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Long term Aquatic Monitoring Protocols for New and Upgraded Hydroelectric Projects

Protocoles de surveillance à long terme des projets hydroélectriques nouveaux et mis à niveau

F.J. Adam Lewis
Andrew J. Harwood
Cory Zyla
Kevin D. Ganshorn
Todd Hatfield

EcoFish Research Ltd. Suite F, 450 8th St. Courtenay, BC V9N 1N5

3190 Hammond Bay Rd., Nanaimo, BC V9T 6N7

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ABBREVIATIONS AND GLOSSARY

ADCP	Acoustic Doppler Current Profiler
APHA	American Public Health Association
BA	Before-After monitoring design
BACI	Before-After Control-Impact monitoring design
CEA	Cumulative Effects Assessment
CEAA	*Canadian Environmental Assessment Act*
CEFI	Canadian Ecological Flow Index
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
CPUE	catch-per-unit-effort
Cumulative Effect	The effect on the environment which results from effects of a project when combined with those of other past, existing, and imminent projects and activities (may occur over a certain period of time and distance).
DFO	Fisheries and Oceans Canada
EEM	environmental effects monitoring
EIA	Environmental Impact Assessment
ECP	Environmental Choice^{M} Program (Environment Canada)
EMP	Environmental Management Plan
FHAP	fish habitat assessment procedure
FIDQ	Fisheries Inventory Data Queries
Flow Ramping	A gradual or progressive alteration of discharge in a stream channel resulting from the operation of a hydroelectric facility
GPS	Global Positioning System

Hydropeaking	The practice of abruptly alternating flows for electrical power generation to match energy demand
HADD	harmful alteration, disruption or destruction (of fish habitat)
HPLC	high-performance liquid chromatography
HSI	habitat suitability index
HSM	habitat suitability matrix
ICOLD	International Commission on Large Dams
IFR	instream flow release
LoA	Letter of Advice
LWBC	Land and Water British Columbia Inc.
LWD	large woody debris
MAD	mean annual discharge
MoE	Ministry of Environment
MW	megawatt
MWLAP	Ministry of Water, Land and Air Protection
NNL	no net loss (in the productive capacity of fish habitat)
PIT	passive integrated transponder
POD	point of diversion
Ramping Rate	The rate of change in discharge measured as a flow per unit time (i.e., m^3/s/s or cfs/s); can also be expressed as the rate of change in stage and measured as vertical change in water surface per unit time (i.e., cm/hr)
RCA	Reference Condition Approach
RISC	Resources Information Standards Committee
ROW	right-of-way
R.P.Bio.	Registered Professional Biologist
RVT	Riparian Vegetation Type
SARA	*Species at Risk Act*
SEM-AVS	simultaneously extracted metals and acid volatile sulfides
TGP	total gas pressure
Upgrade	For the purposes of this document, an upgrade is defined as work that may result in the harmful alteration, disruption or destruction (HADD) of fish habitat and require review under the *Fisheries Act* (R.S.C., 1985, c. F-14) and/or the *Canadian Environmental Assessment Act* (S.C. 1992, c. 37)
UTM	Universal Transverse Mercator
VEC	Valued Environmental Component

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ABSTRACT

The Long-term Aquatic Monitoring Protocols for New and Upgraded Hydroelectric Projects identify suitable methods to evaluate the effectiveness of mitigation and compensation activities undertaken during the development and operation of a project, and to evaluate the project's effects on fish and fish habitat. Furthermore, this document is intended to promote standardized monitoring methodologies that will create consistency in the regulatory requirements of project proponents and allow for the comparison of data across multiple projects in order to evaluate environmental effects and generalize results across projects. Given the need for consistent monitoring over time, the document also details the requirements for baseline monitoring, which are necessary in order to complete an environmental impact assessment (EIA) to meet legislative and regulatory requirements under the *Canadian Environmental Assessment Act* and *Fisheries Act*. The geographic focus of this document is British Columbia and the Yukon Territory, although it may apply elsewhere in Canada.

These protocols are designed to identify key variables, assist the planning and design of baseline and long-term monitoring programs, and provide technical methodology and analysis tools. Accordingly, tools that are pertinent to assessing the biological, physical, and chemical responses of aquatic systems to the development and operation of a hydroelectric project are introduced in the subsequent discussions. The data and knowledge that are obtained through the monitoring protocols presented herein will provide a basis for understanding project-ecosystem interactions in BC and the Yukon, and for improved protection of aquatic habitat.

Three types of monitoring are described in this report: *Compliance Monitoring, Effectiveness Monitoring,* and *Response Monitoring*. Each type is expanded upon in Section 2. In general, the monitoring protocols described here can establish (i.) key indicators by which regulatory agencies can measure compliance, (ii.) tools for evaluating the relative success of mitigation and compensation measures designed to minimize or offset environmental impacts, and (iii.) a mechanism for improving the management of the project and similar projects through the evaluation of project effects and the integration of corporate learning. The protocols are grouped according to specific environmental parameters and details of these parameters are in Table 7 to Table 22. A table of contents for a sample monitoring plan report has been included in Appendix A as guidance.

Six primary parameters are identified that will be monitored for all projects. These include: water flow, mitigation and compensation measures, riparian habitat, water temperature, stream morphology, and fish abundance and behaviour. There are three secondary parameters that should be monitored on a case-by-case basis: water quality, invertebrate abundance, and species at risk. Important conditions and considerations pertinent to the monitoring of these parameters are provided throughout these protocols. For example, some fish populations may require sampling of all critical life phases on an annual basis (i.e. multiple sampling periods each year).

It is acknowledged that the proposed monitoring design will need to maintain a certain level of flexibility and adaptability in order to handle major differences between projects and to incorporate new knowledge and methodologies as they develop. Project-specific concerns will be raised during the EIA and the monitoring program should accordingly be tailored to address effect predictions made in the EIA. Additional monitoring effort may be required for certain environmental parameters depending on project-specific circumstances. Consequently, these protocols avoid a fully prescriptive approach and focus on describing the different types of monitoring that will be required and the range of variables that may require measurement. For those parameters that will be monitored, the level of monitoring set forth

in these protocols is viewed as a minimum requirement due to the variability inherent in physical and biological systems, and the current uncertainty surrounding the relationship between flow and fish populations (Bradford and Heinonen 2008). Ultimately, the monitoring plan design is at the discretion of the professionals undertaking the studies and the regulators overseeing the licensing of the project.

RÉSUMÉ

Les protocoles de surveillance à long terme des projets hydroélectriques nouveaux et mis à niveau déterminent les méthodes appropriées afin d'évaluer l'efficacité des activités d'atténuation et de compensation entreprises pendant l'exécution et l'exploitation d'un projet ainsi que d'évaluer les effets du projet sur les poissons et leur habitat. De plus, le présent document vise à promouvoir la normalisation des méthodologies de surveillance, ce qui permettra d'uniformiser les exigences réglementaires imposées aux promoteurs de projet et de comparer les données entre les différents projets pour en évaluer les impacts environnementaux et généraliser les résultats à d'autres projets. Étant donné la nécessité d'assurer une surveillance uniforme et soutenue, le document détaille aussi les exigences de la surveillance de base pour effectuer une étude d'impact sur l'environnement (EIE) afin de satisfaire aux exigences législatives et réglementaires en vertu de la *Loi canadienne sur l'évaluation environnementale* et de la *Loi sur les pêches*. Ce document porte sur la Colombie-Britannique et le Yukon, mais il peut aussi s'appliquer au reste du Canada.

Ces protocoles sont conçus pour déterminer les variables essentielles, aider à la planification et à la conception de programmes de surveillance à long terme de référence et fournir une méthodologie technique et des outils d'analyse. Par conséquent, les outils visant à évaluer les réponses biologiques, physiques et chimiques des systèmes aquatiques à l'exécution et à l'exploitation d'un projet hydroélectrique sont introduits dans les discussions ultérieures. Les données et les renseignements obtenus grâce aux protocoles de surveillance présentés dans le présent document servent à comprendre les interactions entre les projets et l'environnement en Colombie-Britannique et au Yukon ainsi qu'à améliorer la protection de l'habitat aquatique.

Le présent rapport décrit trois types de surveillance : *la surveillance de la conformité, la surveillance de l'efficacité* et *la surveillance des réactions*. On se penche sur chaque type dans la section 2. En général, les protocoles de surveillance décrits établissent (i) des indicateurs essentiels qui permettent aux organismes de réglementation d'évaluer la conformité; (ii) des outils pour évaluer le succès relatif des mesures d'atténuation et de compensation conçues pour réduire au minimum ou compenser les impacts environnementaux; (iii) des mécanismes pour améliorer la gestion du projet et de projets similaires par le biais de l'évaluation des effets de projet et de l'intégration de l'apprentissage organisationnel. Les protocoles sont regroupés selon des paramètres environnementaux particuliers; les Table 7 à Table 22 donnent des précisions sur ces paramètres. À titre d'orientation, l'annexe A fournit une table des matières d'un exemple de rapport de plan de surveillance.

On a déterminé six paramètres fondamentaux qui seront surveillés pour tous les projets : le débit d'eau, les mesures d'atténuation et de compensation, l'habitat riverain, la température de l'eau, la morphologie du cours d'eau, l'abondance et le comportement des poissons. Selon les cas, trois paramètres secondaires devraient aussi faire l'objet de surveillance : la qualité de l'eau, l'abondance d'invertébrés et les espèces en péril. Des conditions et des considérations importantes relatives à la surveillance de ces paramètres sont contenues dans ces protocoles. Par exemple, pour certaines populations de poissons, il faudra échantillonner tous les stades critiques du cycle de vie annuellement (c.-à-d. plusieurs périodes d'échantillonnage par an).

On reconnaît que le plan de surveillance proposé devrait être suffisamment flexible et adaptable pour pouvoir tenir compte des principales différences entre les projets et incorporer de nouvelles connaissances et méthodologies au fur et à mesure qu'elles sont développées. Des préoccupations propres au projet seront soulevées lors de l'EIE; le programme de surveillance devrait en tenir compte et répondre aux prédictions des effets réalisées dans l'EIE. Un effort de surveillance supplémentaire sera peut-être nécessaire pour certains paramètres environnementaux en fonction des circonstances propres à chaque projet. Par conséquent, ces protocoles évitent une approche purement normative et décrivent plutôt les différents types de surveillance qui seront nécessaires et l'éventail de variables que l'on pourrait devoir mesurer. Pour les paramètres qui seront mesurés, le degré de surveillance établi

dans ces protocoles doit être considéré comme une exigence minimale en raison de la variabilité inhérente aux systèmes biologiques et physiques et à l'incertitude qui entoure actuellement les rapports entre le débit et les populations de poissons (Bradford et Heinonen 2008). En fin de compte, la conception du plan de surveillance relève des professionnels qui entreprennent les études et des organismes de réglementation qui contrôlent la délivrance des licences pour le projet.

1 INTRODUCTION

1.1 PURPOSE AND INTENT

The primary objective of the long-term monitoring described in this report is to evaluate the effectiveness of mitigation and compensation activities undertaken during the development and operation of a project, and to evaluate the project's effects on fish and fish habitat.

A secondary objective of this document is to promote standardized monitoring methodologies that will create consistency in the requirements of project proponents and allow for the comparison of data across multiple projects to evaluate environmental effects and generalize results across projects. These monitoring protocols will therefore also allow for an evaluation of the success of DFO's Habitat Management Program.

In providing guidance for long-term monitoring purposes, and given the need for consistent monitoring over time, the document also identifies the baseline monitoring requirements for completion of an environmental impact assessment (EIA). Figure 1 shows the typical development sequence for a new hydroelectric project developed by an independent power producer and shows the stages at which these protocols will be used to assist in the collection of the necessary data and development of suitable monitoring programs.

1.1.1 Applicable Projects

These protocols identify the parameters and types of monitoring recommended by Fisheries and Oceans Canada (DFO) for the effective long-term monitoring of new hydroelectric projects, as well as those undergoing significant upgrades. Significant upgrades are defined as those that may result in the harmful alteration, disruption or destruction (HADD) of fish habitat and require review under the *Fisheries Act* (R.S.C., 1985, c. F-14) and/or the *Canadian Environmental Assessment Act* (S.C. 1992, c. 37).

The protocols have been developed for British Columbia and Yukon Territory projects, though they may be applicable elsewhere. The protocols apply to small (<50 MW) and large (≥50 MW but <200 MW) run-of-river hydroelectric projects involving streams or lakes, as well as projects that involve the creation of a storage reservoir. They do not apply to mega hydroelectric projects that fall under the *Comprehensive Study List Regulations* (SOR/94-638). As such, these protocols do not apply to hydroelectric facilities that: a) have a production capacity of 200 MW or more, b) involve the construction of a dam that would result in the creation of a reservoir with a surface area that would exceed the annual mean surface area of a natural water body by 1,500 hectares or more, or c) involve the expansion of a dam that would result in the increase in surface area of a reservoir by more than 35 per cent.

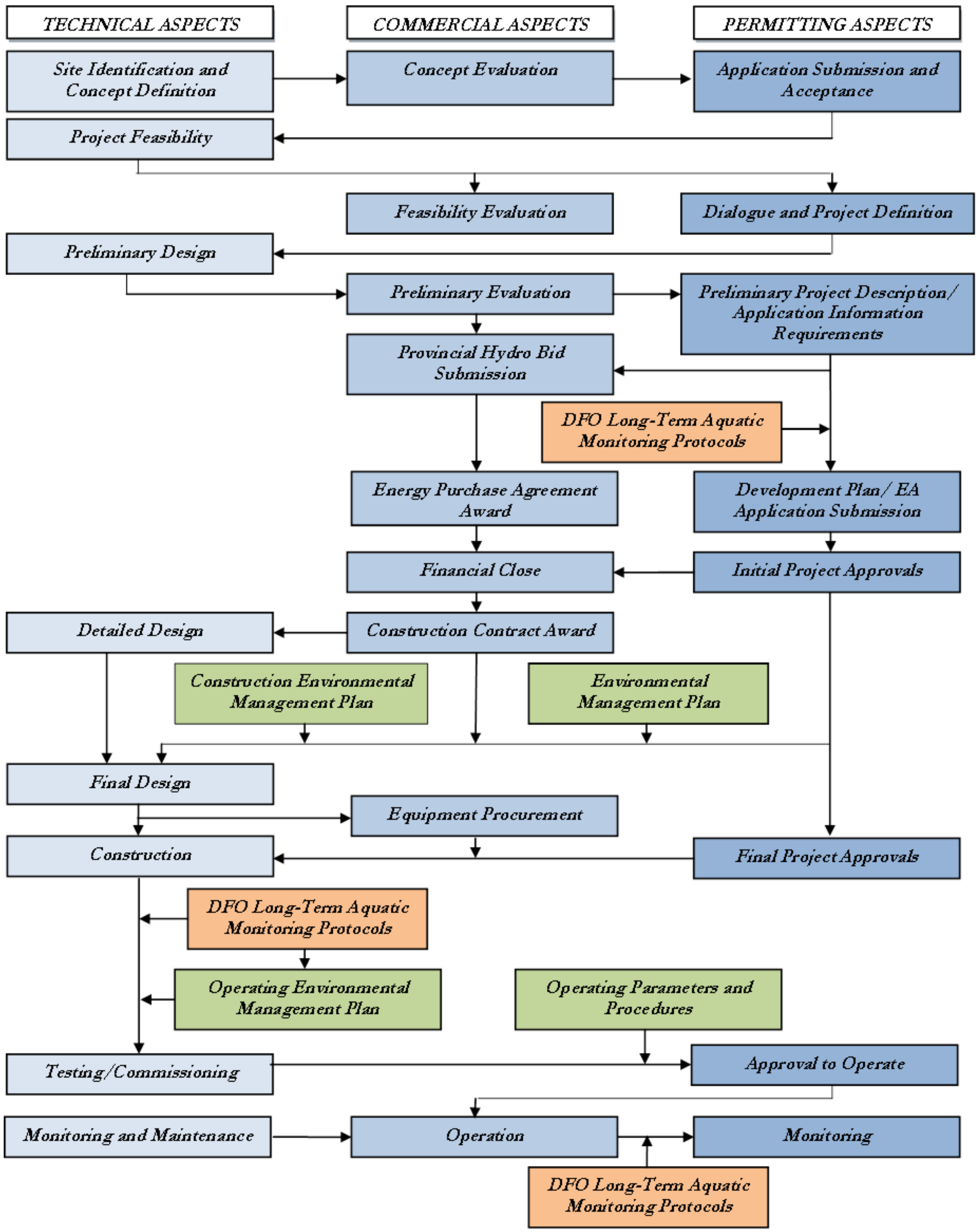

Figure 1. Typical Project Development Sequence for an Independent Power Producer (modified from Province of British Columbia 2010).

1.1.2 Relation to Legislation and Policy

Monitoring is an important component of DFO's regulatory program and is required of most projects as condition of Authorization under the federal *Fisheries Act* (R.S.C., 1985, c. F-14). Monitoring is necessary both to confirm compliance with regulatory requirements and to assess whether these requirements are sufficient to ensure that there is no net loss of the productive capacity of fish habitat. DFO regulates activities under the *Fisheries Act* to prevent obstructions to fish passage (Section 20), to ensure sufficient flows for fish (Section 22), to prevent the killing of fish by means other than fishing (Section 32), and to prevent a HADD (Section 35). Under the *Species at Risk Act* (Government of Canada 2002), projects that may affect listed wildlife species or their critical habitat must adopt measures to avoid or lessen adverse effects, and monitor project effects. The measures taken should be consistent with the applicable recovery strategies and action plans.

When project activities are low risk, DFO Operational Statements may apply. These statements outline conditions and measures for avoiding harmful alteration, disruption and destruction of fish habitat, thus ensuring compliance with subsection 35(1) of the *Fisheries Act* and therefore not subject to monitoring. However, where project activities are not covered under an Operational Statement, this document provides detailed guidance on the appropriate monitoring program components.

When proposed projects have the potential to cause a HADD, DFO applies the guiding principle of no net loss (NNL) of fish habitat productive capacity, set out in the Policy for the Management of Fish Habitat (the Habitat Policy; DFO 1986). Under this principle, DFO will require the proponent to relocate or redesign the proposed development to avoid the potential HADD, or to fully mitigate any impacts the proposed development may have on fish and fish habitat. DFO may authorize a HADD under Section 35(2) of the *Fisheries Act* when the Department is satisfied that all reasonable and feasible measures have been employed to avoid or mitigate impacts, and any potential residual impacts are determined to be insignificant and "compensatable".

An assessment of a HADD from hydroelectric projects should consider the broad definition of fish habitat, which includes "spawning grounds and nursery, rearing, food supply and migration areas on which fish depend directly or indirectly in order to carry out their life processes" (DFO 1985). Accordingly, aquatic invertebrates produced instream, and riparian habitat that supports terrestrial insect production, are part of the habitat that will be assessed.

As outlined in DFO (2010), the decision to authorize a HADD is at the discretion of the DFO Habitat Management practitioner assigned to the project. The decision as to whether compensation is required is policy-based and made after the acceptability of the HADD is determined. Compensation is defined in the Habitat Policy (DFO 1986) as: *the replacement of natural habitat, increase in the productivity of existing habitat, or maintenance of fish production by artificial means in circumstances dictated by social and economic conditions, where mitigation techniques and other measures are not adequate to maintain habitats for Canada's fisheries resources*. If a HADD is authorized on the condition that compensation is completed, a failure to complete that compensation could invalidate the *Fisheries Act* Authorization (DFO 2010). This would, in effect, leave the proponent with a HADD that was not authorized for which they could be prosecuted pursuant to subsection 35(1) of the *Fisheries Act* (DFO 2010). Monitoring to demonstrate the ongoing effectiveness of compensation is therefore a critical component of monitoring programs for projects where a HADD is authorized.

In order to conduct an EIA for a project, and ensure compliance with the federal *Fisheries Act*, DFO will require adequate hydrometric and hydrologic data, analyses, and assessments of flow modifications associated with the project. Also required are appropriate mitigation plans that adequately address fish passage obstructions, physical HADDs, or fish mortality due to entrainment. Furthermore, the proponent is required to monitor compliance with mitigation and compensation measures listed in the *Fisheries Act* Authorization (compliance monitoring), and to determine the effectiveness of these measures in achieving NNL (effectiveness monitoring). Long-term monitoring of the project as a whole will also allow an assessment of how fish and fish habitat have responded to project implementation (response monitoring). Further discussion of these three types of monitoring is provided in Section 2.

1.1.3 Significance to Fishery Resources

These monitoring protocols are intended to yield information on which decisions may be based to protect fishery resources for current and future generations. This goal can be achieved through conducting EIAs and monitoring the key parameters that are relevant to the potential adverse effects predicted in the EIA. These protocols are designed to assist proponents of run-of-river hydroelectric projects, and the concerned regulatory agencies in BC and the Yukon Territory, identify and mitigate potential adverse effects on fish and fish habitat that may result from new and upgraded projects.

There are many reasons to strive for the protection and sustainable management of fishery resources in BC and the Yukon. First, the robustness of fishery resources is an important indicator of the overall aquatic health of aquatic ecosystems. Second, fish are a key component of many ecosystems that affect the dynamics of local and regional food webs and overall ecosystem interactions. Third, fish provide numerous important economic, social and cultural benefits, supporting Aboriginal and recreational fisheries as well as industries such as sport fishing, tourism, and commercial fishing. Fourth and finally, healthy fish communities are considered to be inherently invaluable by many people, providing a source of intrinsic pleasure. As a natural public resource, the management of fisheries has been entrusted to governmental authorities and thus should be protected on behalf of current and future generations who seek to enjoy and use them.

1.1.4 Effects Assessment and Cumulative Effects

Standardized and consistent monitoring facilitates the comparison of project impacts predicted in the EIAs against actual project effects. These results may then be used to identify, minimize, and mitigate potential impacts of similar projects in the future. Such monitoring also allows for the consideration of project effects in concert with other existing or future projects at a regional scale. This analysis is referred to as cumulative effects assessment. Consequently, there may be a requirement that monitoring results are publically accessible, in order to facilitate regional analyses of cumulative effects.

It is important to define cumulative effects to minimize ambiguity surrounding the term. The Canadian Environmental Agency defines cumulative effects as:

> "The effect on the environment which results from effects of a project when combined with those of other past, existing, and imminent projects and activities. These may occur over a certain period of time and distance."

Thus, a cumulative effects assessment (CEA) should consider any potential impacts to fish habitat that are likely to result from the residual environmental effects of multiple hydropower projects, in combination with the effects of other projects that have been or are likely to be carried out[1]. The CEA methodology is based on the framework outlined by the *Canadian Environmental Assessment Act* (CEAA) guidelines (Hegmann *et al.* 1999). The following actions are taken during a CEA:

- Identification of residual environment effects of the Project;
- Identification of spatial and temporal boundaries appropriate for addressing cumulative effects;
- Identification of past, present, and reasonably foreseeable future projects for inclusion in the CEA;

[1] Future projects are considered only if they will be carried out as defined by CEAA, which is normally taken to mean projects and activities for which regulatory approval has been granted or will be sought.

- Analysis to characterize potential interactions between residual environment effects of the hydropower projects identified in the AEA and likely effects of other projects that have been or will be carried out;
- Identification of mitigation measures to avoid and/or reduce identified cumulative environmental effects;
- Characterization of residual cumulative environmental effects using magnitude, geographical extent, duration, frequency, reversibility and context; and,
- Determination of the significance of residual cumulative environmental effects and the likelihood of any predicted significant adverse residual cumulative environmental effects; determination made by comparing cumulative residual effects against thresholds and/or land use objectives.

Any project that is proposed for a stream or watershed with other licensed users must consider the cumulative effects of water withdrawal. The CEA is important as the individual environmental effect of one project may be significantly less than the cumulative environmental effect of multiple hydroelectric projects on the same river. For instance, there may be cumulative effects when a cluster of projects situated in the same watershed share ecological habitat, general access, forest service roads, transmission lines, transformer, control and protection circuitry, and construction facilities such as docks and staging areas. The impacts from each individual project (e.g. increased erosion and sediment loading, rapid flow fluctuations, decreased riparian vegetation, etc.) may be considered insignificant with mitigation, but the cumulative effects of a cluster of projects may produce an overall significant adverse effect to fish and fish habitat.

Cumulative effects can affect Valued Ecosystem Components (VECs) such as water quality, fish and fish habitat, and fish species in a number of ways. Water quality may be affected through cumulative changes to water temperature, suspended sediments, and/or overall water chemistry. Even if the effects of a single hydro project are minimal and largely mitigated though best practices, the cumulative effects of multiple projects have the potential to produce a significant residual effect. For example, sediment loadings may be negligible from an individual project, but significant when the effect of a cluster of projects is combined. Another example is flow ramping, where residual effects associated with ramping rates of a single project may not significantly impact fish but flow ramping from additional projects in the same watershed may collectively have significant adverse effects on the fish community.

Cumulative effects may adversely affect fish habitat such as rearing and overwintering, spawning and incubation, migratory, riparian, and macroinvertebrate habitat, and the effects may be transmitted to fish and fish habitat through a variety of pathways. As one example, a range of cumulative effects may arise from the removal of riparian vegetation as it protects water quality, stabilizes stream banks, regulates stream temperatures, provides cover, and is a source of food organisms and nutrients for fish (Chilibeck *et al.* 1993). Fish species may also be impacted as a result of the cumulative effects produced by a cluster of hydroelectric projects. Generally, cumulative effects that may result from project activities are measured based on their potential to impact fish life-stages, distribution, abundance, and/or growth rates.

In a national review of CEA across Canada, the existing level of follow-up monitoring was identified as a key shortcoming because even the best analysis of cumulative effects is useless without follow-up monitoring and subsequent mitigative action as required (Duinker and Greig 2006). The adoption of standardized monitoring protocols will greatly improve the ability to assess, compare and manage cumulative effects on a regional scale. Methods for analyzing cumulative effects and corresponding measures to mitigate them are described in Hegmann *et al.* (1999). This document should be referred to for further consideration and details pertaining to CEA.

1.1.5 Adaptive Management

Monitoring provides an opportunity for adaptive management (AM) in the operation of the project, whereby DFO may consider adjustments to project mitigations such as minimum flow requirements or ramping rates, levels of habitat compensation, or the design and effort of the monitoring program. The use of AM implies that managers and practitioners recognize that for projects where uncertainty about potential effects is high, management objectives may be more quickly and surely achieved by modifying operations in response to monitoring information.

Science based AM operates on the following premises (PRRIP 2006):

- Uncertainty exists in a managed system, and reduction of uncertainty can improve management;
- Uncertainty can be reduced through adaptive management but can never be eliminated;
- Management decisions must be made despite the uncertainty;
- Long-term monitoring and research programs are established in order to evaluate management decisions and to continually improve the knowledge on which these decisions should be based; and
- Learning about the effects of management will hasten improvement of management decisions in the future, resulting in more rapid and cost-effective attainment of management objectives.

AM first acknowledges uncertainty[2] by improving the understanding of management-ecosystem interactions during project operation and then addresses uncertainty by integrating learning into management activities. For new and upgraded hydro projects, the AM cycle can be applied to improve the understanding of the effects of ramping rates and minimum flows on fish habitat by changing operations in response to learning within the monitoring cycle. Response monitoring is proposed here as a mechanism for incorporating this type of learning into project operations (see Section 2.3).

For AM to be effective, monitoring indicators must be sensitive to anticipated environmental change. This document specifies the potential indicator and specifies the appropriate methods and the intensity of measurement required to detect effects within a monitoring framework. Sensitive indicators can be used to guide decisions during operation by defining thresholds[3] (e.g., exceeding a temperature criterion) and specifying conditional management actions (e.g., release of additional flow).

1.2 TYPES OF HYDROELECTRIC PROJECTS

Hydroelectric projects can be grouped into different types based on physical layout and the mode of operation. Each project type poses common potential impacts to the environment, with some types posing additional potential impacts. Different project types may require different monitoring methods, though the specific monitoring components are mostly common to all projects. The monitoring components recommended here have been organized in two sections: those applied on streams (both creeks and rivers) and those applied on lakes and reservoirs. The term stream-based is used here to refer to typical run-of-river projects lacking a lake intake or reservoir. Note however, that run-of-river projects can have a reservoir or an intake on a lake.

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[2] The use of the term ‘uncertainty’ in this document is consistent with the following definition: *“uncertainty is the situation in which the information that describes a problem under study is deficient or becomes impossible to describe in future settings due to more than one possible outcome*.” (Medema et al. 2008).

[3] A threshold can be broadly defined as a breakpoint between two states of a system. In AM, exceedance of negative thresholds that indicate undesirable system development is a particularly important part of the monitoring process (Sullivan et al. 2010).

All projects have an intake structure (gallery, weir, or dam) that entrains flow, a conveyance structure (penstock, tunnel, or canal) that delivers water downstream, a powerhouse where electricity is generated (surface or underground), and a tailrace (pipe or open channel) that conveys water from the powerhouse back to the stream channel. For environmental assessment and monitoring purposes, hydroelectric projects are divided into upstream, diversion, and downstream sections (Lewis *et al.* 2004). The term section is used to identify the proximity of one or more stream reaches relative to the project intake and powerhouse. An example of typical project layouts showing the location of each section is provided in Figure 2.

The project intake is the point of diversion (POD) on the stream. Intake structures range from a pipe into an existing lake or pond, a gallery on the riverbank with no cross-channel structure, a low head diversion weir[4] across the channel, or a dam that impounds substantial quantities of water. Intakes on streams may cause no measureable increase on the water level upstream (in the case of a pipe or gallery intake), may backwater the channel upstream as a headpond but only within the existing high water perimeter (in the case of a diversion weir), or may backwater beyond the high water mark and inundate riparian habitats (larger diversion weirs and dams). The differences in the potential impacts of each structure are dramatic, and must be considered when environmental monitoring programs are designed. For example, a low head diversion weir will have a high rate of turnover (hourly) and will not alter stream temperature or chemistry in a measureable or significant manner. In contrast, a major dam may substantially increase thermal loading, stratifying the water body and in turn altering water temperatures and chemical processes. This may lead to significant changes in downstream water quality, among other potential effects. Accordingly, the monitoring of a project with a storage reservoir would include water quality monitoring of the reservoir upstream of the dam, as well as in both the upstream and downstream stream sections. In contrast, a low head weir would require water quality monitoring in the upstream and downstream sections, but not necessarily upstream of the weir in the headpond.

The operating mode of hydroelectric projects determines the location and significance of impacts and may influence the type and magnitude of monitoring required. Run-of-river projects by definition do not substantially alter the magnitude or timing of stream flow (except within the diversion reach), maintaining natural flow patterns and changes in water surface elevation upstream of the POD and downstream from the tailrace. Storage projects generally alter both the magnitude and timing of stream flow throughout the affected portion of the stream, holding water back in a headpond, reservoir, or lake reservoir, and releasing it in unnatural patterns downstream from the POD.

The temporal pattern of the storage and release of water can have significant consequences for the environment. Short term (daily or less) storage allows hydropeaking operations (i.e. generate electricity in response to daily demand) that may not alter mean daily flows but that may drastically change the flow magnitude and ramping rate within a day, with consequences to fish and habitat. Natural flow changes are usually relatively slow compared to those induced by hydroelectric operational changes, particularly during low flow periods. Following a flood, natural river flow usually declines slowly over time, in contrast to changes induced by hydro projects, which can be drastic regardless of flow stage. Environment Canada's Environmental Choice[M] Program (ECP) national certification criteria (Electricity - Renewable Low-impact) include projects that "as a maximum, causes as much water to flow out of the headpond as is received in any 48-hour period". However, this does not mean that unbridled flow changes within a 48-hour period are acceptable. Indeed, controls on the rate of flow change are critical to avoid impacts to aquatic habitat.

[4] A weir is a type of small overflow dam used to create a headpond for water abstraction purposes. A widely accepted definition of a large dam is given by the International Commission on Large Dams (ICOLD) as a dam 'having a height of 15 meters from the foundation or, if the height is between 5 to 15 meters, having a reservoir capacity of more than 3 million cubic meters'.

Seasonal storage projects store water during periods of naturally high flows, releasing this water during low flow seasons. Storage projects pose major effects, both positive and negative, to the downstream environment and can affect the upstream environment by altering water levels on a seasonal basis when reservoirs are drawn down. Seasonal storage projects warrant extensive study of downstream and upstream effects and will invariably increase both the number of monitoring components required and the intensity of sampling within each component. While run-of-river projects typically have fewer effects upstream and downstream of the project, significant impacts can nevertheless occur in the diversion reach depending on the magnitude and timing of flows remaining in the stream channel.

Different combinations of project type and operating mode pose different potential impacts to the environment, which in turn require different combinations of components within monitoring programs. To generalize, run-of-river projects with low head weirs will require the fewest components and storage projects with large dams will require the most. However, the number of monitoring components and the magnitude of sampling effort will vary with the specific project layout, environmental characteristics, and the type and importance of the biota present. Proponents are advised that storage projects have the potential to cause complex impacts that will require more intensive monitoring.

1.3 LINKAGE TO ENVIRONMENTAL ASSESSMENT

Water withdrawal and regulation has the potential to create a wide variety of direct and indirect impacts on fish habitat. Changes in water flow affect physical habitat, which in turn can impact fish growth, survival, and reproductive success, as well as food supply. The most significant effects can be expected through well-known pathways described in the literature on the effects of hydroelectric projects. To quantify effects resulting from alteration in river flows (magnitude, frequency, duration, timing, and rate of change), detailed analysis will be required on most streams through an environmental assessment, supported by baseline studies and predictive analysis. Through the assessment process, valued ecosystem components (VECs) relevant to fish and fish habitat will be identified, impact hypotheses constructed, and potential effects quantified. This in turn will guide the selection of parameters for inclusion in the monitoring program.

A linkage diagram is an effective way to relate project actions to physical habitat changes and describe potential impact pathways. A linkage diagram identifies the potential hypothesized effect inferred by the pathway and facilitates the design of both the effects assessment and monitoring program. Understanding these pathways during the environmental assessment helps identify which physical and biological variables are appropriate for monitoring. By clearly specifying potential effects through the linkage diagram, decisions about which components to include and exclude from the monitoring program can be justified and documented. Where potential effects are identified, mitigation and/or compensation will be specified to avoid or offset these effects, and necessary monitoring parameters may be identified to assess the efficacy of mitigation and compensation. Additional guidance on the selection of monitoring parameters and a rationale for their inclusion in a monitoring program are provided in Section 3.

Professionals experienced in the assessment of the effects of hydro projects will identify the likely impacts of a particular project and design a monitoring program that can effectively monitor these effects. As a starting point, Lewis *et al.* 2004 summarized and organized typical impacts relevant to hydro projects in BC and the Yukon that arise from water withdrawal by issue. Literature of the effects of hydro projects provides additional explanation on potential mechanisms of effect, and professionals are advised to keep abreast of the latest published information on these potential effects. A linkage diagram that relates project actions to physical habitat changes will serve to describe potential impact pathways, clearly identifying the potential hypothesized effect inferred by the pathway, and facilitating the design of both the effects assessment and monitoring program. Understanding these pathways during the environmental assessment helps identify which physical and biological variables are appropriate for monitoring. By clearly specifying potential effects through the linkage diagram, decisions about which components to include and exclude from the monitoring program can be explained, justified, and documented.

Impacts from hydroelectric projects can be grouped into two types, operational and footprint. Footprint impacts are permanent impacts associated with project structures that persist continuously until project decommissioning. The riparian and aquatic habitat area flooded behind an intake weir is a footprint impact, as is the riparian and aquatic habitat area occupied at the intake structure and tailrace. Operational impacts are not associated with a project structure, and in theory could be altered during the life of the project by adjusting project control settings. Operational impacts can arise downstream of the intake in the diversion reach and downstream of the powerhouse in the downstream reach.

There is not always a clear-cut distinction between footprint and operational impacts, leading to confusion over which impacts will persist for the life of the project, and which impacts can be readily modified. If an impact can only be avoided by changing the physical structure of a project, it is considered to be a footprint impact. For example, the extent of backwatering by a diversion weir cannot be modified in a substantive way by a change in operation, i.e. the lowering of the headpond level, because that would dewater the intake and prevent project operation. Accordingly, backwatering by a diversion weir is considered a footprint impact. On the other hand, the extent of dewatering downstream of the diversion weir can be ameliorated by increasing the instream flow release, while still allowing the project to operate, albeit with less power generation.

The distinction between footprint and operating impacts is important from a monitoring perspective, since footprint impact monitoring is typically limited to one-time measurement of the affected area (e.g. the areas of riparian clearing and area of aquatic habitat occupied by the diversion weir), whereas operational impacts often require continuous or annual monitoring for several years. The program components identified here address both operational and footprint impacts.

1.4 MONITORING DESIGN

There are several designs available for environmental monitoring programs. Simple before-after (BA) comparisons suffer from the confounding effects of temporal changes in climate and biological variables that may affect the project site independently of project activities. The before-after control-impact (BACI) experimental design addresses this problem by simultaneous monitoring at both the project (‘impact’) and ‘control’ sites (i.e., similar streams sections and/or lakes unaffected by hydroelectric or other water withdrawal projects) for a pre-determined period, both before and after project development. The BACI design accounts for possible environmental variability that affects both the project and the control sites similarly and is therefore the recommended approach for monitoring change in aquatic habitats (Pearson *et al.* 2005).

In the case of run of river projects, control reaches are often located upstream of the diversion reach. This may create a systematic bias because these areas typically are higher elevation, lower flow, lower gradient, more confined, colder, and are less likely to support fish. As a result, apparent differences detected between the impact and treatment sites may have little to do with project effects but may rather reflect covariance in natural differences between reaches. To offset this weakness, monitoring parameters such as temperature, water quality, and invertebrate abundance can be incorporated into the study design to tease out their effect from project-related effects. As Weins and Parker (1995) explain, the inclusion of natural factors in the analysis is a post-facto way of attaining the randomization inherent to traditional experimental design. Measuring natural factors and the response variable simultaneously can quantify natural differences between impact and reference areas. The use of covariates tends to reduce variance and increase the power of tests, but does reduce effective sample size by affecting the degrees of freedom in the analysis.

Successful experimentation design relies on replication. In a BACI design, ‘replicate’ sites are established in the control and treatment reaches. However, the multiple sites sampled within each reach are not independent because upstream conditions influence downstream sites, including the level of effect from flow regulation. This bias is called pseudoreplication (Hurlbert 1984, Stewart-Oaten *et al.* 1986) and the cause is spatial and temporal correlation among sites within the reaches. The effect of pseudoreplication is to bias the estimate of error in estimates of monitoring parameters, possibly to the point that inferential statistics may be unreliable. As in the assessment of unplanned impacts, some level of pseudoreplication is inevitable (Weins and Parker 1995), requiring that the experimental design include strategies to deal with the non-independence among samples. Part of the strategy may be to limit the interpretation of data strictly to the project site and not generalize monitoring results beyond the project-scale.

Differences within a reach in the extent of flow regulation may be correlated with effect, particularly where local inflow varies greatly within a reach. Spatial differences in the magnitude of effect have been used to infer the effects of flow regulation from storage dams on Chinook salmon (Bradford 1994) and the effects of stranding and winter mortality in Atlantic salmon (Ugedal *et al.* 2008). Spatial trends in effect may be detectable in long diversion reaches with significant local inflow. Such systems may provide a passive opportunity to compare the effects of flow, by contrasting effects between years with widely different inflow. Another strategy is to actively vary the level of effect, which allows greater precision in effect measurement and can detect nonlinearity responses. Adaptive management with experimental manipulation of instream flow is a preferred experimental design for assessing the effects of flow alteration and has been used to contrast the effects of small changes in instream flow (Bradford *et al.* 2011). Some projects may afford the opportunity to vary instream flows by year to test the effects regulation.

It is not always possible to obtain two years of baseline data, and the variance between the years may be so great as to limit their utility in a BACI design. Alternate approaches are available, and although not ideal from a theoretical perspective, may in some circumstances yield more definitive results. The before-after design (BA) is one alternative, as is the trend-by-time design described by Wiens and Parker (1995), which requires no baseline data and relies on comparisons of trends in impacted and control habitats. The Reference Condition Approach (RCA) is another design alternative that has grown in popularity in recent years. A brief overview of RCA and its potential application to hydroelectric projects are briefly described here. Refer to Bailey *et al.* (2004) and Environment Canada's CABIN (Canadian Aquatic Biomonitoring Network) program website (http://www.ec.gc.ca/rcba-cabin/Default.asp?lang=En&n=72AD8D96-1) for further information.

The RCA is based on characterizing and grouping undisturbed reference sites over a wide range of natural environmental variation, developing a predictive model that relates the habitat attributes of these sites to their biotic community, and then predicting the expected community assemblage for a particular project site ('test site') in reference condition (Bailey *et al.* 2004). Comparing the predicted community to actual community composition assesses if, and to what extent, the test site is disturbed and not in reference condition. Most RCA models are developed for streams and use benthic macroinvertebrates as indicators of habitat and water quality; however, periphyton (Mazor *et al.* 2006) and fish (Chessman *et al.* 2008) have also been used. Key requirements for applying the RCA design are: sampling at an adequate number of reference sites to fully characterize natural environmental variation, sampling a biotic community that is sensitive to site-scale environmental conditions, and the use of consistent data sampling methods for test sites and reference sites. Environment Canada's CABIN (Canadian Aquatic Biomonitoring Network, http://www.ec.gc.ca/rcba-cabin/Default.asp?lang=En&n=72AD8D96-1) program has national standards for RCA sampling.

1.5 BASELINE DATA REQUIREMENTS

The basis of any effective monitoring program is a reliable baseline data set against which to monitor and compare future conditions. The environmental baseline data collected for the EIA provides the information necessary to predict the environmental impacts of the project, as well as providing the necessary baseline data for long-term monitoring. The baseline characterization of the environment should typically be implemented during the first year of the EIA, using the methods identified here, which are consistent with the methods described in Hatfield *et al.* (2007). However, in general, two years of data should be collected pre-construction (baseline data). After construction, monitoring should continue for several years with the same methods, sites and timing of sampling. The EIA and monitoring programs are thus integrated and consistent, providing more efficient, comparable, and thus more statistically powerful assessment.

Projects with complex environmental issues or highly valuable habitats may require more years of baseline characterization. Streams that support anadromous species, highly valued sport fish or a complex fish assemblage, may need to be monitored for one life-cycle of the anadromous species present, and/or sufficient time to gain a thorough understanding of migration into and out of the project reach. Potamodromy – migration solely within freshwater – is a common life-history trait in the family Salmonidae (Northcote 1997), and other fish families (Lucas and Baras 2001). Understanding how habitat within the project reach supports the existing fish population, both spatially and temporally, is necessary to predict, mitigate and monitor project impacts.

For environmental assessment and monitoring purposes, aquatic systems with hydroelectric projects are divided into upstream, diversion, and downstream sections (Lewis *et al.* 2004). The term section is used to identify the proximity of one or more stream reaches relative to the project intake and powerhouse. An example of typical project layouts showing the location of each section is provided in Figure 2. Monitoring sites should be located in at least two of these sections, and possibly all three.

Where project effects are predicted upstream of the intake weir from backwatering by the headpond, monitoring of these effects should be carried out depending on their predicted magnitude. Although there are no generally accepted rules of thumb for estimating what magnitude of effect warrants monitoring, we recommend more than one year of monitoring bedload accumulation (Section 3.1.5) where infilling of the headpond is expected. If fish are present in the upstream reach, habitat monitoring will be required of the backwatered headpond to assess if habitat conditions have changed significantly from pre-project conditions in the diversion and upstream reaches. Because there are no standards that define what a significant change may be, we recommend comparing the dimension of the predicted headpond to natural pools within the reach. The contrast in pre-project width, length, volume, and spacing of typical habitat types may inform a decision on whether the headpond will represent a locally significant habitat feature. In steep channels the spacing of steps and pools is, on average, two to three times the channel width (Charlton 2008), whereas riffle-pool sequences in gravel-bed channels have spacing of five to seven times the channel width (Keller and Melhorn 1978). Thus, headponds greater than seven times the channel width may be viewed as disrupting the typical pattern of habitat types, which may warrant further monitoring to determine the effects that this has on the availability and suitability of fish habitat and subsequently fish use.

The BACI design is effective when there is a strong correlation in natural conditions across the control and impact sites. Accordingly, establishing these sites in different sections in the same stream is preferred, provided that the fish species and life stages of interest inhabit both control and impact sections. For run-of-river hydroelectric projects with stream intakes, it is recommended that control sites be selected upstream of the intake and headpond to avoid the confounding influence of backwatering, while impact sites be located within the diversion section. However, the selection of a control site is not straightforward because of differences in natural factors between stream reaches, which may influence the results of monitoring.

Where upstream sections may themselves be affected by development (e.g., impacts to fish migration), or where they differ significantly from proposed diversion sections, either biologically (e.g., different fish species present), or morphologically (e.g., upstream section consists of two small, steep tributaries whereas the diversion section is a single larger channel), control sites may be located in a nearby stream that shares similar biological and morphological characteristics. The BACI design will be weaker in this case if variation in natural conditions over time is not similar for the control and impact streams. In some cases where no single section provides an appropriate control, either the before-after design or alternatives may be required. In the event that multiple hydroelectric projects are developed in close proximity to one another, an among-streams monitoring program should be designed. A multi-project comparison provides greater power to the monitoring program to detect real impacts, especially if the streams host similar hydrological, topographic, and biotic conditions.

For projects based at the outlet of a lake, it is also beneficial to identify a control lake to ensure that observed changes are not incorrectly attributed to project impacts. The control lake will ideally be in the same watershed and share similar physical and biological characteristics, such as area, average depth, trophic level, and fish community composition. In terms of size, we suggest a control lake with an area and average depth ±50% of that recorded in the impact lake be considered a suitable control. If no suitable control lake exists, and for those projects in which a new reservoir will be created, a before-after (BA) monitoring methodology will be required. In these circumstances, sampling will be required to determine if observed effects are a result of project or environmental influences. This should include the monitoring the water quality of lake/reservoir inflows, natural factors that will influence post-project conditions and could confound monitoring results.

Where applicable, details on the baseline data requirements for each of the parameters to be monitored are included in the relevant sections below. These requirements are based on the adoption of the BACI approach; however, as noted above, there may be cases where the BACI approach is not the most appropriate design and alternatives such as BA or RCA are more suitable. Baseline and long-term data requirements in these instances will vary by parameter, the amount of natural variability in the parameter being measured, and the magnitude of change (i.e., effect size) that the monitoring program aims to detect (see Section 2.3).

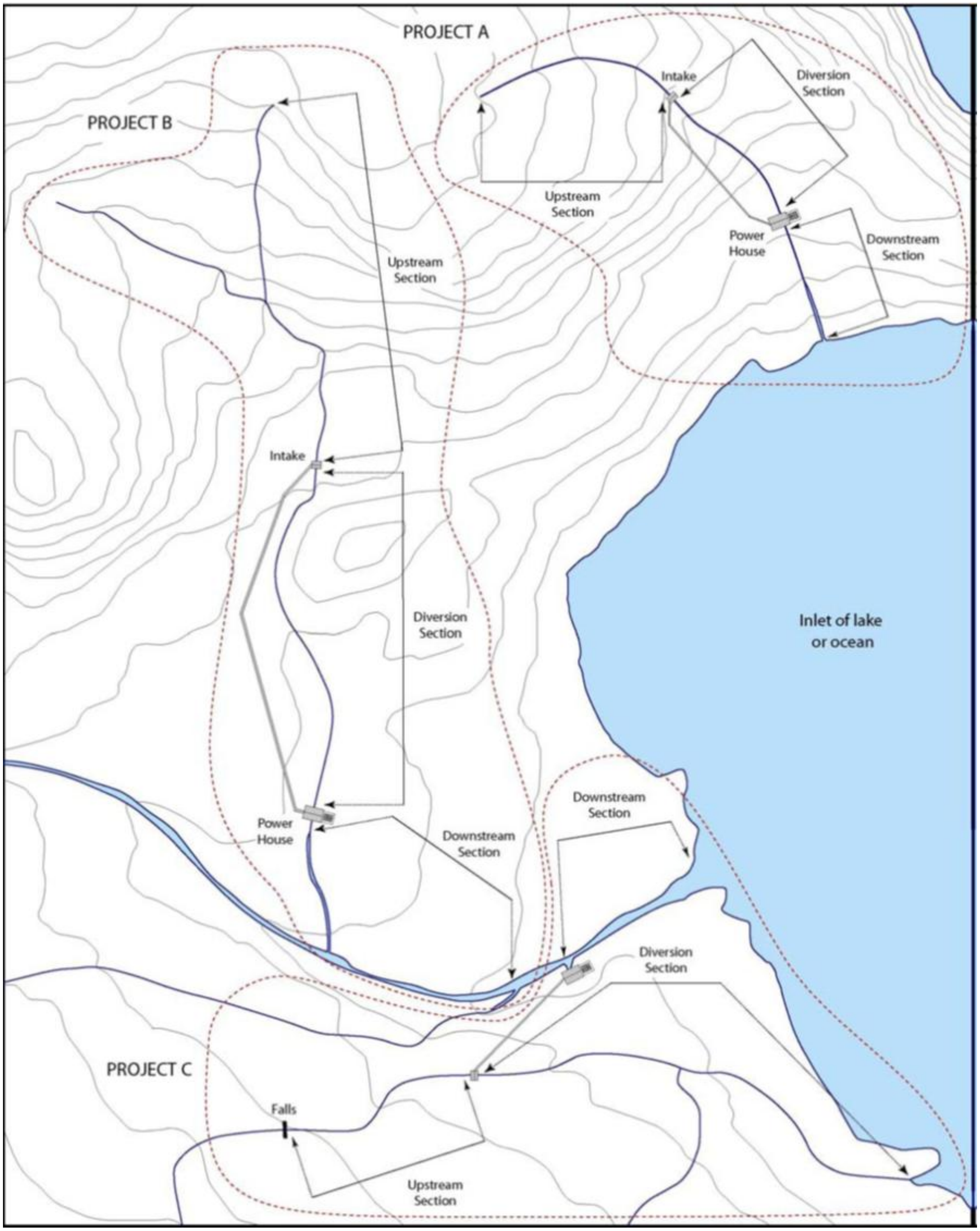

Figure 2.Examples of upstream, diversion, and downstream sections for three hypothetical hydroelectric projects (taken from Lewis et al. *2004).*

1.6 PROFESSIONAL REQUIREMENTS

Monitoring data will be used to assess compliance with provincial water licences, *Fisheries Act* Authorizations and other provincial and federal regulations, as well as to evaluate the effectiveness of these regulations to ensure no net loss in the productive capacity of fish habitat. Accordingly, the design and execution of a monitoring program must be stamped and signed off by a certified professional with appropriate experience (e.g. R.P.Bio.).

Environmental impact monitoring is a specialized field, requiring the collection, analysis, interpretation and reporting of specific physical and biological information. The expectation is that studies will be undertaken as described in the relevant inventory and assessment standards that have been developed. These standards are referenced in this document and their use is recommended wherever applicable. The adoption of alternative methods must be supported by a scientifically defensible argument, with references to peer-reviewed literature that justify the decision.

Professionals must consider a host of constraints when designing sampling programs, including data quality, time and access constraints, and safety concerns. Professionals are expected to make best efforts to obtain the necessary monitoring data, consistent with the ethical standards of their respective regulating bodies[5]. Steep, confined stream channels where run-of-river hydroelectric projects are typically situated can be difficult, costly, and dangerous to access. Although kayaks and rock climbing techniques have been used to access steep canyons, the value of the information collected from such habitats may be minimally superior to that obtained from sampling in adjacent, more accessible habitats. Furthermore, inferring habitat values and potential impacts from adjacent, more accessible sections is likely to be conservative in favour of fish, given that accessible sections usually provide lower gradient and less confined channels with higher quality habitat. Given this, the risks of sampling severe habitats may not be warranted if valid and conservative inferences can be made from nearby habitats.

2 TYPES OF MONITORING

The mandate of DFO's Fish Habitat Management Program is to conserve and protect fish habitat with a view to ensuring the sustainability of Canada's marine and freshwater fisheries resources. As part of the Habitat Management Program, the Habitat Compliance and Monitoring Framework outlines the requirements for monitoring and how results are used to evaluate, modify and improve Program delivery. Three types of monitoring are detailed in the Habitat Compliance and Monitoring Framework:

- **Compliance**: verifying compliance with the habitat protection provisions of the *Fisheries Act*;
- **Effectiveness**: evaluating the effectiveness of regulatory and non-regulatory activities undertaken to conserve and protect fish habitat; and
- **Fish Habitat Health (Response)**: monitoring trends in the quantity and quality of fish habitat.

The structure and types of monitoring required are the same for hydroelectric projects. However, within this document, fish habitat health monitoring is referred to as response monitoring to highlight that monitoring is designed to evaluate the response in fish habitat parameters to a particular development, rather than the general health of fish habitat in a particular region.

Monitoring is important and justifiable for many reasons. In particular, by tracking a given project's actual impacts, monitoring reduces the environmental risks associated with that project, and accordingly allows for project modifications to be made where required. In addition to the three types of

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[5] The College of Applied Biology code of ethics (section 2i) states "In order to maintain professional integrity, the member will not allow his/her professional judgement to be influenced by non-biological considerations."

monitoring outlined in sections 2.1-2.3, monitoring provides data and information that is utilized for a wide range of purposes, such as:

- To establish long term trends in natural unperturbed systems;
- To evaluate measured conditions against a standard or guideline level;
- To detect and evaluate any adverse effects to VECs (e.g. fish species, fish habitat, water quality) at different phases of a project (e.g. pre-development, construction, operation; etc.);
- To perform spatial and temporal analyses of any detected changes and identify relationships;
- To estimate variation that is inherent within a system and to compare estimations with variation observed in other areas.

Overall, the three types of monitoring proposed here can collectively establish (i.) key indicators by which regulatory agencies can measure compliance, (ii.) tools that can be utilized to evaluate the relative success of mitigation and compensation measures designed to minimize or offset environmental impacts, and (iii.) a mechanism for improving the management of the project and similar projects through the evaluation of project effects and the integration of corporate learning.

Figure 3 provides a simplified illustration of the major differences between the three types of monitoring and how they are generally used over the life of a project. Compliance and effectiveness monitoring data are used by DFO staff to evaluate if predictions of the EIA and conditions of the *Fisheries Act* Authorization have been met. Response data are used by DFO staff over the longer term to build corporate knowledge and inform decisions around the review of future projects.

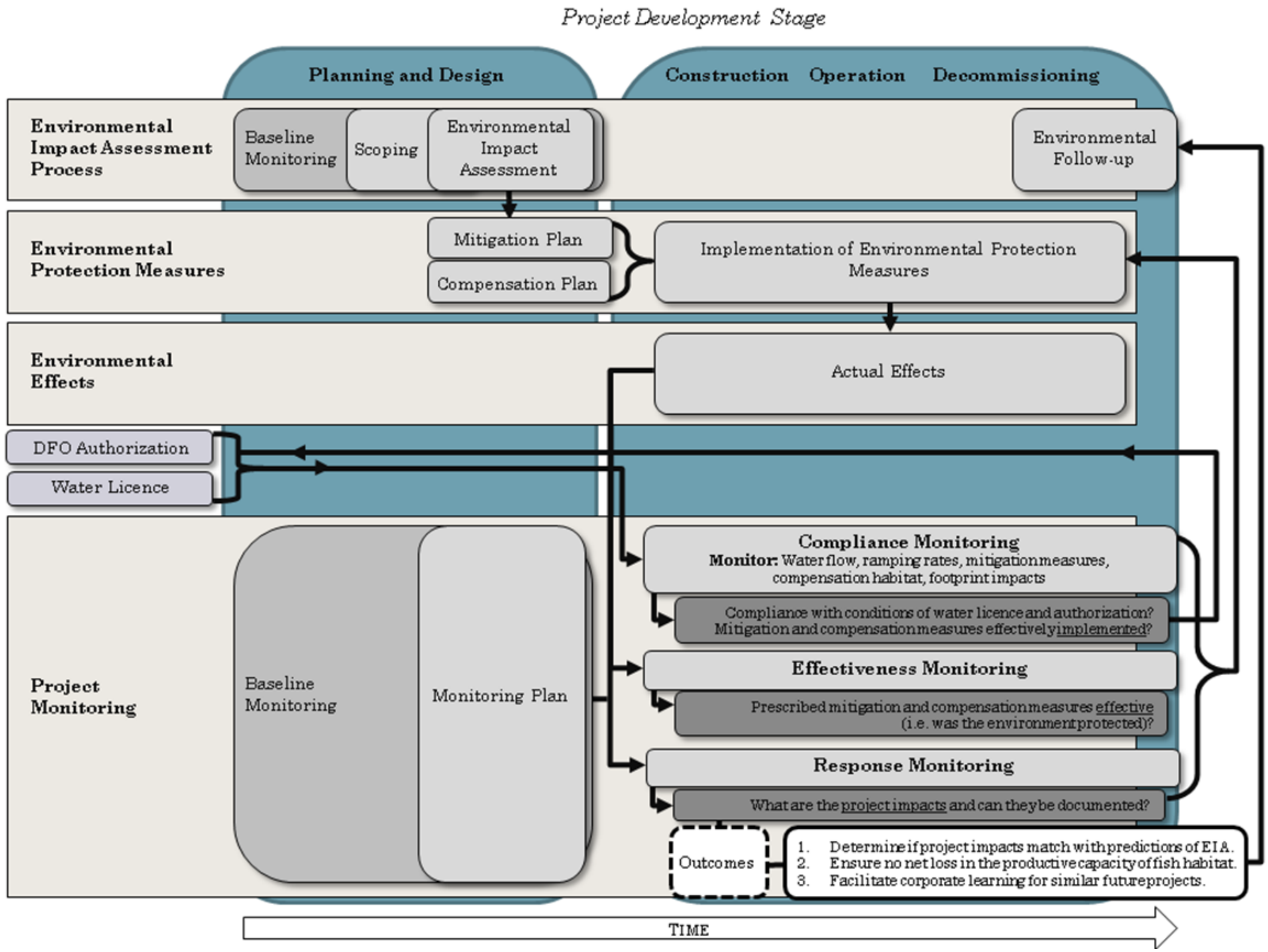

Figure 3.Simplified overview of project development and selected types of monitoring (modified from Everitt 1992).

2.1 COMPLIANCE MONITORING

The objective of compliance monitoring is to evaluate whether the project is complying with the conditions of its water licence and *Fisheries Act* Authorization. The following project components will be monitored for compliance: water flow, ramping rates, mitigation measures, compensation habitat, and footprint impacts.

To ensure consistency and standardization across regions when assessing compliance with Authorizations, letters of advice or operational statements and to aid in tracking information, DFO employs the Program Activity Tracking for Habitat (PATH) system. This computer based tracking system includes a Compliance Monitoring Form that is completed by DFO staff during a site visit, with the information then entered into the system for tracking, storage and analysis purposes. One section of the Compliance Monitoring Form consists of a series of questions, which when assessing compliance with an Authorization are as follows:

- Is the work/undertaking completed as proposed?
- Was the HADD as described in the Authorization?
- Other than the HADD, were the impacts to fish and fish habitat as described in the Authorization?
- Did the proponent conform to the mitigation measures contained in the Authorization?
- Were the mitigation measures effective in preventing impacts to fish and fish habitat?
- Are (or were) there remedial measures or mitigation measures required that are (or were) not in the Authorization?
- If required, were the remedial measures or mitigation measures implemented and/or conformed with?
- Were the compensation requirements implemented as described?
- Is the compensation on the same site?

Similar questions regarding the conformity to requirements, and the use and effectiveness of mitigation measures, are posed when assessing compliance with letters of advice or operational statements. Information on required actions, the need for ongoing compliance monitoring, and dates for future site visits are also entered into the PATH system.

Further guidance on compliance monitoring undertaken by Fisheries and Oceans Canada can be found in the Habitat Compliance Decision Framework (DFO 2007).

2.2 EFFECTIVENESS MONITORING

Effectiveness monitoring evaluates the success of prescribed mitigation and compensation measures stipulated in the EIA and/or *Fisheries Act* Authorization to minimize or offset environmental impacts. Mitigation measures are adopted to avoid or minimize the negative impacts of project construction and operation. In contrast, compensation refers to the intentional activities undertaken to offset unavoidable project impacts. Compensation offsets negative impacts by providing benefits at the impacted site, or as nearby as possible, thus ensuring the no net loss of fish habitat productive capacity.

Mitigation and compensation measures will therefore be monitored for two reasons: a) to ensure compliance with conditions set forth in the water licence and *Fisheries Act* Authorization, and b) to evaluate the effectiveness of the measures in minimizing, mitigating and compensating for project impacts.

2.3 RESPONSE MONITORING

Response monitoring is the repeated and systematic measurement of environmental parameters to test specific hypotheses about project effects on the environment (LGL Ltd. *et al.* 1984). **The objective of response monitoring is to establish empirical links between project development and operation and any impacts on fish and fish habitat**. The outcomes of response monitoring are three-fold: first, to determine if project impacts match with predictions stated in the EIA under the *Canadian Environmental Assessment Act* (CEAA) (S.C. 1992, c. 37) and the *Fisheries Act* Authorization; second, to monitor and manage project effects to ensure that there is no net loss in the productive capacity of fish habitat; and third, to facilitate corporate learning for similar future projects. This type of monitoring therefore plays a critical role in identifying impacts and allowing adaptive management of projects to address these effects.

The criteria for an effective response monitoring program using the BACI approach include the following key elements: a) measurable objectives, b) replication, c) pre-impact information, and d) control sites (Pearson *et al.* 2005). The first three of these elements are also critical when employing a BA monitoring design. Response monitoring programs typically collect data on environmental indicators, which reflect environmental values that are to be protected (Suter 1990). These valued environmental components (VECs) are selected based on legal, political, economic, and ecological relevance, as well as sensitivity to human activity.

These protocols outline the methods required for measuring responses to parameters most likely to be affected by hydroelectric projects. These include physical parameters, such as water quality, water temperature, fish habitat, and stream morphology; as well as biotic parameters relating to the invertebrate, fish and wildlife communities present. Details on the metrics to be studied are provided in the relevant sections below and include: description of the fish species and life-history stages present, the timing of significant migrations, measures of fish abundance, density and biomass, as well as condition factor and size-at-age relationships. Similar metrics describing the abundance, diversity and community structure of invertebrate and wildlife populations are also required. This portion of the monitoring program therefore addresses the complexity of physical and biological responses to changes in flow and habitat.

As outlined in Section 1.4, the BACI approach is proposed as the standard monitoring design to be employed on most projects, with the BA and RCA approaches available as alternatives in cases where the BACI design is not appropriate. Regardless of the approach adopted, effective response monitoring requires sound experimental design, including a sufficient number of monitoring sites and replicates. For decades, power analysis has been recommended to predict the sample size needed to detect biologically significant effects (Peterman 1990); however, a recent literature review on fish responses to regulated flow found that only 2% of studies used power analyses either *a priori* or *post hoc*. Biologically relevant phenomena will go undetected by statistical tests when sample sizes are too small (Murchie *et al.* 2008), thus a minimum level of effort is essential in monitoring studies. Sample sizes are suggested in the following sections based on the adoption of the BACI approach and a power analysis assuming the following: coefficient of variation in samples = 50%, alpha = 0.05, power = 0.8, effect size = 50% (Hatfield *et al.* 2007). The number of sites, sampling frequency per year, and years of sampling prescribed below represent the **minimum acceptable level of effort**. Dauwalter *et al.* (2009) report an average coefficient of variation of 49% in trout populations, yet the coefficient at individual streams varied from 15% to 108%, demonstrating that more intensive sampling will be required at some streams (Pearson *et al.* 2005). The BC government's web-based power analysis tool can assist in designing and developing an appropriate sample size: (http://www.stat.sfu.ca/~cschwarz/Consulting/Babakaiff/).

In practice, proponents will prefer to follow the minimum prescribed here to avoid the cost of more extensive and higher power sampling programs. As such, the data collected through these monitoring programs will not optimize power; however, the sampling methods described below are consistent with current scientific research programs. However, despite the guidance provided here, individual practitioners will invariably execute the studies in different years and with subtle differences in methods, likely increasing variance in results. This will reduce the power of any future effort to garner insights through a meta-analysis across individual monitoring studies. Given this, the sample design suggested here is not intended to substitute for ongoing research on the aquatic impacts of changes in stream flows, nor will this design provide guidance on the extent and intensity of biological sampling required to confidently predict future impacts. However, the monitoring of individual streams will detect large impacts and increase learning by providing information across the landscape, capturing more natural variation than an intensive research study on a small number of streams could. We suggest that monitoring across all individual projects by proponents, combined with more intensive research projects on a smaller number of streams by research groups (industry bodies, government, and academia), is the best approach.

Typically, the response monitoring proposed here must be conducted with two years of baseline data and five years of post-construction monitoring to satisfy minimum statistical power requirements (Hatfield *et al.* 2007). However, more long-term monitoring is required for instream flow (life of project), as well as fish community parameters and compensation habitat (minimum of 1, 2, 3, 5 and 10 years post-construction). Other variations from this initial monitoring schedule are detailed in the relevant sections below. Further long-term monitoring of other parameters may also be required following a review of the results obtained during the first five years of operation. In the majority of cases, the *Fisheries Act* Authorization issued by DFO as part of the permitting process for a hydroelectric project will require renewal following five years of operation. The ongoing monitoring requirements should be assessed at this juncture.

To ensure monitoring is effective, sampling protocols should be standardized so that data quality and collection procedures are consistent across years. For instance, in the case of small hydroelectric projects, annual studies should be conducted at the same time of year and under a similar flow stage. It is also recommended that the sampling design target a specific stream discharge within a particular calendar period, rather than aiming solely for a particular calendar date each year.

Sampling consistent environmental conditions every year is challenging, requiring ready-to-go sampling plans, stand-by staff, and requisitioned equipment that increase the cost of monitoring. However, because environmental variation is large, it is important that sampling be timed to match the most appropriate conditions every year. Along the same lines, the timing of sampling must also consider the fish species and life-history stages present. For example, if Chinook salmon is a key species of interest and fry migrate out of the system in July, then monitoring in August will not effectively assess project impacts on this species. If some years do not afford the required environmental conditions within the specified seasonal sampling window, the program should be deferred to the following year, and the duration of the program extended by one year.

Some parameters, such as flow levels and water temperature, require ongoing, continuous monitoring through baseline, construction and operation. For those parameters that are not monitored on a continuous basis, such as water quality and fish and invertebrate populations, which are monitored once or on multiple occasions in a calendar year, the long-term monitoring program should commence three months after project commissioning and the commencement of supplying power to the provincial grid.

3 MONITORING PARAMETERS

3.1 STREAMS

Table 1 lists the parameters to be included in the monitoring program for a new or upgraded (as defined in Section 1.1) hydroelectric project sited within a stream channel (i.e. lacking a lake intake or reservoir), along with a brief indication of the baseline data required and the duration and frequency of monitoring expected. Parameters listed in Table 1 are primary parameters that must be monitored for all projects. Monitoring of additional, secondary parameters will be required for some projects, depending on effect predictions made in the EIA.

3.1.1 Water Quantity

3.1.1.1 Instream Flow

Background

The flow of water in a stream is a master environmental variable that defines and forms fish habitat and influences productive capacity. Low water flows can impact fish survival and reproductive success by increasing temperatures, lowering oxygen concentrations, and hindering spawning and migration behaviour. In general, flow modification and alteration influence the productive capacity of aquatic habitat. Hydrometric monitoring of stream discharge will measure compliance with the terms and conditions set forth in the water licence and *Fisheries Act* Authorization to protect fish and fish habitat.

Table 1. Monitoring parameters and their associated baseline data requirements, frequency and duration of monitoring for stream-based hydroelectric projects.

			Baseline Requirements		Monitoring Requirements		
Parameter[1]	**Project Component**	**Monitoring Type**	**Frequency**	**Duration**	**Frequency**	**Duration**[2]	**Reporting**[3]
Primary							
Water flow	Instream flow	Compliance/effectiveness	Continuous	Three years	Continuous	Life of project	Annually
	Ramping rates	Compliance	n/a	n/a	Once[4]	Project commissioning	Once[4]
		Compliance	n/a	n/a	Continuous	Life of project	Annually
Mitigation and compensation measures	Construction monitoring	Compliance/effectiveness	n/a	n/a	Once	Construction	Once
	Fish screens and fishways	Compliance/effectiveness	n/a	n/a	Bi-annually	Life of project	Annually
	Compensation projects	Compliance	n/a	n/a	Once	Immediately post-construction	Once
		Effectiveness	n/a	n/a	Annually	Years 1, 2, 3, 5 and 10	Annually
Riparian habitat	Footprint impact verification	Compliance	Once	One assessment	Once	Immediately post-construction	Once
		Effectiveness	n/a	n/a	Annually	Years 1 to 5	Annually
Water temperature	Overall project	Response	Continuous	Two years	Continuous	Years 1 to 5	Annually
Stream morphology	Overall project	Response	Once	One assessment	Once	After 1 in 10 year event, or year 5	Once
Fish abundance and behaviour[5]	Compensation projects	Effectiveness	n/a	n/a	Annually	Years 1, 2, 3, 5 and 10	Annually
	Overall project	Response	Annually[6]	Two years[7]	Annually[6]	Years 1, 2, 3, 5 and 10	Annually
Secondary							
Water quality	Overall project	Response	Quarterly	Two years	Bi-annually	Years 1 to 5	Annually
Invertebrate abundance	Overall project	Response	Bi-annually	Two years	Bi-annually	Years 1 to 5	Annually
Species at risk	Overall project	Response	Species-dependent[8]		Species-dependent[8]		-

1: Primary parameters must be monitored in all projects, monitoring of secondary parameters must be determined on a case-by-case basis.

2: Monitoring may be extended past the prerequisite minimum of five years following the renewal of the *Fisheries Act* Authorization or Letter of Advice (LoA).

3: Non-compliance must be reported within 24 hours and measures taken to ameliorate risk.

4: Ramping rate tests may need to be conducted more than once to capture different species and life stages.

5: It is critical that baseline studies not only provide data on how many fish are supported by the habitat, but how, both in terms of the type of habitat provided (foraging, winter refuge, spawning) and the timing of habitat use.

6: Some fish populations may require sampling of all critical life phases on an annual basis (i.e., multiple sampling periods each year).

7: More than two years of baseline data may be needed in streams that support anadromous species, high-valued sport fish or complex fish assemblages. See text for more details.

8: Baseline data and monitoring requirements for species at risk are species-dependent.

The construction and operation of hydroelectric projects will alter several aspects of the hydrograph including magnitude, duration, frequency, timing, and rate of change (Lewis *et al.* 2004). The greatest change in flow will occur within the diversion section, however, short term changes in flow downstream of the powerhouse may also lead to adverse effects on fish and fish habitat.

In addition to assessing the direct impacts that a hydroelectric project will have on fish and fish habitat because of the altered flow regime, it will be necessary to consider external sources of variability. For instance, climate change may alter hydrographs, thereby affecting the operation of a hydroelectric plant, and potentially exacerbating environmental effects. This will be particularly important in snowmelt dominated hydrographs, where climate change is predicted to result in decreases in snow accumulation, an earlier freshet, and lower summer and early autumn flow volumes (MWLAP 2002, Pike *et al.* 2010 and references therein). Effects will also be apparent in rain-dominated systems where a predicted increase in the frequency and magnitude of storm events will result in increasingly frequent and larger storm-driven stream flow in the winter, and a possible increase in the number and magnitude of low flow days in the summer (Loukas *et al.* 2002, Pike *et al.* 2010).

Baseline Data Requirements

On-site baseline flow levels should be determined by establishing a gauging station according to guidelines for hydrometric data collection (RISC 2009). Although the guidelines for impact assessment (Hatfield *et al.* 2007) require a minimum of one year of data, flow data are critical to the interpretation of changes in the other monitoring components (e.g. fish and invertebrate densities) and thus ideally a minimum of two years of baseline on-site hydrometric data should be available (Water Permitting Information Requirements, MoE 2009). Given the typical development timeline for hydroelectric facilities, three or more years of on-site hydrometric data are generally available prior to construction. The need for on-site hydrometric data is particularly important for run-of-river hydroelectric projects, which are typically located on steep streams that were found to be under-represented in the Water Survey of Canada (WSC) network in gap analyses conducted in the late-1990s (Klohn Crippen 1998, Chapman Geoscience 1999). The under-representation of these streams in the network was attributed to three principal factors: a) the challenge in collecting reliable discharge data in steep, typically cobble-boulder dominated, streams using the standard WSC discharge measurement protocol; b) the difficulty in maintaining instream gauges in streams transporting high levels of sediment and debris; and c) typically unreliable, or seasonally-limited, road access.

Methods of flow monitoring are available in the Land and Water BC Hydrometric Guidelines (LWBC 2005) and the Manual of British Columbia Hydrometric Standards (RISC 2009). They are also summarized in Hatfield *et al.* (2007). Briefly, a rating curve should be developed with a minimum of ten discharge measurements, well distributed over the range of flows experienced in a typical year (e.g. 10% to 200% mean annual discharge (MAD)), with photographs taken of the site at high and low flows. A fully documented methodology for the generation of the rating curve and flow estimates should be described. Discharge measurements may be taken by direct mechanical measurement (e.g. Price AA flow meter), dilution methods (salt or dye), or with an Acoustic Doppler Current Profiler (ADCP).

Monitoring Requirements

Accurate, real-time instantaneous flow data will be monitored through the life of the project to ensure compliance with the water licence, and to provide measures of environmental conditions that will assist in the interpretation of changes in biological components of the monitoring program. RISC (2009) recommends collection of a stage reading every 15 minutes, but this is a minimum requirement and site specific flow regimes often necessitate a shorter recording frequency. For the purposes of verifying compliance with flow ramping requirements in fish-bearing waters, a stage sampling frequency of 15 seconds is recommended with a 2-minute average for storage in the data logger (and submission to the agencies). To ensure compliance with the terms and conditions of the water licence, this stage sampling frequency will be adopted. Flow measurements will be provided for two locations: 1) in the diversion section, downstream of the intake but upstream of any significant sources of local inflow; and 2) in the downstream section, downstream of the powerhouse, but upstream of any significant sources of local inflow. Significant local inflow is defined as 10% of the flow being measured. Local conditions will vary and professional experience will be required when selecting appropriate gauging points.

Once a project is constructed, project structures may allow the accurate measurement of stream flow without ongoing discharge measurements in the channel. There are several methods to accurately measure instream flow once a structure is in place, such as a flow velocity transducer within a dedicated instream flow release (IFR) pipe, or a v-notch or gated orifice at the diversion weir with a water level transducer. Machine settings and real time transducer readings can, when calibrated in combination, provide highly accurate measures of both the flow diverted and the flow released downstream of the intake. However, for the first two years following construction, discharge should be monitored in the channel to confirm the accuracy of measurements based on project structures. At both the diversion and downstream hydrometric gauges, a staff gauge will be established to allow independent verification of flow conditions at any time. Staff gauges also benefit recreational users by allowing them to determine if stream flows are suitable for water-based activities.

The collection of stream channel discharges and updating of rating curves post-project (or establishment if gauge locations change) should follow the Land and Water BC Hydrometric Guidelines (LWBC 2005), as per the baseline discharge monitoring described above. Gauges should be recalibrated following major stream flow events that may alter the coefficients of the rating curve. Data recorded at gauging stations should be downloaded from the logger no less than once per month, to ensure that any equipment malfunctions (e.g. battery loss, equipment damage) do not result in lengthy data gaps.

Instantaneous, continuous monitoring of instream flow will be required for the life of the project, whether measured manually in the stream channel or with project structures. Instantaneous water level and flow data should be available upon request and annual reports on instream flow will be required throughout the life of the project. In addition to this general monitoring requirement, any non-compliance with the water licence should be reported to DFO and MoE within 24 hours, and measures taken to ameliorate the risk of downstream impacts. Non-compliance reports describing the conditions of non-compliance, the contributing factors, and measures taken to minimize immediate and future impacts should be submitted to DFO and MoE within a week of the incident.

A summary of this monitoring program can be found in Table 7.

3.1.1.2 Ramping Rates

Background

A potential environmental effect of hydroelectric projects is the stranding of fish by operational changes in stream flow. Rapid changes to stream flow can dewater habitat and strand fish, which can lead to mortality through desiccation, freezing, or increased predation. Fish stranding by hydroelectric operations, defined as the separation of fish from their primary water body (river or reservoir) and leading to injury or mortality, has been known for decades and studied extensively in the past 10 years in Canada and Norway (e.g. Cushman 1985, Hvidsten 1985, Bradford 1997, Hunter 1992, Saltveit *et al.* 2001, Halleraker *et al.* 2003, Irvine *et al.* 2008). Stranding can occur by entrapment in a side channel or pool (trapping or isolation), entrapment between substrate clasts (interstitial stranding,), or by beaching on substrate (Cathcart 2005). Unauthorized fish mortality violates Section 32 of the *Fisheries Act* and must be avoided.

Potential stranding effects are mitigated by controlling the rate of operational flow change, a procedure known as flow ramping. Flow ramping is defined here as a gradual or progressive alteration of discharge in a stream channel resulting from the operation of a hydroelectric facility. Ramping rate is defined as the rate of change in discharge measured as a flow per unit time (i.e., m^3/s/s or cfs/s) (Cathcart 2005). Regulatory agencies have identified generic ramping rates to protect fish from flow ramping. The generic ramping rates adopted by DFO are based on stage change rather than volume change: 2.5 cm/hr when fry are present and 5.0 cm/hr at all other times, although no ramping may be allowed under some conditions (Hunter 1992, Higgins 1994, Cathcart 2005), and a single rate may not provide protection in all streams (Irvine *et al.* 2008). The development and testing of these rates is underway at many projects in the Province.

The effects of flow ramping and the factors influencing fish stranding are complex (Irvine *et al.* 2008). Stranding risk is extremely variable among different streams and within a given stream, and even the generic rates could pose a threat to fish and habitat under certain conditions. The potential operational effects of ramping differ among projects, reflecting stream-specific channel morphology, diversion flow magnitude, and the fish species and life stages present. Ramping risk may vary with flow and season, demanding that individual proponents investigate the response of stream habitat and fish in a specific stream to flow ramping.

Ramping issues are particularly acute for hydropower installations that produce electricity using hydropeaking, or pulse power generation, which generate electricity during times of peak demand (Scruton *et al.* 2008). Several hydrological characteristics of downstream flow may also be altered by hydropeaking, including magnitude, duration, timing, rate of change (ramping rate) and frequency of changes in flow (Magilligan and Nislow 2005, Arthington *et al.* 2006). As a result, hydropeaking can substantially alter the quantity and quality of habitat available to fish on a daily basis (Moog 1993, Valentin *et al.* 1996). Habitat quality may be impaired by the continuous wetting and dewatering of the substrate, which can reduce the overall productive capacity of the fluvial habitat (Morrison and Smokorowski, 2000). Adverse effects may be direct (e.g. stranding, mortality or habitat abandonment) or indirect (e.g. downstream displacement, volitional movement, depleted food production, increased physiological stress) (Moog 1993, Valentin *et al.* 1996, Bradford 1997, Scruton *et al.* 2003, Scruton *et al.* 2005).

Even if the flow changes are not drastic enough to kill fish, they can interrupt feeding, migration, and spawning behaviours, causing fish to migrate from preferred habitats, thus effectively reducing the value of these habitats. These effects, though transient, may recur often enough to harmfully alter fish habitat, violating Section 35 of the *Fisheries Act*. Some have categorized these effects as sub-lethal behavioural responses (Saltveit *et al.* 2001, Floodmark *et al.* 2002). Early studies of hydropeaking focused on severe impacts such as stranding (e.g., Bradford 1997, Valentin *et al.* 1996), while more recent research is moving towards sub-lethal impacts to non-stranded fish, including behavioural and physiological responses (e.g. Halleraker *et al.* 2003, Floodmark *et al.* 2002, Murchie and Smokorowski, 2004, Berland *et al.* 2004). In regards to fish growth, one study noted that no measurable impacts on growth were identified as a result of short-term experimental exposures to fluctuating water levels (Floodmark *et al.* 2006). Whether severe or sub-lethal impacts (or both) will result from hydropeaking operations on a given stream will vary depending on several key factors.

The magnitude of the effects of hydropeaking generally depends on the capacity of fish to respond to temporary, often severe habitat alterations, and their ability to find and exploit hydraulic refugia (Valentin *et al.* 1996). Overall, the key factors that determine the potential effects of hydropeaking on fish include (i.) the rate of flow change and duration, (ii.) time of day (light), (iii.) season and/or temperature, (iv.) behaviour of fish, (v.) fish species and life stage (size), and (vi.) the morphology and substrate character of the stream (Steele and Smokorowski 2000, Halleraker *et al.* 2003). The first of these factors, the rate of operational flow change and duration, is the primary mechanism that is controlled to limit the impacts of hydropeaking and other causes of rapid flow change (e.g. turbine start-up and shutdown due to planned or unplanned outages, etc.).

In light of the potential impacts of flow changes on fish and fish habitat, regulatory agencies have been working with industry to develop a set of protocols to evaluate, manage, and mitigate these impacts. Among these are ramping rates that have been developed based on previous research (Hunter 1992, Cathcart 2005). Nevertheless, the monitoring of fish stranding due to flow changes and the development of protocols for the assessment and mitigation of ramping effects is an area of active investigation in BC, and thus the protocols proposed here can be expected to evolve over time as more local experience is gained.

Ramping rates are restrictions on the rate and time of diversion, storage, or use of water from a stream to protect instream flow requirements for fish and/or fish habitat. At present, generic standard ramping rates followed by DFO are 2.5 cm/h when fry are present and 5.0 cm/h at all other times, although no ramping may be allowed under some conditions (Hunter 1992, Higgins 1994, Cathcart 2005). These generic rates are risk-averse and although they may not avoid all stranding, particularly that from isolation and subsequent dewatering over a prolonged period, they are within the range of natural hourly ramping rates seen at low flows in the Pacific northwest (see Hunter 1992) and have proven effective at some hydroelectric projects. Downramping rates of 2.5 cm/h when fry are present and 5.0 cm/h at all other times should therefore be applied unless monitoring studies demonstrate that less stringent rates minimize the risk of fish stranding to a level that is acceptable to the regulatory agencies.

Fishless diversion sections can tolerate stage change rates higher than those established for fish-bearing sections; however, there is little guidance on what these rates should be. Natural stage change rates provide conservative guidance of stage change rates for fishless streams.

Cathcart (2005) identifies 10 key items that can influence the ramping rate required to avoid stranding, hence different projects may ultimately be able to implement more rapid ramping rates. However, unless otherwise demonstrated by a ramping study, the generic rates will be followed and fish-bearing diversion and downstream sections will generally require ramping tests. Fishless diversion sections will not require ramping tests. There may be some streams where channel confinement and slope preclude the establishment of study sites. Such streams are also unlikely to have sites with high rates of fish stranding, hence, if study sites cannot be established because of these concerns, it is likely that the study is not required. Nevertheless, such circumstances are expected to be rare.

Monitoring Requirements

The monitoring of ramping rates applies continuously throughout the life of the project, as both planned and unplanned outages may occur at any time. For instance, ramping may be induced when an unplanned outage causes the turbine to shutdown in situations where there is insufficient flow for a hydroelectric plant to generate electricity *and* maintain the minimum instream flow requirement in the diversion reach. Similarly, an unexpected equipment malfunction of electromechanical equipment (e.g. loss of transmission services due to tree fall or ice build-up) or component of the water conveyance system may induce ramping as an immediate plant shutdown is required to protect the system from further damage and to perform emergency repairs and maintenance. Thus, ramping rates will be monitored and evaluated continuously because of the potential impacts that inappropriate rates may have on fish and fish habitat in the diversion reach and downstream of the project.

Project commissioning is the ideal time to conduct ramping tests because water control structures are in place, allowing a controlled experiment to be conducted, and it is imperative that ramping rates that are protective of fish are in place prior to operation. Generic ramping rates are typically stringent, reflecting the stage change criteria used on streams that support juvenile life stages of anadromous fish. If evaluated in a field test, ramping rates may be modified to optimize project operations while still meeting fish protection requirements. It is important to monitor the effects of ramping rates on individual project streams in the field because of among-stream variation in physical conditions, fish species type, and fish behaviour.

Cathcart (2005) identifies a 9-step protocol for deriving ramping rates for run-of-river hydroelectric developments in British Columbia, which can be initiated during the EIA to identify appropriate ramping rates. The ramping tests and monitoring protocol proposed here is the elaboration of Step 8: Test Ramping and Standard Verification, described in Cathcart (2005) as: “If necessary, test ramps should be conducted to determine flow and stage changes at critical sites, after facility construction at the discretion of Fisheries and Oceans Canada. Test ramps would be the basis for verifying the validity of the interim ramping rate recommendations, and eventually the final operational ramping rates upon final approval from Fisheries and Oceans Canada.”

The test ramps allow the monitoring of ramping rate effectiveness. The tests follow several of the steps in the ramping protocol prepared for DFO (Cathcart 2005), which are repeated here and elaborated on to provide additional guidance.

1. Identify aquatic species at risk by stream section

During the EIA the fish species and life-history stages present will have been identified. This information should be brought forward into the ramping tests to guide selection of the target species/life stage, and the timing and stream section of interest for the tests. Fishless diversion sections will not require ramping tests; however, fish-bearing diversion and downstream sections will require tests. The tests should focus on the most sensitive species and life stages present in a stream section. Additional tests may be required at different times of year to determine if less stringent ramping rates are permissible at other times of year.

2. Identify sensitive stranding sites

Sensitive sites are those with the highest potential rates of fish stranding. By designing ramping rates to protect these sites, less sensitive sites are also afforded protection. Sensitive sites are found in a variety of locations, particularly where the river cross-section has a relatively flat slope, typically at a gravel bar or sand bar. Side channels or pools are also sensitive sites as they are preferred by juvenile fish for rearing. Micro-stranding sites are found on cobble bars, where roughness creates refuges that juvenile fish prefer, but may be reluctant to leave during a ramp down, resulting in stranding.

Potential sensitive sites both within the diversion and downstream sections should be identified prior to the ramping tests. Sensitive sites may extend far downstream from the project. The study boundary should be located far enough downstream to ensure that no sites further downstream suffer a higher degree of stranding during ramping events.

At least five sensitive sites should be identified within each of the downstream and diversion stream sections. Each site should consist of a minimum of 10 m of streambank, and extend out into the stream to the limit of dewatering observed. In order to be able to determine whether the ramping rates being tested are protective, the species and life-stage of interest must be present within the sensitive sites immediately prior to and during the ramping tests.

3. Define the stage discharge relationship at sensitive sites

Ramping tests take place following project construction, when flows can be controlled at the powerhouse. As the timing and magnitude of flow released from the powerhouse will be known, and discharge will be known in the diversion and downstream sections from the continuous recording gauges installed there, the response of flow to operational changes can be monitored. During such tests, a stage sampling frequency of 15 seconds is recommended, with a 2 minute average for storage in the data logger (and submission to the agencies). In addition, stage must be continuously monitored at the sensitive sites during the ramping tests. The flow data inferred from the stream gauges and the stage data collected at the sensitive sites are combined to provide a stage discharge relationship at the sensitive sites. Where more than 10% local inflow enters between the stream gauges and the sensitive sites, an additional stream gauge should be established closer to the sensitive sites.

Once the sites are selected, temporary stage gauges must be installed. These can be manual gauge plates or continuous stage recorders. Manual gauge plates (60 cm length) can be fixed to the bank, large boulders, rootwads or large woody debris (LWD), or hammered in the stream bed. This will allow field staff to instantaneously monitor water level during the tests and record water levels. It may be more efficient to install a transducer and logger at every sensitive site to facilitate data collection and subsequent analysis.

4. Measure habitat change

Fish habitat data should be monitored at all sites prior to, during, and following the test. Habitat data recorded will include wetted edge location relative to a reference point, dominant cover types, mesohabitat type, substrate composition, a general description, and GPS coordinates. Temporary cross-sectional pins should be set in the ground to provide a horizontal control for the wetted edge measurement. At least two photopoint monitoring stations will be established at each site, and photos will be collected (and repeated) at each of the cross-sections measured. Drawings of each site showing the location of photopoint monitoring stations and recording gauges will also be prepared.

The sites should be monitored from the beginning to the end of each commissioning test to document the extent of dewatering. At each site, the change in the location of the wetted edge is multiplied by the site length to derive the area dewatered. In the case of small streams or isolated pools, the location of each wetted edge can be recorded.

5. Quantify fish stranding

The presence of the species and life-stage of interest within the sensitive sites must be confirmed immediately prior to the ramping tests, otherwise the tests will be inconclusive. Where wetted areas become dry post-ramp, loose substrate where fish could hide will be excavated and overturned to confirm fish presence/absence. Extensive and diligent searching is required to ensure that small fish hidden in the interstices of the substrate are found. Fish found will be captured, enumerated by species and age class, and their status regarding stranding recorded (either as stranded or isolated in a pool). The condition of the fish will be recorded and comments on stranding mortality should be provided.

The number of fish captured per metre of shoreline can be expanded by total length of similar shoreline in the stream section to estimate the total number of fish stranded.

6. Ramping protocol definition and documentation

Following project commissioning and the ramping tests, the results of the study should be evaluated to identify stage change rates that minimize the risk of fish stranding to a level that regulatory agencies are willing to authorize. The methods, results of searches for stranded fish, as well as stage and flow data should be presented in detail to facilitate a critical review of the outcome of each test.

Once confirmed, ramping rates will be described in an operating protocol that details steps to avoid non-compliance and lists mitigation measures that are in place to avoid harmful impacts to fish should violation of the ramping rates occur (e.g. fish salvage protocol). A report on the ramping tests and a copy of the operating protocol must be submitted to DFO and MoE. Thereafter, compliance with the prescribed ramping rates should be monitored during operation, not just during start up and shut down procedures. Non-compliance with the ramping rates must be reported to DFO and MoE. Reports describing the conditions of non-compliance, the contributing factors, and measures taken to minimize the chances of recurrence should then be submitted to DFO and MoE within a week of the incident. In addition to non-compliance reports, details on ramping events throughout the year should be reported in the annual reports on instream flow, which should be provided throughout the life of the project.

Summary details on this monitoring program can be found in Table 8.

3.1.2 Mitigation and Compensation Measures

All hydroelectric projects require mitigation and/or compensation measures to offset project impacts on fish habitat, with the measures detailed in the project EIA. The mitigation and compensation measures adopted are project-specific; however, a few common mitigation measures and compensation habitats are described. The frequency of monitoring and effort required depends on the measures adopted, and are therefore discussed in more detail below.

3.1.2.1 Construction Monitoring

To protect fish and fish habitat, various best management practices are employed during construction in and around streams. These are outlined in a document published by the BC Ministry of Water, Land and Air Protection (MWLAP 2004), and include: reduced risk timing windows; work area isolation; fish salvage; deleterious substance and spill management; concrete materials use; sediment, runoff and erosion control; vegetation management; and site restoration. Adoption of these best management practices are required to ensure compliance with the provincial *Water Act* Regulation’s Protection of Habitat (Section 42(1)) and Protection of Water Quality (Section 41), as well as the *Fisheries Act*. The above list is not comprehensive, and all construction monitoring requirements should be compiled into an Environmental Management Plan (EMP) and submitted to the regulatory agencies for approval prior to construction (see Figure 1).

Along with best management practices, monitoring activities are implemented to ensure compliance with the protocols and assess whether the mitigation measures are effective in protecting fish and fish habitat. Construction activities must be monitored full-time at the start of construction and during any instream works or sensitive activity, and on a daily basis during other construction activity (MWLAP 2004). The environmental monitor must be an appropriately qualified professional and will have the authority to modify or halt any activity if it is deemed necessary to protect fish and wildlife populations or their habitats. Within 60 days of the project’s completion, a monitoring report must be completed by the environmental monitor and submitted to MoE and DFO. Monitoring requirements are summarized in Table 9.

Further details on the implementation of the best management practices, along with the requirements for the monitoring report are provided in MWLAP (2004).

3.1.2.2 Fish Screens and Fishways

For many projects on fish-bearing streams, mitigation measures may include a fish/debris screen, such as a Coanda screen, engineered to prevent the entrainment of fish, and a fishway allowing fish to move upstream and downstream of the intake. The condition of the screen and fishway will be inspected on an annual basis prior to, and during, critical times such as the downstream migration of juvenile fish, or the upstream migration of spawning adults. Any factors that may impair, delay or block fish migration identified during these inspections will be reported to DFO and addressed as soon as possible to minimize disruption to fish migration. Key issues are the impingement of juveniles on the screen, which depends on the effectiveness of the screen and the volume of water diverted (Hatfield *et al.* 2003), and efficiency of upstream migration by adults through the fishway, which depends on flow conditions and the physical condition of the fishway. The condition of the screen and fishway will be documented with photographs during monitoring, and the design flow confirmed with on site flow measurements.

In addition to monitoring the physical condition of the screen and fishway, the effectiveness of fish passage will be evaluated. To obtain an accurate understanding of movement in the area of the intake, and thus evaluate the effectiveness of the fishway, monitoring will need to begin prior to construction of the intake and fishway. Baseline information on the number of fish that migrate past the proposed intake location and the duration of the migration period will be collected prior to construction. The methods used to monitor fish passage under baseline and operational conditions will depend on the life stage and species of concern. If upstream migration is blocked, fish will hold in the fishway and below the diversion weir and may be visible from shore. However, direct sampling will likely be required to detect fish presence, given that upstream migration is typically timed with higher flow periods when foot surveys are less effective at detecting fish. Snorkel surveys, underwater video cameras, a trap box survey, and mark-recapture coupled with electrofishing surveys may be employed to monitor migration. The capture of sexually mature fish in spawning coloration below the diversion weir or in the fishway, concurrent with their absence in upstream sections, is evidence of a migratory impediment. Fish abundance in stream habitats in the 100 m of channel downstream of the intake and in the 100 m section upstream of the headpond may by comparison provide a quantitative measure of the fish holding below the diversion weir. However, a number of factors can influence relative abundance, and careful interpretation of the results will be required.

The frequency of monitoring required will depend on the length of the migratory period, but at a minimum, abundance will be determined once before the migratory period and again at the peak of migration. An annual report that details the status of the fish screens and fishway and any maintenance performed will be produced in accordance with the *Fisheries Act* Authorization.

In streams with high fish values and important populations of migrating fish, more intensive techniques specifically designed to assess fish migration may be required. These techniques include: passive integrated transponder (PIT) tags (Aarestrup *et al.* 2003), intragastric radiotelemetry tags (Keefer *et al.* 2004) and hydroacoustics (Ransom *et al.* 1998, Steig and Johnston 1996).

Details on the monitoring of fish screens and fishways are summarized in Table 10.

3.1.2.3 Habitat Compensation

Background

Compensation habitat is often required by hydroelectric projects to offset negative impacts that cannot be avoided or mitigated against. The habitat compensation required and created will vary on a project-specific basis, and thus the type and frequency of monitoring required will also vary. However, as an example of the monitoring that will be required, the monitoring described below is based on the excavation of a new stream channel, or the improvement of access to an abandoned side channel, for rearing fish and adult spawning. Pearson *et al.* (2005) examine the design and methodology of monitoring programs to assess fish habitat compensation projects that should be reviewed for guidance during the development of the project-specific monitoring program.

Monitoring Requirements

All compensation habitats should be designed by an appropriately experienced environmental professional and constructed in compliance with the construction monitoring protocols detailed above. Following completion of the compensation habitat, an ‘as-built’ survey will be conducted to determine whether the quantity of habitat constructed is in compliance with the Authorization. As DFO generally requires compensation habitat to be constructed prior to the completion of the project infrastructure and the onset of operational impacts, verification as to whether the compensation habitat is sufficient may come at a later date. An ‘as-built’ survey report should be submitted to DFO for the completed compensation habitat. The report should be submitted electronically and provide UTM coordinates for all compensation works.

To verify habitat quantity, the following physical measurements of the compensation habitat should be taken: channel length, bankfull and wetted widths, substrate size, and cover area by type (large woody debris, cobble substrate, overhanging vegetation and undercut bank). A cross-channel transect will also be established in each hydraulic unit, with depth, velocity, cover, and substrate being recorded. Following compliance monitoring, effectiveness monitoring will be conducted on a periodic basis to determine whether the compensation habitat is providing good quality habitat for the focal species.

To determine the quality of the compensation habitat, the physical dimensions and flow within the constructed habitat should be scored using the same habitat suitability indices employed in the instream flow assessment, i.e. wetted width and weighted usable width, calculated using provincial Habitat Suitability Index (HSI) curves (see Lewis *et al.* 2004) for a detailed methodology). The physical characteristics of the compensation habitat will be assessed following construction and then 1, 5 and 10 years post-construction, with the condition of riparian vegetation being included in the monitoring to ensure establishment of planted material. Additional monitoring after 10 years, and in the intervening period between 5 and 10 years post-construction, may be required. Ongoing monitoring requirements will be dependent on the performance of the compensation habitat.

As another aspect of the effectiveness monitoring, juvenile fish abundance will be determined following the same methodology outlined in Section 3.1.6. Adult fish will also be enumerated and mapped through a snorkel survey, coinciding with peak spawning of the focal species. Adults will be enumerated by species, sex, condition and status (live or dead). Adult and juvenile fish abundance will be monitored after 1, 2, 3, 5 and 10 years. An annual report describing the results of both habitat and fish abundance surveys will be produced.

Details on the monitoring of compensation habitat can be found summarized in Table 11.

3.1.3 <u>Footprint Impact Verification</u>

Background

The construction and operation of hydroelectric projects will inevitably impact aquatic and riparian habitats. The scope of these impacts are typically predicted and outlined in the EIA submitted to MoE and DFO as part of the project approval process. In order to ensure compliance with the project certificate and make sure adequate compensation habitat is created, it is necessary to measure the actual footprint impact post-construction. The information collected also provides insight into the accuracy of the predictions made within the EIA, and may therefore be used to increase the accuracy of future predictions.

Baseline Data Requirements

Predicting the aquatic and riparian habitat loss associated with a project involves mapping followed by ground-truthing in the field. Initially, aquatic and riparian habitat losses are estimated using the General Arrangements and associated shape files to calculate habitat loss associated with project infrastructure and right-of-ways (ROW) using ArcGIS, or similar mapping software. For the purposes of calculating habitat loss, aquatic habitat is defined as any permanent or temporary wetted area that serves as habitat for one or more life-history phases of an aquatic organism. Riparian habitat loss is calculated relative to the riparian management zone which is 20, 30 or 50 m wide, depending on fish presence and stream class and gradient, as defined in the Riparian Management Area Guidebook (FPC BC 1995). Both permanent and temporary habitat losses must be estimated.

To determine the quality of aquatic and riparian habitat to be lost, rather than simply the quantity, field assessments will be conducted. All aquatic habitats to be lost will be described and mapped following the guidelines in Johnston and Slaney (1996). In addition, a minimum of five riparian sites will be assessed, with priority given to areas permanently affected by clearing, for instance at the intake and powerhouse locations, and those associated with fish-bearing reaches. Information will be collected on the riparian class, seral stage, stand age, plant species composition, relative species abundance, existing disturbance indicators and proximity to a water course. A list of all parameters to be measured or estimated during the riparian assessment is provided in Table 2. The data collected should then be used to assess the functional condition of the riparian zone based on the ecosystem characteristics (species assemblage, soil moisture and nutrient regimes, acidity/alkalinity, and hydrodynamics, see MacKenzie and Moran 2004) and the Riparian Vegetation Type (RVT) rating system (Poulin and Simmons 1999).

Information gathered on the quantity and quality of habitat to be lost will influence the amount and type of compensation habitat required. The data collected will provide the baseline against which to compare the actual footprint impact and determine whether mitigation and compensation techniques were effective in maintaining (or improving) riparian habitat function.

Monitoring Requirements

To verify the actual footprint impact of a hydroelectric project, impacts to both aquatic and riparian habitat will be measured. This ‘as-built’ survey should be conducted immediately following completion of the project infrastructure, with a survey report being submitted to DFO upon completion. The report should be submitted electronically and provide UTM coordinates for all project infrastructure. The physical dimensions of each structure and ROW that impacts the riparian zone or aquatic habitat should be measured in the field or through high resolution aerial photography. The nature of the impact will be documented using the same characteristics described in the original footprint impact assessment including vegetation and aquatic habitat type. For aquatic habitat, the bed material should be described in the impact zones (e.g. concrete, rip-rap). For riparian habitat, the condition of the reseeding/replanting will be documented. Accurate dimensions of all impacted areas should be provided, along with details of any disturbance outside of the legal ROW.

Disturbed riparian areas must be re-vegetated in accordance with the DFO (2006) guidance on riparian re-vegetation, as well as any local regulations. Species used for re-vegetation must be native to the area. Monitoring should occur late in the growing season on an annual basis for a period of five years following the completion of construction. Successful replanting is defined as a survival rate of 90% of the stock. If more than 10% of the planted stock dies over one year, replanting will be required. Likewise, additional erosion control may be required to stabilize vegetation on steep, erodible soils and ensure successful long-term vegetation. Replanting of lost vegetation and all additional remediation should occur within a maximum of eight months following disturbance. To ensure the greatest likelihood of survival, replacement grasses, shrubs and trees should be planted during the spring and/or fall depending on the local climatic conditions. Monitoring results and details of any upgrades required and performed should be documented in an annual report.

Details on this monitoring program are summarized in Table 12.

Table 2. Riparian assessment parameters and methodology.

Parameters	Units or Qualifier[1]	Measured (M) or Estimated (E)	Method
Coordinates	UTM	M	GPS
Forest Region	---	---	BC Forest Region
Biogeoclimatic zone, subzone, variant	---	---	BC biogeoclimatic zone maps
Date of Cut/Stand Age/Field Estimated Stand Age	Years	E	Provincial vegetation cover information or estimate visually in the field based on professional judgement. Code – Limits (years) 1 – 1-20 2 – 21-40 3 – 41-60 4 – 61-80 5 – 81-100 6 – 101-120 7 – 121-140 8 – 141-250 9 – 251+
Seral Stage	1,2,3,4	E	1. Establishment 2. Thinning 3. Transition 4. Shifting Mosaic (MoF 1998b)
Photos	---	---	Vertical and Horizontal pan
Stems per Hectare	SPH	M	Count deciduous and coniferous stems with DBH >0.12 m in a 11.28 m radial plot and multiply by a factor of 25
Riparian Area Aspect	Degrees	M	Compass
Gradient Perpendicular to Creek	%	M	Clinometer
Gradient Parallel to Creek	%	M	Clinometer
Overstory Vegetation	Relative %	E	Visual assessment of relative abundance
Understory Vegetation	Cover Scale	E	Visual assessment of relative abundance Cover Scale for the estimation of foliage cover (MoF 1994) + – <1 % 1 – 1-5 % 2 – 5-25 % 3 – 25-50% 4 – 50-75% 5 – >75%

[1] Descriptive data do not have units or qualifiers.

Table 2. Riparian assessment parameters and methodology (continued).

Parameters	Units or Qualifier[1]	Measured (M) or Estimated (E)	Method
Meso Slope position	Categorical		Assessment of a plot's location relative to its catchment area (MELP & MoF 1998)
Substrate description	%	E	Visual estimate of substrate composition (MELP & MoF 1998)
Realm/Class	Categorical	---	Field Manual for Describing Terrestrial Ecosystems (MELP & MoF 1998) Tc = Shrub carr; Ff = fringe Th = High meadow; Wb = Bog Tm = Wet meadow; Wf = Fen Ts = Saline meadow; Wm = Marsh Fl = Low bench; Ws = Swamp Fm = Middle Bench
Presence of Red or Blue Listed Species	Y/N	---	Visual assessment of sample area
Wildlife and Significant Trees	---	---	Catalogue any trees perceived as significant with respect to wildlife or cultural values; record waypoint, DBH and photo.
Other Notable Plant Species	---	---	Description of flora from the herbacious layer that was observed in abundance
Wildlife Observations	---	---	Description of wildlife sightings or evidence of wildlife use
Disturbances	---	---	Description of any historical or evident disturbances
Fish Habitat Riparian Value	L, M, H, C	E	Subjectively designate as Low, Medium, High or Climax based on the site's status level of disturbance and proximity to the watercourse
Riparian Vegetation Type (RVT) (MoF 2002)	1,2,3,4,5	E	RVT 1 - Understocked with conifers and brush sites RVT 2 - Overstocked conifers RVT 3 - Conifers overtopped by deciduous trees RVT 4 - Deciduous dominated stands lacking conifers RVT 5 - Mature stands or those not requiring

[1] Descriptive data do not have units or qualifiers.

3.1.4 Water Temperature

Background

Water temperature effects are one of the primary environmental issues for hydroelectric projects (Annear *et al.* 2002). Small changes in water temperature have the ability to cause significant impacts to fish. Water temperature tolerance levels vary between species and between life-history stages. McCullough (1999) reports that warm temperatures can reduce fecundity, decrease egg survival, delay growth of fry and smolts, reduce rearing density, and increase exposure to disease. Meanwhile, freezing temperatures and the build up of ice during winter can result in entombment, decreased egg to fry survival (Curry *et al.* 1995), increased predation risk (Valdimarsson and Metcalfe 1998), and a decrease in habitat availability (Craig 1989). Eggs are the most temperature-sensitive salmonid life stage (Hicks 2000); however, adults are also sensitive to temperature effects. The National Marine Fisheries Service (1996) characterized properly functioning temperature conditions for adult Pacific salmon as between 10.0 and 13.9°C, with those inhabiting water between 13.9 and 15.5°C considered “at risk”. The water temperature guidelines for the protection of freshwater aquatic life as specified in Oliver and Fidler (2001) state 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 is not to exceed 1°C/hr.

The reduction of water flows associated with a run-of-river hydroelectric project can, depending on the season, either increase or decrease stream temperature. Periods of extreme water temperature in summer and winter often coincide with periods of low flow, when water diversion projects may not be operating. However, there may be periods of heightened sensitivity to diversion-related temperature change, when a relatively large change in flow may coincide with an extreme temperature change.

Ice conditions in regulated rivers are often highly variable due to artificially induced variation in flow and temperature (Huusko *et al.* 2007). Such conditions may preclude the formation of stable surface ice and perpetuate an unstable, dynamic environment associated with frazil and anchor ice (Ashton 1986) that is typically regarded as having negative implications for overwintering fish (Huusko *et al.* 2007). The formation of frazil and anchor ice may affect microhabitat use by salmonids as a result of ice avoidance (Brown and Mackay 1995, Brown 1999, Jakober *et al.* 1998, Simpkins *et al.* 2000), by altering water velocities and depth in pools (Komadina-Douthwright *et al.* 1997, Brown *et al.* 2000) and through the creation of anchor ice dams (Stickler *et al.* 2008). Several studies have found that fish are forced to move more frequently when influenced by frazil or anchor ice (Brown 1999, Jakober *et al.* 1998), which may have negative effects on energy reserves and subsequently survival (Brown *et al.* 2011). However, salmonids do not avoid frazil and anchor ice under all conditions, with Stickler *et al.* (2007) observing a lack of avoidance behaviour in streams dominated by coarse substrates.

Research suggests that predicting the formation and dynamics of frazil and anchor ice, and their effects on the behaviour, microhabitat selection and survival of fish, may be highly context-specific and dependent on the habitat characteristics and ice regimes of individual rivers (see reviews by Huusko *et al.* 2007 and Brown *et al.* 2011). Furthermore, while ice regimes are often regarded as having negative impacts on fish populations, particularly in regulated rivers (Saltveit *et al.* 2001, Dare *et al.* 2002, Scruton *et al.* 2005), there are no studies that quantify overwinter survival in these impacted rivers (Saltveit *et al.* 2001) or that convincingly show that ice limits survival (Huusko *et al.* 2007). This is likely due, in part, to the difficulties associated with sampling in winter, but also because of the complexity of physical and biological factors that affect fish survival.

Nevertheless, if the EIA for a project noted that operation may increase the likelihood of frazil and anchor ice build up, additional habitat and fish biological monitoring is likely to be required to ensure that no adverse effects on overwinter survival arise.

Baseline Data Requirements

As part of the EIA, temperature models should be developed that predict the effects of the new flow regime on temperature. Due to the established interaction between air and stream temperature, with air temperature being the greatest contributing factor to increases in water temperature (Bartholow 1989, Poole and Berman 2000), temperature models must examine the relationship between air temperature, water temperature and flow. Such models may also be used to model the future impacts of global climate change on effects of the hydroelectric project. The predicted rise in air temperature associated with global climate change has already been shown to increase stream temperatures in British Columbia (MWLAP 2002), and such changes will affect different life-history stages and species differently depending on location and current conditions (Nelitz *et al.* 2007).

Water temperature should be monitored by installing continuous temperature monitors in the study stream at three locations: upstream of the intake and headpond (control), in the diversion (impact), and downstream of the powerhouse. If the downstream monitoring site is expected to have nearly identical temperatures to the site in the lower diversion section prior to project commencement, water temperature loggers may only be needed upstream of the proposed headpond, and at the lower end of the proposed diversion. The temperature loggers should be installed and set to collect water temperature every hour or less. Two temperature loggers should be mounted at each site on separate anchors to reduce the risk of data loss or corruption. Water temperature data should be downloaded a minimum of twice per year, or more often if practical. A minimum of two years of continuous water temperature data should be collected prior to project construction.

Air temperature and other meteorological data may be required for modelling the effects of change in water flow on water temperature. The data requirements will depend on the site and model used for prediction.

Monitoring Requirements

Monitoring water temperature throughout the year will allow detection of any changes compared to baseline levels. Any significant changes can then be factored in to operational protocols and support the analysis of other monitoring components, such as invertebrate and fish abundance. Water temperature data should be reviewed annually to determine project effects on stream temperature and assess whether such effects may be biologically significant and affecting the growth, survival or reproductive success of the fish population. Temperature data collected during operations should be incorporated into the temperature models developed for the EIA to improve the effect predictions for temperature and flow extremes.

Temperature monitoring supports the interpretation of key monitoring parameters, such as changes in fish abundance and growth which are sensitive to temperature both before and after project operation. Seasonal variation in temperature presents different concerns, whose importance varies between streams, depending on hydrology and climate. During summer, high temperatures may be exacerbated by water withdrawal to critical thresholds that may affect fish survival: monitoring will quantify the magnitude of project operation effect on stream temperatures and allow for an evaluation of whether such changes are likely to adversely affect the fish population. Conversely, low temperatures during winter may be exacerbated by flow withdrawal, leading to increased frazil and anchor ice formation that have the potential to affect over-winter survival and fish growth.

The level of monitoring required will depend on the severity of potential impacts and the sensitivity and value of the fish species and life stages present. Requirements for additional monitoring of icing issues should be identified in the EIA, but may include: an overview survey to measure ice build up in the diversion section, noting the location, extent and characteristics of the ice; the installation of additional temperature and discharge loggers in locations utilized by fish and sensitive to ice formation; fatty acid composition tests to monitor fish condition; and the implantation of PIT tags to monitor fish movement and overwinter survival.

An annual report should be prepared describing observed water temperatures, assessing any potential impacts. Any potential harmful effects to the productive capacity of fish habitat resulting either from extreme low temperatures and ice buildup in winter, or high temperatures in summer, will require the development of appropriate mitigative measures through consultation with the regulatory agencies.

Details on the monitoring program for water temperature are summarized in Table 13.

3.1.5 Stream Channel Morphology

Background

As a result of modifying stream flow, hydroelectric projects have the potential to impact channel stability, channel geomorphology, and sediment transport and deposition. These impacts may occur both upstream and downstream of the intake, within the headpond and diversion channel, respectively, as well as below the powerhouse. Modifications to stream channel morphology may directly or indirectly alter physical habitats used by fish (Lewis *et al.* 2004), and may therefore lead to HADDs. For this reason, stream channel morphology must be monitored before project implementation and again during operations.

Baseline Data Requirements

Guidelines for the required level of geomorphology assessment are provided in Lewis *et al.* (2004). The geomorphic assessment of channel morphology should begin at a regional scale to describe the physical characteristics of the watershed, physical channel condition, influences of water and land use on channel processes, and the potential impacts of the proposed water use on present and future conditions. The primary concern from a biological perspective is how the physical form and function of the river channel is affected by project operation and what effect any changes in the flow and sediment regimes will have on fish habitat.

On a finer scale, the assessment will consider project effects on stream morphology in the diversion section, downstream of the powerhouse, and upstream of the intake where the creation of a headpond has the potential to affect sediment storage and transport and thus affect sediment transfer to downstream reaches. Within each of these locations, a number of transects should be established to define the baseline representative profile against which to monitor morphological change. It is important that all transects are located in alluvial/semi-alluvial sections. Transects downstream of the powerhouse should be upstream of any significant tributaries that may influence the morphology or bed composition of the channel. A minimum of five transects should be established in the diversion channel, while a minimum of two transects should be located in each of the upstream and downstream sections. The exact location and number of transects will be determined by a licensed professional with experience in river geomorphology. Sediment size analysis associated with the monitoring should follow the standard Wentworth Scale (Bunte and Abt 2001).

Once transects have been established, the following procedures will be carried out:

- A substrate survey near the transects in all three sections to characterize the substrates forming riffles and boulder steps.
- Photo survey points established near the transects in all three sections, and on significant riffles, boulder steps and bar forms.
- A thalweg profile in the diversion section of sufficient length and sampling detail to characterize important morphological attributes relevant to fish habitat (following Roper *et al.* 2002).
- Aerial photogrammetry over the diversion section and upstream of the intake at low flow conditions (~ 30% MAD or less) to document pre-development conditions. Georeferenced, low-level digital photogrammetry is suitable as long as the scale and resolution of the imaging is adequate (estimated to be 1:1,000). RISC (1996) provides appropriate techniques and methodology for this work.

Monitoring Requirements

A stream morphology assessment should be conducted following the first large flood event that occurs after project commissioning (i.e. the first 1 in 10-year event, or greater, as determined by hydrology recordings at the intake), or alternatively, five years after construction, whichever comes first. More frequent surveys may be required if project construction and operation have the potential to alter the sediment regime to an extent that may affect the productive capacity of fish habitat, as determined in the EIA. The same measurements will be taken as during the baseline survey to monitor change, with the addition of sediment sampling in the headpond to determine the volume and type of sediment accumulated, and a detailed topographical survey to determine the extent of the area inundated and the effects to the floodplain. A report detailing the changes observed, any immediate concerns from a fish habitat perspective identified, and a re-assessment of the long-term impacts likely to result from project implementation should then be produced.

Details on this monitoring program can be found summarized in Table 14.

3.1.6 Fish Community

Background

Fish community monitoring is only relevant to hydroelectric projects developed on fish-bearing streams. In such cases, the construction and operation of a hydroelectric project has the potential to directly or indirectly impact various metrics of fish community health, including abundance, density, condition, biomass, size-at-age, distribution, timing of migration and survival. Initial monitoring efforts will establish all species and life-history stages that use the proposed diversion reach and/or may be affected by downstream influences of the project. On streams with diverse species assemblages and high ecological values, it may be appropriate to monitor the entire fish community. On streams with relatively simple fish assemblages, it may be appropriate for extensive sampling to concentrate on a target species. Nevertheless, abundance data should be collected for all species given the potential for unanticipated impacts to arise, and the need to identify changes in the fish community.

It is important that the rationale for selecting a target species is carefully considered. Although anadromous fish have significant cultural, recreational, and economic importance, they may not be the most appropriate for characterizing project impacts. In general, monitoring anadromous fish species adds increased variability to the data through additional external factors stemming from their life-history, such as ocean survival, fishing pressure, etc. This high variability may greatly influence the monitoring results and significantly reduce the power of the analyses. In contrast, the results obtained from monitoring the density and biomass of a resident fish population, such as rainbow trout, are more likely to demonstrate changes, if any, within the stream. The combined effects of any changes to water flow, quality and temperature on fish growth and survival will likely also manifest themselves greater in a fish species that is present throughout its life cycle, than one present for only a portion of its life. However, depending on geographical location and river morphology, the situation may not be so straightforward. Rainbow trout confined to freshwater systems have shown migratory behaviour between mainstem rivers, tributary streams and lakes (Northcote 1997 and references therein), and thus their residency within the proposed diversion reach cannot be assumed. Moreover, the success of an anadromous stock within a particular river, while also influenced by external factors, may be critically linked to habitat within the proposed diversion reach. If anadromous fish migrate into the diversion reach for a portion of their life cycle, changes in flow may completely eliminate their use of the diversion reach through altered cues, impaired passage, or changes to the habitat that diminishes its functionality. Circumstances may therefore dictate that all species of importance are monitored.

Permits will be required for sampling or collection of fish in all waters. Fish Collection Permits from the Ministry of Environment and Habitat Monitoring and Assessment Licenses from DFO should be in place prior to fish sampling. Fish data collected under these permits must be submitted to the Province, following the Fish Data Submission process (www.env.gov.bc.ca/fish_data_sub/index.html).

Baseline Data Requirements

Metrics of fish community health must be studied in two stream sections: an impact section and a control section, both of which should be of similar quality habitat. Lewis *et al.* (2004) provide detailed methods for defining the study area and study sections. The impact section should be located within the diversion, as this is the area where the greatest impacts are expected. The control section would ideally be located upstream of the proposed intake and headpond; however, this may not be possible for biological (e.g. different fish species present), or morphological (upstream section consists of two small, steep tributaries whereas the diversion section is a single larger channel) reasons. In these cases, a different unregulated stream nearby with similar physical characteristics and fish species may provide an appropriate control. Alternatively, as discussed in Section 1.4, approaches other than the BACI design such as a BA or RCA may be considered.

Upstream controls must be carefully selected because they can be adversely affected by project development, in instances where migration is impaired by the intake, or where the upstream section is backwatered far upstream of the intake. The validity of an upstream control site may be compromised if fish migration past the intake, either upstream or downstream migration by adults or juveniles, is significantly impaired. Migration may be key to maintaining the productive capacity of fish habitat on some streams. Where intakes are built adjacent to natural barriers, upstream migration is not a concern; however, downstream reaches may benefit from recruitment from isolated upstream reaches.

Within each section, high quality fish habitats should be selected for sampling. A minimum of five sample sites should be established in each of the control and impact sections (Lewis *et al.* 2004). These sites should be sampled using methods appropriate for local conditions and the species of interest. In the majority of cases, multiple-pass electrofishing with depletion (multi-pass) is the preferred method for numeric assessment (Seber and LeCren 1967, De Leeuw 1981, Murphy and Willis 1996). However, electrofishing may result in mortality or injury (e.g., McMichael *et al.* 1998, Holliman *et al.* 2010), and may not be permitted for all species and under all environmental conditions. In such instances, appropriate alternatives that adequately characterize and monitor the health of the fish population must be found (see below for a discussion of alternatives).

The key factors that affect electrofishing effectiveness are conductivity, temperature, visibility, and habitat (depth and flow). Electrofishing is only considered effective where conductivity is greater than 30 µS/cm and water temperature is greater than 4° C (MoF 1998a, Lewis *et al.* 2004). Where conductivity is low, salt blocks can be added upstream of the sampling site to increase conductivity to an acceptable level. A provincial condition under the fish collection permit process in BC states that “no electrofishing is to take place in waters below 5°C” (Appendix A, No. 11). During cold periods many species of salmonids become largely nocturnal and hide in the substrate during the day. Therefore, in cold water conditions (i.e. <5°C), electrofishing activities may be scheduled at night so that fish are captured and not shocked while buried in the substrate. Lewis *et al.* (2004) also place conditions on water visibility (>25 cm) and habitat. A sufficient level of visibility is necessary if fish are to be captured, however, even where visibility is low, electrofishing can still be used as a method to detect species presence. High water depths and high flows also set physical limitations on electrofishing (i.e. to crews and equipment).

Another issue for electrofishing is the possibility that fish will be injured. Several studies have reported substantial numbers of pulsed direct current (i.e. electrofishing) caused spinal injuries and associated haemorrhages in rainbow trout and other species (Holmes 1990, Meyer and Miller 1990, Wyoming Game and Fish Department 1990, Fredenberg 1992, Newman 1992, Roach 1996, Taube 1992, McMichael 1993, Zeigenfuss 1995, Dalbey *et al.* 1996, Grisak 1996, Thompson *et al.* 1997, Snyder 2003). Other harmful effects such as bleeding at gills or vent and excessive physiological stress have also been documented (Snyder 2003). Therefore, particularly in cases where species of concern are located within the sampling area, electrofishing may pose too high of a risk to be used (i.e. risk of injuring or killing the species). Significantly fewer spinal injuries have been reported when direct current, low-frequency pulsed direct current (≤30 Hz), or specially designed pulse trains were used (Snyder 2003).

Fish eggs may also be potentially injured by electrofishing. Consequently, another provincial condition under the fish collection permit process (Appendix A, No. 12) states that “electrofishing may not be conducted in the vicinity of spawning gravels, redds, or spawning fish, or around gravels which are capable of supporting eggs or developing embryos of any species of salmonid at a time of year when such eggs or embryos may be present”. A more in-depth review of electrofishing and its effectiveness can be found in most fisheries techniques books and manuals (e.g. Murphy and Willis 1996, Bonar *et al.* 2009).

When electrofishing is adopted, multiple-pass electrofishing should follow the methods outlined in Hatfield *et al.* (2007). Fine mesh stop nets capable of barring the passage of all fish present should be used to encompass individual sample areas of at least 100 m^2. At each sampling site, habitat data must be recorded, including depth, velocity and substrate present within the enclosure, to assist in quantifying usability (see Hatfield *et al.* 2007). The length of the electrofishing site must also be recorded along with at least three measurements of site width. These site measurements allow for the calculation of fish density and biomass, which can be compared across sites and between years.

Abundance estimates from electrofishing with depletion are frequently biased (Peterson *et al.* 2004) and may not be possible in streams where water clarity and temperature or turbulence prohibit effective sampling. Glacial streams may be too turbid for effective electrofishing during the growing season, clearing sufficiently for electrofishing only when temperatures drop below the permitted range for this method. Furthermore, electrofishing with depletion may miss larger juveniles (Korman *et al.* 2010) and can lead to biased estimates of juvenile fish abundance, even when both backpack and boat electrofishing are used to sample the wider variety of habitats presented in these larger streams (Korman *et al.* 2009). Mark-recapture experiments provide more precise capture probabilities, avoiding the bias inherent in depletion methods. Snorkeling can be a superior method of detecting larger juvenile salmonids (Korman *et al.* 2010); however, hiding behavior during daylight negatively biases counts, particularly under lower temperatures. Nighttime snorkeling can overcome these biases (Thurow and Schill 1996, Thurow *et al.* 2006, Hagen *et al.* 2010). A combination of snorkeling, which is more effective at detecting larger fish, and electrofishing, which is more effective at detecting smaller fish, can offset the size biases of each method alone, leading to superior estimates of population abundance (Korman *et al.* 2010).

The appropriate method for a particular project, or combination of methods for fish sampling, will require consideration of the capture probability of the species/life stages of interest, as well as the physical conditions of the site, including temperature, conductivity, turbidity, and channel type. A biased abundance estimate such as electrofishing with depletion may provide a reliable metric to compare abundance between study sites and over time. However, the methods chosen should consider conditions both prior to and during project operation, which will alter flow and other factors that can influence capture probability. Flow reductions may increase capture probability, in turn overestimating the relative abundance in diversion reaches and biasing monitoring results.

A combination of methods will be employed to overcome the limitations of a single method, with sampling extending into other seasons to ensure that the entire fish community is adequately characterized and the manner in which the available habitat is used in different seasons is understood.

Snorkeling, minnow trapping, or another sampling method (e.g., angling, beach seining, fyke nets, drift nets) should be employed as a secondary sampling method to overcome any limitations of the primary sampling method. A second sampling method may sample different species or life-history stages, and extend sampling into other seasons to ensure that the entire fish community is adequately characterized and the manner in which the available habitat is used in different seasons is understood. Even in streams with relatively simple fish assemblages, migration into and out of the proposed diversion reach may occur to take advantage of good quality foraging, refuge or spawning habitat. It is thus important to gather as much information as possible on how the available habitat is used prior to project development so that impacts can be better predicted, monitored and mitigated. The amount of fishing effort expended (e.g. electrofishing seconds, trap soak time) will be recorded to calculate catch-per-unit-effort (CPUE), which provides an indication of the relative abundance of fish at different sites.

Regardless of the sample method used, in all cases it is beneficial to collect specimens so that length, weight condition and fat content can be measured, as these attributes may be more sensitive to environmental changes and display less variability. Biological attributes may provide high power resolution of effects if individually marked fish are sampled over several years. The species, length and weight of all fish captured should be recorded, along with any observations of abnormalities. A Field Key to the Freshwater Fishes of British Columbia exists to aid in the identification of species (RISC 1994). Voucher specimens should be collected for species that cannot be confidently identified in the field (RISC 1997a). Aging structures should also be collected to provide an indication of age classes and growth. These physical data will be used to evaluate baseline fish condition and size-at-age relationships. All data collected will meet or exceed the existing inventory standards (RISC 2001), with details of sampling (e.g. electrofisher settings) and site conditions (turbidity, temperature, conductivity) recorded because differences between years may aid in the interpretation of results.

A minimum of two years of baseline fish community data should be collected before construction of the project. However, more extensive sampling will likely be required in streams that support anadromous species, highly valued sport fish, or a complex fish assemblage. In such instances, it may be necessary to monitor for one complete life-cycle of the anadromous species present, and/or sufficient time to gain a thorough understanding of how the habitat is used, both spatially and temporally. The timing of sampling will vary between streams, depending on the fish species present and the hydrological and temperature regime. For example, on Vancouver Island, sampling for salmonids will likely take place during September or October, coinciding with the period of low flow during the growing season. However, in interior streams dominated by snow and glacial melt, the most critical period may be overwinter and fish may be most easily sampled in early spring, although electrofishing may not be effective or permissible at that time.

In addition to the collection of baseline data on fish populations, fish habitat will also be assessed during the EIA as it is critically important in determining the carrying capacity of a stream. Microhabitat data are collected as part of the instream flow assessment (see Lewis *et al.* 2004), but habitat information on the mesohabitat and macrohabitat scales should also be collected following the Fish Habitat Assessment Procedure (FHAP) (Johnston and Slaney 1996). Further details on the baseline requirements for fish habitat can be found in Hatfield *et al.* (2007). Aside from the continuous monitoring of flow over the life of the project (Section 3.1.1.1) and the occasional monitoring of stream channel morphology (Section 3.1.5), ongoing monitoring of physical fish habitat will likely not be necessary during operations. However, if changes in fish populations are observed, specific habitat features may need to be monitored to determine whether changes have occurred as a result of project operations, and whether these changes are likely to have played a role in the observed changes to the fish population. For example, if there is a decline in fry recruitment, this may be a result of reduced intra-gravel velocities induced by flow reduction. In this instance, monitoring studies may be required to quantify the effects of flow change on spawning habitat and egg-fry survival.

Monitoring Requirements

The same sites should be sampled during each monitoring period to allow paired comparisons in statistical tests, thereby increasing statistical power. The sampling sites should therefore be georeferenced, photographed, and marked in the field to ensure that the same location is used repeatedly across years. The timing of sampling should also be consistent across years. Fish abundance will in general be monitored 1, 2, 3, 5 and 10 years post-construction, with a report produced on an annual basis. All metrics described above should be measured and evaluated for differences between baseline and post-construction conditions. When evaluating monitoring results in relation to the baseline it is important to consider multiple life stages of the target species, any other species present, and the effects of environmental variables, such as temperature (Murchie *et al.* 2008). Quantitative multivariate analyses should be performed wherever possible, with power analyses conducted to evaluate the ability of the tests performed to detect biologically significant changes. The power of the statistical tests should be reported along with the significance of the test results.

Impacts from backwatering or flooding of the stream channel upstream of the headpond may also affect fish. These impacts should be monitored by sampling fish density post-construction and comparing observed densities to those sampled in the upstream section before construction. Electrofishing may not be the most appropriate method of fish enumeration given the greater depth of headponds. Accordingly, snorkelling, seining, or other methods may need to be considered. The appropriate methodology will be selected once the project is operational and the headpond can be examined to determine the habitat characteristics, which will determine the efficacy of potential sampling methods. Evaluating the density of fish in the headpond area pre- and post-construction will consider the changes in habitat, and how these are likely to impact the species and life stages present.

Details on the monitoring of fish community can be found summarized in Table 15.

Additional Fish Response Monitoring

The baseline and long-term monitoring described above should be considered the minimum amount required for the development of a hydroelectric project on a fish-bearing stream. While it may not be appropriate to assess the impacts on anadromous (or other migratory) species by collecting juvenile density data, DFO will require baseline and long-term monitoring of anadromous stocks (or other stocks of management concern) using additional monitoring methods. For example, multiple-pass removal electrofishing cannot be used to monitor chum and pink salmon due to their very short periods of freshwater residence. Similarly, the freshwater rearing periods of juvenile Chinook are stock-dependent and can range from a period of weeks to a year or more (McPhail 2007). In cases of limited freshwater residence, some measures of adult abundance and fry outmigration are likely to be required. Additional monitoring may also be required for non-anadromous species or stocks of particular importance or sensitivity to human development (e.g. bull trout). The most appropriate methods for monitoring in these situations will vary on a case-by-case basis.

The methods employed to collect baseline information must be of an appropriate type and extensive enough to adequately characterize the existing fish population and its habitat use, and subsequently monitor any potential project impacts. The timing of sampling must also be appropriate because of the prevalence of migration into and out of tributaries from large rivers, lakes and the ocean by different species and life stages. For example, recent work on bull trout has illustrated the variety of life-history strategies adopted by the species, including adults that make multiple migrations into and out of the marine environment (Brenkman and Corbett 2007). The nature of the long-term monitoring required in these cases will be driven by the identification of potential impacts in the EIA, and should be determined through consultation with the regulatory agencies. Examples of the type of baseline characterization and monitoring that may be required are: monitoring fry outmigration using fyke nets or drift nets (Conlin and Tutty 1979); monitoring juvenile migration using PIT tag technology (e.g. Aarestrup *et al.* 2003); monitoring adult migration using radiotelemetry tags and either mobile or fixed antenna (e.g. Keefer *et al.* 2004); monitoring adult salmonid migration using fixed-location split-beam hydroacoustics (Ransom *et al.* 1998); determining life-history patterns through otolith microchemistry (e.g. Gillanders 2005, Brenkman and Corbett 2007); and monitoring spawner distribution and density through angling, snorkel surveys and redd counts. A summary of the various field sampling protocols for studying salmonids was recently published by the American Fisheries Society (Johnson *et al.* 2007) and should be consulted when choosing the appropriate methodology.

Adoption of multiple sampling methodologies allows for a more thorough evaluation of fish responses to flow regulation on an individual and population level. Integration of the results on multiple fish species with invertebrate population metrics and environmental data, such as water temperature, also allows for an evaluation of ecosystem response. To complete the assessment of fish responses to project development at all four biological levels (cellular, individual, population and ecosystem), physiological studies may be required to measure responses at the cellular level. A recent literature review revealed an under-representation of studies that monitored the response to river regulation at the cellular level (Murchie *et al.* 2008). The monitoring of sublethal consequences to the prescribed flow regime may therefore be required on certain projects where individual or population level effects occur, but are not readily explained by the data collected for the standard monitoring program. Halser *et al.* 2009 recommend the monitoring sub-organismal responses (e.g., physiological or energetic consequences) of individual fish to hydropower infrastructure and operations, particularly to assess fish responses to fluctuating flows and fishways. Approaches that show promise for studying fish sub-organismal response include behavioural, energetic, genomic, molecular, forensic, isotopic, and physiological tools. A number of well-developed physiological techniques now exist that can be applied in the field (see Wikelski and Cooke 2006), which may be required to monitor specific issues at particular projects.

In addition to the monitoring of fish populations, changes to fish habitat may be of critical importance. For instance, the dewatering of spawning gravels both within the diversion section and the downstream section is of particular importance given that hydroelectric projects are often located on upstream reaches where fish migrate to spawn. Although the spawning habitats in these reaches may be limited in area, they can be critical to local populations of fish, supporting adult spawners and the recruitment of juveniles to extensive downstream reaches. The FHAP is to be used during the EIA to quantify the spawning gravels in the diversion section, providing a baseline estimate of habitat (see Lewis *et al.* 2004). Although geomorphologic studies monitor changes in sediment, providing some post-construction assessment of substrate, alterations in incubation habitat quality may be subtle and not visible as a change in substrate. For example, reduced intra-gravel velocities induced by flow reduction may in turn reduce egg-fry survival. In some cases, therefore, post-construction monitoring studies may be required to quantify the effects of flow change on spawning habitat and egg-fry survival. An example of the study design and methodology to monitor egg incubation and egg-fry survival is provided in Baxter and McPhail (1999). Growth rates during the fry stage have also been shown to vary with changes in flow caused by hydropeaking (Korman and Campana 2009). Studies of fry otolith microstructure may therefore be required if impacts on juvenile growth and condition are revealed during monitoring studies.

3.1.7 Water Quality

Background

Water use can affect water quality indirectly by altering the volume of water remaining in a channel, or directly by returning water of altered quality to the river channel (Hatfield *et al.* 2007). Reduction of flow can modify levels of dissolved oxygen, pH, low-level macro-nutrient parameters (N, P), total suspended solids, total dissolved gas pressure (TGP), total alkalinity and electrical conductivity. Water quality parameters will be maintained within strict parameter levels to ensure the protection of fish and fish habitat. Water quality alteration is expected during the construction phase of hydroelectric projects, when small, short-term increases in suspended sediments may occur despite the use of best management practices. Longer term changes in suspended sediment concentrations may also occur due to altered dilution ratios, resulting from reduced flows in the diversion section and inputs from other tributaries. Water quality issues may also arise where reservoirs are planned or headponds will inundate vegetation. Concerns in these instances include mercury methylation and subsequent bioaccumulation (Lewis *et al.* 2004).

The objective of monitoring water quality is to identify biologically significant changes to specific water quality parameters stemming from project development and operation. Long-term monitoring of water quality may not be required for all projects, with the decision as to whether to monitor or not dependent on the water quality data collected during baseline monitoring, and the potential impacts identified in the EIA. Water quality is a secondary monitoring parameter (Table 1), which should be monitored if the EIA predicted project-related changes in water quality that may affect the productive capacity of fish habitat.

Baseline Data Requirements

The same three locations used for monitoring water temperature should be used to monitor water quality: upstream of the intake and headpond (control), in the diversion, and downstream of the powerhouse (Lewis *et al.* 2004). As was the case for water temperature monitoring, water quality need only be assessed upstream of the proposed headpond and at the lower end of the proposed diversion prior to construction, unless water quality is expected to be different downstream of the proposed powerhouse, for instance by the presence of an incoming tributary. To establish baseline conditions, water quality samples should be collected on a quarterly basis for two years prior to project construction.

Some water quality parameters (e.g. dissolved oxygen and TGP) can be measured in situ using appropriate equipment and methodology (RISC 2006). For other parameters, water quality samples should be collected and handled following approved protocols outlined in the Ambient Freshwater and Effluent Sampling Manual (RISC 1997a), and sent to an accredited environmental laboratory for analysis. Unless a specific quality assurance/quality control (Qa/Qc) protocol is agreed upon, samples should be taken in triplicate to reduce the risk of erroneous data resulting from travel or field contamination. Further details on the design of a water quality monitoring program are outlined in the Guidelines for Designing and Implementing a Water Quality Monitoring Program in British Columbia (RISC 1998a). Table 3 lists the water quality parameters that will be sampled during the baseline characterization.

Table 3. List of water quality parameters to be sampled on stream-based hydroelectric projects.

Dissolved Oxygen	Ortho-phosphorus	Dissolved Organic Carbon*
Total Gas Pressure	Total Phosphorus	Sulfate*
Alkalinity: Total	Total Dissolved Solids	Total Metals (including Ultra Trace Mercury and Methylmercury)*
Nitrogen: Ammonia	Total Suspended Solids	
Nitrogen: Nitrate	Turbidity	Dissolved Metals (including Ultra Trace Mercury and Methylmercury)*
Nitrogen: Nitrite	Specific Conductivity	
pH		

* Parameters only need to be measured if the stream is the receiving water for a lake that has been dammed (or a reservoir that has been created) and soil and vegetation around the lake are expected to be flooded.

Monitoring Requirements

Water quality monitoring will be required if the EIA identified parameters that may be affected by the project to a degree that the productive capacity of fish habitat may be adversely affected. The protocol, frequency and timing adopted for long term monitoring will depend on the parameter being monitored and the duration, frequency and timing of potential effects identified in the EIA. For instance, critical periods exist for measuring some parameters and these vary among streams. The parameters, timing and frequency of sampling must therefore be identified by a qualified professional (Lewis *et al.* 2004). For some projects, water quality samples may only be required biannually, coinciding with low flow events at the beginning and end of the growing season (most likely April and October). Other projects may require quarterly or more frequent sampling of some parameters.

If long-term monitoring of water quality is required, samples will be collected in years 1 through 5 post-construction, to coincide with the frequency of other monitoring components, unless there is a defensible rationale to vary from this schedule. The RISC manual Guidelines for Interpreting Water Quality Data (RISC 1998b) provides direction for screening, editing, compiling, presenting, analyzing, and interpreting water quality data.

Details on this monitoring program can be found summarized in Table 16.

3.1.8 Invertebrate Drift

Background

Macroinvertebrates and their habitats are included in instream flow assessments because salmonid growth and abundance have been shown to be correlated to the abundance of drifting invertebrate prey (e.g. Huryn 1996). Maintenance of food sources for fish is therefore the primary motivation for macroinvertebrate monitoring. However, the density, biomass and community composition of invertebrate drift are indicators of stream productivity, and therefore also serve as an indicator of general system health. Numerous studies have shown changes in invertebrate density, distribution and taxonomic composition in response to flow regulation, although the magnitude of biological response varies among locations and with characteristics of the regulated flow regime (Harvey *et al.* 2006, Wills *et al.* 2006, Dewson *et al.* 2007).

Monitoring invertebrate drift is a secondary monitoring parameter (Table 1) and may not be required for all projects. The decision to monitor or not depends on results from baseline monitoring of invertebrates and fish, and the potential project impacts identified in the EIA. For example, long-term monitoring of invertebrates is likely required if the EIA determined that project effects may adversely affect the invertebrate population to the extent that the productive capacity of fish habitat may be reduced. Also, invertebrates monitoring may be required for non-fish-bearing streams as the primary biotic indicator of project effects on the stream ecosystem, and to ensure that the food supply to downstream fish-bearing reaches is maintained. The inclusion of invertebrates in the long-term monitoring program should be based on professional judgement and discussion with the regulatory agencies.

Baseline Data Requirements

As per Hatfield *et al.* (2007), baseline data on invertebrate drift density, biomass and community composition should be collected in a minimum of three locations, one within the diversion section (impact), one upstream of the intake and headpond (control), and one downstream of the tailrace. Further sampling sites may be required depending on the length of the proposed diversion, with the goal of adequate representation of the affected stream reach. The downstream section may also be critically important for the assessment of impacts to fish habitat, particularly if the diversion and upstream sections are fishless. It is important that sampling sites are located in representative habitat in the downstream half of a riffle section. To the extent possible, drift samples will be taken in areas with water velocities of 20 to 40 cm/s. All sites will be georeferenced so that the same sites can be used for future monitoring.

Two years of baseline data on invertebrate drift should be collected. It is recommended that sampling occur twice during the main growing season (usually May through October): once at base flow conditions, and once during low to moderate flows, with at least one month between the two sampling dates to avoid autocorrelation and pseudo-replication. Sampling windows will be narrow on streams dominated by snow and glacial melt, and where high flows persist until cold weather conditions.

Invertebrate drift should be characterized using vertically fixed drift nets that are suspended and fixed in the water column using rebar (or another method of securing them without affecting flow) for a set period of time. Five replicate samples should be collected simultaneously at each site on each sampling day. It is recommended that the mesh size of the samplers be 250 µm to capture invertebrates most typically consumed by fish. Drift should be sampled in the daytime to reflect prey abundances available to fish. However, sampling in mid-day in low productivity streams should be avoided. Sampling should begin as close to dawn as possible (but at least one hour after dawn, as per Hatfield *et al.* 2007) with nets deployed for a sufficient period to gather an adequate drift sample and minimize variance (typically four to six hours, but may be shorter depending on drift conditions). For further details on the methodology to be used for the collection of invertebrate drift refer to Appendix A in Hatfield *et al.* (2007).

All invertebrate drift samples should be preserved for analysis in the lab following RISC methods (1997b), where they should be filtered, sorted into size classes, identified to family or genus, enumerated and weighed. Enumeration may rely on subsamples depending on the abundance of invertebrates in each sample. Taxonomic identification to family level should be performed on all samples, with identification to the level of genus, where possible, being done for at least one of the five samples. Density (# of individuals) and biomass (mg dry weight) data will be expressed as units per m^3 of water, where volume is the amount of water filtered through the net during the set. Community composition will be examined by calculating family richness (# of families present), family dominance (top five ranked families in terms of % contribution to total biomass), family diversity (Simpson's diversity index scores), and community structure (Bray-Curtis Index). The Bray-Curtis similarity index is a commonly used measure of multi-taxa invertebrate communities when quantifying the relative resemblance of samples (e.g. diversion reach vs. control, pre- and post-development). These metrics will therefore allow a comparison to be made between seasons and sites prior to construction, and provide the required baseline information against which to monitor change using the BACI or a suitable alternative approach.

Monitoring Requirements

If long-term monitoring of invertebrate drift is required, sampling should occur in years 1 through 5, with samples collected from the same sites as those used during baseline surveys. Monitoring should occur twice in the growing season at similar flows to those sampled prior to construction to facilitate comparison with baseline data using the BACI or a suitable alternative approach. In addition to evaluating changes to the metrics described above, the Canadian Ecological Flow Index (CEFI) enables a multispecies assessment of the effects of flow alteration that is minimally influenced by confounding factors (e.g., stream type, organic enrichment) (Armanini *et al.* 2011). The CEFI may therefore act as a valuable tool in assessing whether flow-related ecosystem impairment is occurring as a result of project operation. A report describing the results and comparing them to the baseline should be produced on an annual basis.

Details on this monitoring program can be found summarized in Table 17.

3.1.9 <u>Species at Risk</u>

In addition to the potential impacts on fish and fish habitat, hydroelectric projects have the potential to impact aquatic species at risk, primarily through habitat loss or degradation. The *Species at Risk Act* (SARA) (Government of Canada 2002) provides protection for legally listed species and their critical habitats, and is administered by the Minister of Environment, Minister of Fisheries and Oceans and Parks Canada. The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) provides advice to government on the status of wildlife species and was established as a legal entity under SARA. COSEWIC assesses and classifies the status of wildlife using the best available information on the biological status of a species, including scientific knowledge, community knowledge, and Aboriginal traditional knowledge. Once COSEWIC designates an aquatic species as endangered or threatened, DFO must provide advice to the Minister of Environment on whether the species should be listed for legal protection under SARA.

It is the responsibility of the proponent to identify any species at risk that inhabit the project area. Species identification may be through dialogue with regulators, examination of COSEWIC and SARA species lists, and through field studies. Examples of SARA-listed species that may be impacted by hydroelectric projects within British Columbia are the speckled dace (*Rhinichthys osculus*) and the Northern red-legged frog (*Rana aurora*). Potential impacts to these species or their critical habitat must be identified and mitigation measures set forth in the EIA to avoid or lessen adverse effects. Mitigation measures will be consistent with the applicable recovery strategies and action plans, and monitoring will occur to determine project effects on the species and/or the critical habitat.

A permit under Section 73 of SARA will be required for any activity that affects a listed wildlife species, any part of its critical habitat, or its residences. Further information on species at risk and permitting requirements can be found on the SARA public registry (http://www.registrelep-sararegistry.gc.ca/default_e.cfm) and the DFO website (http://www.dfo-mpo.gc.ca/species-especes/index-eng.htm).

If species of concern are identified for the project area, baseline data and monitoring requirements will be designed specifically for that species and its habitat requirements, behaviour and vulnerability to project impacts. Note that very strict specifications for monitoring and data collection are likely to be required in the design of the monitoring program. The design of the monitoring program should be based on information contained within the species' status report commissioned by COSEWIC, as this will usually contain the best available information on the biology and habitat requirements of the species. COSEWIC status reports are available online at: http://www.sararegistry.gc.ca/sar/assessment/status_e.cfm.

3.2 LAKES AND RESERVOIRS

For hydroelectric projects situated at the outlet of a lake, or those intending to flood large areas to create new reservoirs, monitoring requirements will almost certainly be more extensive than for stream-based projects. Minimum baseline data collection will follow the lake inventory requirements as outlined in the Reconnaissance (1:20,000) Fish and Fish Habitat Inventory (RISC 2001). Due to the potential impacts of water storage and drawdown, additional information may be required through increased sampling effort or the use of more techniques than outlined in the RISC process. Such additional monitoring required on lakes and reservoirs will be developed on a case-by-case basis using the residual effects predictions of the EIA as a starting point for development of the monitoring program.

Table 4 lists the additional parameters that will be included in the monitoring program for a new or upgraded (as defined in Section 1.1) hydroelectric project that involves a lake or reservoir. The stream-based parameters described in Section 3.1 will still require monitoring in the diversion and downstream sections. The lake monitoring requirements described below will also be conducted at a suitable control lake (see Section 1.4) following the BACI design, or the BA monitoring design may be used when no suitable control exists. As was the case for stream-based projects, the individual components of a monitoring plan will vary on a project-specific basis. However, primary baseline parameters listed in Table 4 are those that will be monitored for all projects, while secondary parameters will be required for some projects, depending on potential residual effects identified in the EIA.

Table 4. Additional monitoring parameters and their associated baseline data requirements, frequency and duration of monitoring for hydroelectric projects involving a lake or reservoir.

		Baseline Requirements		Monitoring Requirements		
Parameter[1]	**Monitoring Type**	**Frequency**	**Duration**	**Frequency**	**Duration[2]**	**Reporting[3]**
Primary						
Bathymetry	Response	Once	One assessment	Every 5 years	Life of project	Every 5 years
Water quantity	Compliance/Effectiveness	Continuous	Three years	Continuous	Life of project	Annually
Limnology and water quality	Response	Quarterly	Two years	Bi-annually	Years 1 to 5	Annually
Fish habitat	Response	Once	One assessment	Annually	Years 2 and 5	Annually
Fish abundance and behaviour[4]	Response	Annually[5]	Two years[6]	Annually[5]	Years 1, 2, 3, 5 and 10	Annually
Secondary						
Zooplankton and invertebrate abundance	Response	Bi-annually	Two years	Bi-annually	Years 1 to 5	Annually
Species at risk	Response	Species-dependent[7]		Species-dependent[7]		-

1: Primary parameters must be monitored in all projects, monitoring of secondary parameters must be determined on a case-by-case basis.

2: Monitoring may be extended past the prerequisite minimum of five years following the renewal of the *Fisheries Act* Authorization or Letter of Agreement.

3: Non-compliance must be reported within 24 hours and measures taken to ameliorate risk.

4: It is critical that baseline studies not only provide data on how many fish are supported by the habitat, but how, both in terms of the type of habitat provided (foraging, winter refuge, spawning) and the timing of habitat use.

5: Some fish populations may require sampling of all critical life phases on an annual basis (i.e., multiple sampling periods each year).

6: More than two years of baseline data may be needed in lakes that support anadromous species, high-valued sport fish or complex fish assemblages. See text for more details.

7: Baseline data and monitoring requirements for species at risk are species-dependent.

3.2.1 Physical Lake Characteristics

Background

For hydroelectric projects located at the outlet of a lake, it will be necessary as part of the EIA process to provide general information on the characteristics of the lake and predict what impact, if any, the project will have on the physical aspects of the lake. For instance, installing a dam will increase sedimentation levels over the long term, while increasing access to the lake may alter land use around the lake as a whole, thus potentially subjecting the ecosystem to additional stressors unrelated to the hydroelectric project itself.

The immediate impacts will be far greater if a reservoir is being created by flooding riparian habitat. In this instance, the area to be impacted will need to be surveyed beforehand to determine the loss of aquatic and riparian habitat, with additional information collected following project commissioning to determine the actual footprint impact and describe the physical nature of the new reservoir. The baseline aquatic, riparian and actual footprint impact assessments will be conducted following the methodologies described in Section 3.1.3. Table 17 outlines the components of a bathymetry monitoring program for lake-based hydroelectric projects.

Baseline Data Requirements

The baseline data required include information on terrain characteristics, such as lake setting, lake basin genesis, aspect, hillslope coupling, slope stability, land use and access, as well as shoreline characteristics, including shoreline type, cover and recreational facilities, if any. Full details of the requirements can be found in the RISC (2001) standards. A series of photographs illustrating the physical and biological features of the lake will also be collected.

Lake bathymetry is essential for the evaluation of the potential effects of storage projects. Many lakes have already been surveyed in British Columbia, with bathymetric maps readily available online from the Fisheries Inventory Data Queries (FIDQ). If not available from previously conducted work, a bathymetric survey will be conducted following the methodology in the Bathymetric Standards for Lake Inventories (RISC 1999) to provide details on mean and maximum depth, volume, and extent and distribution of littoral areas. In addition to being the baseline against which to monitor long-term sedimentation following project commissioning, this bathymetric map will be required in planning other aspects of the baseline studies, such as the location of sampling sites, as well as providing initial information on the types of fish habitat available.

Monitoring Requirements

Changes to the physical properties of a lake from storage operations are expected to be minimal and occur over a long period of time. However, there may be increases in sedimentation from shoreline erosion, altered deposition patterns at tributary mouths, and changes in land use that may affect the other parameters being measured and will therefore be collected to aid in the interpretation of results. A bathymetric survey and review of physical parameters is therefore required every five years following project commissioning, with a report produced describing the results and any changes that have occurred.

3.2.2 Water Quantity

Baseline monitoring requirements for water quantity at a hydroelectric project involving a lake or reservoir are the same as those described for a stream-based project. Initially, lake elevation and discharge at the outflow must be monitored by installing a suitably located gauging station, established following guidelines set forth in the Manual of British Columbia Hydrometric Standards (RISC 2009). The guidelines for impact assessment (Hatfield *et al.* 2007) require a minimum of one year of on-site hydrometric data. However, a minimum of two years of baseline on-site hydrometric should be collected given that lake elevation and discharge data are critical to the interpretation of changes in the other monitoring components (Water Permitting Information Requirements, MoE 2009). Given the typical development timeline for hydroelectric facilities, three or more years of on-site hydrometric data may be available prior to construction. Project impacts on lake levels and downstream flow, and the concomitant impacts on water quality, fish habitat and aquatic and terrestrial wildlife, will be described in the EIA along with the mitigation and compensation measures that will be employed. Monitoring requirements to ensure compliance with, and the effectiveness of, prescribed lake elevation limits, instream flow requirements and ramping rates are as described in Section 3.1.1.1 and Section 3.1.1.2.

3.2.3 Limnology and Water Quality

Background

The objective of monitoring water quality is to identify biologically significant changes to specific water quality parameters stemming from project development and operation, and to ensure that water quality parameters are maintained within levels that protect fish and fish habitat. Patterns of water storage and release that vary from natural conditions have the potential to alter water quality in a lake or reservoir. For instance, inundation of riparian habitat on a short-term or regular basis will introduce additional nutrients to the waterbody. Furthermore, significant retention or release of water during the summer months is likely to impact the depth of the thermocline and/or the timing of its formation, while water levels during winter will impact ice formation and the amount of dissolved oxygen under the ice. As part of the EIA, numerical temperature models will be developed that predict the effects of the proposed operation regime on water elevations in the lake, and how these changes will impact temperature and dissolved oxygen concentrations, particularly at the critical periods in summer and winter. Depending on the proposed operation regime, the location of the intake pipe, and the location from which spill water will be obtained (i.e. surface or deep), stream water temperatures may also be impacted in the diversion and downstream sections. These potential temperature changes will also be modelled for the EIA.

Water quality alteration may also occur during the construction phase of hydroelectric projects, when small, short-term increases in suspended sediments may occur both downstream and within a localized area of the lake, despite the use of best management practices. Table 18 outlines the components of a limnology and water quality monitoring program for lake-based hydroelectric projects.

Given the potential impacts that operation of a hydroelectric facility may have on the productivity of a lake or reservoir, estimates of phytoplankton biomass should be determined in conjunction with the monitoring of physicochemical water quality parameters. Phytoplankton are microscopic algae that occur as unicellular, colonial, or filamentous forms and constitute the base of the food chain in lake and reservoir ecosystems. They have long been used as indicators of water quality in lentic environments (Rawson 1956, Palmer 1969, Stoermer and Yang 1969) given their varying sensitivities to nutrient concentrations, organic, and chemical wastes, as well as their quick response to environmental change (due to their short life cycles). Their abundance and species composition therefore indicate the water quality of the waterbody in which they are found (APHA 1999). Nevertheless, their transient nature and patchy distribution can make data interpretation difficult and the information collected is best used in conjunction with the physicochemical and other biological data collected.

Phytoplankton biomass is typically estimated by determining the concentration of photosynthetic pigments, primarily chlorophyll *a* (APHA 1999 and references therein). Chlorophyll *a* constitutes approximately 1 to 2% of the dry weight of planktonic algae, the concentrations of which can be determined by spectrophotometric, fluorometric, and high-performance liquid chromatographic (HPLC) techniques (see APHA 1999 and references therein). Chlorophyll *a* data are often used as an indicator of the productivity of an aquatic ecosystem in monitoring programs (e.g., the Environmental Effects Monitoring (EEM) program for metal mines; Environment Canada 2002).

Baseline Data Requirements

Physicochemical Parameters

A georeferenced limnological station should be established at the deepest point in the lake so that limnology data and water samples are collected through the entire water column and from the same location each season and year. Depending on the bathymetry of the lake and the location of the proposed dam, additional sampling stations may be required. For instance, if a lake consists of two deep basins separated by a shallow shelf that hinders water mixing, samples may be required from both basins. The following baseline limnology and water quality data should be collected on a quarterly basis for a minimum of two years.

A Secchi depth should be determined at each sampling location, along with a dissolved oxygen/temperature profile. Water samples should then be collected at the surface (at 0.5 m depth) if the lake is <6 m deep, and at the surface (0.5 m depth) and bottom (1 m above the bottom) if the lake is >6 m deep. For Qa/Qc purposes, samples will be taken in triplicate to reduce the risk of erroneous data resulting from travel or field contamination. Samples will be sent for analysis at an accredited environmental laboratory as soon as possible to avoid deterioration. Further details on water quality sampling procedures are explained in the Ambient Freshwater and Effluent Sampling Manual (RISC 1997a), and the Guidelines for Designing and Implementing a Water Quality Monitoring Program in British Columbia (RISC 1998a) provide further details on program design. The water quality parameters that will be examined during baseline data collection, in addition to dissolved oxygen, are listed in Table 5.

Total and dissolved metal concentrations in water should be assessed as part of the baseline data requirements to examine the potential effects of local geology and land use, and assist in the determination of potential project impacts during the EIA process. The requirement to include metals analysis in the long-term monitoring program will be dependent on the baseline results and the findings of the EIA. Similarly, the need to monitor both alkalinity and total phosphorus can be assessed following the EIA.

As a result of concerns over mercury methylation and bioaccumulation following flooding of soil and vegetation, dissolved organic carbon and sulfate (which can affect bioaccumulation, USEPA 2010), total mercury, dissolved mercury, total methylmercury, and dissolved methylmercury should also be measured in water quality samples (Table 5). Note that due to the ubiquitous nature of mercury and the ultra-trace nature of mercury tests, field blanks should be collected and should incorporate all aspects of sampling operations, including filtration.

Mercury methylation tends to be highest in surface sediments containing freshly deposited organic material and in warm shallow sediments; it is also a concern following the flooding of dry land due to mercury methylation in newly flooded organic material (CCME 2003). Accordingly, if flooding of land is expected, sediment quality sampling should be conducted for both lake sediments and the soil that will be inundated following dam construction. The behaviour of mercury in sediments and the bioavailability to aquatic life is dependent on a number of physicochemical parameters (Environment Canada 1997, CCME 2003, USEPA 2010). The parameters that should be quantified in sampling of lake sediment and soil to be inundated are provided in Table 6. Further information regarding mercury and methylmercury in sediments can be found in USEPA (2010), CCME (2003), and CCME (1999).

Following the first summer sampling, continuous water temperature loggers should be installed at various depths at the limnological station, with the number and depths of loggers determined based on the water temperature/dissolved oxygen profile. A similar array of loggers should be installed relative to the thermocline in the reference lake. A minimum of two temperature loggers should be installed and anchored at each limnological site to measure surface water and deep water temperatures every hour or less. Water temperature data should be downloaded a minimum of twice per year, or more often if practical. To account for temperature differences that occur with depth, water temperature loggers should either be installed to maintain a constant depth despite elevational changes, or be corrected for changes in water surface elevation. Despite the continuous recording of water temperature, temperature/dissolved oxygen profiles are still required on each subsequent quarterly sampling date. A minimum of two years of continuous water temperature data should be collected prior to project construction.

In addition to the parameters listed in Table 5, transparency is an additional parameter that will be monitored to meet other standards, such as the EcoLogo criteria for renewable low-impact electricity certification.

Table 5. List of physicochemical water quality parameters to be sampled for lake or reservoir hydroelectric projects.

Temperature/Dissolved Oxygen Profile	pH	Dissolved Organic Carbon*
Total Gas Pressure	Ortho-phosphorus	Sulfate*
Secchi Depth	Total Phosphorus	Total Metals (including Ultra Trace Mercury* and Methylmercury*)
Alkalinity: Total	Total Dissolved Solids	
Nitrogen: Ammonia	Total Suspended Solids	Dissolved Metals (including Ultra Trace Mercury* and Methylmercury*)
Nitrogen: Nitrate	Turbidity	
Nitrogen: Nitrite	Specific Conductivity	
Nitrogen: Total		

* Parameters only need to be measured if soil and vegetation are expected to be flooded.

Table 6. List of physicochemical sediment quality parameters to be sampled for lake or reservoir hydroelectric projects (lake sediment and soil to be inundated following dam construction).

Ammonia (available)	Redox Potential
Nitrate	Particle Size Analysis
Nitrite	SEM-AVS (Simultaneously Extracted Metals and Acid Volatile Sulfides)
Total Phosphorus	Metals (including Ultra Trace Mercury and Methylmercury)
Sulfate	Loss on Ignition (to Normalize Sediment Mercury Concentrations)
pH	Temperature (lake sediments only)

Sampling only needs to be conducted if soil and vegetation are expected to be flooded.

Biotic Parameters – Phytoplankton

Given the potential impacts that operation of a hydroelectric facility may have on the productivity of a lake or reservoir, estimates of phytoplankton biomass through measurement of chlorophyll *a* on a quarterly basis for two years. More frequent sampling is likely to be required in the growing season to determine how productivity changes over time and how this may affect the fish population. Furthermore, given the transient nature and patchy distribution of phytoplankton biomass (Moss 1998, Scheffer 2004) sampling will be required not only at the limnological station at the deepest point in the lake, but at a number of other sites. The number of sampling points, location, depth and frequency of sampling required will depend on the size, morphology and nutrient inputs into the lake or reservoir, but must be sufficient to gain a good understanding of the abundance and distribution of phytoplankton and how this influences the productive capacity of fish habitat. Sampling requirements should therefore be determined on a case-by-case basis

The taxonomic composition of the baseline phytoplankton community will also be determined so that project effects on community composition can be determined. Samples for both chlorophyll *a* and taxonomy should be collected in triplicate from each sampling location. Guidance on sampling methodology can be found in the Standard Methods for the Examination of Water and Wastewater for plankton (Method #10200) published by the American Public Health Association (APHA 1999), and adopted for the EEM program (Environment Canada 2002).

Phytoplankton community composition should be examined by calculating family richness (# of families present), family dominance (top five ranked families in terms of % contribution to total biomass), family diversity (Simpson's diversity index scores), and community structure (Bray-Curtis Index). These metrics will allow a comparison to be made between years and sites prior to construction, and provide the required baseline information against which to monitor change using the BACI, BA, or RCA approach.

Monitoring Requirements

Water quality and phytoplankton will be monitored in years 1 through 5 after project commissioning, after which the need for a water quality monitoring program should be re-assessed. In cases where dry land or vegetation is flooded, sediment quality will also be monitored in years 1 through 5. At a minimum, long-term monitoring of physicochemical water quality parameters will be conducted in the summer and winter, and productivity should be monitored at least twice during the main growing season by determining phytoplankton biomass and community composition. More regular sampling may be required based on the potential for residual effects on water quality or productivity identified in the EIA. Similarly, the number and location of sampling sites should be based on professional judgement and through discussion with the regulatory agencies. Results of water quality monitoring should be reported on an annual basis.

3.2.4 Fish Habitat

Background

The impacts to fish habitat from water retention and release are likely to be concentrated in the littoral zone, which provides the majority of fish spawning and rearing habitat within most lakes. The form and severity of impacts will depend on factors such as the slope and substrate characteristics of the littoral zone, the type and extent of aquatic and riparian vegetation, and the fish species present and their use of the littoral zone and/or tributaries. Fluctuating lake or reservoir levels may affect the amount and quality of spawning and rearing habitat, alter the accessibility of spawning grounds for species that spawn in tributaries, change the amount and species composition of aquatic and riparian vegetation, alter the input of nutrients into the lake, impact egg to alevin survival through desiccation or increased risk of ice scour, and alter bank stability and thus impact sediment input.

The scope of potential impacts to fish habitat will vary depending on littoral zone characteristics. For example, the same decrease in lake elevation will cause more aquatic habitat to be lost, in terms of surface area, in littoral areas with shallow slopes than those with steeper slopes. To exacerbate this greater quantity of habitat loss, littoral zones with shallow slopes are often better quality fish habitat, with cobble and boulder substrates, compared with steep littoral zones, which are often characterized by bedrock or silt substrates that are less frequently used by fish.

Table 19 outlines the components of a fish habitat monitoring program for lake-based hydroelectric projects.

Baseline Data Requirements

Results of the bathymetric and limnological surveys will quantify the area of deep water and littoral habitat, with littoral habitat typically <6 m depth (RISC 2001), although this can vary depending on water quality and light penetration. A shoreline habitat assessment will also be conducted to determine the quality and variety of habitats present within the littoral zone. The littoral zone habitat assessment should be conducted using geocoded and orthorectified aerial photographs combined with ground inspection of the habitat either by boat or walking the shoreline. The littoral zone should be delineated and mapped into habitat units based on depth, substrate, vegetation and cover. Details to be recorded, as percent coverage in each habitat unit, include: substrate types present and the degree of embeddedness by fine sediment; the presence and areal extent of macrophyte communities; and the presence of large woody debris or overhanging vegetation cover. The resulting shoreline habitat map should identify spawning and rearing areas for lake-resident species that do not use tributaries to spawn. These data can also be used to create a Habitat Suitability Matrix (HSM) model (Minns *et al.* 2001, Frezza and Minns 2002) similar to the HSI models used to determine instream flow requirements.

As some lake-resident species use tributary streams to spawn and rear, it is also necessary to conduct fish habitat surveys in the inlet and outlet streams. The first reach of all inlets and outlets will be surveyed according to the 1:20,000 stream inventory standards (RISC 2001). Particular emphasis should be placed on describing barriers to fish passage and the extent and quality of spawning and rearing habitat.

Monitoring Requirements

The littoral zone mapping exercise and habitat surveys on inlets and outlets should be repeated two and five years after project commissioning and the results compared with the baseline. Particular attention should be focused on key spawning and rearing areas identified during the baseline studies. For instance, shallow, sheltered bays that often contain fine substrates and aquatic vegetation provide spawning and rearing habitat for certain species. These areas may be particularly vulnerable to changes in water level, either through isolation and drying up, or depth increases that result in the loss of aquatic vegetation. Monitoring results should be reported to DFO on an annual basis with significant changes highlighted, along with the potential impacts of these changes to the fish populations present.

In addition, any fish habitat compensation projects that affect lake habitat will need to be monitored on a more regular basis to ensure that the habitat is functioning as designed. Monitoring of habitat compensation projects is required in years 1, 2, 3, 5 and 10 (see Section 3.1.2.3).

3.2.5 <u>Fish Community</u>

Background

The potential effects of a hydroelectric project on fish community health within a lake or reservoir are expected to result from changes in water quality and temperature, zooplankton and benthic invertebrate abundance and diversity, and habitat availability and accessibility. As described in Section 3.1.6, monitoring of the fish community will first establish all species and life-history stages that use the lake or proposed reservoir, the proposed diversion reach and the downstream reach. In systems with diverse species assemblages and high ecological values, it may be appropriate to monitor the entire fish community. In systems with relatively simple fish assemblages, it may be appropriate for extensive sampling to concentrate on a target species, which may or may not be the same species as the focal species selected for monitoring below the dam. Nevertheless, abundance data should be collected for all species given the potential for unanticipated impacts to arise, and the need to identify changes in the fish community. Fish sampling permits from DFO and the Province must be in place prior to fish sampling.

Table 20 lists the components of a fish community monitoring program for lake-based hydroelectric projects.

Baseline Data Requirements

Fish species presence, relative abundance, distribution, timing of migration and community characteristics, such as condition and size-at-age relationships, will be determined using a minimum of two gear types appropriately suited to the range of habitats present. The standard gear types for sampling lake habitat are gillnets and minnow traps. As described in the Fish Collection Methods and Standards (RISC 1997a), both six-panel floating and sinking gillnets with mesh size ranging from 25 mm to 89 mm should be deployed perpendicular to the shore in both shallow, littoral habitat and deep water habitat. The location and depth of gillnet sets should be recorded and monitored in the same approximate locations on an annual basis. The number of gillnet sets required will vary according to the size of the lake and complexity of habitat available. Soak times will also vary depending on the density of fish present. Lakes that are densely populated will require short soak times to minimize mortalities, while those that are sparsely populated will require longer soak times to adequately determine population size. The number and soak time of gillnet sets should be based on professional judgement and experience. In addition to the deployment of gillnets, a minimum of six minnow traps must be set overnight in shallow water habitat (<1 m deep) to sample juveniles and small-bodied species (RISC 2001).

Sampling using gillnets and minnow traps are considered the minimum requirement to determine fish presence and abundance. Alternative methods may also be required to determine fish distribution relative to available habitat, or to capture different species or life-history stages (see Weaver *et al.* 1993, Fago 1998). Alternative fishing methods include fyke nets (Ruetz *et al.* 2007), hydroacoustic surveys (see Stables and Thomas 1992), crayfish traps (large minnow traps set overnight in depths from 2 to 12 m), setlines, angling, electrofishing and beach seining. Wherever applicable, soak time and the number of fish captured in each net or trap should be recorded in order to calculate catch-per-unit-effort (CPUE). Sampling effort must be sufficient to adequately describe the fish community present, in terms of biomass and relative abundance, and its habitat use.

To aid in the determination of population density for the focal species, a mark-recapture program is recommended. Certain projects where significant lake effects are anticipated, or where sensitive fish species or life stages exist, may also require additional studies examining fish diet, distribution of overwintering fish, fry growth in nearshore environments (e.g. Korman and Campana 2009), and migration into and out of the lake (Gillanders 2005). The amount of baseline data required will depend on expected project impacts, and is therefore at the discretion of the professionals undertaking the studies and should be determined in consultation with the regulatory authorities.

All fish captured should be counted and identified to species. A Field Key to the Freshwater Fishes of British Columbia exists to aid in the identification of species (RISC 1994). Voucher specimens should be collected for species that cannot be identified confidently in the field (RISC 1997a). For each species, all individuals up to a maximum of 200 should be measured (fork length), and all individuals will be counted. Sixty randomly selected individuals (or all if $n < 60$) should be sampled for weight, sex, maturity (visually if possible, and only by internal examination if an incidental mortality) and age (take samples from several representatives of each size group of each species). These physical data will be used to evaluate baseline fish condition and size-at-age relationships. A colour photograph of at least one representative fish of each species should be taken.

The federal mercury guidelines for the protection of aquatic life (CCME 2003) state that to attain the highest degree of environmental protection, all Canadian Environmental Quality Guidelines for mercury (water, sediment, tissue, and soil) should be applied. Accordingly, mercury in fish should also be quantified if soil and vegetation are expected to be flooded by a lake or reservoir project. Should fish inhabit the lake and the stream to be affected by the project, both lake and stream populations should be the focus of study. If there are no fish in the lake but fish are present in the stream affected by the project, they should be the focus of study. Section 4.2 of USEPA (2010) provides sampling guidance for studying mercury concentrations in fish, including species, ages, parameters to be sampled (total mercury, methylmercury, lipid content, length, weight, and age), sample type (i.e., composite samples), study design, sampling frequency and timing, and sample size.

A minimum of two years of baseline fish community data should be collected before construction of the project. However, more extensive sampling will likely be required in systems that support anadromous species, highly valued sport fish, or a complex fish assemblage. In such instances, it may be necessary to monitor for one complete life-cycle of the anadromous species present, and/or sufficient time to gain a thorough understanding of how the habitat is used, both spatially and temporally. Sampling should initially be conducted in August or September during the growing season, although depending on the species present, other seasonal sampling periods may be required.

Monitoring Requirements

Fish community health will be monitored 1, 2, 3, 5 and 10 years post-construction. Net and trap locations from baseline data collection will be georeferenced to ensure that the same approximate location is sampled repeatedly in years post-commissioning. This will allow the use of paired comparisons with greater statistical power. The level of sampling effort and timing of sampling should also be consistent across years, with sampling occurring late in the growing season during August or September. To maintain the effectiveness of the mark-recapture study in determining population density of the focal species, additional marking of individuals may be required as the population ages. As was the case for stream-based monitoring, requirements for the adoption of additional sampling techniques and analyses will depend on the baseline results and identification of potential impacts in the EIA. Details on the monitoring and population assessment requirements may therefore vary on a case-by-case basis and are to be determined through consultation with the regulatory agencies.

3.2.6 Zooplankton and Benthic Invertebrates

Background

The inclusion of zooplankton and benthic invertebrates in a long-term monitoring program may be required for two reasons. First and foremost, zooplankton and benthic invertebrates are a key component of fish diet, and are thus an important component of fish habitat protected under the *Fisheries Act*. Secondly, because they occupy a lower trophic level than fish, they are often affected more rapidly by adverse or positive change and therefore serve as an early warning system and indicator of general ecosystem health. However, long-term monitoring of zooplankton and benthic invertebrates may not be required for all projects, with the decision as to whether to monitor or not dependent on the data obtained on invertebrate and fish populations collected during baseline monitoring, and the potential impacts identified in the EIA.

Table 21 outlines the components of a zooplankton and benthic invertebrate community monitoring program for lake-based hydroelectric projects.

Baseline Data Requirements

At a minimum, sampling will occur in conjunction with water and phytoplankton sampling and occur twice in the main growing season in two separate years. However, more frequent sampling may be required in the growing season to determine how productivity changes over time and how this may affect the fish population. As was the case for phytoplankton monitoring, sampling will be required not only at the limnological station at the deepest point in the lake, but at a number of other sites given the patchy distribution of zooplankton and benthic invertebrates (Moss 1998, APHA 1999). The number of sampling points, location, depth and frequency of sampling required will depend on the size and morphology of the lake or reservoir, and the use of the available habitat by different species and life-stages of fish. Sampling requirements should therefore be determined on a case-by-case basis. The goal of baseline monitoring is to characterize the zooplankton and benthic invertebrate populations and facilitate an assessment of whether project construction and operation are likely to affect these populations as well as the fish population within the lake or downstream. Monitoring should therefore focus on habitats most likely to be affected by project development and/or those most likely to be used by the different species and life-history stages of fish present. Baseline data will also provide the information against which to monitor change using the BACI, BA, or RCA approach, if the EIA determines that residual adverse effects may occur.

Zooplankton should be collected using a conical net with a specific mesh size that must be consistent between sampling periods. Suitable mesh sizes range from 64 µm to 256 µm, with the mesh size required for a particular lake depending on the productivity of the lake. The smallest mesh size that does not result in clogging of the net should be used. Vertical tows are often used to collect a composite sample of the zooplankton present. Using this methodology, the net is lowered to a particular depth and pulled up through the water column at a rate of 0.5 m/s. The distance the net travels through the water should be recorded so that the total volume of water that passes through the net can be calculated. The net and cod end contents should then be rinsed into a clean sampling jar and the contents should be fixed with formalin for taxonomic identification and enumeration. Three replicate samples should be collected at each sampling location on each sampling date. Density and biomass data should be expressed as units per m^3 of water, where volume is the amount of water filtered through the net during the tow. Further details on various zooplankton sampling techniques are provided in APHA (1999) and the Freshwater Biological Sampling Manual (RISC 1997c).

Benthic invertebrates should be collected using an Ekman grab sampler and each sample sieved through a 200-µm mesh. The contents of the sieve should be rinsed to remove as much sediment as possible and the samples should be fixed in formalin for later taxonomic identification and enumeration in a laboratory by a qualified professional. Three replicate samples should be collected at each sampling location on each sampling date. Density and biomass data should be expressed as units per m^2, where area represents the size of the Ekman sampler used. For further details on the methodology for the collection and analysis of benthic invertebrates, refer to the Freshwater Biological Sampling Manual (RISC 1997c).

For both zooplankton and benthic invertebrates, community composition should be examined by calculating family richness (# of families present), family dominance (top five ranked families in terms of % contribution to total biomass), family diversity (Simpson’s diversity index scores), and community structure (Bray-Curtis Index). These metrics will allow a comparison to be made between years and sites prior to construction, and provide the required baseline information against which to monitor change using the BACI, BA, or RCA approach.

Monitoring Requirements

The long-term monitoring of zooplankton and benthic invertebrates is likely to be required if the EIA determined that project effects may adversely affect these populations to the extent that the productive capacity of fish habitat may be reduced. In these circumstances, sampling will be conducted in years 1 through 5, and should occur a minimum of twice in the main growing season on comparable dates with baseline data collection to facilitate comparison with baseline data using the BACI, BA, or RCA approach. The number and location of sampling sites should be based on professional judgement and discussion with the regulatory agencies. A report describing the results and comparing them to the baseline should be produced on an annual basis.

3.2.7 Species at Risk

Water storage areas associated with hydroelectric projects have the potential to impact species at risk, particularly if inundating large areas of terrestrial habitat for the creation of a new reservoir, or significantly altering water levels in existing lakes. However, as described in Section 3.1.9, no standard requirements for baseline data collection or monitoring are detailed in this document because the requirements will vary widely depending on the species of concern. It is the responsibility of the proponent to identify any species at risk that inhabit the area through dialogue with regulators, examination of COSEWIC and SARA species lists, and through field studies. A permit under Section 73 of SARA will be required for any activity that affects a listed wildlife species, any part of its critical habitat, or its residences. Potential impacts to these species or their critical habitat will be identified and mitigation measures set forth in the EIA to avoid or lessen adverse effects. Mitigation measures will be consistent with the applicable recovery strategies and action plans, and monitoring will occur to determine project effects on the species and/or the critical habitat.

Once a species of concern has been identified, baseline data and monitoring requirements should be designed specifically for that species and its habitat requirements, behaviour and vulnerability to project impacts. Note that there are likely to be very strict requirements for monitoring and collection that will be incorporated in the design of the monitoring program. Further information on species at risk and permitting requirements can be found on the SARA public registry (http://www.registrelep-sararegistry.gc.ca/default_e.cfm) and the DFO website (http://www.dfo-mpo.gc.ca/species-especes/index-eng.htm). The design of the monitoring program should be based on information contained within the species' status report commissioned by COSEWIC, as this will usually contain the best available information on the biology and habitat requirements of the species. COSEWIC status reports are available online at: http://www.sararegistry.gc.ca/sar/assessment/status_e.cfm.

4 REPORTING

All baseline data should be compiled in a report for agency review following completion of project construction. In each subsequent year, an annual monitoring report must be submitted that documents the findings of the previous year's monitoring and compares these results to the baseline. Some components such as stream channel morphology are not monitored on an annual basis, in which case the results of this monitoring should be included in the relevant annual report. Annual monitoring reports should detail the methods employed, the results of the monitoring, a comparative quantitative analysis of monitoring results to baseline conditions, and any recommendations for changes to project operation and/or the monitoring program and schedule.

Proponents that used assumed data to determine sample sizes in their proposed response monitoring plan must submit a revised response monitoring plan within 60 days of project completion. The revised plan should include power analyses completed on the actual baseline data to confirm appropriate sample sizes for response monitoring. If power analysis on the actual data indicates that there is no statistical justification for adjusting the response monitoring plan, a brief technical note should be submitted to the agencies within 60 days of project completion.

The effectiveness of any compensation works and the impacts of flow alteration in the diversion section must be quantified and compared to baseline conditions. In addition to the production of an annual monitoring report, the proponent must continue to communicate with the Province and DFO to ensure that the regulatory agencies are satisfied that the monitoring program meets the intent of reducing the uncertainties associated with the planned operating regime.

The exceptions to the annual reporting requirement are as follows:

- the construction monitoring report,
- the 'as-built' survey reports,
- the ramping rate study report, and
- the reporting on any non-compliance, emergency or unusual occurrences.

The construction monitoring report describing any environmental issues that arose during project construction should be submitted to the Ministry of Environment and DFO within 60 days of project completion (MWLAP 2004). Separate 'as-built' survey reports should be submitted for the project infrastructure and compensation habitat, with the report deadline being 60 days after completion of construction. The report describing the ramping rate study and results should be submitted within 30 days of the completion of commissioning tests. Further ramping rate tests and refinement of the prescribed ramping rate will be conducted through consultation with DFO. Any non-compliance events or emergency situations involving stream flows, ramping rates, water temperature extremes, or issues with either the fish screen or fishway, must be reported to MoE and DFO via telephone or email within 24 hours. Non-compliance reports describing the conditions of non-compliance, the contributing factors, and measures taken to minimize immediate and future impacts must then be submitted to DFO and MoE within a week of the incident. Non-compliance reports must be submitted in electronic format and comply with all requirements set forth by MoE in the Water Licence, and DFO in the *Fisheries Act* Authorization.

After five years of post-construction monitoring, a summary report will be required that evaluates the need for additional monitoring. At this stage, the *Fisheries Act* Authorization or LoA issued by DFO as part of the permitting process for the hydroelectric project will require renewal. The ongoing monitoring required after five years of operation will be determined at this juncture.

Monitoring reports should be prepared following a standard format suggested by the Council of Science Editors (2006). Sample documents may also be available from agency staff. All reports will be certified by an appropriately qualified professional.

In addition to the submission of standard monitoring reports, it is expected that regulatory agencies will collaborate in the development of a standardized data submission process to aid in the assessment of local and regional impacts of multiple projects. Standardized electronic forms for data submission will be created, similar to those that currently exist for data submission to the Fisheries Information Summary System (MoE 2008). Once this database has been established, the provision of long-term monitoring data will be a requirement of the DFO *Fisheries Act* Authorization or LoA, and will be governed by the regulatory agencies. The usefulness of such a resource for comparing data across many projects will rely on the adoption of the standardized monitoring methodologies outlined in this report.

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Table 7. Components of an instream flow monitoring program for hydroelectric projects.

Component	Description
Objective	To ensure compliance with instream flow releases
Description	Stage pressure sensors and channel discharge measurements
Comparison Criteria	Discharge measurements over a range of flows (i.e., between 10% and 200% MAD)
Location	Typically at and downstream of the intake, and downstream of the powerhouse
Duration	Headpond or reservoir stage monitoring for the life of the project. Discharge measurements may be terminated if headpond stage has been shown to accurately measure channel flow in the diversion section.
Methods	Continuous pressure transducers and/or velocity meters
Sample area	For pressure transducers: in headpond or river channel downstream of intake and powerhouse; for velocity meters: in instream flow release pipes.
Parameters	Stage in mm; discharge in m^3/s
Sensitivity/accuracy	±2 mm for pressure transducers (i.e., discharge rating accuracy of <7% with 20+ verticals)
Sample no.	To calibrate pressure sensors, 10 discharge measurements (20+ verticals) per stream; for headpond sensors, 6 measurements are to be taken at the level of minimum flow release to provide high accuracy during low flow levels
Frequency	15 second scan, two minute log
Timing	Continuous
Measure constraints	For pressure transducers, select a mainstem site with adequate protection from debris for the standpipe, avoid placing transducer downstream of major local inflow, and avoid sites that dewater in low flow. Wherever possible a stable hydraulic control (i.e. bedrock) should be used.
Analytical test	n/a (compliance monitoring)

Table 8. Components involved in testing and determining ramping rates for hydroelectric projects.

Component	Description
Objective	To test the effectiveness of standard ramping rates and, based on test results, determine long-term ramping rates that minimize the risk of stranding fish. *Flow ramping* is defined here as a gradual or progressive alteration of discharge in a stream channel resulting from the operation of a hydroelectric facility, with a *ramping rate* defined as the rate of flow change (i.e., m^3/s or cfs) or stage change (cm/h) per unit time (Cathcart 2005)
Description	Monitor ramping rates, survey for fish stranding
Comparison Criteria	Standard ramping rates are 2.5 cm/h when fry are present, and 5.0 cm/h at all other times
Location	Downstream of the intake and downstream of the powerhouse
Duration	Tests to be conducted during project commissioning to determine acceptable long-term ramping rates, after which compliance with these ramping rates will be monitored continuously for the duration of the project
Methods	Ramp down at the specified rates and measure the resulting stage change in sensitive habitats downstream of the powerhouse and intake; survey sensitive habitats for fish stranding
Sample area	Spot locations in sensitive habitats downstream of the powerhouse and intake
Parameters	Ramping Rate in cm/h; number of fish stranded
Sensitivity/accuracy	±2 mm
Sample no.	Variable
Frequency	Once or twice during project commissioning, depending on the presence of fry, and then continuously once long-term ramping rates have been determined
Timing	When fry and juvenile fish are present; if a project is commissioned when fry are not present (January – May), an additional test should be made when flows are below design flow levels and when fry are present (i.e. worst case conditions). Once these tests are complete, ramping rates will be monitored continuously through interpretation of flow data to ensure compliance with prescribed ramping rate (see Table 7).
Measure constraints	n/a
Analytical test	n/a

Table 9. Components of a construction monitoring program for hydroelectric projects.

Component	Description
Objective	To comply with the federal *Fisheries Act* and provincial *Water Act* in protecting fish habitat.
Description	Monitoring of construction and implementation of mitigation measures such as: work area isolation; fish salvage; deleterious substance and spill management; concrete materials use; sediment, runoff and erosion control; vegetation management; and site restoration.
Comparison Criteria	n/a
Location	All construction situated either instream or in the riparian zone
Duration	Continuous throughout project construction
Methods	Full-time monitoring at the start of construction and during any instream works or sensitive activity, and on a daily basis at all other times. Documentation of construction through notes and photographs.
Sample area	Construction site and downstream area
Parameters	n/a
Sensitivity/accuracy	n/a
Sample no.	n/a
Frequency	During construction
Timing	During construction
Measure constraints	n/a
Analytical test	n/a

Table 10. Components of a fish screen and fishway monitoring program for hydroelectric projects.

Component	Description
Objective	To monitor the effectiveness of fish screens in preventing fish entrainment and fishways in allowing migration
Description	Examine Coanda screens and fishways prior to and during critical times and take steps to improve performance, if required. Use fish abundance data to make inferences on the effectiveness of the fishway in facilitating migration.
Comparison Criteria	Baseline fish distribution upstream and downstream of the intake can be used as an indication of fishway effectiveness.
Location	Fishways and screens
Duration	Lifespan of project
Methods	Juvenile and adult fish sampling will be dependent on habitat type and fisheries resources, but may include electrofishing, snorkel surveys, PIT tag monitoring, radiotelemetry tags and hydroacoustics (see Table 15 for more details).
Sample area	Upstream and downstream of the fishway; at the fish screen
Parameters	Catch-per-unit-effort (#fish/sec, # fish/hr); density (# fish/m^2); biomass (g/m^2), water level in mm
Sensitivity/accuracy	±0.1 g; ± 2 mm (water level)
Sample no.	n/a
Frequency	Bi-annually
Timing	Prior to, and during, critical times such as rainbow trout spawning (April 15 to May 15) and during the low flow period
Measure constraints	Fish abundance and density: conduct during critical times; preferably with water clarity >30 cm; and water temperature ≥ 5°C; release all fish unharmed; standardize effort by area and intensity
Analytical test	Paired comparisons between sites upstream and downstream of fishway

Table 11. Components of a compensation habitat monitoring program for hydroelectric projects.

Component	Description
Objective	To evaluate the effectiveness of compensation habitats in compensating for lost habitat and assess if no net loss in the productive capacity of fish habitat is achieved as a result of project construction and operation.
Description	Measurement of habitat dimensions, evaluation of habitat quality through physical parameter measurements (depth, velocity, substrate, cover) and monitoring of water level and temperature. Confirmation of fish use of compensation habitats through juvenile and adult fish sampling.
Comparison Criteria	Should habitat characteristics change such that habitat suitability is reduced, the compensation habitats will be restored as necessary.
Location	Compensation habitats
Duration	10 years
Methods	Evaluation will be done by measuring the physical dimensions of the constructed habitat and calculating habitat useable area. Water level and temperature measurements will generally follow the guidance in Table 7 and Table 13, respectively. Juvenile and adult fish sampling will be completed following methods in Table 15.
Sample area	Compensation habitats
Parameters	CPUE (#fish/second, # fish/hour); density (#fish/m^2); biomass (g/m^2), Temperature (°C), water level in mm
Sensitivity/accuracy	±0.1 g; ±0.1°C; ± 2 mm (water level)
Sample no.	Minimum of two samples of juvenile abundance in compensation habitat; single survey of adult abundance
Frequency	Fish abundance and density in years 1, 2, 3, 5 and 10; physical characteristics when the compensation habitat is completed, then 1, 5 and 10 years after construction.
Timing	Year round for temperature and water level; habitat measurements and fish sampling late in growing season
Measure constraints	Fish abundance and density: sample when flows are between 30 and 50% MAD; water clarity >30 cm; and water temperature ≥ 7°C; release all fish unharmed; standardize effort by area and intensity; measure habitat usability to standardize areal unit measure
Analytical test	Use BACI design if improving existing habitat, or use paired site comparisons with year as a factor

Table 12. Components of a footprint impact verification program for hydroelectric projects.

Component	Description
Objective	To quantify the as-built footprint impact areas and characteristics
Description	Measure areal extent and magnitude of impact
Comparison Criteria	Areal measures and characteristics laid out in environmental impact assessment
Location	Intake, penstock, powerhouse, access roads, transmission line
Duration	One time measurement following project construction; annual vegetation assessment for five years post-construction
Methods	Measurements on-the-ground and/or from aerial photos based on the overlap of project structures and work areas: evaluation of magnitude of effect based on impact assessment criteria. Document instream bed characteristics and riparian condition. Document success of re-vegetation: replant with native species as necessary
Sample area	Areal measurement of entire area, supported with length and width measurements of individual sites.
Parameters	Area in m^2
Sensitivity/accuracy	± 10%
Sample no.	n/a
Frequency	One-time footprint impact verification survey, followed by annual vegetation assessment
Timing	Following project completion, when mitigation of disturbed areas has been completed, and then annually late in growing season.
Measure constraints	n/a
Analytical test	n/a

Table 13. Components of a water temperature monitoring program for stream-based hydroelectric projects.

Component	Description
Objective	To determine project effects on stream temperature and assess whether project-related effects are biologically significant and may affect the growth, survival or reproductive success of the fish population
Description	Temperature
Comparison Criteria	2 years of baseline data, including maximum, minimum and average temperatures in critical periods
Location	Diversion section (impact), upstream (control), and downstream (impact, during operations only)
Duration	2 year pre-construction baseline and 5 years post-construction
Methods	Continuous temperature recorders
Sample area	Spot locations at downstream end of diversion section, below the diversion section and in upstream section above the influence of the headpond
Parameters	Water temperature in °C
Sensitivity/accuracy	±0.2°C
Sample no.	One sampling location in each section (two temperature monitors at each site); more sites may be required in streams where ice build-up was identified as having potential residual adverse effects in the EIA
Frequency	Hourly (or less)
Timing	Continuous
Measure constraints	Select mainstem site away from temperature edge effects; avoid sites that dewater in low flow
Analytical test	BACI: express in appropriate format for issues being addressed, e.g. for fish rearing: degree days in growing season: days when temperature is >18 °C, >20 °C, or <1°C

Table 14. Components of a stream channel morphology monitoring program for stream-based hydroelectric projects.

Component	Description
Objective	To monitor project impacts on channel stability and sediment conditions during operations and evaluate how any changes will affect the availability and suitability of fish habitat
Description	Topographical surveys, surface substrate surveys through tape grid samples; photo survey points; aerial photography; bedload substrate surveys
Comparison Criteria	Pre-construction and post-construction, following a 1-in-10 year flood event or after five years, whichever comes first
Location	Headpond; two transects downstream of the powerhouse; five transects in the diversion section, where practical
Duration	Pre-construction survey and after a 1-in-10 year flood event or after five years, whichever comes first
Methods	Photo survey points and tape grid surveys in diversion and downstream sections; detailed topographical survey, bulk sediment and photo point sampling in the headpond; overflight with 1:1,000 scale photos. Thalweg survey profile in diversion section.
Sample area	n/a
Parameters	n/a
Sensitivity/accuracy	n/a
Sample no.	Detailed survey in headpond, and a minimum of two transects downstream of the powerhouse, and five transects in the diversion section
Frequency	Once pre-project, and once after a 1-in-10 year flood event or after 5 years, whichever comes first
Timing	Survey transects following a large flood event (1-in-10 year flood)
Measure constraints	n/a
Analytical test	n/a

Table 15. Components of a fish community monitoring program for stream-based hydroelectric projects.

Component	Description
Objective	To monitor fish community health during operations and identify any changes in abundance, density, condition, distribution or timing of migration
Description	Number of fish by species and life stage per unit area; body weight and fork length of all fish captured; scale samples from a range of size classes; area of sampling; usability of habitat; date of first and last observance during migration period; temperature, alkalinity and conductivity
Comparison Criteria	A minimum of 2 years of baseline data
Location	Diversion section (impact) and upstream of intake and headpond (control) (or alternative control)
Duration	A minimum of 2 years of baseline data and 1, 2, 3, 5 and 10 years post-construction
Methods	a) Electrofishing via the removal method using 3 or more passes in a net enclosed area; b) snorkelling or minnow trapping or angling; c) on-site measurement of fork length and weight; d) scale collection; e) lab analysis of age; f) photo-documentation of site; g) measure depth, velocity and substrate in enclosure to quantify habitat usability (see Hatfield *et al.* 2007).
Sample area	Minimum 100 m^2 per electrofishing site: greater area required if fish density <0.1 fish /m^2
Parameters	CPUE (# fish/sec, # fish/hr); density (# fish/m^2); biomass (g/m^2 or g); age (yr); fork length (mm)
Sensitivity/accuracy	±0.1 g; ±1 mm
Sample no.	10 sampling sites in total: 5 in diversion (impact) section, 5 in upstream (control) section (or alternative control)
Frequency	A minimum of 2 years of baseline data; 1, 2, 3, 5 and 10 years post-construction
Timing	Late in growing season
Measure constraints	Conduct when flows are between 30 and 50% MAD; water clarity >30 cm; and water temperature ≥ 7°C; release all fish unharmed; standardize effort by area and intensity; measure habitat usability to standardize areal unit measure
Analytical test	BACI: normalize data and use ANOVA or use bootstrapping tests of difference between groups (rotating comparisons) if data fail normalization tests (Kruskal-Wallis). Examine potential to combine all streams in a general linear model with stream, period, treatment (control) as factors and fish abundance, biomass or density as a dependent variable.

Table 16. Components of a water quality monitoring program for stream-based hydroelectric projects.

Component	Description
Objective	To determine whether water quality changes during operations to the extent that the productive capacity of fish habitat may be adversely affected
Description	Dissolved oxygen, total gas pressure, turbidity, total suspended solids, total dissolved solids, specific conductivity, total alkalinity, pH, total phosphorus, ortho-phosphorus, ammonia, nitrite, and nitrate. If the stream is the receiving water for a lake that has been dammed (or a reservoir that has been created) and soil and vegetation around the lake are expected to be flooded, then the following should also be measured: dissolved organic carbon, sulfate, total metals (including ultra trace mercury and methylmercury), and dissolved metals (including ultra trace mercury and methylmercury).
Comparison Criteria	2 years of baseline data; average, minimum and maximum parameter values
Location	Diversion section (impact), upstream (control), and downstream (impact, during operations only)
Duration	2 year pre-construction baseline and for 5 years during operations
Methods	In situ data collection with water quality meters (n = 3) and collection of samples for laboratory analysis (n = 3)
Sample area	Spot locations at downstream end of diversion section, in upstream section above influence of headpond, and downstream of powerhouse (during operations only)
Parameters	Dissolved oxygen (mg/L and % saturation), total gas pressure (ΔP in mm Hg), turbidity (NTU), total suspended solids (mg/L), total dissolved solids (mg/L), specific conductivity (µS/cm), total alkalinity ($CaCO_3$ mg/L), pH, total phosphorus (mg/L), ortho-phosphorus (mg/L), ammonia (mg/L), nitrite (mg/L), and nitrate (mg/L). If the stream is the receiving water for a lake that has been dammed (or a reservoir that has been created) and soil and vegetation around the lake are expected to be flooded, then the following should also be measured: dissolved organic carbon (mg/L), sulfate (mg/L), total metals (including ultra trace mercury and methylmercury) (mg/L), and dissolved metals (including ultra trace mercury and methylmercury) (mg/L).
Sensitivity/accuracy	Varies by parameter
Sample no.	One site in each sample area, n = 3 per sampling site
Frequency	Pre-construction: quarterly; post-construction: twice a year (may be quarterly or more frequent depending on site conditions)
Timing	Pre-construction: during typical flows of each season; post-construction: low flow periods near the beginning and end of the growing season
Measure constraints	Select mainstem sites, avoiding sites immediately downstream of significant local inflows
Analytical test	BACI: normalize data and use ANOVA or use bootstrapping tests of difference between groups (rotating comparisons) if data fail normalization tests use a Kruskal-Wallis test. Examine potential to combine all streams in a general linear model with stream, period, treatment (control) as factors

Table 17. Components of an invertebrate drift monitoring program for stream-based hydroelectric projects.

Component	Description
Objective	To test whether changes occur in the density, biomass or community composition of the invertebrate drift population to the extent that the productive capacity of fish habitat in the diversion and/or downstream sections may be reduced
Description	Monitor density, biomass and diversity of invertebrates by genus/family per unit flow
Comparison Criteria	2 years of baseline data
Location	Diversion section (impact), upstream of intake and headpond (control), and downstream of tailrace. Further sampling sites may be required depending on the length of the proposed diversion reach.
Duration	2 years of pre-construction baseline and 5 years post-construction
Methods	a) drift net samples soak for 4-6 hours; b) taxonomic identification to genus or family; c) photo documentation of site; d) measure depth and velocity and discharge to quantify flow (see Hatfield *et al.* 2007)
Sample area	Drift net sampler (30 cm x 30 cm mouth, 1 m length) or equivalent; 250-μm mesh
Parameters	Number of individuals (#) and biomass (mg dry weight) per unit of volume (m^3); family richness (# of families present); family dominance (% contribution of total biomass from five most abundant families); Simpson's diversity; community structure (Bray-Curtis index)
Sensitivity/accuracy	n/a
Sample no.	5 replicates (i.e., nets) per site on each sample date
Frequency	Twice per year in the growing season (May - September) (separated by one month, if practical).
Timing	Under base flow conditions in the growing season
Measure constraints	Where feasible, conduct when flows are between 30 and 50% MAD; water clarity >30 cm; and water temperature ≥ 7°C; all nets placed in downstream half of riffles
Analytical test	BACI: normalize data and use ANOVA or use bootstrapping tests of difference between groups (rotating comparisons) if data fail normalization tests (Kruskal-Wallis). Examine potential to combine all streams in a general linear model with stream, period, treatment (control) as factors and invertebrate abundance, biomass or density as a dependent variable.

Table 18. Components of a bathymetry monitoring program for lake-based hydroelectric projects.

Component	Description
Objective	To monitor project-related changes in bathymetry (e.g., sedimentation) that may adversely affect the availability and suitability of fish habitat
Description	Monitor changes in mean and maximum depth, volume, extent, and distribution of littoral zone habitat
Comparison Criteria	Baseline survey
Location	Control and impact lakes
Duration	Life of project
Methods	Lake surveyed in a series of transects from a motor-powered boat, equipped with depth sounder. See RISC 1999 for detailed methodology
Sample area	Control and impact lakes
Parameters	Mean and maximum depth (m), volume (m^3), area of littoral zone (m^2), percentage of littoral zone habitat (%)
Sensitivity/accuracy	± 1 m; ± 1 m^3; ± 1 m^2
Sample no.	n/a
Frequency	Every five years post-construction
Timing	Open water season
Measure constraints	n/a
Analytical test	Compare depth, volume and area changes against baseline

Table 19. Components of a limnology and water quality monitoring program for lake-based hydroelectric projects.

Component	Description
Objective	To determine whether water quality changes during operations to the extent that the productive capacity of fish habitat may be adversely affected
Description	Water: Secchi depth, dissolved oxygen and temperature profile, total gas pressure, turbidity, total dissolved solids, total suspended solids, specific conductivity, total alkalinity, pH, total phosphorus, ortho-phosphorus, ammonia, nitrite, nitrate, total nitrogen, sulfate*, dissolved organic carbon*, total metals (including ultra trace mercury* and methylmercury*), and dissolved metals (including ultra trace mercury* and methylmercury*)
Comparison Criteria	2 years of baseline data; average, minimum and maximum parameter values
Location	Impact and control lakes
Duration	2 year pre-construction baseline and for 5 years during operations
Methods	In-situ data collection with water quality meters and continuous temperature loggers, and collection of samples for laboratory analysis
Sample area	Limnological station at the deepest point of the lake (other stations may be required depending on lake bathymetry), sample at surface (0.5 m depth) if lake is <6 m deep, sample at surface and bottom (1.0 m above substrate) if lake is >6 m deep; continuous temperature loggers at various depths (dependent on thermocline)
Parameters	Water: Secchi depth (m), temperature (°C), turbidity (NTU), specific conductivity (µS/cm), dissolved oxygen (mg/L and % saturation), total gas pressure (ΔP in mm Hg), pH, total dissolved solids, total suspended solids, total alkalinity, total phosphorus, ortho-phosphorus, ammonia, nitrite, nitrate, total nitrogen, sulfate*, dissolved organic carbon*, total metals (including ultra trace mercury* and methylmercury*), and dissolved metals (including ultra trace mercury* and methylmercury*) (all mg/L) Lake Sediment and Soil to be Inundated*: ammonia (available) (mg/kg), nitrate (mg/kg), nitrite (mg/kg), total phosphorus (mg/kg), sulfate (mg/kg), pH, redox potential (mV), particle size analysis (%), loss on ignition (to normalize sediment mercury concentrations, %), SEM-AVS (simultaneously extracted metals and acid volatile sulfides, µmol/kg), metals (including ultra trace mercury and methylmercury, mg/kg)
Sensitivity/accuracy	Varies by parameter
Sample no.	Minimum of one site per lake, n = 3 at each sampling site and depth
Frequency	Quarterly water quality samples; hourly temperature recordings
Timing	Late in winter, spring, summer, fall; continuous water temperature recording
Measure constraints	n/a
Analytical test	BACI: normalize data and use ANOVA or use bootstrapping tests of difference between groups (rotating comparisons) if data fail normalization tests (Kruskal-Wallis). Examine potential to combine both lakes in a general linear model with lake, period, treatment (control) as factors

* Parameters only need to be included if soil and vegetation are expected to be flooded.

Table 20. Components of a fish habitat monitoring program for lake-based hydroelectric projects.

Component	Description
Objective	To monitor changes to the quality and availability of fish habitat, particularly in the littoral zone
Description	Monitor the amount and quality of spawning and rearing habitat, accessibility to spawning grounds located in tributaries, amount and species composition of aquatic and riparian species, and document areas of bank instability
Comparison Criteria	Baseline survey
Location	Shoreline assessment and bathymetric survey (see Table 18) of control and impact lakes
Duration	Ten years
Methods	Shoreline assessment using geocoded and orthorectified aerial photographs in conjunction with a boat or foot survey. Littoral zone delineated into zones based on depth, substrate, vegetation and cover
Sample area	Littoral zone of control and impact lakes
Parameters	Depth (m), substrate, vegetation and cover (%)
Sensitivity/accuracy	± 1 m; ± 5%
Sample no.	n/a
Frequency	Two, five and ten years post-construction
Timing	Surveys to be conducted late in growing season to determine extent of vegetative cover
Measure constraints	n/a
Analytical test	Qualitative assessment of changes in habitat quality and availability based on comparison of baseline and post-construction surveys

Table 21. Components of a fish community monitoring program for lake-based hydroelectric projects.

Component	Description
Objective	To monitor fish community health during operations and identify changes in abundance, density, condition or distribution
Description	Number of fish by species and life stage per unit effort; body weight and fork length of all fish captured; scale and fin ray samples from a range of size classes, mercury-related data*
Comparison Criteria	Two years of baseline data
Location	Impact and control lakes
Duration	2 years of baseline data and for 10 years during operations
Methods	a) gillnets; b) minnow traps; c) hydroacoustic surveys; d) crayfish traps; e) electrofishing; f) beach seines; g) angling; h) on-site measurement of fork length and weight; i) scale and fin ray collection; j) lab analysis of age; h) mercury body burden*
Sample area	Dependent on lake size and habitat complexity
Parameters	Gillnets: # fish/100 m^2/24 hr minnow and crayfish traps: # fish/hr; electrofishing: # fish/min; beach seines: # fish/m^2; angling: # fish/hr; length: mm; weight: g; age: yr. Mercury related sampling*: Section 4.2 of USEPA (2010) provides sampling guidance for studying mercury concentrations in fish, including species, ages, parameters to be sampled (total mercury: mg/kg normalized to lipid content; methylmercury: mg/kg normalized to lipid content; lipid content: mg/kg; length: mm; weight: g; and age: yr), sample type (i.e., composite samples), study design, sampling frequency and timing, and sample size
Sensitivity/accuracy	±0.1 g; ±1 mm
Sample no.	Dependent on lake size and habitat complexity
Frequency	2 years of baseline data; 1, 2, 3, 5 and 10 years post-construction
Timing	Late in growing season
Measure constraints	n/a
Analytical test	BACI: normalize data and use ANOVA or use bootstrapping tests of difference between groups (rotating comparisons) if data fail normalization tests (Kruskal-Wallis). Examine potential to combine all set locations in a general linear model with lake, period, treatment (control) as factors and fish catch-per-unit-effort as a dependent variable

* Parameters only need to be included if soil and vegetation are expected to be flooded. These parameters should also be sampled in fish in the stream that is affected by the project.

Table 22. Components of a zooplankton and benthic invertebrate community monitoring program for lake-based hydroelectric projects.

Component	Description
Objective	To test whether zooplankton and benthic invertebrate communities are affected by project development to the extent that the productive capacity of fish habitat may be affected
Description	Monitor density, diversity and taxonomic composition of zooplankton and benthic invertebrates by genus/family per unit area or volume
Comparison Criteria	Minimum of 2 years of baseline data from control and impact lakes
Location	Limnological station at the deepest part of the control and impact lakes
Duration	Minimum of 2 years pre-construction baseline and 5 years post-construction
Methods	Zooplankton: conical net with mesh size between 64 and 256 μm towed at constant rate from known depth at 0.5 m/s; benthic invertebrates: Ekman grab samples sieved through a 200-μm mesh; taxonomic identification to genus or family
Sample area	Dependent on size of conical net sampler and Ekman grab sampler
Parameters	Number of individuals (#) and biomass (mg dry weight) per m^3 or m^2; family richness (# of families present); family dominance (% contribution of total biomass from five most abundant families); Simpson's diversity; community structure (Bray-Curtis index)
Sensitivity/accuracy	n/a
Sample no.	Three replicate samples at each sampling location on each date
Frequency	Annually
Timing	Once late in the growing season (August/September)
Measure constraints	n/a
Analytical test	BACI: normalize data and use ANOVA or use bootstrapping tests of difference between groups (rotating comparisons) if data fail normalization tests (Kruskal-Wallis). Examine potential to combine lakes in a general linear model with lake and treatment (control) as factors and zooplankton/invertebrate density as a dependent variable.

APPENDIX A: SAMPLE OPERATIONAL ENVIRONMENTAL MONITORING PLAN

TROUT CREEK HYDROELECTRIC PROJECT: OPERATIONAL ENVIRONMENTAL MONITORING PLAN

Prepared for:
Trout Creek Hydropower Inc.

Prepared by:
Jeremy R. Fisher, R.P.Bio.
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