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Pacific Region | Canadian Science Advisory Secretariat
Science Response 2014/011

TECHNICAL REVIEW OF THE EFFECTS OF THE SITE C CLEAN ENERGY PROJECT ON FISH AND FISH HABITAT OF THE PEACE RIVER, BRITISH COLUMBIA

Context

British Columbia Hydro and Power Authority (BC Hydro, hereafter 'the Proponent') is proposing to construct and operate a hydroelectric dam at Site C on the Peace River, near Fort St. John, British Columbia (the Site C Clean Energy Project, hereafter 'the Project'). The proposed Site C Project will be the third in a series of hydroelectric dams constructed on the Peace River, and will be operated as a run-of-river facility downstream of the two existing reservoirs. The construction phase of the Project is expected to last 8 years, with the facility in operation for over 100 years. No decommissioning phase is proposed for the Project. Key project components include an earth fill dam, a generating station, reservoir, access roads, and two new 500 kV AC transmission lines. Construction of the 60 m tall dam would move the current point of flow regulation from the Peace Canyon Dam downstream to Site C and create an 83 km long Reservoir.

The Peace River serves as fish habitat and is an important migration corridor between habitats that fish rely on to complete their life cycle. Potential effects of the Project include changes to fish habitat quantity, quality and availability (e.g., changes to water temperature, flow, sedimentation, aquatic productivity and others); changes to fish abundance, health and survival (e.g., changes to species diversity, distribution, and relative abundance). Mitigation proposed to offset these potential effects includes the construction of additional habitat features, development of 'like for like' fish habitat compensation, riparian planting, provision of upstream fish passage via a trap and haul facility, and the incorporation of project design considerations to minimize fish entrainment, reduce sedimentation, avoid fish stranding and reduce total dissolved gas. The Proponent has proposed monitoring and follow-up programs to evaluate the effectiveness of mitigation measures and to monitor project effects on fish and fish habitat.

The Site C Clean Energy Project is subject to an environmental assessment by a Federal/Provincial Joint Review Panel. Fisheries and Oceans Canada (DFO) will be asked to present evidence at Public Hearings scheduled for January, 2014 in relation to its expertise on the effects of the Project on fish and fish habitat, the efficacy and adequacy of mitigation measures, compensation options, monitoring and follow-up programs proposed by the Proponent, and the conclusions reached in the Environmental Impact Statement (EIS) for the Project.

DFO's Pacific Region Fisheries Protection Program has requested DFO Science to provide a scientific evaluation of the EIS, to assist in the development of DFO's submission to the Site C Clean Energy Project Joint Review Panel.

Specifically, the objective of this Science Response is to address four questions:

1. Does the EIS accurately characterize aquatic productivity and processes affecting aquatic productivity within the proposed reservoir upstream of Site C?
2. Are the conclusions drawn in the EIS, in relation to aquatic productivity post-dam construction, valid?

3. Does the EIS accurately characterize potential effects on fish species and fish habitat upstream and downstream of Site C during the operation phases?
4. Are the conclusions drawn regarding extent, duration and magnitude of residual and cumulative effects on fish species and their habitats reasonably valid?

Note that throughout this review, citation of the August 2013 Environmental Impact Statement (EIS; BC Hydro 2013) will refer to Volumes (Vol), Sections (Sect), Parts and Appendices (App). Pagination in the main EIS volumes will be in form of *xx-nn* referring page *nn* of Section *xx.* The term "baseline" is used in this report to refer to the current (pre-Site C) conditions as referred to in the EIS.

This Science Response Report results from the Science Special Response Process conducted in November 2013.

Background

The Peace River is a large tributary of the Mackenzie River with origins in the northern Rocky Mountains, eventually flowing east to the Peace-Athabasca Delta in northern Alberta. For fish, the Peace River is species-rich relative to other British Columbia rivers as it has been colonized by representatives of Arctic, Pacific and Great Plains fauna during deglaciation (Lindsey and McPhail 1986). Peace Canyon played an important role in limiting the upstream colonization of most Great Plains species; however a number of Pacific species such as the Northern Pikeminnow (*Ptychocheilus oregonensis*) and Mountain Whitefish (*Prosopium williamsoni*) have become established downstream of the canyon.

The construction of two mainstem dams (Bennett [1968] and Peace Canyon [1980]) in the Peace River at Peace Canyon and the creation of two reservoirs (Williston and Dinosaur) have altered fish habitat and fish abundance, diversity and distribution. Of significance for the Site C project is the productivity and fish species composition of the two existing reservoirs, as these will have a strong influence on downstream receiving environments. Conditions within the reservoirs have changed since formation and the fish communities are continuing to evolve (Stockner et al. 2005, Sebastian et al. 2009).

The regulation of flows downstream of the Peace Canyon Dam has had well documented impacts on the stream channel due to the reduction in peak flows (Church 1995). It is also likely that there have been impacts on fish fauna due to changes in temperature, turbidity and seasonal flow patterns, as well as the impacts on fish mortality and habitat disruption due to large daily fluctuations in flows (Cushman 1985).

Thus, the current fish diversity, abundance and productivity are the result of the zoogeographical history of the region, overlain with the effects of the existing hydroelectric development. Extensive studies on the river, reservoirs and their fish populations have been conducted by BC Hydro and others through the Peace-Williston Fish and Wildlife Compensation Program, Peace River Water Use Plan and specifically for the Site C EIS. These form the basis for the evaluation of the effects of the Site C project.

Analysis and Response

The Site C Reservoir

Construction of the Site C dam will create an 83 km long, approximately 1 km wide reservoir that will extend upstream to the tailwater of the Peace Canyon Dam. In addition to inundating the Peace River valley, the reservoir will backwater the lower reaches of tributary streams, particularly those of the Halfway and Moberly Rivers. Maximum reservoir depth will be approximately 55 m at the face of the dam (Sect 4).

Typical operating range of the reservoir is relatively narrow (0.6 m) and generation flows at the dam will be tightly tied to those of the Bennett and Peace Canyon dams. The water turnover time is estimated to be 20-30 days (App Q3, Fig 5.2), with values at the higher end of this range in the spring and summer when generation releases are lower.

Future Site C Reservoir Aquatic Productivity

Primary Productivity Modeling

The Proponent employed the CE-QUAL-W2 model (Cole and Wells 2008) (Vol 2, App P, Part II) to estimate future water quality and primary production biomass within the proposed Site C Reservoir, as inputs to secondary production and fisheries modeling (i.e., species-specific biomass models, ECOPATH model; Christensen and Walters 2004). The goal of this modeling exercise was to assess fish assemblages and production changes associated with transformation from a riverine to a lacustrine system. In the absence of data on the Site C Reservoir, the Proponent used extensive physical data (i.e., bathymetry, hydrodynamics, climate), and more limited water quality (i.e., nutrient chemistry, total suspended solids (TSS) and primary production data (i.e., phytoplankton and periphyton) from Dinosaur Reservoir and the Peace River to calibrate the CE-QUAL-W2 model. Simulations using the CE-QUAL-W2 model were then run on the Site C Reservoir to forecast future conditions at two time periods: 1) early reservoir operation, and 2) late reservoir operation. A sensitivity analysis was also performed to assess the potential range of variability in phytoplankton and periphyton biomasses resulting from variations in flow, TSS, and limiting nutrients.

The CE-QUAL-W2 model (Vol 2, App P, Part I) forecasts seasonal algal biomass peaks (July-Sept) forced almost exclusively by nutrient loadings from the tributaries, with early- and late-operation phases predicted to exhibit similar production levels, due to projections of minimal shoreline erosion (0.42-0.67 M tonnes/yr), and more limited effects on water column turbidity and shading of primary producers. Overall primary production in the Site C Reservoir is projected to be similar or greater to productivity estimated for the existing Peace River downstream of the Peace Canyon Dam. A sensitivity analysis indicated that the majority of variation in primary production and biomass was noted in the periphyton (600-900%), as opposed to phytoplankton (~5% change), which is commensurate with the purported importance of periphyton to Site C Reservoir primary production, the uncertainty in future euphotic zone/littoral zone depths, and the rapid flushing rate of the reservoir causing removal of plankton.

As the principal “bottom-up” forcing used in the ecosystem modeling, the primary production outputs of the CE-QUAL-W2 model are crucial to accurately describing future reservoir production, and fish and fisheries productivity. The Proponent acknowledges a moderate level of confidence in the model predictions, citing the predicted algal production values are within the same order of magnitude as observations for nutrients, phytoplankton and periphyton (Vol 2, App. P, Part I). It is worth noting, however, that subtle (certainly sub-order-of-magnitude) changes in nutrients, particularly phosphorus, can have large influences on algal productivity and higher trophic levels (Wetzel 2001), and this level of model accuracy may not be sufficient to fully characterize future reservoir production.

Reconstruction of Nutrient Time Series for CE-QUAL-W2 Model Calibration

The Proponent highlights that nutrient loading to the reservoir drive the principal changes in algal biomass. Provided other factors don’t seasonally or ultimately limit autotrophic production (i.e., light transmittance or mixing regimes), this assertion may be reasonable given the rapid flushing of the reservoir, and the ultra-oligotrophic nature of source waters from the Dinosaur Reservoir. The Proponent indicates that nutrient loadings from the tributaries to the Site C Reservoir "originate primarily from TSS releases", and they use TSS as a surrogate variable to develop time series of limiting nutrients (orthophosphate, PO_4^{-3}; ammonia, NH_3; and nitrate, NO_3^-), during the CE-QUAL-W2 calibration (Vol 2, App P, Part II). This time series development is based upon limited field data, and weak predictive relationships (TSS-PO_4^{-3}, $r^2 = 0.67$; TSS-NH_3, $r^2 = 0.42$; TSS-NO_3^-, $r^2 = 0.14$; Vol 2, App P, p 20), some of which may not even be statistically significant. While the Proponent suggests the predictive relationships are adequate as there are no systematic biases in the predictive models, there is only moderate visual correspondence between observed and modeled data for nutrients (*see* Vol 2, App P, Fig 4.60). Such questionable model inputs, which are deemed of moderate certainty by the Proponent, likely result in uncertainty in the future algal biomass predictions for the Site C Reservoir, and uncertainty in secondary and fish production estimates that modeled upon them.

As noted by the Proponent, temporal limitations exist in the phytoplankton and periphyton sampling, which in turn limit assessment of the representativeness of the data, and the validity of relationships between periphyton and phytoplankton predictions and observations for both the Dinosaur Reservoir and Peace River (Vol 2, App P, Part II, p 39). Indeed, minimal correspondence is evident between observed and modeled values for phytoplankton production at both early- and late-stages of reservoir development, and no observational data are plotted for periphyton (*see* Vol 2, App P, Fig 4.58-4.59). These observations demonstrate uncertainty in the accuracy of the CE-QUAL-W2 model calibration, and subsequent predictions of algal biomass in the Site C Reservoir.

Site C Reservoir Total Suspended Solids (TSS) and Light Limitation of Autotrophic Production

Given the importance of light limitation on primary productivity in nearby Williston Reservoir (Stockner et al. 2005), which is ultimately the primary source water to the proposed Site C Reservoir, it is unclear why several parameters governing the influence of light on autotrophic production (both phytoplankton and periphyton) were altered during CE-QUAL-W2 model calibration (Vol 2, App P Part II, p 35). These include: 1) suspended solids settling rates, 2) light extinction resulting from suspended solids (lowered to "promote phytoplankton and periphyton growth when high concentrations of TSS are present in the body of water"; Vol 2, App P Part II, p 35), 3) maximum periphyton growth rates (increased "to promote growth of periphyton biomass"; Vol 2, App P Part II, p 35), and 4) the ratio between periphyton biomass and chlorophyll *a* (lowered "to control peripyton growth as a result of light limitation"; Vol 2, App P Part II, p 35).

These changes effectively reduce the inhibitory influence of TSS (light limitation via shading) on modeled algal production in the Site C Reservoir. Light and nutrients can have antagonistic effects on both phytoplankton and periphyton production (Wetzel 2001). Accurate characterization of the light limitation and nutrient stimulation effects must be established to have confidence in predictions of future primary production in the Site C Reservoir. The increasing gradient of algal production eastward along the reservoir predicted by the model, thus may be positively related to nutrient inputs from inflowing tributaries and shoreline erosion as purported by the Proponent (Vol 2, App P, Part II, p 48), but should also be negatively influenced by the higher suspended sediment loads (TSS), which follow a similar gradient. The magnitude of influence of these "light adjustments" on modeled phytoplankton and periphyton biomass is unclear, but may present substantial uncertainty in the modeled primary production in the Site C Reservoir.

The Proponent's sensitivity analysis yields counterintuitive results on the effects of TSS on periphyton production that contrast with known inhibitory effects of TSS on autotrophic production (i.e., shading, siltation; Wetzel 2001). For instance, for contrasting high and low TSS concentrations during the early phase of reservoir development, with nutrients and flows held constant at average values, TSS appears to exert a stimulatory effect on periphyton biomass in both clearwater (Peace 1: High TSS, 0.21 g/m^2; low TSS, 0.089 g/m^2; Vol2, App. P, Part II, Table E.9) and turbid sites (Mouth of Halfway River: High TSS, 0.65 g/m^2; low TSS, 0.305 g/m^2; Vol2, App. P, Part II, Table E.9). If nutrient and flow parameters are truly held constant in the sensitivity analysis, there is no known physical basis for such a relationship, raising concerns about the accuracy of the modeling if the aforementioned “light adjustments” made during the model calibration lead to an overestimation of future primary production.

Site C Reservoir Secondary Production & Fish Forage Predictions

Secondary production (e.g., invertebrates) in the Site C Reservoir, important forage for the future fish guild, is predicted to be 89-121% of the current levels in the Peace River, and exhibit a structural shift from nearly 100% benthic invertebrate production (current state) to a mix of benthos (74 - 81%) and zooplankton (19 - 26%) in the Site C Reservoir (Vol 2, App P, Part III). The shift from benthos to plankton would be reasonably expected given the transformation from a riverine to lacustrine aquatic environment. The prediction, however, that limited overall changes in secondary production will occur relative to current conditions in the Peace River, generalizes invertebrate biomass availability to the future fish guild, as the utility of prey items to fish species varies both within and across diverse invertebrate groups (i.e., zooplankton vs. benthos).

In lakes with moderate planktivore densities, herbivorous zooplankton biomass typically builds throughout the growing season, tracking environmental influences such as temperature and grazable phytoplankton availability (Wetzel 2001). In the Site C Reservoir, however, zooplankton entrainment losses are expected to be significant, due to the short water residence time. As noted by the Proponent, the difference between zooplankton generation times and reservoir water residence times will be important to the development of prey items for planktivorous fish such as Kokanee (*Oncohrynchus nerka*) and Lake Whitefish (*Coregonus clupeaformis*) residing in the reservoir (Vol 2, App P, Part III, p 32). Generation times vary considerably amongst zooplankton taxa. The Proponent notes that certain *Daphnia* species have generation times of ~28 days, which is greater than the average residence time of the Site C Reservoir (~22 days), but potentially less than the hydraulic residence time during much of the growing season (except during the July freshet), which would enable completion of at least one generation. Other smaller cladoceran taxa such as *Bosmina (*generation time ~18 days), and smaller-bodied copepods have generation times less than predicted reservoir water retention, and thus would likely complete one or more life cycles during their residence in the Site C Reservoir (Vol 2, App P, Part III, p 31-32).

Given such disparities in life history, the effect of entrainment on zooplankton assemblages is likely to be large, selecting for species that have smaller body size and more rapid regeneration rates. While the Proponent indicates zooplankton biomass will be higher than in Dinosaur Reservoir (5 day water residence time), the relatively short residence time for the Site C Reservoir is likely to suppress overall zooplankton production. Reductions in available zooplankton biomass and selection for smaller body sizes in a turbid-water environment are not commensurate with productive planktonic food webs for visually-feeding planktivores such as Kokanee and Lake Whitefish. For instance, larger cladoceran zooplankton, such as *Daphnia* spp., which promote efficient trophic energy transfers (Mazumder and Edmundson 2002), and are the preferred food source for planktivores (i.e., *O. nerka*, juvenile trout; Lazarro 1987; Luecke and Brandt 1993) may be strongly selected against, reducing overall energy flows to pelagic planktivores and pisciovores targeted in fisheries in the Site C Reservoir.

The balance between zooplankton entrainment losses to the lower Peace River and species-specific generation rates will dictate the zooplankton assemblage and biomass in the Site C Reservoir available to planktivorous fish. The related impacts on survival of planktivorous fish , such as Kokanee and Lake Whitefish, are largely unknown, as body mass accrual in the growing season may influence overwinter survival. In the Proponent's ECOPATH models, zooplankton densities were held constant. The Proponent indicates that zooplankton biomass was not limiting to fish production in any ECOPATH scenario (Vol 2, App P, Part III, p 61). If this assertion is accurate, it suggests that species such as Kokanee and Lake Whitefish will not become sufficiently productive components of the ecosystem to be limited by ultra-oligiotrophic conditions and an almost-certainly depauperate food web (in contrast to what has been observed in Williston Reservoir, Sebastian et al. 2009) through some other population-regulating mechanism(s) (e.g., top-down predation). If bottom-up forcing of fish biomass by zooplankton is indeed important, as is broadly true for *O. nerka* in lakes (Shortreed et al. 2001; Hyatt et al. 2004), and if the Proponent's models do not explicitly incorporate algal and zooplankton species assemblage information, the magnitude and nature of trophic energy flows presented in the ECOPATH modeling may not be accurate. Moreover, since modeled secondary production in the Site C Reservoir is directly dependent upon the primary production inputs from the CE-QUAL-W2 model, uncertainty in the predictions of primary production will be translated to uncertainty in predictions of secondary production. Ultimately, the possibility for reduced trophic efficiencies may result in less numerous and/or smaller sized pelagic fish populations than those predicted, reducing for fish biomass production and fishery opportunities.

Generalities Regarding the Future State of Site C Reservoir Productivity

The aforementioned uncertainties identified in the aquatic productivity modeling (CE-QUAL-W2, ECOPATH) make it difficult to evaluate the absolute future primary and secondary production in the Site C Reservoir. Using the Proponent's literature review from other Canadian reservoirs, and the existing ecosystem data on Dinosaur Reservoir (Vol 2, App P, Part I) and Williston Reservoir (Stockner et al. 2005), some general conclusions can be drawn regarding future ecosystem state. A commonality in reservoir formation is an initial trophic upsurge, followed by reductions in reservoir nutrients and productivity (Vol 2, App P, Part III). The Site C Reservoir may experience this initial productivity increase in response to leachate from inundated soils, but the rapid flushing rate is likely to dampen this response within the Reservoir. As the vast majority of source water would arrive at the Site C Reservoir from the oligotrophic to ultra-oligotrophic Williston and Dinosaur systems, which are amongst the lowest productivity reservoirs in British Columbia (Vol 2, App P, Part I; Stockner et al. 2005), it is highly likely that the Site C Reservoir will generally exhibit similar limnological characteristics. These source waters, coupled with a relatively short hydraulic residence time, turbidity, entrainment and loss of plankton and nekton communities will most likely result in an oligotrophic reservoir with a low productivity food web for resident fish species.

Reservoir Fish and Fisheries

The Proponent predicts there will be a substantial increase in the biomass of harvestable fish in the reservoir over the baseline (riverine) conditions (Vol 2, p 12-39). They note the species composition will change as some riverine species will decline in abundance, while others, particularly those that are entrained from upstream reservoirs, may increase. As a consequence, the Proponent suggests the project will have a positive impact on fishing opportunities (Vol 3, Table 24-21).

Most of the predicted increase in fish abundance is due to the expansion of pelagic (lake) species (Lake Whitefish and Kokanee). The Proponent conducted detailed modelling of Kokanee population projections based on extensive experience with Columbia River reservoirs, augmented with sampling data from the Williston and Dinosaur Reservoirs (Vol 2, App Q3). The

Kokanee population in these reservoirs appears to be growing (Diversified Environmental and Mainstream Aquatics 2011) and large numbers of Kokanee are entrained through Bennett and Peace Canyon dams as is evidenced by the catches of age-1 and 2 Kokanee in the Peace River (Mainstream Aquatics 2010). It is predicted that Kokanee population in the Site C Reservoir will be supported by entrainment from Williston via the Dinosaur Reservoir. Population growth in the Site C Reservoir will be limited by slow fish growth and high rates of entrainment through the Site C dam because of the short residence time of water in the reservoir. Most fish are predicted to spend less than a year in the reservoir before being swept downstream. Some natural reproduction may occur, but the contribution to the adult population will also be limited by entrainment. The predicted density of Kokanee in the reservoir was 0.18 kg/ha, which corresponds to a total biomass for the reservoir of 17 t. The average size of Kokanee is predicted to be 25 cm and 0.22 kg (Vol 2, App Q3).

The Proponent’s modelling of the Peace River Bull Trout (*Salvelinus confluentus*) population suggests the population can be sustained after the construction of the dam and reservoir, and that persistence will likely be enhanced to some degree if upstream passage at the dam can be successfully implemented. The results of the population model are contingent on a series of assumptions that are required in the absence of data or a reliable means to predict the response of the population to future conditions. Key assumptions about the productivity and behaviour of the population should be treated as hypotheses to be tested as part of the adaptive management plan for the fish passage system. Some of the more critical assumptions are that the population is highly productive in the juvenile phase so that a loss of some spawning adults will not result in a reduction in juvenile production from the Halfway River, and the assumption that the different life history types are <u>not</u> the result of subtle genetic subdivisions within the population. If these assumptions are falsified, then mortality or losses through the Site C dam may have more significant implications for population abundance and diversity. It seems likely that other sources of mortality (harvest or habitat related) will have to be carefully managed during the adaptive management phase as the current population is relatively small and could become critically so if mortality from all sources is excessive.

As noted by the Proponent, the Arctic Grayling (*Thymallus arcticus*) population found in the Peace River may be at significant risk as a result of the proposed inundation of the Peace and lower portion of the Moberly River, and the presence of the dam just downstream of the Moberly River. The Moberly River is the largest source of recruitment for Arctic Grayling in the Peace River mainstem (Earthtone and Mainstream 2013; Taylor and Yau 2013). In Williston Reservoir, Arctic Grayling have declined as a result of the inundation of riverine habitats and isolation of natal streams (Northcote 1995). Under certain circumstances, transport of fish between the Moberly and Peace River tailwater may contribute to population persistence, but only if the collection efficiency of fish migrating down the Moberly River is very high. Many of the Arctic Grayling migrations occur in the early spring months when capture of fish from the Moberly River will be difficult. On the balance of evidence it appears there is high likelihood that only a small fraction of the baseline population may be sustained by trap and haul mitigation methods.

The biology of many of the smaller non-game fish is poorly understood and prediction of the responses of these species to reservoir creation is highly uncertain. Although the Proponent predicts the abundance of the aggregate called “small fish, suckers and Northern Pikeminnow” will increase in biomass in the reservoir, it seems likely that some species will not persist and there is a risk of a loss of species diversity in the reservoir relative to the baseline condition.

In summary, although the Site C Reservoir will be larger than the existing river in terms of wetted area and volume, it will likely be unproductive due to the nature of the inputs from the upstream reservoirs, the high flushing rate, shoreline instability and the potential for turbidity in the eastern half. The evidence supports the Proponent’s view that the fish community will change, as it has in other reservoirs, and there is potential for loss of biodiversity as some species will be negatively impacted by the dam and the reservoir environment.

Implications for harvest

The Proponent notes a "residual positive effect on fishing activities is expected" (Vol 3, Table 24.21). This conclusion appears to result from the use of the ECOPATH modelling that predicted increases to future fish biomass and potential harvest.

The approach for estimating harvest in the ECOPATH model is very simplistic as it assumes that current harvest rates for the river can be applied to the reservoir. It is noted that the harvest rate for Kokanee (5%) is "assumed" (Vol 2, App P, Pt 3, p 47) and is considered "conservative" (*Ibid*, p 61) although the recent creel survey indicates no harvest of Kokanee in the Peace River below the Peace Canyon Dam (Robichaud et al. 2010) and little in Dinosaur Reservoir (Stiemer 2006). Much of the predicted increase in harvest by the ECOPATH model for the proposed reservoir is due to the contribution of Kokanee.

In a separate analysis of Kokanee population and harvest dynamics the Proponent notes the predicted abundance and size of Kokanee in the Site C Reservoir are unlikely to attract angler effort (Vol 2, App 2, p 64) and will result in a low quality fishery. This is consistent with the findings of creel surveys for Dinosaur Reservoir, which indicated that Kokanee are not a target species and few are caught (Stiemer 2006).

Rainbow Trout (*Oncorhynchus mykiss*) are the most abundant species in creel surveys for the Peace River above Site C (Robichaud et al. 2010) and are also a targeted species in Dinosaur Reservoir (Stiemer 2006). The Proponent does not provide an explicit analysis of the expected trend in Rainbow Trout abundance other than the suggestion that the population will remain similar to baseline levels (Vol 2, App P, Part 3, App 6D Table 6D.1). It is possible that the Rainbow Trout population in the upper reaches of the Reservoir will be maintained through a combination of entrainment and natural recruitment from streams draining into the upper section of the reservoir. Modelling suggests the first 10 km of the reservoir will have clear water and relatively strong currents (Vol 2, App I, Fig 4.2) that might provide a suitable environment for salmonids to take advantage of benthic drift and food sources entrained through the Peace Canyon Dam.

No species-specific analysis is provided for Lake Trout (*Salvelinus namaycush*) but this is an important and targeted species in the current Dinosaur reservoir fishery (Stiemer 2006). If a significant population becomes established in the Site C Reservoir this species could be a contributor to the fishery.

In summary, the prediction of a large increase in the harvest of pelagic fish in the proposed reservoir is not supported by the Proponent's species-specific population modelling, or by existing angler patterns. Forecasts of potential angler effort are highly uncertain, not only because the fate of the key fish populations is difficult to predict, but other factors such as ease of access or non-harvest values can influence effort patterns. It seems likely that the tailwater of the Peace Canyon Dam will continue to provide fishing opportunities for salmonids, however, the low overall productivity of the reservoir may limit its attractiveness to anglers relative to other opportunities in the region.

Peace River downstream of Site C

The Peace River immediately downstream of Site C to the Alberta border has a diverse fish community reflecting the mixing of Pacific and Arctic biota with Great Plains species. A total of 25 species have been captured in recent surveys (Vol 2, App O, Table 5.2.4). The relative abundance of fish is also greatest in this region, likely due to the distance from the Peace Canyon dam (distance and tributary inflows attenuate the effects of flow regulation), and the presence of key tributary streams that are the spawning and juvenile nursery areas for many species.

For this region, the Proponent's productivity analyses suggest a 20-40% increase in fish biomass will occur after completion of Site C, however, significant changes in fish species composition is predicted to occur. It is noted (Vol 3, p. 24-32) that the increase in biomass is largely due to a predicted "doubling of mountain whitefish which are assumed to benefit from increased water clarity downstream of the dam".

In considering the effects of the dam, and the changes in flow, sediment transport and water temperature, the Proponent predicts that the fish community downstream of Site C will be similar to that below the Peace Canyon Dam (Vol 2, p 12-48). It is predicted that Arctic Grayling, Bull Trout, Mountain Whitefish and Rainbow Trout populations will persist and may extend their distribution downstream to the Alberta border (Vol 2, p 12-48). The Proponent suggests that "most of these populations would be maintained by recruitment from the Site C Reservoir" (Page 24-28) augmented by an unknown and uncertain recruitment from the Pine River.

To mitigate some of the changes caused by the Site C dam, the Proponent proposes to alter the side-channel complexes in the reach below the dam to increase wetted area, and reduce the risk of fish stranding during flow decreases. It is suggested that these measures will reduce impacts to fish habitat (Vol 2, Table 12.19) and will fully mitigate effects of stranding (Vol 2, Table 12.19).

In reviewing the Proponent's approach to predicting changes in fish populations downstream of the dam, some key shortcomings were identified that generate uncertainty in the Proponent's conclusions and are reviewed below.

Using ECOPATH in a regulated river

Predicted changes in fish biomass are derived from ECOPATH, a mass-balanced food web model (Christensen and Walters 2004), augmented with qualitative judgment. This approach is best applied in a fully mixed simple ecosystem such as a large stable waterbody; there are few if any applications of ECOPATH in river systems. ECOPATH models the flow of matter from the lowest trophic levels up through consumers and predators using basic information on trophic efficiencies, life history, and diet information and yields predictions of the biomass of species or groups of species in a steady-state situation.

The ECOPATH application for the Site C project does not explicitly account for many of the complexities of a regulated riverine environment as listed below.

The modelling of invertebrate food sources is unrealistic

The base of the food web is invertebrate production, and food availability was calculated from a predictive model that used the density of invertebrates in colonization baskets placed in continuously wetted depths of the river. This is not a realistic portrayal of the true abundance of food for fish as only a fraction of the stream bed is actually used by most fish (the margins). These are the areas that are most impacted by the daily fluctuations in water levels caused by hydropeaking (Gislason 1985). Further, only a fraction of invertebrates in the stream bed are actually available to fish near the streambed-water interface or as drift. The flux of phytoplankton, invertebrates, organic debris transported through the dam from the reservoir and tributaries is not considered. These factors may explain why the estimated benthic abundance (even when reduced by 70% over the baseline condition as predicted by the empirical modelling) was not considered limiting to fish populations. Empirical studies have demonstrated a link between invertebrate production and fisheries productivity in tailwaters (Pender and Kwak 2002); an observation that is not consistent with modelled results.

Interactions between life history and physical habitat are not specified

In structured environments such as river networks the abundance of fish, particularly adult stages, is partially a function of the food web. However, fish abundance will also be shaped by physical habitat preferences, migration, barriers to migration, the location and nature of spawning and nursery habitats, and those aspects of physical habitats that are altered by development. These considerations are not explicitly modelled in the ECOPATH analysis; nor are ontogenetic shifts in diet and habitat use (i.e., from the larval, juvenile to adult stages). The presence of some of these factors are acknowledged by the Proponent and ad-hoc adjustments are made to the model based on a qualitative assessment of predicted responses of the key species to the development ("dam and habitat consequence factors", Vol 2, App P3, Table 6.3). Although no analysis is provided, it appears that these adjustments or weightings have considerable influence on the ECOPATH model results independent of food web effects. For example, the adjustment factors reduce predator populations, which are assumed to not respond favourably to development, and double the abundance of Mountain Whitefish, which is the dominant fish near Site C. These adjustment factors seem to be the main determinant of the predicted increase in biomass and harvest.

Simplistic perspective on harvest

Harvest rates are assumed to remain constant, and as a result harvest is predicted to increase proportionally as fish biomass increases. This approach ignores the dynamics of angler effort, which will depend on ease of access and boating, catch rates, fish size and the attractiveness of the reservoir relative to the river.

The physical environment below the dam is not characterized correctly

In a number of places in the documentation, reference is made to small "incremental" changes in the flow regime downstream of the Site C dam, as well as an increase in water clarity that will lead to the expansion of the Pacific and Arctic fish fauna downstream towards the Alberta border. Comparisons are also drawn between the environment below the Peace Canyon Dam and that below Site C, both in terms of the physical environment and fish fauna. There are, however, some key differences between these environments as discussed below.

Suspended sediment

Current sediment loads from Peace Canyon Dam are generally very low, and were assumed to be negligible (App I, Fig 3.5a) in the sediment modelling. There are minor inputs of sediment during freshet from the small tributary streams upstream of the Halfway River. Thus the Peace River, for the first 20 km below the Peace Canyon Dam, can be characterized as a clearwater stream. Sediment contributions during freshet from the Halfway and Moberly rivers cause the Peace mainstem to become more turbid during spring and early summer. Sediment increases occur in the fall when storms result in discharge events. Peak suspended sediment levels of 500-1000 mg/L at Site C are typical during freshet under baseline conditions. Sediment levels are <5 mg/L through the winter months (App I, Fig 3.7b).

After reservoir creation, sediment (primarily clay) from major tributaries and shoreline erosion will remain in suspension in the lower half of the reservoir. The reservoir tends to smooth out peaks in sediment inputs. During freshet the expected suspended sediment levels in the Peace River below Site C dam are predicted to be in the range of 50-100 mg/L (App I, Fig 4.9); in simulations using data from 2007 the peak was approximately 125 mg/L, corresponding to a turbidity >200 NTU. Turbidity (measured as NTU) was found to be related to the concentration of clay (mg/L) as Turbidity = 1.64[clay].

For the other seasons the predicted turbidity below the Site C dam is modelled to be greater than baseline level (App I, Fig 5.6b) partly as a result of shoreline erosion and suspension of clay in the reservoir. Peaks of 10-100 NTU do occur, especially in the fall and early winter months (Fig 5.6b), however most of the time turbidity is <10 NTU.

In summary, the Proponent's modelling predicts Peace River from the Site C dam to the confluence of the Pine River will be considerably more turbid than the tailwaters of the Peace Canyon Dam. For most of the year the suspended sediment levels are low, but significant turbidity during the growing season will remain, although at lower levels than currently occur in the Peace River upstream of the Pine River.

The reduction in peak sediment loads caused by the dam and reservoir will have some effect on sediment levels below the Pine River, 16 km downstream of Site C, but those differences will be minor (App I, Fig 5.10) due to the large contributions of the Pine River. For the non-freshet periods there is little difference between baseline and operations sediment levels for any location on the Peace River downstream of the Pine River.

Flow regime

Hydrographs for the Site C facility (Vol 2, App I, Appendix D unlabelled figure at PDF document Page 55) indicate the project will be used for hydropeaking with flow releases from the dam ranging from 1500-2300 m^3/s during the day to 400-1500 m^3/s at night tracking the daily cycle of energy demand. Currently discharges from the Peace Canyon Dam are similar but it takes 10-12 hours for water to reach the Site C area such that high water levels occur at night, rather than during the day. Thus, there will be a phase shift in flows with Site C compared to the baseline period. There will also be an increase in river stage (water level) amplitude below Site C associated with hydropeaking. The predicted daily range in stage is 1.0-1.5 m with Site C, compared to 0.5-0.75 m for baseline period. The difference is due to the attenuating effect of the river channel downstream of the Peace Canyon Dam and the buffering effect of freshet flows from the Halfway and Moberly rivers.

The increase in amplitude of river stage is attenuated slightly downstream of Site C due to inflows from major tributaries and the dissipation of energy in the channel, but the increase in amplitude remains at approximately 1.0 m for much of the year at Alces, near the Alberta border (*Ibid*, PDF page 59).

Biological Implications of Changes to the Downstream Environment

The preceding review suggests that some of the conclusions regarding fish populations and habitat conditions below Site C during the operations phase should be reconsidered.

Invertebrate biomass below the dam may be overestimated

Statistical modelling of invertebrate colonization baskets placed downstream of the Peace Canyon Dam suggests the distance from the dam plays a strong role in determining invertebrate abundance. That model is then used to predict that invertebrate abundance will be reduced by 70% from baseline conditions downstream from Site C due to the construction of the dam. This analysis does not account for the observation that waters released from Site C will be more turbid than water released from Peace Canyon Dam, and significantly so during the growing season. Turbidity will impact primary productivity and may have direct effects on invertebrates. The invertebrate modelling also does not account for the effects of hydropeaking on habitats along the margins of the river as the sampling was done in deep water that was always inundated. The 1-1.5 m daily change in river levels will impact invertebrate production in the shallow habitats that many fish use (Cushman 1985); indeed the analysis of invertebrate baskets that were dewatered in the Peace River (Vol 2, App 3, App 5b) illustrates those effects.

The river below Site C will not be clear and will not be similar to the environment below Peace Canyon Dam contrary to claims made in the EIS (Vol 2, p 12-48)

While Site C will trap some sediment from tributary inputs, sediment modelling suggests the water released from the dam will be more turbid than that released from the Peace Canyon Dam at all times of the year, and will be more turbid than the baseline conditions at Site C during the winter months. Predicted suspended sediment and turbidity levels below Site C will be lower than baseline during freshet, but the magnitudes are biologically significant. Predicted suspended sediment levels of 50-100 mg/L (equivalent to 80-160 NTU) are sufficient to inhibit primary productivity due to light limitation (Lloyd et al. 1987) and can affect visually-based foraging by fish such as Mountain Whitefish and Arctic Grayling. Downstream of the Pine River the changes in sediment regime are unlikely to be meaningful for fish because of the large contribution of sediment from the Pine River. Site C will reduce peak sediment levels downstream of the Pine River, but predicted levels are still high. During winter a small increase in turbidity is predicted to occur below the Pine River, as the sediment levels will be elevated in the reservoir due to the suspension of clay. Thus the assertion that the “coldwater” fish species group will expand in range towards the Alberta border due to increased water clarity is not supported.

The effects of hydropeaking on river productivity are not considered in the modelling

Re-regulation of the Peace River at Site C, and the use of this facility for hydopeaking increases the amplitude of stage changes over the baseline condition downstream of the dam site. Hydropeaking causes stream margins to dewater on a daily basis; depending on the cross-sectional geometry, a daily 1-1.5 m change in stage could expose tens of metres of river shoreline each day. The shallow margins of the stream channel, as well as small side and backchannel areas are areas of high primary and secondary production, and are used as nursery areas for larval and juvenile fish, and for all ages of small bodied species. Hydropeaking may also disrupt spawning and the survival of eggs deposited on the stream bed (Cushman 1985). These effects appear in the monitoring data for the Peace River below the Peace Canyon Dam (Vol 2, Appendix O) that show lower catch rates for small fish in the reaches downstream of the dam relative to sampling conducted further downstream (the exception is for fish directly entrained from the dam).

The increased amplitude of flow changes continues downstream of the Pine River, and can be expected to have negative impacts on fish in that reach, including juveniles that might recruit to the Peace River from spawning grounds in the Pine River or other tributaries.

Uncertainty about the predicted increase in Mountain Whitefish

Mountain Whitefish are predicted to double in abundance below the Site C dam, largely based on the erroneous view that increased water clarity will provide more suitable habitat (Vol. 2, App P, Part 3, Table 6D2), presumably for all life stages. Recent studies using elemental analysis show that recruitment (the production of juvenile fish from spawning and nursery habitats) of Mountain Whitefish is mainly generated from tributaries, rather than the mainstem Peace River (Earthtone and Mainstream 2013). Available data indicates 80% of adults in the Peace River migrate to tributaries to spawn, and return to the Peace River; juveniles produced by this spawning migrate downstream to rearing areas in the mainstem. The construction of the dam and creation of the reservoir may interrupt this pattern for segments of the Mountain Whitefish population that spawn in the Moberly and Halfway rivers and rear near, or below. the dam site. Some juveniles produced by such spawning may be entrained through the dam to the downstream river reach, but adults are unlikely to be able to return to upstream spawning areas. Over time that segment of the population will decline as it cannot replace itself; the provision of upstream passage is unlikely to fully mitigate the disruption to migration. Mountain Whitefish production from tributaries located downstream of Site C is unlikely to be affected significantly by the Project, unless the increase in amplitude of flow reduces the survival of young fish rearing along the margins of the Peace River. Mountain Whitefish spawning may occur in the reach below the dam where water clarity will be good during the fall months, but the productivity of this reach will be impacted by the large daily changes in water levels associated with hydropeaking.

Decline in Arctic Grayling

The elemental analysis (Earthtone and Mainstream 2013) also reveals that most (28/38 fish; 74%) Arctic Grayling caught in the Peace River below Site C were from spawning in the Moberly River. Most of the other fish were from the Beatton River, located downstream from Site C. Only under specific hypotheses and scenarios regarding fish passage can this population be maintained; the most likely scenario in the fish passage alternatives analysis results in the reduction of the population size by 68%. This scenario is based on the assumption that juvenile Artic Grayling migrating into the Moberly River embayment will perish; downstream trapping and transfer of some of these fish to the Site C tailwater, and effective transfer of adults upstream to the Moberly River to spawn is required to maintain a greatly diminished level of abundance. More pessimistic scenarios about the trap and transport program will lead to more diminished populations below Site C.

Thus, the weight of evidence does not support the assertion of large increases in Mountain Whitefish or other salmonid populations below Site C, or the expansion in range to the Alberta border. Other species will be variously impacted by the effects of flow regulation, changes in sediment regime, entrainment from the reservoir and the interruption of migratory behaviours. The tailwater area may support some of the larger bodied species such as Walleye (*Sander vitreous*) and Bull Trout that forage on fish entrained by the dam. The overall impact of these changes on the Peace River fish community is difficult to predict as some species may be impacted while others will benefit.

Conclusions

The Proponent has conducted a detailed set of studies and analyses that provides a considerable knowledge base for the prediction of the likely effects of the Site C project on fish and fish habitat. It has long been recognized that predicting the effects of hydroelectric developments on aquatic biota is very difficult and unexpected outcomes and surprises are common, particularly for higher trophic levels (Hecky et al. 1984). Nonetheless some of the Proponent’s conclusions regarding effects appear at odds with the information base; alternative interpretations are provided in this report. The following are responses to the four objectives outlined for this report:

1. Significant uncertainty likely exists in the CE-QUAL-W2 primary production outputs, which can impact predictions of production at higher trophic levels (i.e., invertebrates, fish). In particular, methods used during model calibration (i.e., nutrient time series reconstruction from TSS, modification of primary producer relationships to TSS) may be inappropriate, as evidenced in the results of the Proponent’s sensitivity analyses. Entrainment effects on zooplankton forage for planktivores in the Site C Reservoir are expected to result in an invertebrate forage with low abundance and poor quality that will impact planktivorous fish productivity.
2. This review of the Proponent’s field studies and analyses supports the conclusion that the Site C Reservoir will be large and relatively unproductive, as is the case with the existing reservoirs located upstream in the Peace system. Low nutrient loads, turbidity and high flushing rates will limit aquatic turbidity.

3. Consistent with the Proponent's conclusions, the evidence suggests that some species will decline and may become extirpated in the area of the reservoir as a result of the change in habitat type and the barrier caused by the dam. Although the biomass of fish present in the reservoir may exceed that of the existing fish populations in the river, the pelagic fish biomass density is likely to be low and there is some uncertainty as to the nature of the fishery that may develop. There is little support for the conclusion that a large increase in the abundance of salmonid species will occur downstream of Site C due to the effects of flow regulation, turbidity, low primary and secondary productivity, and the barrier to migration caused by the dam. For the reach immediately below the dam some species will decline, but others may be favoured by the changes. Further downstream it is unclear whether any significant changes will occur over the baseline condition.

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This Report is Available from the

Center for Science Advice (CSA) Pacific Region
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ISSN 1919-3769

Correct Citation for this Publication:

DFO. 2014. Technical Review of the Effects of the Site C Clean Energy Project on Fish and Fish Habitat of the Peace River, British Columbia. DFO Can. Sci. Advis. Sec. Sci. Resp. 2014/011.

Aussi disponible en français :

MPO. 2014. Examen technique des effets du projet d'énergie propre du site C sur les poissons de la rivière de la Paix (Colombie-Britannique) et leur habitat. Secr. can. de consult. sci. du MPO, Rép. des Sci. 2014/011.