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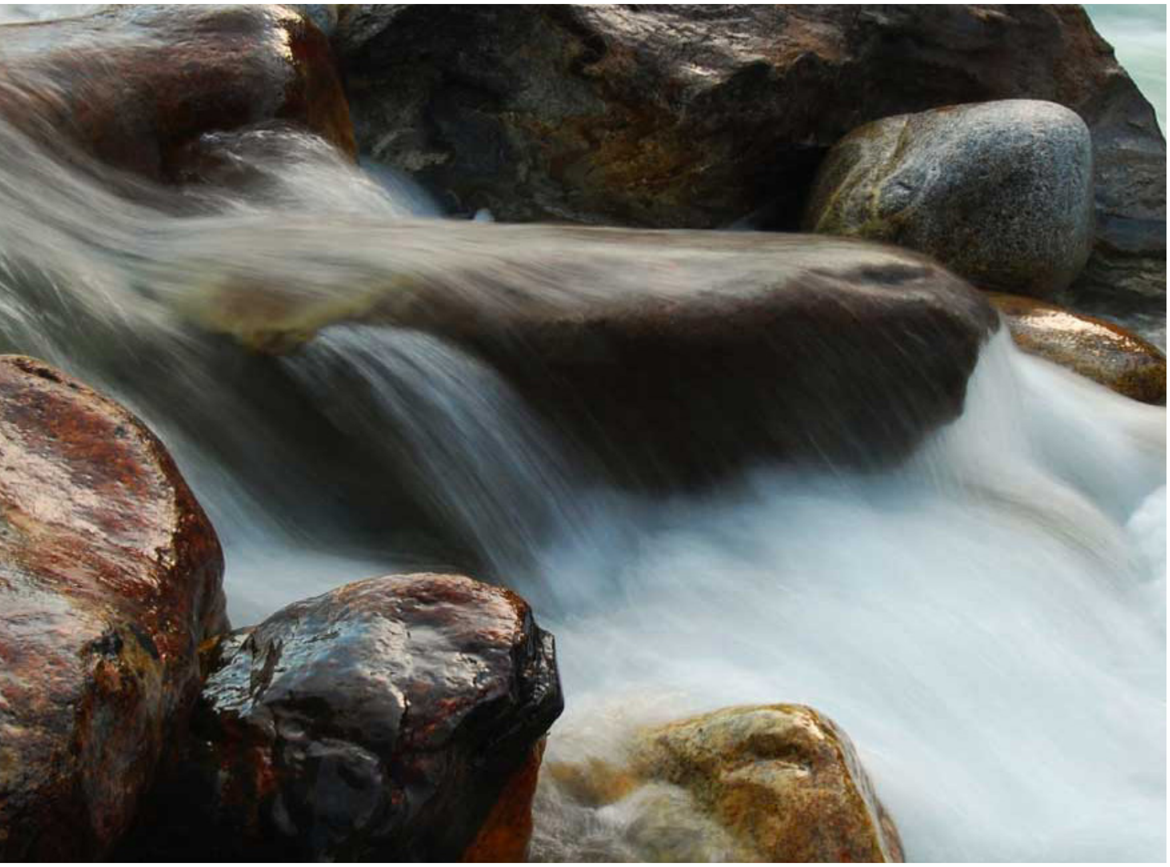

January 30, 2014

INDEPENDENT REVIEW:

Potential Impacts of Run-Of-River Power Hydroprojects on Salmonids

Commissioned by Clean Energy B.C.

Preface … An Overview & Recommendations by Pacific Salmon Foundation

In British Columbia, our electrical power is typically produced, transmitted, and managed by the BC Hydro and Power Authority (BC Hydro). In recent decades, alternative energy sources have become increasingly important as BC Hydro looks to meet increased demands, manage their costs, and minimize environmental impacts (water and wildlife, climate change effects, and air quality). British Columbia's demand for electricity is currently 57,000 GWh/yr and is expected to increase by 40% over 20 years (www.bchydro.com/irp). Presently, our supply of electrical power is provided by 34 BC Hydro facilities and 82 other facilities built and managed by Independent Power Producers (IPPs). In 2013, IPPs provide 27% of the current supply produced from a variety of energy sources including 44 non-storage hydro projects (23% of IPP power, and 6% of BC's current demand)[1]. Non-storage hydro is otherwise referred to as Run-of-River (RoR) Hydro projects. IPPs may also play an important role in meeting the future energy demand. BC Hydro has signed Electricity Purchase Agreements (EPAs) involving 45 new IPP facilities that are at varying degrees of development[2]. Non-storage hydro projects could play a significant role in these future projects accounting for 30 projects and providing half of the total projected supply of 6,892 GWh/yr. For comparison, if constructed, BC Hydro's Site C project on the Peace River is designed to produce 5,100 GWh/yr. If the new IPPs plus Site C were developed, in aggregate these projects would supply only half of the expected increase of 40% over our current usage!

Each hydro-electric project in BC will also be associated with an environmental cost. The scale of impact can vary greatly from large reservoirs flooding timber and agricultural lands to much smaller IPP projects with much more localized effects (except for the Alcan facility at Kemano, built in 1957). IPP facilities, however, involve more numerous sites and evoke concerns about their cumulative effects across BC. And, to get to the focus of this review, projects involving streams and rivers in BC also generate immediate concerns for our newest official symbol of British Columbia, the Pacific salmon[3] (February 2013).

The Pacific Salmon Foundation (PSF) is a charitable foundation dedicated to the conservation and restoration of Pacific salmon in British Columbia and the Yukon. Consequently, when approached by Clean Energy BC (CEBC)[4] to conduct the first independent review of IPP Run-of-River Hydro projects, we accepted the responsibility although with some admitted reluctance. Much of what people know of RoR facilities is likely based on media coverage noting incidences of fish kills, non-compliance events, and destruction of natural habitats. As a science-based organization, we were immediately concerned about the quality and quantity of data available for review, the extent of involvement of the companies within CEBC, and the receptivity of people to an industry solicited review.

In hindsight, recognition of these concerns was important in designing and conducting the study and I am thankful that PSF undertook the work. The study is an objective evaluation of potential impacts

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[1] www.bchydro.com/energy-in-bc/acquiring_power/meeting_energy_needs/how_power_is_acquired.html

[2] On August 30, 2013, Bill Bennett (MLA) announced that BC Hydro would possibly cancel 10 EPAs and defer another nine … but the sites and types of energy plant were not presented.

[3] Pacific salmons include 7 species: sockeye, pink, chum, coho, Chinook, steelhead, and cutthroat trout. Each of these salmon include a freshwater, migratory, and ocean life history phase (i.e., they are Anadromous).

[4] Clean Energy BC (CEBC) is an industry trade association representing and advocating for clean energy projects and developers (www.cleanenergybc.org).

on salmonids[5], provided transparency through a Public Advisory Panel and use of peer review committees, and has collated an information base previously unavailable on salmonids and RoR in BC. The latter is now a valuable resource for future research and evaluations. The Foundation does wish to recognize CEBC and its members for their environmental accountability in soliciting the review, and the significant improvement in environmental monitoring that has evolved during the expansion of the industry. However, as you will read in the report, our ability to evaluate impacts to BC's salmonids at this time is limited by a lack of data in the case of older RoR sites and premature assessment in many of the more recent and monitored sites (incomplete post-development monitoring programs).

The study's process began with a set of questions posed by CEBC, reviewed by PSF, and then formalized in a letter of agreement between PSF and CEBC. The eight questions involved are listed in Section 1.1 of the report and form the basis of the conclusions/discussion in Section 8. PSF subsequently accepted proposals from two respected Vancouver companies involved with environmental consulting, and awarded the work to ESSA Technologies Ltd (Vancouver, BC). The number of companies invited to submit proposals was limited as several companies had involvement with IPP companies and two others declined to submit proposals.

Methodology and Transparency

A reader's confidence in this report will be influenced by the methods applied, the transparency of the process, and the clarity of the outcomes. The Foundation is comfortable with the methods applied and transparency, but we do acknowledge that results are likely less definitive than many people may have expected. However, these outcomes are not a reflection of poor company participation or differences between review teams, but a reflection of (1) highly different levels of monitoring and information between facilities depending on when they were developed and what reporting was required by the Province of BC at that time; (2) the evolution of monitoring guidelines coincident with the development of facilities since 1985; and (3) the timing of this review, which is in the midst of the environmental monitoring programs for the most recently developed facilities. The latter programs have the most comprehensive monitoring programs for assessments but require a few more years to complete observations. There has been a very strong trend from little to no environmental monitoring required for the early projects to thorough monitoring requirements for the most recent projects (especially following the 2006 Open power call).

In examining the scientific method to be applied, PSF considered three primary factors in supporting the proposed methodology developed by ESSA Technology: (i) a *robust* methodology that can be applied to different levels of information quality and quantity; (ii) *repeatability* of the method if others wished to replicate the investigation; and (iii) *accountability* of the results … an information system that enables others to evaluate decisions and track results. The Foundation supports the methodology presented and applied by ESSA Technology Ltd.

Transparency is also an important element of public review and was required by CEBC in their original request to PSF. Transparency was provided by involvement of the Public Advisory Committee (PAC, Table 10 in the report) and the use of scientific peer review (Table 11 in the

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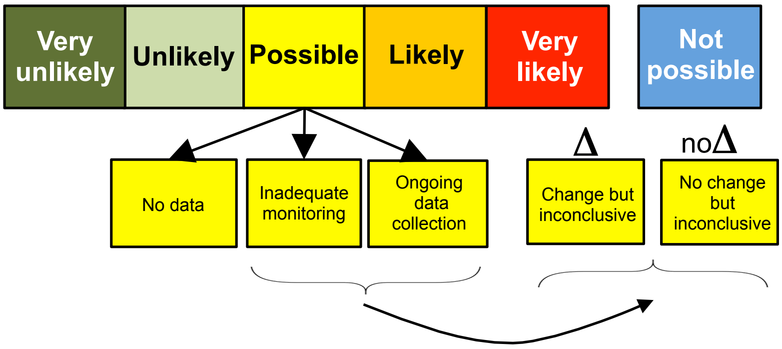
[5] Salmonid is a generic name for a group of fishes that includes Pacific salmon, trouts, grayling and whitefish. Species outside of the Pacific salmon are resident in freshwater (i.e., are non-migratory).

report). A seeming conflict in this study was the objective to be transparent but also a requirement to respect the corporate interests of the CEBC member companies. *The Pacific Salmon Foundation agreed to conduct the study under a Confidentiality Agreement that would protect the company and facility analyses within the public report*; but a second, separate facility-specific report will be prepared that provides direct feedback to CEBC. Peer reviews that required detailed analyses of facility assessments in order to assess the methodology were conducted under confidentiality agreement that restricts the PAC and peer review members from disclosing information specific to any facility. Consequently, the public report speaks to summary results by pathways and stream reaches, but does not provide results by facility. However, PAC members and reviewers are free to discuss process and results; and the reports of both peer reviews are incorporated directly into this public report (Appendix 5 and 8). Comments about any particular facility must be directed to CEBC and the company; all materials collected and project specific analyses will be provided to CEBC as products of this review. As part of PSF's contractual agreement, CEBC has committed to working with its member companies to address specific issues identified in this study.

Readers should also understand the scope of this review (see section 1.4, page 11). **To be clear on the objective of this study; this report evaluates the evidence for and against impacts of RoR Hydro facilities on salmonids in proximity to each facility. It is not a compliance audit that evaluates the extent of operators being compliant with requirements of water licenses or Fisheries Act authorizations.** Two recent reports have commented on these issues (Menzes 2012, Hatfield 2013). Nor does it address broader ecological effects of development, roads and transmission lines, or cumulative effects on salmonids (although ESSA comments on the latter). While these are valid issues, they were beyond the scope of the study requested.

With the above background information, this brings us to the actual conduct of the study by ESSA Technologies and in consultation with the PAC and PSF. The initial steps undertaken included (i) examining the distribution of salmonids (What is their exposure to the sites?); (ii) identification of the pathways that could impact salmonids (What are the physical and environmental factors that potentially impact fish, either directly or indirectly?); and (iii) the collection of the available information. The latter involved the information from each facility (licenses, environmental assessments, and monitoring reports), published technical literature, and information from the regulatory agencies.

As material were received, the ESSA teams reviewed the reports for documented evidence for or against effects by pathway then assessed the likelihood of effects through a 'weight of evidence' approach using all available information (the process is extensively described in Appendix 4). For each facility, stream section, pathway, and linkages or mechanisms within each pathway; evaluators rated the likelihood for or against an effect as (see page 19 for definitions):



An assessment may be ‘Not Possible’ if there is no exposure to a pathway, typically because salmonids were not present in a project area or the potential exposure had been mitigated.

An important interim step in the process was an independent review of the proposed study design and evaluations by PAC and a peer review team (Appendix 7). Before undertaking the full review of the 44 facilities within the study, ESSA applied the proposed method to four sites (only 2 were reviewed due to the time required) and explained their decision process and summary ratings. The review endorsed the proposed methodology and provided constructive criticism and additional considerations to improve the methodology; their report is Appendix 5 of this public report. After incorporating this advice, ESSA undertook the full evaluation and prepared their report. To evaluate the consistency of these assessments between the teams within ESSA, ESSA sub-sampled facility results and conducted cross-team evaluations. The key tables summarizing their assessment are Table 13 (conclusions by stream section and information content) and Table 14 (conclusions by each impact pathway and information content). The draft report was then submitted to PAC for comments, and for an independent scientific peer review (documented in Appendix 8). However, to more fully understand the report, we likely need to clarify the conclusion or rating of “Possible”.

Interpreting “Possible”

While the word ‘possible’ is logically included in a progression from Very Unlikely to Very Likely, it may be more understandable to consider this conclusion as inconclusive. The rating of ‘possible’ may be reached for three reasons: no data was provided for an assessment but salmonids are exposed to a known stressor/effect, monitoring is/was on-going but concerns were identified about the method applied, or monitoring is on-going with acceptable methods but monitoring is incomplete yet (monitoring guidelines frequently recommend two years of information collected before a facility is built followed by five years after completion). As defined in the text, “possible” indicates that salmonids may be exposed to a potential impact pathway but that “the evidence is insufficient to conclude that the pathway is either likely or unlikely at this point in time.” However, if monitoring has been occurring then there is additional information about what has or has not been observed to-date. For example, in Figure 13 and for facilities with monitoring reports (top row), Upsteam reach assessments indicate 6 facilities with on-going monitoring with five suggesting no change in salmonid abundance or composition observed to-date; Diversion reach assessments indicate 15 facilities with on-going monitoring with 13 suggesting no change or impacts observed to-date; and in the Downstream reach, the same comparison indicates 3 of 5 suggesting no change or impacts observed to-date. This obviously emphasizes the differences in monitoring programs between reaches, but also it indicates that to-date 21 of 26 comparisons do not indicate changes or impacts. *But for the same reason that these facility/reach evaluations are in the "possible" category*, the results must be considered tentative because of on-going assessments and results based on a very short time period.

In this review, "possible" should not be confused with non-compliance to regulations as reported by Menzies (2102) and Hatfield (2013) and media articles. The monitoring programs in this review relate to 'response' monitoring; i.e., changes to fish and/or habitats related to a facility; or, effectiveness monitoring (e.g., evaluating fish production from compensation work). Confusion with compliance is certainly understandable though due to reports of fish mortalities associated with ramping rates (changes in water flows and availability of habitat). This is clearly a direct impact on fish, some portion of which may be salmonids. If these mortalities were extensive or occurred frequently, then we would expect to detect effects through the monitoring programs. But if it is infrequent and limited (particularly on small juvenile fish), the effect of these losses may not be detectable by a monitoring program due to the numerous other factors that can effect fish abundance over time. More recently, the identification and recording of any fish mortality has become a component of recommended monitoring protocols (Lewis et al, 2013).

Compensation for Fish Habitat

When the construction and operation of a project is expected to have negative impacts on fish habitat that cannot be avoided or mitigated, compensation is required to offset the effects. The amount and nature of the habitat compensation required varies between projects but typically requires twice as much habitat replaced as is lost. Under the Fisheries Act, habitat is used as a proxy for fish abundance and a standard practice is to conclude that compensation has resulted in no net loss in abundance if there is no net loss in productive fish habitat. However, to really assess the change in salmonid abundance requires evaluation of fish abundance in the habitats before development and then to assess the effectiveness of the compensation in terms of fish production in the post-development period.

In this study, the question posed was whether habitat constructed does replace the lost or affected fish habitat resulting in no net loss in abundance of salmonids and species composition.

For the 44 facilities involved, compensation was not required for 16 sites, 20 sites were assessed to be "possible" for the question posed (above), and for eight sites no consideration was given because we were unable to determine if compensatory was required, and if so, was it completed (no response to inquiries; see Figure 14). For the 20 facilities assessed as "possible", monitoring of salmonids in the compensatory habitat had not occurred or been reported for 13 facilities, and had occurred at seven facilities. At these seven facilities, the evidence suggested that compensation has offset losses in salmonid habitat.

It is important to note that it is standard practice under the Fisheries Act to use habitat as a proxy for fish abundance and conclude that compensation has resulted in no net loss if there is no net loss in habitat. However, without estimates of the reduction in salmonid abundance as a result of the operation of the facility, and net change in salmonid abundance as a result of the compensation habitat, the reviewers could not reach conclusions regarding any actual change in salmonid abundance.

Information Availability by Facility

As the review commenced, it was immediately evident that there were major differences in the quality and quantity of information available depending on the age of the facility. While this likely reflects the information required by the regulatory agencies at various times and the evolution of monitoring protocols over time; the result was a very limited ability to evaluate effects on salmonids for the oldest facilities and greatly increased capacity for newer facilities. The differences were substantial enough that ESSA, PSF, and PAC agreed that results should be presented separately for three periods of facility development: Early phase (1993 Power calls and earlier), Transition phase (2000 through 2003 power calls), and Modern (2006 to 2010 calls). Table 2 of the report (page 15, copied below) identifies the distribution of facilities by Period and information content. Differences in information availability is also dependent on the stream reach (Up-stream, Diversion, and Downstream), see Figure 3 in report.

General categories of information provided by run-of-river hydroelectric project operators (rows) and time periods for Power calls (columns).

Type of information	Early power calls	Transition power calls	Modern power calls	All facilities
Monitoring reports	1	7	15	**23**
Basic facility information [a]	6	5	3	**14**
No information	4	3	0	**7**
All Facilities	**11**	**15**	**18**	**44**

[a] Basic information included such documents as the water license, pre-project fish inventories, development / construction plans, maps and approvals, ramping studies, parameters and procedures reports, environmental impact assessments, DFO letters, and operations fact sheets.

What was the value of this review?

At this time, we cannot report definitively about the impact of RoR Hydro projects on salmonids in BC; and for this reason I previously suggested that some people will be disappointed and/or surprised by the state of our understanding. Of the 44 facilities involved, at 23 facilities information on monitoring programs was acquired, at 14 facilities basic information that could still be informative was acquired and at 7 facilities no information was received at all but information could be inferred from maps, GIS systems, and regulator agencies. But even consideration of just the information-rich monitored facilities (n=23), this review concluded that between 15 and 23 of these projects (range based on stream reach) as being inconclusive regarding impact on salmonids (i.e. Possible rating). There are certainly risks to salmonids through water intakes (entrainment), ramping in the diversion reach, and habitat changes that have killed fish including salmonids, but these losses of individual fish and/or individual events are not evident, at this time, in effects on salmonid populations and monitoring metrics assessed over time.

While more conclusive evaluations will require at least a few more years of monitoring, the foundation believes the study has been worthwhile and important as it:

i) Provides the first comprehensive collation of reports by facilities and opportunity for public review of the state of monitoring. This information was not available from regulatory agencies and is now an important product of this review and will be available for future evaluations.

ii) Presents a robust analytical framework for evaluating impacts and the existing monitoring programs. The analytical method has been reviewed and was supported.

iii) Provides the first accounting of monitoring programs and assessment capabilities across an industry that has expanded in BC since 1985 and could significantly increase again through the existing EPAs signed with BC Hydro. And

iv) conducting the review has improved our overall understanding of the industry and areas that have improved or are in need of attention for assessments and regulatory over-sight.

Possibly as important as any other value is the dialogue opened with an industry that understands that environmental and public accountability is appropriate and expected in BC.

PSF Commentary and Recommendations

As a foundation dedicated to Pacific salmon and BC's salmon communities, this has been an informative study and will likely result in an on-going dialogue. The extent of association of salmonids with RoR Hydro facilities was much greater than expected and indicates a risk to BC salmonids that is not yet fully understood. Risk assessment requires the quantification of two elements: the likelihood of an event (as in this report), and the impact or cost of an event if it occurs, and if there are cumulative effects of multiple events. For salmonids, assessment of impacts should be considered at the population level and requires monitoring of population dynamics beyond the localized effect of a facility (i.e., this introduces an expanded level of evaluation), but also introduces an added uncertainty in attributing cause and effect. Population level effects on fish populations involve many factors (forest impacts on streams, fishing, annual climate variation, etc.) beyond the direct impact of a facility and its operation. If the need is to measure the impact of a facility, then the monitoring programs will need to ensure they are capable of isolating that effect (i.e., simulation modeling is a tool widely used in ecological assessment and design of monitoring programs). Further, the risk that is deemed acceptable will likely differ between salmonid species. For example, Bull trout frequently utilize the headwaters of rivers and exist in small populations; whereas Rainbow trout typically occur widely in BC and have much larger populations. Bull trout may then be sensitive to infrequent and small fish losses that would have little impact on Rainbow trout. And, for all of the salmonids, the location of a facility relative to a core population is likely an important factor in the resilience of a population to facility impacts. If a facility effects habitat used by a small portion of a population then it is likely insensitive to that effect. But if a facility fragments and obstructs migrations for a population, then impacts would be expected to be greater. Monitoring programs can inform these types of assessments but directed research may also be necessary to measure a species'/population's productivity (rate of reproduction and resilience) and its local abundance and seasonal movements.

This review has revealed major differences in information availability over time and between facilities. While the absence of monitoring of the early facilities was unexpected and likely merits a response (see below), the improvements in monitoring programs and the strength of the current protocols are substantial and noteworthy improvements that provide a basis for more informative and quantitative assessments in the near future. However, even with this improvement, we note three issues to be addressed:

1) How to assess potential impacts from the Early period and early Transition facilities?

2) Are the existing monitoring programs adequate to assess the performance measures presented in the most recent monitoring protocols in Lewis et al. (2013)?

3) Given the apparent lack of evaluation of monitoring programs by our regulatory agencies, how can these monitoring programs be more informative to an interested public in BC?

To address issue (1) would require new programs comparing the present state of salmonid populations exposed to facilities to proximal (near-by) populations that are not. These studies are of interest since they represent the longest exposure of a population to the early facilities, but they don't have the pre-facility baseline information for comparisons. Instead, salmonids in streams with facilities would be compared to other, multiple streams within their immediate area. We fully acknowledge that a number of variables could affect these comparisons but if the contrasts were replicated for a few to several RoR Hydro developments, these comparisons could provide useful insights into longer term impacts that the current monitoring projects are unlikely to be able to provide for several years yet.

Table 6 of this report addresses issue (2) and indicates good correspondence between Lewis et al. and the monitoring programs provided for this review. However, see Section 9.1 of the report for a discussion of monitoring.

The third issue is particularly concerning. The companies conducting monitoring have presented some very thorough evaluations of their programs *but the lack of independent review and analysis is a serious deficiency in environmental over-sight.* Monitoring without independent review is uninformative to the regulatory agencies and the public … and is clearly not in the best interests of the companies conducting the monitoring. Collection of data without critical examination leaves uncertainty whether samples sizes are sufficient and whether assumptions required during the design of monitoring programs were appropriate. Independent examination of empirical data as it is being collected is a requirement not an option, and without this step the public can not be assured of responsible development.

With respect to recommendations, the PSF supports the five recommendations presented by ESSA Technologies but wishes to emphasize Section 9.5 (Centralized Monitoring Database and Analyses) and conclude with comments on integrated planning of future facilities and overall cumulative effects.

PSF recommends that the IPP companies and CEBC examine establishing an internal process for information collation (a secure data system across facilities) and build an analytic capacity in order to periodically report on compliance, environmental assessments, and effectiveness of mitigation. If the regulator agencies do not have capacity to maintain a centralized data system and analyses, then industry could lead (as they essentially did in soliciting this review) and more fully utilize their investments in monitoring. Many of the companies continually evaluate their monitoring efforts. The next step in accountability would be to report publicly and provide access to the information systems for periodic independent assessments. Some people will, of course, object to industry analyzing their own monitoring programs, but a system of random audits and recurring reviews through regulatory agencies, universities, or non-government organizations would likely be sufficient to build public confidence.

While this review did not address cumulative effects of Run-of-River hydro facilities, as the number of hydro projects increase there will be increasing pressure to address their full ecological impact, not just limited to BC's salmonids. The monitoring of present facilities will identify key risk factors to salmonids (e.g., distribution of sensitive populations, fragmentation of migration paths, ensuring ecological flows) and demonstrate if habitat compensation is effective; but these localized concerns may become minor in approvals of projects as BC's power demand continues to increase. We should also be open to acknowledging potential benefits of RoR projects that could provide power and water storage under climate change scenarios and the rapid loss of ice sheets in BC. These types of complex trade-offs and values require a more integrated ecological assessment in planning future RoR facilities and evaluation of cumulative effects. Through the Public Advisory Committee associated with this review, we are aware of the research and landscape planning work though Dr. Wendy J. Palen, SFU, (http://www.sfu.ca/biology/faculty/palen/Wendy_Palen/Research.html).

From her project website, Dr. Palen and her research collaborators will endeavor to develop spatially explicit cumulative impacts models.

> "The primary goal is to identify where there are the best opportunities for developing renewable energy while minimizing cumulative impacts to biodiversity and ecosystem services. This approach integrates the economics of power production (costs, revenue, and power capacity), estimates the physical impacts of small hydropower for species and ecosystems, and articulates the tradeoffs that may exist between biodiversity conservation and renewable energies under different development scenarios."

As BC Hydro's 2013 Integrated Resource Plan reports, BC is likely to need ~40% more power over the next twenty years (www.bchydro.com/irp). Planning to meet this demand, plus account for climate change, pending implementation of BC's Water Sustainability Act, and BC's complex landscapes all argue for a more integrated and comprehensive planning process involving government, academics, industry, and public representation; as exemplified above.

Next Steps

This study has been an important start to understanding and evaluating Run-of-River Hydro in BC. ESSA Technologies' report and PSF have provided recommendations to more fully inform future evaluations of impacts on BC's Pacific salmon. The monitoring basis for evaluation will improve steadily over the next few years and an archive of reports and data has been collated. What happens next could be a critical step in objective evaluation and ensuring environmental accountability for this industry. PSF will present this report to CEBC for their follow through, but equally important is the response of regulatory agencies; particularly to inform the public that expects environmental over-sight and accountability. Doing so is the best way to support BC's newest official symbol, the Pacific salmon.

Acknowledgements

The Pacific Salmon Foundation acknowledges the foresight of Clean Energy BC and their member companies in requesting this review and their assistance to ESSA Technologies Ltd in the conduct of this research. I gratefully recognize ESSA Technologies for their dedication to the task. We entered the research with limited understanding of what data was actually available; the collation of data and reports is now a significant product and provides an important legacy for future evaluations. Their responsiveness to reviews and comments was welcomed. Finally, the involvement of the Public Advisory Committee, the science review team, and a PSF steering committee has provided important guidance and wisdom in the process.

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End

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Independent Review of Run-of-River Hydroelectric Projects and their Impacts on Salmonid Species in British Columbia

ESSA Technologies Ltd., Vancouver, BC

Limnotek Research and Development Ltd., Vancouver, BC

Water Smith Research, Kelowna, BC

Citation: Connors, B.M., D.R. Marmorek, E. Olson, A.W. Hall, P. de la Cueva Bueno, A. Bensen, K. Bryan, C. Perrin, E. Parkinson, D. Abraham, C. Alexander, C. Murray, R. Smith, L. Grieg, and G. Farrell. 2014. Independent Review of Run-of-River Hydroelectric Projects and their Impacts on Salmonid Species in British Columbia. 157 pp + xiv.

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Executive Summary

Background

Salmonids (which include salmon, trout, char, whitefish and grayling) are very important to the people and ecosystems of British Columbia (BC). In recent years, concerns have been raised about the potential for run-of-river hydroelectric projects to adversely affect resident and anadromous salmonids in BC. These concerns led three entities to jointly commission and fund an independent review of run-of-river hydroelectric projects in BC: the Clean Energy Association of British Columbia (CEBC), the Gordon and Betty Moore Foundation, and the Living Rivers Trust Fund (established by the Province of BC). The Pacific Salmon Foundation (PSF) was asked to lead the review.

The PSF conducted a competitive proposal process, and chose ESSA Technologies Ltd. to complete the review. A Public Advisory Committee consisting of academic, First Nations, industry and non-governmental organization (NGO) participants provided feedback during each stage of the review. The focus of the review was the 44 stream-based run-of-river facilities currently operating in BC.

A typical stream-based run-of-river facility consists of a weir or low-head dam that enables the diversion of water through a penstock, tunnel or canal to a lower elevation powerhouse with a turbine where electricity is generated. The diverted water is then discharged back into the stream channel either directly or through a short channel called a tailrace. The structure of a typical run-of-river facility naturally separates a project into three sections or stream reaches: the section immediately upstream of the point of diversion, the diversion section between the point of diversion and the point at which diverted water is returned to the stream, and the section downstream of the tailrace.

Environmental monitoring at run-of-river projects

Monitoring and reporting requirements for run-of-river hydroelectric projects have evolved significantly over time. The oldest facilities were the least likely to have monitored salmonids and the aquatic environment, as their permits often did not require such monitoring. The newest facilities were the most likely to have standardized, well-designed monitoring of salmonids and the aquatic environment, consistent with current regulations. The evolution of monitoring requirements has influenced the availability of data, which in turn affects our ability to evaluate the impact of run-of-river facilities on salmonids at different projects. Monitoring studies have been most commonly conducted in the diversion reach, with less monitoring effort in the reaches upstream and downstream of facilities.

Scope and limitations of review

Our review is limited in scope to the questions presented in Section 1.1 related to impacts on Pacific salmonids. It does not address broader ecological effects of development, roads and transmission lines, or cumulative effects on salmonids (although we do touch on the latter in Section 7) or other terrestrial and aquatic ecosystem components. While these are all valid concerns related to run-of-river hydroelectric projects, and should be considered an important part of any discussion about trade-offs between conservation and development, they were outside the scope of this review.

In addition, our review was not a compliance audit. Two recent reports have evaluated compliance of run-of-river facilities with their water licences and Fisheries Act Authorizations.

Our report relies primarily on monitoring reports and information provided to us by operators of run-of-river hydroelectric facilities. As mentioned, older facilities have little or no monitoring of salmonids. Most projects with monitoring programs did provide us with their monitoring reports, although there were a few exceptions (described below).

Fish populations naturally vary in abundance from year to year, which adds noise to any signal created by run-of-river projects. While monitoring can detect large changes in salmonid abundance (e.g., a 50% increase or decrease), it is difficult or impossible to detect smaller magnitude changes at most facilities.

Approach

We examined the available evidence for and against *hypothesized impact pathways* describing potential ways in which run-of-river hydroelectric projects may affect salmonids in BC. Over the last three decades, the *impact hypothesis* (or *pathways of effect*) approach has been applied to hundreds of problems in impact assessment and resource management.

We developed a set of potential impact pathways based on the experience of experts in salmonid ecology and population dynamics, hydrology, environmental monitoring and aquatic ecology. These pathways included barriers to migration, mortality due to entrainment in the penstock, changes in habitat, alteration of the natural hydrograph, movement of sediment and organic material (primarily wood), changes in food production, stranding due to fluctuation in the wetted width of stream channels, and loss of habitat connectivity. The form and content of these pathways were further refined as additional information became available through our review of the literature, feedback from independent experts on a science panel (described below), and suggestions from the Public Advisory Committee.

We then systematically evaluated the evidence for and against each impact pathway. Our evaluations relied upon the information acquired from facility operators (including baseline and operational monitoring data and reports), supplemented with information provided by regulatory agencies, spatial overlays of facility sites and digital maps of fish habitat and fish presence, peer-reviewed journal articles, and other publications.

Based on all of this evidence, we determined the relative likelihood of each pathway being true, arriving at one of six possible conclusions for both the overall pathway and its component cause-effect links:

- Very unlikely: exposure to a stressor is unlikely. For example there is a screen over the penstock intake that physically prevents the entrainment of fish.
- Unlikely: exposure to a stressor occurs, but there is strong evidence that this exposure has not changed salmonid abundance or habitat.
- Possible: there is exposure to a stressor but it is not possible to conclude that this has caused a change in salmonid abundance or habitat. *Possible* means that the evidence presently available is insufficient to conclude that the pathway is either *unlikely* or *likely*. Evidence is considered insufficient when there is no monitoring data, when monitoring data or monitoring design are inadequate, or when monitoring is ongoing but currently insufficient to evaluate the likelihood of a pathway being true.
- Likely: there is strong evidence that exposure to the stressor has changed salmonid abundance or habitat.
- Very likely: there is very strong evidence that exposure to the stressor has changed salmonid abundance or habitat.
- Not possible: exposure to the stressor is not possible (e.g., there are no salmonids within the run-of-river project area).

We assessed impacts at each run-of-river facility at three different spatial scales: stream sections (four assessments), impact pathways (10 assessments), and cause-effect links within each impact pathway (70 assessments). At the stream section and overall impact pathway scale, the hypotheses evaluated were concerned with changes in salmonid abundance. At the scale of cause-effect links within each impact pathway, the hypotheses evaluated were concerned with changes in the underlying factors that may lead to changes in salmonid abundance (e.g., availability of food, changes in flow, stranding in stream margins). Across all facilities we evaluated the evidence for and against 3,696 hypotheses (i.e., 84 impact hypothesis assessments at each of 44 facilities).

The PSF organized an independent science review workshop to assess whether the proposed methods were rigorous and scientifically defensible. The science panel concluded that our methods were appropriate, had been applied in a scientifically defensible manner and led to justifiable conclusions for the example assessments they reviewed. The science panel made several suggestions to further improve our methods, which were incorporated.

Acquisition of facility information

We were able to acquire detailed monitoring information from 23 facilities, including pre-project and post-operational monitoring reports (in some cases up to 15,000 pages of documents for a single facility). We acquired basic facility information from 14 facilities, including water licences, coordinates and, in some instances, baseline monitoring reports. We were unable to acquire any information from operators at seven facilities. For these facilities, we relied solely on spatial overlays of facility locations and digital maps of fish habitat and fish presence.

Salmonid presence at run-of-river facilities

We found that salmonids were present upstream, in the diversion reach, or downstream at 43 of the 44 operational facilities. Both resident and anadromous salmonids were less likely to be found in the upstream reach than in the diversion or downstream reaches. Resident salmonids such as trout were about 16 times more likely to be present in upstream reaches than were salmon and steelhead, five times more likely to be found in diversion reaches, and twice as likely to be found in downstream reaches.

Conclusions by stream section

The conclusions we reached at the stream section level were based on evaluating the hypothesis that salmonid abundance or species composition has changed within a given stream section as a result of the operation of the facility, regardless of the underlying mechanism. We summarize the conclusions at this scale in Table E1 (below) and in the text following the table. Conclusions regarding the overall pathways of effect and the cause-effect mechanisms within each overall pathway are described in Section 5 and Appendix 6 of this report.

Table E1. Summary of conclusions reached by stream section when considering the hypothesis that salmonid abundance / species composition has changed as a result of the operation of a run-of-river hydroelectric facility.

	Not Possible	**Unlikely**	**Possible**	**Likely**	**Rationale for "Possible" conclusions [a]**		
					% no data	% inadequate monitoring	% ongoing monitoring
Upstream reach	12	1	30	1	80%	17%	3%
Diversion reach	7	0	36	1	58%	17%	25%
Downstream reach	5	0	39	0	87%	5%	8%
Compensation	24 [b]	0	20	0	65%	35%[c]	0%

[a] Rounded to nearest percent.

[b] Includes 8 facilities for which no information on compensation activities were provided and 16 facilities that did not require compensation.

[c] Authorizations under the Fisheries Act have required a certain area of habitat to be created to compensate for lost habitat (usually a multiple of the area of lost habitat), but have generally required neither monitoring of the density of fish within the compensation area, nor comparisons to pre-project densities in the area affected by the facility. Density comparisons have however been conducted for some projects.

UPSTREAM REACH

Hypothesis: *changes in salmonid abundance and species composition in the upstream reach are attributable to the operation of the run-of-river project*.

Changes in salmonid abundance and composition in the upstream reach may occur as a result of entrainment in the penstock, stranding on spillways, changes in upstream habitat or as a result of blocking upstream passage.

We concluded this hypothesis was *unlikely* at one facility, *possible* at 30 facilities, *likely* at one facility and *not possible* at 12 facilities where salmonids were absent from the upstream reach, usually because of steep gradients.

At 24 of the 30 facilities where we concluded the hypothesis was *possible,* monitoring of salmonids in the upstream reach had not occurred or been reported (i.e., the hypothesis cannot be tested), and five facilities had inadequate monitoring. At one facility, monitoring is ongoing and following protocols that may yield more definitive conclusions once the first phase of post-operational monitoring is complete.

DIVERSION REACH

Hypothesis: *changes in salmonid abundance and species composition in the diversion reach are attributable to the operation of the run-of-river project.*

Salmonid abundance and species composition may change in the diversion reach as a result of changes in the movement of sediment and fish food, changes in flow and salmonid habitat availability, and due to changes in temperature and oxygenation.

We concluded this hypothesis was *not possible* at seven facilities because salmonids were not present in the diversion reach. At one facility we concluded this hypothesis was *likely* and at the remaining 36 facilities we concluded this hypothesis was *possible*.

At 21 of the 36 facilities where we concluded the hypothesis was *possible,* monitoring of salmonids in the diversion reach had not occurred or been reported (hypothesis untestable). Six facilities had inadequate monitoring and nine facilities had ongoing monitoring following protocols that may allow for more definitive conclusions once the first phase of post-operational monitoring is complete.

DOWNSTREAM REACH

Hypothesis: *changes in salmonid abundance and species composition in the downstream reach are attributable to the operation of the run-of-river project*.

Changes in salmonid abundance and species composition downstream of a facility may occur as a result of changes in the movement of sediment and fish food, stranding of salmonids following rapid changes in flow or as a result of changes in total dissolved gas pressure.

The downstream reach was the least monitored of the three stream sections. Most permits did not require such monitoring to be implemented due to the fact that downstream salmonid abundance is highly variable and considered to be a weak detector of downstream impacts. Instead of abundance, monitoring at some newer facilities is focused on juvenile mortality following ramping incidents (five facilities had direct evidence of stranding mortality and 11 more had indirect evidence of stranding mortality). However, in regards to changes in salmonid abundance, we concluded this hypothesis was *possible* at all 39 facilities where salmonids occurred in the downstream reach. At the remaining five facilities this hypothesis was *not possible* because salmonids were not present in downstream reaches.

There was no monitoring of salmonids in the downstream reach at 34 of the 39 facilities where we concluded that this hypothesis was *possible*. Two facilities had inadequate monitoring and three facilities had ongoing monitoring following protocols that may allow for more definitive conclusions once the first phase of post-operational monitoring is complete.

COMPENSATION

Hypothesis: *the construction of compensatory habitat has resulted in no net loss of salmonid abundance within the project area.*

We concluded this hypothesis was *possible* at 20 facilities. At 16 facilities, compensation was not required at the time the project began operation. No conclusion was possible at the remaining 8 facilities because we were unable to determine if compensation activities were ever required.

At the facilities where the hypothesis was considered *possible,* there was no monitoring of salmonid abundance in the compensation habitat at 13 facilities. Estimates of gains in salmonid abundance were inconclusive at the remaining seven facilities. It is important to note that it is standard practice under the Fisheries Act to use habitat as a proxy for fish abundance and to conclude that compensation has resulted in no net loss in abundance if there is no net loss in habitat. As explained in footnote c to Table E1, the area of compensation habitat is usually a multiple of the area of lost habitat. However, without estimates of the reduction in salmonid abundance as a result of the operation of the facility, and gains in salmonid abundance as a result of the compensation habitat, we could not reach definitive conclusions regarding no net loss in salmonid abundance.

Overall conclusions

Our review of multiple lines of evidence indicates that run-of-river hydroelectric facilities have the potential to negatively affect salmonids and their habitat. We found that mortality to individual fish (due to entrainment or stranding downstream of a facility) and changes to salmonid habitat (due to changes in flow or movement of sediment and organic matter) were *likely* or *very likely* at a number of facilities. However, at the population level, we only found *evidence* of changes in salmonid abundance attributable to facility operation at one facility (in the diversion reach) and evidence of changes in species composition at one facility (in the upstream reach). For most of the impact pathways we considered, there were data limitations or currently inconclusive monitoring studies preventing us from concluding these overall pathways were either *likely* or *unlikely*; this resulted in a conclusion of *possible.*

We reached more definitive conclusions (i.e., a conclusion other than *possible*) for the following pathways:

- changes in salmonid abundance in the upstream reach due to entrainment in the penstock were *very unlikely* at four facilities and *not possible* at 12 facilities;
- changes in salmonid abundance and species composition in the upstream reach due to alteration of upstream habitat were *likely* at one facility, *unlikely* at one facility and *not possible* at 12 facilities;
- changes in salmonid abundance and species composition in the upstream reach due to the facility blocking upstream migration were *not possible* at 21 facilities;
- changes in salmonid abundance in the diversion reach due to alteration of flow and / or movement of sediment and food were *likely* at one facility and *not possible* at seven facilities;
- changes in salmonid abundance in the diversion reach due to changes in temperature and / or dissolved oxygen were *very unlikely* at three facilities and *not possible* at seven facilities;
- changes in salmonid abundance in the downstream reach due to stranding and / or alteration of movement of sediment and food were *not possible* at five facilities; and
- changes in salmonid abundance in the downstream reach due to changes in total dissolved gas pressure were *very unlikely* at seven facilities and *not possible* at five facilities.

Of the 23 facilities that provided detailed monitoring data, 10 had ongoing monitoring programs that, though primarily focused on the diversion reach, may allow for a more complete evaluation of at least large magnitude changes in resident salmonid abundance (i.e., >50% change) once the first phase (typically five years) of monitoring is complete. Smaller magnitude changes in resident salmonid abundance or changes in anadromous salmon abundance are less likely to be detected at these facilities given current monitoring protocols, except where there is relatively low natural variation in salmonid abundance.

Recommendations

- **Monitoring** – ***Monitoring should be aligned as closely as possible with recently developed long-term monitoring protocols***. Monitoring is a critical part of evaluating impacts of run-of-river hydroelectric facilities on co-occurring salmonids. However, monitoring on its own is not a panacea to resolve all outstanding uncertainties concerning impacts on salmonids. Not all impact pathways we considered could be evaluated with the current monitoring protocols, which are designed to allow for the detection of changes in fish abundance, and where that is not considered feasible (i.e., downstream reaches), detection of proxies of effect such as fish stranding. Gaps in monitoring (relative to the impact hypotheses we evaluated) include: spawning success and egg-to-fry survival in downstream reaches and compensation habitat; upstream and downstream movement of salmonids in the downstream reach; and salmonid rearing success, growth and abundance in the downstream reach. Targeted research and multi-facility comparative analyses (see recommendations below) coupled with implementation of recently developed long-term monitoring protocols at all facilities will be the most effective way to reduce uncertainties related to impacts of run-of-river projects on salmonids. However, the benefits of additional monitoring will vary from one facility to another depending on the specific attributes of each site. For example, high natural variability in downstream salmonid abundance at some sites may preclude the use of this metric as a useful indicator of effects.

- **Targeted research** – ***Not all impact pathways can be evaluated with monitoring; targeted research can fill gaps and develop partnerships.*** Targeted research focused on the information gaps identified above, as well as the effectiveness of particular mitigation approaches (e.g., for avoidance of entrainment or stranding mortality), should be conducted across a subset of facilities, and would benefit from partnerships between the operators, CEBC, academics and regulatory agencies. The results of such targeted research could then be contrasted with, or used to support, long-term monitoring findings. Additionally, targeted research could evaluate the cumulative impacts of multiple pathways at a single facility, or (across multiple facilities) the consequences of site and facility variability on the magnitude and form of impact.

- **Analyses across run-of-river-projects** – ***Analyzing monitoring data across many facilities could increase the ability to detect effects, due to the larger sample size***. A multi-project evaluation using common monitoring metrics and standardized responses would help to elucidate what site characteristics reduce or increase impacts on salmonids. This may be particularly insightful once many of the facilities with ongoing monitoring complete five years of post-operational monitoring in the next two to three years.

- **Simulation modelling – *Simulation modelling can synthesize research, improve understanding, suggest novel mitigation approaches, and increase the cost-effectiveness of monitoring.*** At sites with good data, and those with targeted research, simulation models could be used to integrate information and explore how changes in ramping rates, fish stranding and other factors might influence salmonid population dynamics. Models are not a replacement for continued environmental monitoring. Instead, they can help to increase understanding, identify key site factors, focus monitoring on the most useful information affecting outcomes, and identify key points for mitigation.

- **Centralized compliance and monitoring database – *A centralized database should be developed to house monitoring data, accelerate learning by analyzing these data, and track compliance.*** It was difficult to acquire monitoring documents for many of the run-of-river facilities. We recommend that a single, central database be developed to track water licence requirements and subsequent compliance, and also organize and store monitoring data. This would speed up the rate of learning about impacts on salmonids, facilitate the analyses across facilities and simulation modelling described above, improve the foundation of knowledge for evaluating new permit applications, and provide increased capacity for management evaluations and assessments.

Scientifically defensible evaluations of impacts to salmonids require extensive monitoring data. Monitoring of the aquatic environment at run-of-river hydroelectric projects has changed dramatically over time. At many older facilities where salmonids are present but there is limited or no monitoring, we will never be able to draw defensible conclusions about their impacts on salmonids. However, recently developed long-term monitoring protocols have improved (and should continue to improve) our ability to evaluate impacts. Some of the newer facilities we evaluated are part of the way through long-term environmental monitoring programs that include many of these recently developed monitoring protocols. As a result, though we currently find ourselves with insufficient information to conclude impacts on salmonids are either *likely* or *unlikely* at most facilities, subsequent evaluations of ongoing monitoring efforts, coupled with targeted research, should help to deliver more definitive conclusions in the near future.

Definitions

Anadromous: Fish that are born in freshwater migrate to sea for part of their lives and then return to spawn in freshwater.

Coefficient of variation: The ratio of the standard deviation to the mean, which characterizes the degree of variability in relation to the mean value of the population.

Diversion reach: The section of stream or river between the point of diversion and tailrace.

Downstream reach: The section of stream or river immediately below the tailrace where natural flow in the stream or river is restored following diversion through the penstock and powerhouse.

Entrainment: The unintentional transport of fish via the flow of water into the penstock.

Flow ramping: A gradual or progressive alteration of discharge (flow volume) in a stream channel resulting from the operation of a hydroelectric facility.

Headpond: Natural or artificial pond or lake created to back-flood a point-of-diversion (pipe or penstock) used for storage.

Penstock: Pipe or conduit that carries water from the point of diversion to turbines in a powerhouse.

Ramping rate: The rate of change in flow (measured as flow per unit time (m^3/s) or vertical change in water surface level per unit time (cm/hr)) from the powerhouse back to the river or stream from which it was diverted.

Rearing success: Survival and growth of fish between the time of emergence from the gravel to various life stages such as when they either migrate downstream or spawn as mature fish.

Spillway: The stream section that returns the flow of water over the weir back to the diversion reach.

Tailrace: Channel conveying water away from the turbines and powerhouse (after it has been used) to the downstream section of the stream or river.

Upstream reach: The section of stream or river immediately above the weir and point of flow diversion.

Weir: Low-head dam built across a stream or river to raise the water level in the headpond and back-flood or divert water into the penstock.

Weighted usable area: A measure of the capacity of a stream reach to support the fish species and life stage being considered, expressed as a weighted habitat area for a given flow; incorporating velocity, depth, and substrate preferences.

1 Introduction

1.1 PROJECT BACKGROUND

The term ”salmonids” refers to all fish in the family Salmonidae, including salmon, trout, chars, freshwater whitefishes and graylings. Salmonids, and in particular anadromous salmon, are iconic in British Columbia (BC). While salmonid populations in some areas of BC are healthy, others have declined in productivity or abundance or are of conservation concern (e.g., Ward 2000; Marmorek et al. 2011; Peterman and Dorner 2012; Riddell et al. 2013). There is keen interest in understanding the relative importance of different factors causing recent changes in the productivity and abundance of salmonids, including freshwater and marine habitat conditions, harvest rates, hatcheries, hydroelectric facilities and climate change. Conclusively determining the relative importance of such factors is very challenging, due to gaps in both information and understanding, and the multiple habitats utilized by salmonids throughout their life cycle.

Hydroelectric power generation is the most important source of electricity in BC. Large dams account for ~80% of the power produced within the Province in a given year. The impoundment of rivers and streams to generate electricity is known to have adverse impacts on salmonids, particularly through studies at large hydroelectric dams. Large hydroelectric dams can: impair juvenile and adult migrations; change the supply and movement of water, sediment and wood, causing changes in rearing and spawning habitats; strand fish due to fluctuating water levels; cause smolt and fry mortality from entrainment in penstocks and passage through powerhouse turbines; mobilize contaminants in newly constructed reservoirs; and change the food sources on which fish depend (Baxter 1977; Ligon et al. 1995; Poff et al. 1997; Rosenberg et al. 1997; Independent Scientific Group 1999; Schaller et al. 1999; Budy et al. 2002; Irvine et al. 2009; Barnthouse 2013). Many of the potential impacts at larger hydroelectric dams also apply to smaller run-of-river hydroelectric projects (e.g., Graham 1985; Hirst 1991a,b; Hatfield et al. 2003, 2007; Lewis et al. 2004; Steele and Smokorowski 2000; Linnansaari et al. 2013) which do not necessarily store large volumes of water for power generation (see following section for description of run-of-river facilities). The ***potential*** for run-of-river facilities to impact fish production is the reason why there are guidelines, Environmental Assessments, and monitoring associated with the construction and operation of facilities in BC. However, the magnitude of these effects on salmonid population size, productive capacity and sustainability remains uncertain.

The increased number of run-of-river facilities constructed and being considered in BC in recent years, along with uncertainty in the magnitude of potential impacts on salmonids, led three entities to jointly commission and fund an independent review of run-of-river hydroelectric projects in BC: the Clean Energy Association of British Columbia (CEBC), the Gordon and Betty Moore Foundation, and BC’s Living Rivers Trust Fund. The Pacific Salmon Foundation (PSF) was asked to lead the review and tasked with looking at the issue through a series of questions:

1. Are run-of-river hydro projects negatively impacting salmonids? If “yes”,
    a. Where is this occurring? Are locational, regional, or site issues contributing factors?
    b. What aspects of operations are problematic, considering river segments:
        i. Upstream
        ii. Diversion reach and in-stream flow requirements
        iii. Downstream and ramping
    c. What is the impact? Does it involve direct mortality, life cycle impairment, or affect ecological functions?
    d. Are there more problematic periods of time – seasons of the year, and / or operations?
2. What are fish mitigating and compensating features of run-of-river hydro projects?
    a. What are these, and can their effectiveness be evaluated?
    b. Which ones are most effective?
    c. Have they met their intended objectives?
3. Can changes associated with a run-of-river project (both positive and negative) be isolated from other landscape impacts, and accumulated effects of other developments?
    a. How site specific are impacts – project by project?
    b. What generalizations if any can be a made about scale of projects or multiple projects in the same drainage?

The PSF conducted a competitive proposal process, after which the PSF contracted ESSA Technologies Ltd. to conduct the review. A commitment of the review process was to create a Public Advisory Committee consisting of academic, First Nations, industry and non-governmental organization (NGO) participants to provide feedback during each stage of the project.

The focus of this review is on privately owned hydroelectric projects that received Energy Purchasing Agreements with BC Hydro over the past three decades. Fifty-three operational facilities and 15 non-operational facilities were initially identified by CEBC to be included in the review (Table 7 in Appendix 1). Of the 53 operational facilities, seven were identified as lake / storage type small hydro with characteristics that differed from typical stream-type run-of-river hydroelectric facilities, two were very small non run-of-river hydro for personal / private use, and one was identified as not being in operation after all. With the addition of one facility identified as having only recently begun operations, the resulting 44 operational run-of-river facilities were the focus of this review (Table 7 in Appendix 1).

1.2 RUN-OF-RIVER HYDRO IN BRITISH COLUMBIA

Typical run-of-river facility

A typical stream-based run-of-river facility consists of a weir or low-head dam that enables the diversion of water through a penstock, tunnel or canal to a lower elevation powerhouse with a turbine where electricity is generated. The diverted water is then discharged back into the stream channel either directly or through a short channel called a tailrace. The typical structure of a run-of-river facility naturally separates a project into three sections or stream reaches: the section immediately upstream of the point of diversion, the diversion section between the point of diversion and the point at which diverted water is returned to the stream, and the section downstream of the tailrace (Figure 1). Run-of-river facilities vary in size from small facilities capable of producing less than half a megawatt of power to facilities capable of producing over 100 megawatts of power.

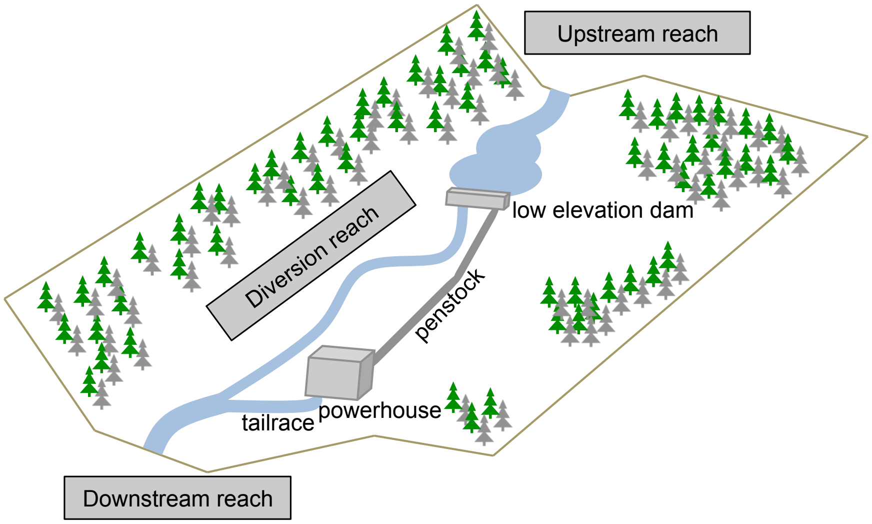

Figure 1: Schematic of a typical run-of-river hydroelectric facility illustrating the location of the intake, penstock and powerhouse and the resulting upstream, diversion and downstream reaches.

Run-of-river projects are differentiated from larger storage hydroelectric projects by the fact that they do not store water upstream of the intake. Instead, water continues to flow through the head-pond with water turnover occurring frequently relative to a storage reservoir. Consequently, a typical run-of-river project does not substantially alter the magnitude and timing of stream flow upstream and downstream of the diversion reach, though the operation of a run-of-river facility does alter flow within the diversion reach (Lewis et al. 2013).

History of run-of-river in BC

In the most general sense, run-of-river is the original form of hydroelectric power generation (e.g., water wheels) predating storage reservoirs at large hydroelectric facilities, which now account for most of the electricity generated in BC in a given year. Run-of-river hydroelectric operations began in BC in the early 1900s (e.g., Cascade Power and Light Company on the Kettle River), before most hydroelectric dams were constructed during two major building booms in the 1920s-1940s and 1950s-1970s. Following the second major dam building boom, calls for proposals for private run-of-river power began, resulting in the licencing of 16 facilities. A decade after the commissioning of these run-of-river projects, the government rekindled interest in run-of-river power production by making a series of new clean energy power calls starting in the 1980s (Table 1).

Table 1: History of clean energy power calls in BC and the number of small hydroelectric power facilities that resulted from each call. Not all of the facilities in this table are currently in operation, and not all of these facilities were considered in this report. See Appendix 1 and Section 2.1 for further details.

BC Hydro Power call	Number of facilities
1985 Negotiated EPA	1
1985 Non-Integrated Areas RFP	1
1988 Greater Than 5 MW	1
1989 Less than 5 MW	12
1993 Non-Integrated Areas RFP	1
2000 RFP	2
2001 Greater Than 40 GWh	3
2001 Less Than 40 GWh	8
2003 Green Power Generation	4
2006 Open Call	14
F2006 CFT	1
2008 Standing Offer Program	5
2009 Non-Integrated Areas RFP	1
2010 Clean Power Call	10
2010 Negotiated EPA	2
2010 Standing Offer Program	1
Unknown	1

Regulatory and monitoring landscape

Run-of-river hydroelectric projects are developed and operated under environmental regulatory and permitting oversight from: BC's environmental assessment office (EAO); BC Forests, Lands, and Natural Resource Operations (FLNRO); BC Ministry of Environment; the Canadian Environmental Assessment Act (CEAA); Fisheries and Oceans Canada (DFO); and Transport Canada (MOT; through the Federal Navigable Waters Protection Act).

Monitoring is required as part of the permitting of run-of-river hydroelectric projects and involves compliance, effectiveness and response monitoring (Lewis et al. 2013). Compliance monitoring evaluates whether a project complies with the conditions of the water licence and any requirements of the Fisheries Act Authorization for the project. These conditions and requirements (e.g., ramping rates, instream flow release (IFR), mitigation and compensation) are typically based on detailed studies of the project area before the construction of a project and during commissioning. Effectiveness monitoring assesses the prescribed mitigation and compensation measures in addressing the potential impacts of a facility. Response monitoring is the "repeated and systematic measurement of environmental parameters to test specific hypotheses about project effects on the environment" (Lewis et al. 2013). While we considered reports and data pertaining to all three types of monitoring, this report focuses on response monitoring as it relates most directly to the terms of reference for the review (i.e., questions and testable hypotheses related to potential project impacts on salmonids).

The 104-year old provincial Water Act is the primary piece of water management legislation in BC and the key legislative instrument for establishing regulatory and monitoring requirements for run-of-river hydroelectric projects. The Water Act is applied by a number of Statutory Decision-Makers (SDMs) in regional offices around the Province, as well as SDMs based out of Victoria, resulting in variability in monitoring and reporting requirements among regions. In addition to variation across regions, monitoring and reporting requirements for run-of-river hydroelectric projects have evolved over time, and can be broadly divided into three regulatory and monitoring periods: early, transitional, and modern (Scott Babakaiff, FLNRO, personal communication, April 22nd 2013). Figure 2 shows the distribution of run-of-river projects across the Province and over these three regulatory and monitoring periods.

The early period (up to 1993) was characterized by little standardized monitoring of aquatic organisms, including salmonids, or their habitats. There were few Fisheries Act Authorizations issued related to the harmful alteration, disruption or destruction (HADD) of fish habitat. During this period the statutory decision makers in each regulatory region were typically engineers and the primary focus was on water allocation and human safety.

During the transition period (2000-2003), appreciation increased for the potential aquatic impacts of run-of-river project operations. This period included the establishment of the British Columbia Instream Flow Guidelines for Aquatic Habitat, which were comprised of two components: the Instream Flow Thresholds (Hatfield et al. 2003; Lewis et al. 2004) and the Instream Flow Assessment Methods (Hatfield et al. 2007). These documents specified the information needed to support applications to dam, divert, or extract water from streams in BC, and were designed to consider the effects of run-of-river projects, focusing primarily on the diversion reach effects, although both upstream and downstream effects were identified and highlighted for assessment in these guidelines.

The most recent or 'modern' period (2006 to the present), has seen broader adoption of the instream flow and monitoring guidelines that emerged from the transition period. The modern period has also seen an increased emphasis on the standardization of operational and environmental monitoring requirements, which are described in Operational Parameters and Procedures Reports and Long-term Environmental Monitoring Plans that are specific to each site. Operational Parameters and Procedures Reports describe key operating requirements and procedures for how the project will be monitored (to verify compliance with water licence conditions and commitments) as well as reporting commitments. Long-term Environmental Monitoring Plans detail the potential biological, physical, and chemical responses to run-of-river project development and operation, and detail how they will be monitored. The monitoring guidelines that arose from the transition period have been revised and expanded in a comprehensive document detailing methodologies for the long-term environmental monitoring of small hydroelectric projects in BC (Lewis et al. 2013).

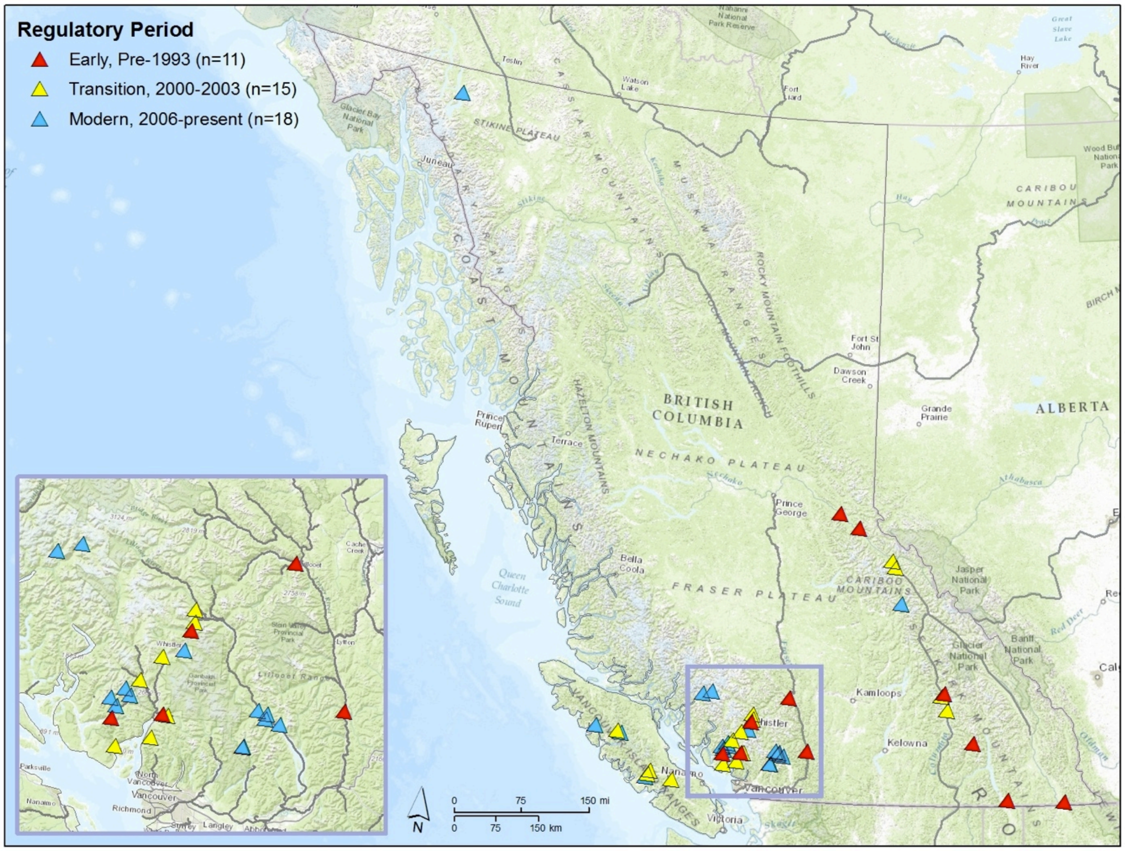

Figure 2: The distribution of operational facilities in British Columbia and the general regulatory and monitoring period in which each facility began operations. The sample sizes in the legend for each regulatory period correspond to the number of facilities that were the focus of this report.

Understanding these changes in the monitoring and regulatory requirements in BC is essential for guiding expectations about the types of monitoring data available to evaluate the impact of run-of-river hydroelectric projects on salmonids, and how requirements of the industry have evolved. The oldest facilities are the least likely to have consistent monitoring of salmonids and the aquatic environment. Transition period facilities are more likely to have monitoring data but the quality and quantity of data varies by facility. The newest facilities are the most likely to have standardized monitoring of salmonids and the aquatic environment, at least in the diversion reach (Figure 3).

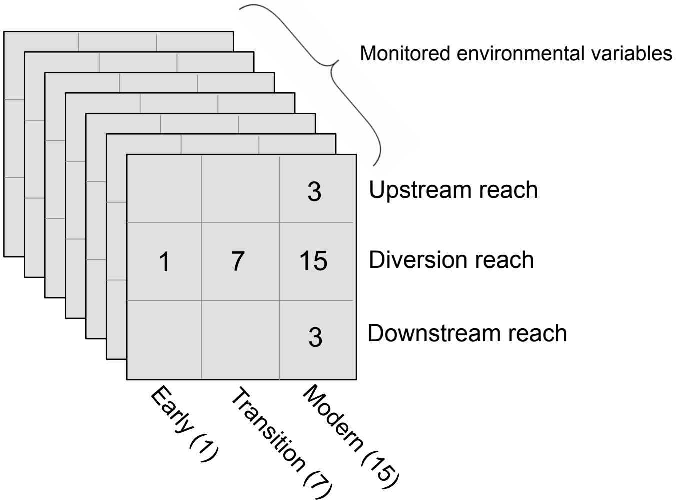

Figure 3: Occurrence of monitoring at facilities that provided monitoring reports by stream reach and monitoring / regulatory period. The number in each cell corresponds to the number of facilities with monitoring programs ***specifically designed to monitor salmonid abundance in a given stream reach***. The numbers at the bottom are the total number of facilities from each time period. For example, of the 15 modern facilities that provided monitoring information, all 15 monitored salmonid abundance in the diversion reach, three monitored salmonid abundance in the upstream reach and three monitored salmonid abundance in the downstream reach. The sections of the cube are intended to illustrate that numerous environmental variables may be monitored at a given facility.

1.3 ASSESSING AND DETECTING IMPACTS ON SALMONID POPULATIONS

Most human activities have impacts; some activities can have lasting effects on species and the environment whereas others may not cause significant or measurable changes to populations or ecosystem attributes. Unless a run-of-river facility is completely inaccessible to fish both upstream and downstream of the diversion reach, the construction and operation of a run-of-river hydroelectric facility can be expected to have at least some localized impacts on fish, some portion of which may be salmonids. Very localized impacts on some individuals though may or may not have biologically significant impacts at the broader population scale. Further, many facilities have Fisheries Act Authorizations to account for anticipated impacts to salmonid habitat. These compensation requirements reflect the potential for run-of-river hydroelectric projects to affect salmonids and their habitats. The key question that emerges from this baseline understanding, and serves as the focus of this report, is: ***To what extent do these potential impacts result in quantifiable changes in the abundance of salmonids within the upstream, diversion, and downstream stream reaches of a run-of-river hydroelectric project?***

Three questions naturally follow from this overarching question and are considered in this review:

1. What are the pathways that may affect salmonids, either directly or indirectly?
2. Is monitoring sufficient to identify impacts on salmonids and determine the causes of those impacts?
3. Are mitigation and compensation efforts sufficient to offset any losses in salmonid abundance, and do monitoring data confirm their effectiveness?

Salmonid populations vary through time as a result of natural variation in environmental conditions that influence birth and death. Disentangling natural variation from effects relating to human activity is challenging. The inherent variability of fish populations and imperfect measurements of abundance often make it difficult to detect impacts on fish populations even when large effects are present (e.g., Pella and Myren 1974; Korman and Higgins 1997; Williams 1999; Ham and Pearsons 2000; Bradford et al. 2005). The design of monitoring programs is critical. The data from poorly designed monitoring programs may be inadequate to distinguish between alternative hypotheses, often with large management implications (Walters et al. 1988; McAllister and Peterman 1992).

A before-after-control-impact (BACI) monitoring approach is often considered the gold standard monitoring design (Stewart-Oaten et al. 1986; Underwood 1993, 1994). A BACI design, in the context of run-of-river hydroelectric projects, is based on the monitoring of impact (i.e., project) and control (i.e., similar non-project) sites both before and after the development of a run-of-river project (Figure 4d). This design accounts for the potentially confounding effect of natural variation unrelated to the project (e.g., year to year changes in climate which affect salmonid abundance positively or negatively at both the control and project sites). However, a BACI design cannot account for internally-driven trends in populations that may be unrelated to a run-of-river project and are not shared between the control and impact sites. In such cases, the BACI design can generate spurious results. Therefore, the results of population monitoring at a single site will be the most informative when supported with other information (such as process-based research, or the monitoring of other factors) to aid in the interpretation of the monitoring results.

In some instances, the history of a project and site-specific circumstances make a BACI design impossible. In such situations, environmental monitoring and evaluations may be based on other designs, such as: comparisons of the project site to a reference condition considered to be representative (reference-impact design; Figure 4a); comparisons of post-project and pre-project conditions without a control site (before-after design; Figure 4b); or post-project comparisons to a control site if no pre-project 'before' data exist (control-impact design; Figure 4c). Where it is necessary to use these alternate monitoring designs, the cost will be a reduced ability to detect an effect and attribute causation to the operation of a run-of-river facility.

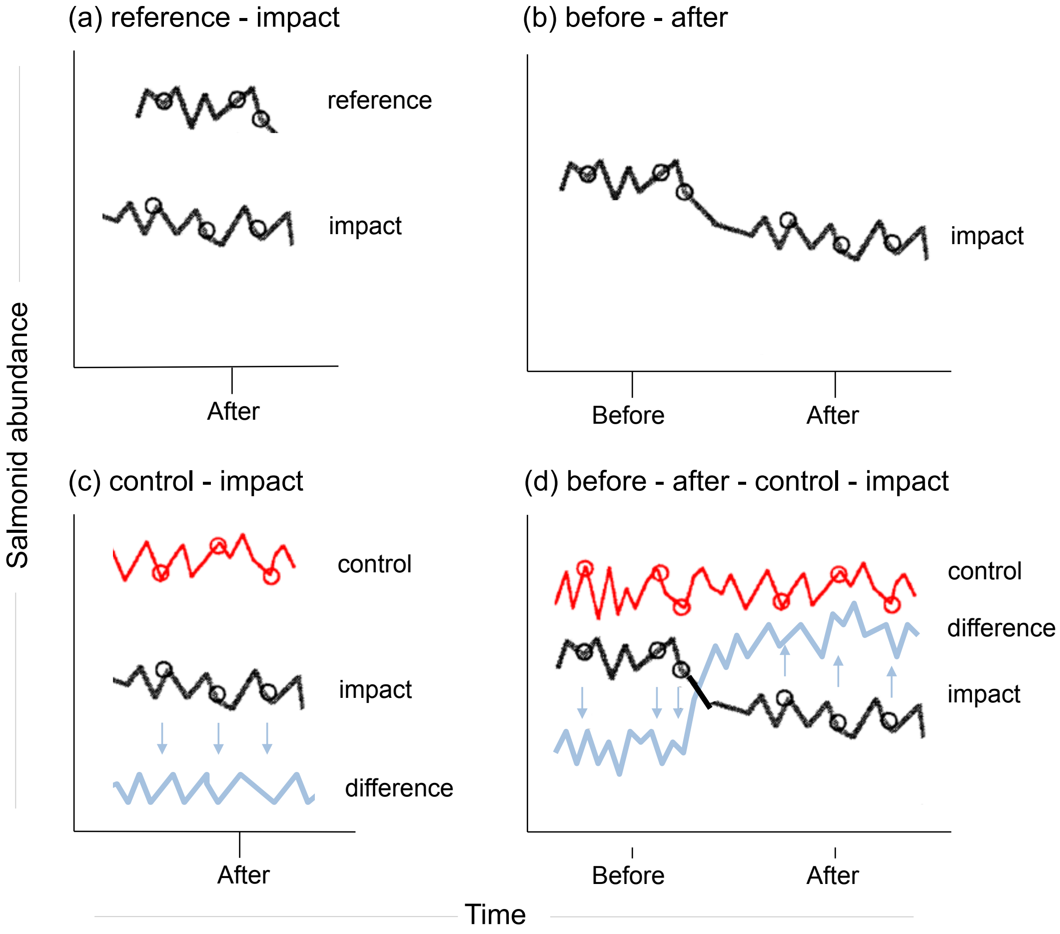

Figure 4: Schematic of various monitoring programs designed to detect the effect of anthropogenic activities on salmonid abundance. In (a) salmonid abundance is quantified after a project has begun operation (impact or project site) and contrasted against a reference condition, which is considered to be representative of the types of streams where the project exists. A weakness of this monitoring design is that the impact site may differ from the reference condition for reasons other than the operation of a run-of-river project. In (b) salmonid abundance is monitored before and after a project is constructed. This design accounts for changes over time, but is limited by the lack of data from a control site to account for potential non-project factors that may have led to change in abundance (e.g., climactic changes). In (c) a control site is selected that is as similar as possible to the impact site except for the presence of the run-of-river project. This design accounts for the potential confounding influence of unknown factors in space but is limited by the lack of data prior to the operation of the project and so the difference between control and impact may still be due to a confounding factor (i.e., inherent differences in salmonid abundance between the control and project / impact site which existed before the project was constructed). In (d) salmonid abundance is monitored at control and impact sites before and after the operation of a project. This approach accounts for potential confounding factors in space and time and contrasts the difference between control and impact from before project construction to afterwards. Figure is adapted from Schwartz (1998).

Our ability to assess change over time also depends in the sampling effort invested. Statistical power is the probability of detecting an effect, provided an effect is truly there. The statistical power to detect changes in fish abundance due to human activities depends on the size of the effect which we would like to be able to detect (e.g., a 25% or 50% change), the amount of natural variation in fish abundance, measurement error, and the number of samples upon which the estimate is based (Peterman 1990). Effects of a larger size (e.g., 50% change) are easier to detect than smaller ones (e.g., 25% change) and lead to higher statistical power (and confidence in the outcome). Higher levels of natural variability and / or measurement error reduce statistical power unless one increases the number of samples upon which an estimate of abundance is based (i.e., sample size and the degree of replication).

What magnitude of impact on salmonid abundance is likely to be detected based on monitoring at a run-of-river facility in BC? Given the natural variability in abundance typical of resident salmonids, detecting a reduction in abundance of at least 50% in eight out of 10 cases requires two years of baseline monitoring and five years of post-operational monitoring at five sites within the control area and five sites within the impact area (i.e., a 50% effect size, 0.8 statistical power, and 0.05 significance level) (Lewis et al. 2013). At facilities without baseline monitoring, limited replication of monitoring sites and / or high natural variation in the measured variable (e.g., invertebrate drift or anadromous salmonids), we can expect that monitoring will detect only very large changes in the measured variable, if any.

Current fish monitoring guidelines (Lewis et al. 2013) are designed to detect a change in resident fish density in the diversion reach of more than 50%, which is a minimum effect size based on the duration of monitoring and natural variability outlined in the previous paragraph. FLNRO requires that baseline monitoring be used to generate site-specific estimates of statistical power, and the duration of post-project monitoring (minimum five years) may end up being longer if baseline analyses demonstrate high natural variability in fish density. Conversely, at some facilities, there may be low natural variability, which may allow five years of post-project monitoring to detect less than a 50% change. Ironically, run-of-river projects in watersheds with very low fish densities are the most likely to need more years of post-operational monitoring of salmonid abundance because they tend to have greater natural variation in fish densities and measurements than watersheds with high densities of salmonids (where relatively fewer years of monitoring will achieve the desired statistical power).

Though monitoring of salmonids at run-of-river projects focuses on salmonid abundance, productivity (i.e., the total number of adult fish produced per spawner) is a more direct measure of the “health” of a salmonid population. This is because productivity describes the ability of a population to sustain itself. However, estimating productivity requires more detailed information than fish density, including estimates of spawner abundance and the number of fish produced by each spawning generation. Consequently, it is rarely, if ever, monitored at run-of-river projects.

Direct mortality of fish is a potential effect that could be of great concern from a conservation and management perspective. However, in instances when abundance exceeds the carrying capacity of the environment, limited mortality may not affect the overall abundance or sustainability of a population. For example, mortality among juvenile fish may actually improve the growth and survival of the remaining juveniles and older age classes through reduced competition for resources. This is usually described as a "compensatory response" in fish populations where a reduction in the abundance of adults is a fraction of the mortality of eggs or juveniles (e.g., Moussalli and Hilborn 1986; Myers 2001; Scheuerell et al. 2006; Alexander et al. 2006). Consequently, it is very difficult to attribute changes in salmon abundance to specific causes unless an extensive monitoring program has been designed and implemented.

Finally, the most ecologically relevant scale for considering impacts on salmonids needs to be identified. For anadromous salmonids, management agencies have shifted their focus over the past few decades from individual streams, spawning reaches or watersheds to conservation units (CUs). Conservation units capture unique ecological, life-history and genetic attributes of a population or collection of populations (DFO 2005). These conservation units can be made up of many (or few) discrete spawning populations and are now considered in many instances to be the most appropriate scale for managing and conserving anadromous salmonids. The Canadian Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and the International Union for the Conservation of Nature (IUCN) use a concept similar to conservation units known as designatable units, which are defined as discrete and / or evolutionarily significant populations relative to other populations. Both the BC Ministry of Environment and the US Fish and Wildlife Service use a similar concept for bull trout (a resident salmonid) called "core areas" (USFWS 2008, 2012; Hagen and Decker 2011). In the US, bull trout recovery plans are organized around core areas, each containing one or more local population(s); multiple core areas combine to make up a Distinct Population Segment (USFWS 2008, 2012).

We have focused our review at the scale of the individual run-of-river facility and the stream reaches where the potential for impacts on salmonids exists (i.e., downstream, diversion, and upstream reaches). We chose this scale because it is the scale typically used for monitoring and is, therefore, the appropriate scale for assessing impacts. However, we recognize that the most appropriate scale for considering population dynamics, local adaptation, and conservation is a larger spatial scale like the conservation units described above. Localized impacts or short-term impacts should ultimately be considered within this broader context.

1.4 SCOPE AND LIMITATIONS OF THIS REVIEW

This report evaluates the evidence for and against impacts of run-of-river hydroelectric facilities on salmonids in BC. The report is primarily based on a review of completed monitoring reports from run-of-river facilities that are produced by registered professionals subject to regulation by independent bodies (e.g., the College of Applied Biology) as well as information provided to us by run-of-river operators and published literature.

The provincial agencies responsible for regulating the industry and evaluating compliance with monitoring and operational requirements (i.e., those detailed in each project's water licence) were unable to compile and provide us with all monitoring reports submitted by project operators. As a result, it was more efficient and effective for us to request the reports directly from the operators. As is detailed in Section 2.1, however, not all operational run-of-river projects currently have, or have had, monitoring programs in place. While most projects with monitoring programs did provide their monitoring reports, there were a few exceptions (described below).

This review is limited in scope to the questions presented in Section 1.1 related to impacts on Pacific salmonids. *It does not address broader ecological effects of development, roads and transmission lines, or cumulative effects on salmonids (although we do touch on the latter in Section 7) or other terrestrial and aquatic ecosystem components*. While these are all valid concerns related to run-of-river hydroelectric projects, and should be considered an important part of any discussion about trade-offs between conservation and development, they were outside the scope of this review.

Lastly, this review was not a compliance audit that evaluated the extent to which operational run-of-river projects meet the requirements of the water licences or Fisheries Act Authorizations issued to them. As previously noted, two recent reports have evaluated compliance across a number of run-of-river facilities in BC (Menzes 2012; Hatfield 2013).

2 Methodology

We applied a weight of evidence (WOE) approach to systematically evaluate potential impacts on salmonids at the scale of individual run-of-river facilities. We examined the available evidence for and against a suite of *hypothesized impact pathways* that describe the ways in which run-of-river hydroelectric projects have the potential to affect salmonids. These impact pathways covered barriers to migration, mortality due to entrainment in the penstock, changes in habitat, alteration of the natural hydrograph, movement of sediment and organic material (primarily wood), changes in food production, and stranding due to fluctuation in the wetted width of stream channels.

Our evaluation relied upon information acquired from facility operators (including baseline and operational monitoring data and reports), which we then supplemented with information provided by regulatory agencies (i.e., FLNRO), spatial information acquired through GIS analyses, peer-reviewed journal articles, technical reports (Figure 5), and site visits to five facilities.

The conclusions reached from this evaluation can be synthesized at three scales (Figure 5):

1. Stream section (i.e., upstream, downstream or diversion reach and compensation habitat), which asks: "*has salmonid abundance or species composition changed coincident with the operation of the run-of-river project within a given stream section?"*;

2. Hypothesized impact pathway, which asks: *"is there evidence for or against change in salmonid abundance which is attributable to a particular pathway of effect?"*; and
3. Individual hypothesized cause and effect links within each impact pathway, which asks: *"is there evidence for or against the individual mechanistic links that comprise a hypothesized impact pathway of effect?"*

In the following sections of the report we describe the sources of information, the impact pathways considered, the weight of evidence methodology, and the results of our evaluation of hypotheses related to changes in salmonid abundance by stream sections and impact pathways. More detailed descriptions of each hypothesized pathway are provided in Appendix 6, as well as the conclusions we reached at the individual pathway link level which describe the mechanistic cause-effect pathways (e.g., changes in sedimentation, flow or invertebrate drift) that make up an overall impact pathway.

2.1 ACQUISITION OF FACILITY INFORMATION

We relied on individual run-of-river operators for access to information. According to the terms of reference for this review, information from run-of-river operators was kept confidential, and individual facilities have not been identified in this report. In a few instances, when information was not available from operators, FLNRO was able to provide the information they had available. However, FLNRO does not currently have a central repository and tracking system for run-of-river projects.

We requested reports and documents from run-of-river hydroelectric project operators related to the monitoring and evaluation of facilities specifically related to flow, aquatic organisms including salmonids, and sediment transport, including before / after monitoring programs, environmental impact assessments and pre-project baseline information. A complete list of the documents we requested can be found in Appendix 2. We originally requested information by letter (dated February 8th 2013) and then both CEBC and ESSA followed up with individual operators by email and phone until July 31st 2013.

Thirty-four of the 44 facilities we contacted provided at least some information in response to our request. Of the remaining 10 facilities, six did not provide information by our deadline of July 31st, 2013, and four declined to participate in the review. For three of the facilities that declined to participate (one from the transition power call era and two from the modern power call era), we were able to acquire basic information from FLNRO. As described in Section 2.4 we compiled geo-spatial information for all facilities. At the seven facilities for which we were unable to acquire any documentation we relied solely on the geo-spatial information.

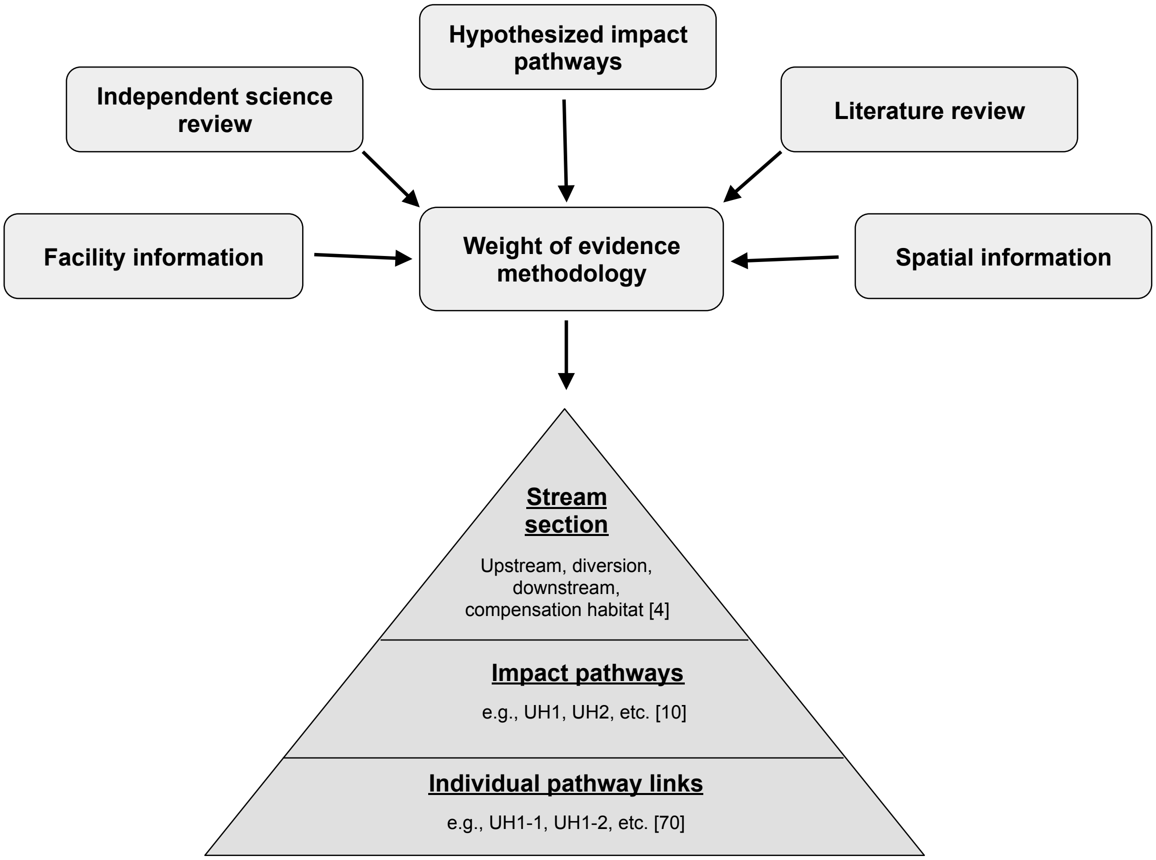

Figure 5: Schematic of the sources of information used to evaluate the evidence for the impact hypotheses using a weight of evidence approach. The triangle represents the three scales at which the evidence for the hypothesized impact pathways could be synthesized; numbers in square brackets refer to the number of unique hypotheses considered at each scale.

The information provided by operators ranged from the water licence issued by the Province prior to the facility beginning operation to detailed pre-project and post-operational monitoring reports (in some cases up to 15,000 pages of documents for a single facility). Most facilities that began operations in the modern era (i.e., 2006 or later power calls) provided monitoring reports, with the exception of two that declined to participate and one facility that provided only basic information (Table 2). Earlier projects had less information available. Of the 15 facilities that came into operation during the transition era, seven provided monitoring reports, five provided only basic information and three provided no information at all. Only one of 11 facilities from the early era provided monitoring information.

The majority of modern facilities that were able to provide monitoring reports were partially through their current monitoring programs (Figure 6).

Table 2: General categories of information provided by run-of-river hydroelectric project operators by regulatory / monitoring era.

Type of information	Early power calls	Transition power calls	Modern power calls	All facilities
Monitoring reports	1	7	15	**23**
Basic facility information [a]	6	5	3	**14**
No information	4	3	0	**7**
All Facilities	**11**	**15**	**18**	**44**

[a] Basic information included such documents as the water licence, pre-project fish inventories, development / construction plans, maps and approvals, ramping studies, parameters and procedures reports, environmental impact assessments, DFO letters, and operations fact sheets.

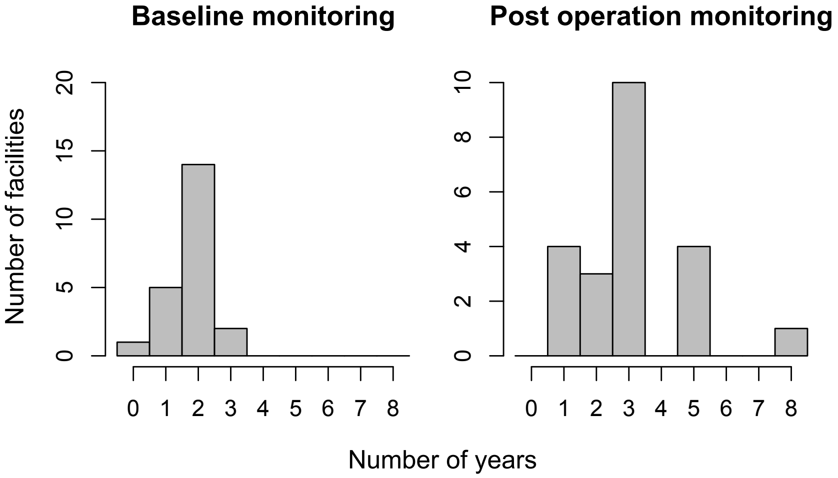

Figure 6: The number of years of pre- and post-operational environmental monitoring reported in the environmental monitoring documents reviewed for this study (23 facilities total).

2.2 IMPACT HYPOTHESIS APPROACH

We took an “impact hypothesis” approach to organize possible impacts of run-of-river hydroelectric projects on salmonids. This approach (also called Pathways of Effect) is a robust organizing framework for analyzing hypothesized effects of human activities. Over the last three decades the use of an impact hypothesis (or pathways if effect) approach has been applied to hundreds of problems in impact assessment (e.g., Bernard et al. 1989; Jones et al. 1996; Clarke et al. 2008; Giguère et al. 2011) including run-of-river hydroelectric projects (Lewis et al. 2004).

Our approach expanded upon previous efforts to identify run-of-river pathways of effect (Lewis et al. 2004) by developing a series of step-models, called impact hypothesis diagrams (or IHDs; Appendix 6). Each hypothesis is represented as a box-and-arrow diagram that illustrates the cause-effect pathways linking run-of-river hydroelectric project operation and configuration to the abundance, species composition and growth of salmonids within a specified stream section.

The models were developed by experts in salmonid ecology and population dynamics, hydrology, environmental monitoring, and aquatic ecology. These hypotheses were then further refined as additional information became available through review of the literature, feedback from other experts (Section 2.6 and Appendix 4) and the Public Advisory Committee. We structured the impact hypotheses around a typical run-of-river hydro facility with upstream, diversion and downstream reaches (Table 3 and Figure 7).

Table 3: The specific hypotheses related to each of the overall impact pathways considered in this report**. All hypotheses are phrased as though they were true so that they form a testable assertion, but they are not necessarily true (or false).** Multiple lines of evidence were used to assess the likelihood of each hypothesis, though in most cases evidence was insufficient to conclude that the hypothesized effect was either likely or unlikely.

Pathway ID	Hypothesis
UH1	Entrainment of fish in the penstock and / or stranding in the spillway *does* cause a decline in salmonid abundance in the upstream reach.
UH2	The creation of a headpond *does* change salmonid species composition or abundance in the upstream reach.
UH3	The construction of a dam and associated works *does* impair the upstream passage of salmonids resulting in a change in salmonid species composition or abundance in the upstream reach.
DVH1	Construction of a dam and diversion of water *causes* a change in the timing and magnitude of the import of gravel, larger sediment, large woody debris and fish food organisms to the diversion reach resulting in changes to the area and quality of spawning and rearing habitat and change to salmonid growth and abundance in the diversion reach.
DVH2	Change to patterns of flow in the diversion reach compared to conditions in the absence of impoundment *causes* change in salmonid movement, growth and abundance in the diversion reach.
DVH3	Change to patterns of flow in the diversion reach compared to conditions in the absence of impoundment *causes* change in temperature and oxygen conditions sufficient to affect salmonid growth and abundance in the diversion reach.
DWH1	Construction of a dam and diversion of water *causes* change in the timing and magnitude of import of gravel and larger sediment and large woody debris and fish food organisms to the downstream reach resulting in changes to the area and quality of spawning and rearing habitat and change to salmonid growth and abundance in the downstream reach (this hypothesis carries through the concepts outlined in DVH1 but in the downstream reach).
DWH2	The rate at which water is released from the powerhouse (ramping rate) *does* strand fish and change the production of fish food organisms leading to change in salmonid growth and abundance in the downstream reach.
DWH3	Entrainment of air in the power plant *does* change total dissolved gas conditions

	downstream of the project sufficiently to cause gas bubble disease and affect salmonid growth and abundance in the downstream reach.
CH1	Off-channel constructed fish habitat *does* replace lost fish habitat and fish production in the project area resulting in no net loss in the species composition and abundance of salmonids.

The details of the impact hypothesis approach are provided in Appendix 4. Appendix 6 also contains a detailed description of each impact pathway, impact hypothesis diagrams and a list of project and site factors that can increase or reduce impacts.

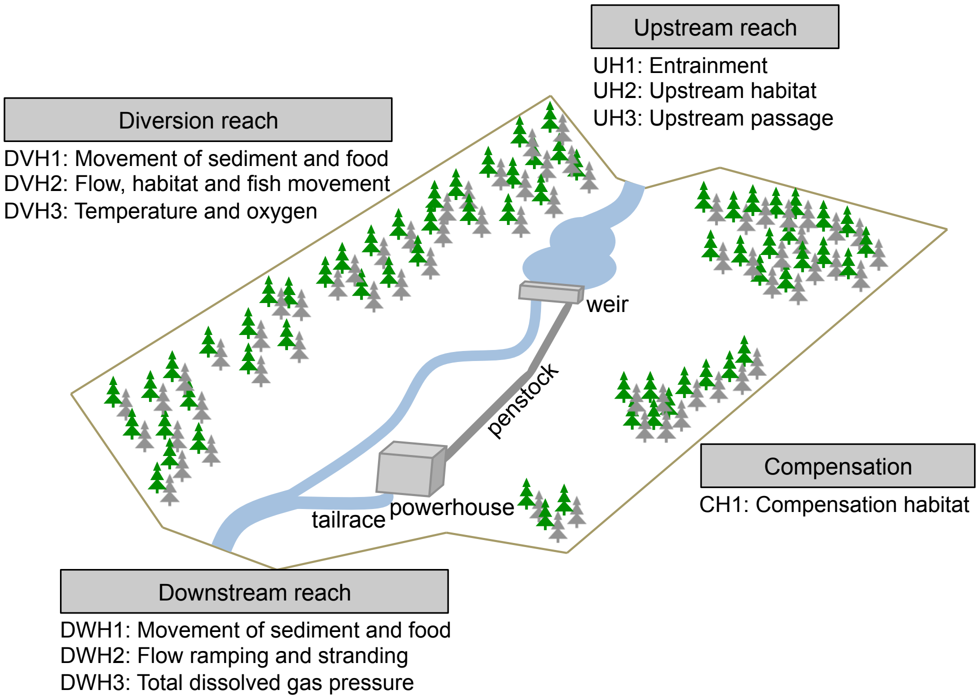

Figure 7: A schematic of a typical run-of-river hydroelectric facility and the 10 overall impact pathways considered in this report.

2.3 LITERATURE REVIEW

Early in the review, we searched online science publication databases, and used expert input and feedback from the Public Advisory Committee to identify journal articles and other literature and information related to the interaction of run-of-river hydroelectric projects with the aquatic environment. We then reviewed and summarized the literature relevant to each impact hypothesis linkage and pathway. For each publication, we considered the extent to which it did or did not provide evidence relevant to each impact pathway, and its relevance to run-of-river projects in BC (i.e., were the facilities and sites described in the publication comparable to BC run-of-river projects?). Appendix 6 summarizes the literature relevant to each impact pathway.

There are limitations to the existing literature. Many studies have been done on storage type hydroelectric projects and rivers that are much larger than those typical of the BC run-of-river projects evaluated in this report. Therefore, findings from these projects may not be applicable to our study. On the other hand, the effects of flow changes in stream reaches in general have been extensively studied. Studies do exist on facilities and streams more comparable to those being evaluated here, but many are located in parts of the world with different biophysical conditions and biota, and may therefore not be applicable to salmonids in BC. In our review (Appendix 6), we included studies that are useful for describing mechanisms of impact, but have been careful to indicate the details regarding each cited study, to allow the reader to judge its applicability to the settings and projects examined in this report.

2.4 SPATIAL INFORMATION

We supplemented the above-described information with publicly available spatial information relevant to the impact hypotheses. This information included the location of the intake, penstock and powerhouse, which allowed us to identify the upstream, diversion and downstream reach for each facility. We also determined the known and inferred occurrence of salmonids within a watershed relative to each stream section. Known fish occurrence was based on all fish observation records that are currently available from a compilation of several data sources including the Fisheries Information Summary System (FISS) and the Consolidated Waterbody Surveys (CWS). This dataset represents “presence only” and does not include records where it was determined a species was absent. For reaches where fish presence was not confirmed by observation records, we inferred resident salmonids were present / absent by using a salmonid maximum accessibility model. The maximum accessibility model is based on presumed passage abilities of Bull trout using a gradient cutoff of 25% for fish bearing vs. non-fish bearing streams. The model also considers major known obstructions as barriers to accessibility. The resulting inferred distribution of resident salmonids was precautionary because it erred on the side of salmonids being present in a given stream section.

In addition to complimenting the information acquired from facility operators, these spatial data were particularly important for 19 facilities lacking other information. The details of locating project facility components, defining areas of interest and calculating the spatial metrics are described in Appendix 3.

2.5 WEIGHT OF EVIDENCE METHODOLOGY

After compiling information from operators, the literature and the spatial metrics, we used a Weight of Evidence (WOE) approach to systematically evaluate the evidence for and against hypothesized impact pathways and linkages at each facility and stream reach. This approach (described in detail in Appendix 4, with examples) allowed us to synthesize and evaluate the available evidence in a way that was transparent, systematic and logical (Forbes and Callow 2002; Burkhardt-Holm and Scheurer 2007).

The WOE methodology applies an ordered set of questions to systematically evaluate the available evidence for and against an impact in each pathway. The questions form a decision framework that allows conclusions about the ***relative likelihood of each hypothesis***, leading to one of six possible evaluations, described as our conclusions (Figure 8):

- Very unlikely: exposure to a stressor[1] is unlikely. For example there is a screen over the penstock intake that physically prevents the entrainment of fish.
- Unlikely: exposure to a stressor occurs, but there is strong evidence that this exposure has not changed salmonid abundance or habitat.
- Possible: there is exposure to a stressor but it is not possible to conclude that this has caused a change in salmonid abundance or habitat. *Possible* means that the evidence is insufficient to conclude that the pathway is either *unlikely* or *likely* at this point in time.
- Likely: there is strong evidence that exposure to a stressor has changed salmonid abundance or habitat.
- Very likely: there is very strong evidence that exposure to the stressor has changed salmonid abundance or habitat.
- Not possible: exposure to the stressor is not possible (e.g., there are no salmonids within the run-of-river project area).

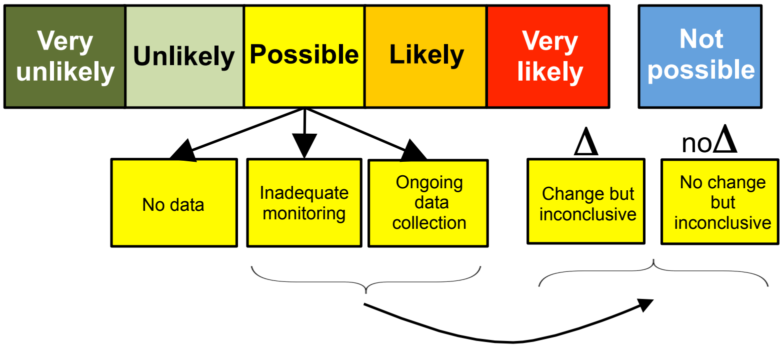

Figure 8: Schematic of weight of evidence conclusions. As explained in the text, we subdivided "possible" conclusions based on how we arrived at the "possible" conclusion (3 yellow boxes under "possible"). Two of these three subdivisions can be further categorized based on whether the performance measure under consideration appeared to change at all (bottom rightmost boxes).

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[1] A 'stressor' is a physical, chemical or biological attribute of fish habitat which if altered can potentially negatively affect a fish population (e.g., changes in flow, temperature, total dissolved gas, sediment, large wood, food supply).

We further subdivided the *Possible* conclusion into three subcategories, reflecting the reasons for this conclusion:

1. there were no data with which to evaluate the hypothesis, often the case for older projects ("*Possible - No data*");
2. there was insufficient confidence in the collected data to draw a conclusion due to problems with the design or implementation of monitoring (e.g., no controls or replication of sampling locations) ("*Possible – Inadequate monitoring*"); and
3. currently inconclusive but monitoring is ongoing and following protocols that should allow for a conclusion other than *possible* to be reached in the future ("*Possible - Ongoing data collection*").

The conclusions that were "*Possible – Inadequate monitoring*" and "*Possible - Ongoing data collection*" could be further broken down into situations in which:

a) there was a change detected in a performance measure but we were not confident in this assessment ("Change but inconclusive") due to problems with the design or implementation of monitoring; or

b) there was no change detected but we were not confident in that assessment ("No change but inconclusive") due to problems with the design or implementation of monitoring.

We applied the WOE methodology in three steps, proceeding from the most detailed scale to the most aggregated scale. We illustrate this in Figure 9 with a hypothetical example. First, we examined individual links within a single impact pathway (e.g., entrainment at the penstock; link UH1-1 in Figure 9). Our second step was to roll up the conclusions reached for all links along a pathway (e.g., in Figure 9 UH1-1 and UH1-3 form a 'penstock entrainment to salmonid abundance' pathway). Thirdly, we rolled up all pathways that applied to a given stream section. In total we evaluated the evidence for 70 individual links, 10 overall pathways and 3 stream sections, plus compensation habitats across 44 run-of-river hydroelectric projects. This review, therefore, included a grand total of 3,696 individual assessments (hypothesis evaluations).

Overall impact pathway conclusions were based on the link with the least *probable* conclusion (i.e., leftmost box in Figure 8). For example, the penstock pathway on the left side of Figure 9 consists of one link that is "very likely" (UH1-1) and one that is "possible" (UH1-3). Therefore, the overall conclusion for the penstock pathway would be that impacts are "***possible***". Fish are *very likely* to enter the penstock (UH1-1), but effects of such entrainment on salmonid abundance / species composition are only *possible*, so the whole pathway on the left side becomes *possible*. Similarly, on the right side of Figure 9, the overall conclusion for the "*very unlikely*" – "*unlikely*" spillway path is "***very unlikely***". If fish are *very unlikely* to enter the spillway (link UH1-2 in Figure 9), then the whole pathway on the right hand side becomes very unlikely (links UH1-2 and UH1-4).

There were often multiple pathways within one impact hypothesis diagram (e.g., 2 pathways in Figure 9 – a “***possible***” penstock pathway on the left side and an “***unlikely***“ spillway pathway on the right side). We arrived at an overall conclusion for a given diagram based on the most probable of the multiple pathways. For example, in Figure 9 the overall conclusion for the entire diagram is “***possible***”, because that is the most probable of the two pathways.

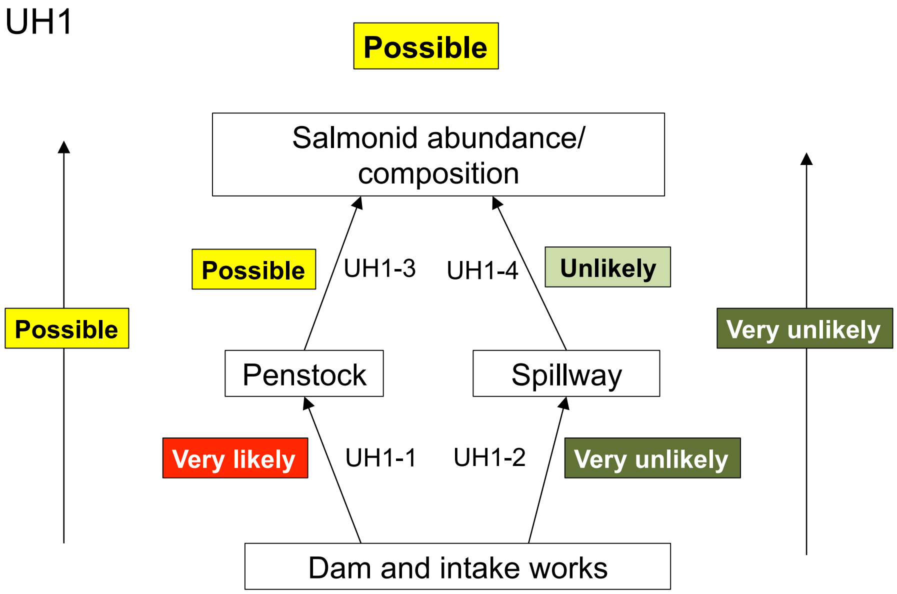

Figure 9: A hypothetical example of how conclusions at the scale of individual hypothesized cause-and-effect links were rolled up to a conclusion at the overall pathway level.

We made conclusions at the stream section level (i.e., upstream, downstream, diversion reaches, and compensation habitat) by considering the hypothesis that salmonid abundance or species composition has changed within a given stream section as a result of the operation of the facility, regardless of the underlying mechanism.

At the stream section level, we further subdivided those conclusions that were “*Possible – Inadequate monitoring”* into three categories based on the reason for the inconclusive conclusion:

1. methodology used to quantify salmonid abundance did not generally follow protocols outlined in Lewis et al. (2013);
2. documents we reviewed contained insufficient explanation or analysis of existing data; or
3. weaknesses in the monitoring design (e.g., no controls or baseline data).

2.6 INDEPENDENT PEER REVIEW OF METHODOLOGY

Independent peer review is a cornerstone of the scientific process. The PSF organized an independent science review workshop to ensure that our proposed methodology was rigorous and scientifically defensible. For the workshop, the PSF assembled a science panel comprised of experts in aquatic and salmonid ecology, hydrology, geomorphology, spatial analysis, run-of-river monitoring, and environmental assessment. During the workshop, the science panel was asked to review the application of the proposed methodology to two run-of-river projects, one with considerable monitoring data, and one with more limited data. The PSF asked the science panel to answer four questions:

1. Has the analytical team used an appropriate methodology for this study?
2. Has the methodology been applied in a consistent and defensible way?
3. Are the conclusions reached using the methodology justified for the example facilities and impact hypotheses?
4. What improvements to the methodology would you suggest?

The science panel concluded that on balance the proposed methodology was appropriate (Q1), had been applied in a scientifically defensible manner (Q2), and that the conclusions reached using the methodology were generally justified for the example facilities and impact hypotheses considered at the workshop (Q3). The science panel made several suggestions to further improve the proposed methodology. In particular, it was recommended that we more thoroughly document the process by which the evaluation teams reach their conclusions. These recommendations have been integrated into the methodology described in this report. Appendix 5 contains the final report of the independent science panel from the review workshop. The science panel did not independently verify the final results of the application of the methodology to the facilities in our review (except for the three they reviewed during the workshop). The panel did, however, review a draft version of this report, and their general comments are contained in Appendix 8.

3 Occurrence of salmonids at run-of-river facilities

We assessed fish species presence / absence based on monitoring reports provided by operators and spatial metrics on the occurrence of salmonids throughout watersheds in BC. Ten salmonid species were identified as present at run-of-river facilities (Table 4) and salmonids were present in at least one stream section at 43 of the 44 operational facilities that were the focus of this report (Figure 10).

Table 4: Salmonid species and their known or inferred presence at facilities considered in this report. The first number in the occurrence column is the number of facilities where the species was documented in monitoring reports provided by operators. The number in parentheses is the number of facilities where occurrence was inferred from fish observation points in FISS (see Appendix 4 for details). Summing both numbers in the occurrence column provides the total number of facilities (out of 44) with a given species present.

Species	**Scientific name**	**Life history** [a]	**Occurrence**
Arctic Grayling	*Thymallus arcticus*	Resident	1 (0)
Bull Trout	*Salvelinus confluentus*	Resident [b]	10 (4)
Cutthroat Trout	*Oncorhynchus clarkii*	Resident [b]	12 (5)
Dolly Varden	*Salvelinus malma*	Resident [b]	10 (2)
Rainbow Trout	*Oncorhynchus mykiss*	Resident	17 (11)
Whitefish	*Prosopium williamsoni*	Resident	0 (3)
Chinook	*Oncorhynchus tshawytscha*	Anadromous	5 (4)
Coho	*Oncorhynchus kisutch*	Anadromous	12 (3)
Chum	*Oncorhynchus keta*	Anadromous	6 (0)
Pink	*Oncorhynchus gorbuscha*	Anadromous	4 (2)
Sockeye	*Oncorhynchus nerka*	Anadromous	0 (1)
Steelhead	*Oncorhynchus mykiss*	Anadromous	3 (2)

[a] Here life history refers to whether the species is resident (i.e., remained in freshwater all its life) or anadromous (i.e., migrated to ocean following a period of rearing in freshwater) at the facilities considered in this report.

[b] These species can exhibit anadromous life-history traits, but have been classified here as resident based that is their dominant life-history strategy.

Both resident and anadromous salmonids were less likely to be found in the upstream reach than in the diversion or downstream reaches. Resident salmonids were about 16 times more likely to be present in upstream reaches than were anadromous salmonids, were 5 times more likely to be found in diversion reaches, and were twice as likely to be found in downstream reaches (Figure 10).

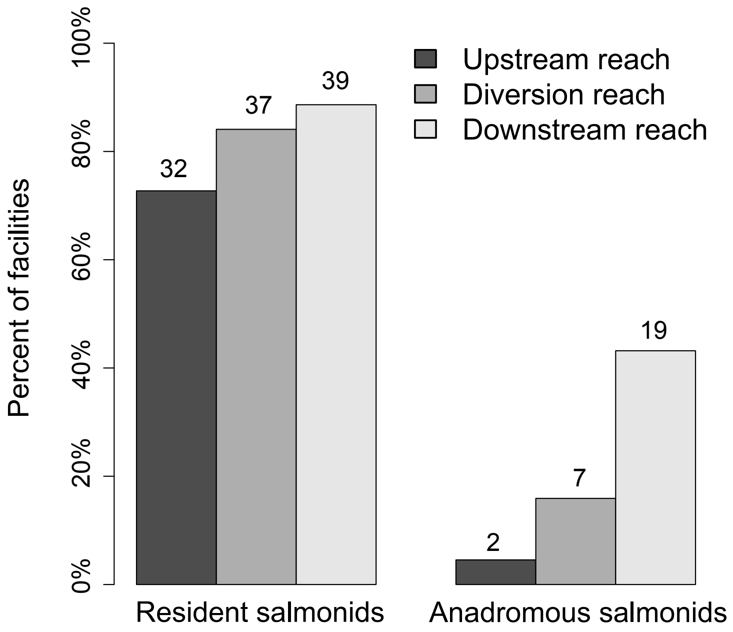

Figure 10: Percent of operational run-of-river hydroelectric facilities identified for this review where resident and anadromous salmonids are present. Bars show the number of projects with known or inferred resident (left side) and anadromous (right side) salmonid occurrence. We based our inferences on species presence on fish surveys and monitoring reports provided by operators and the spatial metrics described in Appendix 3.

4 Synthesis of evidence by stream section

This Section details the WOE conclusions that were reached by stream section (top portion of the triangle in Figure 5). At this scale we asked the following question for each stream section: ”*Has salmonid abundance or species composition changed coincident with the operation of the run-of-river project,* regardless of the underlying mechanism?*”*. The WOE conclusions based on each overall hypothesized impact pathway and individual cause-effect links describing mechanisms are described in Section 5 and Appendix 6, respectively.

Note that **all hypotheses are phrased as though they were true so that they form a testable assertion, but they are not necessarily true (or false)**.

4.1 UPSTREAM REACH

Hypothesis: changes in salmonid abundance and species composition in the upstream reach *are* attributable to the operation of the run-of-river project.

We concluded this hypothesis was *unlikely* at one facility, *possible* at 30 facilities, *likely* at one facility and *not possible* at 12 facilities. This impact pathway is not possible if it was inferred that salmonids were not present within the upstream reach, due to either the absence of salmonids or habitat which was inaccessible due to steep gradients.

This hypothesis was *likely* at one facility because before-after monitoring demonstrated that the creation of a headpond resulted in increased abundance of Dolly Varden relative to rainbow trout, thereby altering the upstream species composition of salmonids. At another facility this hypothesis was *unlikely* because before-after monitoring in the upstream reach provided strong evidence that species composition and abundance of salmonids had not changed following the creation of the headpond.

At the 30 facilities where the hypothesis was considered *possible,* monitoring of salmonids in the upstream reach had not occurred or been reported at 24 facilities (p*ossible - no data)*, five facilities had inadequate monitoring (*possible – inadequate monitoring)* and one facility had ongoing monitoring that would allow for future examination of the abundance of salmonids in the upstream reach *(possible – ongoing data collection)* (Figure 11).

A total of six facilities fell into the two *possible* categories where data were available, but were insufficient to draw conclusions (i.e., the two rightmost *possible* boxes in Figure 8). At five of these six facilities, the available evidence suggested there was no change in the abundance of salmonids in the upstream reach; at the remaining one facility, there was evidence of change. However, the available evidence was considered inadequate at all six facilities for one of the following reasons (Figure 12):

1. monitoring was still ongoing – one facility;
2. there were weaknesses in the monitoring design (e.g., no controls or baseline data) – five facilities.

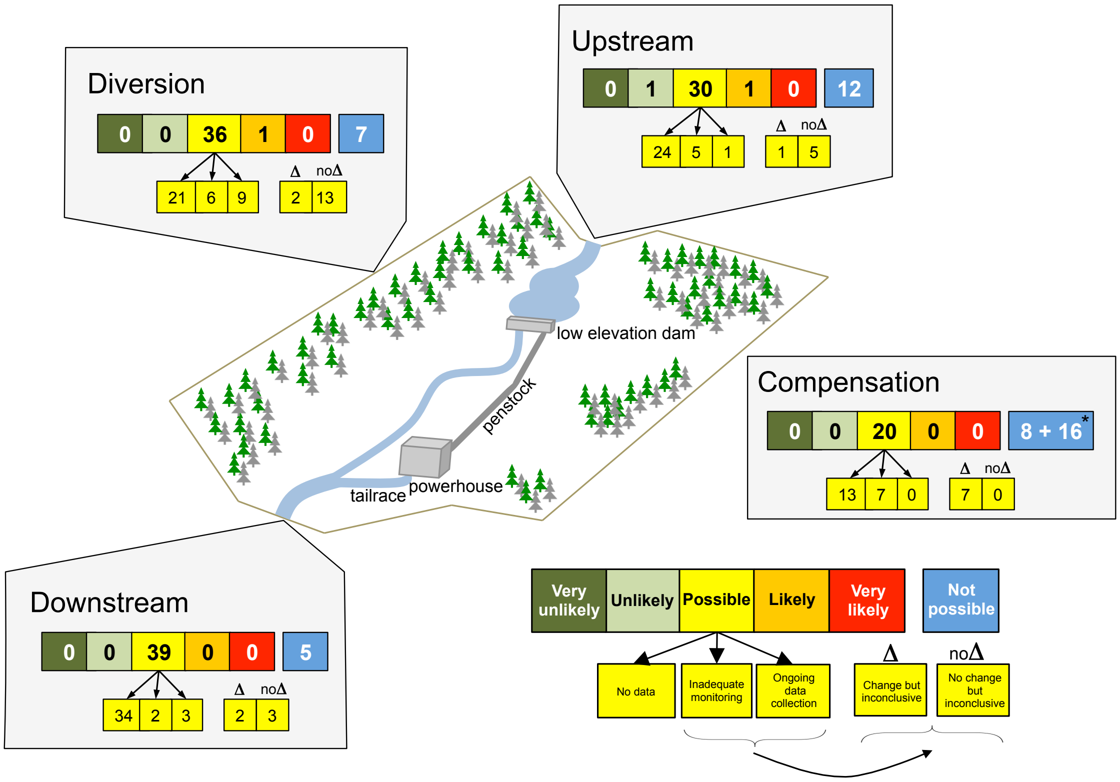

Figure 11: Weight of evidence conclusions for each stream section and compensation habitat for all facilities considered in this report. The number in each box corresponds to the number of facilities with a given likelihood conclusion (legend in bottom right). The asterisk (*) in the *not possible* box for compensation is to denote that for this pathway at 8 facilities no conclusion was possible. Sixteen additional facilities did not require compensation.

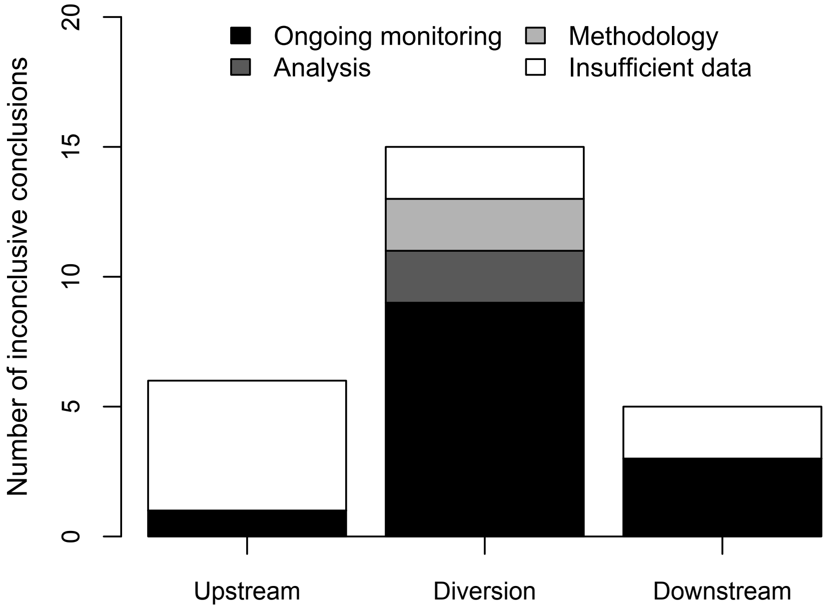

Figure 12: Breakdown of reasons for inconclusive conclusions related to changes in salmonid abundance across stream sections. The four possible reasons for an inconclusive conclusion are: monitoring is ongoing and not yet complete ("Ongoing monitoring"); the methodology used to quantify salmonid abundance was not considered adequate (based on Lewis et al. 2013; "Methodology"); there was no analysis of, or sufficient information on, existing data in the documents reviewed ("Analysis"); or there was insufficient data upon which to base a conclusion (e.g., no controls or baseline data; "Insufficient data").

4.2 DIVERSION REACH

Hypothesis: changes in salmonid abundance and species composition in the diversion reach *are* attributable to the operation of the run-of-river project.

We concluded this hypothesis was *not possible* at seven facilities where salmonids were not present in the diversion reach. At one facility this hypothesis was *likely* and at the remaining 36 facilities we concluded this hypothesis was *possible* (Figure 11).

We concluded this hypothesis was *likely* at one facility because there was strong evidence of a difference between salmonid abundance in the control and diversion reaches after (but not before) the operation of the facility (i.e., significant interaction between time and treatment in BACI analysis). The data suggest that without the run-of-river project the abundance of salmonids in the diversion reach would have increased over the monitoring period commensurate with an observed increase in abundance at the control sites.

At the 36 facilities where the hypothesis was considered *possible,* monitoring of salmonids in the diversion reach had not occurred or been reported at 21 facilities (*possible – no data*), six facilities had inadequate monitoring (*possible – inadequate monitoring*) and nine facilities had ongoing monitoring that would allow for future examination of the abundance of salmonids in the diversion reach (*possible – ongoing data collection*) (Figure 11).

At the 15 facilities where monitoring of the diversion reach is currently inconclusive (six classified as "*possible – inadequate monitoring*" and nine as "*possible - ongoing data collection*"), the available evidence suggested there was no change in the abundance of salmonids in the diversion reach at 13 facilities, while two facilities had evidence of change. The available evidence was considered inadequate at these 15 facilities for the following reasons (Figure 12):

1. monitoring was still ongoing – nine facilities;
2. methodology used to quantify salmonid abundance did not generally follow protocols outlined in Lewis et al. (2013) – two facilities;
3. documents we reviewed contained insufficient explanation or analysis of existing data two facilities; or
4. weaknesses in the monitoring design (e.g., no controls or baseline data) – two facilities.

4.3 DOWNSTREAM REACH

Hypothesis: changes in salmonid abundance and species composition in the downstream reach *are* attributable to the operation of the run-of-river project.

The downstream reach was the least monitored of the three stream sections. Most permits did not require that monitoring be done there because abundance is considered to be a weak detector of potential downstream impacts (Lewis et al. 2013). Instead of abundance, monitoring at some newer facilities is focused on juvenile mortality following ramping incidents (see Appendix 6 for more details). Based on the available data and information, we concluded this hypothesis was *possible* at all 39 facilities where salmonids occurred in the downstream reach. At the remaining five facilities this hypothesis was *not possible* (Figure 11).

At the 39 facilities where the hypothesis was considered *possible,* monitoring of salmonid abundance in the downstream reach had not occurred or been reported at 34 facilities (*possible - no data*), two facilities had inadequate monitoring (*possible – inadequate monitoring*), and three facilities had ongoing monitoring that would allow for future examination of the abundance of salmonids in the downstream reach (*possible – ongoing data collection*) (Figure 11).

At the five facilities where monitoring is currently inconclusive (two classified as "*possible – inadequate monitoring*") and three as "*possible – ongoing data collection*"), the available evidence suggested there was no change in the abundance of salmonids in the downstream reach at three facilities, and evidence of change at two facilities. The available evidence was considered inadequate at these five facilities for one of the following reasons (Figure 12):

1. monitoring was still ongoing – three facilities; or

2. weaknesses in the monitoring design (e.g., no controls or baseline data) – two facilities.

4.4 COMPENSATION

Hypothesis: the construction of compensatory habitat *has* resulted in no net loss of salmonid abundance within the project area.

We concluded this hypothesis was *possible* at 20 facilities. For 16 facilities, compensation was not required at the time the project began operation. No conclusion was possible at the remaining 8 facilities because we were unable to determine if compensation activities were ever required (Figure 11).

At facilities where the hypothesis was considered *possible,* there was no monitoring of salmonid abundance in the compensation habitat at 13 facilities (*possible – no data*) and outcomes were considered inconclusive at the remaining seven facilities (*possible – inadequate*) (Figure 11). At these seven facilities, the evidence suggested that compensation has indeed offset losses in salmonid abundance because lost habitat was replaced. However, we still considered these seven cases inconclusive because the compensation works were designed to offset losses in *habitat* as opposed to *salmonid abundance*. It is important to note that it is standard practice under the Fisheries Act to use habitat as a proxy for fish abundance and conclude that compensation has resulted in no net loss in abundance if there is no net loss in habitat. However, without estimates of the reduction in salmonid abundance as a result of the operation of the facility, and gains in salmonid abundance as a result of the compensation habitat, we could not reach definitive conclusions regarding any net loss in salmonid abundance.

4.5 CONCLUSIONS BY INFORMATION TYPE AND AGE

The facilities that provided the monitoring information evaluated in this report were typically the newest facilities (i.e., “modern” period) while those that provided basic or no information at all tended to be “transition” and “early” period facilities respectively (Table 2). Thus, it is not surprising that when we grouped conclusions by the type of information provided, only the facilities that provided monitoring information yielded conclusions other than *possible* or *not possible* (Figure 13).

The group of facilities for which monitoring reports were available included 10 facilities that have ongoing monitoring (primarily in the diversion reach). This monitoring was designed in such a way that it should be possible to detect large changes in resident salmonid abundance in the future. There were fewer facilities with ongoing monitoring designed such that it would be possible to detect large changes in salmonid populations in the upstream and downstream reaches (Figure 13).

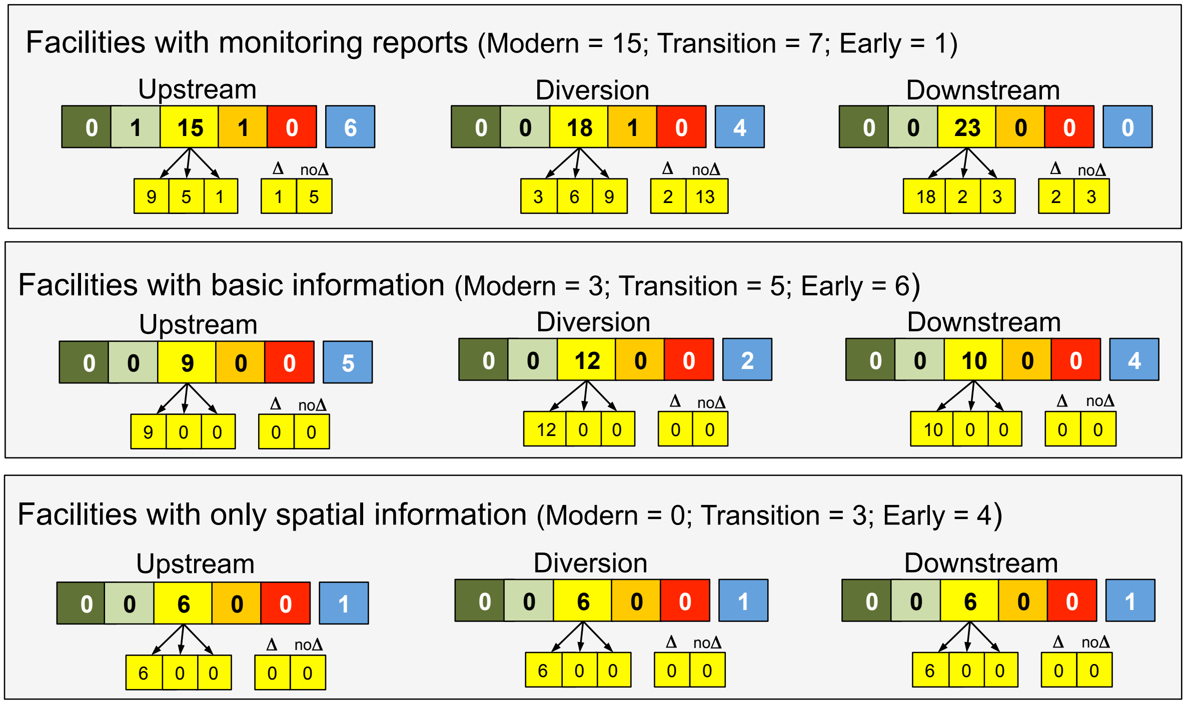

Figure 13: Weight of evidence conclusions for each stream section grouped by the type of available information used to reach conclusions. The number in each box corresponds to the number of facilities with a given conclusion (Figure 8). The number of facilities from each power call period (Modern, Transition and Early) is denoted in brackets in each box.

5 Synthesis of evidence by impact pathway

This Section details the WOE conclusions that could be reached at the scale of individual hypothesized impact pathways (middle portion of the triangle in Figure 5). The question we asked at this scale is: *“is there evidence for or against changes in salmonid abundance or species composition attributable to each of the ten overall pathways of effect?”* The conclusions reached for each individual mechanistic cause-effect link within the overall pathways described here are provided in Appendix 6.

Note that **all hypotheses are phrased as though they were true so that they form a testable assertion, but they are not necessarily true (or false)**.

5.1 UH1: ENTRAINMENT

Hypothesis UH1: Entrainment of fish in the penstock and / or stranding in the spillway *does* cause a decline in salmonid abundance in the upstream reach.

Fish entrainment involves fish being drawn into the penstock and then passing through the turbines. The risk of entrainment depends on the presence and effectiveness of intake screens and on the volume of water being diverted (Hatfield et al. 2003). The probability of entrainment increases as the volume of water diverted increases. Facility factors that can influence this impact pathway include: the presence / absence of screening on the intake; the change in water pressure from the headpond to the penstock, turbines and tailrace; the size and design of the turbines; and ramping rates. Site factors that affect this pathway include the abundance of salmonids in the upstream reach and their seasonal migratory behaviour.

Hypothesis UH1 was considered *very unlikely* at four facilities where the use of a Coanda screen prevented salmonids from being entrained in the penstock, and *possible* at 28 facilities. We concluded hypothesis UH1 was *not possible* at 12 facilities due to salmonids either not being present in the upstream reach or not being able to access this habitat due to steep gradients (Figure 14).

At the facilities where the hypothesis was considered *possible,* monitoring of salmonids in the upstream reach had not occurred or been reported at 20 facilities. Five facilities had inadequate monitoring and three facilities had ongoing monitoring that would allow for future examination of the abundance of salmonids in the upstream reach. Although we found the evidence to be inconclusive, it suggested there was some change in the abundance of salmonids in the upstream reach at one facility, but no change at seven facilities (Figure 14).

Our conclusions about the individual links in the UH1 pathway are detailed in Appendix 6. In summary, we concluded that entrainment of salmonids in the penstock *likely* results in mortality at 28 facilities where there were salmonids in the upstream reach and no evidence of mitigation in place to prevent entrainment. Eight other facilities, which we concluded had salmonids in the upstream reach, had mitigation measures in place to prevent entrainment. Of these mitigation measures, Coanda screens were very effective at minimizing the potential for entrainment. The effectiveness of more experimental systems, including strobe lights and underwater acoustic deterrents, appeared to be limited.

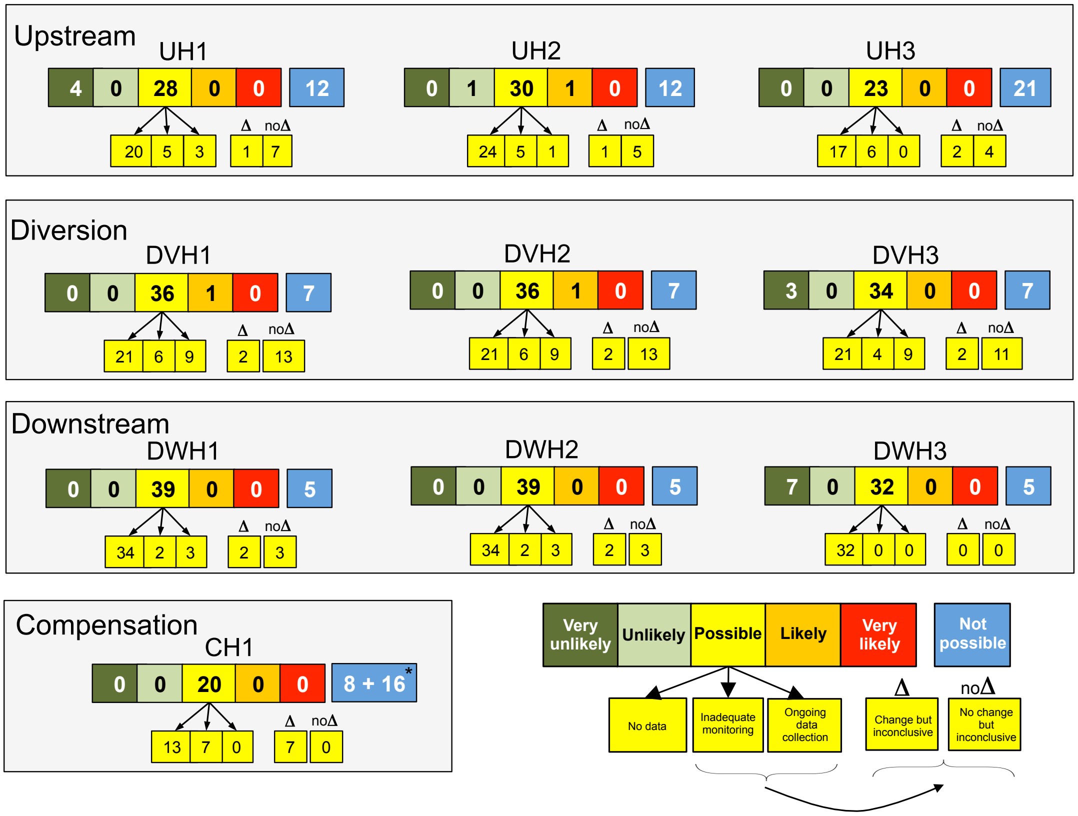

Figure 14: Weight of evidence conclusions for each overall impact pathway based on all facilities considered. The two numbers in the *Not possible* box for Compensation (with the asterisk) correspond to those facilities at which no conclusion was possible (8) and those that did not require compensation (16).

5.2 UH2: UPSTREAM HABITAT

Hypothesis UH2. The creation of a headpond *does* change salmonid species composition or abundance in the upstream reach.

Run-of-river facilities typically utilize a diversion weir (or small dam) to create a headpond where water is diverted into the penstock. The use of a diversion weir may cause no measureable increase in upstream water level, may increase water levels upstream within the bankfull channel through backwater effects, or may backwater beyond the high water mark and inundate riparian habitats (Lewis et al. 2013). Streamflow dynamics shape the physical habitat within a channel, which in turn influences the species composition of species that utilize it (Bunn and Arthington 2002). As a result, the conversion of habitat upstream of the diversion weir from stream habitat to lake-like habitat can alter local species distributions (Butler and Wahl 2011) and potentially lead to a decrease in limiting habitat for some life stages and / or an increase in limiting habitat for others.

Facility factors which influence this impact pathway include: the size of the headpond; and the effectiveness of sediment management practices in removing large diameter sediment. Site factors that affect this pathway include: the abundance and species composition of salmonids in the upstream reach; and the type of habitat upstream of the weir before construction.

Hypothesis UH2 was considered to be *unlikely* at one facility, *possible* at 30 facilities, and *likely* at one facility. We concluded that UH1 was *not possible* at 12 facilities where salmonids were either not present in the upstream reach or were not able to access this habitat due to steep gradients (Figure 14). The hypothesis was *likely* at one facility because before-after monitoring demonstrated that the creation of a headpond resulted in increased abundance of Dolly Varden relative to rainbow trout, thereby altering the upstream species composition of salmonids. At the facility where UH1 was *unlikey*, BACI monitoring of the species composition and abundance of salmonids in the upstream reach provided strong evidence that species composition and abundance had not changed following the creation of the headpond.

At the facilities where we concluded the hypothesis was *possible,* monitoring of salmonids in the upstream reach had not occurred or been reported at 19 facilities, five facilities had inadequate monitoring and one facility had ongoing monitoring that would allow for future examination of the abundance and species composition of salmonids in the upstream reach. Although we found the evidence to be inconclusive, it suggested there was some change in the abundance and species composition of salmonids in the upstream reach at one facility, but no change at five facilities (Figure 14).

Our conclusions about the individual links in the UH2 pathway are detailed in Appendix 6. In summary, there was clear evidence of the alteration of habitat in the headpond at 11 facilities, and so the hypothesis that the construction of a weir results in a change in upstream habitat was considered *very likely* at these 11 facilities and *likely* at the remaining 33 facilities.

5.3 UH3: UPSTREAM PASSAGE

Hypothesis UH3. The construction of a dam and associated works *does* impair the upstream passage of salmonids resulting in a change in salmonid species composition or abundance in the upstream reach.

Small-scale hydropower stations, including run-of-river projects with relatively low dams, represent potential barriers to the upstream / downstream movement of fish and other biota. For species that use different habitats in different phases of their life, the connectivity of those habitats is fundamental to life cycle completion. Lack of availability of one or more habitat, or poor connectivity between habitats, may fragment a population and / or lead to declines in abundance. Migratory fish species are particularly susceptible to disruptions in connectivity between habitats. Facility factors that can influence this impact pathway include: the magnitude and timing of spill over the weir; and the presence / absence of fishways and fish ladders. Site factors that affect this pathway include: natural barriers to salmonid movement and migration; the presence / absence of migratory salmonids upstream of the facility; and the timing of upstream migration.

We concluded that hypothesis UH3 was *possible* at 23 facilities (Figure 14). At these facilities, monitoring of salmonids in the upstream reach had not occurred or been reported at 17 facilities. Six facilities had inadequate monitoring and no facilities had ongoing monitoring that would allow for future examination of the abundance and species composition of salmonids in the upstream reach. Although we found the evidence to be inconclusive, it suggested there was some change in the abundance of salmonids in the upstream reach at two facilities, but no change at four facilities.

At 21 facilities we concluded this hypothesis was *not possible* because salmonids were not present (12 facilities) or because movement of resident salmonids between reaches was not possible because, for example, there was a barrier to upstream movement in the upper section of the diversion reach (nine facilities).

Our conclusions about the individual links in the UH3 pathway are detailed in Appendix 6. In summary, we concluded that it was *possible* that diversion weirs could act as a barrier to fish movement at approximately half of the facilities we considered (23 facilities). These *possible* conclusions were primarily because there were no data with which to assess the extent to which the weir does, or does not, impede the upstream movement of salmonids (17 facilities), or because monitoring was ongoing (four facilities). Those sites where monitoring was ongoing were facilities with fishways in place but no baseline information on the number of fish that typically migrated past the intake site prior to construction.

5.4 DVH1: MOVEMENT OF SEDIMENT AND FOOD

Hypothesis DVH1. Construction of a dam and diversion of water *causes* a change in the timing and magnitude of the import of gravel, larger sediment, large woody debris and fish food organisms to the diversion reach, resulting in changes to the area and quality of spawning and rearing habitat and changes to salmonid growth and abundance in the diversion reach.

Impoundments and diversions can disrupt the connectivity of river systems and alter sediment and organic matter redistribution within a watershed (Renöfält et al. 2010; Walters and Post 2011). The degree to which large sediment and channel-forming elements get trapped in the headpond area depends on the characteristics of the diversion structures. Small dams have the greatest potential to pass sediment, particularly during high flow events (Kondolf 1997). Altering the timing and magnitude of downstream movement of sediment and organic material can lead to changes in salmonid rearing habitat and juvenile survival (Suttle et al. 2004; Harvey et al. 2009).

Facility factors that can influence this impact pathway include: the use and effectiveness of approaches to remove accumulated sediment and large woody debris from the headpond (e.g., sluicegates); the magnitude and frequency of flow diversion; and the length of the diversion reach. Site factors that affect this pathway include: the channel type in the diversion reach, including gradient and cross-sectional shape; the abundance of salmonids in the diversion reach; and the amount of spawning and rearing habitat in the diversion reach.

Hypothesis DVH1 was considered *possible* at 36 facilities, *likely* at one facility and *not possible* at seven facilities because salmonids were not present in the diversion reach (Figure 14). We concluded this hypothesis was *likely* at one facility because there was strong evidence of a difference between control and diversion reach salmonid abundance after (but not before) the operation of the facility (i.e., significant interaction between time and treatment in BACI analysis). The analysis suggested that without the run-of-river project, the abundance of salmonids in the diversion reach would have increased over the monitoring period commensurate with an increase in abundance at the control sites.

At those facilities where we concluded the hypothesis was *possible,* monitoring of salmonids in the upstream reach had not occurred or been reported at 21 facilities, and for six facilities monitoring was considered inadequate. Nine facilities had ongoing monitoring that would allow for future examination of the abundance and species composition of salmonids in the diversion reach. Although we found the evidence to be inconclusive, it suggested there was some change in the abundance of salmonids in the diversion reach at two facilities, but no change at 13 facilities (Figure 14).

Our conclusions about the individual links in the DVH1 pathway are detailed in Appendix 6. In summary, we concluded that changes in sediment recruitment, retention and species composition as well as invertebrate drift were *possible* at all facilities. Changes in spawning success as a result of changes in the timing and magnitude of the import of gravel and larger sediment were also considered *possible* at all facilities with salmonids in the diversion reach (37 facilities). We concluded changes in rearing success were *unlikely* at two facilities, *likely* at one facility and *possible* at the remaining facilities with salmonids in the diversion reach.

5.5 DVH2: FLOW, HABITAT AND FISH MOVEMENT

Hypothesis DVH2. Change to patterns of flow in the diversion reach compared to conditions in the absence of impoundment *causes* change in salmonid movement, growth and abundance in the diversion reach.

Flow plays a profound role in the lives of fish in freshwater, with critical life events (e.g., timing of reproduction, spawning behaviour, egg survival, growth patterns and recruitment) linked to the flow regime. Changes in flow within the diversion reach as a result of diverting water down the penstock can result in changes in habitat for benthos and salmonids (Dewson et al. 2007; Wu et al. 2009; Mueller et al. 2011; Walters and Post 2011) as well as reduced invertebrate production (Deitch et al. 2009). Changes in flow can also reduce food production and habitat connectivity. Alteration to habitat and food production may both result in reductions in salmonid growth and survival (Lewis et al. 2013).

The unnatural timing of rising flows in regulated reaches can lead to the loss of cues for fish migration (Bunn and Arthington 2002), affecting the timing of fish movements even when environmental flows are released (Larinier 2008). Disruption of migratory timing and pattern may impede salmonid reproduction (Bunn and Arthington 2002). Alternatively, depending on channel morphology and flow dynamics, the reduction of peak flows could have a positive effect on habitat conditions for juvenile salmonids (Robson et al. 2011).

The facility factors most likely to influence this impact pathway include: the length of the diversion reach; the magnitude, frequency and timing of flow diversion; and minimum flows in the diversion reach. Site factors that affect this pathway include: natural barriers to salmonid movement and migration; the abundance of salmonids in the diversion reach; and the amount of spawning and rearing habitat in the diversion reach.

We concluded that hypothesis DVH2 was *possible* at 36 facilities, *likely* at 1 facility and *not possible* at 7 facilities because salmonids were not present in the diversion reach (Figure 14). As discussed under hypothesis DVH1, we concluded this hypothesis was *likely* at one facility because there was strong evidence of a difference between control and diversion reach salmonid abundance after (but not before) the operation of the facility (i.e., significant interaction between time and treatment in BACI analysis, control site abundance increased more post project than diversion reach abundance).

At those facilities where we concluded the hypothesis was *possible,* monitoring of salmonids in the diversion reach had not occurred or been reported at 21 facilities, and six facilities had inadequate monitoring. Nine facilities had ongoing monitoring that would allow for future examination of the abundance and species composition of salmonids in the diversion reach. Although we found the evidence to be inconclusive, it suggested there was some change in the abundance of salmonids in the diversion reach at two facilities, but no change at 13 facilities (Figure 14).

Our conclusions about the individual links in the DVH2 pathway are detailed in Appendix 6. In summary, we concluded changes in flow in the diversion reach *very likely* (3 facilities) or *likely* (41 facilities) resulted in changes in habitat based on either empirical estimates of change in usable habitat or first principles / literature, respectively. We also concluded that changes in invertebrate drift were *possible* at all facilities as a result of alterations to flow in the diversion reach. For two facilities, we concluded it was *unlikely* that changes in flow had led to the alteration of upstream movement of juveniles and spawners and downstream movement of smolts.

5.6 DVH3: TEMPERATURE AND OXYGEN

Hypothesis DVH3. Change to patterns of flow in the diversion reach compared to conditions in the absence of impoundment *causes* changes in temperature and oxygen conditions sufficient to affect salmonid growth and abundance in the diversion reach.

In regulated river systems, including run-of-river operations (Lewis et al. 2013), modified flow regimes are often accompanied by shifts in the thermal regime (Bunn and Arthington 2002). Reduction of flow can also modify levels of dissolved oxygen (Lewis et al. 2013). Depending on species sensitivity and life-history stage, these changes in habitat attributes can affect development and survival of salmonids. Even small changes in water temperature have the ability to cause significant impacts to fish (Clarke et al. 2008; Lewis et al. 2013). Warm temperatures have been shown to reduce fecundity, decrease egg survival, delay growth of fry and smolts, reduce rearing density, and increase exposure to disease (McCullough 1999). Low levels of dissolved oxygen can decrease growth rates or cause mortality among sensitive species (McCullough 1999).

Facility factors that can influence this impact pathway include: the length of the diversion reach; the magnitude, frequency and seasonal timing of flow diversion; the geographic location of the facility (e.g., coastal vs. Southern Interior), which can influence temperatures experienced in the watershed; and minimum flows in the diversion reach. Site factors that affect this pathway include: riparian vegetation; channel roughness; and the abundance of salmonids in the upstream reach, their life stage and seasonal migratory behaviour.

We concluded this hypothesis was *very unlikely* at three facilities where, based on monitoring, there was no evidence of changes in temperature and dissolved oxygen following the operation of the facility (Figure 14). We concluded this hypothesis was *possible* at 34 facilities and *not possible* at seven facilities because salmonids were not present in the diversion reach. For those facilities where we concluded the hypothesis was *possible,* monitoring of salmonids in the diversion reach had not occurred or been reported at 21 facilities, and four facilities had inadequate monitoring. Nine facilities had ongoing monitoring of salmonids in the diversion reach that would allow for future examination of the abundance and species composition of salmonids. Although we found the evidence to be inconclusive, it suggested there was some change in the abundance of salmonids in the diversion reach at two facilities, but no change at 11 facilities. Our conclusions about the individual links in the DVH3 pathway are detailed in Appendix 6.

5.7 DWH1: MOVEMENT OF SEDIMENT AND FOOD

Hypothesis DWH1. Construction of a dam and diversion of water *causes* a change in the timing and magnitude of import of gravel and larger sediment, large woody debris and fish food organisms to the downstream reach resulting in changes to the area and quality of spawning and rearing habitat and change to salmonid growth and abundance in the downstream reach.

This hypothesis carries through the concepts outlined in DVH1, because the processes at work in the diversion reach ay also occur in the downstream reach. The presence of weirs and penstocks can alter the amount and distribution of woody debris and gravel downstream of run-of-river projects (Lovekin and Hotte 2009). Reduced stream flow via flow diversion limits the recruitment of gravel and larger sediment into downstream channels (Baker et al. 2011). Below the dam, including in the downstream reach, large woody debris and other channel-forming elements become less prevalent. Altering the timing and magnitude of downstream movement of sediment and organic material may lead to changes in salmonid rearing habitat and juvenile survival (Suttle et al. 2004; Harvey et al. 2009).

Facility factors that can influence this impact pathway include: the use and effectiveness of approaches to remove accumulated sediment and large woody debris from the headpond (e.g., sluicegates); the size of the headpond; the magnitude and frequency of flow diversion; and the length of the diversion reach. Site factors that affect this pathway include: the channel type in the downstream reach, including gradient and cross-sectional shape; the size and shape of sediment; the degree of benthic food production in the diversion reach; the abundance of salmonids in the downstream reach; and the amount of spawning and rearing habitat in the downstream reach.

Hypothesis DWH1 was considered *possible* at 39 facilities, and *not possible* at five facilities (Figure 14). At those facilities where the hypothesis was considered *possible,* monitoring of salmonids in the downstream reach had not occurred or been reported at 34 facilities and monitoring was considered inadequate at two facilities. Three facilities had ongoing monitoring that would allow for future examination of the abundance and species composition of salmonids in the downstream reach. Although we found the evidence to be inconclusive, it suggested there was some change in the abundance of salmonids in the downstream reach at two facilities, but no change at three facilities (Figure 14).

Our conclusions about the individual links in the DWH1 pathway are detailed in Appendix 6. In summary, we concluded that changes in sediment recruitment, retention and species composition as well as invertebrate drift in the downstream reach were *possible* at all facilities with a downstream reach (39 facilities). Changes in rearing and spawning success as a result of changes in the timing and magnitude of the import of gravel and larger sediment were also considered *possible* at all facilities with salmonids in the downstream reach.

5.8 DWH2: FLOW RAMPING AND STRANDING

Hypothesis DWH2. The rate at which water is released from the powerhouse (ramping rate) *does* strand fish and change the production of fish food organisms leading to changes in salmonid growth and abundance in the downstream reach.

Flow ramping is change in the rate at which water is discharged from the penstock into the downstream reach (Cathcart 2005). A common finding in studies of hydropower facilities has been that more rapid flow fluctuations have a greater potential to strand fish downstream (Nagrodski et al. 2012). When a facility decreases or suddenly stops flow though the penstock, changes in flow downstream occur until the water that has stopped flowing through the penstock is diverted back through the diversion reach. The longer the diversion reach, the longer it will take for flow to be restored downstream of the powerhouse. Turbines that stop the flow of water through the powerhouse when they shut down (e.g., Francis turbines) can result in greater ramping rates than turbines that maintain flows (e.g., Pelton turbines). The use of by-pass valves, which allow for flow to be diverted around a Francis turbine, can reduce the potential for flow ramping.

When decreases in flow are rapid, downstream habitat can be temporarily dewatered. The cross-sectional shape and type of the downstream channel will influence the extent to which rapid changes in flow result in dewatered stream margins. Flow variation in deep, narrow channels will result in less dewatered habitat than in shallow, wide channels. Dewatering of stream margins can lead to the stranding of salmonids (particularly juveniles) and mortality as a result of drying out, freezing, or increased predation (e.g., Cushman 1985; Hvidsten 1985; Hunter 1992; Bradford 1997; Saltveit et al. 2001; Halleraker et al. 2003; Irvine et al. 2009).

In addition to the factors listed above, facility factors that can influence this impact pathway include: the frequency and seasonal timing of ramping incidents and emergency shutdowns; the gradient of the diversion reach; and the implementation of stranding surveys and fish recoveries following ramping incidents. Additional site factors in the downstream reach that affect this pathway include: the abundance and life stage of salmonids that are present; and the amount of spawning and rearing habitat.

For the 39 facilities with salmonids in the downstream reach, we concluded hypothesis DWH2 was *possible* (Figure 14). For the five facilities where salmonids were not present in the downstream reach, the hypothesis was considered *not possible*. For those facilities where the hypothesis was considered *possible,* monitoring of salmonids in the downstream reach had not occurred or been reported at 34 facilities. For two facilities, monitoring of salmonid abundance was considered inadequate. Three facilities had ongoing monitoring that would allow for future examination of the abundance and species composition of salmonids in the downstream reach. Although we found the evidence to be inconclusive, it suggested there was some change in the abundance of salmonids in the downstream reach at two facilities, but no change at three facilities (Figure 14).

Our conclusions about the individual links in the DWH2 pathway are detailed in Appendix 6. Monitoring of salmonid abundance and species composition in the downstream reach is typically not required because it is considered to be a weak detector of potential downstream impacts (Lewis et al. 2013). Instead of abundance, monitoring at some newer facilities is focused on juvenile mortality following ramping incidents. Three facilities had direct evidence of stranding mortality due to rapid changes in flow in the downstream reach attributable to facility operation (Appendix 6). An additional eight facilities had indirect evidence that stranding mortality may have occurred (i.e., violations of ramping rate limits during sensitive times of year for juvenile salmonids).

5.9 DWH3: TOTAL DISSOLVED GAS PRESSURE

Hypothesis DVH3. Entrainment of air in the power plant *does* change total dissolved gas conditions downstream of the project sufficiently to cause gas bubble disease and affect salmonid growth and abundance in the downstream reach.

A condition known as “gas bubble disease” can occur in salmonids when water is super-saturated with gas. Super-saturation can result from the entrainment of air into the spill of water from dams (Hildebrand 1980). Gas super-saturation and gas bubble disease in salmonids has been an issue at larger hydroelectric facilities, particularly during periods of high flow and spill (Weitkamp and Katz 1980). In lower head diversion projects where the water is released before re-entering the stream and is no longer under pressure, there is less potential for gas bubble disease (Hildebrand 1980) and any impact would likely be very localized. It isn’t well known to what extent air is entrained into water entering the penstock at run-of-river facilities, and Lewis et al. (2013) recommend monitoring total dissolved gas pressure (i.e., the degree of super-saturation).

For seven facilities, we concluded hypothesis DWH3 was *very unlikely.* Monitoring at these facilities indicated no increase in total dissolved gas pressure in the downstream reach due to entrainment of air in the penstock. For 32 facilities, we concluded this hypothesis was *possible* (no total dissolved gas pressure data had been collected), and at the remaining five facilities the hypothesis was considered *not possible* because salmonids were not present in the downstream reach (Figure 14).

5.10 CH1: COMPENSATION

Hypothesis CH1. Off-channel constructed fish habitat *does* replace lost fish habitat and fish production in the project area resulting in no net loss in the species composition and abundance of salmonids.

When the construction and operation of a project is expected to have negative impacts on fish that cannot be avoided or mitigated, compensation habitat is required to offset the effects. The amount and nature of the habitat required will vary with each project. Typically twice as much habitat is required to be created to compensate for habitat that is lost (Quigley and Harper 2006).

We concluded that hypothesis CH1 was *possible* at 20 facilities (Figure 14). Monitoring of salmonids in the compensatory habitat had not occurred or been reported for 13 facilities, and had occurred but was considered inadequate at seven facilities (Figure 14). For these seven facilities, the evidence suggested that compensation did offset losses in salmonid abundance. However, these seven cases were still considered inconclusive because the compensation works were designed to offset losses in *habitat* rather than *salmonid abundance*. Under the Fisheries Act, habitat is used as a proxy for fish abundance and so it is standard practice to conclude that compensation has resulted in no net loss in abundance if there is no net loss in habitat. However, without estimates of the reduction in salmonid abundance resulting from the operation of the facility, and gains in salmonid abundance resulting from the compensatory habitat, we could not reach definitive conclusions regarding any net change in salmonid abundance.

We concluded that hypothesis CH1 was *not possible* for 16 of the remaining 24 facilities, because compensatory habitat was not required at the time of project development. For the last 8 facilities, no conclusion was possible because we were unable to determine if compensatory habitat construction was required.

6 Non-operational run-of-river projects

Fourteen non-operational run-of-river hydroelectric facilities, in various stages of development, were identified at the outset of the review. All are expected to have a generating capacity of more than 10 mW, and diversion reaches ranging from two to nine kilometres in length. In comparison to operational run-of-river facilities, non-operational facilities involved fewer very small facilities but were otherwise of similar size to the present operational facilities (Figure 15). The projected lengths of diversion reaches at non-operational facilities do not appear to be any longer than current operational facilities (Figure 15).

All non-operational facilities (except for one where we were unable to determine the location of the diversion reach) are predicted to have resident salmonids in the upstream, diversion and downstream reaches (Figure 16). Anadromous salmonids are predicted to be present within the upstream, diversion and downstream reaches at 25%, 33% and 66% of facilities, respectively (Figure 16).

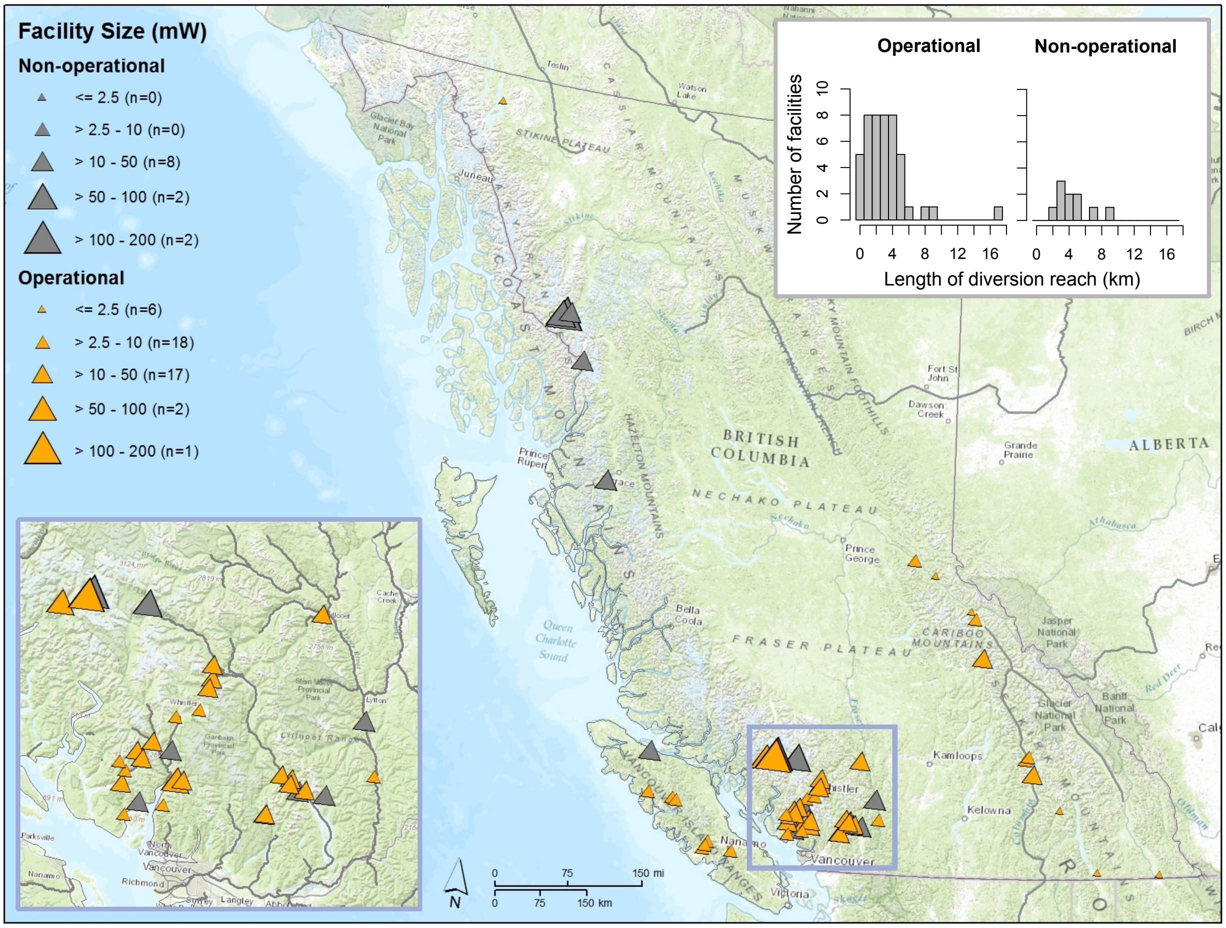

Figure 15: Distribution and size (in MWs) of non-operational run-of-river hydroelectric projects in various stages of commissioning in BC. Inset illustrates distribution of diversion reach lengths between operational and non-operational facilities. Note only 12 non-operational facilities are plotted because coordinates could not be acquired for two facilities.

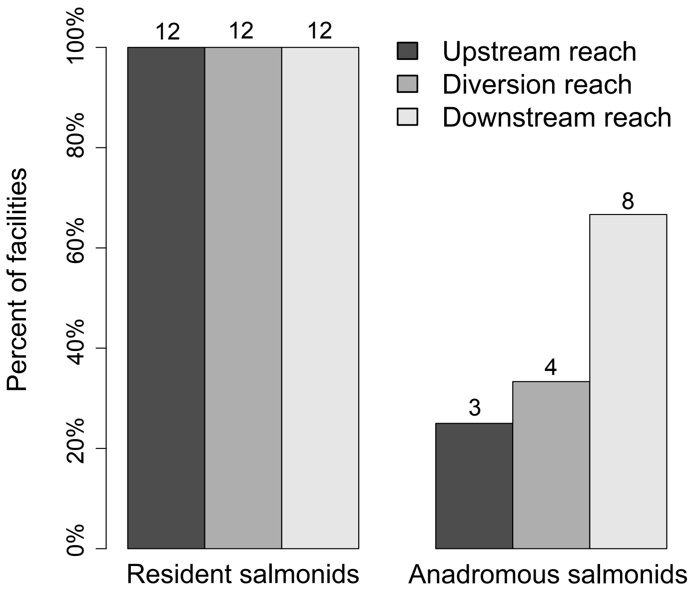

Figure 16: Percent of non-operational run-of-river hydroelectric facilities identified for this review where resident and anadromous salmonids are present. Bars show the number of projects with known or inferred resident (left side) and anadromous (right side) salmonid occurrence. We based our inferences about species presence on the spatial metrics described Appendix 3.

7 Cumulative effects

As described in Section 1.3, this review focused on the following question:

> *To what extent do the impacts of run-of-river hydroelectric projects result in quantifiable changes in the abundance of salmonids within the upstream, diversion and downstream reach sections of a hydroelectric project?*

Ultimately, however, stakeholders may be more interested in a broader question:

> *What harm is being caused to the overall condition of salmonid populations by run-of-river hydroelectric projects?*

The latter is a cumulative effects question, and answering it for any given salmonid population requires an understanding of:

a) The condition of a fish population relative to thresholds of abundance or productivity, or limits of acceptable change, given natural variability in climate and other factors; and
b) The relative contribution of run-of-river projects within the full suite of anthropogenic stresses on the population.

The conservation of a valued ecosystem component (e.g., a salmonid population) depends on ensuring that the combined effects from all stresses on the populations are kept below the point at which negative effects occur (Duinker and Greig 2006). The significance of any one stressor can only be assessed within the larger context of what other stressors are involved, and the resilience of the valued ecosystem component to their aggregate effects. Therefore, assessing the long-term effects of run-of-river projects on salmonid populations cannot be done in isolation from other stressors (e.g., forestry, mining, urbanization, oil and gas development, agriculture, water withdrawals).

Multiple run-of-river projects may have an aggregate effect on salmonid populations. For example, consider two projects on the same river, each causing a 20% reduction in the movement of sediment downstream. One might conclude that neither project's impact reduces levels below 80% of pre-project levels. However, if the first project reduces sediment movement downstream to 80% of pre-project levels, then the second project's 20% reduction acts on levels that are at 80%, rather than the original 100%. Thus, downstream of the second project, sediment movement is reduced to 64% of historic levels. If an alteration in the movement of sediment to below 70% was deemed the level that would significantly affect fish populations, an exceedance of that threshold might not be detected by examining each facility independently. When monitoring is conducted on a project-by-project basis, assessment of impacts at one project may not account for the additive or synergistic effects of impacts, or mitigations, on the same population from another project.

Space and time are both important dimensions in cumulative impact assessment. Some cumulative impacts may take years or decades to appear. For example, in the sediment movement scenario above, depending on the distance between facilities, tractive force, etc, a spawning substrate deficit downstream of the second facility may take years to appear. In this case, monitoring will simply be looking in the rear view mirror; scenario projections may be needed to anticipate and avoid such impacts.

Well designed BACI monitoring done at the scale of individual projects will help to isolate the impacts of each project on salmonid habitat and abundance in upstream and diversion reaches. However, project-level monitoring alone is unlikely to be sufficient to isolate effects in downstream reaches; it is also unlikely to determine the overall effects of multiple facilities, or to proactively anticipate and mitigate their cumulative effects.

Current monitoring protocols are not designed to examine cumulative effects of multiple projects and other landscape level stressors on salmonids, and our review did not specifically evaluate cumulative effects. Thus, the cumulative effect of multiple run-of-river projects and other landscape level activities remains a gap in the understanding of how run-of-river hydro projects may affect salmonids in BC. However, it should be noted that initiatives are currently underway to develop approaches to quantify cumulative effects on salmonids, e.g., the Skeena Lake Sockeye Conservation Units Habitat Report Cards by the Pacific Salmon Foundation, the Cumulative Effects Assessment Framework pilot projects by the Province of BC, and ongoing research at Simon Fraser University.

8 Conclusions

In this section of our report, we structure our conclusions around the eight guiding questions that motivated this review (see Section 1.1).

8.1 ARE RUN-OF-RIVER HYDRO PROJECTS NEGATIVELY IMPACTING SALMONIDS? IF SO WHERE IS THE IMPACT OCCURRING AND ARE LOCATIONAL, REGIONAL, OR SITE ISSUES CONTRIBUTING FACTORS?

We found that salmonids were present in at least one stream section at 43 of the 44 operational facilities that were the focus of this report. Both resident and anadromous salmonids were less likely to be found in the upstream reach than in the diversion or downstream reaches. Resident salmonids such as trout were about 16 times more likely to be present in upstream reaches than were salmon and steelhead; they were five times more likely to be found in diversion reaches, and twice as likely to be found in downstream reaches (Figure 10).

At 17 of the 44 operational facilities, salmonids were very likely present but we had no information on salmonid abundance beyond spatial data from GIS analyses upon which to further evaluate their presence and therefore the pathway.

Our review of the available literature confirms that run-of-river hydro projects have the potential to negatively affect the abundance of salmonids. However, based on the monitoring documents reviewed for this report, we found *evidence* of change in abundance attributable to the operation of a facility at only one facility (in the diversion reach), and evidence of change in species composition at only one facility (in the upstream reach). *The absence of evidence for negative effects on salmonid abundance does not preclude that such impacts do occur, as there are serious data gaps (especially for older facilities), and monitoring challenges in detecting such effects*. For most of the impact pathways we considered, there were data limitations or currently inconclusive monitoring results preventing us from concluding these pathways were either *likely* or *unlikely*, resulting in an outcome of *possible* at this time.

We reached more definitive conclusions (i.e., a conclusion other than *possible*) for the following pathways.

- UH1: Changes in salmonid abundance in the upstream reach due to entrainment in the penstock were *very unlikely* at four facilities and *not possible* at 12 facilities.
- UH2: Changes in salmonid abundance and species composition in the upstream reach due to alteration of upstream habitat were *likely* at one facility, *unlikely* at one facility and *not possible* at 12 facilities.
- UH3: Changes in salmonid abundance and species composition in the upstream reach due to the facility blocking upstream migration were *not possible* at 21 facilities.

- DVH1 / 2: Changes in salmonid abundance in the diversion reach due to alteration of flow and / or movement of sediment and food were *likely* at one facility and *not possible* at seven facilities.
- DVH3: Changes in salmonid abundance in the diversion reach due to changes in temperature and / or dissolved oxygen were *very unlikely* at three facilities and *not possible* at seven facilities.
- DWH1 / 2: Changes in salmonid abundance in the downstream reach due to stranding and / or alteration of movement of sediment and food were *not possible* at five facilities.
- DWH3: Changes in salmonid abundance in the downstream reach due to changes in total dissolved gas pressure were *very unlikely* at seven facilities and *not possible* at five facilities.

At older facilities, we may never be able to draw conclusions about the likelihood of impacts on salmonid abundance. However, re-established monitoring at older facilities could be compared to reference conditions to gain insight into whether large magnitude changes in salmonid abundance in the diversion reach have occurred. Of the 23 facilities that provided detailed monitoring data, 10 had ongoing monitoring of salmonids that follow recently recommended long-term monitoring protocols (Lewis et al. 2013). These investigations, primarily focused on the diversion reach, should allow for a more complete evaluation once the first phase (minimum five years) of monitoring is complete. As a result, we currently find ourselves with insufficient information to conclude that impacts on salmonid abundance are either *likely* or *unlikely* at most facilities; however, subsequent evaluations of ongoing monitoring will help to deliver more definitive conclusions and close existing knowledge gaps regarding large magnitude (>50%) changes in resident salmonid populations within diversion reaches at modern facilities. Smaller magnitude changes in resident fish populations, and changes in anadromous salmonid populations, are less likely to be detected by current monitoring protocols than are larger changes, except where densities of resident fish populations have lower than average natural variability. Detection sensitivity can also be increased with multi-facility analyses (discussed below in Section 9.3).

We could not evaluate the extent to which locational, regional and site-specific factors correlate with impacts because there were so few facilities for which we could conclude that impacts were *likely* or *unlikely*.

8.2 WHAT ASPECTS OF OPERATIONS ARE PROBLEMATIC, CONSIDERING RIVER SEGMENTS?

Monitoring is focused on the diversion reach at all run-of-river hydroelectric projects because it is the stream section that experiences reduced flow as a result of facility operation. However, depending on the distribution of salmonids within a run-of-river project area, it may be the upstream or downstream reaches that are the most likely to be affected. For example, the diversion reach may have steep gradients with limited salmonid habitat, but the reaches downstream of the powerhouse or upstream of the weir may encompass rearing and / or spawning habitat. In these cases, flow ramping downstream or a loss of connectivity upstream may be more important for salmonids than changes in flow in the diversion reach. Because of the emphasis of monitoring in the diversion reach, and because there were so few instances where we could conclude that impacts to salmonids were *likely* or *unlikely*, we are currently unable to evaluate with confidence which river sections are most at risk for impacts. However, the answer to this question is also likely to be very site specific.

8.3 WHAT IS THE IMPACT? DOES IT INVOLVE DIRECT MORTALITY, LIFE CYCLE IMPAIRMENT, OR AFFECTS ECOLOGICAL FUNCTIONS?

To assess the potential mechanisms of impacts on salmonids, we evaluated the individual cause-effect links within each impact pathway. For most cause-effect links, there was insufficient information to conclude that impacts were either *likely* or *unlikely*; this resulted in a conclusion of *possible.*

However, we reached a conclusion of *likely* or *very likely* for the following cause-effect links (see Appendix 6 for additional details).

- UH1-1: Based on the absence of mitigation works to prevent entrainment, relevant literature and first principles, entrainment was considered *likely* to cause fish mortality at 28 facilities. There are no facilities where changes in salmonid abundance or species composition were considered *likely* through this mechanism.
- UH2-1: Based on relevant literature and first principles, construction of a dam and associated works was considered *likely* to cause a loss of lotic habitat area and a gain of lentic habitat area and / or aggradation of the upstream reach at 33 facilities. Based on monitoring reports, we concluded that this link was *very likely* at 11 other facilities. There was only one facility where changes in salmonid abundance or species composition were considered *likely* through this mechanism.
- DVH1-1: Based on relevant literature, we concluded that at 44 facilities it was *likely* that construction of a dam and associated works, including the water diversion, changed the timing and magnitude of recruitment of gravel and larger sediment and large organic matter to the diversion reach. There was only one facility where changes in salmonid abundance or species composition were considered *likely* through this mechanism.
- DVH2-1: Based on relevant literature, we concluded that at 41 facilities it was *likely* that changes in flow in the diversion reach temporarily reduced weighted usable area for

benthos and salmonids. Based on monitoring reports, we concluded that this hypothesis was *very likely* at three facilities. There was only one facility where changes in salmonid abundance or species composition were considered *likely* through this mechanism.

- DVH1-5 / DVH2-8: Based on monitoring, we concluded that it was *likely* at one facility that reduced growth and rearing success had occurred due to changes in diversion stream channel or wetted width.
- DWH2-1: Based on relevant literature and the absence of known mitigative works to eliminate ramping effects, we concluded at 32 facilities that rapid changes in the rate of change in discharge from the powerhouse *likely* caused some reductions in weighted usable area for benthos and salmonids in the downstream reach. Based on monitoring reports, we concluded this hypothesis was *very likely* at nine facilities. There were no facilities where changes in salmonid abundance or species composition were considered *likely* through this mechanism.
- DWH2-3: We found evidence that ramping rates at eleven facilities exceeded the rates established for the facility to prevent fish stranding and mortality. Based on monitoring reports, we concluded that mortality due to stranding downstream of the powerhouse was *very likely* at three facilities.
- CH1-1: Because 17 facilities had undertaken compensation activities under the auspices of a Fisheries Act Authorization, we concluded that hypothesis CH1-1 was *likely* (i.e., salmonid habitat had been reduced as a result of the construction and operation of a facility prior to any compensation activities). However, there was no information on lost and / or gained habitat at six facilities, the estimates of lost or gained habitat were not based on empirical measurements at two facilities, and verification of the amount of habitat lost or gained were ongoing at six facilities. At three facilities in addition to the 14 above, it was *very likely* that there had been a reduction in salmonid habitat as a result of the construction and operation of a facility prior to any compensation activities. At all 20 facilities there were compensation works in place that were designed to offset these losses in salmonid habitat.

For the facility where we concluded it was *likely* that reduced growth and rearing success occurred due to changes in diversion stream channel or wetted width, we also concluded that changes in salmonid abundance were *likely*. Therefore, for this facility the available evidence suggests that changes in abundance at the stream section level are a consequence of reduced growth and rearing success attributable to changes in the diversion reach.

For the facilities where we concluded mortality due to stranding downstream of the powerhouse was *very likely*, we also concluded that changes in salmonid abundance were *possible* because monitoring of salmonid abundance in the downstream section was inconclusive. As a result, we were unable to determine the population level consequences of these sources of individual mortality at the stream section level because mortality of individual fish does not necessarily translate into an impact on the overall fish population.

Key uncertainties that emerged from our review of the evidence for and against the hypothesized cause-effect links include:

- UH1: rates of entrainment at individual facilities and the relative influence of entrainment and / or spillway mortality on population level abundance at facilities without mitigation measures in place;
- UH2: the extent to which changes in habitat specific to the headpond do or do not influence populations of salmonids upstream of a facility;
- UH3: the extent to which migratory salmonids utilize upstream reaches in watersheds with run-of-river projects and the importance of potentially lost / fragmented habitat to the population as a whole;
- DVH1: the extent to which the diversion reach has the potential to be affected by changes in the movement of sediment and organic matter, and the time scale over which this may occur;
- DWH2: how individual mortality due to stranding manifests itself at the population level; and
- CH1: how the creation of compensatory habitat translates into increased rearing or spawning success and, ultimately, increased population size.

8.4 ARE THERE MORE PROBLEMATIC PERIODS OF TIME – SEASONS OF THE YEAR, AND / OR OPERATIONS?

Some metrics, including temperature and flow, are typically monitored continuously or semi-continuously within a project area throughout the year. Other metrics, such as salmonid abundance and invertebrate drift, are typically monitored annually or semi-annually depending on the facility in question. Even at those few facilities which did have monitoring that occurred on a seasonal basis, we did not have sufficient contrast in our results to explore which times of year were more problematic than others. Generally speaking, times of year that have the potential to be more problematic than others will depend on site specific characteristics, but may include: winter and / or summer when low flows can lead to temperature-related impacts on incubating eggs or rearing salmonids; spring when altered flows may affect the upstream migration of species like steelhead that use ephemeral high flows to reach headwater spawning habitat; and spring / early summer when young of the year may be particularly susceptible to stranding as a result of fluctuations in flow.

Because there were so few instances where we could conclude there were or were not impacts to salmonids, we are unable to provide a rigorous assessment of whether or not some facilities are more problematic than others. However, based on the information reviewed, we were able to identify a number of factors (listed in Table 5) that are likely to result in increased or reduced potential risk to salmonids.

Table 5: Facility factors that may lead to higher or lower risk to salmonids.

Risk Factor	Higher Potential Risk	Lower Potential Risk
Fish presence	Salmonids present in upstream, diversion, and downstream reaches	No salmonids in upstream, diversion, or downstream reaches
Weir	Acts as barrier to upstream movement of salmonids	Fishways that allow upstream movement of salmonids
Flow ramping	No control in the event of emergency / unexpected shutdowns	Ability to control ramping rates based on powerhouse design and operations
Diversion reach Channel structure	Long and low gradient, with alluvial channels and high quality salmon spawning and rearing habitat	Short and high gradient
Downstream reach channel structure	Shallow and wide channels that may provide important rearing habitat for juvenile salmonids	Steep sided banks that minimize stranding
Entrainment	No entrainment mitigation	Mitigation measures to eliminate entrainment into the penstock (e.g., Coanda screens)

8.5 WHAT ARE FISH MITIGATING AND COMPENSATING FEATURES OF RUN-OF-RIVER HYDRO PROJECTS? CAN THEIR EFFECTIVENESS BE EVALUATED AND WHICH ONES ARE MOST EFFECTIVE AND HAVE THEY MET THEIR INTENDED OBJECTIVES?

Mitigation measures at run-of-river projects include: instream flow and ramping rate requirements to protect instream flow for fish and / or fish habitat; measures to reduce / eliminate entrainment in the penstock (e.g., screens over the intake); alterations to weirs to allow for continuous flow through spillways that may otherwise strand fish; fishways that enable upstream movement of salmonids from diversion to upstream reaches; various engineering considerations in the powerhouse allowing for controlled ramping of flow (e.g., bypass valves); alterations to the shape of downstream channels (such as reconnecting isolated pools) to minimize stranding risk; and fish stranding surveys and recovery following rapid dewatering of stream margins. Mitigation requirements at individual facilities will vary depending upon the attributes of each site and the risk factors listed in Table 5. These mitigation requirements have evolved over time in response to learning from monitoring (e.g., Coanda screens after observing entrainment mortality, bypass valves after observing stranding impacts).

The effectiveness of mitigation measures was typically evaluated by operators at the facilities for which we were provided monitoring reports. Continuously monitored flows in diversion and downstream reaches are often compared to instream flow requirements and ramping rates to evaluate the extent to which operational instream flows protect fish and / or fish habitat at a given facility. Instream flow and ramping rate thresholds are typically determined based on detailed facility-specific studies of the relationship between flow (and changes in flow) and changes in habitat or the risk of stranding.

Coanda screens were considered very effective at eliminating the potential for the entrainment of fish into the penstock while more experimental mitigation strategies like bubble curtains and strobe lights appeared to have limited effectiveness. Alterations to weirs to allow for continuous flow through spillways were effective at reducing stranding risk in the spillway but their effectiveness is likely to be site-specific due to the shape and length of the spillway and the ability to keep it continuously wetted.

Fishways were effective at allowing for some upstream movement of salmonids at four facilities that provided documentation of their use. However, the extent to which natural upstream movement was restored through the construction of fish passage devices was typically very difficult to determine.

The use of bypass reduction valves minimized rapid changes in flow as a result of emergency shutdowns. However, monitoring reports indicate that even at facilities where bypass reduction valves were installed there were still occasions where ramping non-compliance occurred. This outcome demonstrates that the bypass reduction device on its own does not completely eliminate the potential for rapid changes in flow to occur.

Lastly, fish stranding surveys and fish recovery following rapid dewatering of stream margins occurred at some facilities but not at others (e.g., remote sites). While these initiatives are likely to reduce fish stranding and mortality where they occur, their potential for eliminating all potential fish stranding is difficult to assess.

Compensation habitat at run-of-river projects typically consisted of constructed off-channel rearing and spawning habitat built downstream of a facility to offset known (or predicted) losses in fish habitat from the construction and operation of the project. For the facilities where we were able to evaluate compensation efforts, there was often evidence that compensation habitat had offset lost salmonid habitat. However, it was difficult for us to evaluate the extent to which the compensation habitat offset losses in salmonid abundance because compensation is designed to offset losses in *habitat* as opposed to salmonid *abundance* and because of a lack of detailed information on the amount of habitat gained and lost at some of the facilities we reviewed.

8.6 CAN CHANGES ASSOCIATED WITH A RUN-OF-RIVER PROJECT (BOTH POSITIVE AND NEGATIVE) BE ISOLATED FROM OTHER LANDSCAPE IMPACTS, AND ACCUMULATED EFFECTS OF OTHER DEVELOPMENTS?

The ability to disentangle the relative influence of multiple processes potentially affecting salmonids is a function of the design of the monitoring program used to evaluate salmonid responses. In particular, the ability to isolate potential run-of-river effects from the effects of other stressors will depend on the type of control or reference sites that are part of the monitoring design.

As detailed in Section 1.3, a monitoring program that includes the monitoring of salmonids before and after the onset of facility operation at sites both within the project area and outside it (i.e., a Before-After-Control-Impact (BACI) monitoring design) allows the separation of facility effects from other factors that influence salmonid abundance. Differences in salmonid populations between control and impact sites after but not before the onset of facility operation are indicative of facility impacts (which could be either positive or negative). When the same before / after change in salmonid populations occurs at both control and impact sites, the response is likely not related to the facility.

For facilities where a BACI monitoring program in the diversion reach is in place (15 of the 23 facilities that provided monitoring reports), we can be reasonably confident that as monitoring continues, large magnitude changes in resident salmonid abundance that are detected and attributed to the operation of a run-of-river project have been appropriately isolated from responses to other landscape-level stressors that have occurred at the same time. However, without historic estimates of salmonid abundance (i.e., prior to the occurrence of other potential stressors), impacts to salmonids that occurred before the operation of a facility (e.g., due to logging or natural disturbance in a watershed prior to facility operation) will remain difficult, if not impossible, to detect. It is also possible in some cases that the facility or 'treatment' sites may be exposed to different risks from non-facility factors than the control site (e.g., landslide risk from historic logging or natural terrain instability), which could lead to either an underestimate or overestimate of facility impacts.

8.7 HOW SITE SPECIFIC ARE IMPACTS – PROJECT BY PROJECT?

Since so many of our hypothesis evaluations ended up with a conclusion of *possible*, we did not have enough contrast in our results to compare salmonid responses on a facility by facility basis (e.g., were facilities with longer diversion reaches more likely to affect salmonids?). Nonetheless, we expect that impacts will be site-specific because of variation in salmonid occurrence and abundance across facilities. Additionally, variation in facility and site characteristics among run-of-river hydroelectric projects in BC should also contribute to site-specific impacts (as discussed above in Section 8.4). This variability emphasizes the need to include site-specific attributes in the design of monitoring programs as a backdrop for interpreting the patterns they uncover.

8.8 WHAT GENERALIZATIONS IF ANY CAN BE A MADE ABOUT SCALE OF PROJECTS OR MULTIPLE PROJECTS IN A DRAINAGE?

Because there were very few instances where we concluded that impacts to salmonids were *likely* or *unlikely*, it is currently not possible to draw general conclusions about the effect of project scale or the effect of multiple projects within a drainage. Our review found three instances of watersheds with multiple consecutive facilities along an individual stream. In one of these watersheds, monitoring and evaluation has occurred independently for each of two facilities, but there has been no monitoring below the most downstream facility. Therefore, it was not possible to evaluate the potential impacts of both facilities in combination. In the other two watersheds, the facilities have only recently begun operation; monitoring is ongoing and should provide some insight into the potential consequences of multiple projects operating simultaneously within a watershed.

On a broader scale, there are 12 Freshwater Atlas Watershed Groups (collections of drainage areas with an average size of 3,850 km^2), with more than one currently operational run-of-river hydroelectric facility. This includes two Watershed Groups each with six currently operational run-of-river facilities. To the best of our knowledge, there is no ongoing monitoring and no pending plan to assess the potential for impacts to occur across facilities at this scale. See Section 7 for additional discussion of the potential for multiple facilities to affect salmonids.

9 Recommendations

The recommendations that arise from our review fall into five categories: 1) monitoring; 2) targeted research; 3) analyses of impacts across facilities; 4) modelling; and 5) centralized information storage and analysis.

9.1 MONITORING

Monitoring requirements at run-of-river facilities have evolved considerably over time. Recently developed long-term monitoring protocols for run-of-river projects are described in Lewis et al. (2013). These monitoring protocols should allow for the evaluation of many of the impact pathways we considered in this report. However, monitoring on its own is not a panacea for resolving remaining uncertainties concerning the impacts on salmonids, and not all impact pathways can be fully evaluated with the current monitoring protocols (Table 6). Performance measures that are not specifically incorporated into current monitoring protocols include: spawning success and egg-to-fry survival in the downstream reaches and in compensation habitat; upstream and downstream movement of salmonids in the downstream reach; and salmonid rearing success, growth and abundance in the downstream reach.

Table 6: Performance measures that comprise the impact pathways considered in this report, broken down by stream section for the facilities that provided monitoring information. Performance measures that are part of current long-term monitoring protocols (Tables 9-17 in Lewis et al. 2013) are denoted by an "**x**".

Performance Measure	**Lewis *et al.* (2013) long-term monitoring protocols**	**Facilities with monitoring of performance measure / number of facilities where applicable**
Upstream Reach		
Entrainment	**x**	4 / 17
Spillway stranding	**x**	1 / 14 [a]
Habitat area	**x**	12 / 23
Stream channel morphology	**x**	1 / 23
Fish passage	**x**	4 / 17
Salmonid abundance / species composition	**x**	3 / 17
Diversion Reach		
Habitat area	**x**	8 / 23
Stream channel morphology	**x**	12 / 23
Water quality (temperature and dissolved oxygen concentration)	**x**	17 / 23
Salmonid food organisms	**x**	12 / 23
Salmonid rearing success and growth	**x**	10 / 19
Upstream / downstream movement of salmonids	**x**	3 / 19
Salmonid spawning success; egg survival	**x**	0 / 19
Salmonid abundance / species composition	**x**	10 / 19
Downstream Reach		
Habitat area	**x**	11 / 23
Stream channel morphology	**x**	7 / 23
Water quality (total dissolved gas pressure)	**x**	10 / 23
Salmonid food organisms	**x**	9 / 23
Salmonid rearing success and growth		3 / 23
Upstream / downstream movement of salmonids		0 / 23
Salmonid stranding / mortality	**x**	9 / 23
Spawning success; egg survival		0 / 23
Salmonid abundance / species composition		3 / 23
Compensation		
Habitat area	**x**	7 / 17 [b]
Salmonid food organisms		0 / 17
Salmonid rearing success and growth [c]	**x**	6 / 17
Salmonid spawning success [c]; egg survival		7 / 17
Salmonid abundance / species composition [c]	**x**	7 / 17

[a] the number of facilities with known spillways or without information about the occurrence of a spillway

[b] the number of facilities which provided information related to compensation plans designed to offset lost habitat

[c] salmonid rearing / spawning success and abundance are currently being monitored in the compensation habitat at 6, 7 and 7 facilities respectively. However, compensation is designed to offset losses in habitat as a proxy for rearing / spawning success or abundance and so direct estimates of rearing / spawning success or abundance losses were not quantified at each facility. As a result, while we highlight that monitoring is ongoing at these facilities, it is considered inadequate to evaluate the overall hypothesis of no-net loss in salmonid abundance.

Current monitoring protocols do not cover all aspects of the impact pathways that we evaluated because, in some cases, monitoring is not considered feasible. For example, monitoring salmonid abundance and movement in the downstream reach is not considered practical because large natural variably in abundance induced by migrations of freshwater salmonids and even greater variability in anadromous salmon makes designing and implementing a monitoring program with sufficient power to detect even large magnitude changes in abundance logistically and financially very challenging. Therefore, Lewis et al. (2013) recommend that monitoring focus on proxies of effect that can be more reliably monitored, including the frequency and magnitude of stranding and individual mortality as well as changes in invertebrate populations in the downstream reach.

In the case of salmonid abundance, current monitoring protocols are designed to detect large magnitude changes in resident salmonid abundance (>50%) over a relatively short period of time (~5 years) (Lewis et al. 2013). This minimum effect size is intended to balance the level of monitoring effort with the goal of detecting effects. The shortcomings of the current protocols include the inability to detect: smaller magnitude changes that may act as an important leading indicator of change; changes that take time (>5 years) to manifest themselves or only do so under certain conditions; and changes in anadromous salmonid populations (though it is noted that baseline and long-term monitoring of anadromous fish may be required in some instances).

Monitoring at many of the operational facilities we considered did not completely align with the protocols laid out in Lewis et al. (2013). However, this is not surprising because these protocols were developed subsequent to the construction and operation of the projects we evaluated. A recent compliance audit (Hatfield 2013) evaluated the extent to which long-term monitoring at 22 run-of-river projects aligned with the monitoring protocols in Lewis et al. (2013), though most of these projects were commissioned prior to the completion of Lewis et al. (2013). This audit concluded that there was often a need for more ramping studies prior to commissioning of facilities to better understand the risks different ramping rates pose to salmonids. Hatfield (2013) also found that the number and location of transects for geomorphic monitoring were often less than what was recommended in Lewis et al. (2013). Additionally, monitoring of fish compensation habitat was often lacking; when it did occur, it was typically missing comparisons to habitat-suitability indices (Hatfield 2013).

Multiple run-of-river projects operating in the same watershed have the potential to result in cumulative impacts on a salmonid population. These impacts may not be readily detectable by monitoring programs that focus on individual facilities. In the instances were multiple facilities operate in the same watershed, we recommend that monitoring not be done in isolation at each facility. The potential for multiple impacts to interact across facilities within a watershed should be considered in the design of monitoring programs at each facility (e.g., monitoring the reach below the most downstream of all facilities in the watershed), and in the interpretation of their results.

While it is recognized that monitoring programs will always have to be tailored to the specifics of a given project, emphasis on generating comparable monitoring information across facilities would allow for greater evaluation and analyses of potential impacts in the future (e.g., see Section 9.2 below).

Lastly, an independent science panel may help to facilitate the periodic review and update of the proposed long-term monitoring protocols described in Lewis et al. (2013). Such a panel could also identify research priorities and provide advice on study design, and suggest targeted research priorities that could be implemented through academic, government and industry partnerships (see following Section 9.2).

9.2 TARGETED RESEARCH

The gaps in knowledge that emerge from contrasting monitoring protocols with the impact pathways we evaluated highlight areas where targeted research could compliment information gained from ongoing monitoring programs. These gaps include:

- the consequences for salmonids of reduced habitat connectivity in watersheds where they occur with run-of-river facilities;
- the extent to which diversion and downstream reaches are affected by changes in the movement of sediment and organic matter, and the time scale over which this may occur;
- the consequences of changes in flow and geomorphic processes on spawning success and egg development in diversion, and particularly, downstream reaches;
- the extent to which impact pathways associated with run-of-river operations may result in changes in salmonid abundance that are smaller than the current minimum detectable effect size (i.e., 50% change);
- understanding how the timing and magnitude of individual stranding events manifest at the population level; and
- the cumulative effects of multiple run-of-river facilities operating in a single watershed.

Targeted research focused on these information gaps, as well as on the effectiveness of particular mitigation approaches (e.g., for avoidance of entrainment or stranding mortality), could be conducted across a subset of currently operational facilities. Research efforts would benefit from partnerships between operators, CEBC, academics and regulatory agencies. The results of such targeted research could then be contrasted with, or used to support, long-term monitoring findings. Additionally, targeted research could be designed to allow for the evaluation of the cumulative impacts of multiple pathways at a single facility and be conducted across multiple sites and facilities to elucidate the consequences of site and facility variability on the magnitude and form of impact.

9.3 ANALYSES ACROSS FACILITIES

Even when the protocols in Lewis et al. (2013) are followed, monitoring programs may still only be able to detect large magnitude changes in resident salmonid abundance. Smaller magnitude changes or impacts to anadromous salmonids and other aquatic community members may go undetected. The power to detect these changes could be increased by testing hypotheses across multiple watersheds and run-of-river projects. If data are collected in a consistent and comparable manner, then statistical analyses could be applied across multiple facilities (e.g., Marmorek et al. 2004; Roni et al. 2010)

Multi-project analyses would increase the power to detect smaller effects and allow for conclusions to be drawn across run-of-river projects in the province. Combining such an analysis with facility and / or site characteristics would enable the evaluation of what, if any, site characteristics mediate impacts on salmonids. This approach could also control for potentially confounding factors like climactic gradients. Decision analysis can be used to determine the optimal combination of years of monitoring and number of watersheds to consider for a desired detectable effect size (e.g., Keeley and Walters 1994; MacGregor et al. 2002).

It may be quite feasible to conduct multi-project analyses within just 2-5 years. Within two years (i.e., by 2015), many of the 23 facilities currently conducting monitoring will have completed five years of post-operational monitoring; by 2018, all 23 will have completed at least five years of post-operational monitoring.

There are three additional evaluations that could be quite informative. The first is a detailed hydrologic analysis of flow data, which are routinely collected at all facilities. For example, changes in the flow regime within the diversion reach, particularly the timing, magnitude, and persistence of low and high flows, flow variability, and ramping rates could be calculated. The intent of the analysis would be to determine changes in the flow regime that might be problematic to fish productivity and survival, and to identify opportunities for mitigating these impacts. The second evaluation would be a review of all known violations of Fisheries Act Authorizations related to run-of-river hydropower projects. This exercise would provide additional insight into the breadth and depth of potential impacts on salmonids. A cautionary note on this second point is that the mortality of individual fish does not necessarily translate into an impact on the overall fish population, for reasons discussed in Section 3.3. Lastly, regional and watershed specific estimates of stream fish biomass, based on data from Provincial databases, could be compared to monitoring results in those cases when baseline or control stream sampling is unavailable to evaluate whether there is evidence of change in salmonid biomass from before to after the onset of facility operation.

9.4 SIMULATION MODELLING

Simulation modelling has long been a valuable tool in salmonid ecology, conservation and management (e.g., Bradford et al. 2005; Alexander et al. 2006; Harvey and Railsback 2007). In the context of run-of-river hydroelectric projects, simulation modelling could be used to explore if, to what extent, and under what conditions, there is the potential for run-of-river projects to affect salmonid populations. Simulation models could be developed based on detailed monitoring information at well-monitored sites (including sites that are the focus of targeted research), and used to evaluate alternative hypotheses about thresholds of impacts. Such models could then be used together with well monitored, limited impact management experiments to explore how changes in, for example, ramping rates, flow in the diversion reach, or geomorphic processes might influence salmonid population dynamics.

Simulation-based exercises are not intended to be a replacement for continued environmental monitoring. Models can however help to identify critical uncertainties that would benefit from additional field-based study, while also shedding light on the range of impacts one might expect to occur under different assumptions about salmonid ecology and run-of-river project configuration.

9.5 CENTRALIZED MONITORING DATABASE AND ANALYSES

One of the most significant challenges to the completion of this project was the acquisition of information related to flow, aquatic organisms and salmonids for run-of-river facilities. Our efforts to identify and acquire the information needed to evaluate the impact hypotheses was significantly delayed and hampered by the absence of a single central repository for documents submitted by run-of-river projects. We were unable to acquire a complete inventory of information holdings related to run-of-river facilities from the Province. We learned that operators were not required to submit annual reports to the Province, even for facilities at which long-term environmental monitoring was required. However, the Province was able to provide information for some of the facilities that declined to participate in this review.

The lack of a central repository for information and the absence of a tool to track compliance have also been noted in two recent reports related to compliance of run-of-river projects with requirements stipulated in Water Licences and Fisheries Act Authorizations (Menezes 2012; Hatfield 2013). A single, central database with spatial attributes could be used to track water licence requirements and subsequent compliance. Such a compliance database is currently under development by FLNRO in the South Coast region.

A compliance database could also store and organize data that are generated as part of baseline and operational monitoring. Such a database could serve as a powerful tool for synthesizing monitoring data and evaluating impacts across run-of-river operations in BC (for example by an independent science panel, as suggested in Section 9.1). Additionally, such a tool would directly facilitate the targeted research, across-facility analyses, and simulation modelling described in Sections 9.2, 9.3 and 9.4. Investigators from industry, government and / or academia could access the centralized database for future evaluations of impact hypotheses, such as those completed in this report, while keeping such information confidential and facility non-specific as was done in this study.

As part of our review, we created a database detailing our application of the WOE approach to the impact pathways and component cause-effect links at each of the facilities we reviewed. For each of the 70 individual hypotheses considered at each facility, the database contains details on the salmonid species and life stage present, the type of monitoring information collected (including methodology, timing and duration), and the conclusions reached in the reports reviewed. This information is complemented by the details of our WOE evaluation including: whether there is exposure to the stressor; whether there has been a change in the performance measure (and confidence in that conclusion); whether there is correlation / consistency with the change in exposure (and confidence in that conclusion); and other evidence beyond facility-specific information (for or against support for the hypothesis). If it was not possible to evaluate the hypothesis, it was noted whether there is ongoing monitoring that will enable evaluation of the hypothesis in the future and if ongoing monitoring follows the guidelines outlined by Lewis et al. (2013). Uncertainties about the ability to test the hypothesized link are detailed as well as any other relevant information. This database could be used as a starting point from which a centralized monitoring database could be built.

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Appendix 1. Facilities Considered in Report

The list of the 53 operational and 15 non-operational facilities identified in Appendix 1 of the RFP for this project is reproduced in Table 7. Of the 53 operational facilities, seven were identified as lake / storage type small hydro with characteristics that differed from typical stream-type run-of-river hydroelectric facilities, two were very small non run-of-river hydro for personal / private use, and one was identified as not being in operation after all. One additional facility was identified as having recently begun operations. The resulting 44 operational run-of-river facilities were the focus of this report.

Table 7: Operational and non-operational run-of-river hydroelectric facilities in BC, with their corresponding facility type the regulatory and monitoring era in which they began operations (Section 1.2.3), as well as their size, location and the type of information acquired for our review (Section 2.1). Note that operational, stream-type run-of-river hydroelectric projects (in bold) were the focus of this report.

Type	Era	Facility name	Location	Call process	Capacity (MW)	Energy (GWh)	Information type
Stream	Early	**Akolkolex**	Revelstoke	1989 Less Than 5 MW	10	50	Basic information
Stream	Early	**Boston Bar Hydro (Scuzzy Creek)**	Boston Bar	1989 Less Than 5 MW	6	38	Basic information
Stream	Early	**East Twin Creek Hydro**	McBride	1989 Less Than 5 MW	2	6	Basic information
Stream	Early	**Goat River**	Creston	Unknown	1	Unknown	No information
Stream	Early	**Mamquam Hydro**	Squamish	1988 Greater Than 5 MW	58	250	Monitoring reports
Stream	Early	**McDonald Ranch**	Grasmere	1989 Less Than 5 MW	< 0.5	< 0.5	Basic information
Stream	Early	**Robson Valley (Ptarmigan Creek)**	McBride	1989 Less Than 5 MW	4	26	No information
Stream	Early	**Salmon Inlet (Sechelt Creek SCG)**	Sechelt	1989 Less Than 5 MW	17	68	Basic information
Stream	Early	**Seaton Creek Hydro (Homestead)**	New Denver	1989 Less Than 5 MW	< 0.5	1	No information
Stream	Early	**Soo River**	Whistler	1989 Less Than 5 MW	13	65	Basic information
Stream	Early	**Walden North**	Lillooet	1989 Less Than 5 MW	18	54	No information

Stream	Transition	**Ashlu Creek Water Power**	Squamish	2003 Green Power Generation	50	269	Monitoring reports
Stream	Transition	**Brandywine Creek Small Hydro**	Whistler	2001 Less Than 40 GWh	8	34	Basic information
Stream	Transition	**China Creek Small Hydroelectric**	Port Alberni	2003 Green Power Generation	6	25	No information
Stream	Transition	**Furry Creek**	Lions Bay	2001 Less Than 40 GWh	10	40	Monitoring reports
Stream	Transition	**Hauer Creek (aka Tete)**	Valemount	2001 Less Than 40 GWh	2	13	No information
Stream	Transition	**Hystad Creek Hydro**	Valemount	2000 RFP	6	20	Basic information
Stream	Transition	**Marion 3 Creek**	Port Alberni	2001 Less Than 40 GWh	5	18	Basic information
Stream	Transition	**McNair Creek Hydro**	Sechelt	2001 Less Than 40 GWh	10	38	Monitoring reports
Stream	Transition	**Mears Creek**	Gold River	2001 Less Than 40 GWh	4	20	Basic information
Stream	Transition	**Miller Creek Power**	Pemberton	2000 RFP	30	118	Monitoring reports
Stream	Transition	**Pingston Creek**	Revelstoke	2001 Greater Than 40 GWh	45	193	Basic information
Stream	Transition	**Rutherford Creek Hydro**	Pemberton	2001 Greater Than 40 GWh	50	172	Monitoring reports
Stream	Transition	**South Cranberry Creek**	Revelstoke	2003 Green Power Generation	9	26	No information
Stream	Transition	**South Sutton Creek**	Port Alberni	2001 Less Than 40 GWh	5	26	Monitoring reports
Stream	Transition	**Upper Mamquam Hydro**	Squamish	2001 Greater Than 40 GWh	25	108	Monitoring reports
Stream	Modern	**Barr Creek**	Tahsis	2006 Open Call	4	16	Basic information
Stream	Modern	**Bone Creek Hydro**	Kamloops	2006 Open Call	20	81	Basic information
Stream	Modern	**Canoe Creek Hydro**	Ucluelet	2008 Standing Offer Program	6	16	Monitoring reports
Stream	Modern	**Cypress Creek**	Gold River	2008 Standing Offer Program	3	12	Basic information
Stream	Modern	**Douglas (EPA B)**	Mission	2006 Open Call	33	41	Monitoring reports

Stream	Modern	**East Toba River (EPA A)**	Powell River	2006 Open Call	123	449	Monitoring reports
Stream	Modern	**Fire (EPA B)**	Mission	2006 Open Call	23	98	Monitoring reports
Stream	Modern	**Fitzsimmons Creek**	Whistler	2008 Standing Offer Program	8	36	Monitoring reports
Stream	Modern	**Lamont (EPA C)**	Mission	2006 Open Call	27	105	Monitoring reports
Stream	Modern	**Lower Bear Hydro**	Sechelt	2008 Standing Offer Program	10	46	Monitoring reports
Stream	Modern	**Lower Clowhom**	Sechelt	2006 Open Call	11	48	Monitoring reports
Stream	Modern	**Montrose Creek (EPA A)**	Powell River	2006 Open Call	73	266	Monitoring reports
Stream	Modern	**Pine Creek**	Atlin	2009 Non-Integrated Areas RFP	2	5	Monitoring reports
Stream	Modern	**Stokke (EPA B)**	Mission	2006 Open Call	22	94	Monitoring reports
Stream	Modern	**Tipella (EPA B)**	Mission	2006 Open Call	18	76	Monitoring reports
Stream	Modern	**Upper Bear Hydro**	Sechelt	2008 Standing Offer Program	10	46	Monitoring reports
Stream	Modern	**Upper Clowhom**	Sechelt	2006 Open Call	11	48	Monitoring reports
Stream	Modern	**Upper Stave Energy (EPA C)**	Mission	2006 Open Call	33	144	Monitoring reports
Stream	Non-operational	Big Silver - Shovel Creek	Harrison Hot Springs	2010 Clean Power Call	37	159	n/a
Stream	Non-operational	Box Canyon	Port Mellon	2010 Clean Power Call	15	54	n/a
Stream	Non-operational	Cranberry Creek Power	Revelstoke	2006 Open Call	3	11	n/a
Stream	Non-operational	Culliton Creek	Squamish	2010 Clean Power Call	15	74	n/a
Stream	Non-operational	Dasque - Middle	Terrace	2010 Clean Power Call	20	81	n/a
Stream	Non-operational	Forrest Kerr Hydroelectric	Stewart	2010 Negotiated EPA	195	942	n/a
Stream	Non-operational	Kokish River	Port McNeil	2010 Clean Power Call	45	186	n/a

Stream	Non-operational	Kwoiek Creek Hydroelectric	Lytton	2006 Open Call	50	147	n/a
Stream	Non-operational	McLymont Creek	Stewart	2010 Negotiated EPA	66	244	n/a
Stream	Non-operational	South Cranberry Creek 2	Revelstoke	2010 Standing Offer Program	< 0.5	6	n/a
Stream	Non-operational	Tretheway Creek	Mission	2010 Clean Power Call	21	81	n/a
Stream	Non-operational	Upper Lillooet River	Pemberton	2010 Clean Power Call	74	270	n/a
Stream	Non-operational	Upper Toba Valley	Powell River	2010 Clean Power Call	124	315	n/a
Stream	Non-operational	Volcano Creek	Stewart	2010 Negotiated EPA	18	52	n/a
Lake	Early	Doran Taylor	Port Alberni	1989 Less Than 5 MW	6	23	n/a
Lake	Early	Hluey Lake	Dease Lake	1993 Non-Integrated Areas RFP	3	5	n/a
Lake	Early	Morehead Creek	Williams Lake	1989 Less Than 5 MW	< 0.5	< 0.5	n/a
Lake	Early	Ocean Falls	Bella Bella	1985 Non-Integrated Areas RFP	15	12	n/a
Lake	Modern	Raging River 2	Port Alice	2006 Open Call	8	30	n/a
Lake	Modern	Tyson Creek	Sechelt	F2006 CFT	9	53	n/a
Lake	Non-operational	Long Lake Hydro	Stewart	2010 Clean Power Call	31	139	n/a
Lake	Transition	Zeballos	Zeballos	2003 Green Power Generation	22	93	n/a
Personal / private use	Early	Coats IPP	Gabriola Island	1985 Negotiated EPA	< 0.5	1	n/a
Personal / private use	Transition	Eagle Lake C2 Micro Hydro	West Vancouver	2001 Less Than 40 GWh	< 0.5	1	n/a

Appendix 2. Information Requested from Operators

At the outset of this review, operators of the facilities listed in Table 7 (Appendix 1) were contacted to request information to aid in our review. Following the submission of the letter (attached below), CEBC and ESSA followed up with individual operators to request the following documents:

- Operating Parameters and Procedures Reports;
- Operating Environmental Monitoring Program;
- Annual Operating Parameters and Procedures compliance reports;
- Annual Operational Environmental Monitoring Program reports;
- Documentation on habitat compensation efforts;
- Documentation on existing barriers to salmonids unrelated to the facility, either downstream or in the project area;
- Latitude and longitude for the facility including the location of the intake, end of diversion reach, and powerhouse;
- Documentation on emergency shutdowns, including cause and known / potential impacts;
- Water licence; and
- Any additional reports and documents related to the monitoring and evaluation of facilities specifically related to flow, aquatic organisms including salmonids, and sediment transport, including before / after monitoring programs, environmental impact assessments and pre-project baseline studies.

The original letter sent to all operators requesting support for information acquisition is provided below.

ESSA Technologies Ltd.
600 - 2695 Granville Street
Vancouver, BC, Canada V6H 3H4

Phone: 604-733-2996
Fax: 604-733-4657
Email: dmarmorek@essa.com
Web: www.essa.com

February 8, 2013

[Companies / Facility owners]

Dear Mr. / Ms. ####:

Re: **Independent review of run-of-river hydro projects and their impacts on salmonid species in British Columbia — support for information acquisition.**

Further to the signed contract from the Pacific Salmon Foundation on December 11, 2012, ESSA Technologies Ltd. is very pleased to begin the aforementioned review. We have assembled a highly experienced and qualified project team with relevant experience in fisheries, environmental assessment, and power projects. We are very grateful for the opportunity to synthesize and evaluate existing information.

To synthesize information, we first need to acquire it! We are writing to you to help us get what we need for our review as soon as possible, given the very tight time lines on this review. Our information needs are broken down into two broad categories: 1) Administrative, operations and engineering and 2) technical & biological data.

Administrative, Operations and Engineering	Technical data
1. Time chart for project construction, completion date and start of operations – completed projects, projects actively in construction (only). 2. High-level project design reports (excluding detailed engineering drawings, etc.). 3. Existing background study report(s), including planned operational rules, and pre-project baseline studies. 4. Breakdown of best practices used in the operation of your projects. 5. Identify all emergency shut-downs that have occurred to date, including cause & known / potential impacts. 6. Copy of water licence and associated guidelines / restrictions.	1. Baseline flow data (before project construction) and post-construction operational flow time series. 2. Specific GIS coordinates for location of the project (plus other project maps), including GIS coordinates for points of diversion (diversion reach) and project facilities. 3. Provide background studies / information that identify existing barriers to anadramous fish unrelated to the project. 4. Identify what biological monitoring data and evaluation reports have been

7. A response to this question: *do you regularly review compliance of flows with this licence*?
8. Summarize completed / in-progress mitigation activities built-into the project along with any effectiveness evaluations of these mitigation activities.

completed (including drafts) for the project.

5. List all potentially relevant data holdings for the project that are not already identified above.

In addition, we welcome any of your recommendations on other sources of information to include in our review that may be missing from the list above. We are particularly concerned that we do not miss previous reviews / assessments conducted by the federal and / or provincial government agencies that may not be readily identified or available.

Kindly provide an initial reply by February 20, 2013, including identification of the appropriate point-of-contact information management or communications staff that our team can work with 1:1. We anticipate a large volume of information to consider, and want to ensure that our team maximizes the amount of time available to review what is available. Please send digital copies of all reports to Erica Olson at ESSA Technologies (eolson@essa.com).

Thank-you very much for your time and assistance.

Yours sincerely,

David Marmorek   Clint Alexander

David Marmorek
President
Project Manager, CEBC RoR Hydro Review
ESSA Technologies Ltd.
Direct Tel : (604) 733-2996

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Sr. Director of Operations
Assoc. Project Manager, CEBC RoR Hydro Review
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Appendix 3. Spatial Data Sources

Locating project facilities

We identified where the intake, penstock and powerhouse were located for a given facility based on: 1) facility coordinates provided by the operator (high confidence); 2) the BC Points of Diversion spatial layer to locate the intake in combination with the BC Water Licenced Works spatial layer to locate the penstock (moderate confidence); or 3) visual observation of Google Earth imagery (low confidence).

Defining areas of interest

We delineated the following areas of interest for the spatial metric calculations (Figure 17): A) the upstream watershed; B) the diversion reach; and C) the downstream reach. The upstream watershed is defined as the area upstream of the powerhouse and is based on the Watershed Atlas 1:50K Third Order and Greater watersheds. The diversion reach is defined as a 500 metre buffer (250 metres on each bank) along the Watershed Atlas 1:50K stream centreline, which occurs between the intake and the powerhouse. The downstream reach is defined as a 500 metre buffer along the stream centreline downstream of the powerhouse to the point where a confluence with equal or greater watershed area (relative to the watershed area of zone A) is drained.

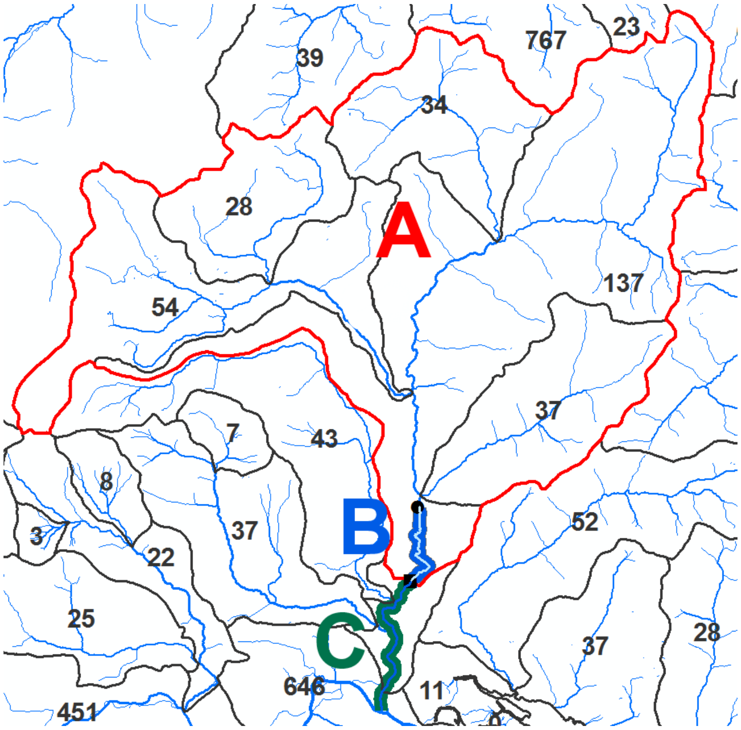


Figure 17: Areas of interest: A) watershed area upstream of the powerhouse, B) diversion reach 500m buffer, and C) downstream reach 500m buffer. Watershed area in square kilometres is shown in black.

Calculating metrics

Spatial metrics were calculated for each area of interest by intersecting an input layer with the areas of interest. Table 8 lists all input base layers and the output metrics that we calculated. Spatial data sources used are listed in Table 9.

Table 8: Input datasets for spatial metric calculations.

Input Layer	Data Source	Processing Steps	Output Metric
Known Fish Observations	GeoBC	Filter to salmonids based on species name attribute	Presence / absence and most recent year observed
Inferred Fish Habitat (modelled bull trout accessible habitat)	Ministry of Environment, Data steward: Craig Mount		Length (km) of inferred fish habitat
BCBC Macro-Reaches (1:50K)	GeoBC		Gradient (%) and channel type code
BCBC Historical Fish Distribution Zones (1:50K)	GeoBC		Length (km) of spawning and rearing habitat
Logging History (RESULTS – Openings)	GeoBC	Filter to logging activity occurring in the last 25 years	Area (km^2) impacted by logging activity
Mineral, Placer and Coal Titles	GeoBC		Area (km^2) of mineral, placer and coal claims and leases
Digital Road Atlas	GeoBC		Length of road (km)

Table 9: The spatial data sources used in this report.

Dataset	Data Source	Description
Known Fish Observations	GeoBC	The Known Fish Observations point data coverage is a dataset that shows all the fish occurrence records for the Province that are currently available from corporate oracle databases. The data are a compilation from several data sources including the Fisheries Information Summary System (FISS) and the Consolidated Waterbody Surveys (CWS). Available at: https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?from=search&edit=true&showall=showall&recordSet=ISO19115&recordUID=43471
Inferred Fish Habitat (modelled bull trout accessible habitat)	Ministry of Environment. Data steward: Craig Mount	Salmonid maximum accessibility model used by the Province based on presumed passage abilities of bull trout. The model uses a gradient cutoff of 25% for fish bearing vs. non-fish bearing streams. The model also considers major known obstructions as barriers to accessibility.
BC Macro-Reaches (1:50K)	GeoBC	This is a provincial coverage of stream macro-reaches. A macro-reach is a homogeneous stream segment delineated through interpretation of reach attributes from the 1:50,000

		National Topographic Series (NTS) of mapsheets. Reach attributes include gradient (as derived from contour interpolation), channel pattern, size of stream, order of stream, major falls, position of the stream in the landscape, and inferred bank materials. These macro-reaches are geo-referenced to the stream centreline network of the BC Watershed Atlas 50K. Each stream is subdivided into one or more macro-reaches that run in a continuous sequence from a stream's mouth to its headwaters. This theme has been used to quantify some aspects of hydrology and fish habitat, and to compare different regions of the province. The upstream and downstream boundary of each macro-reach is located on a stream by its distance, in metres, from the stream mouth. Available at: https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?from=search&edit=true&showall=showall&recordSet=ISO19115&recordUID=47094
BC Stream Centreline Network (1:50K)	GeoBC	One of the spatial views of the BCBC WATERSHED ATLAS 50K, which is the digital basemap representation of the aquatic features depicted on NTS 1 to 50,000 scale Map Sheets. This spatial component of the BCBC WATERSHED DICTIONARY 50K is described below. Available at: https://apps.gov.bcBC.ca/pub/geometadata/metadataDetail.do?from=search&edit=true&showall=showall&recordSet=ISO19115&recordUID=43752
BC Historical Fish Distribution Zones (1:50K)	GeoBC	This is a provincial coverage of inland waters fish species distribution, mapped as stream segments or zones. These fish zones are geo-referenced to the digital stream centreline network of the BC Watershed Atlas 50K. This theme is based on data from the Fisheries Information Summary System (FISS) database that was compiled prior to the year 2000. Each zone represents a section or length of stream where a fish species has been identified and, where known, the extent of its spawning, rearing and holding activities. For mapping purposes each fish species has been assigned to one of three categories: Salmon, Sport Fish, or Other Fish. For anadromous salmon species only, additional zones have been created to show the extent of their upstream migration from the ocean. The upstream and downstream boundary of each fish zone is located on a stream by its distance, in metres, from the stream mouth. Available at: https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?from=search&edit=true&showall=showall&recordSet=ISO19115&recordUID=47234
Logging History (RESULTS – Openings)	GeoBC	RESULTS Openings are administrative boundaries for areas harvested with silviculture obligations or natural disturbances with intended forest management activities on Crown Land. Available at: https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?from=search&edit=true&showall=showall&recordSet=ISO19115&recordUID=52583
Mineral, Placer and	GeoBC	Mineral rights are represented by mineral, placer and coal

Coal Titles		title polygons. The Mineral and Placer Titles layer contains acquired claims and leases within the Province of British Columbia. Coal data represents applications, licences and leases within the Province. A tenure is a form of ownership of mineral rights over a parcel of land (title) which has been acquired by methods set out in the legislation. Available at: https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?from=search&edit=true&showall=showall&recordSet=ISO19115&recordUID=33850
BCBC Points of Diversion	GeoBC	Province-wide spatial layer displaying water licence points of diversion joined with licence information. https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=47674&recordSet=ISO19115
Digital Road Atlas	GeoBC	Digital Road Atlas Demographic Master Partially-Attributed Roads (DGTL ROAD ATLAS DPAR SP) provides partial information about roads in British Columbia. This data set represents the public data that is available for the Digital Road Atlas. Available at: https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?from=search&edit=true&showall=showall&recordSet=ISO19115&recordUID=62280
BC Water Licenced Works	GeoBC	Province-wide SDE layer showing linear works associated with a Water Licence. Available at: https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?from=search&edit=true&showall=showall&recordSet=ISO19115&recordUID=32751

Appendix 4. Weight of Evidence Methodology

Background

The methodology we used to systematically evaluate the evidence for or against the hypothesized impact pathways and linkages at individual run-of-river hydro facilities was based on the weight of evidence (WOE) approach to retrospective ecological risk assessment (RERA) described by Forbes and Callow (2002) and Burkhardt-Holm and Scheurer (2007), as adapted by Marmorek et al. (2011). This approach can be described as a "semi-quantitative method for identifying causal factors that are likely to explain adverse effects occurring in investigated ecosystems" (Burkhardt-Holm and Scheurer 2007).

Retrospective ecological risk assessment is predominantly intended for situations where the adverse ecological impact and the evidence for such impairment already exists, and potential causative factors have already been identified. The objective of RERA is thus to evaluate, for each of the factors under consideration, the likelihood that they may have contributed to the adverse ecological impacts observed. However, for ecological problems the quantity and quality of evidence available to make such evaluations is often very limited and mostly qualitative (Forbes and Callow, 2002). Quantitative data are often sparse, incomplete, poor quality, cover a short period, or are simply non-existent, and the evidence for or against a given factor is often further complicated by the interaction of confounding factors that are uncontrollable or unknown (Forbes and Callow 2002; Burkhardt-Holm and Scheurer 2007). The objective of incorporating a WOE approach into RERA is therefore to provide a structure in which the available evidence can be synthesized and evaluated in an approach that is transparent, systematic, logical, and less subjective (Forbes and Callow 2002; Burkhardt-Holm and Scheurer 2007).

ESSA has previously applied a weight of evidence approach to the evaluation of hypothesized impacts of human activities on aquatic species, including a version of the WOE approach to synthesize the evidence for, and likelihood of, potential drivers (e.g., contaminants, freshwater habitat, climate change, and disease) of declining productivity in Fraser River sockeye salmon (Marmorek et al. 2011).

Adaptation of WOE methodology to assessment of run-of-river impacts on salmonids

We adapted the WOE RERA approach to systematically evaluate, at the scale of individual run-of-river facilities, the available evidence for and against hypothesized impact pathways and linkages describing the potential ways in which run-of-river hydro facilities may impact salmonids in BC.

Our assessment of the weight of evidence extended down to individual mechanistic linkages within each impact hypothesis. At this scale, each linkage has a driver and outcome that are evaluated, but one or both of those elements may only be intermediate outcomes within the overall cause-effect chain that describes the impact pathway.

By adapting the WOE approach we modified previous versions to: 1) include additional steps for evaluating the degree of confidence in change in the physical or biological element under consideration; and 2) allow for a clearer delineation between evaluating information that is specific to a run-of-river facility and more general information from the literature.

Steps in the revised WOE approach

The WOE methodology we applied is centered on an ordered set of questions to systematically evaluate the available evidence for and against each hypothesized impact pathway or linkage. These questions are structured in a framework that allows conclusions to be made about the relative likelihood of each hypothesis at an individual run-of-river hydro facility (Figure 18).

Each hypothesized pathway or linkage consists of a cause-effect relationship describing the influence of a stressor on a physical or biological component that can be described by a performance measure. For example, given the hypothesis “changes in flow lead to reduced invertebrate abundance in the diversion reach”, the stressor is “changes in flow” and the biological component is “invertebrate abundance” whose performance measure could be the invertebrate drift density.

The remainder of this section details each step in the WOE flow diagram (Figure 18). For each step, four things are provided:

- a description of the question being answered in that step, based on Burkhardt-Holm and Scheurer (2007);
- an explanation of the set of possible answers to this question;
- examples to further illustrate the main principles in undertaking that step; the examples are based on the impact hypotheses and linkages in the present review, but are hypothetical and do not represent actual conclusions from a run-of-river hydro facility; and
- additional notes and contextual information, as necessary.

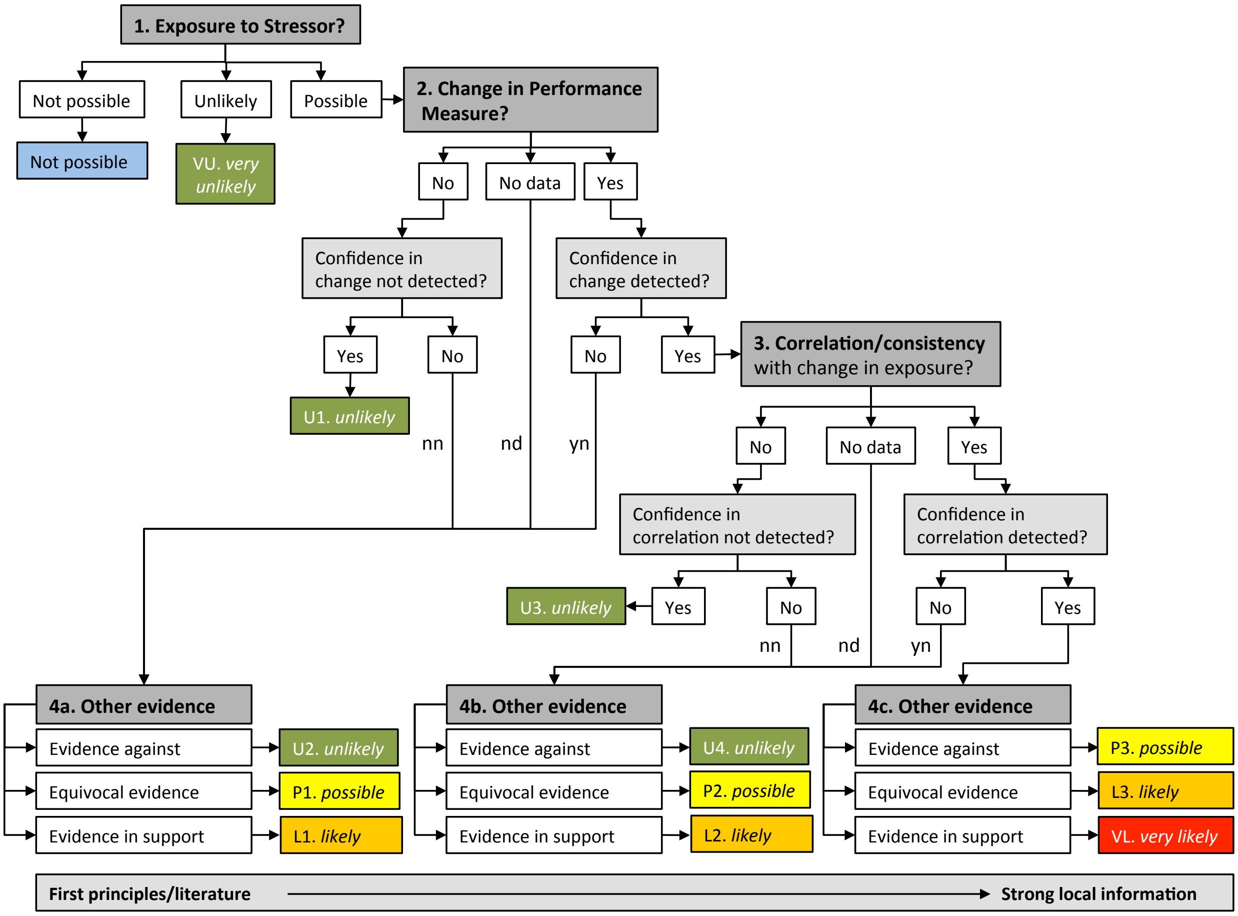


Figure 18: Flow diagram of the sequence of steps used to assign the relative likelihood (coloured boxes) of a given hypothesized impact pathway or linkage, based on the answers to the questions used to challenge the available evidence. This figure is adapted from Burkhardt-Holm and Scheurer (2007, Figure 1) and Marmorek et al. (2011, Figure 3.3-3).

Step 1: Exposure to stressor

Key question: *"Is there evidence that the physical or biological component associated with the performance measure is, or has been, exposed to the stressor described in the hypothesis?"*

Possible answers:

Not possible – There is, or has been, no exposure of the physical or biological component under consideration to the proposed stressor.

Unlikely – It is unlikely that the physical or biological component under consideration has been exposed to the proposed stressor. This conclusion is most relevant when a preceding link in an overall pathway under consideration was considered unlikely.

Possible – There is, or has been, exposure of the physical or biological component under consideration to the proposed stressor. Alternatively, if the likelihood of the preceding linkage in the hypothesized impact pathway was considered “possible”, “likely” or “very likely”, then exposure is also considered possible.

Examples:

Consider the hypothesis “Dewatering of stream margins from flow ramping strands juvenile salmonids reducing the abundance of rainbow trout in the downstream reach”. At a run-of-river facility where there is a downstream reach **exposure is possible**, however, at a facility that discharges water from the powerhouse directly into a lake, **exposure is not possible**.

Step 2: Change in Performance Measure

Key question: *“Has a change in the performance measure occurred?”*

Possible answers:

No – There has been no observed change in the performance measure.

No data - It is not possible to determine whether there has or has not been a change in the performance measure, most likely because there are no data on the performance measure.

Yes – There has been an observed change in the performance measure.

Examples:

In run-of-river Facility A, the abundance of rainbow trout in the downstream reach is 50% lower following five years of operation, so one would conclude **Yes a change in the performance measure has occurred**. Conversely, in Facility B there has been no change in the abundance of rainbow trout in the downstream reach and so one would conclude **No a change in the performance measure has not occurred.**

Additional notes:

- A performance measure is defined as a quantifiable aspect of the physical or biological component being considered in the hypothesis.
- This step only addresses whether there has been a change, but not why, and not whether the change is significant either biologically or statistically.
- This step also does not address whether the change is associated with the proposed causal mechanism.
- Some hypotheses and linkages are associated with multiple performance measures. Multiple performance measures were evaluated separately when assessing the available evidence.

Step 2a: Confidence in Change Detected

Key question: *"Is there a moderate to high level of confidence that the change in performance measure detected in the previous step has actually occurred?"*

Possible answers:

No – The level of confidence in the change detected is low because it is small in magnitude, there is considerable variability in the data, the estimated change is based on few observations, the methods used to quantify the performance measure are not appropriate, monitoring is ongoing and there has not been a quantitative evaluation of the performance measure thus far, or a combination of the above.

Yes – The level of confidence in the change detected is moderate to high because the change is moderate to large in magnitude, there is limited variability in the data, the estimated change is based on many observations, the methods used to quantify the performance measure are appropriate, quantitative evaluation of the performance measure suggests the performance measure has actually changed, or a combination of the above.

Examples:

Consider the previous example with rainbow trout in the downstream reach of Facility A. If the 50% reduction in abundance was based on five years of sampling before and after the change, was shown to be statistically significant, and was based on well establish protocols for enumerating rainbow trout, then **Yes there is confidence in the change detected**.

Conversely, if the 50% reduction in rainbow trout abundance was based on two years of monitoring, the sampling occurred in different areas and times of year in the diversion reach, and the estimates of rainbow trout abundance were based on different monitoring protocols, then **No there is not confidence in the change detected**.

Step 3: Correlation / Consistency with Change in Exposure

Key question: *"Is there evidence of an association between changes in the performance measure and changes in the level of exposure to the stressor, either in time or space?"*

Possible answers:

No – There is no evidence of either a statistical correlation or general consistency between changes in the performance measure and changes in the level of exposure.

No data – It is not possible to determine whether there has or has not been a change in the performance measure, most likely because there are no data or insufficient data available on the change in exposure.

Yes – There is evidence of either a statistical correlation or general consistency between changes in the performance measure and changes in the level of exposure.

Examples:

Consider the situation where there has been a 50% reduction in rainbow trout abundance in the downstream reach and the hypothesis that is being examined is whether this reduction is due to dewatering of stream margins from flow ramping that strands juvenile salmonids causing mortality and reducing the abundance of rainbow trout in the downstream reach.

If ramping rate non-compliance is common at the facility and it has been estimated that 500 juvenile rainbow trout die due to stranding each year then **Yes there is correlation / consistency with change in exposure**.

Conversely, if there is no evidence of ramping non-compliance or stranding of juvenile trout then even though there may be changes in the abundance of rainbow trout in the downstream reach **No there is no correlation / consistency with change in exposure**.

Finally, if ramping rates have not been monitored or reported on at the facility then the answer is **No data**.

Step 3a. Confidence in Correlation Detected

This question operates in an analogous manner to the question on confidence in the change in the performance measure.

Key question: *"Is there a moderate to high level of confidence that the change in performance measure is correlated or consistent with a known change in the degree of exposure to the stressor hypothesized to cause the change?"*

Possible answers:

No – While there is evidence that the performance measure has changed, one cannot conclude with a moderate to high degree of confidence that it is attributable to a change in exposure to the hypothesized stressor because data on change in the stressor are uncertain or not available or because one cannot rule out a possible confounding non run-of-river factor that led to the change in the performance measure.

Yes – One can conclude with a moderate to high degree of confidence that the observed change in the performance measure is attributable to a change in exposure to the hypothesized stressor and not due to a possible confounding non run-of-river factor.

Examples:

Continuing with the example in Step 2, if there is a control stream adjacent to the stream with the run-of-river project on it and monitoring there was done before construction and after the onset of facility operations (e.g., a BACI monitoring design), and there has been no change in the control stream then **Yes there is confidence in the correlation / consistency of change in the performance measure in relation to change in the stressor**.

Conversely, if there was no monitoring at a control stream and it was not possible to rule out that the observed reduction in rainbow trout abundance was attributable to a non run-of-river related factor, then **No there is no confidence in the correlation / consistency of change in the performance measure in relation to change in the stressor**.

Other evidence

In addition to facility specific information, we also considered "other evidence" which we defined broadly to include any potential lines of evidence beyond the facility-specific information used to evaluate the previous questions in the framework. Other evidence was primarily based on peer-reviewed journal articles and technical reports relevant to the hypothesized impact pathways and linkages. For each impact pathway linkage, the evidence was broken into the following three categories.

- **Evidence in support**: The literature provides evidence to support the hypothesis or the hypothesis is considered likely based on first principles. For example, "other evidence" was considered to support the hypothesis that entrainment of salmonids results in mortality if there were no mitigation measures in place.
- **Evidence against**: The literature provides evidence against the hypothesis or the hypothesis is considered unlikely based on first principles.
- **Equivocal/no evidence**: Evidence from the literature is not conclusive (e.g., studies come to contradictory conclusions), or evidence comes from studies that are not directly comparable to environmental conditions and / or run-of-river facilities in British Columbia, or there was no evidence in the literature for or against the hypothesis. The vast majority of links had "other evidence" that was considered equivocal.

Conclusions about relative likelihoods

By applying the WOE methodology to each hypothesized link in each of the 10 overall impact pathways, we could come to one of six conclusions about the relative likelihood of the hypothesis under consideration (for example considering a hypothesis related to salmonid abundance) (Figure 19):

- Very unlikely: exposure to a stressor is unlikely. For example there is a screen over the penstock intake that physically prevents the entrainment of fish.
- Unlikely: exposure to a stressor occurs, but there is strong evidence that this exposure has not changed salmonid abundance or habitat.

- Possible: there is exposure to a stressor but it is not possible to conclude that this has caused a change in salmonid abundance or habitat. *Possible* means that the evidence is insufficient to conclude that the pathway is either *unlikely* or *likely*.
- Likely: there is strong evidence that exposure to a stressor has changed salmonid abundance or habitat.
- Very likely: there is very strong evidence that exposure to the stressor has changed salmonid abundance or habitat.
- Not possible: exposure to the stressor is not possible (e.g., there are no salmonids within the run-of-river project area).

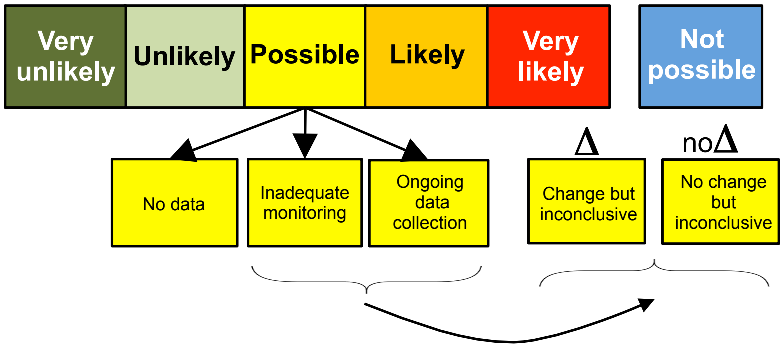


Figure 19: Schematic of the "possible" weight of evidence conclusions. "Possible" conclusions can be further divided depending on how one arrives at the "possible" conclusion. Conclusions that were "possible" because the data were inconclusive could be divided further still based on whether the performance measure under consideration appeared to change at all (bottom rightmost boxes).

We further subdivided the *possible* conclusion into three subcategories, reflecting the reasons for this conclusion:

1. there were no data with which to evaluate the hypothesis, often the case for older projects ("*Possible - No data*");
2. there was insufficient confidence in the collected data to draw a conclusion due to problems with the design or implementation of monitoring (e.g., no controls or replication of sampling locations) ("*Possible - Inadequate monitoring*"); and
3. currently inconclusive but monitoring is ongoing and following protocols that should allow for a conclusion other than *possible* to be reached for a given hypothesis in the future ("*Possible - Ongoing data collection*").

Those conclusions that were "*Possible - Inadequate monitoring*" and "*Possible - Ongoing data collection*" could be further broken down into:

a) those situations where there was a change detected in the performance measure under consideration but we were not confident that this change was real ("Change but inconclusive"); versus

b) those situations where there was no change detected but we were not confident that a change had not occurred ("No change but inconclusive").

We applied the WOE methodology to hypotheses in three steps, proceeding from the most detailed scale to the most aggregated scale. First, we examined individual links within a single impact pathway (e.g., entrainment at the penstock; link UH1-1 in Figure 20). Our second step was to roll up the conclusions reached for all links along a pathway (e.g., UH1-1 and UH1-3 in Figure 20 form a 'penstock entrainment to salmonid abundance' pathway). Thirdly, we rolled up all pathways that applied to a given stream section. In total we evaluated the evidence for 70 individual links, 10 overall pathways and 4 stream sections across 44 run-of-river hydroelectric projects (3,696 individual hypotheses in total).

Conclusions about overall impact pathways were based on the link with the least *probable* conclusion (i.e., leftmost box in Figure 19). For example, if a single pathway was comprised of a "*very likely*" - "*possible*" set of links (penstock pathway on the left side of Figure 20) then the single pathway would be considered "***possible***". Fish are *very likely* to enter the penstock (UH1-1), but effects of such entrainment on salmonid abundance / species composition are only *possible*, so the whole pathway on the left side becomes *possible*. Similarly, on the right side of Figure 20, the overall conclusion for the "*very unlikely*" – "*unlikely*" spillway path is "***very unlikely***". If fish are *very unlikely* to enter the spillway (link UH1-2 in Figure 20), then the whole pathway on the right hand side becomes very unlikely (links UH1-2 and UH1-4).

There were often multiple pathways within one impact hypothesis diagram (e.g., two pathways in Figure 20 – a "***possible***" penstock pathway on the left side and an "***unlikely***" spillway pathway on the right side). We arrived at an overall conclusion for a given diagram based on the most probable of the multiple pathways. For example, in Figure 20 the overall conclusion for the entire diagram is "***possible***", the most probable of the two pathways.

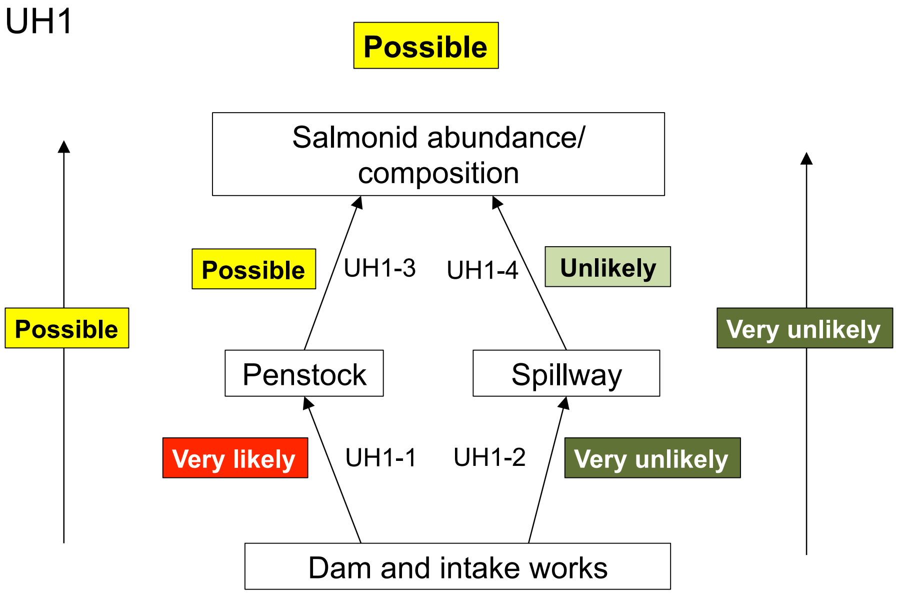


Figure 20: A hypothetical example of how conclusions at the scale of individual hypothesized cause-and-effect links were rolled up to a conclusion at the overall pathway level.

We made conclusions at the stream section level (i.e., upstream, downstream, diversion reaches and compensation habitat) by just considering the hypothesis that salmonid abundance or species composition has changed within a given stream section as a result of the operation of the facility, regardless of the underlying mechanism.

Lastly, we further subdivided those conclusions that were "*Possible – Inadequate monitoring*" at the stream section level, into three categories describing the reason for the inconclusive conclusion:

1. the methodology used to quantify salmonid abundance did not generally follow protocols outlined in Lewis et al. (2013);
2. the documents we reviewed contained insufficient explanation or analysis of existing data; or
3. there were weaknesses in the monitoring design (e.g., no controls or baseline data).

It is important to note that the weight of evidence methodology as we applied it does not explicitly consider interactions among pathways.

A WOE table was completed for each run-of-river facility detailing and justifying the conclusion reached at each step of the WOE evaluation process described above. These WOE tables were then integrated into a single database that could be queried to generate the summaries provided in this report.

Appendix 5. Independent Science Review Workshop

Independent peer review is a cornerstone of the scientific process. The PSF organized an independent science review workshop to ensure that our proposed methodology was rigorous and scientifically defensible. For the workshop, the PSF assembled a science panel comprised of experts in aquatic and salmonid ecology, hydrology, geomorphology, spatial analyses, run-of-river monitoring and environmental assessment. During the workshop the science panel was asked to evaluate ESSA's application of the proposed methodology to two run-of-river projects, one with considerable monitoring data, and one with more limited data. The PSF asked the science panel to answer four questions:

1. Has the ESSA team used an appropriate methodology for this review?
2. Has the methodology been applied in a scientifically defensible way?
3. Are the conclusions reached using the methodology justified for the example facilities and impact hypotheses?
4. What improvements to the methodology would you suggest?

The outcomes of the workshop included written feedback from the science panel on the proposed methodology including suggestions for further refinement and the identification of relevant literature (published articles and technical reports) that would further aid in ESSA's evaluation of the impact pathways.

The complete science panel report is provided below with our responses in bold italics:

Science Review of Run-of-River Hydro Project Assessment Methodology

Panel Conclusions

The panel appreciated the time and energy devoted to development of a methodology to assess potential impacts of Run-of-River projects to salmonids using the diverse nature of the information that is available. We commend ESSA on the weight-of-evidence (WOE) approach they have developed, given the very difficult task of compiling disparate information. We also recognize the challenge of balancing the time ESSA has to devote to this project, which limits what metrics can be compiled (e.g., summaries from proponent's submitted reports vs. analysis of data collected).

We greatly appreciate the time the panel has taken to participate in the review process and provide thorough, constructive feedback, which has greatly improved the methodology in this report.

Overall, we feel that the balance as presented represents a good choice, but make one recommendation. Given the limited number of cases where a reasonable amount of monitoring data have been collected (especially for fish abundance), we suggest that ESSA spend extra time examining those cases to evaluate the data and determine whether conclusions reached are warranted and robust. We suggest that the group adopt a hierarchy for monitoring metrics that follows the structure of Lewis et al. (2013), but place particular emphasis on cases where detecting a change in fish metrics is possible. Similarly, a secondary metric of macroinvertebrate richness or abundance, confidence in the data and conclusions can be assessed from how well the data collection conforms to the monitoring guidelines.

We revised the methodology to place increased emphasis on evaluating data and analyses of salmonid responses in those instances when it was available.

Is the methodology appropriate?

The study team is using the Pathway of Effects (or hypotheses of effects, Jones et al. 1996) approach inventory the likely ways that an IPP could impact salmonid populations. This approach had been used extensively to organize sometimes complex interactions between stressors and components of the ecosystem, and is the approach used by DFO's former habitat management program. Additional examples for the use of the POE approach are found in the USEPA and the EU water directive (refs). Thus we conclude this approach is appropriate. We do note that the POE approach does not consider interactions among linkages, especially with respect to the cumulative effects of a number of pathways on overall salmonid abundance. For example, what is the net effect of adverse impacts identified by one of the pathways, and benefits accrued as a result of compensation works? Without an organizing framework to evaluate individual effects, the team will likely need to rely on an expert-based approach to evaluating the total effect of all confirmed pathways in their final summaries. The additional uncertainty in relying on expert opinion will need to be clearly acknowledged.

We agree that the methodology as we employed it does not consider interactions among linkages and state this in Appendix 4.

Are there any hypotheses that are missing or are in need of revision?

Overall we felt that the team presented a reasonably comprehensive set of impact hypotheses and linkages. A few suggestions did arise from Panel deliberations:

Impact Pathway "UH": One of the impact diagrams (likely UH) needs to have an explicit link for the potential blockage (or passage) of fish upstream around the dam or weir for use in cases where this is identified as a concern.

We added an additional impact hypothesis specifically related to the potential for upstream passage of salmonids to be blocked (UH3).

Impact Pathway "M": Hypothesis (M, "construction and mitigation") should be reconsidered as the pathway seems to be oriented to the evaluation of compensation works. These could be required impacts from any one of the pathways. Further, footprint losses associated with the facility or supporting infrastructure are not considered—presumably the pathway is direct loss of habitat (carrying capacity). This suggests hypothesis M should be split into 2 POEs, one for footprint / construction issues, including loss of habitat, riparian impacts etc., and a second for the evaluation of compensation works. This approach would place greater emphasis on the monitoring of those benefits that could be “applied” against any aspect of the projects’ impacts.

We revised this pathway to directly consider footprint losses in addition to the other impact pathways as well as the extent to which compensation results in no net loss in the species composition and abundance of salmonids (pathway is now CH1).

Impact Pathway “DVH1”: RoR projects are designed to pass sediment, either through sluice gates or by deflating the dam. Theoretically they pass sediment (although it is clear from the design of the sluice gates that they cannot pass sediment efficiently). Nevertheless, sediment is temporally impounded in head ponds and only released at the highest flows. This will cause a cycling between sediment starved and sediment abundant conditions, which will create sediment pulses in the channel. This means that there will be transitory changes in the bed topography and grain-size heterogeneity. There is a risk that this will alter benthic macroinvertebrate communities and potentially have impacts on the fish rearing and spawning habitats and ultimately, population dynamics.

The panel suggests that a pathway that asks if the temporary impoundment of sediment occurs, does it change the timing and magnitude of bedload transport in the diversion reach and downstream and whether it influences the river ecology be considered.

We revised the DVH1 pathway to include the potential for temporary impoundment of sediment to occur with consequences for the timing and magnitude of bedload transport in the diversion and downstream reaches and salmonid rearing success and abundance.

Impact Pathway “DVH2”: The panel felt an important potential stressor that was not clearly identified in the POEs in the potential impact of changes in the seasonal pattern of flows in the diversion reach. While earlier projects with relative small plant capacities would be reasonably expected to have only minor effects on high flow events, newer facilities with larger generation capacity (relative to mean annual discharge [MAD]) could significantly alter flow events that may be important to fish life histories. The sediment pathway could be expanded to include a broader suite of functions that relate to high flow (or alterations from the natural flow regime). These include the recruitment and movement of organic material (including LWD), and the role of high flows on the riparian zone (including the prevention of encroachment, recruitment of plant species, groundwater recharge etc.). We acknowledge that many of these may not be relevant for most IPP sites.

The flow-habitat access PoE (particularly DVH2-6) should be modified to highlight the role of periodic high flows (pulses) in relation to key life-history events, particularly the upstream movements of adults within the diversion reach.

We revised the DVH2-6 pathway to highlight the role of periodic high flows in relation to key life-history events.

Comments on the WOE flowchart.

The project team designed a flow or decision chart to provide consistent, repeatable and defensible process for evaluating the strength of evidence for each of the impact hypotheses. Their approach is an advancement of the WOE analyses of Burkholdt-Holm and Scheurer (2007) for analyzing trout decline in Switzerland, and has similarities to methods developed for the US Clean Water Act (http://www.epa.gov/caddis/). Results from the use of the flowchart are used to populate a large spreadsheet that summarizes all of the information available for the evaluation.

In the workshop, considerable time was spent working through the flowchart to understand its workings and to ensure that the conclusions reached with respect to the strength of evidence were internally consistent. This was needed as some of the strength of evidence ratings could be arrived at by multiple paths in the diagram. The following suggestions were made:

1. The final ratings (under 4. Other evidence) should have unique identifiers so that the path that was taken to reach the final ranking could be reconstructed. A hierarchical coding system, not unlike the one used by COSEWIC for its risk ratings, could be developed.

We revised the WOE analyses to individually track each possible pathway to arrive at a given conclusion. This recommendation greatly improved our ability to tease apart the reasons for various conclusions (particularly those that were considered possible).

2. There was discussion about the “confidence” rating scheme and it was suggested that more detail should be added to the spreadsheet to permit a more useful analysis of the state of the evidence during the rollup. Adding additional branches to the flowchart was not view as needed. The following may be useful to consider for the rating scheme:
    a. Use the Lewis et al. monitoring guidelines (and the DFO Science Advisory Report) as a standard for the assessment of the quality or state of the monitoring program. These are the current standards, and provide a useful benchmark for monitoring programs. It is recognized the monitoring requirements will evolve over time as more experience is gained. If the project team has the expertise to evaluate the technical adequacy of the approach used, that will be a useful consideration.
    b. Have a category that allows for the fact that there is an adequate monitoring program, but insufficient years of data.
    c. If data and time allow, have a category (bin) that includes situations where condition (a) is met (monitoring meets Lewis guidelines) but data appear insufficient to detect a significant change with reasonable power.
    d. Be able to identify cases where there it is determined that there is a mismatch between the data gathered and the conclusions drawn. For example, is a

conclusion reached based on a visual assessment of the data that would not withstand a formal testing procedure?

e. Identify cases where proper power analyses have been conducted to evaluate what effects sizes could have been detected with the current monitoring scheme.

We revised the WOE analyses to evaluate conclusions (and our confidence in them) based on the monitoring guidelines described in Lewis et al. (2013). This allowed us to track situations where adequate monitoring is ongoing but not currently conclusive and when monitoring was sufficient to infer changes have not occurred. We also tracked all hypotheses for which a power analysis was conducted to determine what effect sizes are likely to be able to be detected given the monitoring program in place.

3. Revisions to the final ratings.
   a. Left most column of ratings under "4.Other evidence"- suggest Evidence in support be matched with *likely* to account for cases where there is strong empirical data from other sources, a compelling body of literature, or first principles for a cause-effect relation that may obviate the need for site-specific monitoring data. For example, monitoring data is not needed to demonstrate that a turbine will cause some mortality, or a weir will block passage.
   b. The phrase No / neutral evidence in all cases could be changed to equivocal to more accurately reflect instances where there is mixed or ambiguous scientific evidence. See Norris et al. (2012) for a further discussion.
   c. Finally it was noted that in this scheme the evidence collected in the monitoring programs was always "filtered" through the literature evidence. This is not unreasonable but some judgment will need to be applied on the relative weights applied to the literature and the evidence in hand. Biological responses are often site-specific and if the empirical evidence is especially compelling it should not be diluted by a lack of concordance with the literature. This comment applies to the far right column under **4. Other evidence,** where higher ratings than those given could be applied if the empirical evidence is strong (despite the evidence).

We revised the "other evidence" step in the WOE analyses to reflect the continuum from first principles to strong site-specific empirical evidence. We also revised the terminology from "no / neutral evidence" to "equivocal evidence".

The current narratives used to describe the evidence ratings (*relative likelihoods*) will need to be refined based on modifications to the flowchart.

The narratives were revised based on modifications to the weight of evidence flow diagram.

Diagnostics.

The Panel felt it would be useful to have a few key flow diagnostics as part of the project summary table to assist the team in evaluating the results from the various monitoring projects. Ideally these indicators would be the result of a statistical analysis of flow monitoring data but we recognize that this is likely beyond the scope of the review project. It may be possible to characterize the basic flow conditions using information provided in the water licence and supporting information to generate these diagnostics. Key indicators could include the mean annual discharge (MAD), the seasonal minimum flow releases at the point of diversion (as % of MAD, and % of historical flow, using a monthly or similar time step) and the maximum diversion flow (absolute and relative to MAD). A fish periodicity chart showing the timing of key life events can be useful to evaluate the implications of changes in the flow regime on fish populations.

At those facilities for which it could be acquired, we supplemented our WOE evaluations with information on flow including MAD and maximum allowable diversion of flow.

There is potential to make available regional expectations for stream fish biomasses that could be used to compare monitoring results to if baseline or control stream sampling is unavailable. These data are housed in Provincial databases and analyses.

Our experience was that newer facilities that did not have baseline data did make use of these data from Provincial databases to inform the interpretation of post-operational monitoring data. The acquisition of regional expectations of stream fish biomass across all facilities was beyond the scope of the current review, however, we note the utility of such an exercise in Section 9.2.

Additional considerations.

Rating relative impacts across facilities

It may be useful to develop a semi-quantitative scale for ranking ROR facilities based on the magnitude of any effect sizes. This could involve, as an example, identifying a sliding scale of No Detectable Effects on any pathways (a “1”) to Detectable Effects on 4 or more pathways (a “4”). Such a scale would allow individual operators to know how they perform relative to the industry average, and also facilitate identification of factors associated with increasing effect sizes at ROR operations (see below).

This is an excellent idea. Ultimately, because so many of our hypothesis evaluations ended up with a conclusion of possible, we did not have sufficient contrast in our results to explore and identify factors associated with increasing effect sizes on salmonids or to develop a ranking of run-of-river facilities.

If effects are detected at a site, is it due to poor operations or inadequate flow licensing?

An assessment of the adequacy of licenced flows and a compliance assessment (degree to which actual flows conformed to licenced flows) are likely both beyond the scope of the ESSA contract. Nevertheless, the global interpretation of patterns across facilities will be improved if it is recognized that the magnitude of impacts from a ROR operation and the probability of detecting an impact will depend on 1) the operation of the facility, and the degree to which operations deviate from licenced requirements, and 2) the adequacy of the licenced flows established by the regulator to protect instream values. If licenced flows are inadequate to protect instream processes, then impacts of the ROR operation may be significant, regardless of the diligence of the facility operator. In the interests of correctly identifying causation and adaptively managing regulatory requirements there is value in differentiating between these drivers, to the extent possible.

The hypothesis that effect size should be related to the adequacy of licenced flows is illustrated below. In the first figure effect size (or probability of detecting an effect, which should be proportional to effect size) should increase with decreasing licenced flows (e.g., as a proportion of MAD), assuming that impacts become more likely at lower flows. A more nuanced expectation would be that the effect size should scale with the difference in flow between the control and diversion reaches (as a proportion of MAD), i.e., effect size should increase with the proportion of flow diverted from the diversion reach (Fig. 2). Fig. 1 represents a threshold hypothesis impact, Fig. 2 also indirectly represents a threshold hypothesis, i.e., the larger the diversion, the more likely some undefined threshold will be crossed.

Regional effects (different symbols in Figures) may also arise because of regional differences in the natural flow regime (e.g., summer and winter low flows) that might increase regional sensitivity. Although actual flows would be a better index of impact potential than licenced flows (as it was noted in discussion, actual flows typically exceed licenced flows), one would expect a strong correlation between licenced and actual flows across sites.

We recognize that time constraints may likely prevent ESSA from doing this sort of quantitative analysis of emergent effects; nevertheless it may facilitate detection of emergent patterns if they can keep these hypotheses in mind and see if a qualitative pattern emerges from their data.

Fig. 1

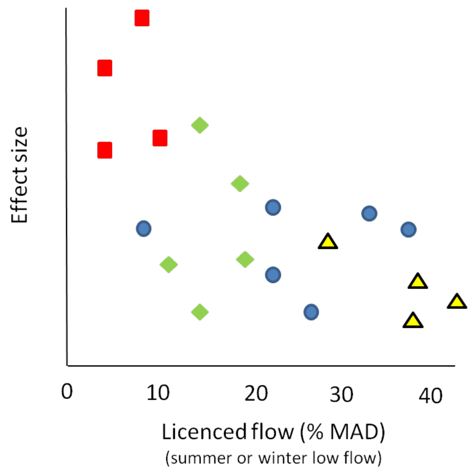
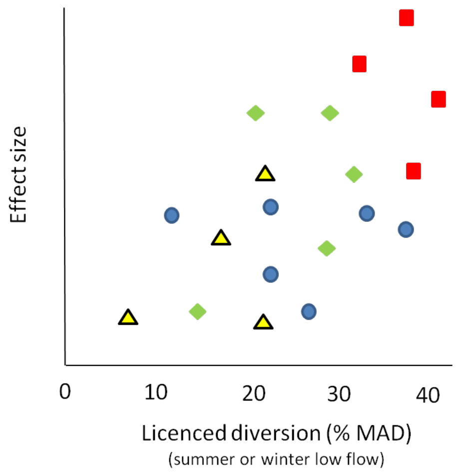


Fig. 2



Site-level GIS attributes

After reviewing the planned collection of geo-spatial information for each site, we have several suggestions for different datasets that might be useful (e.g., higher resolution) as well as other parameters that can be calculated from existing datasets as outlined below.

- Fish passage dataset is available from Craig Mount (MOE, craig.mount@gov.BC.ca) that would be useful to include.
- Road density estimates per watershed are currently based only on Digital road atlas data, however you might consider including the forest roads data from GeoBC (existing, and active permits).
- In addition to mining claims, it may be reasonable to also include water licence applications (for all kinds of uses) and forest tenure applications, both available from Geo BC.
- Similarly, Crown land right of way tenures (for utilities, oil & gas, communications, water, transmission) are available on GeoBC (Tantalis layers).
- The forest data used to estimate the proportion of watershed harvested in the last 25 years is known to be highly inaccurate. Marvin Eng (marvin.eng@gov.BC.ca) at the Forest Practices Board has a better quality data layer of logging history that he may be willing to share.
- Similarly, the Forest Practices Board (and hectares BC) have layers with Mountain Pine Beetle damage (current and future predictions) that may be worth including.
- Nature Conservancy of Canada Ecoregional assessments calculate conservation priorities for terrestrial and aquatic biodiversity and may provide a broader context for each site. W. Palen and V. Popescu can provide these data (shape files) as needed.
- As previously suggested, rather than focusing exclusively on potential habitat for bull trout, we suggest that you also consider including a broader assessment of the diversity of the fish assemblage within each sub-watershed, which is available in the Watershed Evaluation Tool (WET), Version 5 (Sept. 2008), which includes layers on fish richness, threatened and endangered species, probabilities of occurrence for all salmonids, etc.

- It also appears that no information is provided on attributes (lengths, sizes, capacity, type) of new roads and powerlines constructed for each project (or improvements to existing roads). This is likely an important consideration for water quality and related to the sediment as well as habitat hypotheses.
- Existing powerlines should be included similar to road density within the project watershed.
- Another issue that has arisen for many projects is the importance of tributary crossings of the penstock and newly constructed roads. In many cases, penstocks are run underground and these crossings can impose new barriers as well as direct physical disturbance to the watershed (including fishes within the diversion reach). An estimation of the number of tributaries affected should be included.
- Lastly proximity (distance, area within watershed) to protected areas could also provide additional context for land use within each project watershed.

Many of these geo-spatial layers could be very informative for evaluating the cumulative consequences of multiple activities on salmonids within a watershed in addition to informing some of the impact hypotheses that were the focus of this report. These suggestions were only provided to us after the receipt of the rest of science panel's report and following the completion of analyses and drafting of the final report. As a result, these suggestions could not be incorporated into the current review. Nonetheless, these suggestions are worth careful consideration in subsequent analyses.

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Appendix 6. Impact Pathways and Conclusions

In this appendix we describe the results of our weight of evidence evaluation for each impact pathway and individual cause-effect linkages. We begin each section (corresponding to individual pathways) with an overview of the literature relevant to the pathway. There are limitations to the existing literature. Many studies have been performed on hydroelectric projects and rivers that are much larger than the BC run-of-river projects evaluated in this report, and their findings therefore may not be applicable to our review. Other studies have been completed on similar sized streams and projects, but occurred in parts of the world with different biophysical conditions and biota, and may therefore also not be applicable to salmonids in BC We have included studies that are useful for describing mechanisms of impact, but have been careful to indicate the details regarding each cited study, to allow the reader to judge its applicability to the settings and projects examined in this report.

This literature review is followed by a table describing the overall hypothesized impact pathway as well as individual cause-effect hypotheses within the impact pathway. The table includes run-of-river and non run-of-river factors affecting each hypothesis. We then present an Impact Hypothesis Diagram illustrating the overall pathway and its component cause-effect linkages. The diagram includes a summary of conclusions reached for each linkage and is followed by a description of the conclusions reached for individual links and overall pathways. Lastly we highlight the relevance of the pathway to management decisions and describe any critical uncertainties in our understanding of the overall impact hypothesis.

Note that all hypotheses are phrased as though they were true so that they form a testable assertion, but they are not necessarily true (or false).

UH1: ENTRAINMENT OF FISH AND SPILLWAY STRANDING

General discussion

Fish entrainment involves fish being drawn into the penstock and then passing through the turbines. The risk of entrainment depends on the presence and effectiveness of intake screens and on the volume of water being diverted (Hatfield et al. 2003); the probability of entrainment increases as volume diverted increases.

Entrained organisms experience physical stress (e.g., changes in gas pressure, sheer forces associated with turbulence, and contact with turbine blades), which can lead to injury and mortality (Hatfield et al. 2003).

Mortality rates depend on turbine type and size (Čada 2001), project scale, and fish size; higher mortality rates occur for larger fish (Skalski et al. 2002). While Pelton turbines are assumed to cause full mortality of virtually all fish and macroinvertebrates (Čada 2001; Hatfield et al. 2003), recent studies on Francis turbines in New Zealand at a facility passing an average of 6.5 m^3/s (Dedual 2007) found a survival rate of 95% for juvenile rainbow trout. Studies of large hydropower facilities on the Snake and Columbia rivers using Kaplan turbines (which are similar to Francis turbines) have found mortality rates ranging from 0 to 15% for smolts (Skalski et al. 2002).

Entrained fish can also experience indirect and deferred effects. Even though latent effects of passage can be substantial (Hatfield et al. 2003), they have been less rigorously studied than direct effects (Čada 2001). Exposure to a sequence of eight large dams and reservoirs on the Snake and Columbia rivers, including water intakes and bypass structures, has been found to be a cause for delayed mortality in the salmon populations of the Snake River (Budy et al. 2002; Petrosky and Schaller 2010; Haeseker et al. 2012).

The probability that fish will become stranded on the spillway of a run-of-river facility is dependent on the design of the facility. Evidence from studies of direct effects indicates lower fish mortality due to stranding on spillways than due to entrainment into penstocks (Hatfield et al. 2003). However, entrainment over spillways into the diversion reach may constitute a large source of mortality due to indirect effects, but few studies of such effects have been done (Hatfield et al. 2003).

Fish populations can be affected by multiple stressors. The impacts of entrainment and turbine mortality associated with hydropower operations may be confounded by other stressors, such as overfishing, habitat destruction, pollution, and invasive species (Barnthouse 2013). In more remote areas of British Columbia, confounding effects of other stressors on run-of-river facilities are more likely to be related to forestry and mining.

While entrainment and spillway stranding (risk of injury or death) are obviously significant to the individual fish, they are not necessarily significant to the population. Some model-based studies (e.g., Nisbet et al. 1996 and Perry et al. 2003) suggest that potentially significant impacts might occur, but most research on entrainment and turbine mortality has not attempted to determine impacts at the population level (Barnthouse 2013), and has focused on large hydroelectric projects. Populations of anadromous species in systems with multiple dams are the ones most likely to be affected by mortality related to hydropower operations due to cumulative impacts. For example, a major decline in the production of salmon and steelhead on the Columbia River between the 1960s and 1970s, particularly among the upriver stocks, was attributed to the presence of multiple hydropower dams on the river's mainstem (Raymond 1979; Schaller et al. 1999). These dams are, however, much larger than those evaluated in this review, and are situated along the main migratory routes of salmon and steelhead stocks.

There is also a lack of scientific evidence about the effects of stranding on fish populations, and in particular about the effects of stranding over the dam spillway. In their literature review of fish stranding (including 72 studies related to hydropower operations), Nagrodski et al. (2012) found that effects of stranding range from negligible sub-lethal impacts on individual fish to negative impacts on the recruitment of a fish population (following high rates of stranding at early life-history stages). They noted that stranding effects can be mitigated by fish salvage, ramping rate limitations, and physical habitat works (e.g., contouring the channel form to minimize stranding).

Causal Pathway

UH1. Entrainment of fish in the penstock and / or stranding in the spillway *does* cause a decline in salmonid abundance in the upstream reach

Links	Description of Link	IPP Factors Affecting Pathway	Non-IPP Factors Affecting Pathway
1	Entrainment of salmonids in the penstock *does* cause mortality	• Size and design of turbines • Change in water pressure from the headpond to the penstock, turbines, and tailrace • Use of Coanda screen • Ramping rate	• Abundance of trout / char / salmon in the upstream reach • Seasonal migratory behaviour of trout / char / salmon in the upstream reach
2	Stranding of fish in the spillway *does* cause mortality	• The length of spillway • Amount of continuous flow over dam (i.e., intermittency of flow) • Spillway design (e.g., gradient, cross-sectional shape, etc.)	• Abundance of trout / char / salmon in the upstream reach • Frequency / magnitude of rainfall causing spill at the dam
3	Mortality due to entrainment *does* reduce fish abundance in the upstream reach	• Rate of water withdrawal into the penstock • Size of the zone of entrainment in the headpond relative to total area of habitat in the headpond that is used by fish • Strobe lights / other devices to reduce rate of entrainment	• Relative importance of entrainment on population regulation • Abundance of trout / char / salmon in the upstream reach
4	Mortality due to stranding of fish in the spillway *does* reduce fish abundance in the upstream reach		• Abundance of trout / char / salmon in the upstream reach

Evidence for and against pathway

We considered the hypothesis that entrainment of salmonids in the penstock results in mortality to be *likely* when there was no evidence of mitigation in place to prevent entrainment and there were salmonids in the upstream reach. As a result, we concluded hypothesis UH1-1 was *likely* at 28 facilities. At 4 facilities there was clear evidence entrainment was not occurring due to the use of Coanda screens over the intake. At the remaining 12 facilities, the hypothesis was *not possible* because salmonids were not present in the upstream reach (UH1-1 in Figure 21).

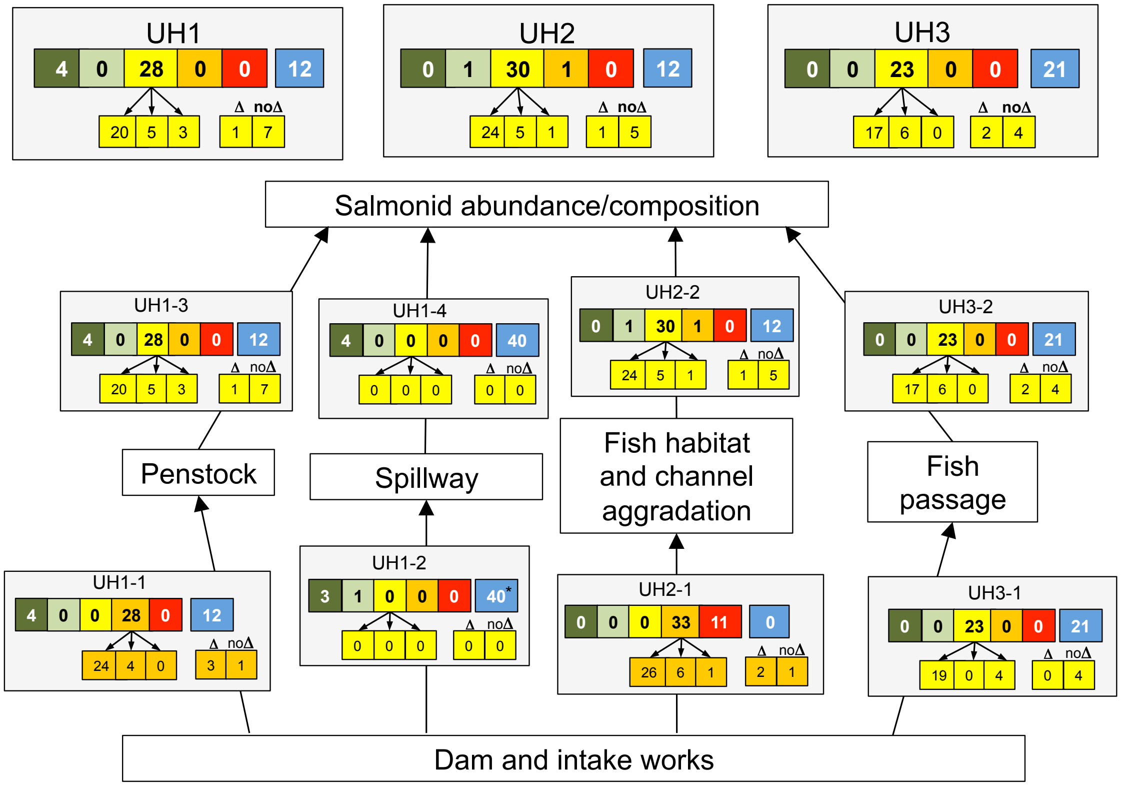

Figure 21: Impact hypothesis diagrams for hypotheses UH1, UH2 and UH3 and corresponding weight of evidence conclusions for each linkage and the overall pathways. The number in each box corresponds to the number of facilities with a given conclusion (Figure 19). The asterisk (*) in the blue *not possible* box for UH1-2 is to denote that for this pathway this number denotes the number of facilities at which no conclusion was possible and the number of facilities where the link is not possible. For UH1-1 and UH2-1 the breakdown of conclusions under the *likely* box is equivalent to those under the *possible* box; in these two instances the conclusions have been shifted to *likely* because of evidence from the literature and first principles.

At those facilities where mortality due to entrainment was considered *likely,* direct estimates of entrainment had either not occurred or been reported at 24 facilities. Four facilities had inconclusive estimates of entrainment, three of which suggested entrainment was occurring while one suggested it was not (UH1-1 in Figure 21).

In most cases spillway mortality could not be assessed because of a lack of information on the structure and extent of a spillway at the facility (28 facilities). One facility identified spillway stranding as a source of mortality and had taken mitigative measures. Three other facilities had clear evidence that spillway mortality was not possible (UH1-2 in Figure 21).

Eight of the facilities, which we concluded had salmonids in the upstream reach, had mitigation measures in place to prevent entrainment. Of these mitigation measures, Coanda screens were very effective at minimizing the potential for entrainment. The effectiveness of more experimental systems, including strobe lights and underwater acoustic deterrents, appeared to be limited.

At 11 facilities with unknown mitigation for entrainment, five had Pelton turbines, which would probably result in mortality for all entrained fish. The remaining six facilities had Francis turbines, which may have a lower mortality rate for entrained fish than Pelton turbines. However, if entrained fish are resident salmonids then entrainment will still result in their displacement from upstream habitat.

Overall, we concluded hypothesis UH1 was *very unlikely* at four facilities, *possible* at 28 facilities and *not possible* at 12 facilities (UH1 in Figure 21).

At those facilities where we concluded hypothesis UH1 was *possible,* monitoring of salmonids in the upstream reach had not occurred or been reported at 20 facilities, five facilities had inadequate monitoring, and three facilities had ongoing monitoring that would allow for future examination of the abundance of salmonids in the upstream reach. Although we found the evidence to be inconclusive, it suggested there was some change in the abundance of salmonids in the upstream reach at one facility, but no change at seven facilities (UH1 in Figure 21).

Relevance of causal pathway for management decisions and critical uncertainties

Entrainment has the potential to occur at all facilities where salmonids are present immediately upstream of the headpond. Mitigation measures such as Coanda screens, when they can be used, are very effective at eliminating the potential for entrainment. When entrainment is known to occur but cannot be mitigated, losses due to entrainment mortality are taken into account when determining required compensation.

Stranding in spillways is project specific; some facilities may have spillways tens of meters long while others may have no spillway at all.

Critical uncertainties for this pathway include quantifying rates of entrainment at individual facilities, and the relative influence of entrainment and / or spillway mortality on population level abundance at facilities without mitigation measures in place.

UH2: LOSS OF STREAM HABITAT AND GAIN OF LAKE HABITAT

General discussion

Run-of-river diversion intakes on streams may cause no measureable increase in upstream water level (e.g., in the case of a pipe or gallery intake), may increase water levels upstream within the bankfull channel through backwater effects (e.g., in the case of a diversion weir), or may backwater beyond the high water mark and inundate riparian habitats (e.g., in the case of larger diversion weirs and dams) (Lewis et al. 2013). The magnitude of the effect depends primarily on the size of the diversion weir (Lewis et al. 2013).

Flow affects many riverine processes (e.g., Poff et al. 1997; Richter et al. 1997, 1998). Significant changes in streamflow dynamics, including the magnitude, timing, persistence, and / or frequency of flows or flow variations, can affect the physical habitat in streams, which in turn is a major determinant of biotic composition (Bunn and Arthington 2002). Significantly altered flow dynamics can modify or degrade ecosystems (Renöfält et al. 2010), though the magnitude of such impacts depends on the degree of flow modification. Even low-head dams can convert flowing (lotic) habitat into low-velocity (lentic) habitats with fine substrates and little available cover (Butler and Wahl 2011).

Stream flow plays a profound role in the lives of fish, with critical life events linked to flow regime (e.g., phenology of reproduction, spawning behaviour, larval survival, growth patterns and recruitment) (Bunn and Arthington 2002). Examples of measured impacts from dams have included the following: conversion of lotic habitat to lentic habitat through construction of low head dams decreased the abundance and altered the distribution of channel catfish in Illinois (Butler and Wahl 2011); low dams altered community structure, productivity and diversity of various taxonomic groups in five rivers in Bavaria (Mueller et al. 2011); and low-head structures at run-of-river facilities lowered the abundance, richness, and biotic integrity of fish and invertebrate assemblages in areas impounded compared to free-flowing reaches in the Fox River (Wisconsin) (Santucci et al. 2005).

Causal Pathway

UH2. The creation of a headpond *does* change salmonid species composition or abundance in the upstream reach

Links	Description of Link	IPP Factors Affecting Pathway	Non-IPP Factors Affecting Pathway
1	Construction of a dam and associated works *causes* a loss of lotic habitat area and a gain of lentic habitat area and / or aggradation of upstream reach	• Volume of headpond • Water residence time in the headpond • Effectiveness of sediment management practices in moving large diameter sediment particles past the dam	• Type of habitat (lotic or lentic) present immediately upstream of the dam before the dam was constructed • Water temperature • Gradient of the upstream

			reach and water depth • Amount and size mix of bedload moving down the reach
2	Loss of lotic habitat area and a gain of lentic habitat area and / or channel aggadation *causes* a change in the species composition and abundance of fish species in the upstream reach.	• Surface area of headpond • Depth of the headpond • Water residence time in the headpond • Water velocity	• Composition of fish species in the upstream reach before construction of the dam • Type of habitat (lotic or lentic) present immediately upstream of the dam before the dam was constructed • Water temperature

Evidence for and against pathway

There was clear evidence of the alteration of habitat in the headpond at 11 of the facilities examined and so the hypothesis that the construction of a weir results in a change in upstream habitat was considered *very likely* (UH2-1 in Figure 21). At the remaining facilities, 26 had no information on the headpond, six had inadequate information on the change in habitat in the headpond and one had ongoing monitoring. At these 33 facilities, hypothesis UH2-1 was considered *likely* because we assumed that in the absence of evidence to the contrary, the construction of a weir would result in some form of upstream habitat change (UH2-1 in Figure 21).

Upstream changes in salmonid abundance as a result of alteration to habitat were uncertain, largely because monitoring has not occurred or been reported (24 facilities), was inadequate (five facilities), or was ongoing and was still considered inconclusive (one facility) (UH2-2 in Figure 21). However, at one facility there was strong evidence of a change in the composition of salmonid populations in the upstream reach. At this facility, we concluded hypothesis UH2-2 was *very likely* because the creation of the headpond resulted in an increase in Dolly Varden relative to rainbow trout in the headpond, thereby altering upstream species composition. At another facility there was strong evidence that the species composition and abundance of salmonids in the upstream reach had not changed due to alteration of habitat upstream and so we concluded hypothesis UH2-2 was *unlikely* (UH2-2 in Figure 21).

Overall, the hypothesis that the creation of a headpond has resulted in changes in salmonid species composition or abundance in the upstream reach was considered *very likely* at one facility, *possible* at 30 facilities, and *unlikely* at one facility. We concluded that the hypothesis was *very unlikely* at 12 facilities where there were no salmonids present in the upstream reach (UH2 in Figure 21).

At those facilities where we concluded the hypothesis was *possible,* monitoring of salmonids in the upstream reach had not occurred or been reported at 24 facilities, five facilities had inadequate monitoring and one facility had ongoing monitoring that would allow for future examination of the abundance and species composition of salmonids in the upstream reach. Although we found the evidence to be inconclusive, it suggested some change in the abundance and species composition of salmonids in the upstream reach at one facility, but no change at five facilities.

Relevance of causal pathway for management decisions and critical uncertainties

The alteration of habitat upstream of the weir is an almost inevitable consequence of the construction and operation of a run-of-river hydroelectric project. Like entrainment in the penstock, habitat alteration upstream will be a consideration at almost all run-of-river hydroelectric facilities. However, the extent to which habitat is altered upstream will be a function of the size of the headpond and upstream channel characteristics. Loss of habitat due to weir construction and headpond creation is typically accounted for in the footprint impacts at a facility and incorporated into compensation plans / calculations.

A key uncertainty related to alteration of upstream habitat is the extent to which changes in habitat specific to the headpond do or do not influence populations of salmonids upstream of a facility. This will depend in part on the relative importance of habitat immediately upstream of the weir in relation to other upstream reaches.

UH3: FISH PASSAGE

General discussion

Small-scale hydropower stations, including run-of-river projects with relatively low dams, represent barriers to the upstream / downstream movement of fish and other biota. Evidence from run-of-river operations in France, where most facilities have low-head dams and are located in mountainous and foothill areas, suggests that even low-head dams cause at least some delay in migration (Larinier 2008). Well-designed fish passes can substantially improve fish pass efficiency, and reduce migration delays to a matter of days or hours. However, the residual effects of barriers to passage can be cumulative when multiple facilities are developed on the same river system (Larinier 2008). Fishways are often effective at allowing for some upstream movement of salmonids at those facilities that employ them. However, the extent to which natural upstream movement is restored through the construction of fish passage devices is very difficult to determine unless there are pre-project estimates of the movement rates of fish past the location of the weir and headpond.

The fragmentation and isolation of fish populations by in-stream barriers can result in reduced fitness for organisms that rely on habitats that have been rendered inaccessible. For species that use different habitats for different phases of their growth, the connectivity of those habitats is fundamental to life cycle completion. Lack of availability of one or more habitats, or poor connectivity between habitats, can lead to population decline (Lucas et al. 2009). Most diadromous fish species are particularly susceptible to disruptions in connectivity between habitats (Baras and Lucas 2001). A study of small-scale run-of-river hydropower in Portugal found that population size structure above compared to below barriers differed significantly for brown trout (*Salmo trutta*), with a greater proportion of smaller individuals upstream (Santos et al. 2006). However, this same study found no significant differences in fish species richness, diversity, or faunal composition upstream compared to downstream from barriers, no matter what kind of fish pass was present. The authors concluded that cover, depth and coarse substrate were the main factors responsible for structuring the fish assemblages (86% cyprinid, 10.2% salmonid, 3.8% other). These variables created a rich, patchy, heterogenous habitat that provided the conditions required to maintain the assemblages despite the presence of the hydropower facilities.

Causal Pathway

UH3. The construction of a dam and associated works *does* impair the upstream passage of salmonids resulting in a change in salmonid species composition or abundance in the upstream reach

Links	Description of Link	IPP Factors Affecting Pathway	Non-IPP Factors Affecting Pathway
1	Construction of a dam and associated works *creates / does not create* a barrier to the upstream movement of fish	• Magnitude and timing of spill over the dam • Presence of a fishway • Height of dam	• Presence of migratory salmonids in the upstream reach before construction of the dam • Timing of upstream migration relative to flow regime
2	The partial or complete blockage of fish passage past the dam *causes* a change in the species composition and abundance of fish species in the upstream reach.		• Composition and abundance of migratory salmonids in the upstream reach before construction of the dam

Evidence for and against pathway

We concluded that it was *possible* that diversion weirs could act as a barrier to fish movement at approximately half of the facilities we considered (23 facilities) (UH3-1 in Figure 21). These *possible* conclusions were primarily because there were no data with which to assess the extent to which the weir does, or does not, impede the upstream movement of salmonids (17 facilities), or because monitoring was ongoing (four facilities). Those sites where monitoring was ongoing were facilities with fishways in place but no baseline information on the number of fish that typically migrated past the intake site prior to construction.

Five of the facilities where we concluded hypothesis UH3-1 was *possible* had anadromous fish (or bull trout) upstream of the weir while 18 had only resident salmonids upstream of the weir. We would expect the ecological consequences of impediments to upstream fish passage to be more pronounced for migratory species like bull trout and anadromous salmon than for resident salmonids because access to upstream habitat may be critical to the completion of the life cycle for these migratory species. At those facilities where it was quantified, resident fish were often shown to move very little between stream reaches.

At nine facilities, there was strong evidence (e.g., presence of a natural barrier to migration) that movement between reaches did not occur prior to the construction of the weir, so we concluded hypothesis UH3-1 was *not possible* at these facilities along with the 12 facilities without salmonids in the upstream reach (UH3-1 in Figure 21).

Overall, we concluded hypothesis UH3 was *possible* at 23 facilities and *not possible* at 21 facilities (UH3 in Figure 21).

At those facilities where we concluded hypothesis UH3 was *possible,* monitoring of salmonids in the upstream reach had not occurred or been reported at 17 facilities, and six facilities had inadequate monitoring of the abundance and species composition of salmonids in the upstream reach. Although we found the evidence to be inconclusive, it suggested there was some change in the abundance of salmonids in the upstream reach at two facilities, but no change at four facilities (UH3 in Figure 21).

Relevance of causal pathway for management decisions and critical uncertainties

This pathway is most relevant to facilities with salmonids that are expected to migrate into upstream sections of the watershed from lower reaches.

Key uncertainties for this hypothesis include: the extent to which migratory salmonids utilize upstream reaches in watersheds with run-of-river projects; and the importance of the lost / fragmented habitat to the population as a whole.

The identification of provincial datasets on the occurrence of migratory salmonids like steelhead and bull trout in upstream sections of watersheds with run-of-river projects could further clarify the importance of this pathway. Such datasets could also provide baseline data against which to compare post-operational estimates of upstream salmonid abundance.

DVH1: MOVEMENT OF SEDIMENT AND FOOD

General discussion

In-stream barriers and water diversions can disrupt the connectivity of river systems and lead to alteration of the processes of sediment and organic matter redistribution (Renöfält et al. 2010; Walters and Post 2011). The degree to which large sediment and channel-forming elements get trapped in the headpond area depends on the characteristics of the diversion structures. Small dams have the greatest potential to pass sediment, particularly during high flow events (Kondolf 1997). Some facilities are also designed to allow operators to flush the headpond periodically to remove accumulated sediment.

The presence of weirs and penstocks can alter the amount and distribution of woody debris and gravel to the diversion reach in run-of-river projects (Lovekin and Hotte 2009; Nelitz et al. 2011). For example, on the Jordan River (Vancouver Island, BC), large woody debris is essentially absent from the diversion reach below Elliott Dam, and spawning gravels of only low to moderate quality occur intermittently (Cascadia Biological Services 2006). Reduced flows can also result in excessive accumulation of fine sediments leading to channel aggradation, a process whereby the level of the streambed rises and pools are filled in due to sediment deposition.

Water diversion schemes can cause the accumulation of fine sediments in the diversion reach, increasing embeddedness of stream-bed gravels and resulting in habitat degradation (Baker et al. 2011). Additionally, fine sediment delivered to the diversion channel by tributaries can accumulate in spawning gravels if flood flows are reduced to the point where they are inadequate to flush the riverbed clean (Kondolf 1997). Smaller streams are more susceptible to fine sediment accumulation than larger streams due to a higher surface area to volume ratio (Baker et al. 2011).

Poor gravel recruitment can affect the availability of spawning substrate, and the accumulation of fine sediments can clog available gravels and reduce the survival of overwintering eggs and embryos. These impacts can be deleterious for both incubating and emerging salmonids. For example, reduced dissolved oxygen caused by silt deposition was identified as the reason for high egg mortality in the diversion reach of the Jordan River (Vancouver Island, BC) (Cascadia Biological Services 2006).

Channel erosion below dams is frequently accompanied by a change in particle size on the bed, as gravels and finer materials are winnowed out and transported further downstream, leaving an armor layer of large gravel, cobbles, or boulders (Kondolf 1997). The increase in particle size can threaten the success of spawning by salmonids, which use gravels with median diameter (up to about 10% of their body size) to incubate their eggs (Kondolf and Wolman 1993).

Through impacts on fish food organisms, increased embeddedness caused by the deposition of fine sediment can also reduce rearing success (Harvey et al. 2009). Fine sediment (silt and sand) accumulation clogs river-bed gravels, and can cause pronounced reductions in benthic densities and diversity (Wu et al. 2009) and species composition (Suttle et al. 2004). The deposition of fine sediments causes a shift toward burrowing invertebrate taxa, which are unavailable as prey for salmonids (Suttle et al. 2004). A reduced long-term supply of macroinvertebrates, which provide important energy resources through the summer, may adversely affect recently hatched juvenile salmonids (Suttle et al 2004), thereby impacting rearing success.

We found no studies that explicitly explored the effect of diversion dams on the recruitment of fish food organisms to the diversion reach. Studies of small hydropower that compared fish food organisms upstream with those downstream of dams reported different results; some studies found changes in macroinvertebrate species composition, abundance, density, dominant taxa, and trophic structure (Mueller et al. 2011; Fu et al. 2008) while others (Almodóvar and Nicola 1999) detected no difference in the abundance of benthic macroinvertebrates above compared to below a diversion dam.

Causal Pathway

DVH1. Construction of a dam and diversion of water *causes* a change in the timing and magnitude of the import of gravel, larger sediment, large woody debris and fish food organisms to the diversion reach resulting in changes to the area and quality of spawning and rearing habitat and change to salmonid growth and abundance in the diversion reach.

Links	Description of Link	IPP Factors Affecting Pathway	Non-IPP Factors Affecting Pathway
1	Construction of a dam and associated works including the water diversion *does* change the timing and magnitude of recruitment of gravel and larger sediment and large organic matter to the diversion reach	• Height of dam • Volume of headpond • Rate of flow diversion • Ability to change crest elevation on the dam (e.g., an inflatable dam can be deflated during stormflows allowing stored sediment behind the dam to move) • Use and effectiveness of sluicegate	• Gradient of upstream reach • Frequency / magnitude of spill at the dam and flood due to snowpack / rainfall • Length and gradient of diversion reach • Composition and amount of sediment in the upstream reach that is a source of sediment for the diversion reach as well as composition and amount of sediment in diversion reach
2	Reduced flows *do* lead to the settlement of fine sediment within coarser sediment in the diversion reach resulting in an increase in embeddedness	• Magnitude and frequency of flow diversion • Minimum flow in the diversion reach • Frequency of emergency shutdowns causing all flow to pass through the diversion reach • Water velocity in headpond	• Frequency / magnitude of spill at the dam and flood due to snowpack/rainfall • Length and gradient of diversion reach • Temporal change in the presence / absence and composition of sediment in the diversion reach after the dam is constructed
3	Changes in the timing an magnitude of the recruitment of gravel and larger sediment to the diversion reach *does* result in stream channel degradation in the diversion reach	• Effectiveness of sluicing in moving larger diameters of sediment • Distribution of flow between diversion reach and penstock during sediment mobilization events • Physical removal, and disposal, of sediment from headpond • LWD management at diversion	• Amount and particle size distribution of bedload moving down the reach • Channel type; must be alluvial, not bedrock controlled or previously degraded • Source (upstream vs. bank) and role of LWD in channel structure • Channel gradient and cross-sectional shape
4	Change in particle size distribution in the diversion reach and/or degradation of stream channel *does* change spawning success and egg survival in the diversion reach	• Magnitude and frequency of flow diversion • Minimum flow in the diversion reach • Frequency of emergency shutdowns causing all flow to pass through the diversion reach	• Frequency / magnitude of spill at the dam and flood due to snowpack/rainfall • Length and gradient of diversion reach • Temporal change in the presence / absence and composition of sediment in the

			diversion reach after the dam is constructed • Amount of suitable spawning habitat prior to the project
5	Change in particle size distribution in the diversion reach and / or degradation of stream channel *does* change rearing success	• Magnitude of flow diversion • Minimum flow in the diversion reach • Frequency of emergency shutdowns causing all flow to pass through the diversion reach	• Frequency / magnitude of spill at the dam and flood due to snowpack / rainfall • Length and gradient of diversion reach • Temporal change in the presence / absence and composition of sediment in the diversion reach after the dam is constructed • Amount of suitable rearing habitat prior to the project
6	Change in particle size distribution in the diversion reach and / or degradation of stream channel *does* change the availability of fish food organisms	• Magnitude of flow diversion • Minimum flow in the diversion reach • Size of the headpond (may affect passage of lotic insects that recruit to the diversion reach) • Frequency of emergency shutdowns causing all flow to pass through the diversion reach	• Frequency / magnitude of spill at the dam and flood due to snowpack / rainfall • Length and gradient of diversion reach • Temporal change in the presence / absence and composition of sediment in the diversion reach after the dam is constructed • Amount of organic matter in substrate
7	Construction of a dam and diversion of water *causes* change in recruitment of fish food organisms to the diversion reach	• Rate of flow diversion relative to total flow • Ability to change crest elevation on the dam (e.g., an inflatable dam can be deflated during stormflows allowing stored sediment behind the dam to move) • Minimum flow in the diversion reach • Frequency of emergency shutdowns causing all flow to pass through the diversion reach	• Water temperature • Amount of benthic food production from upstream of diversion reach • Floodplain type (frequency of flooding may influence terrestrial nutrient input into reach
8	Change in spawning success and egg survival *does* reduce salmonid abundance		• Relative importance of spawning habitat in the diversion reach to support fish populations in the project area (diversion and downstream reaches)
9	Change in rearing success *does* change salmonid abundance		• Relative importance of rearing habitat in diversion reach to support fish populations in the project area (diversion and downstream reaches)
10	Change in availability of fish food organisms *does*		• Relative importance of physical habitat in the

	change salmonid growth and abundance		diversion reach to support benthos production in the project area (diversion and downstream reaches)

Evidence for and against pathway

In the absence of empirical evidence against the hypothesis, we concluded that DVH1-1 was *likely* (all 44 facilities) because evidence from the literature clearly supported the hypothesis. We concluded the two other sediment-related hypotheses (DVH1-2 and DVH1-3) were *possible* at all facilities (Figure 22). At most facilities, the monitoring of geomorphic processes in the diversion reach related to hypotheses DVH1-1, DVH1-2 and DVH1-3 had either not occurred or had not been reported (28, 32 and 29 facilities respectively). At the remaining facilities, monitoring related to these three hypotheses was either inadequate (four, one and three facilities respectively) or ongoing (12, 11 and 12 facilities respectively). For those facilities where hypotheses DVH1-1, DVH1-2 and DVH1-3 were inconclusive, monitoring at five, zero, and two facilities suggested there was some change in the monitored variables, and at one, one, and two facilities monitoring suggested there was no change. Twelve facilities had conducted baseline monitoring of stream morphology with plans to reassess stream morphology following the first large flood event that occurs after project commissioning or five years after construction, whichever comes first.

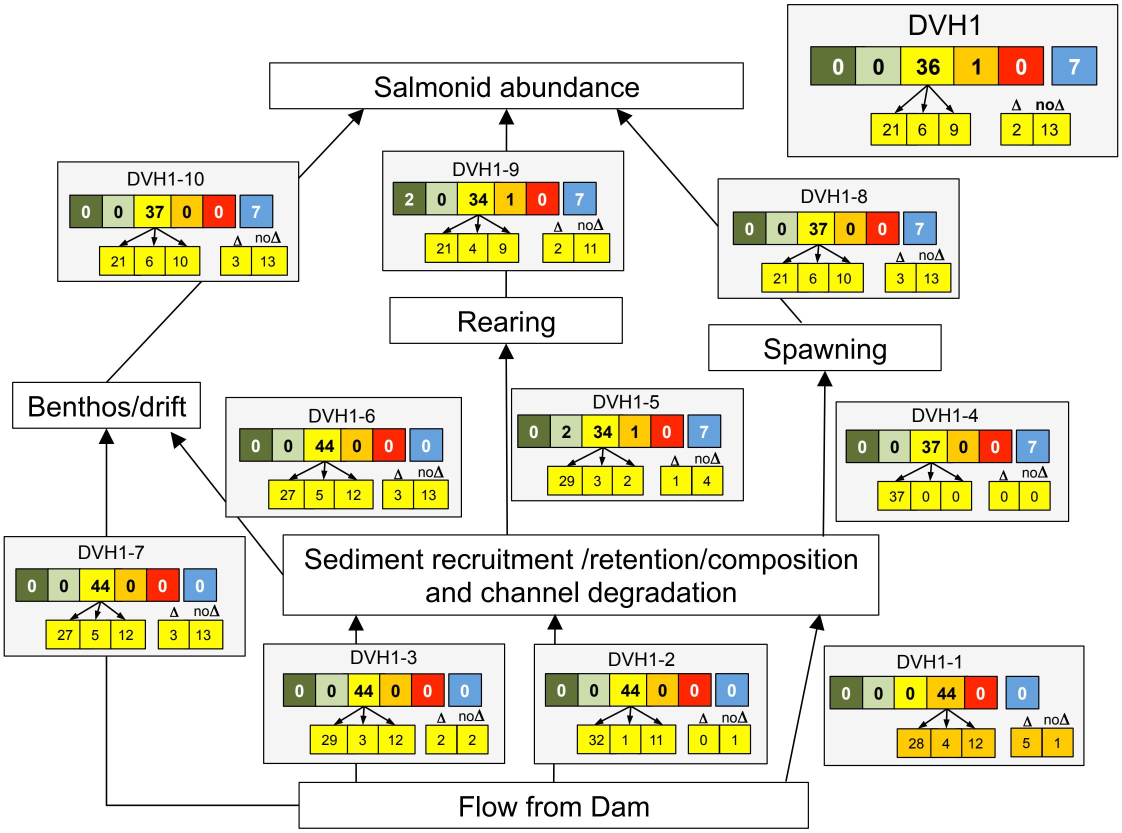

Figure 22: Impact hypothesis diagrams for hypothesis DVH1 and corresponding weight of evidence conclusions for each cause-effect link and the overall pathway. The number in each box corresponds to the number of facilities with a given conclusion (Figure 19). For DVH1-1 the breakdown of conclusions under the *likely* box is equivalent to those under the *possible* box; in this instance the conclusions have been shifted to *likely* because of the evidence from the literature and first principles.

We concluded that the two hypotheses related to changes in invertebrate production in the diversion reach, either due directly to change in flow (DVH1-7) or via changes in geomorphic processes (DVH1-6) were *possible* at all facilities (Figure 22). We reached these conclusions because monitoring had either not occurred or been reported (27 facilities), was inadequate (five facilities) or was ongoing but currently inconclusive (12 facilities). Although monitoring evidence was inconclusive, it suggested that invertebrate abundance and recruitment had changed at three facilities, but not at 13 others (Figure 22).

The majority of facilities that monitored invertebrates monitored invertebrate drift, as recommended in Lewis et al. (2013). However, a few facilities monitored invertebrates by kick sampling. A concern with kick sampling invertebrates, which consists of sampling invertebrates from the riverbed, is that it may not reflect the distribution and abundance of the primary source of salmonid invertebrate food, which is drift.

Spawning success was not directly measured at any facilities for which we had information and so we concluded DVH1-4 was *possible* based on no data at all facilities with salmonids in the diversion reach (37 facilities) (Figure 22).

In contrast to spawning success, rearing success was often quantified at facilities by a combination of minnow traps, mark recapture, and electrofishing. We concluded that hypothesis DVH1-5 was *unlikely* at two facilities where estimates of juvenile abundance and growth showed no evidence of change from before to after the onset of project operations in comparison to control sites. At 34 facilities we concluded DVH1-5 was *possible* because monitoring of rearing success was either not quantified or reported (29 facilities), inconclusive (three facilities) or ongoing and currently inconclusive (two facilities) (Figure 22). At these five facilities, monitoring suggested there was a change in rearing success at one facility and no change in rearing success at four facilities.

At one facility we concluded hypothesis DVH1-5 was *likely* because there was evidence of a difference between control and diversion reach juvenile abundance after but not before the onset of facility operations. This suggests that, in the absence of the run-of-river project, the abundance of salmonids in the diversion reach would have increased over the monitoring period. We concluded hypothesis DVH1-5 was *not possible* at the remaining seven facilities because salmonids were not present in the diversion reach.

We concluded all three hypotheses related to salmonid abundance in the diversion reach (DVH1-8, DVH1-9 and DVH1-10) were *not possible* at seven facilities because salmonids were not present in the diversion reach. At one facility we concluded DVH1-9 was *likely* because there was evidence of a difference between control and impact site resident salmonid abundance after but not before the onset of project operations, and this was at the same facility where changes in rearing success were considered *likely*. We concluded DVH1-9 was *very unlikely* at the two facilities were there was evidence that rearing success had not changed as a result of the operation of the run-of-river project. At the remaining 34 (DVH1-9) or 37 facilities (DVH1-10 and DVH1-8), we concluded changes in abundance were *possible* because monitoring had either not occurred or been reported (21 facilities), was inconclusive (four to six facilities) or was ongoing (nine to 10 facilities).

Overall, we concluded hypothesis DVH1 was *possible* at 38 facilities, *likely* at one facility and *not possible* at seven facilities (Figure 22). At those facilities where we concluded the overall pathway was *possible,* monitoring of salmonids in the diversion reach had not occurred or been reported at 23 facilities, six facilities had inadequate monitoring, and nine facilities had ongoing monitoring that would allow for future examination of the abundance of salmonids in the diversion reach. Although we found the evidence to be inconclusive, it suggested there was some change in the abundance of salmonids in the diversion reach at two facilities, but no change at 13 facilities.

Relevance of causal pathway for management decisions and critical uncertainties

Changes in geomorphic processes and recruitment of organic matter to the downstream reach are likely to occur at most facilities. Approaches to minimizing changes to the timing and magnitude of sediment transport downstream are therefore broadly relevant to management decisions. Such approaches can include routine flushing of sediment from the headpond during high flows.

A key uncertainty for this hypothesis is the extent to which the diversion reach has the potential to be affected by changes in the movement of sediment and organic matter, and the time-scale over which this may occur. It is likely that this will depend in part on the length and gradient of the diversion reach and the channel type in the diversion reach. Diversion reaches that are alluvial will be most sensitive to changes in the timing and magnitude of sediment movement downstream. Bedrock or boulder dominated channels, or previously degraded channels, will be much less sensitive to changes in sediment transport.

DVH2: CHANGES IN FLOW - FOOD PRODUCTION AND MIGRATION / MOVEMENT

General discussion

Water storage and diversion have the potential to result in a wide variety of direct and indirect impacts on fish habitat (Lewis et al. 2013). River diversion associated with run-of-river projects may alter surface water flow, temperature, velocity, water depth and sediment concentration, leading to changes in habitat that are likely to affect fish and fish food organisms (Lovekin and Hotte 2009). Studies of low flow conditions, such as those that occur in diversion reaches, have found that variables such as wetted width, water depth, and water velocity all decrease with declining flows (Dewson et al. 2007; Wu et al. 2009; Mueller et al. 2011; Walters and Post 2011), resulting in a reduction in weighted usable area. Extreme low flow can also alter habitat connectivity and cause streams to become a series of isolated pools (Walters and Post 2011). Less wetted area means less habitat for benthos and salmonids.

Reduced flow and resulting changes in aquatic habitat and resource availability can affect stream communities (Walters and Post 2011), including fish food organisms (Lewis et al. 2013). Studies of low flow impacts on aquatic insect communities have found substantial shifts in biomass, density, size and community composition (Bunn and Arthingon 2002; Baker et al. 2011; Walters and Post 2011), but not necessarily changes in overall abundance (Almodóvar and Nicola 1999) or production (Hatfield et al. 2003). Reduced biomass is driven by decreased habitat availability and decreased insect density in riffle habitats (Walters and Post 2011). Body size likely declines due to slower growth rates and / or increased mortality among larger individuals. Organisms may experience slower growth rates during low flow conditions because of reduced resource availability and increased competition (Walters and Post 2011). Prolonged low flows lead to altered abundance and diversity (Anderson et al. 2006), and physiological stress in aquatic organisms (Renöfält et al. 2010). Additionally, as habitat area contracts, predation may intensify due to increased encounter rates (Lake 2003). Walters and Post (2011) reported significantly increased densities of predatory aquatic insects in pool habitats.

Flow changes affect physical habitat, which in turn can impact fish food supply, fish growth, survival, and reproductive success (Lewis et al. 2013). Where flow reductions have caused a decline in benthic macroinvertebrate biomass, the growth and survival of salmonids might be expected to decline. However, evidence in the literature suggests that reduced salmonid survival under low flow conditions is related more to poor juvenile recruitment than to lack of food. For example, in their study of a trout population downstream of a small hydroelectric power station in central Spain, Almodóvar and Nicola (1999) reported no obvious change in growth but a significant difference in age structure. The authors concluded that the observed decline in the trout population did not appear to be induced by a scarcity of food resources, but rather by a serious reduction in trout production caused by a loss of suitable habitat and a loss of juveniles. Factors closely linked to water discharge such as water velocity were likely responsible (Almodóvar and Nicola 1999).

Changes in base flows have the potential to alter fish community composition via changes in habitat characteristics (Walters and Post 2011; Lewis et al. 2013). Additionally, the unnatural timing of rising flows in regulated reaches can affect the timing of fish movements (Larinier 2008). Disruption of migratory timing and pattern may impede salmonid reproduction (Bunn and Arthington 2002). On the other hand, the reduction of peak flows could have a positive effect on habitat conditions for juvenile salmonids (Robson et al. 2011). However, this effect is dependent on channel morphology and flow dynamics, and therefore is site-specific.

High flow events caused by plant outages and other forced spills have the potential to affect fish in the diversion reach. Rapid changes in river stage can lead to the wash-out (rising flows) or stranding (falling flows) of organisms (Saltveit et al. 2001, in a study on the River Nidelva (Norway) where flows range from 30 to >110 m^3/s). This effect is of special concern for juvenile fish, which rear in shallow shoreline habitats where fluctuating flows will have the greatest impact on habitat availability (Korman and Campana 2009). The presence of coarse elements in the substrata, and areas of low velocity at the micro-habitat scale (e.g., pools) can prevent fish from being washed away during sudden high flows (Santos et al. 2006).

High flow events can also affect fish food organisms in the diversion reach, causing downstream drift, and the elimination of part of the standing crop (Bunn and Arthington 2002).

Causal Pathway

DVH2. Change to patterns of flow in the diversion reach compared to conditions in the absence of impoundment *causes* change in salmonid movement, growth and abundance in the diversion reach.

Links	Description of Link	IPP Factors Affecting Pathway	Non-IPP Factors Affecting Pathway
1	Changes in flow in the diversion reach *do* reduce weighted usable area for benthos and salmonids in the diversion reach	• Rate of flow diversion relative to total flow • Frequency of emergency shutdowns causing all flow to pass through the diversion reach • Minimum flow in the diversion reach	• Cross-sectional shape, length, and gradient of the channel carrying water in the diversion reach • Presence / absence of impassable barriers • Frequency / magnitude of spill at the dam and flood due to snowpack / rainfall • Presence / absence and composition of sediment in the diversion reach that can support spawning and rearing
2	Changes in flow in the diversion reach *do* change production of fish food organisms in the diversion reach	• Rate of flow diversion relative to total flow • Frequency of emergency shutdowns causing all flow to pass through the diversion reach • Minimum flow in the diversion reach	• Cross-sectional shape, length, and gradient of the channel carrying water in the diversion reach • Presence / absence of impassable barriers • Frequency / magnitude of spill at the dam and flood due to snowpack / rainfall • Length and gradient of diversion reach
3	Changes in flow in the diversion reach *do increase* growth rates of juvenile salmonids via increased production of fish food organisms	• Rate of flow diversion relative to total flow • Frequency of emergency shutdowns causing all flow to pass through the diversion reach • Minimum flow in the diversion reach • Temperature changes	• Cross-sectional shape, length, and gradient of the channel carrying water in the diversion reach • Frequency / magnitude of spill at the dam and flood due to snowpack / rainfall • Length and gradient of diversion reach
4	Changes in flow in the diversion reach *do* alter upstream movement of juveniles and spawners and downstream movement of smolts	• Presence of the dam • Rate of flow diversion relative to total flow • Frequency of emergency shutdowns causing all flow to pass through the diversion reach • Minimum flow in the diversion reach	• Cross-sectional shape, length, and gradient of the channel carrying water in the diversion reach • Frequency / magnitude of spill at the dam and flood due to snowpack / rainfall • Presence / absence of impassable barriers • Length and gradient of diversion

		• Presence / absence of a fish ladder	reach • Extent to which spawning areas are upstream of diversion reach • Presence / absence of juveniles rearing to smolt age within / upstream of diversion reach
5	Fish movement patterns that are altered by changes in flow in the diversion reach *do* change fish species composition and abundance in the diversion reach	• Presence of the dam • Rate of flow diversion relative to total flow • Frequency of emergency shutdowns causing all flow to pass through the diversion reach • Minimum flow in the diversion reach • Presence / absence of a fish ladder	• Cross-sectional shape, length, and gradient of the channel carrying water in the diversion reach • Frequency / magnitude of spill at the dam and flood due to snowpack / rainfall • Presence / absence of impassable barriers • Length and gradient of diversion reach • Extent to which spawning areas are upstream of diversion reach
6	High flow events in the diversion reach that are caused by plant outages and other forced spills *causes* displacement of fish from the diversion reach and / or upstream movement of adults in the diversion reach	• Frequency of emergency and other shutdowns causing all flow to pass through the diversion reach • Minimum flow in the diversion reach	• Cross-sectional shape, length, and gradient of the channel carrying water in the diversion reach • Frequency / magnitude of spill at the dam and flooding due to runoff • Amount of snowpack contributing to stream flow in spring and summer • Length and gradient of diversion reach
7	High flow events in the diversion reach that are caused by plant outages and other forced spills *causes* displacement of fish food organisms from the diversion reach	• Frequency of emergency and other shutdowns causing all flow to pass through the diversion reach • Minimum flow in the diversion reach	• Cross-sectional shape, length, and gradient of the channel carrying water in the diversion reach • Frequency / magnitude of spill at the dam and flooding due to runoff • Length and gradient of diversion reach • Presence / absence of sediment that can support benthos
8	Change to depth and velocity compared to hydrologic conditions before the diversion *does* change growth rates and abundance of juvenile salmonids		• Timing of diversion relative to flow regime • Relative importance of growth and rearing during residence in the diversion reach on population regulation and growth within the project area (diversion and downstream reaches)

Evidence for and against pathway

We concluded that it was *very likely* that weighted usable area in the diversion reach has declined after the onset of facility operation at three facilities (DVH2-1 in Figure 23). At the remaining facilities, an empirical assessment of the reduction in weighted usable area had not occurred or been reported (30 facilities), or was inconclusive because of the approach used to estimate and / or predict changes in habitat (six facilities), or because monitoring was ongoing (five facilities). In each of these instances, given the evidence from the literature, we concluded it was *likely* that there has been a reduction in weighted usable area for benthos and / or salmonids in the diversion reach due to reduced flows resulting from project operation (DVH2-1 in Figure 23).

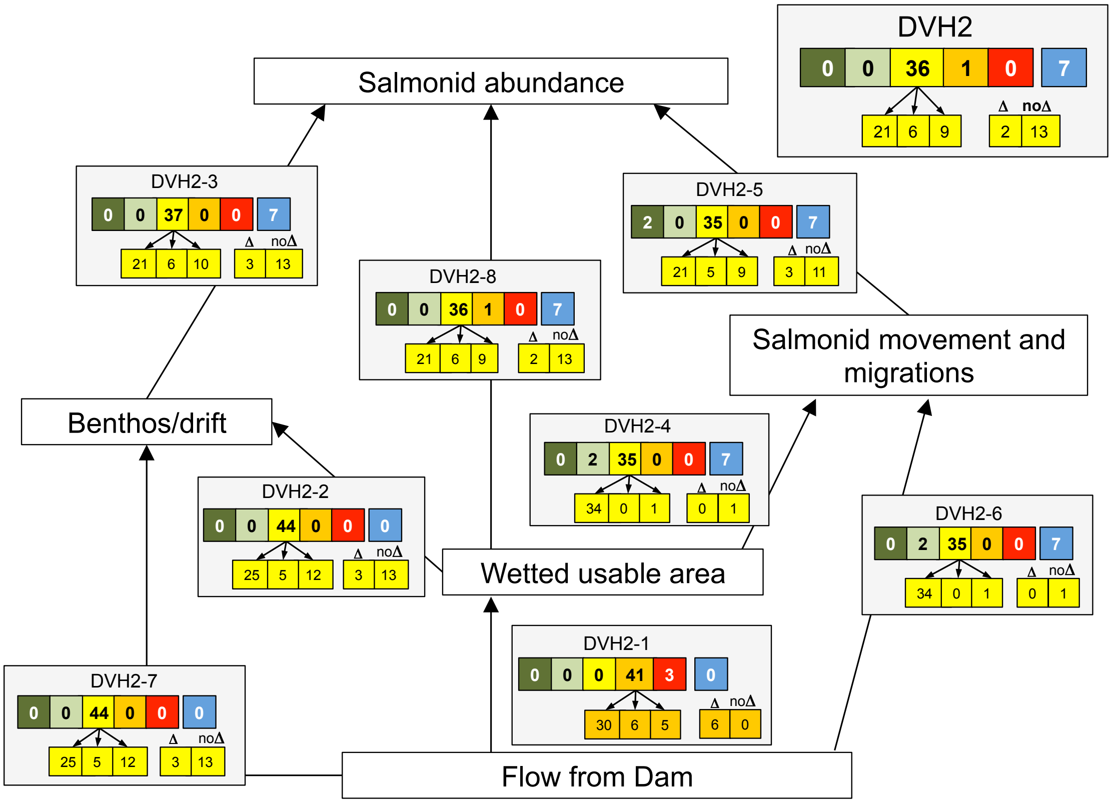

Figure 23: Impact hypothesis diagrams for hypothesis DVH2 and corresponding weight of evidence conclusions for each cause-effect link and the overall pathway. The number in each box corresponds to the number of facilities with a given conclusion (Figure 19).

We concluded that the two hypotheses related to changes in invertebrate production in the diversion reach, either due directly to change in flow (DVH2-2) or via the displacement of invertebrates following high flows (DVH2-7), were *possible* at all facilities (Figure 23). We arrived at this conclusion because monitoring had either not occurred or been reported (25 facilities), was inadequate (five facilities), or was ongoing but currently inconclusive (12 facilities). Although the evidence from monitoring was inconclusive, it suggested that invertebrate abundance and recruitment had changed at three facilities, but not at 13 others.

We concluded that changes in salmonid movement as a direct result of changes in flow (DVH2-4), or due to a reduction in wetted width in the diversion reach (DVH2-6), were *unlikely* at two facilities. We concluded this because mark recapture of resident salmonids suggested there had been no change in resident fish movement within the project area following the onset of operations of the run-of-river project. We concluded these hypotheses (DVH2-4 and DVH2-6) were *possible* at 35 facilities because monitoring had not occurred or been reported (34 facilities) or was ongoing and considered inconclusive (one facility).

We concluded all three hypotheses related to salmonid abundance in the diversion reach (DVH2-3, DVH2-5 and DVH2-8) were *not possible* at seven facilities because salmonids were not present in the diversion reach. At one facility, we concluded hypothesis DVH2-8 was *likely* because there was evidence of a difference between control and impact site resident salmonid abundance after but not before the onset of facility operations. At two facilities, we concluded hypothesis DVH2-5 was *very unlikely* because changes in fish movement were concluded to be *unlikely* in the previous link. At the remaining 35-37 facilities, we concluded hypotheses DVH2-3, DVH2-5 and DVH2-8 were *possible* because monitoring had either not occurred or been reported (21 facilities), was inadequate (five to six facilities) or was ongoing (nine to 10 facilities). At those facilities where monitoring of salmonid abundance was inconclusive, two to three facilities had evidence to suggest change had occurred, and 11-13 facilities had evidence to suggest it had not.

Overall, we concluded hypothesis DVH2 was *possible* at 36 facilities, *likely* at one facility and *not possible* at seven facilities.

Relevance of causal pathway for management decisions and critical uncertainties

This pathway is universal to almost all facilities that have a diversion reach and as such is of broad relevance to management decisions.

A key uncertainty related to this hypothesis is how changes in flow will alter instream habitat and what these changes in habitat will mean for salmonid growth and abundance in the diversion reach. This uncertainty is considered: 1) prior to the operation of a facility by determining instream flow requirements based on instream flow studies; and 2) prior to the construction of a facility by assessing the degree to which fish habitat is expected to change as a result of an altered flow regime prior to the construction of a run-of-river facility.

DVH3: WATER QUALITY – TEMPERATURE AND OXYGEN

General discussion

In regulated river systems, including run-of-river operations (Lewis et al. 2013), modified flow regimes are often accompanied by shifts in the thermal regime (Bunn and Arthington 2002). Even small changes in water temperature have the ability to cause significant impacts to fish (Clarke et al. 2008; Lewis et al. 2013). For adult Pacific salmon, the optimal temperature range lies between 10.0 and 13.9°C, with individuals exposed to temperatures ranging between 13.9 and 15.5°C considered "at risk" (National Marine Fisheries Service 1996). Temperature guidelines for the protection of freshwater aquatic life in BC suggest that mean weekly maximum water temperatures should not exceed ±1°C beyond the optimum temperature range for each life-history phase of the most sensitive salmonid species present, and that the rate of temperature change in natural water bodies should not exceed 1°C per hour (Oliver and Fidler 2001).

Reduction of flow can also modify levels of dissolved oxygen, pH, macronutrients, total suspended solids, and total gas pressure (Lewis et al. 2013). Depending on species sensitivity and life-history stage, these changes in habitat parameters can affect development and survival of salmonids. For example, low levels of dissolved oxygen can decrease growth rates or cause mortality among sensitive species (McCullough 1999; Lewis et al. 2013). Above-optimum temperatures have been shown to reduce fecundity, decrease egg survival, delay growth of fry and smolts, reduce rearing density, and increase exposure to disease (McCullough 1999).

Where water levels are reduced in the diversion reach, winter temperatures may cause a build-up of ice resulting in fish entombment, increased predation risk, and reduced habitat availability due to anchor ice formation (Valdimarsson and Metcalfe 1998; Clarke et al. 2008; Lewis et al. 2013). Ice regimes in regulated rivers are often regarded as having negative impacts on fish populations, but there are no studies that quantify overwinter survival in impacted rivers (Lewis et al. 2013). The effects of flow management on fishes during the winter months require more study (Clarke et al. 2008).

Causal Pathway

DVH3. Change to patterns of flow in the diversion reach compared to conditions in the absence of impoundment *causes* change in temperature and oxygen conditions sufficiently to affect salmonid growth and abundance in the diversion reach.

Links	Description of Link	IPP Factors Affecting Pathway	Non-IPP Factors Affecting Pathway
1	Changes to flow in the diversion reach *do* change the temperature and oxygen concentration in the diversion reach	• Timing of flow diversion • Magnitude of flow diversion • Minimum flow in the diversion reach	• Seasonality (e.g., diversion in winter may lead to colder temperatures and in summer may lead to warmer temperatures) • Riparian vegetation • Channel roughness

2	Changes in temperature and / or oxygen concentrations *do* reduced egg development, fish growth or survival in the diversion reach	• Relative volume of flow diversion • Minimum flow in the diversion reach	• Baseline temperatures in the diversion reach • Seasonality (e.g., if reduced temperature occurs after growing season fish may have already accumulated sufficient degree days)
3	Reduced egg development, fish growth or survival *does* change salmonid abundance		• Baseline survival rates and relative importance of various factors causing mortality over life cycle

Evidence for and against pathway

At three facilities, there was no evidence of a change in temperature or dissolved oxygen in the diversion reach as result of facility operations, so we concluded that hypothesis DVH3-1 was *unlikely*. At the remaining facilities we concluded that hypothesis DVH3-1 was *possible* because monitoring had not occurred or been reported (21 facilities), was inadequate (six facilities), or was ongoing and still considered inconclusive (14 facilities) but will be evaluable in the future. At one of the facilities with inconclusive monitoring, the evidence suggested there had been some change in temperature or dissolved oxygen, but no change was evident at 14 other facilities (DVH3-1 in Figure 24).

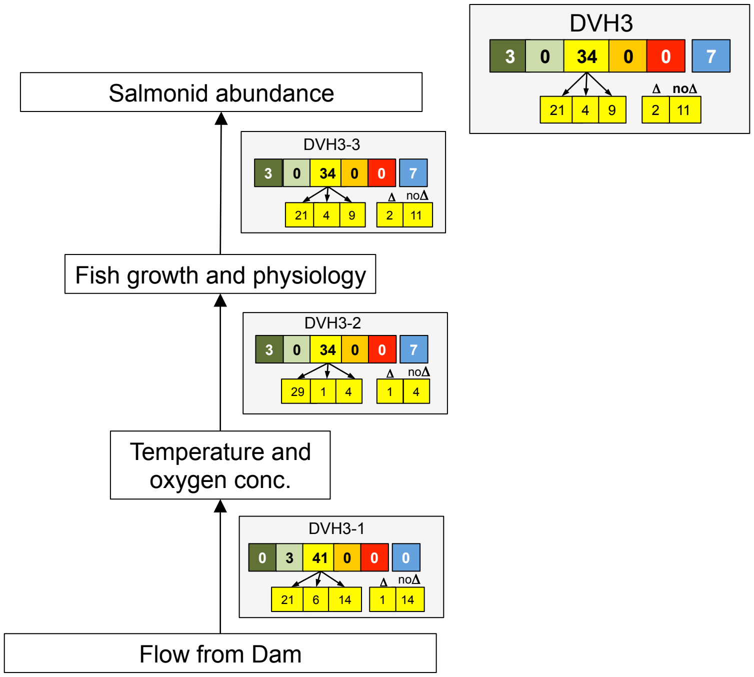

Figure 24: Impact hypothesis diagrams for hypothesis DVH3 and corresponding weight of evidence conclusions for each cause-effect link and the overall pathway. The number in each box corresponds to the number of facilities with a given conclusion (Figure 19).

We concluded that hypothesis DVH3-2 was *very unlikely* at the three facilities with no evidence of changes in temperature and dissolved oxygen (Figure 24). At the remaining facilities with salmonids present in the diversion reach, we concluded DVH3-2 was *possible* because monitoring of fish growth had not occurred or been reported at 29 facilities, was inadequate at one facility, and was ongoing at four facilities. At four of the facilities with inconclusive monitoring, the evidence suggested there had been no change in fish growth in the diversion reach; at one facility, inconclusive evidence suggested growth had changed (DVH3-2 in Figure 24). Monitoring of the physiological condition of salmonids was not reported at any facilities for which we had information.

Overall, we concluded hypothesis DVH3 was *very unlikely* at the three facilities with no evidence of changes in temperature and dissolved oxygen. At those facilities where we concluded the hypothesis was *possible,* monitoring of salmonids in the diversion reach had not occurred or been reported at 21 facilities, four facilities had inadequate monitoring, and nine facilities had ongoing monitoring that would allow for future examination of the abundance of salmonids in the diversion reach. Although we found the evidence to be inconclusive, it suggested there was some change in the abundance of salmonids in the diversion reach at two facilities, but no change at 11 facilities (Figure 24).

Relevance of causal pathway for management decisions and critical uncertainties

The influence of changes in flow on temperature can be multifaceted and vary depending on the region and thermal characteristics of the watershed. However, general guidelines for the protection of aquatic organisms in general, and salmonids in particular, including temperature and dissolved oxygen thresholds, can serve as broadly applicable rules of thumb against which to compare monitoring results.

DWH1: MOVEMENT OF SEDIMENT AND FOOD

General discussion

This hypothesis carries through the processes described in DVH1 to the downstream reach.

The presence of weirs and penstocks can alter the amount and distribution of woody debris and gravel downstream of run-of-river projects (Lovekin and Hotte 2009). Reduced stream flow via flow diversion limits the recruitment of gravel and larger sediment into downstream channels (Baker et al. 2011). In the downstream reach, below the powerhouse, large woody debris and other channel-forming elements are likely to be less prevalent. Changes in the abundance of these structural features may alter downstream fish habitat and reduce opportunities for feeding, hiding and spawning, which in turn can affect rearing success.

Regardless of their purpose, dams and weirs trap sediment, thereby interrupting sediment conveyance (Kondolf 1997). Water released downstream possesses the energy to move sediment, but has little or no sediment load. This clear water typically expends excess energy on erosion of the channel bed and banks for some years following dam construction. Channel erosion below dams is frequently accompanied by a change in particle size on the bed, as gravels and finer materials are winnowed out and transported further downstream, leaving an armor layer of large gravel, cobbles, or boulders (Kondolf 1997). The increase in particle size can threaten the success of spawning by salmonids, which use gravels with median diameter (up to about 10% of their body size) to incubate their eggs (Kondolf and Wolman 1993).

Recruitment of fish food organisms to the downstream reach can be affected by water diversion. Low species diversity in the downstream reach, at the outlet from the powerhouse, has been reported at small hydropower plants in China, and was attributed to fluctuating flows (Fu et al. 2008). However, virtually all fish-bearing streams in British Columbia have tributaries that contribute to downstream fish productivity through the export of invertebrates (i.e., food for fish) and detritus (i.e., food for aquatic invertebrates) (Hatfield et al. 2003). In downstream reaches with such tributaries, the food fish supply should increase with increasing distance from the outlet.

Causal Pathway

DWH1. Construction of a dam and diversion of water *causes* a change in the timing and magnitude of import of gravel and larger sediment and large woody debris and fish food organisms to the downstream reach resulting in changes to the area and quality of spawning and rearing habitat and change to salmonid growth and abundance in the downstream reach.

Links	Description of Link	IPP Factors Affecting Pathway	Non-IPP Factors Affecting Pathway
1	Construction of a dam and associated works including the water diversion *does* change the timing and magnitude of recruitment of gravel and larger sediment and large organic matter to the downstream reach	• Magnitude of flow diversion • Ability to change crest elevation on the dam (e.g., an inflatable dam can be deflated during stormflows allowing stored sediment behind the dam to move) • Use and effectiveness of sluicegate	• Frequency / magnitude of spill at the dam and flood due to snowpack / rainfall • Length and gradient of diversion reach • Composition and amount of sediment in the upstream and diversion reaches that is a source of sediment for the downstream reach • Composition and amount of recruitment of sediment from tributaries into downstream reach
2	Fine sediment *settles* within courser sediment in the downstream reach resulting in an increase in embeddedness	• Frequency of emergency shutdowns causing all flow to pass through the diversion reach	• Frequency / magnitude of spill at the dam and flood due to snowpack / rainfall • Length and gradient of diversion and downstream reaches • Temporal change in the presence / absence and composition of sediment in the diversion and downstream reaches after the dam is

			constructed • Amount and particle size distribution of sediment that is imported from tributaries into downstream reach
3	Changes in the timing an magnitude of the recruitment of gravel and larger sediment to the downstream reach *does* result in stream channel degradation in the downstream reach	• Amount and size mix of sediment entrained through the penstock • Effectiveness of sluicing in moving larger diameters of sediment • Physical removal, and disposal, of sediment from headpond • LWD management at diversion	• Amount and size mix of bedload moving down the reach • Channel type; must be alluvial, not bedrock controlled or previously degraded, alluvial fans are particularly susceptible • Source (upstream vs. bank) and role of LWD in channel structure
4	Change in particle size distribution in the downstream reach and / or degradation of stream channel *does* change spawning success and egg survival in the downstream reach	• Frequency of emergency shutdowns causing all flow to pass through the diversion reach	• Frequency / magnitude of spill at the dam and flood due to snowpack / rainfall • Length and gradient of diversion and downstream reaches • Temporal change in the presence / absence and composition of sediment in the diversion and downstream reaches after the dam is constructed • Amount and particle size distribution of sediment that is imported from tributaries into the downstream reach
5	Change in particle size distribution in the downstream reach and/or degradation of stream channel *does* change rearing success	• Frequency of emergency shutdowns causing all flow to pass through the diversion reach	• Frequency / magnitude of spill at the dam and flood due to snowpack / rainfall • Length and gradient of diversion and downstream reaches • Temporal change in the presence / absence and composition of sediment in the diversion and downstream reaches after the dam is constructed
6	Change in particle size distribution in the downstream reach and/or degradation of stream channel *does* change the availability of fish food organisms	• Size of the headpond (may affect passage of lotic insects that recruit to the downstream reaches) • Frequency of emergency shutdowns causing all flow to pass through the diversion reach	• Frequency / magnitude of spill at the dam and flood due to snowpack / rainfall • Length and gradient of diversion and downstream reaches • Temporal change in the presence / absence and composition of sediment in the diversion reach after the dam is constructed

			• Amount of organic matter in substrate
7	Construction of a dam and diversion of water *causes* change in recruitment of fish food organisms to the downstream reach	• Ability to change crest elevation on the dam (e.g., an inflatable dam can be deflated during stormflows allowing stored sediment behind the dam to move) • Frequency of emergency shutdowns causing all flow to pass through the diversion reach	• Amount of benthic food production from upstream of the downstream reach • Length and gradient of diversion and downstream reaches
8	Change in spawning success and egg survival *does* reduce salmonid abundance		• Relative importance of spawning habitat in the downstream reach to support fish populations in the project area (diversion and downstream reaches)
9	Change in rearing success *does* change salmonid abundance		• Relative importance of rearing habitat in downstream reach to support fish populations in the project area (diversion and downstream reaches)
10	Change in availability of fish food organisms *does* change salmonid growth and abundance		• Relative importance of physical habitat in the downstream reach to support benthos production in the project area (diversion and downstream reaches)

Evidence for and against pathway

Three facilities effectively had no "downstream reach" because the diversion reach and tailrace discharged directly into another water body (e.g., a much larger river or lake). At the remaining 41 facilities, we concluded the hypotheses related to the movement and deposition of sediment and organic matter in the downstream reach were *possible* (DWH1-1 to DWH1-3 in Figure 25). At most of the facilities where we concluded these hypotheses were *possible*, monitoring of geomorphic processes in the downstream reach related to the hypothesis had not occurred or been reported (32-34 facilities). Monitoring of channel morphology and the magnitude and timing of sediment and large woody debris recruitment was inadequate but had occurred at one and two facilities respectively. At seven facilities, baseline monitoring of stream morphology and sedimentation had occurred with plans to reassess stream morphology and sedimentation following the first large flood event after project commissioning or five years after construction, whichever comes first.

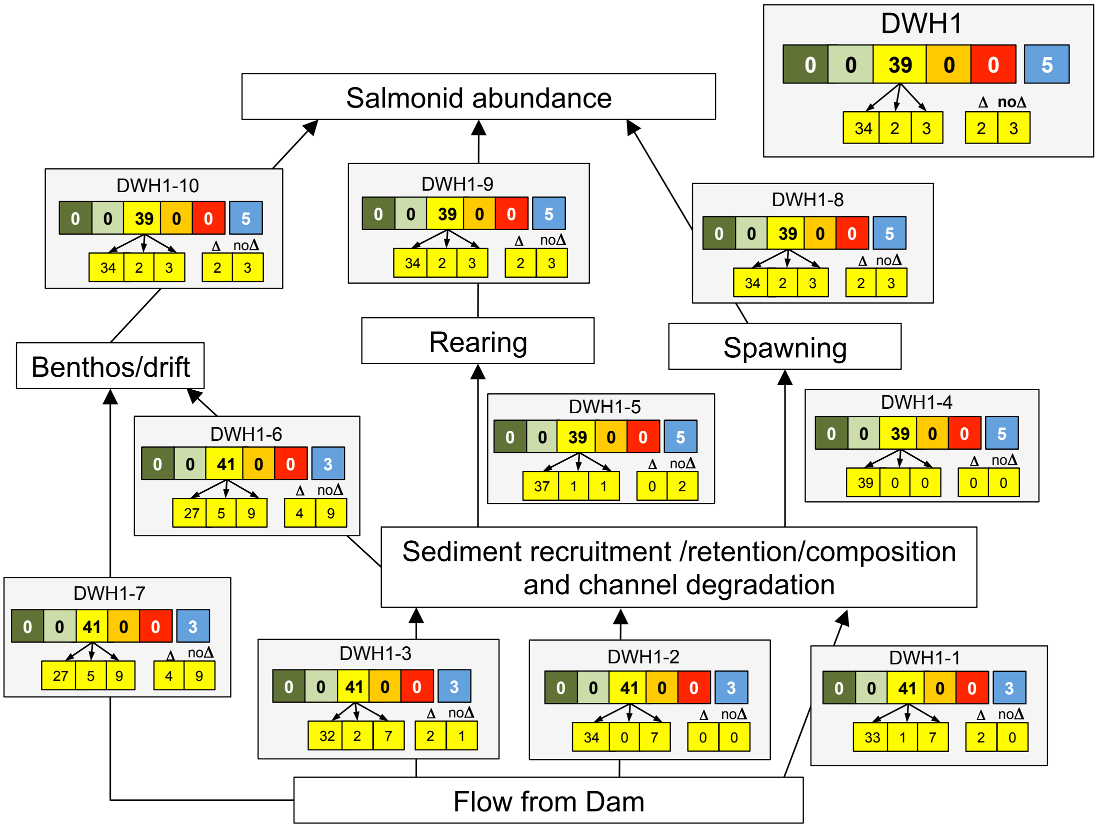

Figure 25: Impact hypothesis diagrams for hypothesis DWH1 and corresponding weight of evidence conclusions for each cause-effect link and the overall pathway. The number in each box corresponds to the number of facilities with a given conclusion (Figure 19).

We concluded that the two hypotheses related to changes in invertebrate production in the downstream reach, either due directly to change in flow (DWH1-7) or via changes in geomorphic processes (DWH1-6), were *possible* at all facilities where salmonids were present in the downstream reach (Figure 25). We reached these conclusions because monitoring had either not occurred or been reported (27 facilities), was inadequate (five facilities), or was ongoing but currently inconclusive (nine facilities). Although monitoring evidence was inconclusive, it suggested that invertebrate abundance and recruitment had changed at four facilities, but not at nine others (Figure 25).

Spawning success was not directly measured in the downstream reach at any facilities for which we had information, so we concluded DWH1-4 was *possible* based on no data at all facilities with salmonids in the downstream reach (39 facilities) (Figure 25).

Rearing success was also not quantified at most facilities in the downstream reach, so we concluded that hypothesis DWH1-5 was *possible* at 39 facilities. Thirty-seven of these facilities did not monitor or provide information on rearing success in the downstream reach. At two facilities, some monitoring of juvenile abundance and growth had occurred but was inadequate at one facility and ongoing at another. Although monitoring evidence was inconclusive, it suggested changes had not occurred at either facility (DWH1-5 in Figure 25).

Overall, we concluded that hypothesis DWH1 was *possible* at 39 facilities and *not possible* at five facilities (Figure 25). At those facilities where we concluded the overall pathway was *possible,* monitoring of salmonid abundance in the downstream reach had not occurred or been reported at 34 facilities, two facilities had inadequate monitoring, and three facilities had ongoing monitoring that would allow for future examination of the abundance of salmonids in the downstream reach. Although we found the evidence to be inconclusive, it suggested there was some change in the abundance of salmonids in the diversion reach at two facilities, but no change at three other facilities.

Relevance of causal pathway for management decisions and critical uncertainties

Changes in geomorphic processes and recruitment of organic matter to the downstream reach are likely to occur at most facilities. Approaches to minimizing changes to the timing and magnitude of sediment transport downstream are therefore broadly relevant to management decisions. Such approaches can include routine flushing of sediment from the headpond during high flows.

A key uncertainty for this hypothesis is the extent to which the downstream reach has the potential to be affected by changes in the movement of sediment and organic matter. It is likely that this will depend in part on the length and gradient of the diversion reach, and on the channel type in the downstream reach. Long, lower gradient diversion reaches may be less likely to have sediment move through them to the downstream reach than short high gradient diversion reaches. Downstream reaches that are alluvial, or alluvial fans, will be most sensitive to changes in the timing and magnitude of sediment movement downstream. Rock controlled or previously degraded channels will be much less sensitive to changes in sediment transport.

DWH2: RAMPING RATES – STRANDING AND HABITAT

General discussion

Flow ramping is change in the rate at which water is discharged from the penstock into the downstream reach (Cathcart 2005). When a facility increases, decreases or suddenly stops flow though the penstock, downstream changes in flow continue until the water that has stopped flowing through the penstock is diverted back through the diversion reach. The longer the diversion reach and the lower the stream gradient, the longer it will take for flow to “catch up” downstream of the powerhouse. Turbines that stop the flow of water through the powerhouse when they shutdown (e.g., Francis turbines) have the potential to result in greater ramping rates than those that do not (e.g., Pelton turbines). The use of by-pass valves, which allow for flow to be diverted around a turbine, can reduce the potential for ramping of flow.

The shape and type of the downstream channel will influence the extent to which rapid changes in flow result in dewatered stream margins. Fluctuations in flow in channels that are U-shaped with steep margins will result in less dewatered habitat than channels that are shallow and flat. In shallow channels, small changes in flow have the potential to result in extensive dewatering of stream margins.

Changes to flow magnitude due to ramping have consequences for fish and their habitat (Lewis et al. 2013). Dewatered stream margins can strand and kill juvenile fish and seriously degrade their habitats (Korman and Campana 2009).

A common finding in studies of hydropower facilities has been that more rapid flow fluctuations have a greater potential to strand fish downstream (Nagrodski et al. 2012). Habitat characteristics are important in predicting survivorship. Reduced water flow, gently sloped streambanks, heavily structured littoral zones, cooler water temperatures, and poor water quality are all conditions that increase the likelihood of fish stranding events. Stranding rates are also species- and life-stage specific, being affected by body size, swimming capacity, behaviour, and morphology (Clarke et al. 2008; Nagrodski et al. 2012). The biological outcomes of fish stranding on individual fish described in the literature range from negligible sub-lethal impacts to direct mortality (Nagrodski et al. 2012). Eggs and recently emerged stages are particularly susceptible to stranding following dewatering.

Other sub-lethal impacts of fluctuating flows include interruption of feeding, migration, and spawning behaviours, and causing fish to abandon preferred habitats, thus effectively reducing the value of those habitats (Lewis et al. 2013). Key factors that determine the potential effects of flow fluctuation on fish include: the rate of change in flow; the duration of the change; the time of day, the season and / or temperature; the behaviour of fish, fish species and life stage (size); and the substrate character of the stream (Halleraker et al. 2003; Lewis et al. 2013).

Declining flows can reduce the availability of one or more habitat, or result in poor connectivity between habitats. In theory habitat fragmentation can negatively affect population persistence, and can lead to population decline or local population extinctions (Wilcox and Murphy 1985). There are, however, few references in the literature that address the specific link between flow ramping and effects at the population level (Nagrodski et al. 2012). In a Norwegian study of a hydropeaking operation on the Alta River, an 80% reduction in the densities of juvenile Atlantic salmon was reported over a period of four years following river regulation, reflecting the response of fish to decreased water flows (Ugedal et al. 2008). In a Spanish study, observed declines in the brown trout population downstream of the diversion dam for a small hydroelectric power station (700 kW) were attributed to recruitment loss, most likely caused by factors closely linked to water discharge such as water velocity and habitat modification (Almodóvar and Nicola 1999).

Causal Pathway

DWH2. The rate at which water is released from the powerhouse (ramping rate) *does* strand fish and change the production of fish food organisms leading to change in salmonid growth and abundance in the downstream reach.

Links	Description of Link	IPP Factors Affecting Pathway	Non-IPP Factors Affecting Pathway
1	Flow ramping at the powerhouse *does* reduce weighted usable area (wetted area, water depth, water velocity, temperature) for benthos and salmonids in the downstream reach	• Presence / absence of a flow bypass • Amount of flow from the diversion reach without a plant outage • Time for flow to reach the downstream reach via the diversion reach following a plant outage. • Presence / absence of works to release a controlled flow of water from the headpond into the diversion reach when there is a plant outage • Control of ramping rate (i.e., planned or emergency) • Duration of dewatering event	• Cross-sectional shape of the downstream channel (e.g., box, flat, V, U) • Magnitude of spill from the dam during plant outage
2	Dewatering of stream margins from flow ramping *does* change the production of fish food organisms among all habitats in the whole downstream reach	• Presence / absence of a flow bypass • Amount of flow from the diversion reach without a plant outage • Time for flow to reach the downstream reach via the diversion reach following a plant outage. • Presence / absence of works to release a controlled flow of water from the headpond into the diversion reach when there is a plant outage • Control of ramping rate (i.e., planned or emergency) • Duration of dewatering event	• Cross-sectional shape of the downstream channel (e.g., box, flat, V, U) • Water temperature in exposed shoreline pools • Presence / absence / area / depth of shoreline pools • Relative importance of dewatered area vs. wetted area for producing benthic invertebrates in the downstream reach • Magnitude of spill from the dam during plant outage

3	Dewatering of steam margins from flow ramping *does* strand fish in the downstream reach	• Duration of dewatering event • Presence / absence of a flow bypass • Amount of flow from the diversion reach without a plant outage • Time for flow to reach the downstream reach via the diversion reach following a plant outage. • Presence / absence of works to release a controlled flow of water from the headpond into the diversion reach when there is a plant outage • Control of ramping rate (i.e., planned or emergency)	• Cross-sectional shape of the downstream channel (e.g., box, flat, V, U) • Life stage of salmonid • Presence / absence / area / depth of shoreline pools • Magnitude of spill from the dam during plant outage • Availability of outflow channels to avoid stranding
4	Mortality of fish from standing due to flow ramping does reduced fish survival and abundance in the downstream reach	• Duration of dewatering event • Presence / absence of a flow bypass • Amount of flow from the diversion reach without a plant outage • Time for flow to reach the downstream reach via the diversion reach following a plant outage. • Presence / absence of works to release a controlled flow of water from the headpond into the diversion reach when there is a plant outage • Control of ramping rate (i.e., planned or emergency)	• Water temperature in exposed shoreline pools • Life stage of salmonid • Presence / absence / area / depth of shoreline pools • Relative importance of dewatered area vs. wetted area as habitat for salmonids in the downstream reach • Magnitude of spill from the dam during plant outage • Shape of the downstream channel (e.g., box, flat, V, U)
5	Dewatering of steam margins from flow ramping *does* reduce salmonid growth rates, survival, and abundance via reduced production of fish food organisms in downstream reach	• Duration of dewatering event • Presence / absence of a flow bypass • Amount of flow from the diversion reach without a plant outage • Time for flow to reach the downstream reach via the diversion reach following a plant	• Water temperature in exposed shoreline pools • Life stage of salmonid • Presence / absence / area / depth of shoreline pools • Relative importance of dewatered area vs. wetted area as habitat for juvenile salmonids in the downstream reach • Magnitude of spill from the dam during plant outage

		outage. • Presence / absence of works to release a controlled flow of water from the headpond into the diversion reach when there is a plant outage • Control of ramping rate (i.e., planned or emergency)	• Shape of the downstream channel (e.g., box, flat, V, U)
6	Flow ramping *does* change upstream movement of juveniles and spawners and downstream movement of smolts	• Duration of dewatering event • Presence / absence of a flow bypass • Amount of flow from the diversion reach without a plant outage • Time for flow to reach the downstream reach via the diversion reach following a plant outage. • Presence / absence of works to release a controlled flow of water from the headpond into the diversion reach when there is a plant outage • Control of ramping rate (i.e., planned or emergency)	• Life stage of salmonid • Magnitude of spill from the dam during plant outage • Shape of the downstream channel (e.g., box, flat, V, U)
7	Fish movement patterns that are changed by flow ramping *do* change fish species composition and abundance in the downstream reach	• Duration of dewatering event • Presence / absence of a flow bypass • Amount of flow from the diversion reach without a plant outage • Time for flow to reach the downstream reach via the diversion reach following a plant outage. • Presence / absence of works to release a controlled flow of water from the headpond into the diversion reach when there is a plant outage • Control of ramping rate (i.e., planned or emergency)	• Life stage of salmonid • Magnitude of spill from the dam during plant outage • Shape of the downstream channel (e.g., box, flat, V, U)

8	Flow ramping *does* reduce the species composition and abundance of fish food organisms in continuously wetted habitat of the downstream reach	• Duration of dewatering event • Presence / absence of a flow bypass • Amount of flow from the diversion reach without a plant outage • Time for flow to reach the downstream reach via the diversion reach following a plant outage. • Presence / absence of works to release a controlled flow of water from the headpond into the diversion reach when there is a plant outage • Control of ramping rate (i.e., planned or emergency)	• Magnitude of spill from the dam during plant outage • Shape of the downstream channel (e.g., box, flat, V, U) • Life stage of salmonid

Evidence for and against pathway

We concluded hypothesis DWH2-1 was *very likely* at nine facilities where there was clear evidence that flow ramping from the powerhouse has led to reductions in the weighted usable area for benthos and salmonids in the downstream reach (Figure 26). The duration of dewatering events was not consistently reported, but for those facilities where it was reported they ranged from a few minutes to 8 hours. At the remaining facilities where there was a downstream reach, monitoring of flow ramping effects on downstream weighted usable area had not occurred or been reported at 28 facilities, was inadequate at two facilities, and was ongoing but currently inconclusive at two facilities. Because it is almost certain that variation in flow from the powerhouse will result in some amount of variation in weighted usable area in the downstream reach, we concluded the hypothesis was *likely* at 32 of the facilities with salmonids in the downstream reach. Three facilities effectively had no “downstream reach” and so we concluded hypothesis DWH2-1 was *not possible* at these facilities.

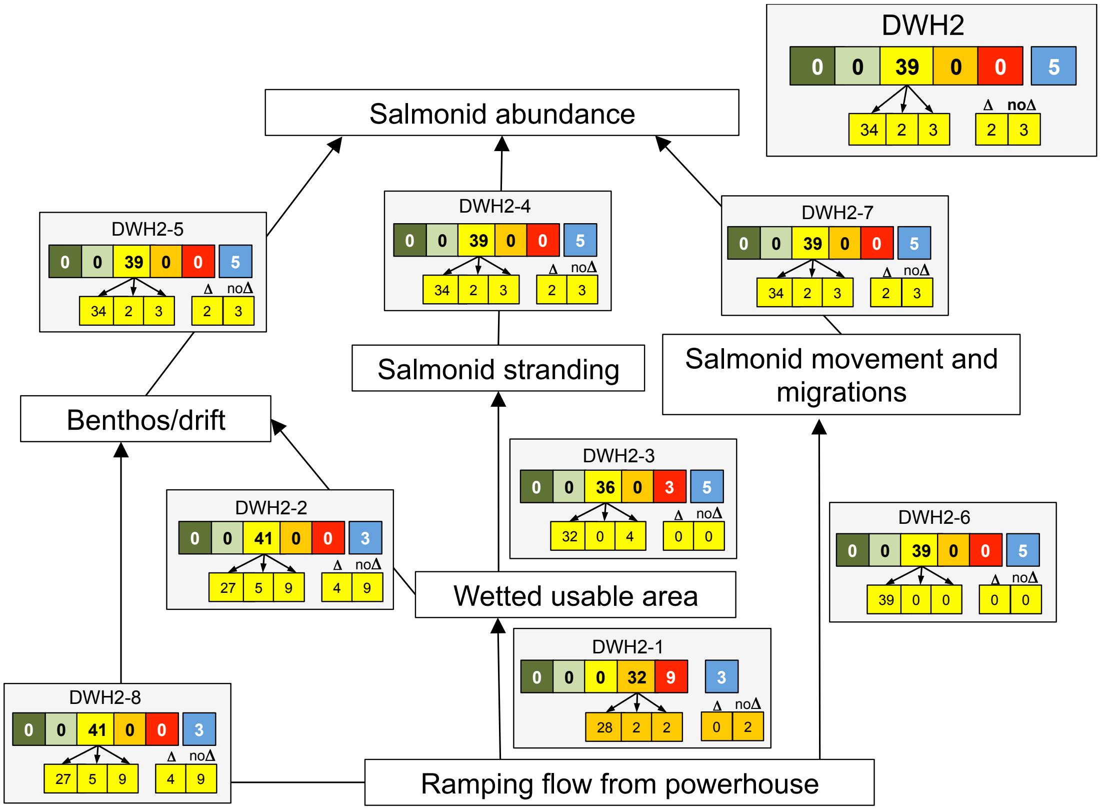

Figure 26: Impact hypothesis diagrams for hypothesis DWH2 and corresponding weight of evidence conclusions for each cause-effect link and the overall pathway. The number in each box corresponds to the number of facilities with a given conclusion (Figure 19).

At most facilities, the extent to which ramping of flow led to stranding and / or mortality of salmonids was unknown. However, at three facilities there was direct evidence of mortality as a result of stranding following flow ramping and so we concluded hypothesis DWH2-3 was *very likely* at these facilities (Figure 26). At the 36 remaining facilities with salmonids in the downstream reach, we concluded mortality due to stranding following dewatering of stream margins was *possible*. At 32 of these facilities, there were no data on actual strandings following ramping incidents with which to further evaluate the hypothesis, while at 4 facilities there was ongoing monitoring of stranding following ramping incidents.

Seventeen facilities provided ramping rate reports / studies. These studies help to set facility-specific ramping rates based on monitoring the effects of reductions in wetted width downstream and strandings during a series of experimental ramping rate tests. Eleven facilities had evidence of ramping rate violations that could lead to stranding and mortality. At those facilities that provided ramping rate non-compliance estimates, there was a tendency for ramping rate non-compliance to occur more frequently during commissioning and / or early in post-commission operation.

Of the 28 facilities for which we had information on turbine type in the powerhouse, nine had Francis turbines. Six of the facilities with Francis turbines also had by-pass valves, which are designed to allow flow to bypass the turbines in the case of a shutdown, thereby reducing the ramping rate.

We concluded that the two hypotheses related to changes in invertebrate production in the downstream reach, either due directly to change in flow (DWH2-8) or via changes in weighted usable area (DWH2-2), were *possible* at all facilities (Figure 26). We reached these conclusions because monitoring had either not occurred or been reported (27 facilities), was inadequate (five facilities), or was ongoing but currently inconclusive (nine facilities). Although we found the evidence to be inconclusive, it suggested that invertebrate abundance and recruitment had changed at four facilities, but not at nine others (Figure 26).

There was no monitoring or reporting of the extent to which ramping of flow from the powerhouse may influence salmonid movement and upstream migration. Therefore, we concluded that hypothesis DWH2-6 was *possible* at all 39 facilities with salmonids in the downstream reach (Figure 26).

Overall, we concluded that hypothesis DWH2 was *possible* at the 39 facilities with salmonids in the downstream reach. At these facilities, monitoring of salmonids in the downstream reach had not occurred or been reported at 35 facilities. At two facilities, monitoring of salmonid abundance in the downstream reach was inadequate, and three facilities had ongoing monitoring that would allow for future examination of the abundance of salmonids in the downstream reach. Although we found the evidence to be inconclusive, it suggested there was some change in the abundance of salmonids in the downstream reach at two facilities, but no change at three others.

It is important to note that before-after abundance monitoring is expected to be a weak detector of flow ramping effects on salmonids downstream of a facility. Consequently, downstream monitoring should focus on intermediate nodes along this impact pathway including juvenile mortality as a result of stranding and invertebrate drift (Lewis et al. 2013).

Relevance of causal pathway for management decisions and critical uncertainties

The rate and duration of operational flow change are the primary factors that can be controlled to limit the impacts of flow change (e.g., turbine start-up and shutdown due to planned or unplanned outages, etc.). Ramping rate studies, which quantify the acceptable range of ramping rates at a given facility, are often required as part of site licensing.

A critical uncertainty for this hypothesis is if, and under what conditions, individual mortality due to stranding manifests itself at the population level.

DWH3: WATER QUALITY – TOTAL DISSOLVED GAS

General discussion

Dissolved gas super-saturation has been shown to have adverse physiological effects on fish and invertebrates (Hildebrand 1980; CEA 2001; Clarke et al. 2008). The main mechanism causing gas super-saturation is the entrainment of air by water as it passes over a spillway and falls into a plunge basin. Gas (primarily nitrogen) is forced into solution under pressure at depth in the plunge basin (Hildebrand 1980). High head dams on the Columbia and Snake Rivers produced surface super-saturation between 120 and 130% in 1966 and 1967 (Weitkamp and Katz 1980).

Exposure to high gas saturation levels (i.e., 110% and greater) can cause fish to exhibit signs of gas bubble disease (Hildebrand 1980, Weitkamp and Katz 1980). Internal bubbles may form in the bloodstream and tissues, disrupting neurological, cardiovascular, respiratory, osmoregulatory, and other functions. Depending on the length and level of exposure, fish mortality may result. Gas bubble disease in fish may also contribute indirectly to fish mortality (CEA 2001). Fish tend to be weakened by exposure, particularly in juvenile life stages. The ability of affected fish to avoid predators can be impaired. Gas bubble disease may also increase the susceptibility of fish to other stresses, such as bacterial, viral, and fungal infections.

The occurrence and severity of gas super-saturation depends largely on dam design and operation (CEA 2001). In lower head diversion schemes where there are no deep plunge pools and entrained air is not carried to depth, there is low potential for gas bubble disease (Hildebrand 1980; Taylor 2010). Additionally, in those facilities where Pelton turbines are installed, water drops to the powerhouse foundation after hitting the turbine runner and is then released under gravity and not pressurized. As a result, gas super-saturation may be less likely to occur. The extent to which air gets entrained in water entering the penstock at run-of-river facilities is not well known, but monitoring total dissolved gas pressure (i.e., the degree of super-saturation) at run-of-river facilities could address this knowledge gap (Lewis et al. 2013).

The effects of fish mortality and impairment from gas bubble disease have been studied much more in laboratories than in the field (CEA 2001). Free-swimming fish may avoid gas bubble disease by moving into deeper waters (Hildebrand 1980; Clarke et al. 2008). Recent monitoring by BC Hydro suggests, however, that higher gas saturation levels do not necessarily deter adult rainbow trout from their normal surface feeding behaviour (CEA 2001).

Causal Pathway

DWH3. Entrainment of air in the power plant *does* change total dissolved gas conditions downstream of the project sufficiently to cause gas bubble disease and affect salmonid growth and abundance in the downstream reach.

Links	Description of Link	IPP Factors Affecting Pathway	Non-IPP Factors Affecting Pathway
1	Entrainment of air in the water diverted through the penstock and powerhouse *does* change the total dissolved gas pressure in the diversion reach	• Type of turbine • Relative rates of flow between penstock and diversion reach	• The degree to which total dissolved gas pressure naturally increases in the diversion reach due to waterfalls etc. • Channel roughness in downstream reach
2	Changes in total dissolved gas pressure *does* exceed physiological thresholds that lead to gas bubble disease in salmonids in the downstream reach		• Life stage of salmonid • Conditions in the downstream reach that influence gas bubble disease threshold (e.g., temperature)
3	Gas bubble disease in salmonids in the downstream reach *does* change salmonid abundance		• Life stage of salmonid

Evidence for and against pathway

At seven facilities with monitoring of total dissolved gas pressure in the downstream reach, we concluded that hypothesis DWH3-1 was *unlikely*. At the remaining facilities where there was a downstream reach, monitoring of total dissolved gas pressure had not occurred or been reported at 34 facilities, was inadequate at four facilities, and ongoing at three facilities. At all seven facilities where monitoring was inconclusive, the available evidence suggested total dissolved gas pressure had not changed (DWH1-1 in Figure 27).

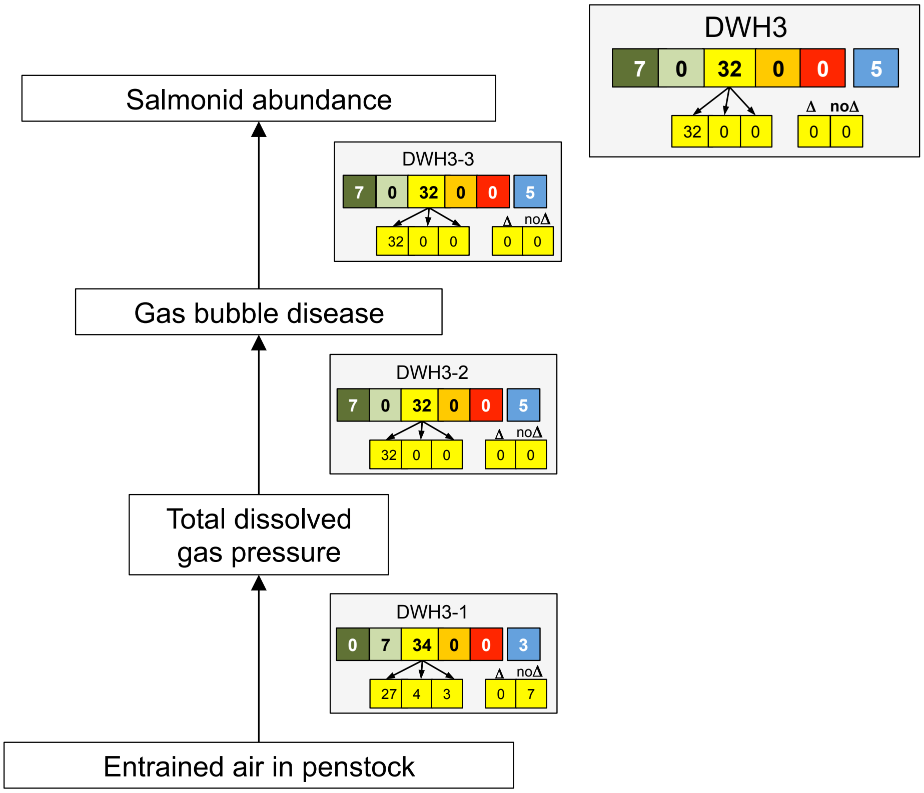

Figure 27: Impact hypothesis diagrams for hypothesis DWH3 and corresponding weight of evidence conclusions for each cause-effect link and the overall pathway. The number in each box corresponds to the number of facilities with a given conclusion (Figure 19).

Because we concluded the bottom link in the pathway (DWH3-1) was *unlikely* at seven facilities, we concluded the subsequent link in the pathway (DWH3-2) was *very unlikely* for these seven facilities. At five facilities where there were no salmonids in the downstream reach (or no downstream reach at all), we concluded hypothesis DWH3-2 was *not possible*. At the remaining 32 facilities, we concluded the hypothesis was *possible* because there was no monitoring of the occurrence of gas bubble disease in salmonids.

Overall, we concluded that hypothesis DWH3 was *very unlikely* at seven facilities because monitoring indicated no detectable increase in total dissolved gas pressure in the downstream reach. At 32 facilities, we concluded this hypothesis was *possible,* and at the remaining five facilities the hypothesis was considered *not possible* because salmonids were not present in the downstream reach.

Relevance of causal pathway for management decisions and critical uncertainties

As a result of our review of the literature, and based on data from those facilities with conclusive monitoring, we determined that this pathway does not appear to be a pathway of effect that is likely to be of significant concern for salmonids at typical run-of-river projects.

CH1: HABITAT LOSS AND COMPENSATION

General discussion

The construction of run-of-river projects and their auxiliary infrastructure (i.e., access roads and transmission lines) can have both direct and indirect effects on the aquatic environment. Direct effects include the temporary ecological disruption of river flora and fauna, and outright habitat loss (Taylor 2010). Indirectly, the creation of access roads into formerly remote and inaccessible areas facilitates vehicle access and angling of fish populations (Lovekin and Hotte 2009). Construction activities and infrastructure may result in increased sediment inputs to streams. The potential for construction-related sedimentation effects is recognized, and regulations have been implemented in an attempt to reduce the risk of excessive sedimentation (MFLNRO 2013). The extent and severity of these effects will depend on the particular characteristics of the project and the mitigation measures implemented during construction.

The creation of a reduced-flow segment between the abstraction point and the point where water returns to the stream can also lead to a permanent change in habitat availability. The likelihood of this impact will depend on the minimum flow released during operations. Changes in habitat as a result of altered flow as well as changes in the upstream reach due to the construction of the weir and creation of a headpond are typically considered when determining project level losses in habitat and associated compensation requirements.

While “no net loss” in productive capacity is the stated goal of compensation, the metric used to evaluate compensation is typically habitat. Compensation habitat is required to offset effects when the construction and operation of a project is expected to have negative impacts on fish that cannot be avoided or mitigated. The amount and type of habitat compensation that is required to achieve “no net loss” is project specific, and depends on the type and productivity of the habitat that is affected, the method of compensation and the certainty of success (DFO 2013). The compensation ratio should be increased in situations where uncertainty of compensation site effectiveness is high (Quigley et al. 2006). Habitat losses and gains may not be evident with any certainty until several years post-development (Mainstream Aquatics Ltd. 2006).

Quigley and Harper (2006) evaluated the effectiveness of habitat compensation for 16 infrastructure projects (none of them a hydroelectric facility) across Canada and found that compensation ratios greater than 2:1 were required for these measures to be effective. Another conclusion of their study was that inherent ecosystem variability requires large differences, or range of variation, in the performance parameters in order to detect responses to compensation efforts.

Habitat development can replace spawning grounds affected by the creation of a headpond. For example, suitable substrates can be placed in tributaries upstream of backwater effects from the headpond to assist stream-spawning species. Downstream of the headpond, gravel can be added to the river to offset loss in gravel recruitment from upstream sources. As an alternative, artificial side channel rearing or spawning channels may be created (CEA 2001).

There are few post-development studies on the effectiveness of constructed spawning or rearing habitats for hydropower facilities in general, and for run-of-river projects in particular. The effectiveness of the habitat compensation measures generally proposed could not be assessed based on the available information.

Causal Pathway

CH1. Off-channel constructed fish habitat *does* replace lost fish habitat and fish production in the project area resulting in no net loss in the species composition and abundance of salmonids.

Links	Description of Link	IPP Factors Affecting Pathway	Non-IPP Factors Affecting Pathway
1	Construction of powerhouse, weir, roads, penstock and transmission lines as well as release of harmful materials (e.g., concrete, infill, fuel) during construction *does* lead to reduction in salmonid habitat	• Same as those for links in upstream, diversion, and downstream reaches related to habitat • Best practices during construction phase • Location of penstock in relation to the waterway • Fish salvage protocols during construction	• Same as those for links in upstream, diversion, and downstream reaches related to habitat
2	The construction of rearing habitat *does* replace lost rearing habitat area and complexity	• Funding from operations • Commitment to monitoring effectiveness of constructed habitat • Partnerships with community groups and regulatory agencies • Regulatory policy	• Physical availability of land and water to construct habitat
3	The construction of spawning habitat *does* replace lost spawning habitat area	• Funding from operations • Commitment to monitoring effectiveness of constructed habitat • Partnerships with community groups and regulatory agencies • Regulatory policy	• Physical availability of land and water to construct habitat

4	Constructed spawning habitat *does* meet or exceed lost spawning success and egg-to-fry survival in the project stream	• Channel maintenance • Funding from operations • Commitment to monitoring effectiveness of constructed habitat • Partnerships with community groups and regulatory agencies • Regulatory policy • Effectiveness of project design	• Water quality • Relative importance of new spawning habitat to support fish populations in the project area
5	Constructed rearing habitat *does* meet or exceed lost production of fish food organisms and juvenile salmonid growth, survival and abundance in the project stream	• Channel maintenance • Funding from operations • Commitment to monitoring effectiveness of constructed habitat • Partnerships with community groups and regulatory agencies • Regulatory policy • Effectiveness of project design	• Water quality • Relative importance of new off-channel habitat for fish growth and population size in the project area

Evidence for and against pathway

Seventeen facilities provided information related to compensation plans designed to offset habitat losses as a result of the footprint of the facility and alteration of flow in the diversion reach. At four facilities, we were provided with documentation that compensatory habitat was not required, and so concluded that hypothesis CH1 was *not possible*. At the remaining 25 facilities, *no conclusion was possible* because we were unable to determine if compensatory habitat construction was required and / or constructed (Figure 28).

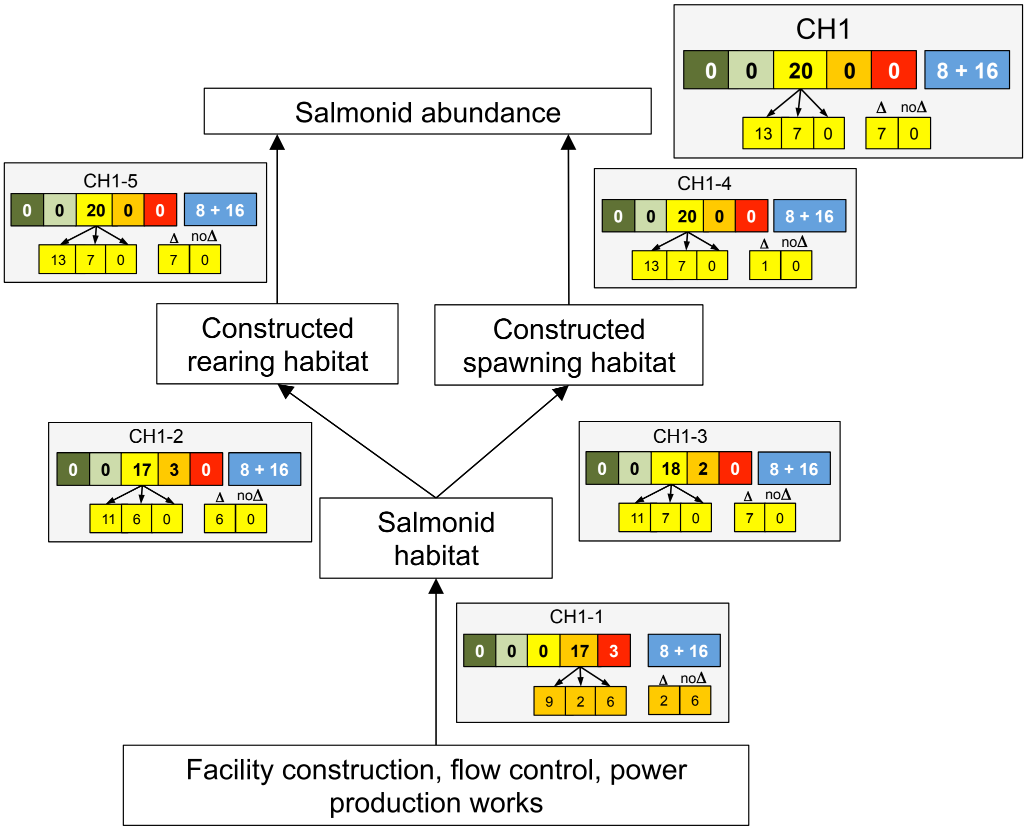

Figure 28: Impact hypothesis diagrams for hypothesis CH1 and corresponding weight of evidence conclusions for each cause-effect link and the overall pathway. The number in each box corresponds to the number of facilities with a given conclusion (Figure 19). The two numbers in the *Not possible* box correspond to those facilities at which no conclusion was possible (8) and those that did not require compensation (16).

Of the 20 facilities that provided compensation information, three had empirical estimates of the amount of reduced salmonid habitat (for which compensation was required), and so we concluded hypothesis CH1-1 was *very likely* (CH1-1 in Figure 28). The remaining 17 facilities had undertaken compensation activities under the auspices of a Fisheries Act Authorization, and so we concluded that hypothesis CH1-1 was *likely*. However, there was no information on lost and / or gained habitat (six facilities), the estimates of lost or gained habitat were not based on empirical measurements at two facilities, and verification of the amount of habitat lost or gained were ongoing at six facilities.

We concluded that the hypothesis that constructed rearing habitat replaced lost rearing habitat was *very likely* at three facilities (CH1-2 in Figure 28). At the remaining 17 facilities with known compensation habitat, we concluded hypothesis CH1-2 was *possible*. For eleven of these 17 facilities, the hypothesis was considered *possible* because estimates of losses and / or gains in rearing habitat were unavailable. Estimates were inconclusive for the remaining six facilities, but suggested lost rearing habitat had been replaced.

At two facilities we concluded that the hypothesis that constructed spawning habitat replaced lost spawning habitat was *likely* (CH1-3 in Figure 28). At the remaining 18 facilities with known compensation habitat, we concluded hypothesis CH1-3 was *possible*. At eleven of these 18 facilities, the hypothesis was considered *possible* because estimates of losses and / or gains in spawning habitat were unavailable. At the remaining seven facilities, estimates were inconclusive but suggested lost spawning habitat had been replaced.

Overall, we concluded hypothesis CH1 was *possible* at 20 facilities. At these facilities, monitoring of salmonids in the compensatory habitat had not occurred or been reported at 13 facilities, and had occurred but was considered inconclusive at seven facilities. At these seven facilities, the evidence suggested that compensation did offset losses in salmonid abundance. However, these seven cases were still considered inconclusive because compensation works were designed to offset losses in *habitat* as opposed to *salmonid abundance*, so the number of fish lost and gained at a facility was not estimated.

Relevance of causal pathway for management decisions and critical uncertainties

The requirement for compensation works is a key management tool to offset lost habitat attributable to the footprint and operation of run-of-river projects.

Given the challenges with quantifying and evaluating the loss of salmonids in the project area and gains in compensatory areas, the focus of compensation is on habitat replacement. It is therefore not surprising that information related to salmonid responses is limited and inconclusive. Therefore, how the creation of habitat translates into increased rearing and spawning success and ultimately population size remains a key uncertainty.

Appendix 7. Public Advisory Committee and Science Panel members

Table 10: Public advisory committee members and affiliations.

Committee member	Affiliation
Bonnie Antcliffe	Fisheries and Oceans Canada
James Casey	World Wildlife Fund BC
Ian Cuthbert	Canoe Creek Hydro Company
Gary Feschuk (David Bates attending)	Sechelt First Nation
Susan Gimse	Squamish-Lillooet Regional District
Matt Kennedy	Innergex Renewable Energy Inc.
Mac Lowry	Alterra Power Corp
Gary MacIssac	Union of BC Municipalities
Alan Martin	BC Wildlife Federation
Dave Moore	Fraser River Salmon Table
Craig Orr	Watershed Watch Salmon Society
Wendy Palen (& Viorel Popescu, Res. Assoc.)	Simon Fraser University
Jim Scouras (1st meeting only)	BC Hydro (no replacement to J. Scouras)
Jordan Point (Deana Machin attending)	First Nations Fisheries Council of BC
John Winter	BC Chamber of Commerce

Table 11: Independent science panel members and affiliations.

Panel Member	Affiliation
Mike Bradford	Fisheries and Oceans Canada
Adam Lewis	Ecofish Research Ltd.
Wendy Palen	Simon Fraser University
Viorel Popescu	Simon Fraser University
Ron Ptolemy	Ministry of Environment
Jordan Rosenfeld	Ministry of Environment and University of British Columbia
Jeremy Venditti	Simon Fraser University

Appendix 8. Independent Science Panel Review of Draft Report

Below is the science panel review of the draft report followed by an individual review from one science panel member that was unable to be included in the compiled science panel review. Our responses to specific points are in bold italics.

Science Panel review of "Independent Review of Run-of-River Hydroelectric Projects and their impacts on Salmon Species in British Columbia" Draft Final Report by ESSA et al. November 2013.

November 22, 2013.

Panel

Mike Bradford (editor); Fisheries and Oceans Canada

Adam Lewis; Ecofish Research Ltd

Ron Ptolemy, Jordan Rosenfeld; BC Ministry of Environment

Viorel Popescu; Simon Fraser University

Craig Orr, Tanis Gower; Watershed Watch

Overview Comments: This is a well-written and researched report that objectively assesses the potential for impacts from run-of-river hydroelectric facilities based on the reported data. However, the overall conclusions reported in the Executive Summary are limited in scope. This is through no fault of the authors – it is largely because at this time the data available of inadequate quality and quantity to evaluate population-level responses of the pathways of effect with confidence. The approach taken to structure the analysis and organize the results is innovative and will be extremely useful for subsequent reviews when more data become available. We also recognize that this project is a key initiative in developing an industry-wide collaborative approach to the evaluation of environmental impacts of this form of energy production.

We believe the overall conclusions of this analysis are:

1. Most facilities are situated such that salmonid populations are potentially exposed to project-related impacts.
2. In most cases the effects of the project on salmonid abundance cannot be assessed because there are no data, or monitoring data are deficient in some way.
3. For those facilities with ongoing monitoring programs another analysis in 5 or more years will be needed to evaluate the utility of these programs.
4. Alternative to salmonid abundance monitoring should be explored as ways to more directly and efficiently assess the impacts of these projects on aquatic ecosystems.
5. Further analysis of the effects of multiple pathways within one facility, project effects not considered in the analysis (e.g., road and infrastructure impacts), and the cumulative effects of multiple projects will be required in the future.

Additional general comments

<u>Monitoring as the method to evaluate impacts.</u> The report concludes (L225+) that ongoing monitoring will go a long way towards resolving pathways of impact and effects sizes, and leaves the impression that in 5 years or less after the completion of the current round of monitoring programs some of the key uncertainties may be resolved. That may be true, but we conclude there is a significant risk that proponent-based monitoring programs may not have the precision needed to detect subtle changes in populations as a result of project operations.

The authors' are in the unique position of having had the opportunity to review all of the currently available monitoring information and they should fully exploit their experience by offering practical solutions for addressing the original questions posed on Page 13. Sufficient data has likely been collected to evaluate whether the questions posed on Page 13 can be realistically evaluated with the monitoring data being collected under the protocols. The results of a number of newer more robust studies are due the next few years; however, we should not be too optimistic about understanding mechanisms of effect when the duration and intensity of monitoring is designed to detect only a 50% effect size. It is reasonable to expect that such large effects in fish abundance will be detected at individual projects, and a synthetic examination abundance along with response metrics such as growth and age composition as well as changes in physical conditions may yield evidence of the dominant mechanisms. We recognize that the authors' did not have time draw together all of the available information at each site for a full analysis, but it would be useful for them to provide some recommendations for future analyses and reviews.

We agree with these general comments but note that while the recently developed long-term monitoring protocols are designed to have the statistical power to detect >50% effect sizes, some facilities have monitoring in place that will be able to detect smaller effect sizes. In the recommendations section of the revised report we place greater emphasis on recommendations for future analyses and reviews.

A necessary compliment to monitoring is targeted research on some of the mechanisms that contribute to population trends; such results can be used in a population modelling or analysis framework to enhance understanding of effect pathways as identified in the report. The report is largely silent on alternative approaches to individual project-based monitoring and CEBC may wish to consider such approaches to accelerate learning about their facilities' impacts. The report it should identify areas (specific pathways, links) in which research coordinated across energy industry, government, consultants, academia is likely to provide answers for questions that would never be tackled in the current monitoring framework (as well as impacts that would).

The absence of a discussion of the role of targeted research was a shortcoming of the draft report. We have revised the report to include a detailed discussion of targeted research and the role it can play in complementing monitoring programs at facilities.

The authors state that the existing literature has serious limitations for application to assessment of effects on run-of-river projects. This is overstated: although there are limitations in inferring effects from other studies, there is more similarity in the effects of these projects with those of the many projects that have been studied from around the world than there are differences. We suggest greater weight could have been placed on inference from the existing literature than is provided in this report, and that most of those inferences would have suggested that many effects were likely.

We infer that "likely" here means "likely to have occurred in the facilities that were studied in the literature", which does not necessarily mean that these effects would occur at all run-of-river facilities or at those which were examined in this study. We

maintain that the variability in site and facility attributes is important to determining outcomes, and limits the transferability of studies from widely varying facilities and sites.

<u>The use of fish abundance as an indicator.</u> The primary indicator for much of the analyses is measures of abundance of salmon in trout in the upstream, diversion, or downstream reaches. The use of this indicator is understandable as it the primary focus of stakeholders, regulators and the public. However, it is also a very difficult indicator to monitor reliably and all analyses of the sampling and statistical properties of stream fish abundance programs suggest that many years of intensive sampling with appropriate protocols are required before meaningful (but <50%) changes in population abundance can be detected.

We note that the original terms of reference for the project (Page 13) speaks more generally to "impacts" on salmonids and an analysis of impacts could take other forms than assessing change in fish abundance. We recognize that time limitations and data availability prevented a detailed analysis of other types of data (flow, temperature, food, fish growth etc.), but feel the report should make note of the gap, especially since these other measures (along with the literature) can support inferences about trends in fish abundance.

We structured the report such that conclusions related to changes in fish abundance and composition are presented in the main body of the report with details regarding potential mechanisms (i.e., the links in the impact pathways) provided in Appendix 6. The revised report now includes some details on conclusions related to mechanisms of impact in the main body of the report and makes it much clearer that Appendix 6 contains the complete results of our review.

<u>Presentation and explanation of results in the Executive Summary.</u> The report would be greatly improved by including a table that summarizes the results. Below is rough example, only partially filled out. This makes it easier for people to take in the results at a glance as most readers will only make use of the Executive Summary.

This is an excellent suggestion, which we have incorporated into the final report.

Hypothesis of changes in abundance	**Not possible**	**unlikely**	**Possible but data deficient**	**likely**	**Possible, but Data deficient breakdown**		
					% not monitored or reported	**% inconclusive monitoring**	**% ongoing monitoring**
Upstream reach	12	1	30	1	63%	17%	20%
Diversion reach							
Downstream Reach	5		39		87%	5%	8%
Compensation							

The "possible" category needs to be more fully explained in the Summary as people will misinterpret "possible" as meaning an actual effect, as opposed to an issue of information limitation. The table helps to consolidate the information and highlights the data deficiency issue. There is additional commentary on the categorization of studies below.

We have revised the report to place greater emphasis on defining what is meant by "possible".

Recommendations. The Recommendations section is a generally good synopsis that provides useful guidance for ongoing refinement of IPP monitoring and impact assessment. The recommendations for centralization of data and to take advantage of existing data to perform key post-hoc impact analyses are particularly apt. However, there is an over-reliance on monitoring as a panacea to resolve outstanding uncertainty, and a failure to highlight the need for targeted research on key issues or pathways that are unlikely to be resolved by regular ongoing monitoring. For example, lines 1736-1738 state:

> *"Recently developed and proposed long-term monitoring protocols provide a detailed description of recommended monitoring at run-of-river projects (Lewis et al. 2012). These monitoring protocols are comprehensive and if / when followed at a given facility should enable the evaluation of the impact pathways we considered in this report."*

This blanket statement seems to me to be overly optimistic, and should be qualified; better monitoring will improve ability to evaluate many pathways perhaps, but certainly not all as implied. Lines 1750-1752 state:

> *"The conclusions of Hatfield (2013) echo our observations in that consideration of downstream impacts as well as changes in geomorphic processes within project areas are two areas where we recommend research and monitoring should continue to be emphasized. We found gaps in occurrence of monitoring in the upstream reach and especially in the downstream reach."*

Clearly there are limitations in the monitoring protocols.

In Section 9.1 it would be useful to spell out some of the types of impacts, levels of power and levels of change that Lewis et al. (2012) protocols are designed to capture. Specifically, comments on whether these requirements are adequate for detecting changes in the full suite of Impact hypotheses/pathways described in this study or listed on Page 13. In the case of the downstream reach, the current monitoring protocol was designed to provide proxies of effect from which effects on fish can be inferred, by reference to the literature. For example the direct monitoring of stranding focusses monitoring effort on the most likely and detectable effect of these projects on downstream abundance, by measuring fish mortality in response to individual ramping events. The report has focussed on fish abundance monitoring and does not make the distinction between that instances where elements of the current monitoring protocol can be used to infer effect, which is an omission. In its current form, the monitoring recommendations section mostly implies that by following the current monitoring protocols abundance information that will be available in a few years will be adequate to assess the impact hypotheses leading to changes in salmonid abundance and composition.

We revised the report to include a comparison of proposed long-term monitoring protocols to the impact pathways examined to highlight limitations to the extent monitoring can inform an evaluation of the impact hypotheses.

We believe there may be a need for targeted research (in addition to monitoring) and should be clearly acknowledged, and elevated to the level of a subsection in the final "Recommendations" section. Such work would only be conducted at a few facilities, and would benefit from a partnership between the operators, CEBC, academics and the regulatory agencies.

Results of targeted research can be used in an analysis framework to evaluate the potential consequences on fish population productivity. The result can then be contrasted with, or used to support, long-term monitoring findings. Such a framework can address the cumulative impacts of multiple pathways at one site. This concept is to some degree captured in the Recommendation called "Simulation Modelling" but we believe this approach should be characterized as a complement, rather than an alternative to monitoring.

We revised the report to include a section on the role targeted research can play in complementing monitoring at facilities to enable a more comprehensive evaluation of the impact pathways we describe in this report.

Lastly, the recommendation for an independent science panel on lines 1774-1775 is a good one; however, we recommend adding text to the effect that the science panel should also "*identify research priorities and provide advice on study design and how research priorities may be implemented through academic, government, and industry partnerships*".

We have added this text to the revised report.

Key comments on the main report.

<u>Historical context of this reports.</u> Panelist Lewis has provided some history of the development of these energy projects as well as the evolution of regulatory and monitoring standards (see his report) and we suggest that the author's revise their introductory material, perhaps in consultation with CEBC to ensure its accuracy.

We revised the introduction of the report to include the detailed and thoughtful context Panelist Lewis provided.

<u>The BACI Model (p. 19).</u> The BACI approach is lauded as the "gold standard" for monitoring programs but it is based on some important assumptions that may not be satisfied in the run-of-river hydropower context. As noted, the BACI design controls for confounding effects of large-scale factors that have similar impacts on the treatment and control streams. The most common scenario is annual variation in environmental factors such as weather or streamflow, which can vary at scales of 100s of km. By including a control stream, the precision of the before/after comparison can be increased as long as the covariation caused by the common factor is large enough relative to measurement error. The use of a control system increases the amount of measurement error in the calculations, which can drown out the benefits of the control stream (Bradford et al. 2005). A control stream can also account for spurious trends, such as a multiyear drought, or changes in ocean survival for salmon populations that can also have a large spatial scale. However, a BACI design cannot account for internally-driven trends in populations that may be unrelated to the "treatment" and are not shared between the control and treatment sites. In such cases the BACI design can generate completely spurious results. Multiple control sites can be used in an asymmetric design to account for the scope of independent variation among control sites, but the cost and logistics of such a design in likely prohibitive. More likely the results of population monitoring at a single site will need to be supported with other information (such as process-based research, or the monitoring of other factors) to aid in the interpretation of the results.

Excellent points. We revised the report to include a discussion of limitations to a BACI monitoring design.

<u>Phrasing of hypotheses (p26 and elsewhere).</u> The hypothesis are untestable as written because they contain both outcomes (does/does not, are/are not). To be consistent (and testable) the "are not" clause should be removed.

The phrasing was done deliberately to avoid the risk that hypotheses stated positively as though the effect were true could be taken out of context as evidence of impacts. However, upon further reflection we have changed the phrasing of the hypotheses and included text that makes it clear that all hypotheses are phrased as though they were true so that they form a testable assertion, but they are not necessarily true (or false).

Description of the “Possible” case (p 31). Since most of the outcomes fell into the “Possible” case, it is important that the reader understand the classification process. Of concern is the “inconclusive” category as inconclusive could have many definitions. Based on the description provided on lines 773-775 and 826+, we recommend that this category be relabelled “Inadequate Monitoring” (or similar) to distinguish these cases from situations where there is good, but ongoing monitoring, or cases where the monitoring is good, but perhaps the effect size is small and challenging to detect with great confidence. Using our proposed approach the 3 boxes under “possible” are defined by the state of the monitoring program/data rather than the results inferred from them (e.g., no data, inadequate data, ongoing data collection). The use of the term “inconclusive” is reserved for the interpretation of whatever data are available for the 2 boxes on the lower right side. The state of monitoring can be readily assessed by the tallies in the “no data”, or “inadequate monitoring” categories.

Excellent points. We have revised the report accordingly.

Identification of data used for hypothesis testing. For many hypotheses there may be fish monitoring data, but also information on one or more of the causal factors (flow, invertebrates, temperature etc.). In sections 4 and 5 it is sometimes difficult to determine which sources of data were used to develop the conclusions. For example, for DWH2, stranding, there is no mention of whether any stranding studies were available- the conclusions seems to rest solely on abundance monitoring.

A similar situation arises in Section 8.3, where information on the evidence cause-effect links are identified. These links could be considered equivalent to “impacts” identified on Page 13. The significance of these linkages is often trumped by the absence of fish population monitoring data that causes the status of the hypothesis to be downgraded to “possible”.

A fuller analysis of the utility of the different types of information would be very useful for designing future studies or analyses.

As described above, we structured the report such that conclusions pertaining to changes in fish abundance and composition are presented in the main body of the report with details regarding potential mechanisms (i.e., the links in the impact pathways) provided in Appendix 6. To provide additional context, we have revised the report to include some details on conclusions related to mechanisms of impact in the main body of the report and make it much clearer that Appendix 6 contains the complete results of our review.

Limitations of the independent peer review. The Panel feels it is important to note that individual monitoring reports were not viewed during its deliberations so no review has been conducted on the author’s assessment of monitoring results, particularly as they relate to their assignment to the various categories of Table 8 or 11.

Similarly it is also suggested that on Line 565 the following be added: “The interpretations have not been independently checked by the science review panel because the information per operator was kept confidential. The evaluations are therefore unverified however methods used for evaluation were reviewed by the Panel.”

The panel signed a non-disclosure agreement that allowed them to review draft assessments of monitoring data from three facilities during the review of the methodology used in the report. However, we recognize that the panel did not have the time to review any of the revised conclusions we reached and so acknowledge in the revised report that the science panel did not independently verify the final results of the application of the methodology to the facilities in the review.

Review of ESSA Technologies "Independent Review of Run-of-River Hydroelectric Projects and their Impacts on Salmonid Species in British Columbia"

Wendy J. Palen, Assistant Professor, Department of Biological Sciences, Simon Fraser University

Overall the authors have done a commendable job given the magnitude of their charge. The document reads well and presents the Weight of Evidence approach in a generally accessible and informative way. I have many small comments, often suggestions for editorial changes (see below), and a few more general comments below.

General comments:

1. The lack of adequate monitoring data prevents broad conclusions about current impacts and needs to be acknowledged more frequently throughout the document.

For example, this sentence: "Since so many of our hypothesis evaluations ended up with a conclusion of *possible*, we did not have enough contrast in our results to..." or some variant on it is used very very often, and obscures one of the real results of this effort. Namely, that *very few* existing Run of River projects have enough monitoring information to evaluate even a simple majority of these impact hypotheses (I'm estimating here because nowhere is this summarized by project). This is not a fault of the framework, as "contrast in the results" seems to suggest, but originates from a lack of data to support any conclusion other than "possible". This is bound to be one of the most important (and controversial) broader conclusions of this effort, and I suggest that the authors are as transparent and up front about this as possible without adding complex language that otherwise obscures the real issue (lack of data at this point in time). This comment applies to many specific places throughout the document, but is intended to be a very general remark. I have highlighted several locations in the specific comments below where adding a sentence or two would be useful.

We revised the report to include a comparison of proposed long-term monitoring protocols to the impact pathways examined to highlight limitations to the extent monitoring can inform an evaluation of the impact hypotheses.

2. Cumulative effects were essentially beyond the scope of this review, but represent one of the biggest knowledge gaps for Run of River impacts to salmonids.

The authors have a unique opportunity to use their perspective on the weight of evidence compiled and synthesized in this document to speak to where the gaps are in our understanding of Run of River impacts on salmonids in BC. The need to evaluate the cumulative effects of multiple projects is clearly one of those gaps and it would be nice to read the authors perspective on this issue. Similarly, I would have appreciated reading more about the authors' perspective on the spatial and temporal scales over which run of river impacts to salmonids could manifest at regional or larger scales, in comparison to natural sources of spatial and temporal variation (especially for anadromous species).

We revised the report to include a slightly expanded discussion of cumulative effects while acknowledging that consideration of cumulative effects was outside the scope of the report.

3. The need for greater transparency in data availability.

The authors do a good job of highlighting the need for a central digital repository for licence-required monitoring reports. I suggest that two additional points need to be raised; the need for original data to be included in monitoring reports, and that the authors acknowledge that these data are currently protected from public or scientific evaluation outside of FLNRO (which I don't believe is mentioned anywhere in this document). The value of carefully collected data never decreases, and for many of the "modern era" projects discussed in this document, it's clear that the proponents are being held to a relatively high standard for monitoring and data collection. It would be a disservice to that effort, to not have those data stored in a format (digitally, raw data) that could be used in the future, and a benefit to the broader scientific community.

Original data were often included in the appendices of the monitoring reports we reviewed. While we have recommended that investigators from industry, government and / or academia be able to access a centralized database of monitoring data, recommendations related to the availability of monitoring reports to the public are outside the scope of this review.

4. Which impact hypotheses can be evaluated given best management practices? Which will require a different approach?

This point is made in several places below in the specific comments (where relevant), but the authors have missed an important opportunity to summarize which of their impact hypotheses (and their component underlying mechanisms) could be robustly evaluated given the current monitoring requirements (and time frames) and which would require a different approach. I think the authors have the perspective of very carefully considering each of these hypotheses, and have done a good job with the data that were available. But this document should also include that perspective when taking a step back from the data limitations, and synthesize for which hypotheses current monitoring is doing a good job of moving towards a rigorous test of impacts, and which we are essentially no further ahead. What would need to change, what are the biggest gaps in our understanding, what are the key questions that research (by partnering eNGOs or academic institutions) could make the biggest contribution to.

We revised the report to include a comparison of long-term monitoring protocols to the impact pathways we examined to highlight limitations to the extent to which monitoring can inform an evaluation of the impact hypotheses. Where gaps exist we argue for the need for targeted research.

5. In several instances (DWH 1-3, DVH 1-2) the base drivers of impact hypotheses are not clearly evaluated.

There is a large gap in logic (at least as presented in the results section) in one component of the study that I hadn't realized until seeing these conclusions that needs to be addressed. When the authors evaluated the more mechanistic hypotheses that could underlie changes in salmonid abundance for either the diversion reach (hypotheses DVH 1-2) or the downstream reach (DWH1-3), little if any data regarding those specific hypotheses are referred to. These sections read as if the authors have jumped over evaluating these possibilities by relying exclusively on the conclusions regarding changes in salmonid abundance. But in many cases changes in salmonid abundance was determined to be "possible". While additional information is provided in Appendix 6, even there the frequency of monitoring for the base variables (sediment, macroinvertebrate drift, etc.) and what could be concluded is not always apparent.

For example, DVH1 & 2 are more mechanistic hypotheses about what could lead to changes in salmonid abundance (sediment & bug interception, flow alteration), and as written there is essentially zero information provided to support the conclusions about the likelihood of them occurring. Perhaps I'm missing something here, but both of these sections seem to have missed actually presenting and evaluating the information that is available about sediment, secondary productivity, or flow. This needs to be fixed, or the limitations of your ability to evaluate these things mechanisms to be presented clearly. As it is, the reader expects to hear about your conclusions regarding the likelihood that sediment or secondary productivity has changed in the diversion reach, and instead what is referred to are data about changes in salmonid abundance (which was covered previously).

Similarly for hypotheses DWH1-3, differentiation among these mechanistic hypotheses was not addressed well (or at all in some cases). The logic used to support various conclusions about numbers of facilities that fell into the different categories was variable. Sometimes data were referred to when the conclusion was "unlikely", and for some conclusions (like "possible") the logic relied upon salmonid monitoring exclusively. This needs to be addressed more clearly, and the limitations of data to evaluate these hypotheses (or your team's time to dig into them) acknowledged.

We structured the report such that conclusions related to changes in fish abundance and composition are presented in the main body of the report with details regarding potential underlying mechanisms of change in abundance (i.e., the links in the impact pathways) provided in Appendix 6. As a result of structuring the report this way we recognize that it could appear as though we did not evaluate the evidence for the mechanisms underlying potential changes in salmonid abundance, which was not the case.

We revised the report to include some details on conclusions related to mechanisms of impact in the main body of the report and make it much clearer that Appendix 6 contains the complete results of our review.

Specific comments:

Executive Summary

P. 7, Line 97: This summary should distinguish between anadromous and resident salmonids, and provide a number of facilities that had each in the three reaches (DS, DR, US).

We respectfully disagree – we felt that this was too much information to include in the Executive Summary.

P. 10, Line 230: The assertion that recently developed long-term monitoring protocols will improve the ability to evaluate key impact pathways seems overly optimistic. One of the important missing points of this document (see general comments above) is that only some of the hypothesized impact pathways (and their lower level components, e.g. Appendix 6) could be rigorously evaluated with the current monitoring requirements even when complying with Lewis et al. 2013. I think it is very important for this document to highlight which pathways are well suited to evaluation given current 'best management practices' and which would require different types of data, or a more research focused (experimental) approach.

As described above, we revised the report to include a comparison of the recently developed long-term monitoring protocols and the impact pathways as well as the role targeted research could play in filling gaps between the two.

Introduction

P. 16, Line 353: This sentence implies that compliance monitoring documents might not have been used in some cases, and I believe this needs to be made explicit. When, if ever, were data ignored (from any type of monitoring)?

All information that was made available was reviewed.

P. 18. beginning Line 424: I suggest this paragraph be written in a more balanced (neutral) way. As written it's focused on reminding the reader that impacts may not be that bad... weird that it wouldn’t acknowledge the possibility of impacts in either direction (local & short term to lasting & long term).

Suggested wording change:

“All industrial activities have impacts, some can have lasting effects on species and the environment whereas others may not cause significant changes to populations or ecosystem attributes. Unless a facility is completely inaccessible to fish both upstream and downstream of the diversion reach, the construction and operation of a run-of-river hydroelectric facility would be expected to have some localized impacts on salmonids, though they may or may not have biologically significant impacts at the broader population scale. Further, many facilities have Fisheries Act Authorizations to account for anticipated impacts to salmonid habitat. These compensation requirements reflect the potential for run-of-river hydroelectric projects to affect salmonids and their habitats.”

We revised this paragraph in the final report.

P. 21, Line 524: This is an excellent paragraph, but it needs to be linked to the challenge of detecting changes in productivity, and the MUCH higher requirements for monitoring that would be necessary (for anadromous species, at a minimum it would require linking measures of juvenile year class abundance, with smolt estimates, with adult returns/spawning surveys each year). I agree that this would provide a much more powerful way to look at potential impacts of Run of River facilities and their operations on salmonid populations, but it is so far outside what is currently required that it would be a disservice for this report to not highlight that gap.

We revised the report to include a discussion of population productivity.

P. 22, Line 554: I think it needs to be more clearly acknowledged that you did not choose the scale of evaluation per se because there was no alternative to using the industry provided monitoring documents that are site-specific. This will be scrutinized heavily, and it is better, in my opinion to be completely open about that limitation rather than to make it seem like it was a choice.

We acknowledge this in the revised report.

Results

P. 33, Table 4 caption. The caption explaining the “Occurrence” column needs to clarify that the number in parentheses, “is the number of **additional** facilities where occurrence was inferred from fish observation points in FISS (Appendix 4).”

We have revised the Table 4 caption.

P. 38. 4.4. Somewhere in this document the number of projects that hold a Fisheries Act Permit authorizing mortality, and requiring compensation habitat needs to be presented. And if that information is not available or clearly discernable (as the first sentence of this section suggests), that needs to be highlighted more clearly by the authors.

We provide these details in Appendix 6.

P. 42, Line 1141: This sentence implies (without any detail) that the hypothesis was not possible “because movement of resident salmonids between reaches was considered very limited based on pre-project mark-recapture studies (9 facilities)”. This is very difficult to assess given no additional detail about those mark-recapture studies. The hypothesis is about impairment of movement, which is a challenging metric to evaluate because movement is difficult to detect, especially over large spatial scales, in complex habitat, and over long time scales, yet even a fraction of the population moving can represent important component of population connectivity.

The quality of the mark-recapture studies needs to be described in some detail here to reassure the reader of your conclusions, or refer the readers to additional detail presented in Appendix 6 (which I couldn't find).

We revised this statement to clarify that hypothesis UH3 was considered* not possible *when there was a barrier to upstream migration. In some instances this was confirmed by mark-recapture studies. We have also revised the report to emphasise the potential importance of even limited migration for population persistence and resilience.

P. 43, Line 1166: This paragraph links directly back to the finding about salmonid abundance in the diversion reach, but provides no information about the likelihood of the mechanism at work (the specific ones presented in DVH1) or how it was evaluated. I find this pretty unsatisfying, that given the specificity of the impact hypothesis, that nothing about data availability on invertebrates or sediment is summarized. Please add a sentence or two about the data availability and conclusions with regard not just to salmonids, but to the base variables that are the focus of these hypotheses.

This is also an example of where this report could highlight the existing gaps in monitoring for what would be required to conclusively evaluate these mechanisms (sediment interception changing spawning/rearing habitat downstream, dam interception of prey or disruption to their availability).

As described above, in addition to the detailed descriptions of our conclusions in Appendix 6, we revised the main body of the report to include some details of the conclusions reached regarding underlying mechanisms. As well, a comparison of proposed long-term monitoring protocols to the impact pathways examined allowed us to highlight limitations to the extent monitoring can inform an evaluation of the impact hypotheses and to describe a role that targeted research could play in filling gaps between the two.

P. 43. 5.5: I have the exact same comment about conclusions in this section as above. There are zero references to any supporting information about the conclusions regarding the specific hypotheses (relating to flow). While I recognize that delving into primary assessments of flow was beyond the scope of this report, it needs to be acknowledged as a limitation not because of a lack of data, but because of the time it would have taken to do independent analyses of flow fluctuations and deviations from the natural flow regime in each location. Again, better to acknowledge this clearly and repeatedly for the readers.

See previous comments.

P. 45, Line 1247: Unlike hypothesis DVH1 & 2, this sentence at least suggests that there were data pertinent to the hypothesis that were considered (oxygen, temperature), but again as above, the other conclusions are based on monitoring of salmonids not of oxygen or temperature. This needs to be expanded to be clear where and when there were data to evaluate these mechanisms, especially in the cases where “possible” was concluded for changes in salmonid abundance.

See previous comments.

P. 46, Line 1246: Again here a discussion is needed of whether the mechanistic components of this hypothesis had been monitored that could provide a basis for evaluating the “possible” changes in salmonid abundance.

See previous comments.

P. 47, Line 1332: I believe this is supposed to say “downstream reach”.

Corrected.

P. 47, Line 1341: Incomplete sentence.

Corrected.

P. 48, Line 1375: Example of where current monitoring (or data) requirements do not match the hypothesis that is being evaluated. If we believe that the hypothesis is important, then the authors should offer their perspective on what kind of data would be needed to rigorously evaluate it.

P. 50, Line 1406: I believe that this section needs to more clearly acknowledge that this report and the analyses supporting it did not attempt to consider cumulative effects, and also acknowledge that large uncertainties exist in our ability to evaluate such effects--but that does not lessen their potential importance for salmonid populations of BC. The authors have a unique opportunity to use their perspective on the weight of evidence compiled and synthesized in this document to speak to where the gaps are in our understanding of Run of River impacts on salmonids in BC. The need to evaluate the cumulative effects of multiple projects is clearly one of those gaps and it would be nice to read the authors perspective on this issue.

We revised the report to include an expanded discussion of cumulative effects while acknowledging that consideration of cumulative effects was outside the scope of the report.

P. 50, Line 1418: The other component that is not included here is over what spatial scale a “population” defined, and the contribution of individuals residing or using habitats affected by a Run of River project construction or operation relative to that scale.

P. 52, Line 1484: This sentence needs to remind the readers of the number of “possible” outcomes to emphasize that most of those are from data limitations or inconclusive monitoring studies.

Corrected.

P. 55, Line 1595: This sentence “As discussed in section 1.3, mortality of individual fish does not necessarily translate into an impact on the overall fish population.” seems overly focused on the possible of density-dependent compensatory response (which I agree is likely), but fails to acknowledge another important possibility, that the monitoring at some of these projects is not particularly sensitive to even moderate magnitude changes in salmonid abundance.

We revised the report to place greater emphasis on limitations of monitoring to detect changes in salmonids abundance at some projects.

P. 55, Section 8.4: This section needs to provide information on how often projects monitored salmonid abundance (and the other things you considered) frequently enough to even attempt to assess seasonal variation. My understanding is that rigorous seasonal data are exceedingly scarce. The way this section is written makes it seem as though the only limitation was the WOE framework and that not enough projects ended up in categories other than “possible”. This appears to side-step the bigger issue that is worth commenting on, which again is discussed above, about whether current required monitoring is sufficient to evaluate these hypotheses or questions. Clearly the answer is no for several of them including this one about seasonality or other operational attributes, and that limitation needs to be highlighted as a fact stemming from this analysis.

We revised the report to include greater discussion of seasonal monitoring as well as the extent to which currently required monitoring allows for a thorough examination of the impact hypotheses we considered.

P. 58, Line 1688: This section discussing the importance of BACI style monitoring designs is good, but leaves out the issue of power and effect size. The authors have an opportunity to summarize the power associated with the existing BACI monitoring programs (at 15 facilities). To my knowledge most are designed around detecting a 50% change in salmonid abundance. If this is the case please state those numbers, and it's worth acknowledging two additional points relative to this: 1. that a 50% decline after 5 years of operation is a very large change in the population status, and some would argue too late for the alarms to be sounded to be of real use from an adaptive management perspective, and 2. that for many of these impact hypotheses, a 50% change in population status might not be expected to occur for a decade or longer, such that not detecting a very large magnitude change at the end of 5 years may not tell us much about the longer-term potential, and certainly doesn't allow a dismissal of the possibility. These are somewhat subtle but very important points that the authors have the opportunity to comment on and should.

We revised the report to incorporate these comments into the section on monitoring.

P. 58, Line 1725: This section should not be limited to "multiple consecutive facilities along an individual stream", but I suggest that the authors also include cases where there are projects on multiple tributaries within the same sub-watershed (of which there are more).

We revised the report to include an estimate of the number of watersheds (at two scales) with multiple facilities.

Recommendations

P. 59, Line 1743: "These monitoring protocols are comprehensive and if / when followed at a given facility should enable the evaluation of the impact pathways we considered in this report." I would suggest that the authors step back from the details of this process, and offer a more nuanced discussion of which hypotheses (and the underlying components/mechanisms) really could be evaluated by the "best management practices" of required monitoring (*sensu* Lewis et al. 2013), and which would require additional data collection, or even a fundamentally different approach (research, experiments, mark-recapture, timeseries analysis, etc.). I believe thus far this has been discussed in an overly simplified fashion—that if all projects were 5 years post operation and had followed the Lewis et al. guidelines, that this process would have been completely informative with regard to all of these impact hypotheses.

See previous comments.

P. 62, Line 1859: I whole heartedly agree with this paragraph, but there is one important point missing, which is that at present such monitoring documents are protected and not available to the scientific community at large who could help advance our understanding of Run of River impacts. The value of existing monitoring data never decreases, but access to it for what amounts to a public resource is something that needs to be raised or at the very least acknowledged.

The report includes a recommendation that investigators from industry, government and / or academia be able to access a centralized database of monitoring data for future evaluations of interactions between run-of-river hydroelectric power, salmonids and the aquatic environment.