Arrow Lakes Reservoir Mid-Elevation Scenarios: Scoping Evaluation

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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.

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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 were enacted. The report does not examine or analyse implications of a stable elevation concept on values or infrastructure above (i.e. Kinbasket reservoir) 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 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. Main issues specific to the ALR – such as fisheries, power generation, archaeological resources, etc. – are assessed.

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 riparian zone (including trees and shrubs). 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 forest 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 forested riparian vegetation establishment and permanence, although mature forest development will likely 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 riparian 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 absent mitigation measures. Tributary stream banks 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 spawning and migration habitat 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 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 and are certainly open for debate. 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.

The report analysis is restricted to the ALR 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 affected resources and values in all sections of the Columbia River upstream of the international border.

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Acronyms

ALGS	Arrow Lakes Generating Station
ALR	Arrow Lakes Reservoir
AOP	Annual Operating Plan
cms	cubic metres per second
DOP	Detailed Operating Plan
ft.	feet
ha	hectares
HLK	Hugh L. Keenleyside dam
m^3/s	cubic metres per second
S1	Scenario 1
S2	Scenario 2
VCT	Vegetation Community Types
WUP	Water Use Plan

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. 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 US 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 reservoir 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 a stable full or near full reservoir pool (Canadian and United Stated 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 Arrow Reservoir. 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 mid elevation constant elevation scenario that was identified and scoped by Thomson (2013).

This report expands on previous stabilized Arrow reservoir studies, 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 with the Arrow reservoir area between the Revelstoke and Hugh Keenleyside dams. Significant potential upstream (Kinbasket reservoir) and downstream (transboundary reach) effects of these scenarios were determined to be out of scope for this project.

2 Historical and Current Hydrological Regime

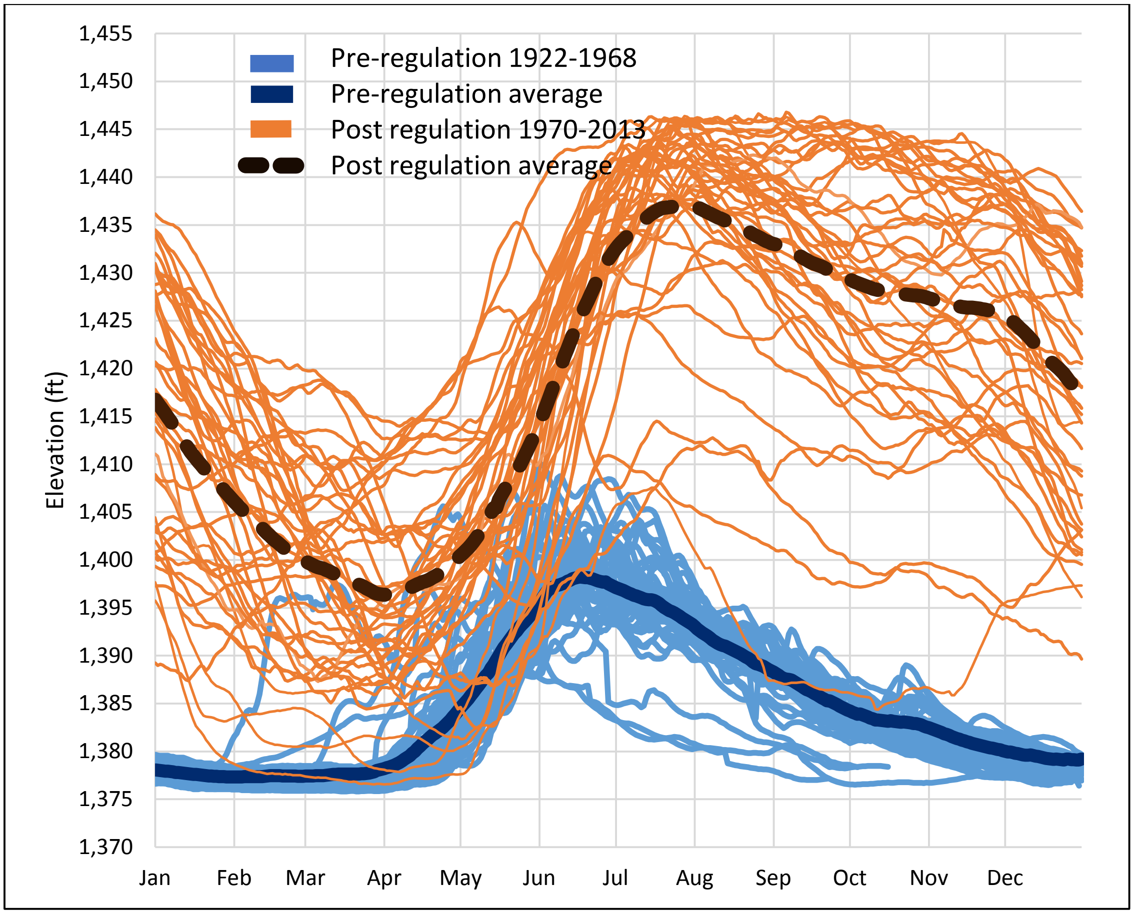
2.1 Historical hydrological regime

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 1). 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 1). 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 observed 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 1,401 ft. (427.0 m.) pre-impoundment versus 1,396 ft. (425.5 m.) to 1,440 ft. (438.9 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 1. 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 1: 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, especially with perennial and 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). Establishment of a reservoir operational regime that allows for establishment and persistence of forested riparian zone vegetation potentially contributes numerous other related benefits

3.1 Development of Two Scenarios

Two Scenarios are evaluated in this report (see Table 1 and Figure 2). 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 can fill up to full pool 1,444 ft. (440.1 m.) during freshet, and the water is released over 2 months in late summer. Scenario 1 is identical to BC Hydro's Alternative 8TT (BC Hydro 2013b) for the Arrow Lakes section of the alternative[1]. 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. (435.9m.) and then more slowly from 1,430 ft. to 1,420 ft. (435.9m. to 432.8 m.). A defining aspect of Scenario 2 is that the drawdown zone above 1,430 ft. (435.9m.) is never inundated for greater than 35 days for reasons outlined below.

Table 1: Comparison of Two Scenarios.

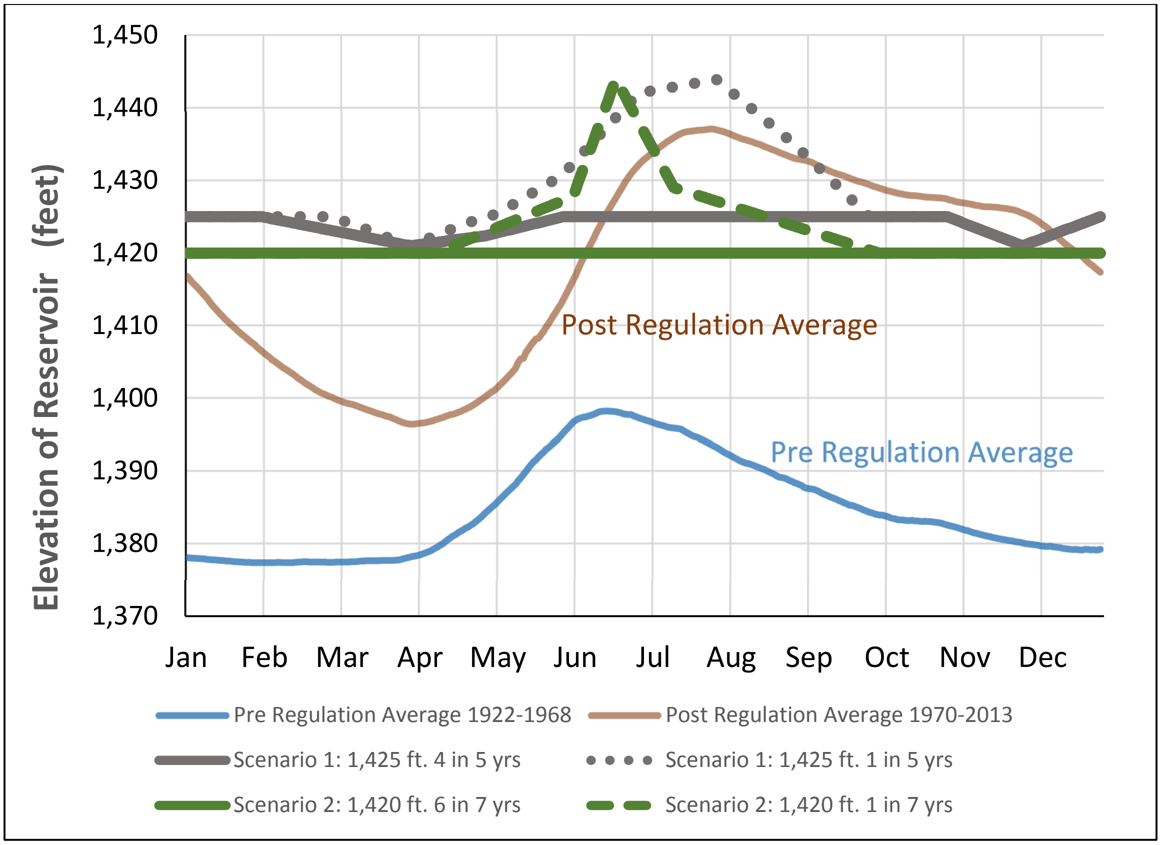
	Scenario 1	Scenario 2
Base constant elevation[1]	1,425 ft. (434.3 m.)	1,420 ft. (432.8 m.)
Maximum flood elevation	1,444 ft. (440.1 m.)	1,444 ft. (440.1 m.)
Flood frequency[2]	1 in 5 years	1 in 7 years
Flood water inundation period	5 months above base elevation	5.5 months above base elevation
Comment	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.

Note 1: Maintaining the reservoir at a constant water elevation without minor fluctuations is not operationally reasonable. Minor fluctuations of a few feet are considered reasonable and do not significantly alter the outcome of this analysis.

Note 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.

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

Figure 2: 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, and 1970 to 2012, 43 years); and pre-dam vegetation mapping that shows the distribution of vegetation in relation to those elevations (Canada Department of Mines and Technical Surveys 1946-57).

2/ Pre-dam vegetation mapping (CDMTS 1946-1957) shows fully developed coniferous and deciduous forests down to an elevation of 1,400 feet around Upper Arrow Lake under natural conditions. In some areas of relatively flat shoreline (<~5% slope; e.g. between Cranberry Creek and Columbia River confluence with the ALR), "scrub", marshes and grasslands extend down to approx. 1390 ft. (423.67 m.). 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.)

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:

- 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 assessment[2] 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.

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.)

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[2] 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.

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 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 480 ha and 1,373 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 water levels.

- 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.

4.2 Vegetation and Wildlife[3]

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. 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 dam footprint. Open wetlands, cottonwood stands, other wet forests, shallow water ponds and lake/ river shoreline habitats were assigned a high habitat loss risk rating.

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 frogs, toads and turtles were also given high to very 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 on the Columbia system in BC, and 92% loss in the Arrow Reservoir reference area. As

[3] Primary author: Greg Utzig

well, flooding of the Arrow Reservoir resulted in the loss of 36% of the small low elevation low gradient streams, along with 1.02 km^2 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 and wetland 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).

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 – 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; Mean, min, max of depths are of the years with inundation for the elevation slice to the next table column depth (based on daily reservoir levels at Nakusp).

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 grass mesic (PC). It is dominated by reed canary grass, but can include minor components of other species, 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 3: Vegetation cross section in drawdown zone, lower Revelstoke Reach. July 13, 2015. ALR elevation 1,422 ft. (433.4 m.)

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 43 8 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 that 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, although there was not significant enough variation in the operating regime to correlate differences in vegetation due to the operating regime, duration of water levels were 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 were 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 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. It appears that the frequency and duration of annual inundation precludes the development of forest and shrub communities (physical abrasion by floating debris and wave action 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 1,430 ft. (435.9 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, including those with trees and shrubs above an elevation of 1,430 ft. (435.9

m), see also 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.

4.2.2.4 Information Needs

- 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 1,420 ft. (432.8m) to better understand soil chemistry, the distribution of substrates, and their suitability for revegetation (including interpretations for potential vegetation community types)
- investigation of the impacts and benefits of rapid inundation and drawdown associated with Scenario 2.

See Table 7b at the end of Section 4 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. However, 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. However, understanding which habitats are most valuable for which species, and how the abundance of those habitats may change under the Scenarios, can provide some information on the potential benefits or impacts of the Scenarios on wildlife.

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 (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 species 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 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 likely impacts toad reproduction 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, can result in nest depredation, 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. Preliminary results indicate that turtles in the drawdown zone have poorer body condition and lower body weights than those living in ponds outside the reservoir.

Songbirds

Ongoing monitoring of neotropical migrant songbirds in the drawdown zone 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) and un-vegetated plots. Grass and sedge habitats generally have a third to half the densities recorded in shrub and wetland habitats.

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).

Shoreline and Waterbirds and shorebirds have been studied for a number of years during the spring and fall migrations, and the nesting season – 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.

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 4: 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 scarcity of ungulate use resulted in a recommendation to abandon the study (Adama and Hawkes 2015).

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

Arthropods

Studies to inventory and monitor selected arthropods have also been undertaken 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.

Revegetation Wildlife Effectiveness

Monitoring of revegetation treatment areas has included the collection of information on songbirds, arthropods, bats and deer (Hawkes et al. 2014), and some of the results were 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 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.

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. Due to the lower baseline elevation, 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, such the old Downie gravel pit near Revelstoke, 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 their continued functioning 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 inflow 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 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. Some snakes that are primarily found in the open grassland habitat will likely see a reduction in habitat availability.

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.

Waterbirds would benefit due to the improved access to wetlands and shallow pond habitats, especially during migration periods. 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 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.

Under both Scenarios, herbaceous vegetation plantings may increase the 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.

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.

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 recommended in Section 4.2.3.
- 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.

See Table 7b at the end of Section 4 for a summary of all issues.

4.3 Erosion[4]

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.

[4] Primary author: Alan Thomson

Figure 5: 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 m^3/s (mandated minimum flow) to 2,124 m^3/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 6: 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 4.2.2 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 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 7b at the end of Section 4 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.

4.4 Fisheries and Aquatic Resources[5]

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), redside 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 redside 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

[5] 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, increased 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 six of the most obvious and potentially significant effects. 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. 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 (Daley et al. (1980); Pieters et al. (1999); Ashley et al. (1999); and numerous other authors).

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 caused slight reduction in productivity in comparison to the pre-dam condition.

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."

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."[6] 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.

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 with woody species, and these reaches will likely remain unconfined, over-widened, braided and shallow and lacking riparian cover. Some authors of this report reason that there is unlikely to be any significant improvement in fish habitat conditions in these drawdown zone reaches or in fish passage conditions to non-inundated reaches above 1,444 ft. (440 m.). An alternate opinion is that in 4 out of 5 years streams will not be building fans and deltas above 1,425 ft. as they do in most years now. During those years with stream downcutting into the old fan/delta deposits some channelization will occur and this may result in improvement of stream access. These geomorphic processes will vary from stream to stream depending on sediment load, stream gradient, 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 of the Arrow reservoir 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:

[6] In 2007, water residence time overall was low; thus the nutrient flushing rate was high.

- 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 7: Cariboo Creek at confluence with ALR; July 14, 2015.

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."

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 longer drawdown zone reaches in tributaries and thus reduced spawner migration success; and (ii) 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 impairment of fish passage in tributaries 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 longer (on average) drawdown zone reaches, predation impacts may be increased.

As noted in Section 4.2.2 of this report with respect to the potential effects on 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). This means that tributary reaches across the drawdown zone between 1,444 ft. (440.1 m) and 1,430 ft. (435.9 m) will become more stable and confined by the development of woody riparian vegetation. This should result in beneficial narrowing and deepening of stream channels, increased sediment transport and improved substrate conditions. This should in turn result in improved spawning, incubation and early rearing success for kokanee and rainbow trout, and thus increased abundance of these species to the extent that under current operations spawning and incubation habitat is limiting to these populations. This is an important and significant difference in effects between Scenarios 1 and 2. Thus Scenario 2, in comparison to both current conditions and Scenario 1:

(i) will likely result in improved late summer and fall (kokanee and bull trout) fish passage and habitat conditions in the upper drawdown zone reaches of some tributaries (between 1,444 ft. (440.1 m) and 1,430 ft. (435.9 m)); and

(ii) is likely to improve spawning and incubation habitat conditions within the drawdown zone reaches of some tributaries as a result of gravel recruitment above the 1,420 ft. (432.8 m.) stabilized reservoir elevation combined with reduced reservoir inundation of redds during the incubation and emergence periods.

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.

Beers (2004) undertook a comparison of littoral primary productivity (periphyton) between the linked Stave and Hayward reservoirs. The Stave reservoir is operated as a storage reservoir with up to 29.5 ft. (9 m.) of fluctuation in reservoir surface elevation. The Hayward reservoir is more lake-like with a maximum annual fluctuation of 1 m. The Hayward reservoir is less than 10% of the surface area of the Stave reservoir. Over a 3 year period, primary productivity (periphyton accrual) in the littoral zone of the Stave reservoir averaged 5.3 gC/m2/yr. whereas the comparable figure in the lake-like Hayward reservoir was 2.3 times higher at 12.3 gC/m2/yr. This difference was found to be statistically significant at the p=0.05 level (two way ANOVA). Moreover, the proportion of total aquatic production from littoral v. pelagic components was 50% littoral in the more stable Hayward reservoir versus 4% littoral in the fluctuating Stave reservoir.[7] Of course, some of this difference can be attributed to the much larger pelagic area of the Stave 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."

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[7] It is important to note, however, that there are significant other differences between the two reservoirs (e.g. morphometry) which might account for some of the differences and that there are also likely significant differences between coastal (e.g. Stave and Hayward) and inland (e.g. Arrow) reservoirs. One notable difference is the two annual hydrograph cycles (two peaks and two lows) in the Stave reservoir versus one annual cycle in the Arrow reservoir.

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, they 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; 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

There has been limited research on the effects of reservoir operations in temperate climates on aquatic plants. 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 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 US 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. 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 introduced carp, yellow perch and walleye 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 functioning[8] large river habitats within the Canadian portion of the Columbia River are: (i) 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

[8] "Functioning" large river habitat is lotic (flowing) in nature and does not have extreme variability in flows due to hydro-peaking operations.

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: 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.

	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.	+	-

	Inferred Effect **Upstream** (river-like) of 1,420 ft. and 1,425 ft. backwater elevation	Inferred Effect **Downstream** (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[9] 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.	+	-

[9] 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.

	Inferred Effect Upstream (river-like) of 1,420 ft. and 1,425 ft. backwater elevation	Inferred Effect Downstream (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.	-	+

	Inferred Effect **Upstream** (river-like) of 1,420 ft. and 1,425 ft. backwater elevation	Inferred Effect **Downstream** (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.).	-	+

	Inferred Effect **Upstream** (river-like) of 1,420 ft. and 1,425 ft. backwater elevation	Inferred Effect **Downstream** (reservoir) of 1,420 ft. and 1,425 ft. backwater elevation
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). 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.	-	+
Juvenile fish population observations (Slivinski and Sykes 2014).		
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).	-	+
2. Inundated reaches are always warmer (spring, summer and fall).	-	+
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.)	+	-
4. Summer: higher overall abundances in reach 1 (most downstream/most inundated) v. reaches 2, 3 and 4.	-	+
5. Fall: higher overall abundance reaches 1 and 2 (downstream of Illecillewaet R., more frequently inundated) v. reaches 3 & 4.	-	+

	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 redside 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 (SARA). A recovery strategy for the species has been developed and formally approved. Three areas within the Revelstoke Reach are in the process of being ordered 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;
- 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 2009, 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;
- 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.

4.4.3 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.

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.

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 5 summarizes the potential effects of Scenario 1 and Scenario 2 operations in comparison to the current operating regime:

Table 5: 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	?	+
Effects on littoral productivity	+	+
Effects on aquatic macrophytes and aquatic invasive species[10]	-	-
Effects on the Revelstoke Reach section	?	?
Effects on burbot	0	0
Effects on white sturgeon spawning and incubation habitat conditions	+	+

Key: ? Uncertain - Negative + Positive 0 Neutral

Given the uncertainties indicated, it is very difficult to evaluate the combined effects of multiple potential changes. As outlined in Section 4.2.1.1 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. 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 huge 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 4.2.1.1 with respect to Scenario 2, the abundance of kokanee as affected by tributary habitat conditions may be increased. 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

[10] An increase in aquatic macrophytes and associated aquatic invasive species is considered to constitute overall harm (negative) to the Arrow reservoir aquatic ecosystem

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 may slightly 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.

4.4.5 Information Needs

As described throughout Section 3.2 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 significant. 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:

- Ecosystem modelling of the ALR, focusing on reservoir hydrodynamics, water residence time patterns, 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 risks associated with development of aquatic macrophyte communities, including invasive aquatic macrophytes and introduced fish species including northern pike, carp, yellow perch and walleye; and
- 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) is essential.

See Table 7b at the end of Section 4 for a summary of all issues.

4.5 Archaeology[11]

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

[11] Primary author: Nicole Kapell

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 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.

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 between 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 1,425ft. (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 3 and would likely be limited to herbaceous species below 1,440 ft. (438.91 m.).

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 3) 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 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 7b at the end of Section 4 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)
- 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 Recreation[12]

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.

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;

[12] Primary author: Greg Utzig

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 shed light on 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. 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 8: 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.

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 9: 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.

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 elevation of 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).

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 establishment of mature 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 would 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 is of considerable importance to 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) 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 to maintain beach formation
- fishers as 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.
- potential interactions with off-road vehicle use

See Table 7b at the end of Section 4 for a summary of all issues.

4.7 Commercial Navigation and Operations[13]

4.7.1 Introduction

Several companies around the Arrow Lakes - Interfor Forest Products, Zellstof 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 m^3 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 tug transports a tow down the lake through the Narrows towards Castlegar over a 10-12 day period.

[13] Primary author: Alan Thomson

Figure 10: 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 11: 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 7b at the end of Section 4 for a summary of all issues.

4.8 Agriculture[14]

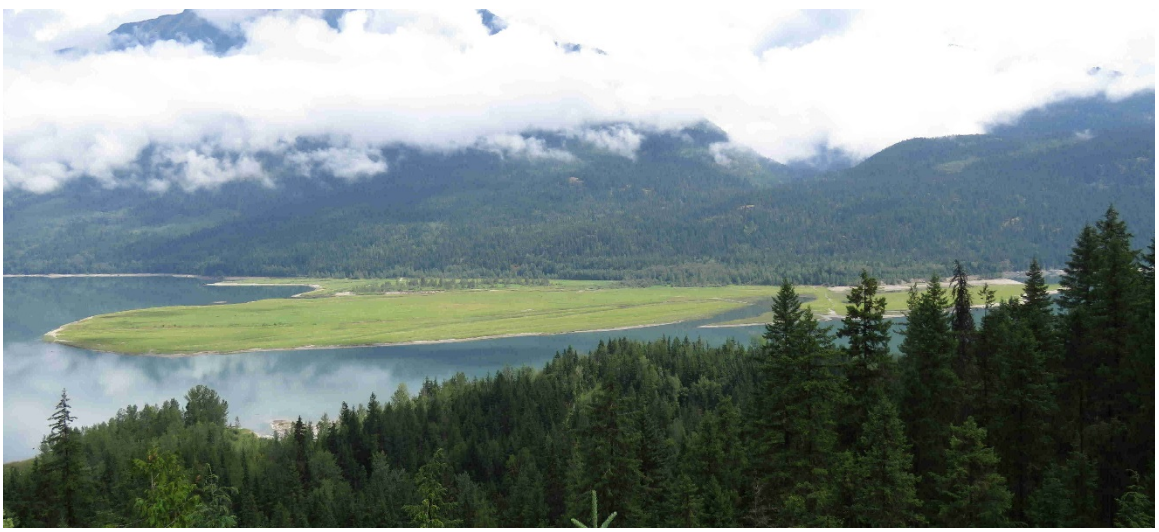
4.8.1 Literature Review

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 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 summarizes agricultural activity prior to inundation, noting various types of agricultural production (Penfold 2012). 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 the 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 12: 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).

[14] Primary author: Greg Utzig

4.8.2 Summary of Interview and On-Site Visit Results

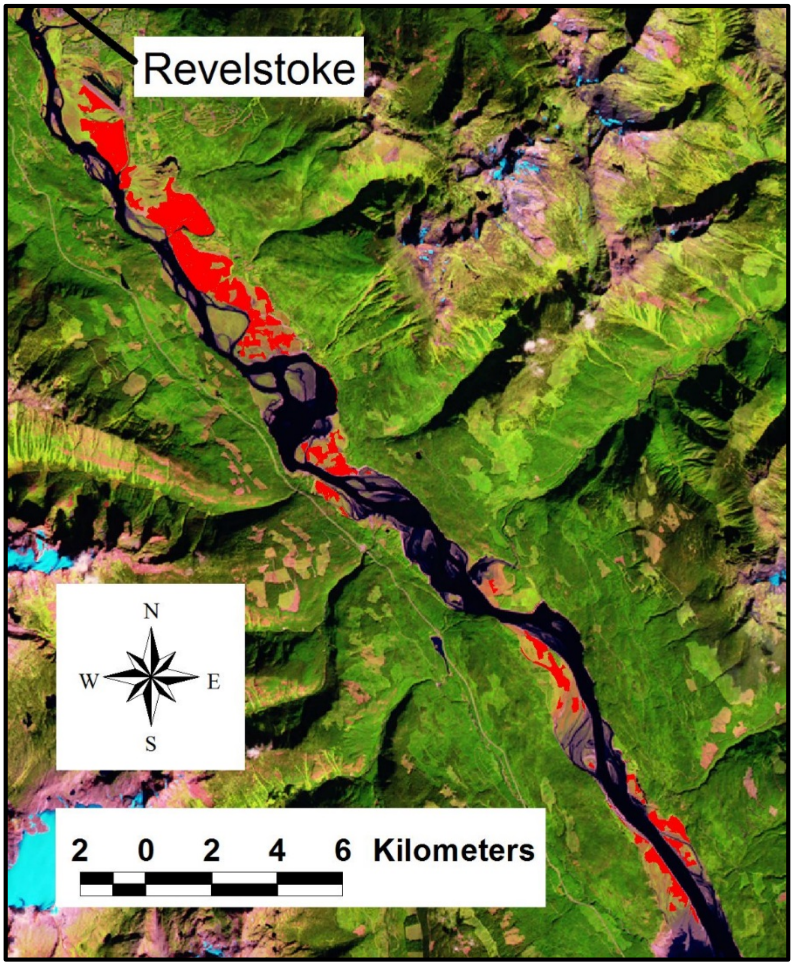
Interviews with agricultural practitioners adjacent to and within the drawdown zone confirmed that there is potential for expansion of agricultural production within the drawdown zone.

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 13: 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 13), 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, Applegrove 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 7b at the end of Section 4 for a summary of all issues.

4.9 Power Generation - Arrow Lakes Generating Station[15]

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 at HLK dam. 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 1 in Section 2.1). 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 period[16].

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

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[15] Primary author: Alan Thomson

[16] 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 is 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 14: 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 US interests (Canadian and United Stated 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 US 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 Stated 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.

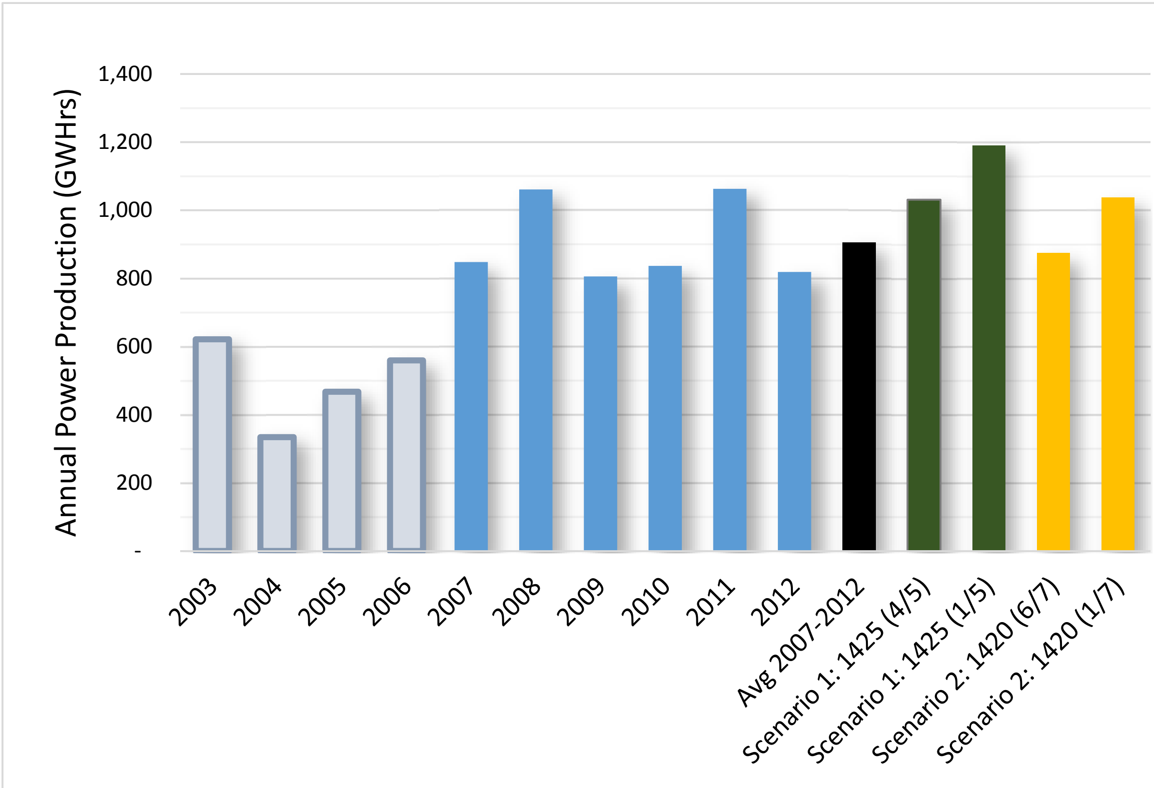
In order to gain an approximate indication of the power generation potential for the two Scenarios under consideration, historical ALGS generation data was used to build a basic model for the two Scenarios. For this high level of analysis and reporting a simple model is considered appropriate to indicate 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 15). 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 15). 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 1,420 ft./432.8 m.) or slightly greater (for 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 15: 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 6). 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 6: 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 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 7b at the end of Section 4 for a summary of all issues.

4.10 Flood Control[17]

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 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. However, discussion of ALR future flood control options requires context. Regardless of the Treaty negotiations between the countries and the final outcome ("Treaty Terminate", "Treaty Continue", "Treaty Plus", etc.) flood control for downstream environments is still required under the CRT "Called Upon" provision that commences once the current flood control agreement automatically expires in September 2024 (unless renegotiated). Under the Called-Upon provision, the US can require that Canada provides flood storage in Columbia River reservoirs once certain conditions (i.e. the US uses all effective US storage first, and forecast flows must have the potential to exceed specified flow targets below the Dalles Dam) have been met. Although agreement between the entities concerning the details of the Called Upon requirement remains outstanding, storage for flood control purposes will be required in Canadian reservoirs as long as Treaty dams exist (BC Hydro 2013a). Under a Called Upon event, 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 US 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 Stated Entities 2010; Bonneville Power Administration 2012). A US 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 US 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

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[17] Primary author: Alan Thomson

benefits that could result in lower reservoir levels "down to 1,425 ft. (434.3 m.) or so" (BPA 2012. pg. 77).

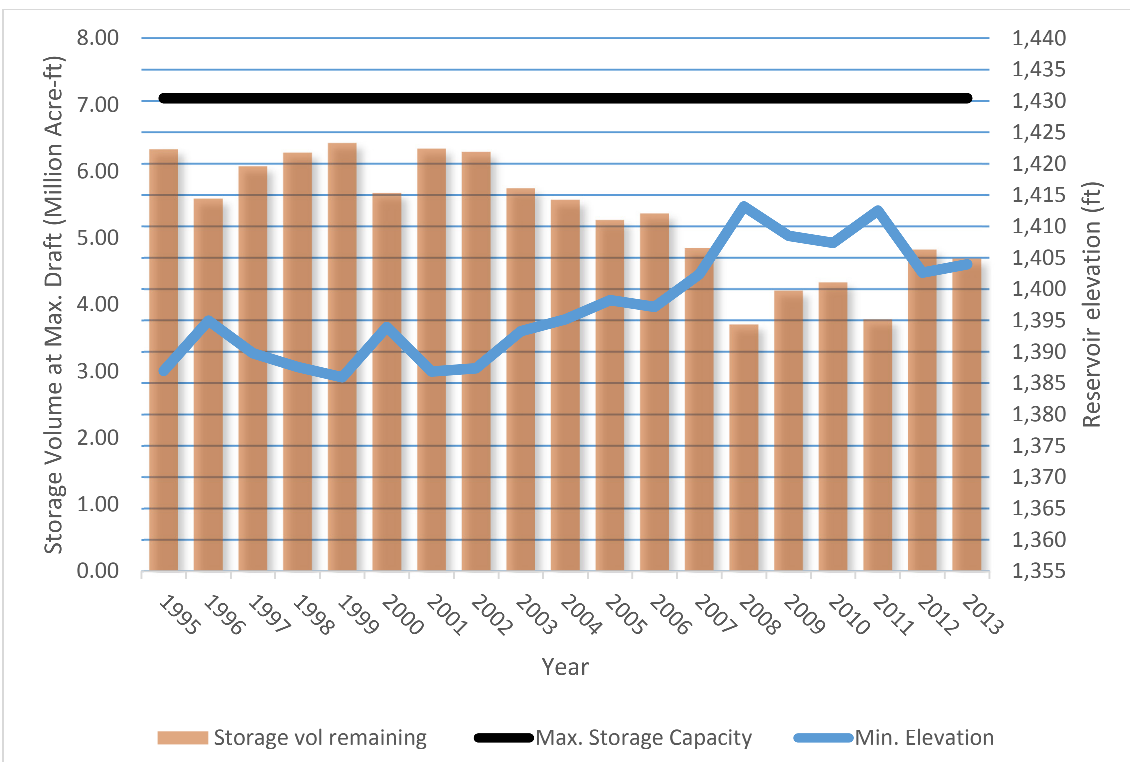
The study conducted by both Entities (Canadian and United Stated Entities 2010) reported that in a Treaty Terminate scenario (where the operation of Canadian reservoirs do not follow CRT operational rules) Canada would be motivated to operate with Arrow elevations higher resulting in reduced flood storage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

4.10.3 Evaluation of Scenarios

For each of the Scenarios, a key issue is how much storage each Scenario will provide. It is also 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 and maximum pool height (1,444 ft. / 440.1 m.). 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 16).

Figure 16: Arrow Minimum Draft Elevation and Storage Capacity 1995-2013



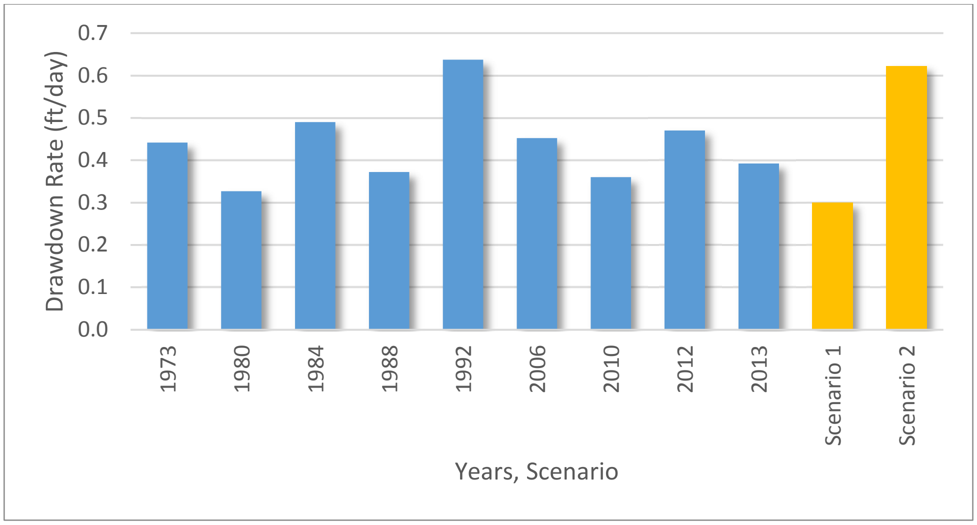
Given a known relationship between the ALR water elevation and storage volume, it is possible to determine flood water storage volumes remaining in the reservoir (Columbia River Treaty Operating Committee 2015). Between 2008 and 2013, the flood storage volume remaining is 3.7 – 4.8 million acre-ft. Scenario 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 remaining 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 remaining 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 capacities in recent years[18].

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 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 examined[19] (see Figure 17). 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.

[18]BC Hydro assumed in the CRT Review Technical Report (BC Hydro 2013b, Appendix D) that future flood control storage requirements for Kinbasket and Arrow Lake Reservoirs will be split 4.08/3.60 million acre-feet.

[19] 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.

Figure 17: Maximum Monthly ALR Drawdown Rate for Scenarios and High Drawdown Rate Years



As Figure 17 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 does not specify a maximum discharge limit for the ALR.

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 4.5);
- Strong currents in the Narrows area that may make 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.

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 7b at the end of Section 4 for a summary of all issues.

Table 7a: 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.	Ave. 112 days (15-209), most years.	Approx. 100 days, no limit, 1 in 5 years.	Max. of 35 days, 1 in 7 years.

Table 7b: 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 impaired access by fall spawners to some tributaries in comparison to current operations.	A Scenario 2 operation would likely result in improved access by fall spawners to tributaries in comparison to current operations and Scenario 1.	

	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 invasive fish species like northern pike.	Scenario 2 would likely result in the expansion of aquatic macrophyte communities, which are likely to support invasive fish species like northern pike, in comparison to both current and Scenario 1 operations.	
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.	

	Current Operations (1995 to 2013)	Scenario 1	Scenario 2	Comment
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.	A Scenario 2 operation will likely improve white sturgeon spawning and incubation habitat conditions, and possibly larval dispersal, in comparison to current conditions but will be neutral in comparison to Scenario 1.	
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.	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. Illegal pot hunting would also be more difficult with improved vegetation establishment above 1,421 ft. (433.1 m).	

	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 spring and summer; 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; 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.).	Herbaceous vegetation increases in diversity, cover and vigour above 1,420 ft. (432.8 m.); tree/shrub 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;	Scenario 1 provides some improvement in herbaceous cover above 1,425 ft. (434.3 m.), while Scenario 2 provides for the development of 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)	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.
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 about 1,430 ft. 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.

	Current Operations (1995 to 2013)	Scenario 1	Scenario 2	Comment
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.
Navigation	1,420 ft. (432.8 m.) and above: optimal for log tow operations 1,410 – 1,420 ft. (429.8 – 432.8 m.): minor reduced log tow capacity through Narrows 1,410 ft. (429.8 m.) and below: major reduced log tow capacity through Narrows	Considered minimum elevation for optimal log tow capacity through the Narrows. 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.	Exceeds minimum elevation for optimal log tow capacity through the Narrows. 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.	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.). Log sort operations would benefit from both Scenarios.

	Current Operations (1995 to 2013)	Scenario 1	Scenario 2	Comment
Agriculture	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	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	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	Agricultural activities would benefit from both Scenarios, with the greatest benefits from Scenario 2.
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 erosion at elevation extremes than in the middle of the range. 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.	Bank erosion in the Revelstoke Reach will occur in reaches were 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 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. 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.	Bank erosion in the Revelstoke Reach will occur in reaches were 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 are undercut and the beach slowly attains the long term stable slope. 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. Whether Scenario 2 would increase or decrease the frequency and magnitude of mass wasting	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
		Whether Scenario 1 would increase or decrease the frequency and magnitude of mass wasting events when compared to current operations is unclear.	events when compared to current operations is unclear.	
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.	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.	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.	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.

4.11 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 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 spawning and migration habitat 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 the 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 elevations. 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 and wetland 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 wetlands, 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. (435.9m.) The consideration of these types of scenario modifications will require further in-depth analysis; for example, a March -April drawdown operation could be harmful for kokanee whereas a short-term storage operation could be beneficial.

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.

	Scenario 1	Scenario 2
Positive or Beneficial Impacts	• increases in 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. • shoreline erosion reduced. • decreased dust generation. • improved commercial navigation and log dump operations • ALGS power generation is slightly greater to that under existing operations. • Increased vegetation and decreased erosion provide mitigation to protect archaeological resources.	• 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. • 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 agriculture opportunities and crops. • shoreline erosion reduced. • improved commercial navigation and log dump operations. • greatly decreased dust generation. • increased vegetation and decreased erosion provide mitigation to protect archaeological resources.
Neutral Impacts	• burbot spawning and incubation success unlikely to be affected.	• ALGS power generation is roughly equal to that under existing operations. • burbot spawning and incubation success unlikely to be affected.

	Scenario 1	Scenario 2
Mixed or Uncertain Impacts	• 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.	• 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	• 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, creating more favourable conditions for invasive aquatic species.	• 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, creating more favourable conditions for invasive aquatic species.

5 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 all 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 kilometres 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.

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 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.)

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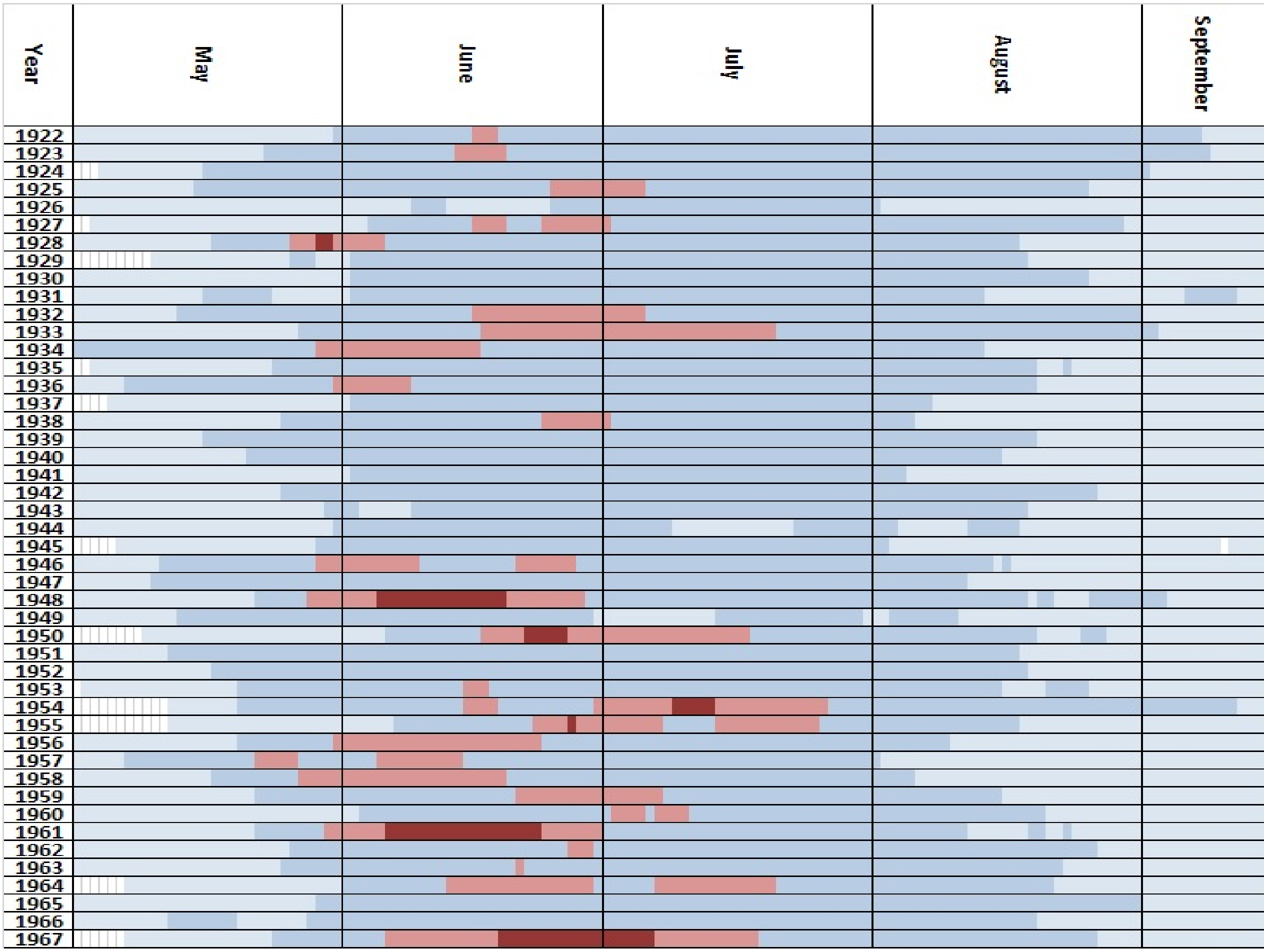
Appendix 1: Number of days Upper Arrow Lake was above water elevations for pre-regulation period 1922-1967



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