canadian treaty reservoirs to maintain current total annual flood storage capacity as defined by the CRT.</p>	<p>There is a minor difference in flood water storage capacity between the Scenarios, with Scenario 2 being slightly better by 0.1 million acre-ft. than Scenario 1.</p> <p>Supplemental upstream storage capacity in addition to these amounts may be required to ensure an equal degree of flood risk reduction at critical downstream locations.</p>

5 Scenario 1 and 2 Assessment Summary and Tradeoffs

In order to reach overall conclusions about both Scenarios when compared to the current ALR operational regime, the values impacted by the Scenarios are summarized in Table 8 below as having a Positive or Beneficial Impact, Neutral Impact, Mixed or Uncertain Impact, or Negative Impact. The values were assessed using similar directional methodology in the BC Hydro's Technical Studies reports (BC Hydro 2013b).

Most of the assessed value results are either positive or mixed/uncertain when compared to the current ALR operational regime. There are also some neutral and negative aspects of the Scenarios. In both scenarios, the successful establishment of riparian vegetation is seen to heavily influence several values in a positive direction, such as erosion, wildlife (ungulates and birds), dust generation, archaeological sites, and fish access into tributaries. Scenario 2 encourages a more robust and permanent mature riparian vegetation community when compared to Scenario 1. Vegetated reservoir banks and shorelines are less prone to wind and wave erosion, and dust generation above the constant elevation would be reduced, more so with Scenario 2. Terrestrial wildlife habitats would increase, notably ungulate winter range because of improved riparian vegetation. Archaeological sites above the base elevation would be better protected from wind and wave erosion and conceal artifacts from pothunters due to establishment of riparian vegetation, more so for Scenario 2. However, since vegetation would not establish within a few feet of the constant elevation, archaeological sites within this zone would be severely degraded or completely lost absent mitigation measures. Tributary stream banks and channels are expected to stabilize with mature vegetation establishment under Scenario 2, which would aid fish access to spawning sites.

Some other values not directly associated with riparian vegetation establishment also move in a positive direction. Commercial navigation is improved equally under both Scenarios, and annual power generation at Arrow Lakes Generating Station is expected to be slightly higher under Scenario 2 than annual power generated under the current operational regime. Agricultural opportunities are expected to increase under both Scenarios, more so for Scenario 2. Bird nest flooding, a concern in the Revelstoke Reach, will decrease for nests above the base constant elevation in non-flood years in both Scenarios. Scenario 2 offers better nest flooding protection over Scenario 1. Herptiles, shorebirds and waterbirds should have better access to wetlands and ponds above the base constant elevation for both Scenarios in non-flood years.

Although there are positive attributes to the scenarios, and in particular Scenario 2, analysis of some values found mixed or uncertain outcomes when compared to the existing ALR operational regime. For both scenarios, most fish related values are uncertain (could be either positive or negative) or mixed, in particular pelagic primary and secondary productivity, kokanee biomass, aquatic productivity values in the Revelstoke Reach, and fish migration conditions in the lower reaches of tributaries for Scenario 1. At the scoping level it is very difficult to evaluate the combined effects of multiple potential changes. Additional research that includes ALR ecosystem modelling, seasonal analysis of fish population life history requirements in the Revelstoke Reach for current operations and two Scenarios, and a comprehensive assessment of risks to current fish stocks and aquatic ecosystems associated with the two Scenarios is required.

Other values that are mixed include shoreline owners' use of waterfront properties. Both Scenarios offer more certainty and consistency over access to the water since it is not fluctuating as under current conditions. However the water's edge would be farther during summer months

and closer during winter months than under current conditions. Under both Scenarios, the frequency and magnitude of mass wasting events are also mixed.

Burbot spawning and incubation success will unlikely to be affected by both Scenarios, and ALGS annual power generation is roughly equal to current annual generation under Scenario 2.

The Scenarios also pose challenges to some values. Flood storage capacity would be reduced almost equally in both Scenarios when compared to current operations, and invasive vegetation species may become established without aggressive revegetation. Shoreline property owners and marina operators would prefer a higher constant elevation than evaluated in this report.

Although this report examines two constant elevation Scenarios that are similar in elevation, it is possible that additional incremental benefits and value tradeoffs may occur from an alternative constant elevation. In general, increasing the constant water elevation level above 1,425 ft. (434.3 m.) would benefit power production, marina operations, and shoreline property owners, but at the expense of less permanent large riverine, wetland and terrestrial habitat in the Revelstoke Reach, flood storage capacity, potential agricultural development, and low gradient stream fish habitat. If the constant elevation were lower than 1,420 ft. (432.8 m.), benefits would increase for wetland and terrestrial habitats, agricultural development potential, flood storage capacity and low gradient stream fish habitat. However these increases would be at the expense of commercial log transport through the Narrows, power production and waterfront land owners' access to the water. It remains unclear the implications of alternate constant water elevations on pelagic fish resources.

In addition to assessing alternative constant elevation Scenarios, other alternatives could also be considered. For example to increase flood storage in the key flood years (1 in 5 years or 1 in 7 years in these Scenarios), there could be an option to drawdown the reservoir 5 or 10 ft. (1.5 – 3 m.) in March or April to increase storage. Alternatively, or in addition, there could be more variation in the “constant” elevation on an annual basis, with a drawdown of 5-10 ft. (1.5 – 3 m.) every year in March or April and/or short-term flooding of 5-10 ft. (1.5 – 3 m.) at freshet to provide for a more natural hydrograph and an increase in annual storage and power production. In Scenario 2 this would still allow for all the vegetation, wildlife and agricultural benefits above 1,430 ft. (435.9 m), but may increase impacts to some archaeological sites and other values. The consideration of these types of scenario modifications will require further in-depth analysis.

It is recommended that before detailed modeling is undertaken further thought be put into designing Scenarios that attempt to maximize ecosystem function and other values, while minimizing impacts on the two primary operational objectives – flood control and power production. Although formulation of alternative Scenarios is beyond the scope of this study, the information provided here should provide a sound basis for that work.

Table 8: Summary Evaluation of Scenario impacts compared with current ALR operations.

Impact Description	Scenario 1	Scenario 2
Positive or Beneficial Impacts	<ul style="list-style-type: none"> • increased vegetation cover and vigour; likely some periodic and temporary increases in vegetation diversity. • increased productivity and diversity of littoral (shallow water) habitats. • improved white sturgeon spawning and incubation habitat conditions. • improved access to wetland and pond habitats in 4 of 5 years above 1,425 ft. (434.3 m) (herptiles, shorebirds and water birds). • less nest flooding in 4 of 5 years. • improved access to terrestrial recreation sites; improved boating. • modest increase in agriculture opportunities. • reduction in shoreline erosion. • decreased dust generation. • improved commercial navigation and log dump operations. • slightly greater ALGS power generation compared to existing operations. • increased vegetation and decreased erosion provide mitigation to protect archaeological resources. 	<ul style="list-style-type: none"> • establishment of tree/shrub and riparian habitats above 1,430 ft. (434.3 m). • increased productivity and diversity of shallow water habitats. • improved fish spawning and migration habitat conditions in the lower reaches of tributaries for resident fish populations as well as potential future anadromous salmon populations. • improved white sturgeon spawning and incubation habitat conditions. • improved access to wetland and pond habitats in 6 of 7 years above 1,420 ft. (432.8 m) (herptiles, shorebirds and water birds). • less nest flooding in 6 of 7 years. • significant increase in terrestrial wildlife habitats including ungulate winter range. • improved access to terrestrial recreation sites; improved boating. • significant increase agricultural opportunities and crop production. • shoreline erosion reduced. • improved commercial navigation and log dump operations. • greatly reduced dust generation. • increased vegetation and decreased erosion provide mitigation to protect archaeological resources.
Neutral Impacts	<ul style="list-style-type: none"> • burbot spawning and incubation success unlikely to be affected. 	<ul style="list-style-type: none"> • ALGS power generation is roughly equal to that under existing operations. • burbot spawning and incubation success unlikely to be affected.

Impact Description	Scenario 1	Scenario 2
Mixed or Uncertain Impacts	<ul style="list-style-type: none"> • effects on reservoir pelagic (open/deep water) productivity and fisheries are uncertain. • mixed effects on fish spawning and migration habitat conditions in the lower reaches of tributaries. • uncertain and mixed effects on aquatic ecosystem productivity and fisheries in the Revelstoke Reach of the Columbia River. • mixed impact on frequency and/or magnitude of mass wasting events. • shoreline property owners have more certainty and consistency over access but greater distance to water during summer months. During late winter/early spring, access distance is less. • conservation of some archaeological sites are improved (above the constant elevation), others are worse (near or at the constant elevation). Opinion is mixed as to whether complete and indefinite site immersion below the constant elevation is positive or negative. 	<ul style="list-style-type: none"> • effects on reservoir pelagic (open/deep water) productivity and fisheries are uncertain. • uncertain and mixed effects on aquatic ecosystem productivity and fisheries in the Revelstoke Reach of the Columbia River. • mixed impact on frequency and/or magnitude of mass wasting events • shoreline property owners have more certainty and consistency over access but greater distance to water during summer months. During late winter/early spring, access distance is less. • conservation of some archaeological sites are improved (above the constant elevation), others are worse (near or at the constant elevation). Opinion is mixed as to whether complete and indefinite site immersion below the constant elevation is positive or negative.
Negative Impacts	<ul style="list-style-type: none"> • on average, storage for flood water is unavailable (but presumably not required) in 4 of 5 years and significantly reduced in 1 of 5 years. • the abundance of aquatic macrophytes (large plants) in shallow water areas around the reservoir is likely to increase, potentially creating more favourable conditions for invasive aquatic species. 	<ul style="list-style-type: none"> • on average, storage for flood water is unavailable (but presumably not required) in 6 of 7 years and significantly reduced in 1 of 7 years. • the abundance of aquatic macrophytes (large plants) in shallow water areas around the reservoir is likely to increase, potentially creating more favourable conditions for invasive aquatic species.

6 Recommended Arrow Lakes Reservoir Operations Evaluation Criteria for Future Operations Modelling

The following section discusses possible new or modifications of existing evaluation criteria for assessing modelling results of future changes in ALR operations.

Evaluation criteria for shoreline erosion currently exists as a soft constraint that tracks number of days the reservoir exceeds the maximum target elevation of 1,440 ft. (438.9 m.) year round, Water elevations above this target may increase bank erosion and exacerbate bank slumping. However, bank erosion occurs at many elevations in the drawdown zone, and affects values such as revegetation sites, recreation sites and infrastructure, etc. A separate soft constraint Performance Measure exists for archaeological sites at known elevations. It may be possible to expand the existing erosion soft constraint analysis to include elevations where other known high risk erosion sites or other values exist, much like that which has been done for archaeological sites.

As a result of extensive WUP-mandated (and other) investigations of the relationship between reservoir elevation and spawner access to tributaries, it should be possible to develop a performance measure which reports length (km) of accessible spawning habitat available at various reservoir elevations during the fall spawning migration periods of kokanee and bull trout (September – October). This measure could be adjusted for accessibility impairment in accordance with the Hawes and Drieschner accessibility index. The measure could also include assessments with and without specific mitigation activities.

With regard to vegetation and wildlife habitat enhancement, the establishment of forested ecosystems provide the foundation for the majority of significant benefits identified under Scenario 2. The establishment of treed riparian vegetation would also enhance channel stability of streams in the drawdown zone, thereby benefiting stream access and spawning habitat for kokanee and trout. Currently, the best available information indicates that achievement of sustainable forest ecosystems requires a significant change in the frequency and duration of inundation. Using the assessment found in this report the recommended evaluation criteria are based on reaching a minimum threshold: the amount of reservoir area that is inundated for less than 35 days per year, with an average frequency of no more than 1 in 7 years.

Scenarios that do not achieve the threshold described above will provide limited benefits for vegetation and wildlife. Decreasing the frequency of inundation of wetland habitats during the growing season and migration windows will increase the availability of key habitats for the years without inundation, but it is unlikely that the quality of the habitats will improve significantly. Decreasing the duration of inundation may have some benefits for vegetation density and vigour, but it is unlikely to result in significant change in vegetation structure or species composition without reaching 35-day threshold and a decrease in frequency of inundation.

Evaluation criteria for agriculture also depends on achieving a minimum number of days where agricultural lands are free of inundation during the growing season. The number of days would vary depending on the agricultural activity under investigation (e.g. grazing, hay production, annual crops, and/or vegetables). Due to the need for spring preparation and planting, the presence of a reliable system of reservoir level forecasting would also be a useful criteria.

Evaluation criteria for recreational users is highly dependent on the type of recreation activity pursued. For shoreline property owners the appropriate evaluation criteria would likely be the

number of days during the summer season (June 1 and Sept 15) where the reservoir was held between 1,430 ft. (435.9 m) and 1,440 ft. (438.9 m). The presence of a reliable system of reservoir level forecasting would also be a useful criteria. For boat-based recreational users (fishing, swimming, picnicking, etc.), the criteria would be the number of days where reservoir levels are between 1,410 ft. (429.8 m) and 1,430 ft. (435.9m.) during the summer season and the number of days where boat ramps are operational. Terrestrial-based recreation users generally prefer lower levels year-round to access more terrain. Criteria for them may be the frequency of years that a minimum area of reservoir footprint is exposed for a minimum number of days, likely with an emphasis on the summer season. For terrestrial users there also are local elevation thresholds where specific recreational features become available (e.g., trails, the Revelstoke Reach rail line, or wetlands for wildlife viewing).

Evaluation criteria for marinas and log dumps are mainly related to the variability of reservoir levels. The less variation, the greater the benefit. Criteria for the marina near the Keenleyside dam should also include flow measurements related to dangerous currents near the marina. Log transport criteria are focused on maintaining a threshold elevation in the narrows (1420 ft. / 432.8 m).

Lastly, it is important to re-emphasize that the report analysis is restricted to the ALR and does not include upstream or downstream values that would be clearly affected if a constant elevation concept were enacted in the ALR. Recommended future analysis of an ALR constant elevation concept should initially evaluate affected resources and values in all sections of the Columbia River upstream of the international border, and later in mid and lower Columbia River sections.

7 References

- Anonymous. 2013. Reed Canary Grass. In Klinkenberg, Brian. (Editor) 2017. E-Flora BC: Electronic Atlas of the Plants of British Columbia [eflora.bc.ca]. Lab for Advanced Spatial Analysis, Department of Geography, University of British Columbia, Vancouver. [Accessed: 03/03/2017 2:32:29 PM]
<http://linnet.geog.ubc.ca/Atlas/Atlas.aspx?sciname=Phalaris%20arundinacea>
- Adama, D.B. and V.C. Hawkes. 2015. CLBMON-11B1. Wildlife Effectiveness Monitoring for Lower and Mid- Arrow Lakes Reservoir. 2014. LGL Report EA3450. Unpublished report by Okanagan Nation Alliance, Westbank, B.C. and LGL Limited environmental research associates, Sidney, B.C., for BC Hydro Generation, Water License Requirements, Burnaby, BC. 13 pp. + Appendices.
- Ashley, K., L.C. Thompson, D. Sebastian, D.C. Lasenby, K.E. Smokorowski, and H. Andrusak. 1999. Restoration of Kokanee Salmon in Kootenay Lake, a Large Intermontane Lake, by Controlled Seasonal Application of Limiting Nutrients in Murphy, T.P. and M. Munawar 1999. Aquatic Restoration in Canada Backhuys Publishers, Leiden, 1999.
- BC Hydro. 2005. Columbia River Water Use Plan. Prepared on behalf of the Consultative Committee for the Columbia River Water Use Plan.
- BC Hydro. 2006. Revelstoke Unit 5 Project Environmental Assessment Certificate Application. Volume 1: Supplemental Information Report.
- BC Hydro. 2010a. Non-Treaty Storage Agreement 2010 Options Assessment: Performance Measure Information Sheet #18 – Arrow Lakes Reservoir: Dust.
- BC Hydro. 2010b. Performance Measure Information Sheet: Arrow Lakes Reservoir Culture and Heritage.
- BC Hydro. 2010c. Performance Measure Information Sheet: Soft Constraints for Arrow Lakes Reservoir Culture and Heritage.
- BC Hydro. 2011. NTSA Stakeholder Forum Report. Non-Treaty Storage Agreement Renegotiation Stakeholder Engagement Process.
- BC Hydro. 2013. Powerpoint presentation by Kelvin Ketchum entitled Columbia/Kootenay flood control March 22, 2013. Available at:
<http://blog.gov.bc.ca/columbiarivertreaty/files/2012/07/BCH-CRT2014-FC-pres-22Mar2013.pdf>
- BC Hydro. 2013a. Canadian Entity's Preliminary View of Columbia River Treaty Post-2024 Called Upon Procedures.
- BC Hydro. 2013b. Columbia River Treaty Review Technical Studies and Addendum. Prepared by BC Hydro and Power Authority.
- BC Hydro. 2014a. Columbia River Water Use Plan 5 Year Review of Soft Constraints Targets; Summary of Participant Input. Available at:

https://www.bchydro.com/content/dam/hydro/medialib/internet/documents/planning_regulatory/wup/southern_interior/2014q1/participant-input-summary.pdf

BC Hydro. 2014b. Columbia River Water Use Plan: 5 Year review of Arrow Lakes Reservoir soft constraints targets – Erosion. Available at:

http://www.bchydro.com/content/dam/hydro/medialib/internet/documents/planning_regulatory/wup/southern_interior/2014q1/erosion.pdf

Beer, J.A. 2004. Littoral Zone Primary Production in a Coastal Reservoir Ecosystem. Thesis submitted in partial fulfillment of the requirements for the degree of Master of Science, University of British Columbia. Pp. x & 112

Bonneville Power Administration. 2012. Assessing the Canadian Hydro Operation Post 2024 in the Absence of the Treaty. Available at: http://www.crt2014-2024review.gov/Files/Final_Report_No_Treaty_Canadian_Operations.pdf

British Columbia. 2014. Columbia River Treaty Review Public Consultation Report. Available at: <http://blog.gov.bc.ca/columbiarivertreaty/files/2013/09/Columbia-River-Treaty-Review-Public-Consultation-Report- March-2014.pdf>

B.C. Conservation Data Centre (BC CDC). 2017. BC Species and Ecosystems Explorer. B.C. Ministry of Environment, Victoria B.C. Available: <http://a100.gov.bc.ca/pub/eswp/> (accessed 3/15/17).

Cameron, I., M. Knighton. 2014. BC Hydro Reservoir Archaeology Program Arrow Lakes Reservoir Archaeological Inventory and Impact Assessment. 2014 Interim Report, Permit # 2013 - 0080.

Cameron, I., N. Lyons, R. Muir. 2013. Archaeology Program Arrow Lakes Reservoir Archaeological Inventory and Impact Assessment. 2011 Final Report, Permit # 2011-0089.

Cameron, I., N. Lyons, R. Muir. 2013a. BC Hydro Reservoir Archaeology Program Arrow Lakes Reservoir Archaeological Inventory and Impact Assessment. 2012 Final Report, Permit # 2011-0089.

Cameron, I., P. Thorogood. 2014a. BC Hydro Reservoir Archaeology Program Arrow Lakes Reservoir Archaeological Inventory and Impact Assessment. 2013 Interim Report, Permit # 2013 - 0080.

Canada Department of Mines and Technical Surveys. 1945 - 57. Columbia River Basin Map Series (Index, M.S.: 6,12,15-24). Surveys and Mapping Branch.

Canadian and United States Entities. 2010. Columbia River Treaty 2014/2014 Review Phase 1 Report.

Carr, W.W., A.E. Brotherston, and A.I. Moody. 1993. Upper Arrow Dust Control Program, Revegetation and Special Studies: Program Summary and Recommendations 1990-1993.

Casselman, J.M. and C.A. Lewis, 1996. Habitat requirements of northern pike (*Esox Lucius*). Can.J.Fish.Aquat.Sci. 53(Suppl.1):161-174

- Columbia Power Corporation. n.d. Service Plan 2014/15-2016/17. Available at:
http://columbiapower.org/wp-content/uploads/2015/02/2015-02-17_FINAL_ServicePlan.pdf
- Columbia River Treaty Operating Committee. 2010. Columbia River Treaty Assured Operating Plan and Determination of Downstream Power Benefits for Operating Year 2014-15.
- Columbia River Treaty Operating Committee. 2015. Columbia River Treaty Detailed Operating Plan for Canadian Storage - 1 August 2015 Through 31 July 2016.
- Cooper Beaudesne and Associates Ltd (CBA). 2015. CLBMON 39: Arrow Lakes Reservoir: Neotropical Migrant Use of the Drawdown Zone, Year 7 (2014). Unpublished report by Cooper Beaudesne and Associates Ltd., Qualicum Beach, B.C., for BC Hydro Generation, Water License Requirements, Burnaby, B.C. 35 pp. + apps.
- Cross, T.K., M.C.McInerny and R.A.Davis, 1992. Macrophyte removal to enhance bluegill, largemouth bass and northern pike populations. Minnesota Department of Natural Resources, Investigational Report 415, 1992.
- CRT Local Governments Committee. 2014. Columbia River Treaty: Draft Recommendations, Summary of November 2013 Feedback From Basin Residents.
- Daley, R.J., E.C. Carmack, C.B.J. Gray, C.H. Pharo, S. Jasper and R.C. Wiegand. 1981. The effects of upstream impoundments on the limnology of Kootenay Lake, B.C. Environment Canada, NWRI, Inland Waters Directorate, Vancouver, B.C. Scientific Series No. 117. 97 p.
- Enns, K. R. Durands, P. Gibeay and B. Enns. 2007. Arrow Lakes Reservoir Inventory of Vegetation Resources (2007) – Addendum to 2007 Final Report prepared by Delphinium Holdings Inc. for BC Hydro.
- Enns, K., and J. Overholt. 2013. CLBMON-12 Arrow Lakes Reservoir Monitoring of Revegetation Efforts and Vegetation Composition Analysis: 2013 Draft Report. Unpublished report by Delphinium Holdings Inc. for BC Hydro Generation, Water Licence Requirements, Castlegar, BC. 65 pages.
- Enns, K., and J. Overholt. 2014. CLBMON-33: Arrow Lakes Reservoir Inventory of Vegetation Resources; CLBMON-12: Arrow Lakes Reservoir Monitoring of Revegetation Efforts and Vegetation Composition Analysis. 2013 Interim Report prepared by Delphinium Holdings Inc. for BC Hydro.
- Evtimova, V. and Donohue, I. 2014. Quantifying ecological responses to amplified water level fluctuations in standing waters: An experimental approach. *Journal of Applied Ecology*. 51. 10.1111/1365-2664.12297
- Fulton, L.A., 1968. Spawning areas and abundance of chinook salmon (*Onchorhynchus tshawytscha*) in the Columbia River Basin -- Past and Present. Special Scientific Report - Fisheries No. 571. U.S. Fish and Wildlife Service.
- Fulton, L.A., 1970. Spawning areas and abundance of steelhead trout and coho, sockeye and chum salmon in the Columbia River Basin -- Past and Present. Special Scientific Report - Fisheries No. 618. U.S. Department of Commerce, National Oceanic and Atmospheric Administration - National Marine Fisheries Service. pp. iii & 37

- Furey, P.C., R.N.Nordin and A.Mazumder. 2006. Littoral benthic macroinvertebrates under contrasting drawdown in a reservoir and natural lake. *J.N.Am.Benthol.Soc.* 2006, 25(1):19-31.
- Global Invasive Species Database. 2017. Species profile: *Phalaris arundinacea*. Downloaded from <http://www.iucngisd.org/gisd/species.php?sc=394> on 03-03-2017.
- Golder Associates Ltd. 2009a. Columbia River Project Water Use Plan; Reference: CLBWORKS-29A. Volume I: Arrow Lakes Reservoir Wildlife Physical Work feasibility Study: 2008. Prepared for BC Hydro. 60pp. + appendices.
- Golder Associates Ltd. 2011. DDMMON#12 Year 1 Report: Duncan Reservoir Erosion Monitoring of Archaeological Sites. Prepared for BC Hydro.
- Golder Associates Ltd. 2012. CLBMON-15a Mid Columbia River Physical Habitat Monitoring. Annual Technical Report – 2011. Report prepared for BC Hydro, Castlegar, BC. Golder Report No. 11-1492-0084. 44 p. + 6 app.
- Green, B. 1997. Unpublished archival research report on upper Columbia anadromous salmon history: distribution, abundance and harvest. 26 p.
- Hawes K. and D. Drieschner, 2012. Arrow Lakes Tributary Fish Migration Access. Year 5 (2012) Fish Migration Passage Monitoring Summary Report. Program No. CLBMON-32 / Q8-8004. Ecoscape Environmental Consultants Ltd. Kelowna, BC. 46pp + maps and appendices.
- Hawkes, V.C. and J. Howard. 2012. CLBMON-11B (29B). Wildlife effectiveness monitoring and enhancement area identification for lower and mid-Arrow Lakes Reservoir: mid- and lower Arrow Lakes Reservoir wildlife enhancement prescriptions. LGL Report EA3274. Unpublished report by LGL Limited Environmental Research Associates, Sidney, B.C., for B.C. Hydro Generation, Water License Requirements, Burnaby, BC. 64 pp. + Appendices.
- Hawkes, V.C., and K.N. Tuttle. 2013. CLBMON-37. Kinbasket and Arrow Lakes Reservoirs: Amphibian and Reptile Life History and Habitat Use Assessment. Year 5 Annual Report – 2012. LGL Report EA3303. Unpublished report by LGL Limited Environmental Research Associates, Sidney, BC, for BC Hydro Generations, Water License Requirements, Burnaby, BC. 67 pp + Appendices.
- Hawkes, V.C., H. van Oort, M. Miller, N. Wright, C. Wood, and A. Peatt. 2015a. CLBWORKS-30 Ecological Impact Assessment – Wildlife Physical Works Project 14 & 15A. Unpublished Report by LGL Limited Environmental Research Associates, Cooper, Beauchesne and Associates, Ecofish Research Ltd. and Okanagan Nation Alliance for BC Hydro, Burnaby BC. 98 pp. + Appendices.
- Hawkes, V.C., J. Sharkey, N. Hentze, J. Gatten, and P. Gibeau. 2014. CLBMON- 11B1. Kinbasket and Arrow Lakes Reservoirs: Wildlife Effectiveness Monitoring and Enhancement Area Identification for Lower and Mid-Arrow Lakes Reservoir. Annual Report – 2013. LGL Report EA3450. Unpublished report by Okanagan Nation Alliance, Westbank, B.C. and LGL Limited Environmental Research Associates, Sidney, B.C., for BC Hydro Generation, Water License Requirements, Burnaby, BC. 63 pp. + Appendices

- Hawkes, V.C., K. Tuttle, A. Leeming, D. Adama. 2013 CLBMON-11B3 Revelstoke Reach Painted Turtle Monitoring Program. Annual Report – 2012. LGL Report EA3414. Unpublished report by Okanagan Nation Alliance and LGL Limited Environmental Research Associates, Sidney, BC, for BC Hydro Generation, Water License Requirements, Burnaby, BC. 34 pp.
- Hawkes, V.C., K.N. Tuttle, and C.M. Wood. 2015b. CLBMON-37. Kinbasket and Arrow Lakes Reservoirs: Amphibian and Reptile Life History and Habitat Use Assessment. Year 7 Annual Report – 2014. LGL Report EA3533. Unpublished report by LGL Limited Environmental Research Associates, Sidney, BC, for BC Hydro Generations, Water License Requirements, Burnaby, BC. 79 pp + Appendices.
- Hawkes, V.C., P. Gibeau, K.A. Enns, J. Sharkey, J. Gatten, and J. Fenneman. 2011. CLBMON-11B1. Kinbasket and Arrow Lakes Reservoirs: Wildlife Effectiveness Monitoring and Enhancement Area Identification for Lower and Mid-Arrow Lakes Reservoir. Annual Report – 2010. LGL Report EA3164A. Unpublished report by LGL Limited Environmental Research Associates, Sidney, BC, for BC Hydro Generations, Water License Requirements, Burnaby, BC. 98 pp. + Appendices.
- Hession, W & McBride, M & E. Pizzuto, J. 2008. Riparian vegetation influence on channel morphology. Proc. AWRA Summer Specialty Conference 2008
- Hildebrand, L. R., A. Lin, M. C. Hildebrand, and D. Fissel. 2014. Effects of Flow Changes on White Sturgeon Spawning, Incubation, and Early Rearing Habitats in the Middle Columbia River (CLBMON-20 and CLBMON-54). Prepared for BC Hydro, Castlegar, BC by Golder Associates Ltd, Castlegar, BC and ASL Environmental Sciences Inc., Victoria, BC. 64 pp. + 3 app and 1 Attachment. Keefer Ecological Services (KES). 2011. CLBWORKS-2 Arrow Lakes Reservoir Revegetation Program Physical Works. Phase 3 Report – 2011 Unpublished report by Keefer Ecological Services Ltd., Cranbrook, BC, for BC Hydro Generation, Water Licence Requirements, Castlegar, BC. 38 pp. + Apps.
- Hunt, P. C. and Jones, J. W. 1972. The effect of water level fluctuations on a littoral fauna. *Journal of Fish Biology*, 4: 385–394.
- Jackson, M.,M. Evelyn, S. McMahon and J. Sheppard. 2010. CBLMON 13. Inventory of Mosquito Populations in the Revelstoke Area. Unpublished report prepared for BC Hydro by Culex Environmental Ltd.
- Ketcheson, M.V., K. Misurak, V. Lipinski, G. Kernaghan, K. Lessard, T. Dool, L. Bradley and E. White. 2005. Columbia Basin BC Hydro Footprint Mapping: BC Hydro Reference Number DFIM040. Report prepared for FWCP:CB, Nelson, BC.
- KWL. 2012. Columbia River Project Water Use Plan. Revelstoke Reach Erosion Protection and Long-Term Monitoring Year 3. CLBWORKS-35 and CLBWORKS-36. Prepared for BC Hydro.
- Lees+Associates. 2015a. CLBMON-14 Boat Ramp Use Study. Mid-Term Analysis Report (Year 4) Implementation Period – 2010-2013. Vancouver, BC. BC Hydro, Water License Requirements.

- Lees+Associates. 2015b. CLBMON-41 Arrow Reservoir Recreational Demand Study. Year 5 Final Report Study Period – 2009-2013. Vancouver, BC. BC Hydro, Water License Requirements.
- Local Governments Committee, Columbia River Treaty. 2012. Columbia River Treaty: Recommendations December 2013.
- Manley, I. and J. Krebs. 2010. Wildlife Species and Population Impacts. Unpublished report prepared for the Fish and Wildlife Compensation Program: Columbia Basin, Nelson, BC.
- Matzinger, A., R. Pieters, K. I. Ashley, G. A. Lawrence, and A. Wüest. 2007. [Effects of impoundment on nutrient availability and productivity in lakes](#). *Limnology and Oceanography* 52(6):2629-2640.
- Miller, M.T. and V.C. Hawkes. 2014. CLBMON-11B4 Monitoring Wetland and Riparian Habitat in Revelstoke Reach in Response to Wildlife Physical Works. Annual Report – 2013. LGL Report EA3413. Unpublished report by Okanagan Nation Alliance and LGL Limited environmental research associates, Sidney, BC, for BC Hydro Generation, Water Licence Requirements, Burnaby, BC. 34 pp. + Appendix.
- Mills, K., D.Huebert, S. Chaluchuk, D. Allan, P. Blanchfield, A. Salki, D. Findlay and M. Stainton. 2004. Impacts of Macrophyte Removal on Norther Pike Biomass and Production (Experimental Lakes Area). Unpub. Powerpoint presentation
- Moody, A. 2002. Vegetation Mapping (1968-2000) of Dust Control Treatment Areas: Revelstoke Reach – Upper Arrow Reservoir. Unpubl. Rpt. prepared for BC Hydro Strategic Environmental Initiatives Program – Evaluation of the Ancillary Benefits of Upper Arrow Reservoir Drawdown Zone Revegetation Project. Vancouver, BC. 15pp. and appds.
- Okanagan Nation Alliance, Golder Associates Ltd., and Poisson Consulting Ltd. 2014. CLBMON-16 Middle Columbia River Fish Population Indexing Survey. Report prepared for BC Hydro Generation, Water License Requirements, Revelstoke, BC.
- Pandit, A.K. 1984. Role of macrophytes in aquatic ecosystems and management of fresh water resources. United States.
- Parkinson, E., and S. Arndt, 2014. Results of a workshop on management policy options for Arrow Lakes. Prepared for Fish and Wildlife Compensation Program and Ministry of Forests, Lands and Natural Resource Operations. 53pp.
- Penfold, G.E. 2012. A Review of the Range of Impacts and Benefits of the Columbia River Treaty on Basin Communities, the Region and the Province. Unpubl. Rpt. for B.C. Ministry of Energy, Mines and Natural Gas – Columbia River Treaty Review. Victoria, B.C. 87pp. Available at: <http://blog.gov.bc.ca/columbiarivertreaty/files/2012/07/A-Review-of-the-Range-of-Impacts-and-Benefits-of-the-Columbia-River-Treaty6.pdf>
- Penfold, G.E. 2012. A Review of the Range of Impacts and Benefits of the Columbia River Treaty on Basin Communities, the Region and the Province. Unpubl. Rpt. for B.C. Ministry of Energy, Mines and Natural Gas – Columbia River Treaty Review. Victoria, B.C. 87pp.

- Pieters, R. *et al.* 1998. Arrow Reservoir Limnology and Trophic Status Year 1 (1997/1998) Report. Fisheries Project Report No. RD 67. Prepared for the Ministry of Environment, Lands and Parks, Province of British Columbia.
- Pieters, R., L.C. Thompson, L. Vidmanic, M. Roushorne, J. Stockner, K. Hall, M. Young, S. Pond, M. Derham, K. Ashley, B. Lindsay, G. Lawrence, D. Sebastian, G. Scholten, F. McLaughlin, A. Wüest, A. Matzinger and E. Carmack. 1999. Arrow Lakes Reservoir Limnology and Trophic Status Report, Year 2 (1998/99). RD 72. Fisheries Branch, Ministry of Environment, Lands and Parks, Province of British Columbia.
- Pieters, R., L. Thompson, L. Vidmanic, M. Roushorne, J. Stockner, K. Hall, M. Young, S. Pond, M. Derham, K. Ashley, B. Lindsay, G. Lawrence, H. Andrusak, D. Sebastian, and G. Scholten. 2000. Arrow Reservoir Fertilization Experiment Year 1 (1999/2000). Fisheries Project Report No. RD 82.
- Plate, E.M. 2014. Mica Dam, Revelstoke Reservoir 2013 – A Literature Review and Field Work to Assess Fish Residency and Total Gas Pressure Supersaturation Risk in the Upper Revelstoke Reservoir. Prepared by LGL Limited Environmental Research Associates for BC Hydro. Pp. viii & 67
- Plate, E.M., Y. Imam, S. Dashti, L. Walker, N. Wright and M. Zimmer. 2014. CLBMON-15a Revelstoke Reach River Physical Habitat Monitoring Project, 2013 (Year 7). Prepared for: BC Hydro, Revelstoke, BC. Prepared by: Okanagan Nation Alliance, LGL Limited and Ecofish Research Limited: 79 pp.
- Robichaud, D., G. Glova and S. Kingshott, 2013. Arrow Lakes Reservoir Burbot Life History and Habitat Use (Year 5). Report prepared by LGL Limited Environmental Research Associates for BC Hydro (Reference:CLBMON-31) pp. vi & 23.
- Rosenau, M.L. 2014. Nearshore habitat utilization by spawning lake char and rearing rainbow trout in Shuswap, Little Shuswap and Mara lakes. Fraser Basin Council Manuscript Report ix + 121 p.
- Roussin, R. 2014. Agricultural Potential for the West Kootenay, B.C. Unpubl. Rpt. prepared for fulfillment of a Master of Land and Water Systems degree at University of British Columbia. Vancouver, B.C. 63pp. Available at: <http://www.cbrdi.ca/wp-content/uploads/Agricultural-Potential-of-the-W.Koots-RRoussin-2014.pdf>).
- Schindler, E., D. Sebastian, T. Weir, H. Andrusak, G. Andrusak, M. Bassett and K. Ashley, 2011. ARROW LAKES RESERVOIR NUTRIENT RESTORATION PROGRAM YEARS 11 and 12 (2009 and 2010) REPORT Resource Management, Ministry of Forests, Lands and Natural Resource Operations, Province of BC, 401-333 Victoria St., Nelson, BC, V1L 4K3
- Schindler, E.U., D. Sebastian, L. Vidmanic, H. Andrusak, J. Stockner, M. Bassett and K.I. Ashley. 2010. Arrow Lakes Reservoir Nutrient Restoration Program, Year 9 (2007) Report. Fisheries Project Report No. RD 128, Ministry of Environment, Province of British Columbia.
- Schindler, E.U., D. Sebastian, L. Vidmanic, H. Andrusak, M. Bassett and K.I. Ashley. 2011b. Arrow Lakes Reservoir Nutrient Restoration Program, Year 10 (2008) Report. Fisheries Project Report No. RD 132, Ministry of Environment, Province of British Columbia.

- Schleppe, J., H. Larratt., N. Swain and C. Whitney, 2014. CLBMON-15b Middle Columbia River Ecological Productivity Monitoring, Annual Report 2013. Okanagan Nation Alliance in association with Ecoscape Environmental Consultants Ltd. & Larratt Aquatic Consulting Ltd. 99pp.
- Slivinski, D. and G. Sykes, 2014. Middle Columbia River Juvenile Habitat Use Assessment (Year 6 of 6) Reference: CLBMON#17 Columbia River Water Use Plan Monitoring Program: Middle Columbia River Juvenile Fish Habitat Use Study Period: 2013-2014. Pp. ix & 91, 5 appendices
- Tabor, R.A. and W.A. Wurtsbaugh. 1991. Predation Risk and the Importance of Cover for Juvenile Rainbow Trout in Lentic Systems. Trans.Amer.Fish.Soc. 120:728-738
- Taylor, M. and B. Lewis. 2011. CLBMON-18 Middle Columbia River Adult Fish Habitat Use Program. Study Period: Year 3 – 2010. Golder Associates (Castlegar, BC) and Carleton University (Ottawa, ON) Report prepared for BC Hydro, Revelstoke Flow Management Plan, Golder Project No. 10-1492-0082. 81 p. + 2 app.
- Thomson, A. 2013. Arrow Reservoir 2024 Options. Powerpoint presentation for the Columbia Treaty Review community session held in Fauquier, BC June 15, 2013. Available at: <http://blog.gov.bc.ca/columbiarivertreaty/files/2012/07/Alan-Thomson-Arrow-Reservoir-2024-Options.pdf>
- Thorley, 2008. Aquatic Habitat Losses and Gains due to BC Hydro Dams in the Columbia Basin. Unpubl. Report prepared for the Columbia Basin Fish and Wildlife Compensation Program, Nelson, BC. 121pp.
- Truelson, R.L. and P.D. Warrington, 1994. Effects of Water Storage Reservoirs on Downstream Water Quality and Aquatic Vegetation: A Literature Review. BC Ministry of Environment, Lands and Parks. Pp. iii & 31
- Utzig, G. and D. Schmidt. 2011. Dam Footprint Impact Summary – BC Hydro Dams in the Columbia Basin. Unpublished report prepared for the Fish and Wildlife Compensation Program: Columbia Basin, Nelson, BC. Available at: http://a100.gov.bc.ca/appsdata/acat/documents/r23145/FWCP_Impacts_Summary_1425054976435_5053647442.pdf
- van Oort, H. and J.M. Cooper. 2015a. CLBMON 36: Kinbasket and Arrow Lakes Reservoirs: nest mortality of migratory birds due to reservoir operations— Year 7, 2014. Unpublished report by Cooper Beauchesne and Associates Ltd., Errington, BC, for BC Hydro Generation, Water Licence Requirements, Burnaby, BC. 32 pp. + Apps.
- United States Army Corps of Engineers. 2003. Columbia River Treaty Flood Control Operating Plans. Prepared by the U.S Army Corps of Engineers, Northwestern Division, North Pacific Region for the United States Entity.
- van Oort, H., and J.M. Cooper. 2015b. CLBMON-40: Arrow Lakes Reservoir Shorebird and Waterbird Monitoring Program. Annual Report – Year 7, 2014. Unpublished report for BC Hydro Generation, Water Licence Requirements, Burnaby, BC. 29 pp. + Apps.

van Oort, H., R.A. Gill, and J.M. Cooper. 2011. CLBMON 11B-2 Revelstoke Reach Spring Songbird Effectiveness Monitoring. Unpublished report by Cooper Beauchesne and Associates Ltd., Errington, B.C., for BC Hydro Generation, Water Licence Requirements, Castlegar, B.C. 40 pp. + apps.

Water Survey of Canada. 2015. Wateroffice Historical Hydrometric Data. Nakusp hydrometric station. Available at: http://wateroffice.ec.gc.ca/search/search_e.html?sType=h2oArc

Wood, C.M. and V.C. Hawkes. 2014. CLBMON-11B3 Revelstoke Reach Painted Turtle Monitoring Program. Annual Report – 2013. LGL Report EA3414. Unpublished report by Okanagan Nation Alliance and LGL Limited environmental research associates, Sidney, BC, for BC Hydro Generation, Water Licence Requirements, Burnaby, BC. 44 pp + Appendices.

Appendix 1: Number of days Upper Arrow Lake was above water elevations for pre-regulation period 1922-1967

Year	May	June	July	August	September	Year	Days > 1,380 ft	Days > 1,390 ft	Days > 1,400 ft	Days > 1,405 ft
1922						1922	203	100	3	
1923						1923	193	109	6	
1924						1924	204	109		
1925						1925	190	103	11	
1926						1926	212	42		
1927						1927	219	87	12	
1928						1928	183	93	11	2
1929						1929	168	81		
1930						1930	187	85		
1931						1931	204	87		
1932						1932	213	111	20	
1933						1933	228	99	34	
1934						1934	238	110	19	
1935						1935	183	89		
1936						1936	193	105	9	
1937						1937	209	67		
1938						1938	199	73	8	
1939						1939	238	96		
1940						1940	214	87		
1941						1941	244	64		
1942						1942	190	94		
1943						1943	199	75		
1944						1944	208	57		
1945						1945	172	66		
1946						1946	175	97	19	
1947						1947	217	94		
1948						1948	196	100	32	15
1949						1949	183	73		
1950						1950	190	78	31	5
1951						1951	192	98		
1952						1952	185	94		
1953						1953	223	93	3	
1954						1954	221	115	31	5
1955						1955	190	72	27	1
1956						1956	208	82	24	
1957						1957	186	87	15	
1958						1958	213	81	24	
1959						1959	225	86	17	
1960						1960	234	79	8	
1961						1961	195	85	32	18
1962						1962	229	93	3	
1963						1963	205	90	1	
1964						1964	206	82	31	
1965						1965	218	95		
1966						1966	215	92		
1967						1967	200	95	43	18

Note: Colour key that indicates number of days water elevation above 1,380 ft., 1,390 ft., 1,400 ft., or 1,405 ft. along right margin.

Appendix 2: Table of listed bird species of potential relevance to changes in the operation of the Arrow Lakes Reservoir as of January 2017 (information supplied by Environment and Climate Change Canada).

Species	MBCA	ECCC – Spp. at Risk (SARA schedule 1)	COSEWIC (rank where assessed)	BC list	Occurrence (B=Breeding) (R=Resident)	Aquatic habitat association	CRT-impact relevance	Hot Spots	Other Comments
Yellow-breasted Chat	Y	Endangered	Endangered (2011)	red	B	riparian	<i>loss of riparian to scouring</i>	occurrences in southern Okanagan, Creston area, near confluence of	Posted Recover Strategy with partial Critical Habitat ID.; sensitive May to July
Forster's Tern	Y	No	Data Deficient (1996)	red	B	marsh, open water	<i>nests sensitive to flooding</i>	Creston	very low numbers - not assessed
Western Screech- Owl (<i>macfarlanei</i>)	N	Endangered	Threatened (2012)	red	R	riparian	<i>water levels change cottonwood</i>	widespread near border	
Lewis' Woodpecker	Y	Threatened	Threatened (2010)	blue	B	riparian	<i>Cottonwood recruitment (and similar)</i>	widespread but sparse in CRT	not sensitive to water levels, RS posted and CH available
Western Grebe	Y	No	Special concern (2014)	red	migrant	marsh, wetland	nests flooded by changing water levels	mainly Creston Valley	good wetland indicator species; sensitive May to July
Great Blue Heron (non-coastal subspp.)	Y	No	Not listed	blue	R	wetlands, riparian	<i>needs low water for foraging</i>	widespread throughout CRT	sensitive year round
Short-eared Owl	N	special concern	Special Concern (2008)	blue	R	marsh, agricultural	<i>flooding of grasslands</i>	widespread but sparse in CRT	sensitive April to July
Clark's Grebe	Y	No	Not Listed	red	B	wetlands	likely the same as Western Grebe	historically a few pairs at Duck Lake	very low numbers; sensitive May to July
American Bittern	Y	No	Not Listed	blue	B	marsh	<i>nests sensitive to flooding</i>	widespread but sparse in CRT	sensitive May to July

Species	MBCA	ECCC – Spp. at Risk (SARA schedule 1)	COSEWIC (rank where assessed)	BC list	Occurrence (B=Breeding) (R=Resident)	Aquatic habitat association	CRT-impact relevance	Hot Spots	Other Comments
Yellow Rail	Y	special concern	Special Concern (2009)	red	R	marsh	numbers fluctuate greatly with interannual changes in water levels	few occurrences but challenging to monitor	
Long- billed Curlew	Y	special concern	Special concern (2011)	blue	B	grassland, wet meadows		Kootenay R from Invermere to border	higher altitude habitat away from river; sensitive May to July
Double- crested Cormorant	N	No	Not at risk (1978)	blue	B	open water	not impacted by water levels	colony in Creston	
Black Swift	Y	No	Endangered (2015)	blue	B	open water, waterfalls	not impacted by water levels	widespread	
American Avocet	Y	No	Not listed	blue	migrant	wetland		Cranbrook and N tip of Arrow Lakes, S Kootenay Lake	breeds in higher altitude habitat away from river; sensitive May to July
Eared Grebe	Y	No	Not listed	blue	B	wetlands	adapted to periodic changes in water levels	widespread	
Barn Swallow	Y	No	Threatened (2011)	blue	B	open habitats	not impacted by water levels	Creston, widespread	nests on structures and forages overhead; sensitive May to July
Common Nighthawk	N	Threatened	Threatened (2007)		B	sparse drawdown	not impacted by water levels	common and widespread	nests above drawdown; sensitive June and July
Horned Grebe	Y	No	Special concern (2009)		B	open water	not sensitive to water levels	only in southern half of CRT	breeds at higher elevation but migrates through river

Bobolink	Y	No	Threatened (2010)	blue	B	grassland	nests sensitive to flooding	Creston	low numbers, outside drawdown; sensitive May to July
Species	MBCA	ECCC – Spp. at Risk (SARA schedule 1)	COSEWIC (rank where assessed)	BC list	Occurrence (B=Breeding) (R=Resident)	Aquatic habitat association	CRT-impact relevance	Hot Spots	Other Comments
Green Heron	Y	No	Not listed	blue	R	wetlands, riparian		low density, not well-	sensitive year round
Least Bittern	Y	No	Threatened (2009)		R	marshes	needs stable water levels	uncommon in BC, no <i>e-bird</i> records	sensitive year round
Rusty Blackbird	N	special concern	Special concern (2006)	blue	migrant	bog		low density	habitat at higher elevation, rapid declines in Canada; sensitive May to July
California Gull	Y	No	Not listed	blue	migrant	wetlands, open water	v. small pop, little known about breeding in interior		

Appendix 3: Responses to Comments Received by the Province on the Arrow Lakes Reservoir Mid Elevation Scenarios – Scoping Evaluation Report – March 2018.

The following table contains responses to all written comments and feedback received from a variety of organizations, First Nations, senior government agencies and the public. Where appropriate, similar comments have been combined. The response to each comment is either found below or in the report section noted. In some cases, the response appears below and in the report

Comment or question	Response	See Report Section
Executive Summary		
Considering the management of ALR in isolation of KIN or LCR is not realistic and questions the utility of such an exercise. Would the proposed scenarios have any impact on how Revelstoke Reservoir is managed? Exploring a stable Arrow option needs to occur relative to the effects on other parts of the system in the form of a cost-benefit analysis. The implication is that habitats in Arrow are more important than KIN or LCR, this despite the measurements of impacts to habitats affected by the creation of Kinbasket Reservoir and the reported impacts to wildlife (as reported in the 2011 Dam Impact Study).	We fully understand the limitations of assessing the ALR scenarios without consideration of effects on upstream and downstream environments. If the scoping level analysis of the ALR scenarios reveals positive effects and warrants additional research and analysis, then the next phase could include potential impacts on some or all other Canadian Columbia River sections and facilities.	Exec. Sum.
What source data were used to derive elevations? The DEM available for ALR is not based on LiDAR, so may not be accurate. Accurate elevation data are required to properly assess the effects of each scenario on habitats in ALR. The flooding frequency and duration appears to only consider the effects on the potential development of mature forest in the drawdown zone. Pre-impoundment conditions included a mosaic of habitats including riparian, wetland, floodplain forest, deciduous stands, etc. What flooding frequency and duration is required to promote the establishment and development of these other important habitats?	<p>The elevations used in the report are derived from the sources referenced. We acknowledge there are questions concerning elevation accuracy (although sufficient for this scoping exercise), and have recommended development of an improved Digital Elevation Model (DEM).</p> <p>We have focused on forested habitats because they are likely the most sensitive to flooding frequency and duration. If forests can survive, then wetlands and flood tolerant shrub communities can certainly survive. As indicated in the report, the map analysis shows that wetland shrub and marsh habitats present are more flood tolerant than forests.</p>	Exec. Sum

Comment or question	Response	See Report Section
<p>A stable ALR is likely to contribute to an increase in vegetative cover at elevations exceeding 434.3 and 432.8; however, this is not a hypothesis. This has been documented in both ARL (and KIN, but for different elevations, the point being that vegetation will develop in the drawdown zone if the duration, frequency, and timing of inundation changes) and is reported in WLR studies CLBMON-10 and CLBMON-33, both of which have indicated that a reduction in the duration, timing, and frequency of inundation at specific elevation bands will promote the natural establishment and development of vegetation communities. Available data should be used to the extent possible to support hypotheses.</p>	<p>The results from studies in the ALR are referenced in Section 4.2. The difference in this study is that we are looking at novel and large changes in frequency and duration that were not considered in the CLBMON studies.</p>	<p>Exec. Sum. 4.2</p>
<p>Words such as "unlikely" and "likely" are being used to promote one scenario over another with respect to the development of vegetation communities in the drawdown zone. Given the amount of work that has occurred in ALR on vegetation it should be relatively straight forward to determine what the extent of vegetation was pre-dam, particularly at elevations that exceed those associated with each scenario and estimate the recovery time for each habitat type. Data from the 2011 Dam Impact Study and the WLR studies can be used to assess impacts (Dam Impact) relative to current conditions (WLR) and use that information to generate estimates of vegetation recovery relative to time (decades, as stated) and potential cover by type. This would provide a much more useful indication of the benefit of one scenario over another.</p>	<p>Actually it is not that straightforward. As the commenter, and our report indicate, there is not an accurate DEM for the dam footprint, and therefore accurate calculations are impossible.</p> <p>Secondly the WLR studies are not actually that useful for estimating recovery time. As shown in the report, only a thin band of the reservoir footprint meets the flood frequency and duration requirements of the Scenarios, and this is confounded by wave scour, erosion and extensive debris scour damage. Therefore the WLR studies have very little re-vegetation data that is directly applicable.</p> <p>One could look at primary succession data for other types of disturbances, or other reservoirs where dams have been removed, but this was beyond the scope of this study.</p>	<p>Exec. Sum.</p>

Comment or question	Response	See Report Section
An increase in riparian vegetation in the DDZ may contribute to an improvement in UWR, which is viewed as a positive result; however, the continued and cumulative effects of adjacent land management do not appear to have been considered in the assessment of a stable ALR. The establishment of riparian vegetation in the DDZ needs to be considered relative to habitat connectivity and future land use in adjacent upland habitats.	Agreed, but beyond the scope of this study. However, given that fire management, forest harvesting and rural development have generally had a negative impact on UWR, it would seem that any increase in UWR in the footprint could be considered a net benefit.	Exec. Sum.
Bird nest flooding is a concern in all higher elevation, flatter areas in ALR, not only Revelstoke Reach. Other areas where this has been noted included Burton Flats, Lower Inonoaklin Road, and Edgewood. Consideration of the effects of the timing, duration, and frequency of inundation need to be made reservoir-wide	Adjusted the wording accordingly.	Exec. Sum.
Section 2.2: Current Hydrological Regime		
The quoted upper levels of the pre-impoundment (“1,401 ft. (427.0 m.)”) and post-impoundment (“1,440 ft. (438.9 m.)”) periods do not match the peak values shown by the dark blue and black lines in Figure 3. Figure 3 shows values closer to 1398 and 1437 ft. respectively.	Adjusted accordingly.	
Section 3: Constant Mid-Elevation Scenarios		

Comment or question	Response	See Report Section
<p>This section would benefit from a description of flows, not just elevations. Provide graphs showing average flows by date in the two scenarios, and as compared to pre-dam and present-day. There is not a straightforward relationship between flows and elevation levels: to maintain the reservoir at a given elevation level, flows will have to increase or decrease with the volumes of water coming into the system. Thus a stable reservoir elevation could theoretically result in different flow dynamics than are present today.</p> <p>Subsequent sections would also benefit from details of the temporal flow patterns. For example, Section 4.4.2.1 discusses the impacts of flows on flushing and upwelling of nutrients, and is difficult to understand when the two Scenarios are described strictly in terms of reservoir elevations.</p>	<p>Agreed. However it is difficult to discuss and analyse flows without determining dam operations upstream of the Arrow Reservoir and without computer modelling of Columbia River operations, both of which were outside the Terms of Reference. Subsequent report phases will incorporate analysis of flow regime and upstream/downstream dam operations.</p>	
Section 3.2: Development of Scenario 2		
<p>Given the areas estimated have low reliability it will be necessary to obtain the data necessary to improve these area estimates. We suggest obtaining the best data available (i.e., LiDAR to generate a high resolution DEM, with the LiDAR data collected when the reservoir is at a low level) to recalculate the area of impacts habitats reported in the Dam Impact Study (to serve as a reliable baseline) and to generate more reliable estimates of area.</p>	<p>Agreed. This is part of the recommendations for further information.</p>	4.2.2.4
<p>Traditional Ecological Knowledge or First Nations knowledge does not appear to have been considered in the assessment of which areas could be revegetated.</p>	<p>This has been added to the recommendations for further information.</p>	4.2.2.4

Comment or question	Response	See Report Section
The 35 day inundation period at a 1 in 7 year frequency appears to be a 'best guess' that has not been validated. Furthermore, thresholds are rarely informative when discussing ecosystem function. Given the natural variability experienced by all ecosystems, it would be more informative to consider a range of conditions under which the ecology of the drawdown zone could develop. While this is acknowledged to some degree in the report via indications that the 1 in 7 frequency is not a hard constraint that must happen once every seven years, there needs to be more consideration of the variability of inundation duration and frequency at different elevations and on different habitats. For example, what happens if the 35 day threshold is exceeded by 10-20% in a given year, but at the same frequency? Will that result in a 'significant' impact on plant mortality? We suggest that a range of values be considered and tested with reliable data to infer what the effects of variable operating regimes would be on the development of habitats in the drawdown zone.	It is better than a “best guess” since it is based on pre-dam historical data and post dam data from the reservoir footprint. Agreed that it needs to be further tested and confirmed.	
The only way functional ecosystems can develop in the drawdown zone of ALR is to provide opportunities for vegetation to establish and develop in the absence of prolonged inundation. The 35 day period and frequency (1 in 7) indicated needs to be validated with respect to the various habitats that could develop in the drawdown zone under more stable conditions. This analysis needs to be elevation- and area-specific. This requires detailed assessments the tolerance of plants to various levels of wet and dry stress that mimic various operational regimes with respect to the duration, timing, and frequency of inundation. Certainly the scenarios examined in this report could be part of that assessment.	Agreed. This is one of the recommendations for further information. Further, a trial of modified operations designed to test vegetation establishment and tolerance over a variety of inundation duration and frequency values (i.e. active adaptive management) is also recommended.	

Comment or question	Response	See Report Section
<p>The element of timing needs considered relative to the duration and frequency of inundation. Flooding plants when they are flowering may prolong the duration over which vegetation becomes established. There are also certain species of plants (e.g., Moss Grass, <i>Coleanthus subtilis</i>) that appear to thrive under current operations that results in temporary flooding of the elevations at which they occur. Stabilising Arrow will undoubtedly have an impact on such species.</p>	<p>This was considered, and the flooding timing proposed in Scenario 3 is coincident with the natural flooding patterns prior to dam construction. The effects on Moss Grass were noted in the text.</p>	
<p>How many years of mapping were reviewed? Is this a singular map or does the period 1947 to 1957 represent a time series. If the former, then the data represent a snap shot in time that could have been representing a land cover that varies over time.</p>	<p>The mapping is not a time series. The mapping of the entire Canadian section of the Columbia River in the 1940s and 1950s was performed over a number of years as the survey crew moved throughout the watershed, but each survey map represents one point in time. The land cover certainly may vary over time; however, given that the ecosystems mapped in the flood zone included mature forests, any variation over this short period is unlikely.</p>	3.2
<p>Cottonwood stands already occur elevations > 435.9 m ASL in ALR. If the intent is to suggest that the spatial extent of cottonwood stands could increase at elevations > 435.9 m ASL, then say so. Otherwise, be more specific with respect to the elevations at which you suggest cottonwood stands could occur. Based on what is known regarding the occurrence and distribution of cottonwood in the DDZ of ALR, the majority of cottonwood occurs near the top of the DDZ (i.e., 440 m ASL), but the elevation distribution varies by reach. An assessment of the relationship of each scenario relative to the development of cottonwood stands should occur by elevation band and location in the reservoir to properly define where cottonwood stands could develop and/or expand under either scenario.</p>	<p>Agreed, however there is no emphasis on cottonwood development in the report. Cottonwood just happens to be the species that is present in flood zones in Kootenay Lake. Given the lack of an accurate DEM and terrain and soil mapping, it is not possible to precisely predict where cottonwoods or other species may occur under the scenarios. Hence the assessments in the report are somewhat general, and there are recommendations to gather further information.</p>	end of 3.2

Comment or question	Response	See Report Section
Which floodplain vegetation communities are being referenced? An inundation frequency that averages 1 in 7 years for a duration of 35 days will have varying effects on wetland, shrub, floodplain, or forested habitats. This metric required refinement to be of any utility when assessing the effects of modified operations on the establishment and development of vegetation communities in the drawdown zone of ALR.	Various vegetation communities are included. Forested habitats were focused on because they are likely the most sensitive to flooding frequency and duration. If forests can survive, then wetlands and flood tolerant shrub communities can certainly survive. As indicated in the report, the map analysis shows that the wetland shrub and marsh habitats present prior to dam construction are more tolerant than forests. This information certainly has utility as it is a metric based on real data, and therefore a reasonable starting point for further assessment. Additional research on and refinement of the metric will occur in subsequent report phases.	3.2
4.1 Introduction		
The system-wide modeling requires the best available data and inclusion of TEK / First Nations expertise, particularly as it relates to the impacts of impoundment and reservoir operations on habitats adjacent to the Columbia River and upper and lower Arrow Lakes. We acknowledge that the report produced here is part of an iterative process, but the lack of consideration of the impacts the two scenarios relative to the rest of the system and the effects of cumulative impacts and climate change on the ecology of the system further degrades the utility of this report.	This is acknowledged in the section referenced. Use of TEK has been added to the recommendations for future report phases.	1.1 4.1 4.2.2.4
Section 4.2: Vegetation		
What increase in area in the drawdown zone would result from the Scenarios?		3.1, Table 1

Comment or question	Response	See Report Section
<p>Discuss time and limitations to terrestrial ecosystem recovery under the Scenarios.</p>	<p>Under Scenario 2, above 1,430 ft. (435.9 m), the rate of ecosystem succession will vary across the reservoir. Periodic establishment of trees, shrubs and other herbaceous species under existing conditions in low water years, demonstrates that revegetation can begin quickly (likely in 1 to 5 years, depending on species and weather conditions), especially in the fringe adjacent to seed sources (potentially up to 100m+). The rate and trajectories of succession will vary depending on substrate, moisture availability, as well as proximity to seed sources. Moist areas with finer textured soils at the upper elevations will likely revegetate more quickly. In general substrate conditions within the Revelstoke Reach, and areas on fans in the Arrow Lakes portion of the reservoir are more favourable to rapid succession although competition with dense communities of reed canary grass and other sedges may slow initial transition in some areas. Coarse textured soils and exposed bedrock sites will be the slowest to revegetate. Under favourable conditions succession to shrub communities will likely take at least 5 years, while development of full forest structure will likely take at least 30 years. Development on less favourable substrates would potentially benefit from soil enhancement and planting. Un-managed off-road vehicle disturbance may slow revegetation in some areas.</p> <p>The growing season weather of the initial non-flood years will also affect the speed of revegetation by determining seed production and seedling survival. The periodicity of the 1 in 7 flood years will also impact the speed of revegetation, the longer the initial non-flood interval, the faster revegetation will proceed.</p> <p>Effective implementation of Scenario 2 will require an adaptive management strategy complete with on-going monitoring and the potential for responses to identified issues. Where appropriate, the responses may include: planting of trees and shrubs, control of invasive species, re-establishment and stabilization of stream channels on fans, fertilization, management of off-road motorized access to minimize disturbance of establishing vegetation, wildfire management and others.</p>	<p>4.2.2.3</p>

Comment or question	Response	See Report Section
<p>Discuss the implications of the Scenarios on Reed Canary Grass that has established in the Revelstoke Reach.</p> <p>Discuss the risk of fire in reed canary grass sections under the Scenarios.</p>	<p>Reed canary grass (<i>Phalaris arundinacea</i>) is a perennial rhizomatous grass native to North America, with widespread occurrences at lower elevations throughout Southern BC (Anonymous 2013). It was first recorded in BC in 1897 and is generally found in wet meadows and along stream banks and lake shores. Introduced cultivars from Europe have likely cross-bred with the native varieties, and these more vigorous hybrids are sometimes classed as invasive (GISD 2017). It prefers fine textured soils and is highly flood tolerant, which likely explains its widespread occurrence in the Revelstoke Reach. It is generally considered of little value for wildlife, and can out-compete other more desirable species, given the right conditions.</p> <p>Given the apparent association of reed canary grass with prolonged annual flooding cycles, it is likely to decrease in cover and vigour as the flooding periodicity changes. To date there are no indications that reed canary grass is a major threat to areas outside the reservoir. As conditions become more favourable for native species in the Revelstoke Reach, those species should be in a position to more successfully compete with reed canary grass above 1,430 ft. (435.9 m). It is possible that reed canary grass will become established at lower elevations than presently occurs due to reduced water depths. Under both Scenarios, wildfire risk in the reed canary grass areas will vary with local fire weather conditions, but is expected to be similar to what it is presently in low water years, and should decrease as reed canary grass productivity decreases.</p>	<p>4.2.1 4.2.2.1</p>
Comment on the ecological importance of annual flooding of grasslands in the Revelstoke Reach.		<p>4.2.1 4.2.2.1</p>
Emphasize active adaptive management and monitoring to better understand how vegetation responds to lack of flooding in wet and dry years and on different substrates		4.2.2.3
4.2.1 Vegetation and Wildlife Habitat Losses		
First Nations were not consulted when considering the impacts to wildlife and wildlife habitat resulting from impoundment and subsequent management of ALR.	Agreed.	1.1

Comment or question	Response	See Report Section
It has been nearly 10 years since the impacts to wildlife and wildlife habitat were assessed. What do current data say about the continued impacts to wildlife and wildlife habitat as a result of continued operations, which differ markedly from the historical average?	See Sections specific to wildlife (aquatic and terrestrial) for reference to the most recent studies included in this report.	4.2, 4.4
There are functional habitats at elevation ≥ 439 m ASL. It is necessary to broaden the scope of revegetation at elevations > 435.9 m ASL to include more than Cottonwood as this species will not form a continuous forest in the drawdown zone. Other functional habitats (wetland, riparian, floodplain, and shrub) that provide wildlife habitat are also desirable. In our opinion, the presence of large stands of cottonwood are not the only indicator of suitable wildlife habitat.	<p>Yes – the report acknowledges that there are some functional ecosystems about 439 m – Section 4.2.2.3. Nowhere does the report suggest cottonwood will be the only vegetation expected to re-vegetate, or the only indicator of suitable wildlife habitat.</p> <p>The intent is that re-vegetation will over the long term include a wide diversity of ecosystems that constitute suitable wildlife habitat.</p>	4.2.2.1
The vegetation communities defined and mapped in ALR require updating. The current extent of mapping is incomplete, the vegetation communities defined are difficult to interpret, and they provide little in the way of utility when considering the distribution and occurrence of wildlife or wildlife habitat. While this critique is specific to the results of the WLR-funded project, the inclusion of them in the stable ALR report is somewhat misleading as it suggests that there is a suitable baseline of existing vegetation against which future comparisons (in terms of increases to riparian, floodplain, or wetland habitats) can be made. Our position is that this is not the case and additional work is required to establish a reliable baseline of existing vegetation.	We agree more extensive vegetation mapping is required. However we are not aware of any data that suggests the existing mapping is inadequate for use in this report (it may be inadequate for other uses). This report is based on existing information, and the current mapping is clearly the best available at present. It is used as a reference for describing the various communities that exist at present.	4.2

Comment or question	Response	See Report Section
During what period of monitoring? 2008 to 2011? If so, then the surcharge event of 2012 and subsequent operations in ALR and their effects on vegetation need to be considered and provided for context.	Yes – 2008 to 2011. We are not aware of any publication summarizing monitoring data for 2012. More investigation of flooding frequency and duration is recommended.	4.2.2.1 4.2.2.4
While in agreement with these statements, we think a more refined assessment of the types of vegetation communities and locations in which they occur is required.	Further investigation is recommended.	4.2.2.4
In addition to ensuring that the effects of an altered operating regime are investigated relative to the fates of invasive species and existing vegetation communities and rare/sensitive species, we believe that consultation with First Nations is required to determine what the effects of an altered operating regime would be on traditional use areas and archaeological sites, some of which are protected by existing vegetation.	Consultation with First Nations has been added to information needs. See Section 4.5 on Archaeology.	4.2.2.4 4.5
This statement seems to indicate that well-developed terrestrial ecosystems must contain trees or shrubs, which is not always the case. This statements also seems to support the pervasive sentiment in the report that habitats in the drawdown zone should have cottonwood trees to be considered productive. As indicated previously, we are of the opinion that other habitat types including floodplain, riparian and wetland habitats are equally important and that the presence of these habitats, which were once present and abundant, should be considered when discussing alterations to the management of ALR.	Given that the vast majority of ecosystems destroyed by the reservoir contained trees and shrubs, meeting that threshold is important. There is absolutely no implication that cottonwood is required. It is clear that wetland ecosystems, especially those without trees and shrubs have a much higher tolerance for flooding so they are implicitly covered by meeting the tree/shrub threshold.	4.2.2.3

Comment or question	Response	See Report Section
Something that appears to have been overlooked with respect to vegetation is the effect that sedimentation has on existing vegetation. Sedimentation rates will vary by elevation and at certain reservoir elevations, the combination of wave action, sediment transport, and longshore drift can combine to either continually scour an area or deposit a large volume of sediment, both of which will reduce the total cover of vegetation at a site. Wave energy in-and-of itself, is not solely responsible for the observed effects on vegetation in all locations. Wave studies have been undertaken in certain parts of ALR and all relevant data should be reviewed and included for discussion and consideration.	Added sedimentation as a possible limiting factor. Also see Section 4.3 on erosion.	4.2.2.3 4.3
Consultation with First Nations is missing from this list.	Added.	4.2.2.4
There is a need to review ALR relative to, not in isolation of, other reservoirs. For example, the response of existing vegetation to reservoir operations has been studied in KIN since 2007, there are vegetation studies in the Carpenter and Duncan Reservoirs, and some data are available for the Peace Region (Williston). This is occurring via CLMBON-35 and relevant information has been included in various WLR reports.	As stated in the introduction to Section 4.2, the problem with the existing CLMBON reports is that they do not consider altered reservoir operating regimes. In general they have produced limited information that is directly relevant to assessing the impacts of the scenarios considered in this report. What is needed is a study regime that includes “active adaptive management”, not just monitoring and assessment of existing operating regimes.	4.2.2.4
Discuss need for management of motorized recreation under changes anticipated under the Scenarios.		4.2.3.3

Comment or question	Response	See Report Section
Section 4.2.3: Wildlife and Wildlife Habitats		
Describe how wetlands in the Revelstoke Reach and other locations around the Reservoir be hydrologically sustained under the Scenarios.	<p>There have been some concerns raised that limiting inundation may result in desiccation of some wetlands and ponds. This may be true of some minor wetlands/ponds, such the old Downie gravel pit near Revelstoke or Lower Inonoaklin Road, however it is not a concern in the primary wetlands described above (Airport Marsh, Beaton Beaver Ponds, Montana Slough and Cartier Bay). To varying extents all of the primary wetlands existed prior to inundation (Ketcheson et al. 2005), and continue to be supplied by surface and groundwater sources not associated with reservoir inundation. Further evidence of independent water sources for the wetlands was confirmed by the continued persistence of standing water during field visits in 2015, an extremely low water year where the reservoir failed to inundate most of the wetlands.</p> <p>Physical works, such as those proposed for enhancement of wetland and pond habitats, could multiply the benefits of both Scenarios in those habitat types. If there is a decision to further investigate either of these Scenarios, it could be useful to include consideration of the proposed operating regime in the ongoing effectiveness assessments for those projects, including any potential effects on water sources. Where lack of reservoir-related inundation would limit the effectiveness of the proposed works, development of external water sources should be investigated</p>	4.2.3.3 4.3.2.3
How would Scenarios affect use of Revelstoke Reach as a flyway?		4.2.3.1
How will Scenarios affect insect population? How will Scenarios affect mosquito population?		4.2.3.2 4.2.3.3
List reservoir species that are listed under SARA, Migratory Bird Convention Act, BC Conservation Data Centre, and BC Wildlife Act.		Appendix 2
Indicate that the wildlife studies help to identify elevation bands of relevance for different vegetation and wildlife habitat niches.		4.2.3.1

Comment or question	Response	See Report Section
Further identify species listed under SARA, Migratory Bird Convention and/or BC-CDC. Reservoir elevations that stabilize access to riparian habitat and allow long term development of riparian and forested habitat would likely increase the area of identified habitat conditions for SARA listed species. For Special Concern SARA listed species such as the Western Painted Turtle (Intermountain – Rocky Mountain Population), demonstrating improved habitat access or expanded area of suitable habitat would be a positive conservation outcome helping to prevent the species becoming threatened or endangered.		4.2.3
Analyses and modelling should take into account SARA relevant information such as relevant threats and actions described in posted (legal) federal Recovery Strategies and Identification of Critical Habitat (CH ID) in those recovery strategies.		4.2.3.4
We do not agree that the VCTs generated for ALR can be used to assess wildlife habitat suitability. See previous comment regarding the need for improved and relevant habitat mapping in the DDZ. Again, not a critique of this report, but of the work associated with that particular WLR study. However, the use of the WLR information in the context of assessing the two scenarios can provide misleading information.	<p>We agree the existing vegetation mapping is not perfect, however we are just quoting existing studies and it is clearly the best information available.</p> <p>We have recommended further mapping and modeling of wildlife habitat.</p>	4.2.3.1 4..2.3.4
Northern Rubber boa (<i>Charina bottae</i>) has also been found in the DDZ of ALR.	Added to the list.	

Comment or question	Response	See Report Section
<p>The timing of inundation of wetlands that occur in the drawdown zone suggests that wetlands are flooded after amphibian eggs hatch into tadpoles. At this time, tadpoles are free swimming and will move with the leading edge of the reservoir where water is warmest. The effects of reservoir inundation on tadpoles in these wetlands varies relative to location. Despite not having a complete understanding of the effects of reservoir inundation on wetland habitats, it is apparent that toads (and other amphibians) are continuing to use the same habitats for breeding year over year. Our position is that a more detailed study of the effects of reservoir inundation of amphibians and wetland productivity is required throughout ALR to better understand the relationships between current reservoir operations and the effects of altered operations on those habitats and the species that use them. A similar study has been ongoing in Kinbasket since 2012.</p>	<p>Altered the wording and added a recommendation for further assessment.</p>	<p>4.2.3.1 4.2.3.4</p>
<p>What is the relevance of females with lower body mass? Either explain the potential implications of this statement or remove, particularly given overall body condition index was similar.</p>	<p>Statement removed.</p>	<p>4.2.3.1</p>
<p>Specify that these data are specific to Revelstoke Reach. A summary of the shorebird and waterfowl species using habitats in south of Shelter Bay is required.</p>	<p>Have noted in the text and added this to the recommendations.</p>	<p>4.2.3.1</p>
<p>Both species of garter snake that occur in ALR are associated with wetland and aquatic habitat. The increase in wetland and shrub habitat that would likely result is opposite to what is being stated here: i.e., greater, not fewer, snakes and habitat suitability would increase.</p>	<p>Wording adjusted accordingly. However, the reports indicate that the snakes do use the grassland habitats.</p>	<p>4.2.3.3</p>

Comment or question	Response	See Report Section
In what kind of habitats? Arthropod species occurrence and distribution is habitat-specific.	Wording adjusted accordingly.	4.2.3.3
An accurate DEM is required to properly assess the total habitat that might be created under either scenario and would need to occur relative to elevation. The total increase in low elevation UWR would need to be compared to the amount currently present, and for each species, to determine significance. The changes in the spatial extent and location of low elevation UWR that would have a benefit for ungulates should also be determine a priori. When making statistical comparisons a result is either significant or it isn't (relative to your stated critical level of alpha). Therefore, a result can't be "nearly" significant" or "very" significant.	<p>Agreed, creation of an accurate DEM is one of the recommendations. Agreed it would be useful to accurately model and map potential habitat types from each scenarios – again this is part of the recommendations.</p> <p>Use of the word “significant” is acceptable when used in a non-statistical context as in this section.</p>	4.2.3.1
Expand on the species for which Critical Habitat has been identified and described in the Recovery Strategies under SARA.	Will be considered for future study phases.	
Consideration of a revegetation program that incorporates elements of traditional use plants does not appear to have been considered. First Nations should be consulted to determine which species are of interest and could be included in a revegetation program.	Have added comments in the recommendations section.	4.2.2.4
An updated DEM is required to complete this exercise and we support the acquisition of data to generate the DEM. This information need requires a reassessment of the mapping used in the Dam Impact Study to recalculate the impacts and subsequent recalculations of the total area, by habitat type and elevation that might be recovered relative to each of the Scenarios presented in the report.	Agreed, and is included as a recommendation.	4.2.2.4

Comment or question	Response	See Report Section
Critical habitat needs to be defined for most species listed by SARA, including the Western Painted Turtle, and this requires the fulfillment of mandates by the federal government.	Agreed, but out of the scope for this report.	
A list of all Species at Risk that could use habitats in and adjacent to the drawdown zone of Arrow Lakes Reservoir is suggested for inclusion in this and other similar reports. Moreover, an assessment of current wildlife use of the drawdown zone and adjacent upland habitats should be completed to determine which species are most likely to benefit from an increased availability of certain habitats in the drawdown zone in the event either of the scenarios examined were to be implemented. It stands to reason that knowledge of the current occurrence and distribution of wildlife throughout Arrow Lakes Reservoir should be used as the basis for any assessment of the response of wildlife to changes in the operations of ALR.	Agreed that this work would be useful, but it is beyond the scope of this preliminary analysis. The recommendations for further work include these concepts.	
Section on amphibians and reptiles suggests that study has mostly occurred in Revelstoke Reach. Revelstoke Reach may be the largest area studied under programs like CLMBON-37 and CLMBON-11B3, but other areas in Revelstoke Reach receive considerable attention including Beaton arm, Burton Flats, Lower Inonoaklin Road, and Edgewood.	Added some text to cover this. Not aware of published information on those areas.	

Comment or question	Response	See Report Section
Disagree with the use of the term significantly with respect to an increase in habitat diversity and availability. The types of habitats that are provided under Scenario 2 (and 1) would need to be modeled relative to current conditions to generate a determination of significance. This comment applies to the use of significance throughout the report when referring to the possible changes that might occur to drawdown zone habitat under either scenario. The term significant is a loaded term, generally retained for referring to the outcome of statistical testing (i.e., a statistically significant result). There is no evidence of statistical analyses being used to assess the direction and magnitude of a response associated with any of the valued components considered in the report.	Use of the word “significant” or “significantly” is acceptable when used in a non-statistical context as found throughout this section. When referring to statistical significance, one should use the term “statistical significance,” not just “significance”.	

Comment or question	Response	See Report Section
A suitable baseline for small mammals and semi-aquatic mammals does not exist for ALR and is required prior to making any determination of response relative to the scenarios examined in the report. The Okanagan Nation Alliance recommends that data on small mammal and semi-aquatic mammal occurrence, distribution, and use of the drawdown zone (seasonal) be examined in detail. Until such data are collected and analysed relative to reservoir operations in ALR, determinations of the response by small mammals to either scenario are speculative at best. Similarly, the responses by large mammals to either scenario require data with which to assess the directionality of any response. The direction of response (positive, negative, unchanging) would also require an assessment of the total area (by habitat type) that is currently impacted by reservoir operations and that would be gained should either scenario be implemented. An ecosystem model / wildlife habitat suitability mapping project is required to accurately define current wildlife habitat occurrence and distribution (by elevation, reach, species, for example) pre- and post-scenario (based on models) implementation. This would require the development of an accurate DEM for ALR.	<p>Agree – we need more study, as suggested in the report recommendations. However, to suggest there would not be a positive response to increased habitat availability is counter-intuitive.</p> <p>Recall that this is a scoping study and not a published scientific paper. The objective is to identify potential scenario outcomes based on professional interpretation of existing studies and knowledge of the subject matter, and suggest where more data and research to fill data and knowledge gaps is required.</p>	
Section 4.3: Erosion		
How does the interface between lacustrine and riverine environments post-dam (HLK) compare to the pre-dam condition?	The elevation of the interface between the free flowing riverine and lacustrine environments pre-impoundment would depend upon the time of year and more specifically discharge in the mainstem river. The pre-dam average freshet peak the Upper Arrow Lake was at elevation 1,398 ft. (426.2 m) and would back up water within the confines of the channel to the Greenslide area, or about 25 km upstream from Arrowhead. At periods outside of freshet, the riverine section would end at the top of Upper Arrow Lakes near Arrowhead.	

Comment or question	Response	See Report Section
Bank erosion of 1 to 2 m per year would add up over the life of the reservoir. Where are the high-erosion areas? Have these hot spots been identified such that they could be evaluated as potential physical works or revegetation trials to increase bank stability and reduce erosion? Are any of these area at or near known archaeological sites?	In general, erosion rates decrease in a downstream direction below Revelstoke. In order to understand specific erosion rates at various locations, refer to the KWL study referenced in this section. No information concerning specific archaeology site locations was made available to the author due to the subject matter sensitivity.	4.3.2
Yes, the revegetation program in Revelstoke Reach succeeded in reducing wind events; however, the predominant species growing in Revelstoke Reach is Reed Canarygrass, which does not provide highly suitable wildlife habitat and outcompetes native vegetation.	Agreed. See Section 4.2.2 for numerous references to and discussion of reed canary grass.	4.2.2
A terrain map of the drawdown zone of ALR depicting areas of high, moderate, and low erosion potential correlated to an accurate DEM is required to properly assess the relationship between the two scenarios examined and the effects of erosion of the drawdown zone of ALR.	Agreed. This is recommended in the report.	4.2.2.4
Section 4.4: Fisheries and Aquatic Resources		
Discuss how the return of anadromous salmon will be affected by Scenarios.		4.4.2.8
Given most of the productivity in the reservoir is from pelagic algae (as opposed to periphyton or macrophytes), this is an important section.....Yet the document does not describe the nature of the flows that would be expected under the two stable-elevation scenarios (ONA)	The nature of the flows that would be expected under the stable elevation scenarios is highly complicated, as summarized in Section 4.4.2. Presumably, “the nature of the flows...” refers to inflows, outflows (HLK discharges), flows through the narrows and water residence time. These are determined by upstream dam/reservoir and downstream operations pursuant to the Columbia River Treaty, the Non-Treaty Storage Agreement and other operating agreements. One possible CRT operating scenario to support a more stable reservoir operations has been modeled (as of November 2017) but other operating scenarios are possible. Section 4.4.5 identifies flow/residence time modelling as an important next step, particularly the second recommendation: “Ecosystem modelling of the ALR, focusing on reservoir hydrodynamics, water residence time patterns, turbidity, water temperature, nutrient dynamics and primary and secondary pelagic, littoral and kokanee productivity”.	4.4.5

Comment or question	Response	See Report Section
<p>The Matzinger et al. (2007) reference is very appropriate..... On lines 1388-1389 Thomson et al. call this a “slight reduction”, but they have not provided criteria or benchmarks as to what reductions would have been considered slight vs. moderate vs. extreme.</p> <p>... Rather than speculate on the degree of difference, we believe the next step would be to extend the existing Matzinger et al. (2007) model to quantify the effects of the two stable reservoir scenarios.</p>	<p>The ‘slight reduction’ is a quote from Matzinger et al (2007), viz: “Overall, UA productivity is slightly reduced compared to conditions without Keenleyside Dam (Table 2)”</p> <p>This is exactly what we propose in Section 4.4.5.</p>	
<p>Matzinger et al. (2007) also considered ‘Seasonal Flow Management’ which is akin to the stable elevation scenarios in that flows must increase and decrease over the year in relation to the seasonal inputs. This decline in productivity, predicted under the stable elevation scenarios, is called a “minor effect” in your report but there are no criteria or benchmarks as to what effect sizes would have been considered minor vs. moderate vs. major.</p>	<p>The ‘minor effect’ was a determination by Matzinger et al (2007), not by the authors, viz: “The mere 2% difference between scenario 7 and the current reservoir operation (scenario 5) indicates that seasonal flow management has only a minor effect (Table 2).”</p>	

Comment or question	Response	See Report Section
<p>Discuss how Scenarios reconcile discharge with nutrient retention. Nutrient flushing has more to do with amount and timing of flow passed through the reservoir than it does from elevation.</p>	<p>Agreed that nutrient flushing has more to do with amount and timing of flow passed through the reservoir than it does from elevation. A more stable Arrow Scenario was modeled in the Columbia River Treaty review technical studies process. The modeled (ALT 7 TT) Scenarios have some small differences from Scenarios 1 and 2, but the Technical Study Addendum Report hydrographs (Keenleyside discharge) are possibly instructive. In comparison to current CRT and NTSA operations, the more stable Arrow Scenarios:</p> <ul style="list-style-type: none"> Have 80 – 180% higher Keenleyside (HLK) discharges during the April – June period; Have steady increases in HLK discharges (90 – 100%) between April and June; and Have smaller decreases (15 – 40%) in July – August discharges. <p>This is suggestive (other conditions being equal) of higher nutrient flushing in the spring (April – June) period and lower nutrient flushing in the summer period. There is less stability in July – August discharges under the ALT 7 TT Scenario in comparison to the current (Treaty Continue) operational regime. Consideration should be given to modeling a Scenario which provides for more stable HLK discharges during the July – September period.</p>	
<p>Discuss how Scenarios will affect nutrient availability given that the riparian areas are projected to revegetate.</p>	<p>There are a wide range of uncertainties about how the proposed ‘stable Arrow’ Scenarios will affect nutrient availability, particularly in the pelagic area of the lake which is critically important for kokanee production as well as the abundance and size of key piscivores (fish-eating fish including rainbow and bull trout).</p> <p>The revegetation of riparian areas, to the extent that it occurs under Scenarios 1 and 2, will have a wide range of ecosystem benefits, mostly for terrestrial ecosystems but to a lesser extent for aquatic ecosystems. Litter from riparian vegetation will, when it falls or is carried into the water, contribute nutrients to the aquatic ecosystem. The relative contributions of aquatic (mainstem and tributary) inflows, nutrient enhancement and from riparian sources cannot be determined in advance, although aquatic and enhancement (fertilizer) contributions currently likely predominate over riparian sources.</p>	

Comment or question	Response	See Report Section
Clarify nutrient supply, retention, flushing rates under current operations (post 2012) when compared to the Scenarios.	2012 and 2013 were high inflow years with differing effects on Arrow reservoir. Despite high inflows in both years: (i) nutrient levels were very low in 2012 and above average in 2013; (ii) phytoplankton biomass was very low in both years; (iii) zooplankton (Daphnia) biomass was very low in 2012 and relatively high in 2013; and (iv) kokanee average size and biomass was very low in 2012 whereas biomass was low in 2013 but average size was quite high. Thus, it is not really possible to compare the effects of a Scenario 1 or 2 operation with a few years of current operations, particularly when there can be marked differences in parameters related to pelagic productivity even between high inflow years.	
What is the baseline for Scenario analysis of fish and aquatics?		4.4.1
There are studies currently underway to assess the higher flows experienced in 2012 (high inflows in 2012 created a flow regime in the Arrow lakes that closely simulated the prescribed WUP ideal sturgeon flows). Data from the juvenile indexing study on the Lower Columbia River is underway and will be analyzed and help assess the benefits of the higher flow regime. Early results from the studies and data analysis are expected in 2 years and this information will better inform on potential benefits of Scenarios to sturgeon.	<p>White sturgeon spawning and early life stage habitat conditions in the only known spawning location between the Keenleyside and Revelstoke dams, adjacent to the city of Revelstoke, are strongly influenced by Columbia River flows (Revelstoke dam discharges) and Arrow reservoir operations. It is possible that the BC Hydro Water Use Plan white sturgeon juvenile indexing study in the Columbia River downstream of the Arrow reservoir will detect increased juvenile recruitment associated with the 2012 high flow event. This will support the hypothesis that sustained high flows (and associated water velocity) during the sturgeon spawning and incubation period are critically important for early life stage survival. It will then be important to determine if the effect is due to increased water velocity, increased turbidity or improvements in substrate conditions caused by the high flows.</p> <p>If sustained high water velocity is determined to be important for white sturgeon early life stage survival, then Scenario 1 or 2 if combined with sustained higher discharges from the Revelstoke dam during the sturgeon spawning, incubation and early life stage period (late July – early September) will likely be beneficial for white sturgeon.</p>	
Comment on how water quality/clarity (including water temperature profile) will be affected in the Arrow Lakes and the Revelstoke Reach by the Scenarios.	Analysis of the impact of the Scenarios on water quality/clarity is beyond the report's scope and is identified as an information need.	4.4.2.1; 4.4.5

Comment or question	Response	See Report Section
Stable reservoir benefits could be further assessed through multiple analyses, including stranding calculations, effective littoral zone modeling and calculation of rearing habitats from perspectives of juvenile salmonids and other littoral life histories.		4.4.5
The consequence of having slightly different stable levels between the Scenarios could be further reviewed against bathymetric mapping, to determine which provides the most littoral area during the growing period based on light penetration and submerged habitat		4.4.5
<p>Uncertainties need to be resolved relating to juvenile sturgeon survival before specific reservoir conditions can be fully assessed.</p> <p>There are issues with all the sturgeon life stages and the focus shouldn't be larval dispersal. Ultimately there will be no change in Sturgeon spawning if backwatering of ALR to 1,440 ft and above is not occurring during the spawning period. Currently, at highest discharges, the backwater effect is actually positive for sturgeon, by helping to diminish unsuitable water velocities >2.5 m/s over the spawning grounds. Spawning has been documented in a very specific location that is not likely to be influenced at all by either of the Scenarios.</p>	<p>Agreed. There have been seven years of the 'Mid-Columbia River Juvenile White Sturgeon Monitoring' project funded by BC Hydro as a Water Use Plan monitoring requirement. (CLBMON 21). Despite the release of more than 54,000 hatchery-produced juvenile white sturgeon (2007-2016) only a total of 22 have been captured. This suggests either that juvenile white sturgeon have very low susceptibility to the capture gear OR that post-release survival of hatchery-produced juvenile white sturgeon is very low. Also there have been no detections of wild-spawned juvenile sturgeon, despite observations of fertilized eggs and larvae in the Columbia River in the Jordan River confluence – Big Eddy area. Taken together, this suggests that there are at least two early survival bottlenecks: (i) from larvae to free-swimming juveniles (August – October of spawn year); and (ii) from yearling juveniles to year 2 and beyond.</p> <p>Both of these life history periods are affected by habitat conditions in the mid-Columbia River, in turn affected by both reservoir levels and Columbia River flows.</p> <p>Reference: Okanagan Nation Alliance. 2016. CLBMON21: Mid-Columbia River juvenile White Sturgeon Monitoring 2013-2015 Investigations. Report prepared for BC Hydro, Castlegar, BC. 26 p. + 3 app.</p> <p>Concerning backwatering, in the non-flood years the Scenarios will not backwater known sturgeon spawning areas and thus will not attenuate high flows.</p>	

Comment or question	Response	See Report Section
<p>Present ALR elevations are typically quite high during White Sturgeon’s July-August spawning period. Although spawning has been observed over a wide range of elevations (432.9 to 440.5 m; See Table 1 in Hildebrand et al 2014), we note that the S1 (434.3 m) elevation level is on the low end of the observed range, and that <i>no spawning has been observed</i> in years with elevations at the S2 (432.8 m) level. This gives us concern that stable elevation levels may be too low for efficient White Sturgeon spawning.</p>	<p>There are twelve years of spawning observations reported in Hildebrand et al (2014). Of these twelve years, 4 years had no spawning/eggs observed. Of the twelve year period, only one occurred with Arrow reservoir elevations below the S2 level (432.8 m). It is true that no spawning or eggs were detected in this year (2001), but no spawning or eggs were detected in three other years with much higher Arrow reservoir elevations – up to 440.0 m. The one observation does not support the identified concern that the proposed stable reservoir elevations “may be too low to efficient White Sturgeon spawning’, especially given the other observations taken from Hildebrand et al (2014).</p>	
<p>The report would have benefitted from a description of flows and velocities (not just elevations) under the S1 and S2 scenarios. ...Regardless, under S1 and S2 elevation levels, we expect inundation of Revelstoke Reach to be minimal, thus near-bottom velocities in the white surgeon spawning areas will likely be driven by Revelstoke dam discharges.</p>	<p>Agreed that a description of flows and velocities would have been beneficial. However, the modelling required to support such a description/analysis is beyond the scope of this study.</p> <p>Agreed that “near bottom velocities....will likely be driven by Revelstoke dam discharges.”</p>	
<p>The Hildebrand et al (2014) report includes the following statements (found in next four rows) concerning: effects of depth; effects of velocity; near bottom velocities and larval drift in relation to REV discharges and ALR elevations; and larval drift and near bottom velocities.</p>	<p>All of the statements in the Arrow report are consistent with the information summarized in Section 4.4.2.7. While there may be “...a higher threshold which near bottom velocity conditions start to negatively affect the suitability of white sturgeon spawning/egg incubation and early rearing habitat” we also note that ‘this upper limit has not been determined” and that the preferred velocity range is between 0.8 and 2.0 m/s.</p>	

Comment or question	Response	See Report Section
<p>At minimum discharge levels (142 m³/s), lower ALR elevations had greater areal extent of near bottom velocities > 1 m/s than at high (441 m) or moderate (437 m) elevations.</p> <p>At maximum discharge levels (2,124 m³/s) and low ALR levels, high velocities were prevalent throughout the study area, with >45% of the near-bottom area experiencing flows >2.0 m/s, which could be viewed as a negative effect. At high elevations, velocities peaked in the more favourable 1 – 1.5 m/s range.</p> <p>“Taken together, the modelling results suggest that at S1 elevation levels, low discharges are required to produce the most favourable near-bottom velocities in the white sturgeon spawning area.”</p>	<p>Agreed – which supports the potential benefits of S1 and S2 for sturgeon spawning.</p> <p>Agreed – but maximum (full capacity) discharge is infrequent and of short duration during the late July – early September white sturgeon spawning and incubation period.</p> <p>We don’t agree with this interpretation. It could be argued that low <i>or moderate</i> discharges are required to produce the <i>most favourable</i> sturgeon spawning velocity conditions, and that maximum discharge conditions (infrequent and short duration) at the S1 ALR level might not result in the most favourable conditions. On the other hand, it is important to remember that lower ALR elevations at minimum (very common at night) had greater areal extent of near bottom velocities > 1m/s than high or moderate elevations. Overall, considering frequency and duration, it is our view that S1 and S2 are favourable with respect to near bottom velocity conditions in comparison to the reference condition.</p>	4.4.2.7

Comment or question	Response	See Report Section
<p>At low ALR levels, there is a flow threshold between 850 and 1,699 m³/s when not met, results in larvae being entrained into the Big Eddy, an area rated as have a low substrate suitability for early larvae.</p> <p>Two augmentation flows (566 and 850 m³/s) were modeled as flow scenarios for the larval drift model. Results indicated that at both these flows and at high ALR levels, larvae were transported downstream into the putative rearing area; whereas at low ALR levels, larvae were entrained into Big Eddy.</p> <p>“Taken together, the modelling results suggest that at S1 elevation levels, high discharges are required to produce the most favourable larval drift conditions.”</p>	<p>Agreed that the modelling results indicate that at low ALR elevations, there is a flow threshold somewhere between 850 (moderate) and 1,699 (high) m³/s required to prevent larval entrainment into the Big Eddy.</p> <p>It may be that high <i>or moderate</i> discharges are required to produce the most favourable larval drift conditions at low ALR levels. It would require flow distribution information under both current conditions and with the stable Arrow (S1 or S2) scenarios to determine the significance of this effect.</p>	
<p>“Unfortunately, at the S1 ALR elevation, there is no ideal Revelstoke Dam discharge rate that will work for White Sturgeon spawning success. At low Revelstoke flows, sturgeon larvae are entrained into Big Eddy instead of reaching the putative rearing area. At higher Revelstoke flows, near bottom velocities are too high over much of the spawning area. <i>This gives us concern that the proposed stable elevations levels may be too low for efficient White Sturgeon spawning.</i>”</p>	<p>As outlined in the rows above, it appears likely that at low ALR elevations, moderate flows produce suitable near-bottom velocities for successful white sturgeon spawning and suitable conditions to provide larval transport through the Big Eddy. We note that moderate flow conditions (between 850 and 1,700 m³/s) have been modelled to occur approximately 50% of the time during the white sturgeon spawning period (Hildebrand et al 2014.) Moreover, we note the benefit of the S1 and S2 ALR elevations during the sturgeon spawning period for the magnitude of the area exceeding the 1.0 m/s near bottom velocity, conditions preferred by white sturgeon.</p>	

Comment or question	Response	See Report Section
<p>Hildebrand et al (2014) state that “Spawning has occurred over a wide range of Revelstoke Dam discharges and ALR levels since the completion of the dam in 1984 and recent studies have shown that eggs are successfully fertilized and a portion of the wild spawn hatches and survives to at least the 2-day old larval stage” (Golder 2012). The absence of any detectable recruitment over this 30 year time frame may suggest that effects of discharge or ALR levels on spawning/egg incubation habitat are not the primary factors preventing successful recruitment of White Sturgeon in the middle Columbia River.</p> <p>This statement indicates that additional problems are facing the ALR White Sturgeon population. It does not, however, negate the possibility that spawning could be negatively impacted by ALR elevations and flows that are outside of the range typically seen over the last 30 years.</p>	<p>We agree with all but the last sentence. It is indeed possible that spawning could be negatively impacted by ALR elevations and flows that are outside of the range typically seen over the last 30 years. However, based on our analysis, summarized in the above response rows and in 4.4.2.7, it is also possible (and perhaps more probable) that spawning could be positively impacted by S1 and S2 ALR elevations.</p>	
<p>A research and monitoring program to address some of data gaps identified in the report could possibly be funded through a Fish and Wildlife Compensation Program “Directed Study”.</p>		4.4.5
<p>Given that invasive mussels are a transboundary issue, this topic could be explored further in the next iterations of this project, given the recent detections in Montana and renewed federal focus on alien invasive species under the Federal-Provincial-Territorial Alien Invasive Species Task Force.</p>		4.4.3; 4.4.5.

Comment or question	Response	See Report Section
Are there any data available that are specific to ALR? Are there any BC Hydro studies that document present-day extent, depth, locations of littoral zones? Can littoral area be estimated from topography and water-clarity data? If so, it would be nice to quantify the possible increases under S1 and S2.	We aren't aware of littoral zone research or data specific to the ALR. It is possible that littoral area changes could be estimated from available digital elevation models and water clarity data, and this will be considered as a possible useful 'next step' in the evaluation of possible more stable Arrow scenarios.	
Change "significant" to "marked"	The word 'significant' can be used when the context is clearly not statistical, and in the context referenced, 'significant' is a better word than 'marked'.	4.4.2.3
Undoubtedly, S1 and S2 would have a positive impact on littoral productivity. We would like to see some attempt made to quantify the effect size. Are there any data from present-day littoral areas in the ALR that can inform expectations of species composition, diversity, densities, etc.?	There is very limited data available from present day littoral areas in the ALR that could inform expectations of species composition, diversity, etc. It is far beyond the scope of this initial assessment to undertake the quantification requested.	4.4.2.3
A succinct review of studies of riparian and wetland vegetation relative to water flow regimes is provided in: Hawkes, V.C and P. Gibeau. 2015. CLBMON-10 Kinbasket Reservoir Inventory of Vegetation Resources. Annual Report – 2014. LGL Report EA3532. Unpublished report by LGL Limited environmental research associates, Sidney, B.C., for BC Hydro Generations, Water License Requirements, Burnaby, B.C. 74 pp + Appendices.	The report cited provides a classification of riparian and wetland vegetation zones for Kinbasket reservoir. It does not provide any information relevant to aquatic macrophyte communities within the littoral zone.	4.4.2.3
We would prefer to see a more quantitative approach, whereby magnitudes of effect sizes are estimated (rather than direction) with respect to the specific S1 and S2 scenarios.	Agreed that a more quantitative approach is desirable; however, given the limitations of existing data, a quantitative approach that is based on currently-available data would be highly speculative and the acquisition of additional relevant data is beyond the scope of this study.	4.4.2.5

Comment or question	Response	See Report Section
We recommend that effort is made to estimate the areal magnitude of the littoral zone increase (based on topography and water clarity). Ecosystem or bioenergetics modeling may be required to estimate the magnitude of the trickle-down effects on fish species.	Quantitative estimation of the magnitude of the increase in the area of the littoral zone would be useful, as would ecosystem or bioenergetics modeling. However, these are beyond the scope of this study.	4.4.4
Section 4.5: Archaeology		
How will the pictograph sites be affected by the Scenarios?	There are several pictograph sites that are completely inundated by the Reservoir and the Scenarios would not have any further effect. There are also several pictograph sites that are above the high water mark that would also not be affected by the Scenarios. As for pictographs that are within the draw down zone, soil erosion would have little to no effect on these sites. It is unclear at this time what effect prolonged inundation would have, as this has never been studied in the Arrow. It could be postulated that the water would eventually wash all traces of the pictographs away.	
In general all inundated sites will experience greater erosion over time than those above the water- minus those affected by slides etc.	It is likely that the sites within the active wave zone will experience more erosion than those below the active wave zone. Archaeologists are attempting to look at what type of wave/current action occur within the top meter or two of water in reservoirs, to get a sense of whether erosion/disturbance is possible in those depths. The most common cause of erosion known occurs at sites that are in the active erosion zone, or the active wave zone. Those sites that are well above the high water mark would not be impacted by wave erosion, and only mildly by wind erosion.	
Understanding impacts would require more detailed information on the affected sites, size, content, condition, stratigraphy, surficial geology, aspect, and sedimentology. The BC Hydro Reservoir Archaeology Program is collecting some of this information but only as it pertains to current Scenarios – additional inventory work would be required.	Agreed, and it would be ideal if future reservoir archaeology work accounted for potential changes to reservoir operations for management planning.	

Comment or question	Response	See Report Section
Erosion protection for archaeological sites below the Scenario high pool would need to be in the form of physical works (i.e. rip-rap, gabion baskets, articulated concrete blankets etc.). Costs for these treatments are high, success is unproven. Vegetation is unlikely to be successful erosion protection for these sites.	We have seen site erosion protection due to vegetation at the higher elevation bands of the active erosion zone in Kinbasket Reservoir. Protection of archaeological sites within the active erosion zone is something that is being dealt with by BC Hydro in consultation with First Nations as a part of the Archaeological Management Plan (AMP).	
Agree that any analyses that considers a modified operation in any part of the system must be done in consideration of the effect on the entire system. We will also emphasize the need to include impacts to culturally important places and effects on First Nations and our traditional territory.	Agreed.	
The most likely Scenario would involve a large mitigation effort aimed at removing Heritage site materials from at least a sample of these affected sites – this is of course subject to First Nations agreeing to the removal. Over time there could also be an undercutting effect in some areas that could extend the reach of the erosion zone back into upslope/vegetated areas that would need to be managed.	Removal of heritage site materials that are vulnerable is a part of the current RAP, and will be ongoing through the AMP. Undercutting currently occurs in several places within the Reservoir and is something that would have to be taken into consideration when looking at erosion effects.	
Section 4.6: Recreation		
The most recreational activity often occurs Easter weekend - when the reservoir is below mid-elevation. Burton and Edgewood are swarming with tourists at Easter every year. With the water level up right now (July), only those who can afford a boat and tow it around are here these days and they are confined to boat ramps for non-boating activities because there is no beach.		4.6.3.2

Comment or question	Response	See Report Section
Waterfront landowners have expressed a desire for higher stable water elevations. This comes at increased risk to property damage from high water.		4.6.3.2
What about the effects of ATVs, dirt bikes, and mud boggers (as a form of recreation) on the existing habitats and archaeology sites in the drawdown zone?	Text added to note this as a concern.	4.6.3 4.6.4
Indicate the lack of recreational inputs from non-boating recreationalists – surveys dominated by boaters.		4.6.3.1
Incorporate findings of the Upper Arrow Drawdown Zone Management Plan and Revelstoke Wetlands Conservation Area Feasibility Study reports. These reports detail the importance of the Revelstoke Reach to the community of Revelstoke and the desire to manage recreation to maintain habitat values and prevent destructive activities.	The importance of maintaining recreation and habitat values in the Revelstoke Reach as described in these two reports is acknowledged and discussed in several sections throughout the Report.	Numerous sections.
Section 4.8: Agriculture		
Scenario periodic flooding will limit agriculture to hay cutting and grazing.	This issue is discussed in Section 4.8.2, and conditions necessary for allowing other types of agricultural crops are outlined. Local contradicts information from agricultural practitioners presently working in the drawdown zone	
Section 4.10: Flood Control		
Discuss the increase in flood risk of Scenarios over existing operations (More likely that reservoir will fill to full pool more often than under current operations.)	As described in Section 3.1, both scenarios only peak at full pool once in 5 or 7 years on average. All other years the reservoir elevation is at 1,420 ft. or 1,425 ft. As such the flood risk is considered managed within the Arrow footprint for the purposes of this analysis. In addition, maintaining a constant elevation will not change the maximum permitted full pool elevation of 1,444 ft (or if surcharged to 1,446 ft under exceptional circumstances). System wide modelling of the Scenarios will further delineate frequency of the flood or full pool events in the reservoir, and changes to the flood risk in downstream sections.	

Comment or question	Response	See Report Section
General		
Discuss climate change and impact on Scenarios		4.1
What do the Scenarios mean for low water years	Low water years were not considered in this analysis. However, future iterations of the stable reservoir elevation concept will include low water years in the analysis.	
Discuss the implications of Scenarios on upstream/downstream environments, as well as Duncan and Libby.	The report terms of reference restricted the analysis to the Arrow Lakes Reservoir footprint, and thus did not include upstream and downstream river sections. The authors acknowledge this is a limitation on the report's analysis. Current and future modelling of the constant Arrow concepts will include analysis of upstream and downstream river sections.	
Need to incorporate First Nations Traditional Ecological Knowledge into report.	Agreed. The BC Ministry of Energy and Mines and Global Affairs Canada are consulting First Nations on the draft report.	
Development restrictions needed to prohibit building within the floodplain.		4.10.3
Discuss whether the Scenarios would have a positive or negative impact on socio-economic values.	The report did not examine the impact of the Scenarios on socio-economic values, such as tourism, economic and community development, land values, etc. However, a stabilized reservoir water level would improve access to the water, visual aesthetics and drive tourism and increased recreational use of the reservoir. Local economies would benefit from increased reservoir use by locals and visitors. Businesses that use the reservoir would also benefit from better access and year round use of the reservoir, and land values in local communities and around the reservoir may increase.	
Keeping Scenario elevations flat without variation does not seem realistic	Agreed. The stabilized reservoir scenarios examined in this report allow for minor fluctuations to occur, but it is more realistic to allow greater fluctuations that mimic natural processes and seasonal variations in runoff. The stable concepts were examined in part to further explore the BC Hydro scenarios 7TT and 8TT (that stabilized the Arrow) and to assess the validity of these concepts. Future iterations of the stabilized theme will include increased variation in water levels (but still be considered 'stable').	

Appendix 4: Arrow Lakes Reservoir Mid-Elevation Scenarios: Scoping Evaluation - Scenario 3 DRAFT

Addendum - Draft - April 24, 2017

G. Utzig and A. Thomson

This Addendum proposes a third Mid-Elevation Scenario for the Arrow Lake Reservoir in response to what has been learned from the information reviewed in the main report. The objectives of the new scenario are:

- to maintain and/or enhance the potential benefits identified for Scenario 2;
- to establish a seasonal pattern of reservoir levels closer to the natural seasonal pattern present in Upper Arrow Lake prior to dam construction; and,
- to allow for flexibility in reservoir management to increase downstream benefits and/or decrease potential downstream negative impacts (e.g. flow increases for fish passage, decreases for flood control).

Scenario 3 maintains the basic structure of Scenario 2: a relatively stable mid-elevation reservoir level in 6 out of 7 years centered on 1,420 ft., and a 1 in 7 year allowance for raising the level to full pool for major flood years. The primary changes associated with Scenario 3 are:

- defining an allowable range and seasonal pattern of elevation variation during the non-flood years (6 of 7 years), and
- allowing increased drawdown during predicted flood years (on average 1 of 7 years).

Records of Upper Arrow Lake levels prior to construction of the Hugh Keenleyside Dam (1922-1968), indicate that the lake varied from 1,375 ft. to 1,409 ft.(34 ft.). Annual variation ranged from 19 ft. to 34 ft., averaging 25 ft. In contrast, annual variation in the reservoir post-dam (1970-2012) has varied from 24 ft. to 70 ft., averaging 47 ft. (see Figure 1)

Scenario 3 proposes that annual variation during 6 of 7 years would target 6 ft. in variation, with an allowance for variation of up to 12 ft. The target elevation range is between 1,417 ft. and 1,423 ft., and the allowable variation is between 1,415 ft. and 1,427 ft. (see heavy dark green line in Figure 2). The upper elevation maximum is intended to protect the potential re-vegetated area above 1,430 ft. from wave action and erosion. The maximum and minimum allowable levels for 6 of 7 years are indicated by the orange and dark blue lines in Figure 2.

Historically the dates of peak elevations in Upper Arrow Lake ranged from May 27th to July 19th, with 90% falling between June 1st and July 15th. The 90% range was used to define the seasonal peaking window for Scenario 3 (red lines in Figure 2).

The 1 of 7 flood year allows drawdown to 1,412 ft. to increase flood storage pre-freshet (see light blue line in Figure 2). As in Scenario 2, flooding above 1,430 ft. must not exceed 35 days, requiring rapid infill and evacuation of the reservoir above this level. The example of a 1 in 7 flood year (heavy light green line in Figure 2) shows an infill rise above 1,430 ft. of 0.9 ft./day and evacuation rate of 0.65 ft. day, reaching a peak of 1,443 ft, just one foot below maximum pool height. Both these infill and evacuation rates, although high, have been achieved in the past. Reduced pool height would be the result of lower infill and evacuation rates if the maximum 35

day target for inundation at 1,430 ft. is to be achieved. Conversely, filling to full pool would require greater infill and/or evacuation rates. The date of the peak should fall between June 1st and July 15th if historical peaking patterns are to be mimicked. If climate change brings earlier peak flows, as is projected at present, the peaking window may have to extend into May. Drawdown to 1,427 ft. at the end of the flooding period should occur as soon as possible, but definitely within 10 days following drawdown below 1,430 ft. to reduce the risk of wave damage to re-vegetated areas above 1,430 ft. In the 1 in 7 years, once the drawdown is below 1,427 ft. the drawdown must then remain below the maximum for the 6 in 7 years (orange line in Figure 2).

The annual storage volume for the 6 of 7 year seasonal target under Scenario 3 is approximately 0.69 million acre-ft. (1,417-1,423 ft.). Utilization of the full potential elevation range for 6 of 7 results in approximately 1.38 million acre-ft. of storage (1,415-1,427 ft.). The 1 in 7 storage potentially increases to approximately 3.83 million acre-ft. (1,412-1,444 ft.).

The intention of providing a “target” for the 6 of 7 year portion of Scenario 3 is to indicate the preferred operating regime for those years. Ideally implementation of Scenario 3 would include an operational rule that requires that at least 3 or 4 of the 6 years should be within 1 foot of the target at all times, and deviations outside that range would only occur under specified conditions (e.g. moderate flood years, or drought conditions). The central concept is to provide more stable reservoir levels while providing for increased flexibility, but only when it is required to meet limited specified requirements (e.g. fish flows, flooding, etc.)

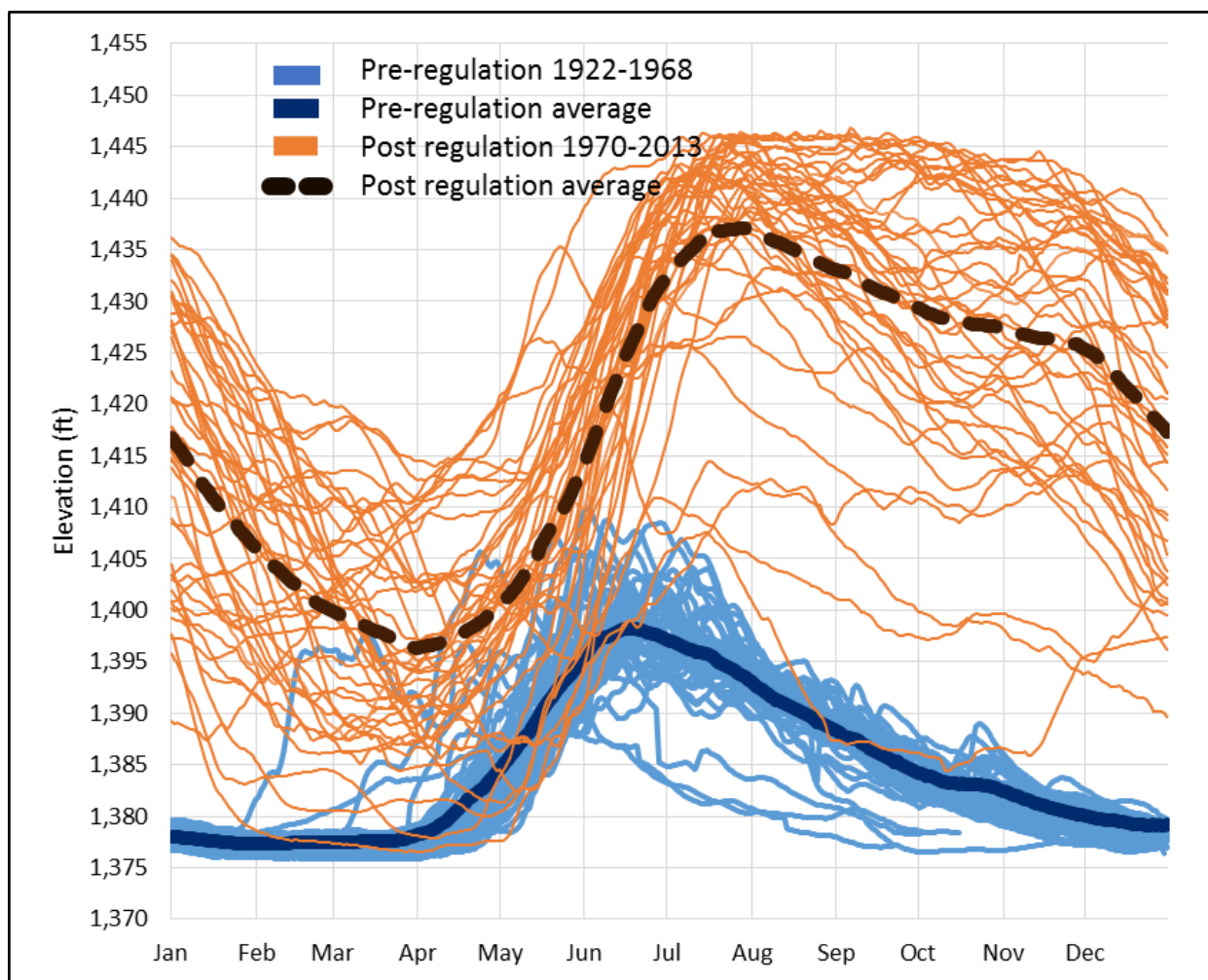


Figure 1. Pre- and post dam elevations in Upper Arrow Lake and the Arrow Lakes Reservoir.

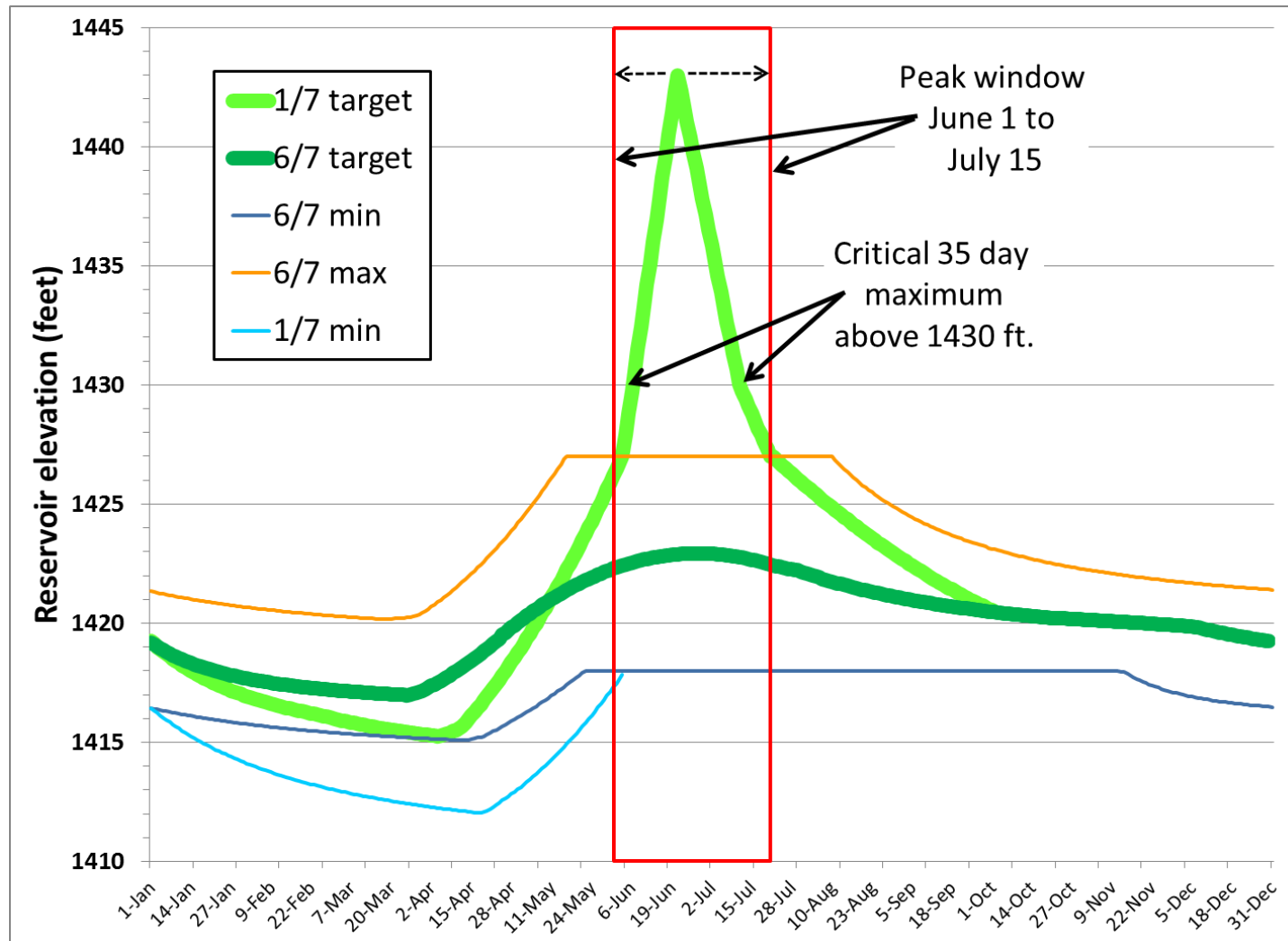


Figure 2. Annual and seasonal patterns in water levels for Scenario 3.