REVIEW OF LONG TERM MONITORING RESULTS FROM SMALL HYDRO PROJECTS TO VERIFY IMPACTS OF INSTREAM FLOW DIVERSION ON FISH AND FISH HABITAT

Context

Innergex Inc. (Proponent) owns a number of small hydro projects in British Columbia that divert water from streams through an intake and penstock to a powerhouse downstream. This subjects the diversion reach between the intake and powerhouse to reduced water flows which may have an impact on fish and fish habitat. Ecofish Research Ltd. has submitted a summary analysis of 5-year Long Term Monitoring results from six small hydro projects in southwestern BC owned by Innergex. The summary report includes results of monitoring salmonid populations, invertebrates, water quality and habitat conditions.

Fisheries and Oceans Canada (DFO) Fisheries Protection Program (FPP) is requesting Science Branch review the Long Term Monitoring Program Summary Report 2010-2014 (Innergex Renewable Energy Inc, 2015), and supporting correspondence. This review will assess the adequacy and evaluate the conclusions of the Long Term Monitoring Program Summary Report with respect to the monitoring of rainbow trout populations and invertebrates. The advice arising from this Canadian Science Advisory Secretariat (CSAS) Science Response will assist in FPP's ongoing responses and guidance provided to the proponent of this and similar small hydro projects in the future.

The Science Response will address these objectives:

1. Assess the adequacy of the data and review methods used to evaluate the effects of flow diversion on rainbow trout populations, and identify gaps.
2. Assess the adequacy of the data and review methods used to evaluate the effects of flow diversion on invertebrates and identify gaps.
3. Evaluate whether the conclusions reached by the Proponent are adequately supported by data and analyses in the Long Term Monitoring report, and amended analyses dated 28 October 2015.
4. Identify key uncertainties, and describe consequences to conclusions of the report and for the monitoring of similar projects.

This Science Response Report results from the Science Response Process of August 2016 on the Review of Long Term Monitoring results from small hydro projects to Verify Impacts of Instream Flow Diversion on Fish and Fish Habitat.

Background

Independent hydro-power projects typically operate as run-of-river facilities which lack live water storage reservoirs for their operation. These projects are often developed with private investment and usually sell their hydro-electric power to utility authorities such as BC Hydro. Their size ranges from a couple megawatts to a couple hundred megawatts, with about 60 plants responsible for ~10% of BC's power production as of April 2016.

While the majority of stream flows are diverted through penstocks from the intake weir to the powerhouse downstream, regulatory agencies require through provincial Water Licences and/or federal Fisheries Act authorizations that minimum flows be released at the intake weir to maintain aquatic resources within the diversion reach between the intake and powerhouse. Regulatory agencies also require long term monitoring (DFO, 2012) to better understand the impact of project construction and operations which effectively substitute naturally fluctuating flows with a stabilized low flow regime in these diversion reaches. Parameters monitored in most cases include water quantity, mitigation, offsetting measures (actions to counter-balance unavoidable impacts to fish and fish habitat), footprint impact verification, water temperature, stream channel morphology, fish community, water quality, invertebrate drift, and species at risk. The Long Term Monitoring Summary Report 2010-2014 (Innergex Renewable Energy Inc, 2015[1]) that is the subject of this Science Response document is the culmination of such a monitoring process conducted on six run-of-river hydro-electric projects in the Upper Harrison/ Stave area of southern British Columbia.

Analysis and Response

The following information sources were reviewed and considered in the development of this Science Response:

- Ecofish Research Ltd. 2015a. Kwalsa and Stave area projects: long term monitoring program executive summary. Memo 1208-4 to Innergex Renewable Energy Inc.
- Ecofish Research Ltd. 2015b. Kwalsa and Stave area projects: long term monitoring program. Fish abundance and biomass: program summary. Contract report for Innergex Renewable Energy Inc.
- EDI. 2015. Innergex Long-term Monitoring Program (LTMP) Kwalsa and Upper Stave Groups: Invertebrate Abundance Effects Analysis. Contract report for for Innergex Renewable Energy Inc.
- Faulkner, S., Yeomans-Routledge, A., Hocking, M., and Lewis, A. 2015. Kwalsa and Stave area hydroelectric plants long term monitoring program. Fish abundance and biomass: program summary. Contract report for Innergex Renewable Energy Inc.

Adequacy of the data and review methods used to evaluate the effects of flow diversion on rainbow trout populations

The fish monitoring program closely follows the sampling design approved by CSAS for the monitoring of small hydroelectric developments (Lewis et al 2011; DFO 2012). A BACI design (Before-After Control-Impact) was implemented that included two years of sampling on the diversion reach and control reach (usually upstream of the dam site) prior to project

[1] Innergex Renewable Energy Inc. 2015. Long Term Monitoring Program Summary Report 2010-2014.

construction, and five years of monitoring afterwards. Standard depletion electrofishing protocols were used that resulted in site-specific estimates of fish density, by age class. Usually five sites were sampled per reach, per year, at the six projects.

The BACI design is effective when there are factors outside of the treatment (which is a change in flow in this case) that affect the response variable at both the treatment and control sites. For example, in the case of age-0 trout in Douglas Creek, there is a correlation between age-0 trout density in the treatment and control reaches across years. This means that factors outside of the diversion reach are having some impact on abundance; some possibilities include annual variation in flood flows, snow pack, temperature, and migration of fish among reaches. The BACI design uses the control data to account for those factors, which should reduce the incidence of spurious results. Sample sizes outlined in the monitoring protocol are designed to have an 80% chance of detecting a 50% reduction in fish abundance, using standard statistical methods with $\alpha = 0.05$.

The study creeks are generally high gradient, have a large water yield, are relatively cold, and have very low levels of dissolved solids and nutrients. Estimated trout densities are low relative to typical trout streams; approximate averages (across all years, sites and streams) by age are Age-0: 0.05 m^{-2}, Age-1: 0.02 m^{-2}, Age-1 0.01 m^{-2}, with a total biomass of 1-2 $g \cdot m^{-2}$. These low densities have at least two important implications: first, it is less likely that suitable physical/hydraulic habitat is limiting populations when the densities are well below those observed in productive streams, meaning that populations may not be sensitive to the effects of flow on physical space. Secondly, population estimates from electrofishing sites that average 100 m^2 in area will be based on only a few captures and will be correspondingly uncertain. This problem is particularly acute for the older age groups, where the average density is roughly equivalent to one fish per site. Imprecise estimates of the abundance of older fish will have very large implications for biomass estimates as these are the largest fish in the population.

Often the Age-0 group is most affected by environmental conditions and can be used as an indicator for change associated with project-related impacts, particularly factors that affect survival in the early life history stages. The Age-0 group will have the most reliable estimates of abundance due to higher catchability and greatest numbers, although interannual variation in abundance is often high due to density independent effects on survival.

The report also includes analysis of results for the older age groups and analyses of combined-age groups. Interpretation of these data is more complex because of the previously mentioned uncertainty about the estimates, and because for the first few years of impact data some of the cohorts were born before flow diversion began so that some of the variation in their abundance may not be due to project effects. However, older age groups may have value for evaluating effects of the project on survival and movement patterns.

The analysis should yield an estimate and standard error for the key BACI interaction term, however, the standard error is not reported in the current presentation. Confidence intervals based on standard errors are often a more intuitive way to assess results and uncertainties compared probability values from frequentist hypothesis tests.

An attempt was made to adjust the density estimates for the reduction in wetted area caused by the diversion. This adjustment is based on the premise that increases in density would be expected if the wetted area decreased and abundance of fish in the reach remained. However, there are a number of complications that may render this simple approach less than adequate. The adjustment is appropriate when sampling is conducted along the margins of the stream, and the habitat conditions in the centre of the channel are similarly suitable for fish as the margins. The adjustment is not likely appropriate for cases such as the larger Upper Stave River where fish densities in the centre of the channel prior to diversion may be low due to high velocities. In this case the loss of high velocity habitat with flow diversion may have only small effects on total abundance. It is also apparent that inflows were on average higher during the operation phase than in baseline period, and this adjustment appears to be incorporating trends in environmental conditions as well as project related effects. The implications of these adjustments are not well documented.

Nonetheless, the change in wetted width for the diversion reach relative to the baseline period most streams is less than 10%, making the adjustments in density relatively minor relative to the estimated increase in abundance observed for many age groups.

In summary, this is a well-structured sampling program that followed protocols approved for sampling small hydroelectric facilities. There are a variety of ways the data can be analyzed and presented, but it seems unlikely the basic findings will be affected by the use of alternative approaches.

Adequacy of the data and review methods used to evaluate the effects of flow diversion on invertebrates

Stream invertebrate monitoring is generally used for two purposes: first, as an indicator of ecosystem stress or change, and second, to monitor food production for fish. The aquatic monitoring protocols list the objective as “To test whether changes occur in the density, biomass or community composition of the invertebrate drift population to the extent that the productive capacity of fish habitat in the diversion and/or downstream sections may be reduced” (Lewis et al. 2011), which puts greater emphasis on fish food (largely based on biomass or abundance) than monitoring of ecosystem stress, which generally relies on changes in community structure and composition.

The protocol for invertebrates of Lewis et al. (2011) is similar to that for fish in that it uses a BACI design with at least two years of pre-project sampling, and five post construction monitoring. It is suggested that five replicate samples of drift be taken at two times during the low flow season.

There were some significant shortcomings in the actual monitoring program for the Innergex sites, and these are well documented by EDI (2015[2]). Perhaps most significant is there was only one year of pre-project sampling, resulting in the assessment of differences between control and impact sites before project being confounded with year effects. In addition, variation in year effects are inflated because there is no temporal (within year) or spatial replication with each year-site combination. The BACI design probably could have been abandoned, and replaced with a simpler control-impact (CI) design that relied on the post-project data only. This design could be justified by the fact that the control and impact sites are quite close together (usually within a few hundred metres upstream and downstream of the diversion weir) such that it may be reasonable to assume longitudinal differences in invertebrate communities that would otherwise confound a CI design can be ignored. This approach would also circumvent data discontinuities that may have occurred as a result of the change in protocols between the baseline and project periods.

While drift density ($\#\cdot m^{-3}$) is often reported (as is the case here), other measures may be more biologically relevant for feeding fish, particularly when comparisons involve changes in flow. Drift

[2] EDI. 2015. Innergex Long-term Monitoring Program (LTMP) Kwalsa and Upper Stave Groups: Invertebrate Abundance Effects Analysis. Contract report for for Innergex Renewable Energy Inc.

load (#·s^{-1}) is the rate of drift production for a river, and drift flux (#·s^{-1}·m^{-2}) is the rate that organisms that pass a single point, scaled by cross sectional area, and is a measure of the availability of food for fish. There may be value in considering these other metrics for evaluating changes in flow since variation in flow will have significant effects on the delivery of drift (e.g., Wooster et al. 2016).

The report also includes a very simple analysis of community structure; more sophisticated methods may yield more insight into changes in the community that may be occurring as a result of the diversion weir, especially since the sampling site in the diversion reach is located a short distance downstream of the weir.

In summary, the conclusion that the invertebrate monitoring program had insufficient precision to identify changes in invertebrate abundance or community due to shortcomings in design and execution coupled with the inherent variability in these types of data is justified.

Evaluation of whether the conclusions reached by the Proponent are adequately supported by data and analyses in the Long Term Monitoring report, and amended analyses

3a Fish

The report concludes there has been an overall increase in fish abundance in the diversion reaches after the projects were completed within the context of the BACI design. These conclusions are reasonably well supported by the evidence presented.

For five of the six creeks there was an increase in Age-0 density at sampling sites in the diversion reach after development (the mean increase based on BACI was 93%, a near doubling in estimated abundance). However, for only one case (Lamont Creek where the increase was 131%) was the difference deemed statistically significant at $p<0.05$. For the one stream that recorded a decrease, that decrease was small (18%) and not significant ($P = 0.87$). Thus there is no evidence to suggest the flow diversion caused a decrease in density of age-0 trout at the sites in the diversion reach, reasonably strong evidence for no change in abundance and some evidence for an increase in abundance.

For the older ages, analysis of the abundance of all ages ≥1 is highlighted here. For this group, an increase in abundance was observed for five of six streams and the average across streams was 72%. Three of five increases were deemed significant, as was the one case where a decrease was observed. The greater proportion of significant results suggests that one or more components of variability may have been lower for the combined-ages group, resulting in more precision in the parameter of interest.

As noted earlier, the interpretation of results for the older age groups is complex as each cohort will have had a different amount of exposure to post-completion flows. It may be worth considering a cohort based analysis to assist in understanding population changes.

3b Invertebrates

The summary report notes that while there is some weak evidence for a decline in the density of drift at the impact sites the results are not significant, due in part to technical challenges with the program and the inherent variability in the data.

The interpretation of drift data can be complex. Drift densities are sometimes related to the density of organisms in the benthos, changes in environmental conditions such as flow or sediment, and life history events for individual species

Differences that may exist in drift between the control (upstream) and impact (downstream) sites also need to be interpreted in the context of localized effects the dam may have on downstream biota. The creation of a headpond may affect the downstream passage of colonizing drift from upstream lotic areas and change the species composition of drift that passes the weir due to production from lentic species in the headpond. The factors can affect the benthos downstream of the weir, and consequently also affect drift. Those effects may attenuate at greater distances from the dam. Because impact sites were all located within a few hundred metres downstream of the weir, effects on drift abundance or composition that are suggested by the data may not be representative of conditions for the whole diversion reach. One or more other sites, further downstream, would be needed to assess this.

Key uncertainties, and consequences to conclusions of the report and for the monitoring of similar projects

4a Fish

The study design, field methods and analysis were consistent with the long-term monitoring protocols (Lewis et al. 2011) and are appropriate for the analysis of the effects of flow diversion on the density of resident trout populations. The current analysis does suggest that there is more variability in the data than was assumed during the power analysis used to support development of the original protocol. In the review of the monitoring protocols (DFO 2012) it was noted that the sampling intensity was the minimum likely to be needed to be sufficient, and that conclusion is supported by the current analysis

Low power can be the result of uncertain estimates at individual sites, high intersite variation within each reach, or large interannual variation. It is not possible with the available information to determine which source of variation is contributing to low power, but such an analysis may be worthwhile to optimize future programs. It may be possible to obtain improvements to the precision of the estimates of change in abundance through alternative designs for the field programs, or changes to the methods used to analyze the data.

While commentary on the utility of standard significant testing for resource management decision making is beyond the scope of this review, it should be noted the data are amenable to a hierarchical form of analysis that will yield direct estimates for the change in abundance (with uncertainty). An increase in precision of the estimates may be possible with these methods, especially in situations where electrofishing captures at individual sites are low.

4b Invertebrates

Invertebrate sampling is challenging as abundance, biomass and diversity will vary substantially among samples, sites, and years and a significant investment in a well-designed program is needed in order to evaluate effects of environmental or habitat change (Miller et al. 2010). As noted by EDI (2015[2]) the scale and scope of the existing monitoring program was insufficient to reliably and usefully detect changes in the invertebrate populations that may have occurred as a result of flow diversion. Further, the full program as outlined in Lewis et al. (2012) may also be insufficient (DFO 2012).

As noted in the summary report, given the inadequacy of the existing protocols, the goal of monitoring the production of food for fish may be more efficiently monitored through observations on the fish themselves by consideration of abundance, growth and production.

A research-level investigation of invertebrate production and drift in relation to flow in small mountain streams may be required to evaluate the need for routine monitoring of drift. Given that changes in water quality, temperature, solar insulation and solar insolation, or organic inputs to diversion reaches that would result in decreases in invertebrate production are unlikely to occur in most small run-of-river facilities, the more subtle effects of flow may only be revealed in very intensive studies that would most likely only be conducted at one or few select streams.

As noted by DFO (2012) an invertebrate monitoring program may best be reserved for situations where large changes in environmental conditions are anticipated that could impact invertebrate drift (e.g., an interbasin transfer or the creation of a large impoundment).

Conclusions

The setting of flows in diversion reaches, and predictions of impacts of flow reductions are often based on heuristic models that assume a monotonic relation exists between flow reductions and impacts to biota, or on habitat models that assume that fish populations are limited by the amount of suitable hydraulic habitat such that habitat can be used as a predictor of fish population response. An increasing number of hydropower projects are being subject to rigorous monitoring programs and the results from those programs are highly variable (Poff and Zimmerman 2010); in some cases pre-project predictions are borne out, but for many others model predictions are not confirmed.

The summary of Innergex monitoring program finds the monitoring framework for fish in streams with small hydropower projects is generally sufficient to detect large changes in abundance, and potentially could be refined to improve power to detect smaller changes. Further analysis and review of invertebrate monitoring programs is needed, as the information generated by Innergex suggests the current programs are too limited in scale to evaluate the effects of flow diversion.

As results from this and other projects become available, it should be possible to generalize about the nature and predictability of the impacts of flow diversions on resident fish populations in the Pacific Region. More detailed analysis in the context of the life history and population biology of each fish species will aid in the interpretation of the monitoring results. This information will be invaluable to proponents and regulators for future projects.

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Sources of information

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