Developing Measures for the Aquatic Habitat Attribute in BC Hydro’s 2005 Integrated Electricity Plan

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EXECUTIVE SUMMARY

The environmental objective for the 2005 Integrated Electricity Plan (IEP) defined by the Provincial Committee of the IEP is to incorporate environmental impacts into the consideration of electricity portfolios. The dominant legislation regulating impacts to aquatic (fish) habitat is the Federal Fisheries Act: most new energy resource options have the potential to cause impacts and thus violate the Fisheries Act.

Biomass, customer cogeneration, and Power Smart options typically pose no risks to aquatic habitat. However, energy generated from natural gas, coal, large hydro, run-of-river small hydro, wind, and geothermal sources all require infrastructure, including access roads and transmission right-of-ways. In addition, large hydro and small hydro resource options rely on water as the ‘fuel’ for energy generation, which they use non-consumptively, returning the water to the river channel, but nevertheless creating potential impacts to aquatic habitat. These impacts are mitigated through environmental design to meet regulatory requirements, then any residual impacts are offset through the provision of compensation at a rate sufficient to offset the risk of failure in either the assessment process or the provision of mitigation and compensation. Despite these environment regulations and the application of best management practices, there are risks that impacts will occur.

Potential measures that can describe the risks to aquatic habitats from different resource options are limited by the existing information on the proposed resource options and our knowledge of links between physical changes caused by these projects and the productive capacity of aquatic habitat. These links have been studied and are reported in the scientific literature and in regulatory agency data.

The primary measure that can be derived from the IEP resource options database is the surface area of aquatic habitat potentially affected by the development. Surface area is the fundamental metric describing aquatic habitat and is proposed here for use as the quantitative measure to describe aquatic habitat. Qualitative comparisons of the nature of impacts between large and small hydro should also be considered when making decisions based on the quantitative measures.

Surface area measures relate primarily to small hydro developments, because these projects have direct effects on aquatic habitat, and also because there are basic physical data available for these projects that can be used to assess impacts. Comparable data are available for relevant aspects of large hydro (Site C) and other resource options. The measures are described and defined in this document, including the equation for calculating surface area, the source of the equation and data inputs, and the assumptions inherent in the calculation. Several variants of the surface area measures calculation are provided; each describes an aspect of aquatic habitat impact expected for a resource option. The surface area measures
quantify effects for: dewatering of the diversion section of small hydro projects; backwater effects of large hydro projects; backwater effects at small hydro projects; footprint effects of weirs/dam on all hydro projects; fish presence (a modifier of other impacts); and stream crossings from access roads, transmission lines, and penstocks/tunnels. To calculate the area of aquatic habitat potentially affected and therefore at risk from the development of a resource option, the appropriate measure variants must be selected, combined, and calculated to yield the area affected in hectares (ha). These measures should be applied cautiously, influencing decisions only if qualitative information on potential impacts provided in this document is also considered.

There are key questions and data gaps that affect decision making around potential aquatic habitat impacts. Most of these questions and data gaps cannot be addressed within the 2005 IEP time frame; some may be addressed before the start of the 2007 IEP. Three key uncertainties have been identified: 1) accuracy of physical data in the resource database; 2) accuracy of the prediction of aquatic habitat effects from physical data; and 3) comparability of predictions between different resource options. These uncertainties have been acknowledged by defining the assumptions inherent to each measure proposed in this study. For the comparison of small and large hydro projects, a qualitative assessment is provided that evaluates the sensitivity of habitat affected by these resource options and evaluates six aspects of aquatic habitat impact. This provides general guidance concerning the nature of small and large hydro impacts that should be considered along with the quantitative measures of aquatic habitat area that is potentially affected.
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1. INTRODUCTION

1.1. Background

The environmental objective for the 2005 Integrated Electricity Plan (IEP) defined by the Provincial Committee of the IEP is to incorporate environmental impacts into the consideration of electricity portfolios. For aquatic habitat, the goal is to reduce environmental impacts to aquatic resources and, if possible, maximize environmental benefits (positive impacts). These objectives are consistent with both broad societal interests and BC Hydro’s corporate policies. Moreover, these objectives are consistent with the regulations that govern the development of projects that have the potential to impact aquatic habitat.

1.2. Regulatory Framework

The dominant legislation regulating impacts to aquatic (fish) habitat is the Federal Fisheries Act enforced by the Department of Fisheries and Oceans Canada (DFO), which states: ‘No person shall carry on any work or undertaking that results in the harmful alteration, disruption or destruction [HADD] of fish habitat.’ (Section 35(1)). A HADD is any change in fish habitat that reduces its capacity to support one or more life processes of fish, including alteration (an indefinite reduction), disruption (reduction of limited period), or destruction (permanent reduction). By causing short and long term changes to fish habitat or its capacity to support fish life processes, most new energy resource options have the potential to cause a HADD and thus violate the Fisheries Act.

The operational definition of fish habitat provides a starting point from which to develop aquatic habitat attributes that can quantify potential impacts of alternative resource options in the 2005 IEP. This definition is articulated by DFO in a decision framework that evaluates the type and magnitude of potential changes to aquatic habitat by posing five questions. By answering these questions, regulators gather the information necessary to support a decision on whether a HADD is created and if so, whether the HADD can be authorized (Section 35(2) permits the Minister of Fisheries to authorize a HADD). The HADD decision framework (DFO 1998) asks five questions:

1. Is fish habitat present at the project site or in an area potentially impacted by the project?
2. Could the proposed project cause a HADD of fish habitat?
3. Can the impacts to fish habitat be fully mitigated?
4. Should the HADD be authorized?
5. Can the HADD be compensated?

To answer these questions regulators require a definition of fish habitat, HADD, potential impact, area of impact, mitigation, adequacy of mitigation, compensation, and adequacy of compensation. DFO scientists recognize that the HADD definition implies ‘...an ability to quantify the effects on fisheries or changes to habitat’. Within this definition, the term harmful implies ‘a measurable, significant degree of effect’ (Minns 1997). To allow the accurate evaluation of impacts, HADDs must be defined in a logical, quantitative manner.

Several other regulations oversee the development of projects that can affect fish habitat. The Fish Protection Act (BC) and the Riparian Areas Regulation, the Species at Risk Act (SARA), and the Canadian Environmental Assessment Act are the more important regulatory tools relevant to the regulation of aquatic habitat impacts. At a more detailed level, policies and guidelines direct specific actions and identify specific methods of assessment. For example, the Instream Flow Guidelines for British Columbia prescribe flow thresholds to protect aquatic habitat and specific techniques for aquatic habitat assessment (Hatfield et al. 2004).

Potential aquatic effects are also limited through BC Hydro's energy acquisition processes. In the process to select projects for contract award, values (used for evaluation purposes only) are ascribed to low impact renewable resources in a specific Call for Tenders, making such projects more competitive and increases their likelihood of being awarded contracts. This in turn enables BC Hydro to reduce the potential for aquatic impacts. In the future, Energy Acquisition calls may require successful tenders that elect to be clean or green to meet and/or obtain Ecologo certification, which can be obtained under Environment Canada’s Environmental Choice Program (ECP) that provides national certification criteria for electricity generation under the ‘Environmental Choice Program, CERTIFICATION CRITERIA DOCUMENT CCD-003’. The criteria have specific technical requirements but also require that potential projects meet existing regulatory requirements, specifically the Fisheries Act.

2. RESOURCE OPTION IMPACTS

The development of most energy resources has the potential to affect aquatic habitat. Biomass, customer cogeneration, and Power Smart options typically pose no risks to aquatic habitat. However, energy generated from natural gas, coal, large hydro, run-of-river small hydro, wind, and geothermal sources all require infrastructure, including access roads and transmission right-of-ways. The construction of this infrastructure disturbs surface materials, leading to increased erosion and a greater potential for sediment and other types of pollutants to enter aquatic
habitats via surface runoff. Access development can also permanently alter aquatic habitat through loss of stream habitat, riparian habitat, and loss of access to potential upstream habitat.

Buried penstocks and pipelines pose risks to aquatic habitat. Small hydro and natural gas projects typically include these components; geothermal projects do not as pipelines that are constructed are within the site and not part of a linear development that is likely to cross many streams. There may also be errors in environmental assessment. For example, these structures may be sited overtop of key habitats, but the compensation for these impacts may not be effective. Construction activities can introduce sediment and the disturbed areas may not remain stable in the long-term. Accidents during construction may introduce sediment or fuel into aquatic habitats. As right of ways (ROWs) for these structures usually must be kept free of vegetation, there is an ongoing potential impact to riparian vegetation. Finally, there is risk of penstock or pipeline rupture.

The magnitude of impact is dependent on the area of land disturbed, the density of aquatic habitat in that area, and the sensitivity of this habitat. The area disturbed will vary between resource types and individual projects, moreover, different regions will have different densities of aquatic habitat and a differing range of aquatic habitat sensitivities. Given that all new developments, with the exception of biomass, customer cogeneration, and Power Smart options, require new access, the extent of impact will be roughly proportional to the area of land disturbed. However, the length (in km) of new access, pipelines and transmission lines should be more indicative of the relative extent of impact and the risk to aquatic habitat.

Linear developments such as roads, pipelines, penstocks, or transmission lines have the greatest impact where they cross a stream. In a review of the impacts of forest road crossings of fish bearing streams, Harper and Quigley (2000) quantified stream habitat, benthic habitat, and riparian habitat losses at 46 crossings in British Columbia. The impact to fish habitat averaged 551 m² per stream crossing, excluding deactivated crossings. Extrapolating from this study to assign the magnitude of risk associated with the development of roads, penstocks, pipelines and transmission lines, we assume that impact will be related to the number of stream crossings and the area affected by each stream crossing. For roads, penstocks, and pipelines we can approximate the area affected with an estimate of 550 m² (rounded down), then expand this for each project by the number of stream crossings.

Risks to habitat from transmission lines will be less than that at road and penstock crossings. Impacts on transmission lines result primarily from the loss of riparian vegetation, which is typically altered at stream crossing sites, though impacts can be mitigated through careful, selective clearing of vegetation. Actual impacts may vary greatly dependent on the width of the ROW and the height of lines at the crossing site, which in turn determines the height to which vegetation must be pruned. In some cases road access is required along the transmission line, and in those cases the same impacts can be expected as at road crossings. For transmission lines alone, impacts may be similar to the level of direct riparian impacts observed from roads.
Harper and Quigley (2000) assessed losses assuming a functional riparian width of 15 m, reporting an average loss of 503 m². The 15 m may be too narrow to offer protection to many streams, but we cannot evaluate this further with the existing information we have on the projects. To move forward at this time, a quantity of 500 m² (rounded down) per stream crossing is proposed as a riparian impact from transmission line crossings, recognizing that there is considerable uncertainty underlying this figure.

Stream crossing density is expected to vary between regions and watersheds. Information on stream crossing density is likely available in some regions, or could be obtained by examining stream mapping of the project site, but is not available at this time. Other information suggests that stream crossing density is most commonly between 0 and 1 stream crossings per km in community watersheds in BC (Decision Support Services, Ministry of Sustainable Resource Management, 2002.), but the applicability of this information to a site proposed for energy resource development in unknown. In a study of Albertan streams, Maywood et al. (1997) reported streams crossing densities for roads averaged 1.8/km. The greater run-off in British Columbia is expected to result in a higher stream crossing density for road crossings.

Not all streams crossed will be fish bearing, so the extent of impact will vary between streams. For small hydro projects on fishless streams, stream crossings along the penstock are expected to be fishless, but stream crossings along the access road may not be. For stream crossings affected by other energy resources, fish presence will be site specific. Given the information available at this time, we have selected a stream density of 1 fish bearing stream per km of road, transmission line, or penstock. Where these structures occupy the same ROW the impact should not be double-accounted, on the other hand, ROW’s will be wider when both roads and penstocks occupy them. For small hydro projects we do not have information on whether the reported road, penstock, and transmission lengths are parallel, nor do we know which projects will use tunnels, which cause less surface disturbance. This creates another uncertainty that could be addressed later with more detailed data on individual projects. At this time we will assume that roads, penstocks, and tunnels occupy separate ROW’s. Penstocks typically do not cross the diversion reach, so this assumption should not double account impact to the diversion reach.

Some specific resource option projects may produce effluent. Geothermal waste water may have negative effects on aquatic systems, although these can be mitigated through the provision of a cooling tower and condensate reinjection. Ancillary facilities associated with energy facilities such as latrines and landfills could also pose a threat to aquatic habitat, however, effective mitigation is readily available and commonly applied such that these effects are unlikely and the risk to aquatic habitat is very low. Any effluent releases to aquatic habitats would be regulated by water quality criteria and which define concentrations that should not pose a significant threat to aquatic habitat. Moreover, such impacts affect habitat downstream of developments for unknown distances: defining the scope of such potential impacts is problematic, particularly if they are to be quantified for comparison among different resource options.
3. SMALL AND LARGE HYDRO IMPACTS

3.1. Defining Hydro Impacts

Large hydro and small hydro rely on water as the ‘fuel’ for energy generation, which is used non-consumptively in that it is returned to the river channel. Large hydro projects impound water behind dams, and small hydro run-of-river projects divert water around a section of stream. Impacts from all hydro projects can be defined broadly within six categories. These are described in the following text along with the potential to mitigate or compensate for such effects.

**Backwater effects:** Impoundment of riverine habitats by dams or weirs causes an increase in depth upstream and a reduction in water velocity. This alters the suitability of habitat, making it less productive for riverine species. Water quality effects are also typically caused by these changes. These effects are common to both large hydro and run-of-river small hydro, however, the magnitude of effect differs greatly. Key water quality effects would be the rise and fall of productivity and methylmercury liberation due to the decomposition of organics caused by flooding of soil. Suspended sediment settling from the major tributaries is also anticipated with Site C development and will impact those species that reside downstream from Site C and prefer more turbid water (walleye, flathead chub, etc.). Temperature will also be affected, with warmer temperatures in summer and a larger ice front in the winter. Impoundments behind major dams (reservoirs) may result in the loss of all habitats for riverine species, whereas behind small dams (headponds) such changes are minor and may in fact be beneficial for riverine species, providing deepwater habitats that provide secure holding and feeding areas. Backwater effects cannot be substantially mitigated leading regulators to offset impacts through provision of compensation habitat.

The backwater effect increases wetted surface area and creates lacustrine aquatic habitat – a reservoir or headpond. In the case of small hydro projects this additional habitat is limited in extent, and in some cases it is within the high water mark of the existing channel. In the case of large hydro such as Site C, the new area can be extensive. The Site C reservoir will occupy 9,440 ha, an increase in wetted surface area of 4,600 ha. Reservoir and headpond habitats tend to be stable environments that provide aquatic habitat, however, they are at some risk from operational changes, particularly from drawdowns that expose benthic organisms and may dewater fish and their habitat. The net effect of the increase in wetted surface area and the risk posed by potential drawdown is unknown. Given that backwater effects on riverine habitat have already been accounted for, the additional potential risk to the newly created lacustrine habitat does not represent a substantial negative effect.

**Dewatering:** Withdrawal of water for run-of-river small hydro reduces flows within the stream between the intake and the powerhouse, a section known as the diversion section. Flow
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reductions reduce the surface area of available habitat and reduce depth and velocity, altering the suitability of habitat for fish. Some level of flow reduction creates no harm for fish, however, excessive flow reduction will reduce productive capacity and cause a HADD. Proponents are required to release a continuous flow throughout the year on all streams. On important fish bearing streams this flow may be substantial. The extent of flow release required in BC streams has been evaluated and flow thresholds have been prescribed (Hatfield et al. 2004). Where sufficient instream flows cannot be provided, compensation may be undertaken within the affected stream section or off site.

**Fish passage – upstream blockage:** Dams and weirs can block the upstream migration of fish species, life history activities critical to reproduction, growth, and survival. Not all streams support fish, and not all fish populations migrate upstream. Fish passage may be provided through mitigation such as fish ladders or modified flow releases. Fish passage cannot always be effectively provided, particularly on large streams. In the case of Site C where a 60 m high dam is proposed (BC Hydro 1980), it will be difficult to provide effective upstream passage for those stocks that presently migrate past the dam site.

**Fish passage – entrainment:** The withdrawal of water into dam intakes at large hydro projects and into penstock intakes on small hydro projects transports fish through power turbines, where they can be damaged or killed through contact with turbine runners and blades. Mortality can be reduced by preventing fish from entering the intakes with a fish screen. Fish screens can be highly effective, however, they may be difficult to operate at larger projects or where debris loads are high. However, injury and mortality generally decrease with turbine size and inversely with head (Eicher Associates 1987).

**Habitat Alteration:** The construction of a dam or weir and tailrace directly affects riparian and aquatic habitat by replacing vegetation, rocks and gravel and fine sediments with concrete and steel. The habitat occupied by these structures no longer provides habitat for fish, invertebrates, or vegetation and therefore these structure create a permanent footprint that is a direct impact to aquatic habitat. These impacts cannot be mitigated but are typically compensated for through the construction or improvement of habitat nearby.

**Downstream Effects:** Hydro projects have the potential to disrupt flow regimes downstream of the tailrace by interrupting river flows. Run-of-river projects by definition have negligible downstream effects because they release water as it is received in the intake. Moreover, these projects often have pressure release valves to provide a continuous flow of water in the event of a shutdown, which would otherwise temporarily reduce flows downstream of the tailrace until flows released at the intake travelled through the diversion section. Despite these precautions, operational errors, accidents, and malfunctions may affect flows downstream of the tailrace and result in short-term fluctuations that could dewater fish and aquatic organisms. Other potential effects are those on water quality, specifically water temperature, dissolved oxygen, and dissolved
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gas. These impacts, though possible, are unlikely to be large at small hydro projects and are expected to be small at Site C (BC Hydro 1980).

In summary, both large hydro and small hydro projects have potential impacts. These impacts are mitigated through environmental design to meet regulatory requirements, then any residual impacts are offset through the provision of compensation at a rate sufficient to offset the risk of failure in either the assessment process or delivery of the compensation habitat. Overall, the goal of existing regulations is to ensure that no net impact or a net gain of fish habitat is achieved. This process can successfully protect habitat, providing that adequate information is obtained to guide the assessment of impacts, the design of mitigation, and to plan and execute the compensation. This is the intent of the regulations, the expected result of their proper application, and an outcome validated in many projects through monitoring. However, there are risks that impacts will occur despite the application of these regulations and best management practices, including state-of-the-art compensation.

There are a number of reasons why regulations, best management practices, and green criteria designs will not always avoid impacts to aquatic habitats. Ecological uncertainty is a key reason: our knowledge of the factors determining productive capacity is incomplete; therefore mitigation may not effectively target impacts or may not be sufficient to prevent habitat losses. Errors in assessment may be made, even by experienced practitioners, and approvals may be granted in error. On occasion, a variance in approval may be granted that contravenes the regulations. Finally, operational errors, accidents, and malfunctions can create impacts even in well designed and properly constructed projects. These represent potential risks to aquatic habitat that other resource options do not pose.

A significant difference between Site C and small hydro projects is the likelihood that compensation will be effective in directly offsetting project-specific impacts. Impact to riverine species from backwater effects and the blockage of upstream migration at Site C will be large, continuous, and irreversible. Riverine populations of some species, including those in tributaries to the reservoir, may be lost. It may not be practical or effective to adequately compensate for these losses on site, leading the proponent to develop a compensation program that focuses more broadly on the Peace River and tributaries. This kind of program is currently used to compensate for historical impacts to fish and habitat at existing BC Hydro dams. Although this approach will provide significant improvements in aquatic habitat in nearby areas, possibly even sufficient to match habitat losses, such a large and risk-prone undertaking does not compare to the smaller types of on-site compensation that are required at some small hydro projects. Given this, Site C poses distinctly different and significantly larger risks to aquatic habitat than do small or even medium hydro projects. On the other hand, the small/medium hydro resource bundle is comprised of 97 projects that in aggregate create impacts over a broad geographic area.
Potential risks to aquatic habitats cannot be readily quantified. We have defined the general factors contributing to risk, but there is insufficient information to provide the basis for a quantitative evaluation. Given this data gap, we have assessed risk using professional judgement as nil, low, medium, or high. Risk can be broken down into two components, the probability of an event occurring and the consequences of that event. For this assessment, the events are the specific potential impacts to aquatic habitat from dams. We have evaluated the sensitivity of aquatic habitats and cumulative effects for both small hydro projects and large hydro (Site C).

The sensitivity of aquatic habitat has been assessed qualitatively by looking at the factors of habitat diversity, habitat productive capacity, and natural habitat stability and evaluating impacts as low, medium, or high (Table 1). Using these factors, aquatic habitat in small hydro streams is expected to have a low sensitivity to impacts while aquatic habitats affected by large hydro have a medium sensitivity.

Impact has been evaluated based on magnitude, frequency, and duration for the six potential impacts of hydro projects (backwater effects, dewatering, upstream blockage, entrainment, habitat alteration, and downstream effects), using qualitative descriptors and summarizing the net effect as low, medium, or high. Table 2 describes impacts from small hydro projects and Site C based on our understanding of these impacts in general, some basic information on the projects, and the application of professional judgement which is essential when comparing a hypothetical 'typical' small hydro project to Site C. For example, considering fish passage, we know that small hydro projects on fish-bearing streams will have some effects. However, fish populations on these streams will typically exhibit very limited if any active downstream movement, in contrast to Site C where we know there are active migrations that will increase the magnitude of entrainment. Also, Site C will operate continuously whereas many small hydro projects have extended periods when they don't operate during low flow periods and cannot entrain fish. Finally, Site C will entrain most of the flow into the turbines whereas many small hydro projects entrain a small portion during higher flow periods when fish migrate.

Downstream effects of both small hydro projects and Site C are considered to be low. Green small hydro projects do not alter the natural flow regime outside of the diversion section as they operate in run-of-river mode. Similarly, Site C will operate in run-of-river mode. Although the flow regime of the Peace River has been significantly altered by existing large hydro projects, Site C will pass the flows that enter the reservoir and will not have incremental effects on the downstream flow regime. There will be some changes to water quality on both Site C and small hydro projects, but these are not expected to be large. These conclusions for Site C are tentative as they are based on information from a 1980 study, and may be revised with additional detailed study.

These factors were considered when assigning the qualitative judgments recorded in Table 2. Overall, small hydro projects are expected to have low impacts, whereas the overall impacts of Site C range from low to high. These qualitative aspects of aquatic impact should be considered when evaluating the quantitative measures defined later in Section 3.2.
Table 1. Aquatic habitat sensitivity for small run-of-river hydro and large hydro (Site C).

<table>
<thead>
<tr>
<th>Habitat Sensitivity</th>
<th>Rationale</th>
<th>Small Hydro</th>
<th>Site C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Habitat Diversity</td>
<td>Number of species present. Highly diverse communities have specialized members more sensitive to environmental change.</td>
<td>low</td>
<td>high</td>
</tr>
<tr>
<td>Habitat Productive Capacity</td>
<td>Highly productive habitats typically have few environmental stressors and so are more likely to be affected by environmental change.</td>
<td>low</td>
<td>medium</td>
</tr>
<tr>
<td>Natural habitat stability</td>
<td>Species in stable habitats are adapted to narrow ranges of environmental parameters and are more sensitive to environmental change.</td>
<td>low</td>
<td>medium</td>
</tr>
</tbody>
</table>

Overall: low, medium

Table 2. Aquatic habitat impact type by magnitude, frequency, and duration for small hydro and Site C.

<table>
<thead>
<tr>
<th>Impact</th>
<th>Magnitude</th>
<th>Frequency</th>
<th>Duration</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Backwater Effects</td>
<td>Small hydro low, Site C. high</td>
<td>continuous, continuous</td>
<td>long, long</td>
<td>low, high</td>
</tr>
<tr>
<td>Dewatering</td>
<td>Small hydro low, Site C. nil</td>
<td>frequent, rare</td>
<td>short, short</td>
<td>low, low</td>
</tr>
<tr>
<td>Fish passage – Upstream blockage</td>
<td>Small hydro low, Site C. high</td>
<td>occasional, continuous</td>
<td>short, long</td>
<td>low, high</td>
</tr>
<tr>
<td>Fish passage – Entrainment</td>
<td>Small hydro low, Site C. medium</td>
<td>medium, medium</td>
<td>seasonal, continuous</td>
<td>low, medium</td>
</tr>
<tr>
<td>Habitat Alteration</td>
<td>Small hydro high, Site C. high</td>
<td>continuous, continuous</td>
<td>long, long</td>
<td>high, high</td>
</tr>
<tr>
<td>Downstream Effects</td>
<td>Small hydro low, Site C. low</td>
<td>rare, continuous</td>
<td>short, long</td>
<td>low, low</td>
</tr>
</tbody>
</table>
3.2. Quantifying Hydro Impacts

The objective of this work is to incorporate environmental impacts into the consideration of electricity portfolios. Ideally this would be accomplished with a measure that quantifies impacts to fish productive capacity at individual projects sites. However, such measures typically take years to collect and are not available for any of the projects under consideration in the resource portfolios. Although Site C was the subject of numerous studies decades ago, much the information is outdated both ecologically and methodologically, precluding its use for reliable inferences (physical data on reservoir area is still expected to be valid). The studies are outdated ecologically because they took place at least 25 years ago, which is equivalent to 5 generations for a fish species that lives for 5 years. Over this time, some species could vanish and others could invade, greatly altering the community structure and ecological relationships. The methods used 25 years ago to measure productive capacity (if it was calculated) are also outdated because we now have more accurate and reliable equipment and methods to make these estimates. Given this situation, we are forced to use more generalized measures that rely on basic physical data that are available for individual projects. For both small hydro run-of-river projects and Site C, reliable basic data are available.

The Green Energy Study for British Columbia (Sigma 2002) provides an inventory of potential small hydro run-of-river projects in BC. Projects in the inventory range in size from 500 kW to about 47 MW and are located in most geographical regions of the Province. The projects used in the IEP overlaps with this database: the small hydro resource bundle contains 90 small hydro projects (<50 MW) and 7 medium projects (>50 MW). Of the total of 97 projects, 67 projects are also in the Sigma database.

The Green Energy Study provides information that can be used to estimate potential effects on fish habitat, including:

A. Streamflow (mean annual flow, cms)
B. Penstock length (m)
C. Head (elevation differential between the intake and powerhouse, m)
D. Fish presence (sport fish, anadromous fish, or other stocks)
E. Drainage area (km²)
F. Length of Transmission Line (km)
G. Length of Access Road (km)

These variables can be used individually and in combination to describe the potential effects of small hydro projects on the aquatic environment. For the 30 projects in the resource bundle
where these data are not available, it will be necessary to assume that general parameter values are the same as for the 67 projects in both the Sigma databases and the resource bundle.

3.2.1. Surface Area

The primary measure that can be derived from the Green Energy Study is the surface area of habitat potentially affected by the development. Surface area is the fundamental metric describing aquatic habitat. Production of fish populations has always been defined on an areal basis in the scientific literature, partly because area is the most convenient index of the spatial extent of an ecosystem, but also because production, the mass of fish produced, can only be compared among ecosystems if it is scaled by the size of an ecosystem. Surface area is integral to the measurement of productive capacity – DFO scientist Minns (1997) defines production on an areal basis, i.e., the number of kilograms of fish tissue produced per year per unit surface area of a lake or stream.

Furthermore, surface area is explicitly identified in regulatory policies and guidebooks on impacts to aquatic habitat, as follows. DFO’s Policy for the Management of Fish and Fish Habitat states:

‘Typically, habitat lost through project development or created through compensation is assessed and described according to physical parameters (e.g. area or volume of habitat; littoral zone; mudflat; saltmarsh; gravel bed) combined with a biological classification.’ (Department of Fisheries and Oceans 1998, p. 8).

In summary, the scientific literature and the interpretation of DFO’s Habitat Management Policy by its own scientists shows that surface area is a key element in the operational definition of the productive capacity of lakes and rivers. Surface area can be calculated with the same units in habitats affected by different resource options. Moreover, surface area can be readily modified by factors that describe quality-based aspects of fish habitat.

Stream surface area can be derived from the Green Energy Study by multiplying the length and width of the affected habitat areas. Stream length is restricted to the section most strongly affected by the project. For small hydro run-of-river projects that will be the diversion section from which water is withdrawn but to which a continuous instream flow release is provided. Stream width is known for a small number of projects in the resource bundle and can be estimated for the remainder using data obtained for BC streams from the Ministry of Water, Land and Air Protection (MWLAP). In the case of Site C there is no water withdrawal, however, the dam will impound 83 km of river, as well as 23.9 km of tributary streams: in combination these areas comprise the upstream section. Stream width is known for Site C and its tributaries such that the total stream area in the upstream section can be calculated – 3,970 ha (BC Hydro 2005).
Wetted width can be predicted from mean annual streamflow. Empirical studies of river channels demonstrate consistent relationships between stream width (or depth or velocity) and stream flow through a power relationship of the form \( x = aQ^b \), where \( x \) is the stream hydraulic parameter of interest (i.e., width, depth, velocity), \( a \) is the coefficient, \( Q \) is flow, and \( b \) is the power function. Typically the relationships are expressed in a logarithmic form and plotted on log-transformed axes. Typical values of the exponent are 0.26 for width, 0.40 for depth, and 0.34 for velocity (Leopold and Maddock 1953). The literature distinguishes hydrometric relationships developed at-a-station from those developed downstream because the exponents of the relationships differ. Downstream relationships are those developed by analyzing different stations, analogous to comparing streams of different mean annual flow.

The MWLAP stream productivity data collected throughout the Province includes measures of standing stock per unit area by species and by physical habitat variables such as wetted width and stream flow (Ptolemy 2005). The database is composed of streams ranging in size from 3.00 cms to 370 cms, which tends to be larger but does overlap the range of mean annual flows in those streams in the Green Energy Study. Streams in the database have gradients of <5%, in contrast to streams where small hydro projects are typically built, which have gradients of 5% or greater. This highlights the need for validation of the predictions of the equation for stream width.

Other sources of data include two published studies on streamflow in the literature. Castro and Jackson (2001) collected width and flow data from 75 streams in the Pacific Northwest. Jowett (1998) collected width and flow data from 73 streams in New Zealand. To evaluate the consistency of relationships across regions and assess the confidence in relationships, these datasets can be compared to the MWLAP data collected from 139 sites. The BC data are restricted to downstream station data; however, the data were collected from 65 streams, with up to 10 stations on an individual stream. In addition, we were able to collect width and streamflow data from 11 small hydro projects in BC, and these can be compared to the published data sets.

Data was obtained from reports on fish habitat and/or environmental impact assessment for projects built/proposed on 11 streams: Upper Mamquam River, Lower Mamquam River, Ryan Creek, Hunter Creek, Log Creek, China Creek, Kokish River, Soo River, Long Lake, Doran-Taylor, and Ucona River. Stream width and flow were not measured with the same method in each of these studies, and the numbers are calculated with different statistics in some cases. For example, in the Pacific Northwest study streamwidth at bankful flow was estimated, rather than at mean annual flow. Despite these differences, we expect trends to show similar forms and exponent values to differ minimally.

Figure 1 shows the relationship between wetted width and streamflow for the four datasets. The MWLAP data set lies between the trend lines predicted by the New Zealand and Pacific Northwest datasets: the small hydro dataset lies within the spread of values in the MWLAP data.
Figure 1. Wetted width versus flow for data sets collected from streams in British Columbia (MWLAP data, Ptolemy 2005), the Pacific Northwest (Castro and Jackson 2001), New Zealand (Jowett 1998), and at select BC small hydro streams (n= 11, various sources). Flow data reflects different statistics, dependent on the source. The trend line is fitted to the MWLAP data.

\[ y = 5.51x^{0.534} \]
\[ R^2 = 0.93 \]
At this time there are insufficient small hydro stream data to confidently evaluate differences with the MWLAP dataset. Accordingly we will use the MWLAP dataset predictive equation, recognizing that further validation may identify an alternative relationship. The power equation for the MWLAP dataset is:

\[
\text{Stream width (m)} = 5.51 \times \text{mean annual flow}^{0.534}
\]  

Eqn. 1

The combined length of tunnel and penstocks between the intake and the powerhouse at potential small hydro sites is reported as penstock length in the Green Energy Study. We assume that penstock length is a reasonable estimate of length of stream channel in the diversion section. Although these lengths are correlated, penstocks lengths maybe shorter than the diversion section in some projects, given that proponents will optimize project design by minimizing penstock length. The Green Energy study estimated penstock length for candidate small hydro streams by selecting the steepest section of creek that was over 10% slope. In practise, small hydro projects are built along stream reaches that are less steep on average, as result, the 10% slope criteria tended used by Sigma estimates shorter penstock/tunnel lengths than are actually proposed or built. This was confirmed by comparing Green Energy study estimates of penstock length (average 2.29 km) to those proposed by proponents in 13 project studies (average 3.77 km). The penstock/tunnel length proposed/built was 1.48 km or 65% longer. When the two datasets were compared, error was greater for projects with shorter penstock lengths. To account for this, we used the slope and intercept of the two data sets to derive the following equation, which will be used to estimate the length of stream channel in the diversion section (the diversion length):

\[
\text{Diversion length (km)} = 0.80 \times \text{Green Energy Study penstock length [km]} + 1.93
\]  

Eqn. 2

For those projects in the resource bundles that do not have corresponding penstock length and flow data in the Green Energy database, the average aquatic habitat surface area based on the 67 projects will be used. Eventually the small hydro resource bundle can be corrected using project-specific data, however we expect equation 2 to yield a reasonable estimate of diversion length.

### 3.2.2. Habitat Quality Factors

The practise of estimating ecological impacts from physical data is well-established in practise and explicitly acknowledged as a common and acceptable method in the HADD decision
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framework (DFO 1998). This method requires referencing a known relationship between physical habitat and fish productive capacity to infer how changes in physical habitat at a specific project site will affect productive capacity at that site. For example, if we have demonstrated that fish production shows a consistent relationship with gradient, we can use gradient as a predictor of fish production. In practice, significant relationships between fish production (i.e., the biomass of fish produced per unit area per unit time) and physical variables are rarely measured, rather practitioners correlate standing stock (biomass per unit area) with physical variables and assume that abundance is closely linked with production (a constant production/biomass ratio). This approach is embedded in the preferred methods for quantifying fish habitat impacts from water withdrawal in BC, wherein the physical variables depth and velocity (and others) are weighted by the suitability for fish, the latter being determined by empirical studies across a number of streams (Lewis et al. 2004).

There are numerous examples in the literature that describe, test, and validate this approach to quantifying fish habitat. They show that physical habitat variables are correlated with fish productivity in the Province, and as such, can be used as potential indicators of habitat quality. To further assess whether these measures can be used to describe potential aquatic impacts across resource options, the database must be examined. This exercise was undertaken for variables that could be derived from the Green Energy Study.

Using drainage basin area, mean annual flow, head, and diversion length we can calculate additional physical variables. Water yield can be calculated as the mean annual flow divided by the drainage basin area. Stream gradient can be calculated as head divided by diversion length. The efficacy of these variables in describing habitat quality is dependent on the strength of relationships between these variables and fish productive capacity, as inferred through standing stock estimates. To assess this we examined the MWLAP database.

The MWLAP stream productivity database provides some limited evidence that water yield and gradient are linked to standing stock. A significant relationship between biomass per unit area and water yield exists in the database (Ptolemy 2005) of the form:

\[
\text{Biomass (g/100 m}^2\text{)} = 652 \times (\text{Water Yield} \left[\text{L/s/km}^2\right])^{0.31}
\]

Eqn 3.

This relationship explains 26% of the variance in biomass. Similar data from Site C that can be reliably compared to this relationship were not available, therefore evaluating productive capacity through this habitat factor to assess aquatic habitat impacts for this project is not feasible at this time.

Stream gradient plays a role in structuring fish distribution in streams. In British Columbia the common rule-of-thumb is that stream reaches of >20% gradient rarely support fish. The Riparian Area Regulation assessment methods identify 20% as a threshold above which streams
may not support fish, although in lake headed streams with step-pool habitats trout and char may be found at steeper gradients. The typical stream in the Green Energy Study has a diversion section gradient of 14.5%, which implies that over half of the streams have gradients that can support fish. The literature provides some limited support for the hypothesis that gradient determines trout standing stock (Isaak and Hubert 2000), but suggest that many stream habitat variables acting simultaneously are the cause of such data patterns. Given this, stream gradient does not provide a useful habitat quality weighting factor.

3.2.3. Fish Presence

Small hydro projects typically avoid major impacts to fish habitat because they are sited on headwater tributaries in canyons that contain barriers to upstream fish passage. Many of these streams do not and have never supported fish, and may not be able to because of habitat limitations. Such streams do not directly provide fish habitat, however, given that the definition of fish habitat includes ‘capacity to support one or more life processes of fish’, fishless streams may indirectly support fish production for an existing or potential fishery. For example, headwater streams contribute nutrients and invertebrates to downstream reaches occupied by fish. In doing so, these high gradient streams effectively support fish production, though separated from fish populations by barriers insurmountable to migratory fish. Studies of Alaskan headwater streams (in a biogeoclimatic region similar to that of many BC small hydro streams) shows that fishless streams export drift and detritus throughout the year, sufficient to support hundreds, even thousands, of juvenile salmonids (Wipfli and Gregovich 2002).

Developments on both fish bearing and fishless streams are governed by the same regulations, requiring the potential impacts from water withdrawal be assessed considering the full definition of fish habitat productive capacity, which includes fishless stream features such as the production of invertebrates (Lewis et al. 2004). Instream flow requirements for fishless streams are typically less than those for fish bearing streams, recognizing that the risks to fish are lower (Hatfield et al. 2004). For the purposes of generating measures for the quantification of the aquatic habitat attribute we have assumed that the existing regulatory process will effectively protect productive capacity in many cases, but acknowledge a residual risk to aquatic habitat from these developments. In the case of fishless streams, that risk is expected to be very low, because fish are not present, eliminating direct impacts such as mortality from dewatering, and also because invertebrates are more tolerant of short term dewatering than are fish. Furthermore, all the risk comes in the form of downstream effects, which we have not considered in detail in this evaluation. The reason for this is two-fold: 1) all resource options that affect aquatic habitat have the potential to affect downstream habitats, simply because water flows downstream; and 2) the geographic scope of downstream effects is difficult to define and increases the complexity of comparisons of the effects of different resource options.
To acknowledge the different risk to aquatic habitat posed by small hydro developments in fish-bearing and fishless streams, habitat measures will be modified by a binary variable (1,0). Developments on fishless streams were assessed a value of ‘0’ indicating that the risk posed is considered minimal. An obvious alternative to the ‘0’ designation would be to use a fractional weighting such as 0.5, 0.25 or 0.1, however, we have no information at this time to support any particular value. Faced with this dilemma we have elected to use ‘0’, as it reflects the difference between fish bearing and fishless streams at a binary level of assessment, a level consistent with the available data.

The approach of differentiated fish-bearing and fishless streams agrees with the BC guidelines for instream flow (Hatfield et al. 2004) and is also consistent with other regulations, such as the Forest Practices Code of BC and the Riparian Area Regulation, both of which provide less protection for fishless streams. Fish presence data are available for streams in the Green Energy Study: these data have not been validated by comparison with project specific data.

4. AQUATIC HABITAT ATTRIBUTE MEASURES

Based on the information available on individual projects and our ability to extrapolate effects on aquatic habitat from basic physical data, we have proposed measures that can be used to represent the potential risk to fish habitat from the development of different resource options. These measures focus primarily on small hydro developments, primarily because these projects have direct effects on fish habitat, but also because there are basic physical data available for these projects that can be used to assess impacts. Comparable data are available for relevant aspects of large hydro (Site C) and other resource options.

Table 3 lists the proposed habitat measures by resource option, defining the measure, the equation for data collection, citing the reference for the parameters used in the equation, and listing the assumptions inherent in the calculation. The equations listed are described in the foregoing text. Each variant of the measure describes an aspect of aquatic habitat impact expected for a resource option. Some of the measures are unique to a particular resource option: measure A describes impacts from dewatering of the diversion section of small hydro projects; measure B describes impacts from backwater effects of large hydro projects (Site C); measure C describes backwater effects at small hydro projects; measure D describes the footprint effects of weirs/dam on all hydro projects; measure E is a modifier of all measures based on fish presence; and measure F describes the impact of stream crossings from access roads, transmission lines, and penstocks/tunnels pipelines.

To calculate the area of aquatic habitat at risk (potentially affected) by the development of a resource option, the appropriate measure variants must be selected, combined as noted, and calculations made with data from the resource options database. For each resource option the
following calculations would be made to yield area affected in hectares (ha) (note the units for each input variable in the notes to Table 3):

1. Run-of-river small hydro  \((A + C + D)*E + F\)
2. Large hydro  \((B +D)*E + F\)
3. Natural gas, coal, wind, geothermal  \(F\)
4. Biomass, customer cogeneration and Power Smart options  none

This calculation will provide measures that can be used to compare the aquatic habitat impacts of different resource options. Caution must be applied when making such comparisons, given the uncertainties and data gaps that are further defined in the next section. From a conservative, science-based perspective one could take the position that the calculations should not be used to make decisions because of uncertainty and insufficient information. However, the challenge faced for the 2005 IEP is to provide the best measures possible with the available information. Despite the lack of detailed information and our inability to validate some of the predictions, these measures are expected to be relatively accurate because they measure surface area. Decisions made with these measures should be defensible providing that the qualitative issues are also considered.
Table 3. Summary of aquatic habitat measures.

<table>
<thead>
<tr>
<th>Measure variant</th>
<th>Area of Potential Impact</th>
<th>Applicable Resource Option</th>
<th>Value or Equation (yields area in ha)</th>
<th>Data Source for Value Equation Parameters</th>
<th>Assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Wetted area subject to dewatering influence</td>
<td>Small hydro run-of-river, diversion section between intake and powerhouse</td>
<td>Area = stream width {Eqn. 1} * diversion length {Eqn. 2} / 10,000</td>
<td>Stream width - Ptolemy 2005; penstock length - Sigma 2002 and the small hydro resource database</td>
<td>Small hydro streams have the same stream width to flow relationships as do typical BC streams</td>
</tr>
<tr>
<td>B</td>
<td>Wetted area - backwater effect</td>
<td>Large hydro (Site C), upstream section including tributaries</td>
<td>3970 ha (already includes part of but not the entire footprint of the dam)</td>
<td>BC Hydro 2005</td>
<td>Assessment data are accurate for physical variables</td>
</tr>
<tr>
<td>C</td>
<td>Wetted area - backwater effect</td>
<td>Small hydro run-of-river, upstream of intake</td>
<td>Area = stream width {Eqn. 1} * weir height / [head/diversion length {Eqn. 2}] / 10,000</td>
<td>Stream width - Ptolemy 2005; penstock length - Sigma 2002 and the small hydro projects proposal</td>
<td>Typical weir height is 3 m; diversion section gradient similar to that at the headpond.</td>
</tr>
<tr>
<td>D</td>
<td>Footprint of hydro dams/weirs</td>
<td>Small hydro run-of-river, large hydro (Site C)</td>
<td>Area = ( (\text{stream width } {\text{Eqn. 1}} \times 10,000)^2 )</td>
<td>Rough estimate - footprint is a square as wide as the stream</td>
<td>Structure impacts habitat at footprint</td>
</tr>
<tr>
<td>E</td>
<td>Fish presence at hydro projects</td>
<td>Small hydro run-of-river, large hydro (Site C)</td>
<td>Fish presence ( 1,0 )</td>
<td>Green Energy Study (Sigma 2002)</td>
<td>Fishless streams are at very low risk from small hydro developments; Green Energy Study is accurate</td>
</tr>
<tr>
<td>F</td>
<td>Area affected by stream crossing</td>
<td>All roads, pipelines/penstocks/tunnels, transmission lines</td>
<td>Area ( \text{ha} ) = ( [(\text{pipeline, penstock, tunnel length + access road length}) \times 550 + \text{transmission line length} \times 500] / 10,000 \text{[see note]} )</td>
<td>Parker and Quigley 2000 - report impact per crossing; assume 1 crossing per km as a rough estimate</td>
<td>Penstock/tunnels and transmission line crossings have similar impacts to road crossings.</td>
</tr>
</tbody>
</table>

**Notes:**
Units are as follows: diversion length (m), head (m), flow (cms), weir height (m), stream width (m), access road length (km), pipeline-penstock-tunnel length (km), transmission line length (km). Geothermal pipelines are not included in the calculation.
Area affected is sum of measure variants, dependent on resource option:
- Small hydro = \( (A + C + D)E + F \)
- Large hydro = \( (B + D)E + F \)
- Other = \( F \)
5. UNCERTAINTIES AND DATA GAPS

We have proposed measures of aquatic habitat attributes based on the information available on individual projects and our ability to extrapolate effects on aquatic habitat from basic physical data. These measures focus primarily on hydro developments, which have direct effects on fish habitat.

There are key questions and data gaps that affect decision making with these measures. Most of these questions and data gaps cannot be addressed within the 2005 IEP time frame; some may be addressed before the start of the 2007 IEP.

There are three key types of uncertainties. The first uncertainty is the accuracy of input data, particularly the accuracy of project data in the resource database. This uncertainty has been addressed to some extent by comparing current applications and built projects with cases in the database to derive correction factors. An example of this is the correction of diversion length to reflect the difference observed between the value in the Green Energy Study and in proposed/built projects. Ideally, such corrections would be made on a case-by-case basis to avoid reliance on a general correction factor. However, filling this data gap is a time consuming undertaking that cannot be completed for the 2005 IEP.

The second key uncertainty is accuracy of prediction of aquatic habitat effects. The reliability of extrapolations of aquatic habitat impacts from available data, such as the MWLAP database, to projects in the resource database is unknown. In the case of stream width there is some evidence that the proposed extrapolation will overestimate aquatic habitat potentially affected by small hydro projects. This uncertainty can be addressed by collecting additional data from proposed/built projects and refining the equation.

The third and largest uncertainty concerns the comparability of measures between resource options. This uncertainty cannot be easily addressed, even if available data is collected and analyzed. For example, although we can calculate the backwater effects in surface area for both small and large hydro projects in the same units, the ecological equivalency of these measures is unknown. This reflects the scale of the impact (being much larger for large hydro), but also our lack of understanding of impact thresholds. Limited backwater effects are expected for small hydro projects and such effects may actually benefit fish habitat locally, rather than cause the negative effects common to much more substantial backwater effects at large hydro projects. These questions have been partly addressed by the qualitative assessment of small and large hydro habitat sensitivity and impact provided in section 3.2.

The uncertainties associated with each proposed aquatic habitat measure have been discussed in the foregoing text. The key assumptions that acknowledge these uncertainties are listed in Table 3. Additional data may be collected to test these assumptions, possibly to a limited extent during the 2005 IEP, or prior to the 2007 IEP.
6. REFERENCES


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