Appendix E

Potential Lower Columbia River Flow Regimes for Fisheries Benefits DRAFT

1.0 Introduction

During the Columbia Water Use Plan (WUP), the investigation of different flow regimes downstream of Arrow was limited to those operations where BC Hydro could successful negotiate alternative flows with the U.S. Entity (i.e. rainbow trout & mountain white fish spawning flows). This was done for practical purposes as flow releases from Arrow are determined by the Columbia River Treaty and other related agreements. In general, change in flows can only be made by mutual consent between the Canadian and U.S. Entities.

Under a Treaty Terminate scenario, a broader range of flow regimes below Arrow would be possible. For this reason, the Columbia River Treaty Fish & Wildlife Technical Committee (CRT-FWC) were tasked with developing alternative flow regimes that could potentially provide fisheries and other ecosystem benefits below Arrow. This was done by first developing flow regime characteristics that are believed to be desirable for fish. These in turn were used as the basis for developing water management alternatives that could be modeled to assess feasibility, success in meeting desired fish flows, and potential impacts on other interests.

The current operating regime was recommended by the WUP and is based on the hypothesis that white fish and rainbow trout abundance is related to egg-dewatering events. This has led to agreements with the U.S. Entity to lower Arrow flow releases in Jan through March while storing more water in Arrow for US flow augmentation in June/July. Thus, this arrangement creates a trade-off between Arrow reservoir levels and Lower Columbia River flows. There is uncertainty surrounding this hypothesis, and recent information from the Water Licence Requirement (WLR) monitoring studies indicates that the number of surviving eggs may not be an important factor limiting the abundance of adult populations.

Although a decision to change from this current operating regime will not be contemplated until the next WUP, information concerning mountain whitefish and rainbow trout has been examined in the context of this review because there are potentially important implications. If dewatering is, or likely could be, a significant factor, then there is justification for continuing the current operation. If, however, there was sufficient evidence to reject this hypothesis in favour of another, then this information would be valuable in considering the relative performance of Treaty scenarios and would also inform any discussions with the U.S. about future arrangements under the Treaty.

This appendix provides a status summary of the priority management fish species in the lower Columbia River (section 2.0), reviews the history of flow management in the Lower Columbia River and summarises results to date from the monitoring program (Section 3.0), describes alternative hypotheses for factors affecting fish abundance and fish health (Section 4.0), and ends with the alternatives selected for modelling as part of these technical studies (Section 5.0).

2.0 Population status of Fisheries in the Lower Columbia River

2.1 White Fish

Mountain Whitefish (*Prosopium williamsoni*) are salmonids (related to trout and salmon) and are the most abundant sportfish in the Lower Columbia River (LCR; Golder 2012). Although abundant, they are not targeted in recreational fisheries. Their abundance and the fact that they spend their entire life history (from egg to adulthood) in the Lower Columbia River make them good indicator species to help assess the quality of the aquatic environment. They spawn between December and April, releasing their eggs over substrate usually in shallow waters. This preference for shallow water spawning makes white fish eggs vulnerable to dewatering due to water levels fluctuations associated with dam operations. Newly emerged (larval) whitefish school near shore and are prone to stranding when water levels suddenly drop.

The Lower Columbia River whitefish population has been tracked by i) monitoring the adult population, ii) monitoring egg survival, and iii) assessing juvenile whitefish habitat use. The earliest of these monitoring studies began in 2001 while others began in 2007. The monitoring studies show that whitefish consistently use the same areas to spawn, and concentrate their spawning in the northern part of the Lower Columbia River mostly near CPR Island and in the Kootenay River below Brilliant Dam. The adult population has remained relatively stable since 2001 with estimates of around 100,000 adults (Ford and Thorley 2012), and there has been a trend towards larger and older whitefish.

2.2 Rainbow Trout population status in the Lower Columbia River

Rainbow Trout (*Oncorhynchus mykiss*) are a sportfish of great recreational importance in the Lower Columbia River (Irvine et al. 2012). Although Rainbow trout adults can cover large distances (McPhail 2007), the Lower Columbia River rainbow trout constitute a single genetic population (Taylor 2002, cited in Irvine et al. 2012). Rainbow trout spawn in the spring, during which time females dig redds (shallow depressions in the substrate) where they deposit fertilized eggs. Rainbow trout need small gravel for their redds (which allow eggs to remain aerated during their development) and this type of substrate is found in shallow waters such as at Norn's Creek fan. However, in large regulated rivers where the spring flood is attenuated due to dam operations, there can be considerable spawning in deeper water in the mainstem which is not subject to dewatering.

The Rainbow trout population in the Lower Columbia River has been tracked through monitoring programs, some since 1999. Programs include i) monitoring the juvenile and adult population, ii) monitoring egg survival, and iii) assessing juvenile habitat use. The adult population has been relatively stable since 2003 but the numbers of juveniles has recently increased (Ford and Thorley 2012). There has been a trend towards a higher proportion of larger rainbow trout.

2.3 White Sturgeon

White sturgeon (*Acipenser transmontanus*) in the Canadian section of the lower Columbia River were listed as endangered under the Species at Risk Act in 2006. Although white sturgeon have successfully spawned in the mainstem Colubmia River since construction of the dams on the Columbia, Kootenay, and Pend d'Oreille systems, there is little evidence that the young are surviving through the early life stages (eggs, larvae, and juveniles) to become sexually mature adults. There are multiple competing hypotheses regarding the mechanisms influencing recruitment failure (McAdam 2013). Work related to recruitment failure hypotheses generally falls into a few major categories across all life stages including substrate suitability and availability, flow related effects, turbidity, predation, and feeding. The majority of the prioritized work focuses on the early life stages from eggs to feeding larvae.

The abundance of the population in the Canadian portion of the Columbia River is estimated to be 1,157 adults (range 414-1899) with an additional 2,003 adults (range 1093-3223) residing in the United States from the border to Grand Coulee Dam. Based on natural mortality rates and population trajectory calculations, this population of white sturgeon is estimated to become functionally extinct by 2044. A conservation aquaculture program was developed and initiated in 2001 to help support the population until it can become self-sustaining. To date, over 150,000 juvenile white sturgeon have been released into the mid and lower-Columbia Rivers. Information from monitoring studies indicate that hatchery juveniles from all year classes released since 2001 are surviving and growing at a high rate in the lower Columbia River. It is quite likely that there will be a very large increase in the adult white sturgeon population in the future due to the large number of juvenile sturgeon that are stocked. The addition of a large number of top predators in the lower Columbia River will likely have substantive effects on the ecosystem that could affect survival rates of whitefish, rainbow trout, and even juvenile sturgeon. It is possible that the effects of stocking a large number of juvenile sturgeon could overwhelm effects of flow on all fish species that use the lower Columbia River.

The WUP consultative committee recommended opportunistic assessments of high flow events be undertaken in years when they occur naturally. The Columbia WUP contains a large package of monitoring studies aimed at increasing the understanding of white sturgeon basic biology, spawning and habitat requirements, movements, growth and survival.

3.0 Rainbow Trout & White Fish Spawning Flows

3.1 Background

In the early 1990s, BC Hydro and regulators became aware of periodic rainbow trout (and, later, mountain whitefish) egg dewatering in the Lower Columbia River. Egg dewatering occurs when higher river flows allow fish to spawn in areas that are exposed to the air if flows are subsequently reduced prior to emergence of larval fish from the river substrate. Although it is generally understood that dewatering events can kill eggs and larval fish, it was uncertain whether such events could have a significant effect on population abundance. There are two reasons for this: 1) the loss of eggs and larvae from dewatering could only be a small (< 10%) fraction of the total number of eggs and larvae; 2) even potentially large losses could be mitigated by improved survival of the individuals that were not dewatered due to density-dependent survival (surviving individuals survive at a higher rate due to lower densities caused by the dewatering). Nevertheless, steps were taken to alter flows in the river in order to minimize the frequency and magnitude of egg dewatering events.

A series of initial ad-hoc agreements with the United States led to the first annually-updated Non-Power Uses Agreement in 1993, in which the two countries make mutual accommodations to Treaty flows for the benefits of fish on both sides of the border. Since that time, increasingly stringent limitations on the ramping rates of discharge from Hugh Keenleyside (HLK) Dam have been implemented to reduce the potential for fish stranding.

Whitefish flow management is achieved by reducing discharge from HLK Dam during the peak spawning period (January 1-21), and then managing excessive flow reductions until March 31. The objective is to minimize the difference between the maximum flow during the peak spawning period (January 1 -21, Q_{Smax}) and the minimum flow prior to egg hatch (January 22 – Apr 1, Q_{Imin}). Rainbow trout flow management provides stable or increasing river levels from 1 April to 30 June. In addition to these rainbow trout spawning protection flows, redds that are at risk of dewatering (high in the drawdown zone) are excavated and transported to sites that will not be dewatered.

These whitefish and rainbow trout flows are negotiated annually with the U.S. Entity in exchange for storing up to 1 million acre feet (MAF) of extra water in Arrow Lake reservoirs for U.S. flow augmentation releases in June/July. However, they do come with trade-offs as the vegetation, wildlife, and recreation interests in the Revelstoke reach at the north end of Upper Arrow Lake reservoir prefer lower water surface elevations during the spring and early summer. The Columbia River WUP recommended that whitefish and rainbow trout flows continue, accompanied by vegetation and wildlife monitoring and mitigation in the Revelstoke Reach.

At the end of the WUP, monitoring studies were proposed to test whether egg protection flows affect the abundance of mountain whitefish and rainbow trout populations. According to the WUP proposal, a second phase of data collection beginning in 2014, will be conducted under a flow regime that increases the extent of dewatering. Discussion and agreement with regulatory agencies would be required before proceeding with changes to further test the spawning flows.

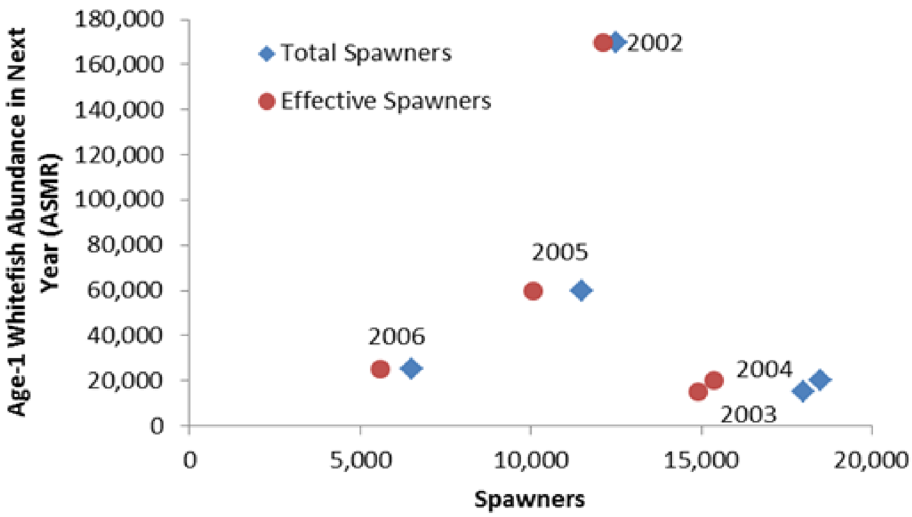
3.2 Evaluating the success of White fish flows

Recent monitoring data suggests that flow modifications have been effective in decreasing the extent of egg dewatering (i.e. situations of high flows followed by lower flows during spawning periods have been much reduced). However, this has not necessarily resulted in large changes in the actual dewatering of eggs; in the case of mountain whitefish, the rate of egg-dewatering has been reduced by 5% to 20% relative to the historical range. There is no indication that this reduction has led to an increase in the abundance of the adult population. The relationship between the number of spawners that lay viable eggs (i.e. those that are not dewatered and recruitment, as indexed by the abundance of age 1 fish, indicates that recruitment is likely more affected by factors other than the number of viable eggs (Fig. 1). The small differences between the total and effective spawners in any year compared to the larger differences in spawners among years indicate that inter-annual variation in spawner numbers is a much larger factor affecting the number of viable eggs than the extent of dewatering.

There are three possible causes for the poor relationship between juvenile abundance and viable egg deposition estimates (Fig. 1): 1) There could be considerable error in estimates of both these variables due to challenges in monitoring fish populations in a large river combined with limitations in the monitoring effort; 2) juveniles contributing to values on the y-axis could be derived from sources of eggs not accounted for in the egg deposition estimates on the x-axis; or 3) strong density dependence in early survival rates result in an effectively flat slope over the observed levels of egg deposition. Higher effective egg deposition does not increase juvenile abundance because mortality in those years would be higher due to greater density. Strong density dependence in early life stages is a common feature for many fish populations.

Figure 1: One-year-old whitefish abundance versus total and effective spawners (2002-2006).

Effective spawner values were computed by reducing the total spawner estimates by the estimated fraction of whitefish eggs dewatered in each year. The difference along the x-axis between each pair of red and blue points represent the proportional egg losses due to egg dewatering.

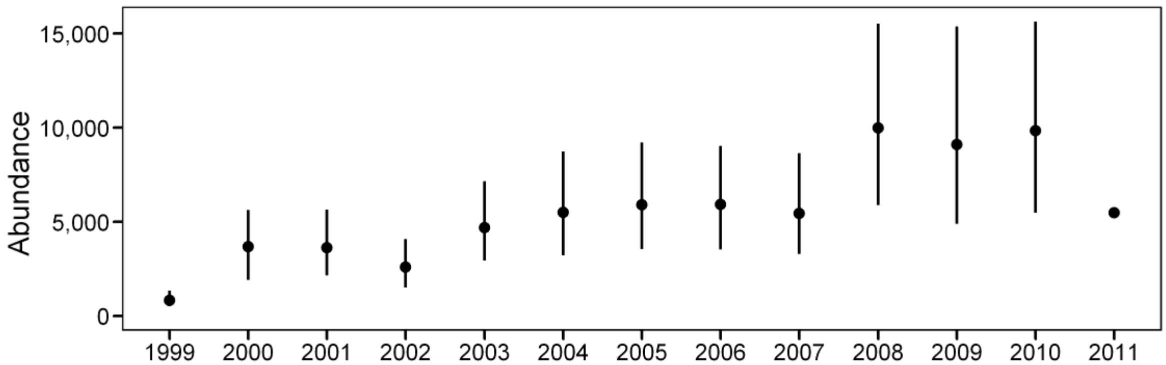


The effects of operations on the whitefish population health are hard to tease apart from other variables, especially since predators such as walleye and sturgeon have become more abundant. Moreover northern pikes have recently become established in the area and could impact juvenile whitefish survival in the long term.

3.3 Evaluating the success of Rainbow Trout Flows

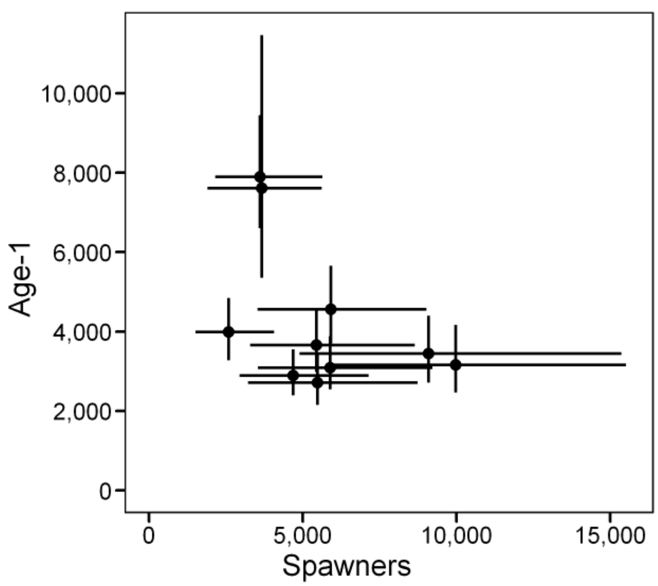
Before implementation of the rainbow trout protection flows, 50 to 75 % of redds near Norn's fan were being dewatered. This has been reduced to 0.75% with the current management practises (Irvine et al 2012). However, it is uncertain whether this improvement has had a positive influence on abundance. Rainbow trout monitoring programs show that spawner abundance has increased since 1999, six years after 1993 when egg protection flows were initiated (Fig. 2). Unfortunately, there are no estimates of abundance prior to 1993 to better line population increases to egg protection flows. The lack of a relationship between spawner numbers in the mainstem and age-1 abundance suggests that the increase in adult abundance is likely not related to egg protection flows (Fig. 3). Strong density dependence in early life stages of salmonids has been well documented in both small and large river systems and explains in part, the lack of a positive relationship between rainbow trout spawner abundance and age-1 abundance in the LCR.

Figure 2: Rainbow Trout Spawner Abundance in the Lower Columbia River (1999 to 2011)



Source: Thorley and Baxter, 2012

Figure 3: Relationship between rainbow trout spawner numbers in the mainstem and Age-1 abundance one year later.

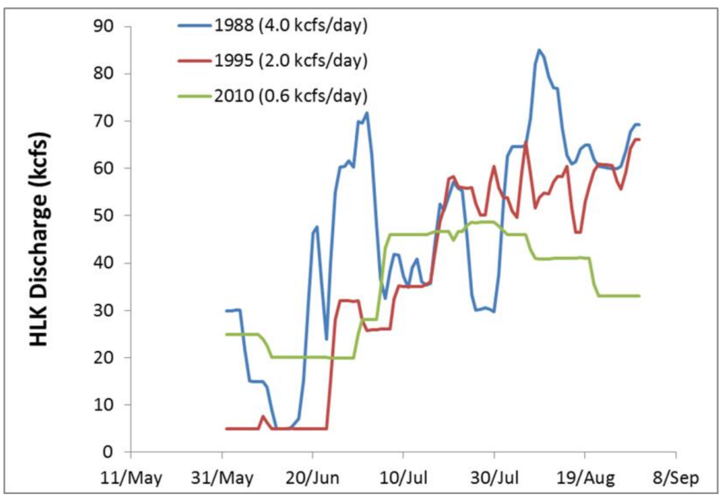


Source: Thorley and Baxter, 2012

It is worth noting that the timing of the increase in rainbow trout abundance has coincided with reduced day-to-day variation in flow from Hugh Keenleyside Dam (Fig. 4). Small trout prefer shallow, low velocity habitat. Sites with these characteristics at low flows are lower elevation areas that are permanently submerged and therefore support high food production. At high flows, these low elevation sites have depths and velocities that are higher than those preferred by small fish. At the same time, higher elevation sites with more appropriate depths and velocities may not have been submerged long enough to be colonized by invertebrates. The result is that, under variable flow conditions, young fish faced with higher flow conditions have a choice of either remaining at low elevation sites that have suboptimal habitat, or moving to high elevation sites that have appropriate habitat, but little or no food. Either choice can result in lower growth and survival of these small fish when flow variability is higher compare to when it is lower.

Figure 1: Trends in mean daily flow from Hugh Keenleyside Dam over the summer

Three years selected to show differences in the extent of day-to-day variation in flow. Values in parentheses show the average day-to-day variation between June and August.



3.4 Conclusions on Effectiveness of White Fish and Rainbow Trout Flows

A decision to change from the current fisheries flows will not be contemplated until the monitoring studies are completed and if changes are recommended, they would occur as part of the WUP review process. However, the CRT-FWC was required to review all new data with the intent of assessing the likelihood that there could be alternative flow regimes that may be beneficial to fisheries in the Lower Columbia, as well as assessing the range of possibilities in a 'Treaty terminate' scenario. The list of competing hypotheses and associated flow management scenarios developed from this review is provided in Section 4.0.

The CRT-FWC did not reach a consensus opinion as to the effectiveness of the white fish and rainbow trout flows. Discussion points included:

- There was agreement that direct evidence linking egg-dewatering to rainbow trout and mountain whitefish populations is weak at best
- While some people felt that there was sufficient evidence at hand to reject the egg dewatering hypothesis as a primary driver of abundance, others felt that more information should be collected before this conclusion could be made
- There was agreement that egg dewatering is only one of several potential hypotheses that explain abundance dynamics in the Lower Columbia River; however it was not the leading or well supported hypothesis.

4.0 Development of Alternative Flow Regimes: Fisheries Hydrograph #1

A systematic approach was taken to develop alternatives to model under a Treaty terminate scenario that may have the potential of benefiting fisheries in the Lower Columbia River. Priority indicator species where identified and hypothesis that may impact population abundance were determined. Rainbow trout and whitefish were grouped together and are discussed in this section. Sturgeon are discussed in Section 5.0.

4.1 Hypotheses for Rainbow Trout and Whitefish Population Abundance

Six hypotheses pertaining to rainbow trout and white fish population abundance were considered:

1. Non-decreasing flows through the incubation period increase egg and larval survival and ultimately recruitment
2. Reduced day-to-day variation in flow from Hugh Keenleyside and Brilliant dams maintain persistent near-shore early-rearing habitat (including food production, movement etc) which increases recruitment
3. High flow events increase interstiatial space and lead to increases in the production of invertebrates, which ultimately increases recruitment, and perhaps growth and fecundity of adult fish
4. Populations are limited by habitat availability during the growing season
5. Adult and juvenile growth are driven by food supply out of Arrow Lake
6. High flows during winter have a high energetic cost to fish that reduces growth and may lead to decreases in survival

These hypotheses were not considered independent of each other and each factor may exert some influence on fish abundance in the Lower Columbia River. However, the impact of some factors can be much more pronounced than others. The purpose of this section is to identify hypotheses related to flow that may impact fish abundance and then determine which hypothesis are most likely to have the largest impact. Other non-flow related items that affect fish abundance such as harvesting, predation were not considered.

Hypothesis 1: Non-decreasing flows through the incubation period increase egg survival and ultimately recruitment

This hypothesis assumes that dewatering of whitefish and rainbow trout eggs lead to substantive decreases in juvenile production, ultimately reducing the abundance of the adult populations. High flow events to stimulate white sturgeon recruitment, or to enhance interstitial spaces and food production, have the potential to scour eggs from the substrate and decrease survival rates. Under assumptions in this hypothesis, these losses also have the potential to lead to substantive reductions in recruitment.

What is the evidence in support of or against this hypothesis?

See discussion in Section 3.0.

For: Dewatered eggs provide direct observations of flow-related mortality.

Against: Limited data for mountain whitefish suggests that recruitment is not strongly related to spawner numbers, and that egg dewatering is a minor factor in determining the number of viable eggs (Fig. 1). There is no indication in the more extensive rainbow trout dataset of a relationship between spawner abundance and recruitment (Fig. 3), suggesting that reductions in egg dewatering are unlikely to have substantive population level effects. Strong density dependent in mortality at early life stages has been documented for many fish populations (Barnhouse et al. 1988, Ellitio 199, Fletcher and Deriso 1988, Rosee t al. 2001), and is consistent with the observation of a flat relationship between spawner numbers and recruitment. Density dependent mortality has been show to offset population-level effects of extensive egg dewatering (losses of 25-50%) for other rainbow trout populations in large regulated river (Korman et al. 2011b). Alternative explanations for increases in adult rainbow trout abundance include more stable flows (as described in figure 1)and possible changes in the harvest rates.

What benefits to Whitefish and Rainbow could we expect with more desirable flows?

No change, as flows designed to limit egg dewatering are currently being implemented. Egg dewatering events have been reduced, as have egg / larvae mortality. Eggs and larvae saved by egg protection flows, that would eventually die due to density dependent mortality via predation, could be an important food source for whitefish and other species. Losses due to dewatering remove this potential ecosystem benefit.

Hypothesis 2: Stable flows maintain persistent near-shore early-rearing habitat which increases recruitment

Small trout prefer shallow, low velocity habitat (e.g., Edmundson et al 1968, Korman and Campana 2009, Korman et al. 2011a) Sites with these characteristics at low flows are lower elevation areas that are permanently submerged and therefore support high food production. At high flows, these low elevation sites have depths and velocities that are higher than those preferred by small fish. At higher discharges, higher elevation sites will have better depths and velocities for small fish, but may not have been submerged long enough to be colonized by invertebrates. The result is that, under variable flow conditions, young fish have a choice of either remaining at low elevation sites that have suboptimal habitat, or moving to high elevation sites that have appropriate habitat, but little or no food. Either choice can result in lower growth (Korman and Campana 2009) and survival of these small fish when flow variability is higher compared to when it is lower.

What is the evidence in support of or against this hypothesis?

For: There are numerous examples where flow stabilization has led to increased fish abundance in regulated rivers (Bowen et al. 1988), Connor and Pflug 2004, Freeman et al. 2001). Habitat and growth is effected by short-term variation in flow (Korman and Campana 2009), as is food production (Benenati et al. 1998, Blinn et al. 1995) With stable flows, sufficient food growth can occur in the shallow river margins that would allow smaller fish to remain there, away from deep water predators. Small trout confined to deeper, faster water for forage could have higher mortality rates especially in the presence of large predatory fish. In the Lower Columbia River, increases in rainbow trout abundance occurred over the same time period when short-term variation in flow was reduced (Fig.'s 2 and 4).

Against: Good cover (e.g. interstices in gravel), low predator density, and a steep slope of river cross-section would minimize impacts of short-term variation in discharge on habitat quality. High slope bottom topography and small increases in velocity all help to minimize the impact of increases in depth at higher flows.

What benefits could we expect with more desirable flows?

Higher growth and survival of juvenile trout and other species with similar habitat preferences can be expected. Adult populations would increase if juvenile to adult survival is not strongly density dependent.

Hypothesis 3: High flow events increase recruitment via increases in juvenile survival and food availability

High flows result in bedload movement which in turn leads to an increase in interstitial space in river substrate and increases in food availability. In the short term, bedload movement could lead to egg loss, downstream displacement of recently emerged fish, and short-term reductions in food availability. These factors could have short-term but negative consequences on fish populations. In the long-term, increased interstitial spaces and food availability could result in improved growth for juveniles and adults and higher juvenile survival rates. The benefits of artificial floods on recruitment of juvenile rainbow trout (via improved growth and survival) has been documented in other large regulated rivers (Korman et al. 2011b). In the Lower Columbia River, high flows may also lead to reductions in nuisance algal species (Didymosphenia geminata) which clog interstitial spaces and reduce invertebrate production.

What is the evidence in support of or against this hypothesis?

For: High flow events have been shown to increase river productivity by flushing fine sediments from coarse river substrates, which in turn have been shown to increase survival rates for juvenile fish (see references above).

Against: There is no evidence that substrate in the Lower Columbia River is embedded (NHC 2007). Fine sediment can be found in small amounts in the interstices of the course substrate on exposed lower banks, but the substrate is not embedded. No information is available for the permanently wetted channel, however given higher velocities in these habitat it seems unlikely they would be embedded if substrates on the bank are not embedded. Fine sediment delivered to the LCR via the Kootenay and Pend d'Oreille Rivers continues to be transported in suspension due to its finer grains size

If true, what flow characteristics would be desirable?

A short term, high flow event required for gravel cleaning and food availability, however, flooding constraints may limit its effectiveness. More work with hydraulic modelling is needed in order to estimate the discharge required to mobilize bedload.

Hypothesis 4: Populations are limited by habitat availability during the growing season

The abundance of many fish populations is often controlled by the availability of habitat for juvenile fish. Our understanding of habitat requirements capacity in river systems generally comes from small systems. Perhaps the closest analogue for the LCR with respect to rainbow trout can be found in the Thompson River system. Here, the majority of juvenile production comes from tributaries suggesting that habitat for small fish in the larger mainstem Thompson River is limited. If this is true, then it follows that habitat for small rainbow trout in the LCR is limited, and that there may be an optimal flow that maximizes the availability of habitat. It is likely that the limitation occurs shortly after emergence, so flows during late spring and over the summer may be most important.

What is the evidence in support of or against this hypothesis?

For: Indirect support for this hypothesis is provided above. There are no documented cases that we know of indicating a limitation in the quantity of juvenile habitat in large rivers.

Against: There are large amounts of low angle shoreline area suitable for juvenile rearing in the Lower Columbia River. It is more likely that the quality of these habitats are limited by food availability and stability (as described for hypothesis 2), rather than the amount of habitat per se.

What benefits could we expect with more desirable flows?

Optimal flows may increase ecosystem productivity or abundance and size of targeted species.

Hypothesis 5: Adult and juvenile growth are driven by food supply out of Arrow Lake

Export of phosphorous, zooplankton, and Mysis shrimp from Arrow reservoir to the Lower Columbia River could be an important driver of food availability for fish in the LCR. Factors that affect the export of this material during the growing season could affect growth and survival of juvenile and adult fish in the LCR.

What is the evidence in support of or against this hypothesis?

For: Research in Kootenay Lake suggests that kokanee growth rates are lower in the main lake but higher in the outlet (i.e. West Arm) because Mysis shrimp are much more available to Kokanee in the West Arm as they are transported over the sill between the main lake and the west arm. Mysis shrimp are an important component of the diet of sturgeon in the LCR.

Against: The relative importance of exported phosphorous, zooplankton, and Mysis shrimp to the diets of LCR fish, relative to locally produced food, is unknown.

What benefits could we expect with more desirable flows?

Higher flows from Hugh Keenleyside Dam during the growing season would increase the export of phosphorous, zooplankton, and Mysis to the LCR, which could be potentially beneficial to the growth and production of fish populations in the LCR.

Hypothesis 6: High flows during winter have a high energetic cost to fish that reduces growth

In northern rivers, there is very limited feeding and somatic growth in fish populations during winter. This occurs because invertebrate production is limited due to cold temperatures, and because fish cannot convert any food that is available into energy due to effects of cold temperatures on their metabolism. In order for fish to survive over the winter they need sufficient energetic reserves and must minimize energy expenditures. Higher flows during winter due to flow regulation may increase energy expenditures and reduce the probability that fish will survive the overwinter period.

What is the evidence in support of or against this hypothesis?

For: In small rivers and lakes, over-wintering mortality is significant factor affecting juvenile survival. Flows in the LCR are higher during winter since impoundment which could increase energetic demands for fish overwinter in many juvenile salmonids. Under certain conditions, young rainbow trout can exhaust lipid reserves in lake (like systems?) and experience high over winter mortality.

Against: Fish are able to find suitable low velocity habitats during winter by moving to slower waters, and by using interstitial spaces in gravel. This is a common strategy observed in smaller river systems.

What benefits could we expect with more desirable flows?

Higher overwinter survival and improved condition of fish by spring.

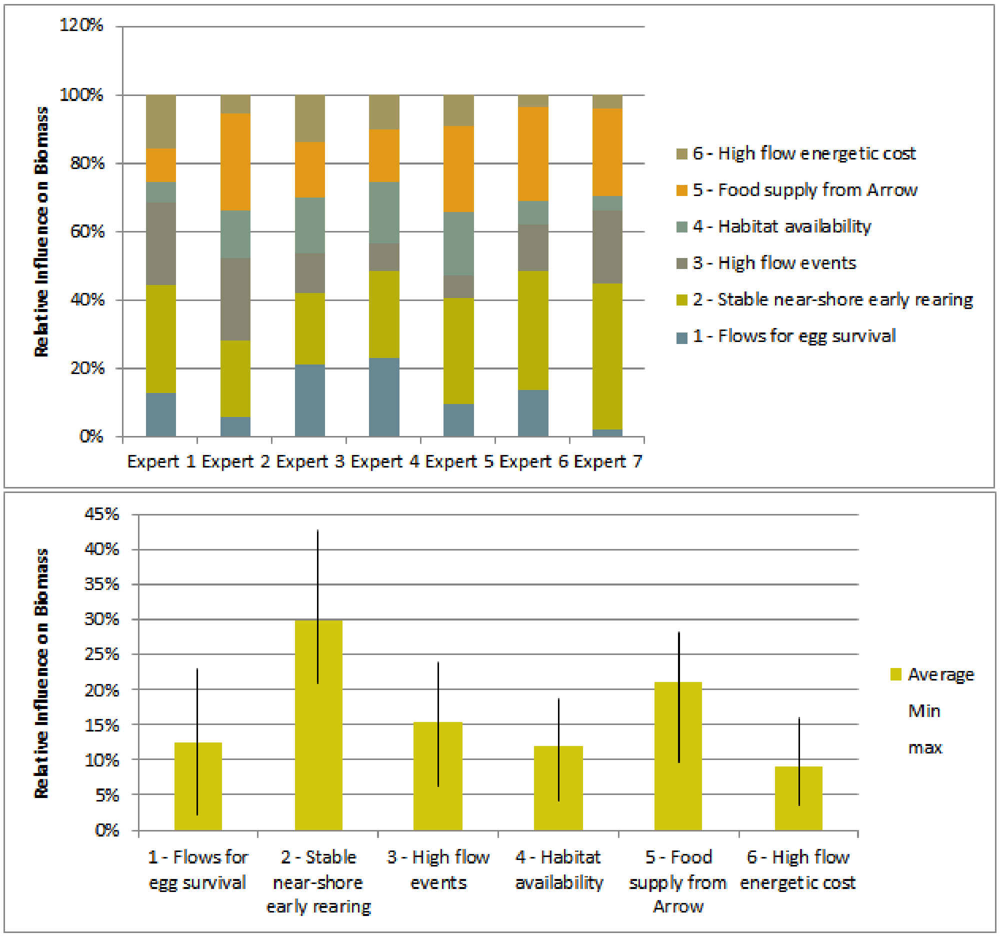
4.2 Relative Importance of Hypothesis

During the February 25-26,2013 CRT_FW committee meeting, members with a fisheries background used an expert elicitation approach to determine the extent of support for hypotheses 1-6 following discussions of evidence for and against each hypotheses (as reviewed above). Members were asked to score the plausibility of each hypothesis for explaining variation in whitefish and rainbow trout biomass in the LCR on a scale ranging from 0 (not plausible at all) to 100 (highly plausible). These scores were then standardized so they summed to 100 across the six hypotheses for each of the seven participants, and presented to the group. A discussion of the rationale of participant scores then ensued, and this was followed by a second round of scoring, which is reflected in Figure 6.

In general, the ranking of alternatives reflect the degree of support for the hypotheses summarized in Section 4.1. The results indicate that hypothesis 2 (short-term flow stability) had highest support (mean of 30%), followed by hypothesis 5 (food supply form Arrow, mean of 21%). There was relatively weaker support for the other hypotheses (means of 9-15%). There was a considerable range in the degree of support for various hypotheses among participants as seen by the width of the confidence intervals. With the exception of hypothesis 2, there was considerable overlap in confidence intervals across hypotheses, indicating that the differences in the mean support were much less than the extent of variance in support across participants. The current egg protection flow policy was ranked third of the six hypotheses, and had about half the mean support (13%) relative to the top-ranked hypothesis (30%).

Figure 5. Results of expert elicitation to determine the degree of support (0% = no support, 100%= maximum support) for six hypotheses about the effects of flow on rainbow trout and whitefish biomass in the Lower Columbia River.

The top graph shows the degree of support by participant, and the bottom graph shows the mean and range of support for each hypothesis across participants.



4.3 Ranking of Alternatives based on Hypotheses

Following the expert elicitation process to score the feasibility of the six whitefish and rainbow trout recruitment hypotheses, participants at the February 25-26 meeting developed constructed scale to rank the impact of each flow alternative for each hypothesis, assuming that hypothesis was the most important one. The scale ranged from -1 (a negative effect) to +2 (a large positive effect). Scores of 0 indicated that there was no substantive effect of the flow regime, while a blank score indicated that there was no information to develop a score. All scores were ranked relative to the reference treaty continue alternative. With the exception of hypothesis 1 (egg survival), there was no difference among scores for whitefish and rainbow trout. However, for hypothesis 1, differences in the incubation period between species resulted in different scores. In this case, the species-specific scores were summed across species to generate an overall score for this hypothesis for each alternative.

Results of the alternative scoring exercise by hypothesis are presented in Figure 6. Alternative 4 TT and reference TT were the first and second ranked alternatives. They scored better than the reference case (Ref TC) for all (4 TT) or almost all (ref TT) hypotheses. These two treaty terminate scenarios outperformed treaty continue ones because they allowed implementation of high flow events (hypothesis 3) and reduced high flows during winter (hypothesis 6). Alternatives 3TT and 6 TT had low rank because of increased flow variation which reduced scores for hypotheses 1 and 2.

Ranking of the flow alternatives for LCR fish was quite uncertain because there was no data to confidently estimate the magnitude of the expected recruitment change given the flow regime. For example, -1 scores for the egg survival hypothesis for whitefish are based on very minor declines in discharge over the incubation period. These changes might be an artifact of the hydrologic modelling process and could likely be avoided by BC Hydro if the scenario was implemented. Similarly, there was large uncertainty about the alternative scores associated with flow changes during winter, high flow events, and for other metrics. Predictions for the LCR fish PM for each flow scenario should be considered highly uncertain.

Figure 6. Comparison of Lower Columbia River whitefish (WF) and rainbow trout (RBT) performance across treaty continue (TC) and treaty terminate (TT) scenarios.

Scores of -1, 0, 1, and 2 indicate that performance is worse, the same, better, or much better relative to the reference TC scenario. Blank cells (hypothesis 4) denotes there was no information to score the alternative. Scores are not species specific except for hypothesis 1. The relative weight of each hypothesis is shown by the means in Figure 5 are displayed in the rightmost column below. The second to bottom row shows the weighted average score for each alternative which depends on the sum product of the expected magnitude of the effect (-1 to +2) and the hypothesis weight. The last row shows the ranking of each alternative (1 is highest rank, 8 is lowest rank).

Hypothesis	Alt Ref TC		Alt Ref TT		Alt 3 TC		Alt 3 TT		Alt 4 TC		Alt 4 TT		Alt 5 TT		Alt 6 TT		Hypothesis
	WF	RBT	WF	RBT	WF	RBT	WF	RBT	WF	RBT	WF	RBT	WF	RBT	WF	RBT	Weight
1 - Flows for egg survival (by species)			-1	0	0	0	-1	0	-1	0	1	0	-1	-1	-1	-1	
1- Flows for egg survival (sum across species)			-1		0		-1		-1		1		-2		-2		13%
2 - Stable near-shore early rearing			1		0		-1		0		1		0		-2		30%
3 - High flow events			1		0		1		0		1		2		2		15%
4 - Habitat availability																	12%
5 - Food supply from Arrow			1		0		0		0		1		1		1		21%
6 - High flow energetic cost			1		0		1		0		2		1		2		9%
Wgt'd Average	0		0.63		0.00		-0.18		-0.13		0.97		0.36		-0.15		
Rank	4		2		4		8		6		1		3		7		

5.0 Development of Sturgeon Alternative (Alt 6TT)

Alternative TT6 simulates a high flow during the spawning and egg and larval incubation period for white sturgeon in the lower Columbia River. The efficacy of these high flow events are highly uncertain, because the cause of recruitment failure is uncertain (McAdam 2013). High flows could potentialy increase interstitial spaces in substrates below spawning areas which would increase egg and larval survival by reducing predation rates. High flows might also reduce predation rates by increasing velocities near the bottom and therefore exclude predators in high velocity spawning areas. Slight increases in turbidity associated with entrainment of fine sediment might also decrease predation rates. Only experimental flow trials or opportunistic assessments of high flow events when they occur naturally (such as in 2011 and 2012) can confirm possible benefits of sturgeons flows. Potential benefits to recruitment from sturgeon flows are not expected to reduce the reliance on the conservation aquaculture program.

As an alternative to high flows, addition of course substrate just downstream of Waneta Dam could be used to test whether increased substrate quality results in survival of egg and larval stages. This approach has a number of advantages because it avoids the high costs and flood risks associated with producing a large flood. Additional work is required before substrate addition is implemented (McAdam 2013).

6.0 At-Risk Species

There are currently four resident fish species in the Lower Columbia basin that are considered at risk: Umatilla Dace, Columbia Sculpin, Shorthead Sculpin, and White Sturgeon. Other species listed by the Conservation Data Center for British Columbia include Longnose Dace, Northern Pikeminnow, Peamouth, and Torrent Sculpin (Table 1). It is not well understood how the flow alternatives might affect these species.

Table 1. Conservation listings of fishes currently recorded in the Lower Columbia basin.

Species	SARA[a]	COSEWIC[b]	CDC[c]
Umatilla Dace, *Rhinichthys umatilla*	Schedule 3, Special concern	Threatened	Red
Columbia Sculpin, *Cottus hubbsi*	Schedule 1, Special concern	Special Concern	Blue
Shorthead Sculpin, *Cottus confusus*	Schedule 1, Threatened	Special Concern	Blue
Longnose Dace, *Rhinichthys cataractae*	N/A	N/A	Yellow
Northern Pikeminnow, *Ptychocheilus oregonensis*	N/A	N/A	Yellow
Peamouth, *Mylocheilus caurinus*	N/A	N/A	Yellow
Torrent Sculpin, *Cottus rhotheus*	N/A	N/A	Yellow

[a]Species at Risk Act; Species designated at risk by COSEWIC (Committee on the Status of Endangered Wildlife in Canada) before the creation of the *Species at Risk Act* must be reassessed according to the new criteria of the Act before they can be added to Schedule 1. Such species are listed on Schedules 2 and 3, and are not yet officially protected under SARA (COSEWIC 2010).

[b]Committee on the Status of Endangered Wildlife in Canada

[c]Conservation Data Centre; Red=ecological communities and indigenous species and subspecies that are extirpated, endangered or threatened in British Columbia; Blue= ecological communities and indigenous species and subspecies of special concern in British Columbia; Yellow= ecological communities and indigenous species and subspecies that are not at risk in British Columbia. B.C. Conservation Data Centre. 2013. BC Species and Ecosystems Explorer. B.C. Minist. of Environ. Victoria, B.C. http://a100.gov.bc.ca/pub/eswp/ (accessed Feb 25, 2013).

Umatilla Dace

(all text in " " taken verbatim from SARA Registry, https://www.registrelep-sararegistry.gc.ca/ ; accessed Feb 25, 2013)

"Populations of the Umatilla Dace in the Similkameen, Kettle, Columbia, Slocan and Kootenay river drainages represent the only known occurrences of the species in Canada…. The species prefers riverine habitat with cobble and stone cover, where the current is fast enough to prevent siltation. The fish are usually found along the river banks, at depths of less than 1 m….Breeding probably occurs in late spring and in summer, if it is similar to closely related species. The young of the year are generally smaller than 40 mm in length. The life span and growth rates of adults have not been determined…The presumed preference of this species for cobble and stone habitat with sufficient current to remove silt, suggests that the fish are vulnerable to habitat changes which increase siltation. Siltation could result from dam construction or run off, changes from riverine to reservoir habitat, and pollution from industrial, agricultural or domestic activities. The impacts of competition from other benthic fish species and predation on the population size of the Umatilla Dace in Canada are not known."

The LCR Umatilla Dace population has been tracked through the WLR monitoring studies (Lower Columbia River Sculpin and Dace Life History Assessment) since 2009. So far the operations of Hugh Keenleyside Dam do not appear to alter natural movements of this species nor to alter its risk of stranding during the Rainbow Trout Protection flow reduction period (late March). There is as yet no specific Umatilla Dace spawning area identified in the study area, and no mature Umatilla Dace has been observed in spawning condition. Juveniles were observed to use seasonally flooded vegetation in the study area.

Columbia Sculpin

(all text in " " taken verbatim from SARA Registry, https://www.registrelep-sararegistry.gc.ca/ ; accessed Feb 25, 2013)

"This species occurs in the Columbia, Flathead, Similkameen and Kettle rivers as well as some of their tributary streams in British Columbia and the adjacent United States…The Columbia Mottled Sculpin is generally known from rocky riffle habitats in rivers and streams…Columbia Mottled Sculpins inhabit river pools in rocky areas below riffles where they disperse to no more than a few hundred metres, only to move back into faster current during the reproductive season. They begin breeding at about two years of age…Sculpin populations have been impacted by unnatural fluctuations in water levels, temperature and flow as a result of release of water from hydroelectric and storage reservoirs. Controlled water flow has created conditions more suitable to other species. Dams have eliminated suitable habitats in some areas. "

The LCR Columbia Sculpin population has been tracked through WLR monitoring studies (Lower Columbia River Sculpin and Dace Life History Assessment) since 2009. So far the operations of Hugh Keenleyside Dam do not appear to alter natural movements (short-term distribution) nor habitat use of this species nor to alter its risk of stranding during the Rainbow Trout Protection flow reduction period (late March). Columbia Sculpin spawning behaviour does not appear to be affected by changes in hydrograph.

Shorthead Sculpin

(all text in " " taken verbatim from SARA Registry, https://www.registrelep-sararegistry.gc.ca/ ; accessed Feb 25, 2013)

"The known Canadian range of this species consists of the Slocan River, the Kettle River, and the mainstem and tributaries of the Columbia River... The Shorthead Sculpin usually inhabits small rivers draining mountainous regions, which have a moderate to swift current and moderately cool water. It occurs in riffle habitats with stones or gravel, used for shelter and breeding…The Shorthead Sculpin may reach sexual maturity at 2 years of age or beyond, and probably lives no more than 5 years…General threats to this species include changes in water quality and quantity…"

The LCR Shorthead Sculpin population has been tracked through WLR monitoring studies (Lower Columbia River Sculpin and Dace Life History Assessment) since 2009. As is the case for other daces and sculpins, the operations of Hugh Keenleyside Dam do not appear to alter natural movements (short-term distribution) nor habitat use of this species nor to alter its risk of stranding during the Rainbow Trout Protection flow reduction period (late March). Shorthead sculpin spawning was observed during the ascending limb of the hydrograph through peak discharge when water temperatures were between 9°C and 15°C (early June to late July).

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