Assessment Methods for Aquatic Habitat and Instream Flow Characteristics in Support of Applications to Dam, Divert, or Extract Water from Streams in British Columbia

  

Final Version

Prepared for:

Ministry of Water, Land & Air Protection and
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List of Abbreviations

BCIFGF	BC Instream Flow Guidelines for Fish
BCIFM	BC Instream Flow Methodology
B-IBI	benthic index of biological integrity
CFSP	critical flow stream period
DFO	Department of Fisheries and Oceans.
EA	environmental assessment
FDIS	Fisheries Data Information System
FHAP	Fish Habitat Assessment Procedure
FISS	Fisheries Information Summary System
HADD	harmful alteration, disruption or destruction
HSI	habitat suitability index
LWBC	Land and Water BC
MAD	mean annual discharge
MWLAP	Ministry of Water, Land and Air Protection
NMAD	naturalized mean annual discharge
PHABSIM	physical habitat simulation
POD	point of diversion
R2D	river two-dimensional model
RISC	Resource Information Standards Committee
TRIM	Terrain Resource Information Mapping
WUA	weighted usable area
WUW	weighted usable width

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Note to Reader

Early in 2003 the Province made available a set of "Working Guidelines"," data collection standards that should be followed when presenting relevant information to fisheries agency staff as part of an application for a water licence. Applicants were asked to adhere to those data collection and presentation formats until release of this document. This Assessment Methods document supersedes the "Working Guidelines". The Assessment Methods build on the "Working Guidelines" by including revisions from MWLAP and DFO agency personnel, and by providing additional methods for detailed assessment. Projects already under review are covered under the specific requirements identified by regulatory review personnel: these requirements may vary from the "Working Guidelines" and the methods presented here.

1.0 SUMMARY

The British Columbia Instream Flow Guidelines for Aquatic Habitat are made up of two components: Instream Flow Thresholds and Instream Flow Assessment Methods. The Instream Flow Thresholds are guidelines designed to protect aquatic habitat in British Columbia streams from excessive water withdrawal. The Assessment Methods are methodology guidelines designed to identify impacts from water withdrawal. This document defines the Assessment Methods for aquatic habitat: Flow Thresholds are defined in a companion document (Hatfield *et al.* 2003). Although these Assessment Methods were designed for small hydro water licence applications, the Assessment Methods are also appropriate for other applications, such as some large hydro projects and applications for consumptive water uses.

Applications to dam, divert, or extract water from streams in British Columbia must be supported by high quality information on hydrology, biology, and habitat from the stream of interest. The Assessment Methods defined in this document are structured into two tiers: those applied at a preliminary 'coarse' screening level and those applied at a detailed level. Applications for water use hoping to meet the Guidelines' Flow Thresholds must provide preliminary level data consisting of a project description, daily hydrological data estimated from regional stations or collected from the stream of interest, biological data including fish presence determined through existing records or direct sampling, and reconnaissance- level fish habitat information. Applications that move to the detailed level will have to provide information at both the screening and detailed levels. Detailed information needs must include: geomorphology, water quality, fish biology, fish habitat, lower trophic levels, ecological function, and cumulative effects.

The two-step process is designed to identify projects that pose a low risk to fish and habitat. Projects that do not meet the 'Guidelines' Flow Thresholds represent a higher risk to the environment and will be subject to greater scrutiny through a requirement for detailed studies. The Assessment Methods identified here are intended to meet the requirements of the *Fisheries Act*. Specifically, information is required to assess a harmful alteration, disruption, or destruction of habitat (HADD) and to develop appropriate mitigation and compensation of project impacts. Although the methods identified here are detailed, proponents have ultimate responsibility in meeting the information requirements of DFO. Accordingly, all detailed studies should be carefully planned and documented to allow external review, should that be requested during or following the study.

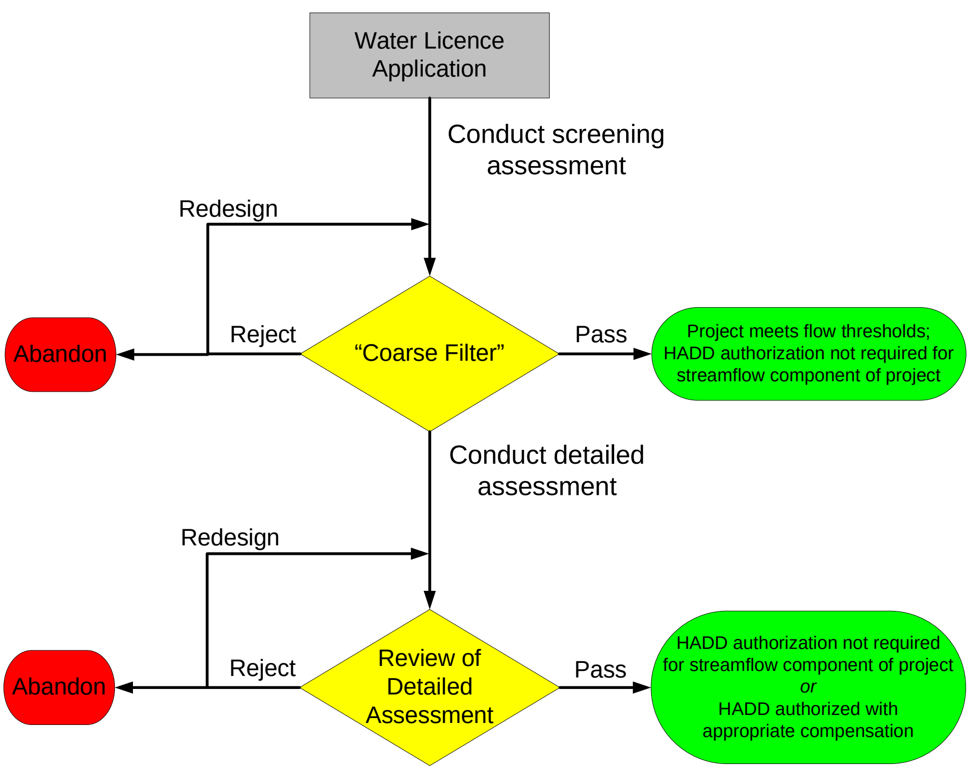
The Assessment Methods provide data collection and analysis procedures that should be followed when presenting relevant information to fisheries agency staff as part of an application for a water licence. It is important to note that these methods only address fish and fish habitat concerns. In some cases, additional detailed studies on other resources (e.g., wildlife, recreation) will be required, but these are not described here. Data must be collected and summarized using the methods described and referenced in this document. All studies should be certified by a qualified professional in the appropriate field (e.g., R. P. Bio., P. Geo., P. Eng., etc.) with demonstrated experience on instream flow issues.

2.0 BACKGROUND

The British Columbia Instream Flow Guidelines for Fish (referred to here as “the Guidelines,” Hatfield *et al.* 2003) were developed by MWLAP, MSRM, LWBC, and DFO to aid in the process of setting instream flows in British Columbia streams. The Guidelines are comprised of two components: Instream Flow Thresholds and Instream Flow Assessment Methods. This document presents the Assessment Methods, and water licence applicants are advised to adhere to these methods for data collection and presentation. By following the Assessment Methods water licence applicants will allow regulators to accurately assess projects in a timely manner.

The Guidelines direct reviewers and applicants through a two-tiered assessment of fisheries concerns related to instream flows (**Figure 1**). The “coarse filter” (i.e., a set of flow thresholds described in the Guidelines) is first applied to a proposed water use. If the coarse filter indicates that fish-flow issues are not a concern, then fisheries regulators would approve the application subject to review of other fisheries concerns (e.g., intake screening, footprint issues, etc.). If the coarse filter indicates a potential fish-flow concern, then the applicant has three options: abandon the project, redesign it to meet the flow thresholds (e.g., alter diversion rates or timing), or collect and present additional information to demonstrate that aquatic habitat concerns are adequately addressed within the proposed flow regime.

Figure 1. General decision schematic for a two-tiered review process to determine instream flow requirements to support aquatic ecosystem values.



In the first tier, the coarse filter is applied using basic project description, hydrological, and biological information specific to the project site. The biological information most critical to this step is fish presence, because the thresholds for adjustment to natural stream flows in the Guidelines change between fish-bearing and fishless streams. Quality hydrological data is also critical, since it quantifies the availability of stream flow for fish and for water extraction. In the second tier, projects are evaluated in greater detail using multiple biological, hydrological and geomorphological parameters.

Information requirements in the preliminary and detailed assessment are additive. Projects that propose to extract flow beyond the Guidelines' flow thresholds require a detailed assessment, but will nonetheless be required to collect all information necessary for the coarse filter. The information needs for both tiers can be summarized as:

1. Description of the proposed project;
2. Description of the natural hydrology, geomorphology, and biology in the watershed;
3. Assessment of how the hydrology, geomorphology, and biology will be affected by the proposed project; and
4. Description of other land and water uses in the area that may interact with the project.

Prior to submitting data and analyses, they should be certified by a professional in the appropriate field (e.g., R. P. Bio., P. Geo., P. Eng., etc.).

The two-tiered review process and data requirements are based on existing environmental legislation, and the information presented from proponents[1] to regulators must be relevant in the context of these existing regulations. The methods identified here are intended to meet the requirements of the *Fisheries Act*, specifically the assessment of harmful alteration, disruption, or destruction of habitat (HADD). The Assessment Methods are detailed, but proponents have ultimate responsibility for meeting information requirements of DFO and other agencies. Accordingly, all detailed studies should be carefully planned and written study proposals should be submitted to regulatory agencies prior to undertaking the studies. DFO has guidelines for determination and authorization of HADD (DFO 1998a), and determination of mitigation and compensation (DFO 1998b). The Assessment Methods are meant to complement these and other existing guidelines.

Biological and hydrological data essential to the screening assessment are identified and described in full in this document. Also, preliminary information on habitat is requested. Although this secondary information is not essential to the screening assessment, it can be collected at little additional cost and provides a context for the interpretation of the fish presence and hydrological data, and will benefit proponents.

[1] In this document the term 'proponent' includes consultants retained for representation and to conduct studies, or any other agent of the proponent.

Information essential to the detailed assessments is only partly described in this document, because the "best" method will vary, particularly among complex projects. The methods identified here are considered adequate for most, but not all, projects. Where exceptional aquatic habitat values are present, regulators in MWLAP and DFO may require studies different to those described here, in order to characterize habitat values and potential impacts. Streams with greater fisheries values and sensitivity to development can expect more rigorous analysis and are likely to require even more detailed assessment than that identified here.

It is important to note that the methods provided here address fish and fish habitat only. Additional information may be required for other purposes during the application review (e.g., to assess the effects of the proposed project on wildlife, recreation, agriculture, or other industries) and proponents should consult with regulators to obtain those information needs and the methods to assess them. Proponents and regulators may wish to use these methods to direct data collection for assessing other resources or project types (e.g., large water withdrawals for industrial or municipal use).

3.0 SCREENING DATA REQUIREMENTS

3.1.1 Description of the Proposed Project

A reliable and sufficiently detailed description of a proposed project is required to conduct a screening of a water licence application. The purpose of the project description is to define the project and to put geographical bounds on the area of influence. The project description should be concise yet include:

1. Project location;
2. Physical facilities;
3. Proposed operating regime; and
4. Area of impact.

3.1.1.1 Project Location

Both preliminary and detailed agency reviews require watershed level information to identify the location of the project and its facilities, as well as the environment affected by the project. The locations of all proposed project infrastructure must be properly geo-referenced, and mapped out on the existing TRIM base (1:20,000). Mapping should show detail of the immediate project area, as well as place the project location in the context of the surrounding watersheds. Mapping and engineering drawings completed at more than one scale may be necessary to do this. Where applicable, mapping should follow RISC mapping standards (e.g., symbology) (see Resource Information Standards Committee Website).

3.1.1.2 Physical Facilities

The project description should include sufficient detail on the physical infrastructure required for the construction, operation, and maintenance of the project. Details include:

1. Dam structures, diversion weir, etc.;
2. Powerhouse structures; and
3. Project lifespan.

3.1.1.3 Proposed Operating Regime

The project description should include sufficient detail on the proposed operating regime. The effect of project operation on flow and sediment transport is critical to the assessment of impacts. Operational details include:

1. General and daily operations;
2. Operations during maintenance; and
3. Emergency procedures.

3.1.1.4 Area of Impact

Water withdrawals have areas of direct and indirect impact. Direct impacts occur in the diversion section. Indirect impacts occur in the upstream and downstream aquatic habitats that could be affected by the project operations. Downstream sections are typically difficult to delimit because they have no obvious downstream boundary (i.e., for any Fraser River tributary they logically extend to the estuary at Steveston, though in practise the extent is far smaller). The downstream impact limit is ideally the point downstream of the project where tributary inflows dilute any significant effect of project operations. In practise this is difficult to define. For the purposes of assessing impacts from hydroelectric projects, the downstream impact limit has been defined as that point downstream where the watershed area is five times that at the powerhouse site. The same ratio applies to consumptive uses; however, the measurement should be relative to the point of water withdrawal. Even in those cases where project flows have important effects on areas below the downstream limit; assessments within the downstream section will likely be adequate to characterize impacts further downstream, since impacts within the downstream section will be more severe than those further downstream. Exceptions to this may exist and the downstream limit may have to be adjusted accordingly.

The upstream section is defined in non-fish bearing streams as the upstream limit of backwatering effects from the headpond or reservoir. In fish-bearing streams, the same definition holds, providing that the instream works do not impede upstream migration. If the instream works do impede upstream migration, the upper boundary of the upstream section is defined as the upstream limit of migration of fish that occupy the diversion section at any life stage, provided that this upper boundary extends past the upstream limit of backwatering effects. Migration limits are usually not well known and vary among streams and species. Migration limits are usually determined by an interaction between biological (e.g., species, life stage, etc.) and physical factors (e.g., flow patterns, barriers, etc.). In practice, the upstream sections will likely need to be defined qualitatively based on site-specific information and inferences from either the nearby watersheds or the literature.

In **Figure 2** the layout of three hypothetical hydroelectric projects is shown. In project A, the project stream runs directly into an inlet of a lake or ocean. The upstream section is the main stream and its tributaries upstream of the intake; the diversion section extends from the intake to the powerhouse; the downstream section is short, running from the powerhouse to the inlet. In project B, the project stream runs into a major river. The upstream section includes the main stream and its tributaries upstream of the intake; the diversion section extends from the intake to the powerhouse; the downstream section extends from the powerhouse, past the confluence with the major river, to the point where a tributary enters that increases the downstream watershed area to five times the area at the powerhouse site. In project C, water is diverted from a sub-basin into the main basin. The upstream section is bounded by an impassable barrier above which there are no fish; the diversion section extends from the intake to the inlet and includes all tributaries in that section; the downstream section extends from the powerhouse to the inlet. Note that between-basin diversions are not usually approved because of multiple impacts, typically of large magnitude, to hydrology, water quality, and ecology.

When the areas of influence have been defined they should be mapped on the 1:20,000 TRIM base or other suitable scales as part of the project description. When the proposed project is properly geo-referenced, existing information on topography, terrain, and infrastructure can be assembled and compared to the project location. Basic information requirements for mapping are laid out in **Table 1**.

Figure 2. Examples of upstream, diversion, and downstream sections for three hypothetical hydroelectric projects.

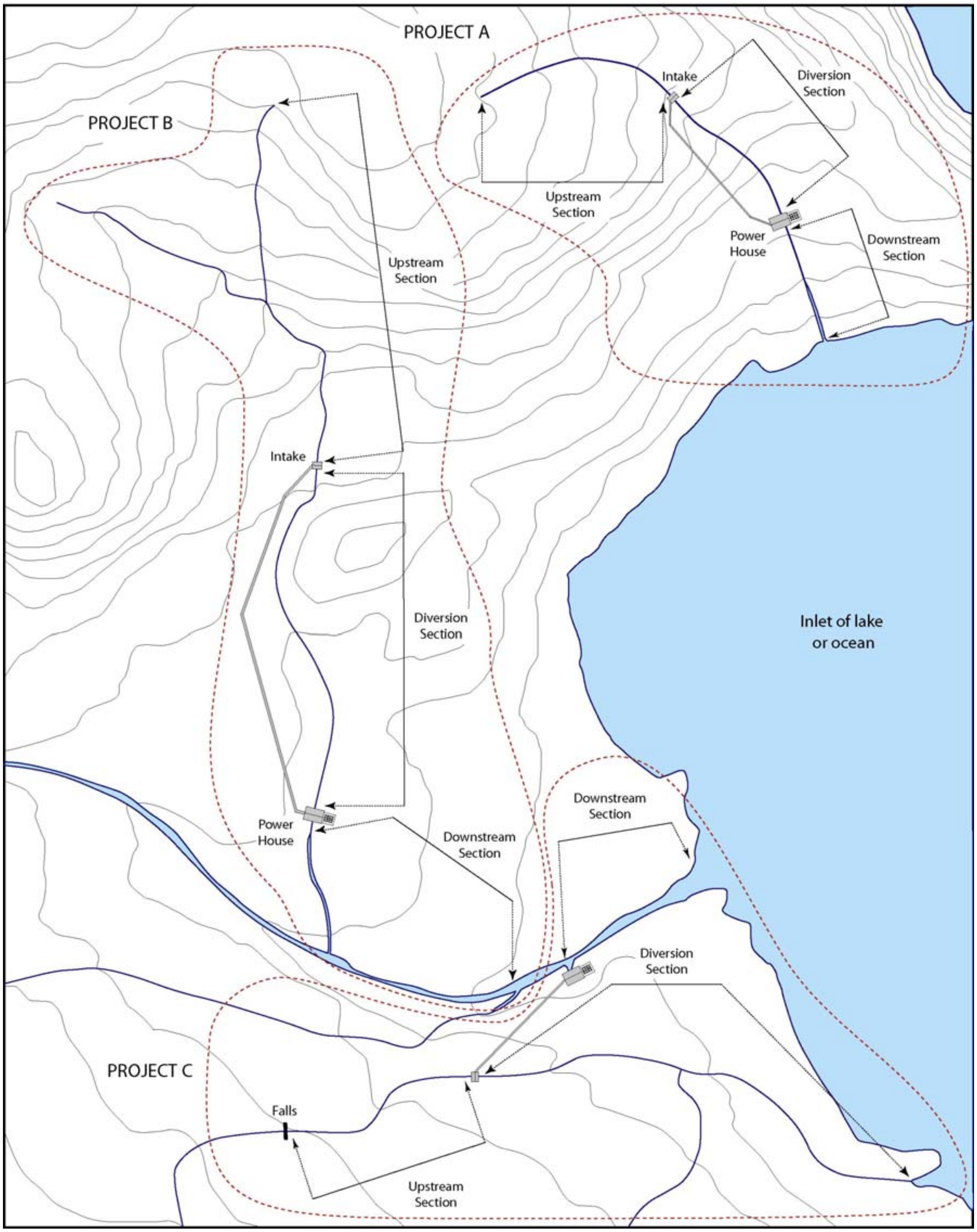


Table 1. Watershed level information by variable, with units, locations, and recommended data sources and methods.

Variable	Units	Locations	Data Sources and Methods
Watershed area	km^2	Point of diversion Point of discharge Downstream impact limit fish migration barriers	Digital Watershed Atlas; Watershed/Waterbody Identifier System
Reach locations	UTM coordinates: watershed code	All reaches within watershed upstream of downstream impact limit	1:20,000 TRIM maps; Watershed/Waterbody Identifier System
Reach gradients	%	All reaches within watershed upstream of downstream impact limit	1:20,000 TRIM maps; Watershed/Waterbody Identifier System
Reach lengths	m	All reaches within watershed upstream of downstream impact limit	1:20,000 TRIM maps; Watershed/Waterbody Identifier System
Stream sections	UTM coordinates; watershed code	Upstream, diversion, and downstream sections (parts of, single, or multiple reaches) of stream(s) affected	1:20,000 TRIM maps; Watershed/Waterbody Identifier System: project layout

3.1.2 Hydrology

The purpose of the hydrology description is to describe natural flow conditions, present flow conditions, and how flows may be altered by the project. In the context of water use it is appropriate that hydrologic information be collected, analyzed, and presented to a high standard. The information submitted by water licence applicants should meet or exceed existing standards (RISC 1998a).

Ideally, the role and function of technical professionals in the design or assessment of any project should be clearly defined. Hydrological engineering, methodology, and assessment are specialized fields of both engineering and geoscience. It is expected that hydrological work should be performed to the current standard of professional practice utilizing methods pertinent for both data and the application, and signed and sealed by a professional in the field of engineering (P.Eng.) or geosciences (P. Geo.).

3.1.2.1 Hydrological Data and Methodology

The basis of all hydrologic data is empirical instantaneous flows, obtained from gauged sites with appropriate validation (i.e., quality assurance through rating curve development, data quality control and calibration). However, most sites of interest to hydropower developers in British Columbia are ungauged, so empirical historic flow records are often not available. There are numerous techniques for estimating flows at ungauged sites. Generally, these methods include estimating runoff from climate data, calculating runoff data from watershed characteristics and river gauging data, and estimating flows from regionalization of gauged data. These methods generally involve the development of relationships between physical factors, climate data, gauged flows, and other modifying factors to model or synthesize flows for ungauged systems.

Regardless of the methods employed, all investigations should involve in situ streamflow metering to collect gauging data at the project. This work may be used to develop or validate data required in the hydrological assessment on an annual, seasonal, or daily basis. The ultimate scope, duration, and evaluation of streamflow data collection is the responsibility of the project proponent and the professional responsible for the analysis of the data. Where records must be developed from gauged records or other data, uncertainty, error, and potential biases should be described and the effects on flows determined. Since operations will be defined relative to existing or naturalized flows, it is essential to understand potential effects of uncertainties in hydrologic modeling and measurement error.

It is in the interest of all project proponents to establish new gauging stations when none exist on the affected streams. Prior to establishment of gauged sites, efforts should be made to rationalize site selections and to ensure relevant climate and meteorological information is also collected as part of the overall project. The standards of operation and data collection for these sites should meet or exceed the standards published by the Resources Inventory Standards Committee (RISC 1998a).

3.1.2.2 Hydrological Data Analysis

For the purposes of summarizing empirical hydrologic information, the entire period of record should be used if the data are reliable. Whether synthetic or empirical data are used, a minimum 20-year continuous record should form the baseline. Records of this length will more accurately reflect natural variation in annual, daily, and seasonal flow than shorter time series. A long hydrologic record will also allow for accurate exploration of project alternatives, if required as part of the review process. Additional shorter time series of flows may be required for assessing events of record or extreme events that influence project operations and impacts (i.e., probable maximum flood events, low flows, etc.) at reduced time scales. Hydrological data measured on the stream of interest near the proposed intake is preferred, but will rarely be available in a 20 year time series. Shorter time series can be used to validate flows predicted from other stations.

The time series of data should be representative of the range of climatic and meteorological conditions expected at the project in the future. The potential impacts of non-stationarity[2] and changes in runoff patterns should be incorporated in any analysis of hydrological data. Where glaciation or high elevation snow pack form a significant portion of the total annual runoff, proponents should address the influence of potential climate change and affects to the watershed hydrology. Assumptions of past hydrological conditions, runoff volumes, timing, and patterns of runoff should be tempered with existing large spatial variation seen between watersheds, between points within watersheds, and the possibility for increased future variation and change.

Hydrologic information should be presented in a manner that communicates the effects of a project at all times of the year. Data should be summarized to facilitate understanding of natural flows in the affected watershed, how the project would affect the hydrograph, and how other water uses would interact with the proposed project. The intent of the analysis and presentation should be to describe operational effects over all relevant time scales. The purpose of the presentation is to understand potential limiting factors for fish, and to understand whether existing water users may already be affecting fish and fish habitat through flow removal. Flow data should be summarized in such a way that does not obscure important information. For example, expressing flow data as monthly means may provide good information about seasonal tendencies in a flow regime, but it can obscure important patterns like short duration high and low flow events, or variation among years.

Presentation of hydrologic data should describe naturalized (i.e., corrected for existing water uses) present and post-project flows for each year in the data time series. Depending on the proposed project, it may be necessary to present data for more than one site. Relevant data include:

1. Existing and proposed water licences;
2. Mean annual discharge (MAD) or estimates of unit runoff for the watershed;
3. Seasonal timing of low flow periods including among-year variance;
4. Monthly means and percentiles (10th, 20th, 30th, 40th, 50th, 60th, 70th, 80th, and 90th),
5. Estimates of variance (e.g.; within and among year variances) in each summary statistic;
6. Estimation of flood and droughts (1: 5 to 1:200 estimates for instantaneous flood events, mean annual, 7-day and 30-day low flows); and
7. Discussion of potential modeling and measurement errors and biases with estimates of error and bias provided where possible.

[2] Non-stationarity in hydrologic data can manifest in different ways such as shifts in mean flow or flow trends that may lead to unreliable parameter estimates and incorrect conclusions.

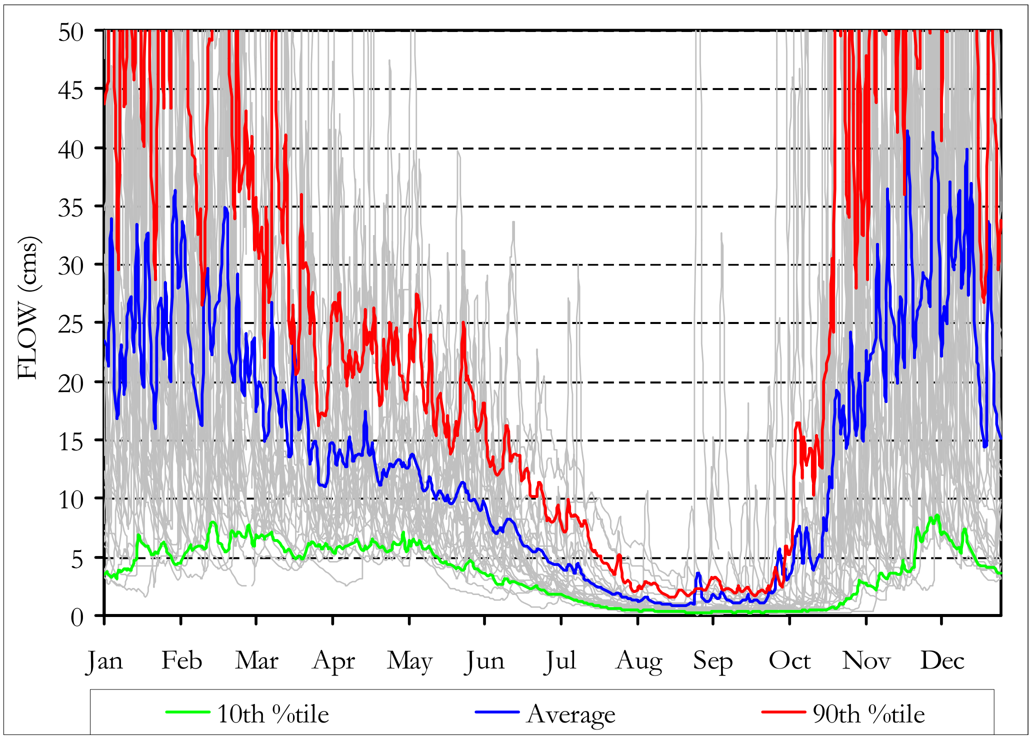
To facilitate understanding, hydrologic information should be summarized in graphical and tabular format. An example of graphic presentation is presented in **Figure 3**. To avoid problems defining "wet, dry, and normal" years, this type of graph should be produced for the entire period of record. Graphical presentation may be duplicated using a logarithmic scale to facilitate comparison of low flows. Where available, additional data such as snow pillow or precipitation records may assist in the presentation and analysis of hydrological (runoff or streamflow) data. This may be particularly relevant in the determination of the range of potential annual inflows to a project site, and the expected runoff conditions within the watershed.

The hydrologic analysis should focus on the stream segment immediately below the point of diversion (POD) because this point is where impacts are likely to be the greatest. Impacts from a project will attenuate as tributary and groundwater inflows enter the stream below the water intake. Accordingly, it is important to quantify flows in the first major tributary downstream of the POD. Furthermore, proposed water uses may interact with other uses to produce a combined significant impact further downstream. For example, water diversions in two or more tributaries may affect water quantity and quality in a particular mainstem section. It is for this reason that other users of water should be properly described for the entire project area (see "Description of proposed project" for a definition of the project area).

Plots of individual year of hydrologic data showing the natural and post-project daily flow should be provided to illustrate the effects of water withdrawal on a daily time step. **Figure 3** shows an example with natural and post-project flows for a hypothetical hydroelectric project on the Englishman River, under a scenario where the maximum diversion threshold is the 80^{th} %tile annual flow, the minimum operating flow is 5% MAD, and the instream flow requirements vary by month according to the Flow Thresholds for fish-bearing streams identified in Hatfield *et al.* 2003.

Figure 3. a) Natural surface flows from Englishman River, Vancouver Island based on 29 years (solid grey lines) of data collected between 1913 and 2000 (MAD = 13.1 cms). The Y axis maximum has been set at 50 cms to clearly show low flows. b) Simulated power flows (pink columns) during 1995 with a run-of-river hydropower project on the Englishman River, assuming a maximum diversion capacity of the 80th %tile annual flow and a minimum operating threshold of 0.66 cms (5% MAD), with an instream flow guideline as per the Flow Thresholds for fish-bearing streams (solid green line).

a)



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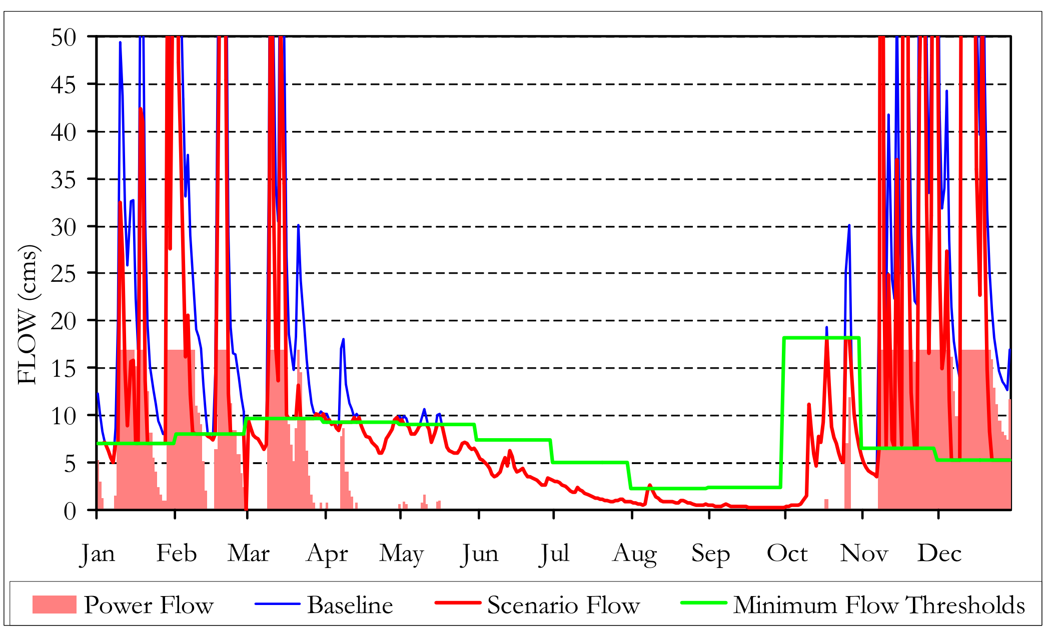


3.1.3 Biology

3.1.3.1 Fish Presence and Absence

Determining the fish-bearing status of all streams in the project area is the most basic yet critical biological information need. All streams lacking reliable data are considered to be fish-bearing Therefore, proponents need to search available records to develop appropriate sampling programs and must obtain appropriate sampling permits from DFO and/or MWLAP. Proponents should also collect the habitat data described in Section 3.1.4.2 (item 3: collecting information as per the 1: 20,000 Reconnaissance Fish and Fish Habitat Inventory Site Card) while conducting the fish presence and absence survey (note: collection of habitat data is recommended but not required for a screening assessment). The Fish Stream Identification Guidebook (Forest Practices Code of British Columbia 1998) describes the procedure used to determine fish-bearing status for forestry. Many of the same procedures are recommended for supporting water licence applications, but more intensive sampling is required because water withdrawals have a more direct influence on fish habitat than forestry. Additional considerations for determining fish-bearing status to support a water licence application are provided below.

A key difference between the methods defined here and in the Fish Stream Identification Guidebook is that observations of barriers and gradients cannot be relied on as a proxy to determine fish-bearing status. Barriers are sometimes confused with limits of fish distribution: for migratory species they often correspond, but barriers do not always indicate limits of distribution. Fish are often present upstream of barriers, possibly because they were present in a watershed before a barrier formed, or were transplanted into the watershed by humans. All stream reaches and tributaries upstream of barriers must be sampled to demonstrate non-fish-bearing status.

Where waterbodies upstream of barriers are rated non-fish bearing, proponents must be able to provide a rationale justifying the ‘complete’ barrier status. Proponents should be able to demonstrate whether a single factor (e.g., fish sampling alone) or the cumulative effects of several factors (e.g., fish sampling, water velocity, barrier height, pool depth at outfall, etc.) were considered in the barrier determination. The assessment of fish barriers should integrate methodologies and data requirements described in Parker (2000).

It is the responsibility of the Proponent to ensure that inventory capture methods are appropriate for the water body, and that procedures follow methods described in RIC Fish Collection Methods and Standards (RISC 1997a**)**. Electrofishing is the preferred method for fish inventory sampling. Stream segments must be sampled using electrofishing if the following conditions can be met: conductivity $> 30\ \mu S$/cm; temperature > 4˚ C at time of sampling; and water visibility > 25 cm. If these conditions cannot be met at any time of year, alternate methods may be considered, but there may be no methods that will work effectively in some conditions. Acceptable alternate methods include the use of any two of the sampling methods from the following: seine netting, gee trapping, angling, and snorkelling. Whatever methods are proposed for use, collection permits must be obtained from the regulatory agencies. Conditions such as temperature must be suitable if an alternative to electrofishing is used (e.g., because juveniles may be concealed during the day or hiding in the substrate, particularly at cooler water temperatures). Snorkelling may be used as a substitute for electrofishing only when stream size and access makes electrofishing dangerous or impractical. Fish data collected must be recorded onto the RIC Individual Fish Data Collection and Summary Forms following procedures outlined in Reconnaissance Fish and Fish Habitat Inventory Program**.**

The season of sampling is a key consideration. Mid-to-upper reaches of fish-bearing streams may support fish, but only in some seasons. Sampling must occur when the stream is wetted and fish are most likely to be present. The appropriate time for sampling should be determined by a review of information from watersheds in the same biogeoclimatic zone.

Habitat connectivity is an important clue to fish bearing status: reaches connecting to known fish-bearing reaches are likely to contain fish. Connectivity should be described and habitats should be sampled during periods when connections allow use of the habitat by fish.

Sampling location must be appropriate and sampling effort must be intense enough to support any determination of non-fish bearing status. The habitat preferred by the species most likely to be present should be specifically targeted (e.g., overwintering areas, pools), however, all habitat types must be sampled, with the exception of chutes and falls (local gradients >35%). A minimum of three 100 m long sections of habitat must be sampled for each stream section, and within subsections that may define fish distribution (i.e., above and below falls). Where stream width is >10m, each sample length should be equal to at least 10 bankfull widths. Proponents are not required to sample where hazards are too great. Where stream reaches are considered too dangerous to sample (e.g., due to presence of chutes or falls), the reach shall be deemed fish-bearing, unless a rigorous assessment of the factors influencing fish presence in a "Non-Fish Bearing Status Report" is accepted by the agencies.

Determination of non-fish bearing status must be made in two consecutive years. This exceeds the requirements of the Forest Practises Code because habitats affected by water diversion may support fish only during part of their life cycle, for example, during migrations downstream. By repeating the measurements in two consecutive years at the time when fish are most likely to be present, the probability of error is reduced. Although fish absence is difficult to prove, a level of certainty must be established by considering the probability and consequences of error, in short, the risk to fish. By sampling with acceptable methods in the appropriate locations and seasons in two consecutive years, project proponents will provide an acceptable level of certainty to the regulators.

Results from presence and absence sampling should be documented using formats described in the Fish Stream Identification Guidebook, and entered into the provincial database using FDIS (a data entry and management tool that includes QA procedures). Determination of fish absence should be made through the submission of a "Non-Fish Bearing Report" and must include a detailed justification and rationale.

The status of fish species present in the area of impact must be defined based on provincial criteria (i.e., are there red-, blue- or yellow-listed fish species present; are any of the species present of special management concern; are there other listed species (non-fish) present that are dependent on aquatic or riparian habitat?). The British Columbia Conservation Data Centre (http://srmwww.gov.bc.ca/cdc/) systematically collects and disseminates information on the rare and endangered plants, animals, and plant communities of British Columbia. Project proponents who have species at risk in their project area should seek advice from regulators with respect to how management actions (e.g., those that may be required under the Species at Risk Act) may affect their proposed project.

3.1.4 Habitat

3.1.4.1 Existing Data

The planning of water use projects can be assisted by existing information about fish, fish habitat, and resource use. The Fisheries Information Summary System (FISS) is a standardized, systematic, province-wide compilation of such data. FISS is digital, fully georeferenced, and linked to the 1:50 000 BC Watershed Atlas. The database can be queried using the provincial web-based tool “Fish Wizard” (http://www.fishwizard.com; Ministry of Water, Land and Air Protection and B.C. Fisheries 2003). Project proponents should note, however, that FISS does not necessarily provide sufficient detail for a screening because many waterbodies have not been previously sampled. Proponents should therefore expect to undertake primary and grey literature surveys along with empirical studies to supplement information available in FISS. Proponents may be required to meet with agency personnel to review information available in regional offices.

3.1.4.2 Basic Habitat Information

All fish habitat information collected should follow the methods and standards of the Reconnaissance Fish and Fish Habitat Inventory Program, a sample-based survey covering whole watersheds (i.e., all lakes, stream reaches, and connected wetlands within the watershed), fourth order or larger, as defined from 1:20,000 scale maps and air photos. These methods will provide standardized information regarding stream and lake biophysical data for interpretation of habitat sensitivity and capability for fish production. An advantage of these methods is that they are designed to be applied with the 1:20,000 Terrain Resource Information Management (TRIM) map base that now covers most of the Province.

The methods for fish habitat assessment procedures are detailed in “Reconnaissance (1:20,000) fish and fish habitat inventory: standards and procedures” (RISC 2001). Briefly, the assessment should follow a sequence of six office and field-based tasks (note that the sixth task is additional to those described in the manual).

1. Identify and code all waterbodies (office task);
2. Identify and characterize all reaches (e.g., confinement, order, pattern, gradient), and record site characteristics at a sample of reaches stratified by reach type (office task);
3. Determine channel morphology, locate and identify obstructions, describe riparian area properties (e.g., vegetation, presence of fisheries sensitive zones), and map habitat locations (Site Card – field task);
4. Identify all lakes; determine lake surface area, elevation, and biogeoclimatic zone; characterize lake riparian area (e.g., vegetation, land use, access); and assess fish production potential (office task);
5. Measure maximum lake depth, water quality (dissolved oxygen, pH, temperature, Secchi depth), and tributary presence (field task); and
6. Determine fish production potential for any lakes used as storage and measure lake bathymetry, lake water quality, and lake tributary water quality (field task).

The information should be presented as per the “Reconnaissance (1:20,000) fish and fish habitat inventory: standards and procedures” (RISC 2001) and entered into the provincial database using the Field Data Information System (FDIS), a data entry and quality assurance tool designed by the province (see http://www.bcfisheries.gov.bc.ca/fishinv/fdis.html). The Reconnaissance level information will be used in the preliminary screening review to assess effects of a project on habitat capability by defining habitat quantity and type. This information, combined with fish presence and absence data, will allow reviewers to assess project effects. Where more detailed studies are deemed necessary by regulatory agencies, the reconnaissance level information will serve as a foundation for additional studies.

4.0 DETAILED DATA REQUIREMENTS

Proponents may be required to undertake specific, detailed instream flow studies following a screening. Detailed information requirements are driven by the *Fisheries Act* and the *Fish Protection Act*, and by the need to provide specific answers to questions posed in the legislation and supporting guides (e.g., Department of Fisheries and Oceans Canada 1986, 1995, 1998a, 1998b).

4.1.1 Approach

Instream flow assessment is a specialized type of environmental impact assessment, which can be defined as:

> "An activity which identifies, predicts, interprets and communicates information, and proposes ameliorative measures, about impacts of a proposed action or development proposal on human health and the well-being of the ecosystem upon which human survival depends." (Sadar 1996)

Instream flow assessment is based on predictions of physical change in rivers that in turn are based on physical laws and theories. Biological theories such as evolution by natural selection help us organize how we assemble and interpret ecological information. However, there are no specific theories or laws to support predictions of how changes in river flow affects fish productivity capacity. As a result, instream flow assessment is built largely upon hypotheses about how river flow affects biological productivity capacity, structured into a framework that links river flow with the physical and biological aspects of fluvial systems. There are different hypotheses to explain the functioning of fluvial systems, which can foster strikingly different interpretations from the same data, leading to opposing conclusions on the magnitude or even the direction of impact. Different interpretations stem partly from using different methods, which may have different measurement error. By standardizing the methods and analysis framework, we hope to reduce measurement error and improve the efficiency of review.

The objective of this portion of the manual is to identify the best methods for detailed studies and to guide the analysis and interpretation of the data. This manual does not attempt to test competing hypotheses underlying instream flow prediction, though by adopting particular methods we are supporting specific hypotheses. We stress that the conclusions drawn for each study will depend on the hypotheses underlying the interpretation and urge instream flow practitioners to consider alternative hypotheses when predicting changes in predictive productive capacity.

Instream flow assessment is multidisciplinary. Detailed studies collect information on multiple physical and biological variables and structure the data into a framework that quantifies environmental change, allowing prediction of the likelihood of specific impacts to fish and habitat, based on underlying hypotheses of how fish respond to habitat change. The detailed data requirements may require an investigation of:

1. Hydrology (described under the screening data requirements);
2. Geomorphology;
3. Water quality;
4. Fish biology:
    1. Species, life stages, and fish population status;
    2. Timing of feeding, rearing, spawning, migration, and other life stages;
    3. Location of habitats used by individual life stages;
    4. Abundance;
5. Fish habitat:
    1. Habitat unit classification;
    2. Microhabitat characteristics by habitat unit (depth, velocity, substrate, cover);
    3. Partial barrier location and physical attributes of barrier (e.g. falls, cascade);
6. Lower trophic levels (periphyton, macrophytes, invertebrates); and
7. Stream and riparian ecology.

The broad and detailed assessment proposed here is similar to the Instream Flow Incremental Methodology (IFIM, Bovee 1982) because: 1) it is incremental, evaluating the effect of flow on habitat over a continuum of flow; 2) because it requires high levels of field effort; and 3) because multiple components are investigated. Like IFIM or any other assessment method, the methods must be 'based on sound science, basic ecological principles, and documented logic that address a specific need' (Instream Flow Council 2002). Therefore, in addition to the guidance given here, proponents are expected to use a scientific approach and ecological principles in preparing a clearly documented study plan.

The methods identified here are incremental in nature, rather than standard setting, reflecting that the need for a detailed study follows from a process where standards (i.e., the Guideline's flow thresholds) have been applied to set limits on the flow regime. Also, these methods are not specifically monitoring or diagnostic (although some are) because the focus of assessment is the prediction of effects (monitoring will be required post-project). In the context of HADD assessment and application of DFO's 'no net loss' principle, incremental methods are ideal for detailed assessments since they offer the opportunity to evaluate alternative project scenarios, quantify the benefits of mitigation, and estimate the quantity of compensation required to meet the objective of no net loss. However, incremental methods are based on a specific hypothesis that productive capacity changes continuously with river flow, and alternative hypotheses such as the natural flow paradigm (Poff *et al.* 1997) suggest a more holistic approach with different methods.

The incremental approach is a framework for investigating a variety of environmental issues within which with specific methods are applied. There are a number of instream flow assessment tools available to examine each issue. On one hand, this creates the opportunity to select a better method for the specific stream of interest. On the other hand, this increases the work of regulators who must familiarize themselves with a wide range of techniques. Consistent decisions are difficult when proponents present different types of information. Also, the wide range of methods creates the opportunity for abuse, as proponents may select inappropriate methods because of cost considerations, because of familiarity with a particular method, or because of a misguided belief that a particular method will yield a favourable result.

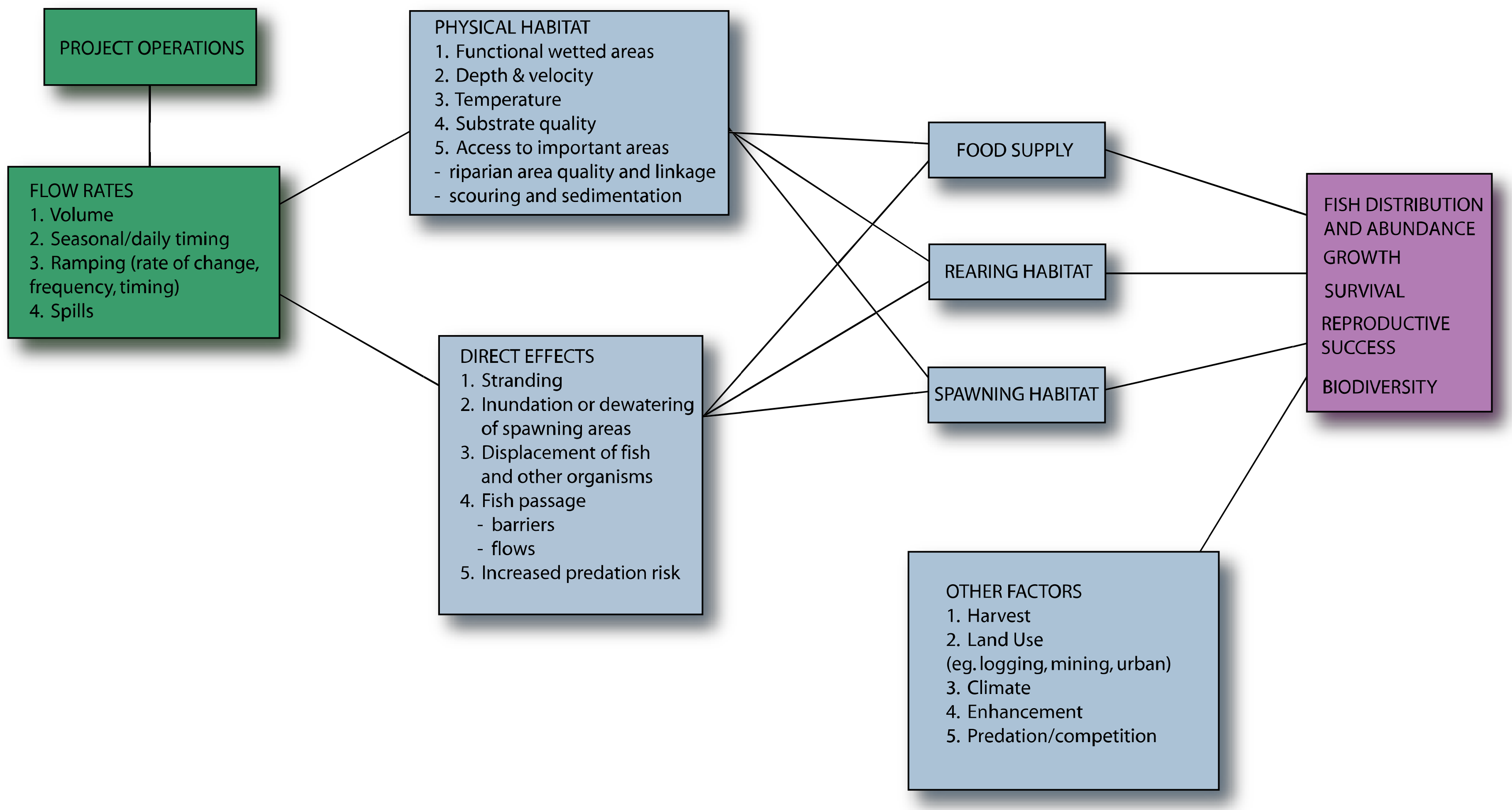
To increase the efficiency of regulatory review, and improve the quality of information at the review stage, specific methods have been identified for some information needs.

As a first step, impact pathways should be defined that link potential project actions to physical changes and then to environmental components such as water quality, aquatic organisms, and fish. This will provide the logical framework that links proposed project operations and potential impacts to the environment. Each link in the linkage diagram represents an issue that may be studied at a detailed level (**Figure 4**). Each of these issues should be elaborated to define the hypothesis underlying the linkage and identify the available data that support the hypothesis. Professional judgement is essential to identifying those issues that require additional study. Data gaps should be clearly identified and linked to proposed studies.

The linkage diagram can clearly identify the research hypotheses underlying proposed studies. Not all hypothesized links may be worth studying: some may be so obvious as to be trivial; others may be too difficult to study within the timeframe available. Each potential study can be identified with the linkage diagram, then decisions about which studies to pursue can be made explicitly and documented.

Water withdrawal has the potential to create a wide variety of direct and indirect impacts that can vary between streams both within and between biogeoclimatic zones. Despite this variance, a number of impacts can be expected to occur in most streams through known pathways with common results that can be appreciated from the example of other water development projects, often allowing impacts to be predicted. These anticipated impacts should be defined during the planning phase of detailed studies to identify which study components should be pursued. The extent of data collection will depend on the likelihood of particular impacts on the stream of interest. While such impacts can only be properly characterized through data collection and analysis, professionals experienced in instream flow assessment will be able to identify the key impacts and in turn focus study resources on the most important issues.

Figure 4. Example of a linkage diagram identifying operation effects on stream flow, physical habitat effects, direct effects on fish and habitat, key components of stream ecology, and affected attributes of fish population ecology. Factors other than stream flow can affect fish population ecology.



Typical impacts arising from water withdrawal are listed in **Table 2**, organized by issue. For each issue, operational changes alter aspects of flow (magnitude, duration, frequency, timing, rate of change) which in turn affect physical habitat. Changes in physical habitat can impact fish growth, survival, and reproductive success, as well as food supply. The impact pathways represent known or expected causal linkages between stream flow and the productive capacity of aquatic habitat. These pathways can also be routes along which productive capacity is increased. For example, rearing habitat for fish can be increased by reducing flow magnitude to levels more suitable for fish, increasing rearing space and in turn fish growth and survival. Similarly, decreases in stream flow can increase water temperature into ranges that increase fish growth. Both positive and negative impacts from water withdrawal should be identified and characterized.

Table 2. List of potential impacts to aquatic habitat from water withdrawal, organized by issue. Operational changes affect physical habitat which in turn may affect specific habitat biological attributes.

Issue	Operational Changes in Flow	Physical Habitat Variable	Potential Impact Mechanism	Biological Attribute Affected
Behavioral cues	flow timing, magnitude, duration and rate of change	none	Delayed and/or premature seasonal flow cues may prompt untimely migration and reproduction, resulting in lower growth, survival and reproductive success.	Life history phase timing
Channel structure maintenance	flow magnitude and duration	depth, velocity, wetted area, substrate composition	Reduced flow magnitude may decrease sediment transport, leading to channel aggradation and changes in habitat suitability and access.	Reduced fish growth, survival and reproductive success
Egg survival - dewatering	flow magnitude and duration	depth, velocity, wetted area	Reduced water levels and velocities post-spawning may decrease egg-fry survival.	Egg-fry survival
Egg survival - scour and erosion	flow magnitude, duration	substrate composition	Increased erosion and deposition may increase sedimentation of incubating eggs, decreasing egg-fry survival.	Egg-fry survival
Flushing flow	Flow magnitude, duration, timing	substrate composition	Decreased sediment transport may increase deposition of fine sediment, reducing habitat suitability for invertebrates and fish.	Food supply and fish growth
Flood pulse	flow magnitude, duration, frequency and timing	depth, nutrients	Reducing number, duration and magnitude of flood pulses or improper flow timing may reduce nutrient transport between riparian and aquatic habitats, reducing aquatic productivity and fish growth.	Fish growth
Floodplain connectivity	flow magnitude and duration	depth	Reduced floodplain inundation may isolate off-channel habitats, impairing movements of aquatic species and nutrients, decreasing growth, survival, and reproductive success.	Habitat connectivity
Food supply - habitat	flow magnitude and duration	depth, velocity, wetted area	Reduced habitat suitability and wetted area for invertebrates may decrease food supply and invertebrate rates, reducing fish growth.	Fish growth and survival
Food supply - nutrients	flow magnitude and duration	nutrient concentrations	Lower nutrient concentrations may decrease aquatic production, reducing fish growth.	Fish growth and survival

Table 2. continued.

Issue	Operational Changes in Flow	Physical Habitat Variable	Potential Impact Mechanism	Biological Attribute Affected
Light penetration	flow magnitude	light intensity	Increased erosion may decrease turbidity, decreasing light penetration and aquatic production, reducing fish growth.	Reduced fish growth and survival
Light penetration	flow magnitude	light intensity	Reduced light penetration may decrease cover and increase predation rates.	Reduced survival
Oxygen	flow magnitude	dissolved oxygen and oxygen saturation	Reduced oxygen concentrations may decrease fish survival.	Fish survival
Ramping and stranding	flow magnitude and rate of change	depth	Reduced water depths and increased flow ramping rates may isolate and strand fish, decreasing survival through increased predation, desiccation, freezing, or heating.	Reduced fish survival
Rearing habitat	flow magnitude and duration	depth, velocity, wetted area	Reduced habitat suitability and wetted area for fish may increase competition for physical space, decreasing growth and survival.	Fish growth and survival
Riparian zone community structure	flow magnitude and duration	depth,	Reduced riparian flooding may alter plant succession, allowing conifers to invade riparian areas dominated by deciduous plants, decreasing habitat suitability and riparian-aquatic energy flows.	Riparian-aquatic energy linkages and habitat suitability
Temperature	flow magnitude	temperature	Reduced water temperatures may decrease fish survival and growth.	Reduced fish growth and survival
Temperature	flow magnitude	temperature	Increased icing may freeze or entomb fish, decreasing fish survival	Reduced fish survival
TGP	flow magnitude	Total gas pressure	Reduced total gas pressure may decrease fish survival.	Fish survival
Tributary access	flow magnitude	depth	Reduced flow levels may expose barriers at tributary confluences, decreasing upstream migration.	Reduced fish growth, survival and reproductive success
Fish passage	flow magnitude, duration, frequency and timing	depth	Reduced flow levels may reduce depths and back flooding, increasing velocities and impairing upstream migration.	Reduced survival and reproductive success
Entrainment	flow magnitude	velocity	Diverted flows will increase velocities near intakes that will entrain fish, leading to mortality during passage.	Reduced survival

4.1.2 Geomorphology

Any works diverting or damming stream flows can alter the relationship between flow, sediment, and channel form, thereby potentially impacting fish habitats. The purpose of a geomorphology assessment is to describe natural channel conditions, whether previous land and water uses have altered channel conditions, and to what extent the proposed water uses will alter present channel conditions. The extent of the assessment will likely be related to the channel form of the stream. For example, a confined bedrock canyon is considerably more stable than an unconstrained alluvial channel, and may require less effort to describe and assess. Channel geomorphology may influence the nature of project impacts to fish and should be described in reasonable detail for the upstream, diversion, and downstream areas of impact.

The detailed geomorphology assessment will describe, for the project watershed, the watershed physical characteristics, the 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. Broadly, the morphology of a channel is a function of its setting, channel sediments, and streamflow hydrology. Channel morphology controls and constrains the interaction of water and physical structures in the stream channel, forming the physical habitat of fish. As both the flow of water (hydrology) and physical geomorphology are inherently dynamic, an understanding of the scale and timing of the underlying physical processes within the watershed is essential. The geomorphological assessment is a critical part of the detailed assessment.

4.1.2.1 Watershed Characteristics

Watershed characteristics are a description of the morphology, physiography, and processes outside of areas that are directly influenced by stream channel processes. This generally includes the bedrock geology, surficial materials or soils, and the recent geological history, including the influences of glaciation, and terrain-modifying processes. While many of the features and processes are non-fluvial, they can significantly influence sediments and morphology of stream channels.

Both active and potentially active terrain features should be documented, assessed, and classified. This includes mass wasting due to larger rock slides and gullies, slope failures and creeps, debris torrents, and avalanche chutes. Source, transport, and deposition areas should be identified and mapped, identifying the nature and type of material or sediment. Both direct and in-direct linkages (e.g., mass wasting into the active channel versus downstream impacts of debris torrents in the upper watershed) are important potential routes of impact to the channel, habitat, and infrastructure (both existing and proposed) that may require impact characterization, risk evaluation, and damage assessment.

4.1.2.2 Land and Water -Use Impacts

This section deals specifically with the anthropogenic impacts unrelated to the natural processes and features. It provides an overview of the current state of the watershed with respect to land and water use issues, thereby providing a context for the assessment of project-related issues.

In most watersheds, there are likely few water-related issues unless there are existing licenced uses within the basin. If there are existing users, then potential issues include both flooding, erosion, and sediment issues at intake or diversion structures. Concerns with respect to influences of regulation and diversion on downstream licenced and riparian users are typically addressed through the water licencing process with Land and Water BC (LWBC).

Impacts from land use may have a larger influence on fish habitat than impacts from water use because many watersheds are subject to ongoing forestry activities, which can impact hydrology and sediment supply. The extent and nature of these impacts varies considerably between among watersheds. Impacts to fish habitat from forestry activities is related to bedrock and surficial geology, natural instabilities, historical harvesting and road building practices, and successful hillslope restoration and road deactivation. The detailed assessment must include a historical analysis of the timing and magnitude of past land- use practices and their influence on hydrology and sediment supply, as well as existing morphological and hydrological impacts. The historical analysis should serve as a reference for an assessment of future conditions (impact assessment). This assessment should be based on professional judgement and interpretation using a combination of large-scale overview (aerial photography) and local site investigations.

4.1.2.3 Channel Assessment

The channel assessment synthesizes watershed characteristics and land use information in an analysis of the stream channel and tributaries that includes all areas influenced or affected by fluvial processes. This area may be extensive in the case of the active floodplain of a low gradient, high order stream. Alternatively, the channel and hydroriparian area may be limited, as in steeper, low order mountainous stream. The basic channel type (alluvial, semi-alluvial, or bedrock), channel size, and channel form should be determined for all project reaches.

Potential impact pathways between channel geomorphology and physical habitat that may be used by fish directly or indirectly (e.g., upstream non-fish bearing reaches) must be identified and well described within the area of impact. Process-based impacts and the linkage of upslope to channel processes or coupling must be addressed. Temporal aspects such as the relative magnitude and frequency of upslope, off-channel processes in the watershed must also be addressed. Many impacts will be influenced by channel form. For example, a confined bedrock canyon is considerably more stable than an unconstrained alluvial channel, but the effects of excess coarse sediment within each channel type differ as do the potential impacts to downstream reaches.

An assessment of channel characteristics is required, including form, dominant discharge, and dominant substrate for the reaches in the area of impact. An understanding of fine and coarse sediment supply sources, transport mechanics, deposition, and fate is required for the project reaches. The interaction between sediment, flow, and setting determines characteristic features of the channel that should be properly described and mapped in the assessment. These features include:

1. Channel shape - width-depth ratio, thalweg location, bars, river planform – meandering, braiding, straight;
2. Channel stability - lateral instability, avulsions, entrenchment; and
3. Bed forms – riffles, boulder riffles, cascades, sediment wedges, LWD.

4.1.2.4 Data Sources and Analysis

The detailed geomorphological assessment should be completed by an experienced licenced professional (P. Eng or P. Geo.) with experience in geomorphology, geology, geotechnical engineering, or similar fields. Overview-level geomorphological data gathering and analysis is usually completed with aerial photograph interpretation. The availability of TRIM data and orthophotos allows use of GIS-based tools for analysis of watershed features.

Detailed geomorphological data is typically collected by field-based surveys and investigations. The type, measures, and methods of data collection are varied, and guidance can be found in the published literature and government publications. Relevant selected references and texts have been included within this document. Information with respect to terrain mapping and classification as well as landslide hazard mapping standards can be obtained from Resources Inventory Standards Committee (RISC 1996). Information on the forestry-related assessment of watersheds, stream channels, gullies, slopes, soil disturbance, and other issues can be obtained from the Ministry of Forests (http://www.for.gov.bc.ca/tasb/legsregs/fpc/GUIDE/Guidetoc.htm, Forest Practices Code of British Columbia 1995).

4.1.3 Water Quality

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. For example, lower flows below a diversion may result in higher temperatures during summer, more frazil ice during winter, or altered dilution of inflows.

To properly assess water use projects, a description is required for historic (i.e., natural) water quality, present conditions, and predicted conditions with the proposed project. The information submitted by water licence applicants should meet or exceed the standards published by the Resources Inventory Standards Committee (see http://srmwww.gov.bc.ca/risc/index.htm). Since water quality is a specialized field we expect all reviews to be signed off by a certified professional (e.g., R. P. Bio., P. Eng., P. Geo., etc.).

4.1.3.1 Water Quality Variables to be Assessed

Water quality can be characterized by numerous physical parameters and constituent concentrations. Although water quality conditions unique to each stream must be considered, a basic set of parameters and associated methods have been defined here to address general water quality concerns. Proponents should obtain the advice of a qualified professional on the need to monitor additional parameters.

Water quality in most watersheds has been altered by anthropogenic activity (e.g., logging, roads, mining, agriculture, water extraction, etc.) upstream of potential water extraction sites. Increased sediment loads, more variable temperatures, and altered nutrient concentrations have been documented in many watersheds following development, with implications for cumulative effects on streams where additional water withdrawal is anticipated. Potential developments must consider these effects by estimating natural water quality parameters. This is important for identifying baseline conditions of water temperature and sediment, parameters with water quality guidelines that limit the change permitted over baseline conditions.

It will be difficult to reconstruct natural water quality at most potential sites. Water quality modelling is a potential tool but it requires extensive background data collection. The utility of short-term sets of water quality data near the POD can be evaluated by comparison to index sites in the same bioregion for which there is a longer time series of water quality data. The Aquatic Ecozone Classification System (Perrin and Blyth 1998) describes limnological and water quality characteristics typical to each bioregion and identifies potential index sites. Interannual variation in water quality data apparent at the index site can be extrapolated, effectively extending the period of record at the site of interest. Also of interest to proponents, the Aquatic Ecozone Classification System provides a framework to optimize the use of existing water quality data, possibly reducing data collection costs. Despite the potential to use regional water quality sites as surrogates for natural conditions, proponents should be aware that in practice, these sites will rarely be representative or free from other impacts. In most cases, control sites will have to be established near the project site in upstream areas that have minimal anthropogenic impacts.

Perrin and Blyth (1998) group water quality parameters into three types: electrochemical, fluvial erosion, and biological. Across these parameters, they specify eight parameters for classifying British Columbia water bodies: dissolved oxygen, pH, conductivity, turbidity, total dissolved solids, total suspended solids, alkalinity, and total phosphorous. This set can be improved by adding parameters that address water quality issues common to water use projects.

Ryder and Kerr (1989) identify temperature, light, nutrients, and dissolved gas as most important to aquatic ecosystems. The Instream Flow Council (2002) recognized temperature and sediment as the primary concerns for water quality assessments. Considering these recommendations and the availability of data for BC streams, a set of parameters has been identified for monitoring at all water use projects (see **Table 3**). Additional parameters may be required by the regulatory agencies where there are site-specific issues, however, this basic set of parameters will meet water quality monitoring requirements for most projects.

Water quality should be sampled following the Ambient Fresh Water and Effluent Sampling Manual (RISC 1997b). The frequency of sampling, number of replicates, unit of measurement, and comments are also provided in **Table 3**. For temperature assessment, continuous recording thermographs should be installed and set to collect water temperature every two hours or less. For water temperature, two replicates are specified, indicating the need to employ two temperature monitors at each site to reduce the chance of data loss or corruption. All other parameters require three replicates per site. The minimum detectable concentration (MDC) must be specified for each parameter, but will partly depend on background concentrations. Index sites can provide typical parameter values for the region that will allow the required MDC to be specified. Cavanagh *et al.* (1998) discuss concerns for water quality sampling and stress the need to focus on critical periods. The 'Comments' field in **Table 3** identifies the critical periods for some parameters, however, these will vary among streams and must be identified by a qualified professional in consultation with regulatory agency personnel.

Procedures for automated water quality monitoring are described in the RIC Automated Water Quality Monitoring Field Manual (RISC 1999). A number of parameters can now be monitored automatically, and when planning detailed assessments proponents should consider the greater sample size that can be achieved with continuous data recording.

Low sample frequencies may erroneously identify stable water quality conditions where occasional extreme events of importance may limit populations. Parameters of particular ecological interest that can be monitored continuously include temperature, DO, pH, TGP, turbidity and conductivity. In situations where nutrients are of concern, in situ chlorophyll-a sensors can provide continuous monitoring. Again, qualified professionals should be involved in selecting key parameters and determining the frequency of sampling necessary to provide adequate certainty on water quality baseline conditions and support impact assessments.

Table 3. Basic water quality parameters to be monitored at water use projects in British Columbia. The minimum frequency of sampling is specified, however, more frequent sampling may be required for some projects.

Variable	Frequency [1]	Replicates per site	Unit	Comments
Temperature	2 hour	2	˚ C	Employ continuous recording thermographs
Dissolved oxygen	Quarterly	3	mg/L	Target low flow periods (summer/winter)
Total Gas Pressure	Quarterly	3	mm Hg	Focussed on high flow and warm water periods
Turbidity	Weekly	3	NTU	Low flow periods
Total suspended solids	Quarterly	3	mg/L	Low flow periods
Specific conductance	Annually	3	μS/cm	CPSF[2]
Total alkalinity	Annually	3	mg/L	CPSF[2]
pH	Quarterly	3	pH units	
Total phosphorus	Quarterly	3	µg/L	
SRP	Quarterly	3	µg/L	
Ammonia	Quarterly	3	µg/L	
Nitrite	Quarterly	3	µg/L	
Nitrate	Quarterly	3	µg/L	

- [1] Minimum frequency; [2] Critical period stream flow (month of lowest flow during the growing season).

4.1.3.2 Sampling Design

To provide useful information for assessing water use projects, water quality data must be collected in a temporally and spatially structured manner. Ideally, water quality monitoring programs for impact assessment should have both test and control sites, begin prior to project start-up, and continue for a defined post-project time period. Baseline assessment is critical to allow the prediction of impacts, and later to verify the accuracy of the predictions and test for a null effect.

Two RISC manuals provide guidelines for designing and implementing a water quality monitoring program (Cavanagh *et al.* 1998; RISC 1999) that should be followed for water use projects. However, in contrast to the design specified in those manuals, baseline data for water use projects must be collected at both upstream and downstream sites. Non-consumptive water uses such as hydroelectric projects will require a minimum of three water quality monitoring sites: one upstream of the project, one in the diversion section, and another downstream of the powerhouse. These three sites are necessary to allow water quality changes in the diversion and downstream sections to be monitored and compared to a relevant control site. Additional sites may be required in each section if substantial modification of water quality is expected.

The location of sites within each stream section may vary depending on site-specific conditions and the water quality parameter(s) being measured. The site in the upstream section should be located upstream of any headpond and downstream of any major tributaries. The site in the diversion section should be located sufficiently far enough downstream of the intake to allow separate outflows from the diversion structure (spillway, fish bypass) to fully mix.

Where substantial modification of water quality is expected, additional measurement sites will be required. For example, where winter temperatures are low and frazil ice is a concern, low flow volumes in the diversion section may promote increased build-up of ice. This effect will be smallest immediately downstream of the intake, since flows from the intake weir or dam would likely be the same temperature as upstream water. Farther downstream, temperatures may decline during winter conditions and frazil ice may develop. Accordingly, a water quality sampling station is required at a relevant site. This rationale would hold for other concerns in the diversion section such as high summer temperatures.

The influence of microhabitat on water temperature must be considered in the sampling design. Stream margins where depths and velocities are lower typically show greater temperature variance than midstream microhabitats. Although the location of interest for predicting average temperature changes may be the thalweg, stream margin temperatures should also be measured and modelled because variation may be extreme at those locations. This may require the establishment of two additional water quality sites in the diversion section: one along the stream margin and another in the thalweg.

Where reservoirs are planned or headponds will inundate vegetation, water quality issues include mercury methylation and subsequent bioaccumulation. These and other complex issues that may arise in reservoirs would require a detailed study and extensive water quality data collection and modelling.

Cavanagh *et al.* (1998) provides procedures for a quality control and assurance process that is integrated into all laboratory and field procedures. RISC (1999) provides QA/QC direction on automated water quality monitoring. By following these practises, proponents will provide reviewers with assurance that the data collection and storage protocols meet defined standards of quality with a stated level of confidence. The data collected for detailed studies may be useful for other future studies and proponents are requested to upload their information into the Water Quality Data Management System (WQDMS), part of BC's Water Inventory Data Management System (WIDM).

4.1.3.3 Data Analysis and Presentation

Water quality information should be presented in a manner that communicates a project's effects at all times of the year. Data should be summarized to facilitate understanding of natural water quality in the affected watershed (inferred if necessary from a regional index site), how the project will affect water quality, and how other water uses will interact with the proposed project. The latter point is crucial for consumptive water uses, which may have downstream effects for great distances and affect other water uses. The purpose of the presentation is to understand the existing limiting factors for fish, whether other water users may already be affecting fish production, and whether the proposed water use will significantly affect fish and fish habitat.

The RISC manual "Guidelines for interpreting water quality data" (RISC 1998b) provides detailed direction for screening, editing, compiling, presenting, analyzing, and interpreting water quality data. Ideally proponents should enter water quality data into the appropriate Ministry databases, WQDMS, and Environmental Monitoring System (EMS) to provide wide access to the information.

4.1.4 Fish Biology

Biological information must be sufficient to assess how a proposed water use will affect fish and fish habitat. Baseline biological information must therefore include:

1. Fish presence and absence throughout the project area;
2. Fish species and life stages present;
3. Indicators of fish abundance;
4. Fish distribution (in space and time);
5. Life history timing; and
6. Source and reliability of information.

Data collected to support a water licence application should meet or exceed existing inventory standards (e.g., RISC 2001 and other documents available at http://srmwww.gov.bc.ca/risc/pubs/aquatic/index.htm), and should be signed off by a fisheries biologist with a professional designation of R.P. Bio. and demonstrated experience with instream flow assessments.

4.1.4.1 Species, Life Stages, and Fish Population Status

Where fish are present within the diversion section, additional data are required on species and life stages of fish present, relative abundance, and fish population status. In practice, this additional information will be collected during fish habitat inventories to establish fish presence. **All fish capture information must be accompanied by detailed habitat data collected at the site of capture**.

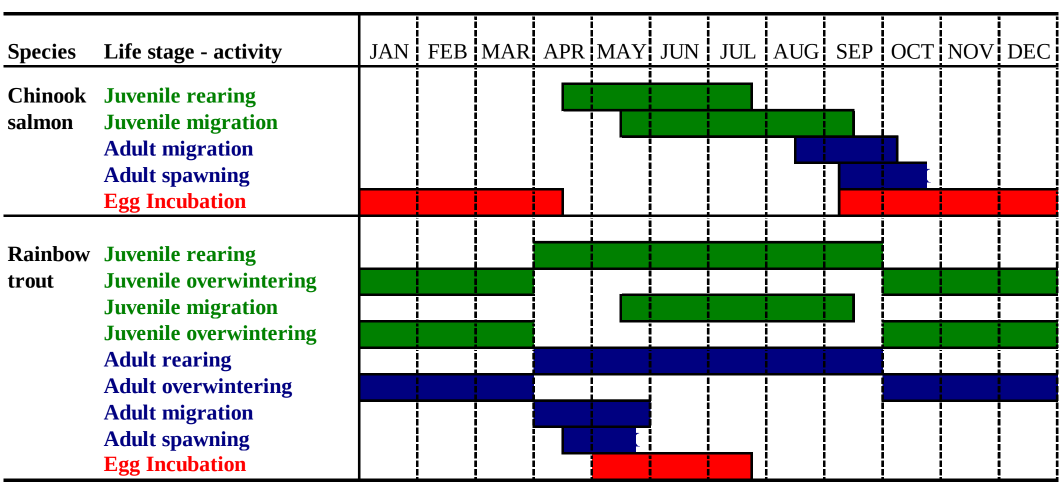
Methods to determine the species and life stages present in a stream and their relative abundances are the same as those used to establish fish-bearing status: electrofishing, snorkelling, minnow trapping, angling, and seining. However, more systematic and intense sampling will be required to provide catch per unit effort and per unit area information that can be used to compare abundance between reaches and make inferences regarding habitat quality. In streams with exceptional fish values, mark-recapture estimates and radio-tagging may be used to gain precise information on abundance and movement patterns.

When identifying the abundance of species and life stages present in the project area, sampling locations should be selected by considering the points identified in Section 3.1.3.1. Detailed biological information should be collected from captured fish including species, life stage, length and weight, maturity, and age (through analysis of scales, otoliths, or fin rays). Length frequency data should be provided to assist in the analysis of age composition and size-at-age. Abundance in different sections of the stream of interest will be calculated based on the number of fish captured or observed per unit area sampled. Abundance indicators should be expressed as the number and biomass of fish caught per unit effort and area. This should be done on a species and life stage basis, with the sample size and appropriate measure of central tendency (mean or median) given, including the variation observed within the site within and among sampling periods. More detailed stock assessments may be warranted in streams with exceptional fish habitats.

4.1.4.2 Life History Timing

Criteria for timing and magnitude of instream flows are determined in large part by the seasonal timing of habitat use by fish in a particular stream. Reliable information on life history timing and use of specific habitats in streams typically requires considerable effort over several years. For this reason it will likely be necessary to use existing data from nearby watersheds, and to supplement it with site-specific data. General sources (e.g., Scott and Crossman 1973) may provide guidance, but are not sufficient for this purpose. Life history timing should be summarized in a species periodicity chart, listing the species and life stages present and the timing of key biological activities. An example is shown in **Table 4.** Other flow-related ecological needs (e.g., geomorphic needs, riparian and floodplain maintenance, etc.) can also be entered in this table.

Table 4. An example of a species periodicity chart, detailing life stage timing by activity for each species of interest.



4.1.4.3 Timing of Habitat Use

Seasonal timing of habitat use describes when and where fish are present in the project area. This is critical information that will help refine the annual pattern of permissible water uses. Key biological activities such as spawning, incubation, migration, active rearing, and overwintering must be defined for all parts of the area of impact for the project. In the absence of detailed information, habitat use may be inferred from the species periodicity table for other streams in the region. Ideally, however, proponents will collect the appropriate site-specific information.

There are many methods for characterizing and quantifying fish habitat use. Direct observation through foot surveys, boat and aerial surveys, and snorkel surveys can provide high quality information quickly in streams with good visibility. Capture methods such as electrofishing, beach seining, downstream trapping, gee trapping, tangle netting, and fence operation can provide point samples that, when spatially aggregated, provide a detailed, quantitative snapshot of fish distribution. If employed in a seasonal sequence, these methods can define the relative abundance of fish by species and life stage over time at different locations. Rare and endangered species may require more detailed investigations. For species at risk listed under SARA, proponents must assess whether the proposed project affects critical habitat needs of the species and determine whether the project s in conflict with the recovery strategy for the species. Specific guidance for species at risk should be sought from DFO.

Further information on recognized fish capture techniques are presented in Fish Collection Methods and Standards - Version 4.0 (RISC 1999). For examples of the types of studies that may be undertaken to support the assessment and monitoring of fish habitat at hydroelectric projects, proponents are directed to examine contemporary studies. BC Hydro has conducted studies on most of its hydroelectric projects over the past ten years under the Water Use Planning and other initiatives, and reports of these projects are in the public domain, documented in Consultative Committee Reports (http://www.bchydro.com/wup/). The Nechako Fisheries Conservation Program (NFCP) has published stock and habitat monitoring programs that assess habitat conditions and stock status in the Nechako River downstream of Kenny Dam. The NFCP has published numerous reports covering a variety of fisheries assessments that provide examples of the types of studies that can be undertaken to identify habitat use (http://www.heb.pac.dfo-mpo.gc.ca/nfcp/index.htm).

4.1.5 Fish Habitat

The purpose of a fish habitat assessment is to describe the abundance and distribution of fish habitats in the project area, whether previous land and water uses have affected the habitats, and to what extent the proposed water uses will affect fish habitat. The reconnaissance level inventory undertaken in the screening assessment provides a framework for developing a sampling plan for the detailed assessments. A sampling plan must be submitted to the regulatory authorities for approval prior to undertaking the sampling program.

4.1.5.1 Approach

Fish habitat assessments for water use projects must predict the effect of changes in water flow on fish habitat and ecological function. These studies are known as instream flow assessments and have a long history of application in British Columbia, North America, and the world. A number of methods have been used to define instream flow needs, as described and reviewed in the Guidelines (Hatfield *et al.* 2003). The approach taken here is to identify a single method that will provide the most important information for decision making in instream flow assessments. Admittedly, there is controversy over instream flow methods and the state of the art does not provide the scientific certainty desired by all instream flow practitioners (Castleberry *et al.* 1996). Despite this limitation, decisions on instream flow use have been made for decades in this Province in the absence of good information. The Province intends to make more informed decisions: this highlights the need to identify the best methods available at this time.

A single method has been defined here for quantifying the effects of flow change on fish habitat in British Columbia. This method has been called the "The BC Instream Flow Methodology" and is described in detail in Appendix A. The method consists of collecting accurate and precise physical habitat data at the site of potential impact, estimating changes in physical habitat by interpolating within measured ranges of values, and inferring from these the response of stream productive capacity. This method implicitly endorses the hypothesis that physical habitat limits fish production in an incremental fashion, predicting change using simple mathematical models that are very specific versions of this hypothesis. If habitat does not limit fish production, then predictions of production changes from water use are unlikely to match future observed changes. Given this, we have identified other components in the assessment methods such as water quality, geomorphology, lower trophic levels, and steam and riparian ecology that can be used in conjunction with this fish habitat method to assess impacts to fish from change in instream flow.

The method has a track record, with habitat data collected in this manner from dozens of B.C. streams providing the basis of many past decisions on water use in BC (though the efficacy of these decisions has rarely been tested, Lewis and Mitchell 1995). Despite current uncertainties in the link between physical habitat and fish production, this approach meets the requirements of the scientific method, a principle of the Guidelines, provided that predicted changes are tested by monitoring post-project. The strength of this approach lies partly in the absence of alternative methods of assessment. Further, there is an established capacity for collecting and analyzing this information within industry, and regulatory personnel have decades of experience interpreting this data.

Proponents are advised to collect physical habitat data using the BC Instream Flow Methodology that is documented in detail in Appendix A. The method consists of the following steps:

1. Each reach is stratified into mesohabitats[3] (pools, glides, runs, riffles, cascades, etc.) so that the composition of each reach can be defined and expressed in linear distance (m) of channel occupied by the habitat unit.
2. Whole-river transects are established within a random selection of mesohabitats and depth, velocity, substrate and cover measurements are taken along a series of verticals along at multiple points across each transect. One or more mesohabitats may be selected as the focus of the assessment, and transects can be randomly selected within those mesohabitats.
3. Each habitat parameter is weighted by a habitat suitability index (HSI) score ranging from 0 to 1. HSI scores will be available on the Ministry web site for most species and life stages of interest. For other life stages and species, HSI scores may be available from other sources. Where they do not exist, curves can be developed in situ or professional opinion can be used to construct a curve, providing this is well documented.
4. Habitat is quantified as the product of HSI scores for each habitat variable and the wetted width of the transect. This calculation yields the weighted usable width (WUW) in m, which is width weighted by the estimated suitability of the habitat for a given fish species at the flow of interest.
5. Within each mesohabitat, transect-specific WUW is aggregated statistically with bootstrapping techniques to yield a median value with confidence limits. This value is multiplied by the length of habitat unit in each reach (assumed to be a constant). This yields the weighted usable area (WUA) in m^2.
6. The habitat-flow relationship is compared to photographs taken at different flows to provide a cross check of the quantitative estimates. Professional judgement can be incorporated at this stage to adjust the habitat flow relationship to reflect both the empirical data and professional judgement.
7. The habitat-flow relationship is used with the flow time series to calculate a habitat time series. Habitat during critical life stages is calculated over the period of record.

The results can be used to quantify the loss in habitat for each life history phase/species of interest under existing conditions and proposed project operations, thereby allowing the quantity of compensation habitat to be calculated. The predicted habitat losses should only apply to specific life history periods that correspond with the species and life history stage of interest. The model can be used deterministically, using the habitat-flow relationship to calculate a habitat time series with variance terms reflecting temporal

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[3] Mesohabitats are equivalent to hydraulic units and overlap with the habitat units used in the Fish Habitat Assessment Procedure.

variance in flow. The significance in differences between operating scenarios can be gauged with the observed confidence intervals from the empirically derived habitat-flow relationship as a guide to significance. Alternatively, an error term can be introduced into the calculation to create a stochastic model that incorporates the uncertainty in the habitat-flow relationship into the habitat time series, and this can be run in a Monte-Carlo simulation to calculate changes in habitat loss.

Our approach differs from that taken in some other habitat methods by focussing on empirical data, thereby avoiding the errors common to hydraulic simulation modelling. This concern arose out of our experience with hydraulic modelling techniques on small to medium sized streams in British Columbia where elements such as high gradients, complex channels, and large roughness make accurate predictions of site-specific velocities difficult. To minimize uncertainty, we have emphasized empirical data collection which will result in highly accurate and precise estimates of habitat quantity at different levels of flow.

The BC Instream Flow Methodology is not the only method of quantifying physical habitat. Regulatory agency personnel may be available to provide advice on the most appropriate method: regardless, proponents should obtain advice from registered professionals with demonstrated experience in instream flow modelling of fish habitat to guide the selection of alternative methods. Two alternative methods are commonly used (PHABSIM and two-dimensional [2D] models), however, these also have numerous pitfalls (Instream Flow Council 2002). For example, 2D modelling does not perform well on high gradient channels with numerous large roughness elements (bolders, bedrock outcrops, large woody debris), habitats typically found in the diversion reaches of projects on small streams. The particular strengths and weaknesses of each method must be considered when selecting the method and later when interpreting study results.

In the United States the most widely used method of physical habitat assessment for instream flow analysis is physical habitat simulation (PHABSIM). The strengths and weaknesses of this approach are well-known (Instream Flow Council 2002). Errors in hydraulic simulation modelling typical in PHABSIM are not usually accounted for in instream flow studies. In streams with moderate roughness, calibration at multiple discharge levels may allow reasonable accuracy. Users should calibrate the model at the lowest discharge level and then test the accuracy in estimating transect-specific WUW at a higher flow. At the higher flow, within a particular mesohabitat type, estimated and empirically measured WUW should on average be within 10% of each other.

The two-dimensional modelling method has been used effectively to model changes in physical habitat in some studies in B.C. These models may be appropriate for high value fish streams because they provide more comprehensive output that is useful in understanding and presenting the effects of changes in flow on fish habitat. These models differ from PHABSIM (a 1D model) in that they collect information throughout the stream channel rather than along individual transects. 2D models incorporate empirical data and provide comprehensive representation of areas including substrate type. A major advantage of 2D models is the ability to model flow in complex channels and capture transverse flow features. Although data collection needs can be limited to collection at a single flow, information will be required at two flow levels in order to validate predictions of depth and velocity, so in practise, data requirements for two-dimensional modelling will be similar to those for one-dimensional modelling.

Corroboration of the empirically derived habitat-flow relationship with a series of photographs taken at different flows can provide a cross-check and an effective documentation of the relationship that can be used to communicate the results to regulators and the public. This method is know as the demonstration flow assessment method (DFA) and has a long history of use, as it was a key component of the Tennant Method, one of the first standard flow setting methods devised (Instream Flow Council 2002). The method consists of photographing a number of sites in the stream at several different flow levels and presenting the photographs to allow comparison of the change in flow at each site. The BC Instream Flow Methodology in Appendix A describes how and where to take the photographs. The photographs can corroborate the empirically derived flow-habitat relationships or may provide additional information that can provide the basis for adjusting the relationships. Any adjustments to the empirically derived relationships must be substantiated with a detailed, written, biologically-based rationale.

4.1.5.2 Assumptions and Limitations

Irrespective of the model used for analysis, the key assumption made when predicting the response of habitat to water withdrawal is that habitat limits fish production. Regulators reviewing proposed projects will assume that aquatic habitat is strongly linked to productive capacity, the crucial performance measure in the *Fisheries Act*. The Guidelines document (Hatfield *et al.* 2003) reviews the literature supporting the hypothesis that stream flow determines fish production. Although only a few examples are found that demonstrate a strong link, a number of factors can affect fish productive capacity, making it difficult to detect fish-flow relationships. Flow has been described as a ‘master variable’ (Poff *et al.* 1997) that controls a suite of physical variables that in turn influence fish production through a number of direct and indirect pathways. Most instream flow assessments, regardless of method, are based on the implicit acceptance of this hypothesis (and indeed this assumption is the foundation of key features of the *Fisheries Act*). Another major assumption is that the area of physical habitat is proportional to the productive capacity of fish habitat. These assumptions cannot be tested when predicting the effects of a proposed project, although they can be evaluated through monitoring of the effects of a project.

A limitation of predictions of habitat quantity and quality made in the proposed method (as well as in PHABSIM and other habitat models) is that fish habitat preference is independent of flow. Although this assumption is typical of instream flow studies, it has rarely been tested. Beecher *et al.* (1993) found that preference remained constant over a range of flows and that habitat use could be predicted with HSI curves developed at a single flow. This finding was criticized (Jager and Pert 1997) and contradicted by Holm *et al.* (2001), who measured fish use of habitat over an 18 fold range in flow in an experimental flume to estimate habitat preferences at different flows. Holm *et al.* found that habitat area predicted with preference curves calculated at different flows varied by up to 200%, creating potentially large errors in modelled estimates of habitat loss. These findings bring into question the validity of using a single set of HSI scores across all flows, but the question is unresolved, though the underlying assumption is a cornerstone to our confidence in habitat predictions.

Underlying the consistency of preference over a range of flows is an apparent tendency of fish to select particular microhabitat characteristics in different mesohabitats. HSI curves used in BC Hydro's Water Use Planning process were developed through a Delphi process of pooling professional opinion and existing data, both based on observations of fish in their preferred mesohabitats. As a result, HSI curves may not predict the useability of habitat throughout the stream. For example, rainbow trout parr are typically found in fast flowing mesohabitats such as riffles and runs. HSI scores collected from these mesohabitat units may not apply well to slower flowing units. This potential weakness can be partly offset when interpreting study results by focussing on those habitat units most critical to the species and life history of interest. For example, in the case of juvenile steelhead, this emphasizes the use of results obtained from fast flowing habitats, given their preference for these mesohabitats (Bugert and Bjornn 1991). The focus on critical mesohabitats allows a more effective and efficient assessment of instream flow requirements and habitat impacts.

Two types of HSI curves are used in instream flow studies: river-specific curves constructed from information gathered from the stream of interest, and general curves that are composites of numerous river-specific curves. River-specific curves may be inaccurate in simulations over broad ranges of flow because they reflect fish behaviour under the conditions of observation, which are typically limited to a single, lower flow. On the other hand, general curves may include stock-specific behaviours (both genetic and environmental) that do not apply to the stream of interest. There are techniques to adjust general curves to local conditions, however, there is controversy over whether these work (Morhardt and Hanson 1988).

Typically river-specific HSI curves exhibit narrower preference ranges than do general curves that have been created by combining curves from several streams. General curves tend to inflate estimates of habitat (Shirvell 1989, Waite and Barnhart 1992), particularly when applied to all mesohabitat types, and this could alter the shape of the habitat-flow relationship leading to differing conclusions about the effects of a particular flow regime on fish habitat. A reasonable response to this may be to collect data from the target stream over a variety of conditions (season, temperature, light, turbidity, water flow). However, the variability in habitat use can be large and is influenced by a number of variables (Bradford and Higgins 2000), so such studies may not be conclusive. Where the importance of the fisheries resource demands the highest possible level of study, regulators may specify that stream- and discharge-specific preference curves be developed. This is similar to the type of research currently undertaken by BC Hydro under the Provincial Water Use Planning Program.

The approach promoted by these Assessment Methods is to use a standard set of HSI curves across the Province for each species/life stage. These curves will be available on on the Ministry website for most species and life stages. HSI scores for depth and velocity are recommended for use on all streams; the inclusion of substrate and cover scores may increase the accuracy of estimates of usable area in some situations (see Appendix A). The advantage of using common curves is that habitat will be quantified in a consistent manner across all streams in the Province. Proponents and regulators will use the same benchmarks when comparing habitat quantity. Reviewers will be more confident when comparing studies because the assumptions within the models have been standardized. Variance in modelling results from setting multiple variables is a known problem in PHABSIM (Gan and McMahon 1990). There are risks in using a single HSI curves: stream and flow specific behaviour may be adaptive and the use of standard HSI curves will not reflect the quality of habitat at a given flow. We judge this risk to be smaller and more predictable than the error introduced by allowing investigators to select HSI curves from the existing large number of curves available in the literature. Where bias from general HSI curves are of concern, studies to develop river-specific curves can be undertaken, or other curves can be used if a defensible rationale is provided.

4.1.6 Lower Trophic Levels

Periphyton and invertebrates are key components of stream productive capacity implicit in the Federal definition of fish habitat which includes "…food supply and migration areas on which fish depend, directly or indirectly, in order to carry out their life processes." Invertebrate production within stream channels can be an important contributor to fish production in streams. In small streams, invertebrates produced in riffles may be the most important component of fish diets. Specific data needs are difficult to define in advance, for they vary greatly between among streams. Where a high value fish stream has been identified, it may be necessary to undertake detailed studies on primary and secondary production by sampling lower trophic levels and evaluating the effects of flow change on their productivity. Proponents should rely on the advice of professionals and may choose to consult with the regulators to determine whether or not lower trophic levels require a detailed study on the stream of interest.

The Freshwater Biological Sampling Manual (RISC 1998c) defines the minimum requirements to ensure quality and consistency of the field aspects of biological data collection. The manual defines the essential tasks in collecting representative samples and in preventing deterioration and contamination of the samples before analysis. It also provides advice on the different types of information that can be collected and what it can be used for. Data on lower trophic levels may provide an opportunity to assist development of the Benthic Index of Biological Integrity (B-IBI) which is currently under development by MWLAP. This can document current conditions in the study reach to serve as a baseline for later monitoring comparisons.

Effects of stream flow on invertebrates can be assessed using a physical habitat simulation similar to that described for fish habitat in Section 4.1.5. HSI curves for invertebrates are available and will be available on the Ministry web site. These curves can be used to calculate weighted usable area for invertebrates and an invertebrate habitat times series which together can provide estimates of how physical habitat available for invertebrates changes between baseline and post-project conditions.

4.1.7 Stream and Riparian Ecology

The ecological value of natural flow has been theorized in the Natural Flow Paradigm (Poff *et al.* 1997) which holds that native biota and the ecosystem have evolved in the context of natural patterns of flow that vary widely over time scales of days, weeks, and years, thereby creating a dependence on natural variation for survival and reproduction. According to this theory, PHABSIM type studies are deficient because they ignore most stream biota and address habitat needs for a select group or life history only. Moreover, the effects of natural flow variability are not incorporated into PHABSIM, indeed, the benefit of flow stability is implied and often applied in the simple minimum flow prescriptions derived from these studies.

The natural flow regime may have the following benefits for the ecosystem:

1. Instream flow – providing physical habitat in historic quantity and quality;
2. Water quality – maintaining temperature, oxygen, nutrients, and light within normal ranges;
3. Flushing flow – removing sediment and organic debris from gravel substrates;
4. Channel maintenance – recruiting gravel and large organic debris to stream channel through erosion, transport and sorting of substrate;

5. Flood pulse – alternately wetting terrestrial habitats, providing access for fish and fertilizing floodplains with dissolved nutrients, and drying them, allowing for rapid terrestrial growth that in turn supports aquatic life during periods of wetting;
6. Connectivity – linking stream channel habitats with off-channel and riparian habitats; and
7. Source of behavioural cues – initiating critical behavioural changes in fish, e.g. inducing migration in response to flow change.

These benefits may or may not be provided in a specific stream. For example, off channel habitats are rare in the steep, canyon-walled reaches typically favoured for water diversion. Also, the natural flow regime may provide sub-optimal physical habitat for some species at certain times: water velocities in canyons may be too high for juvenile fish to withstand. Each issue should be addressed by presenting appropriate physical (hydrology, geomorphology) and/or biological (habitat or behaviour) data to demonstrate the importance (or lack thereof) of the issue as it relates to the proposed project.

To address ecological considerations, proponents should answer the questions and provide information as outlined in **Table 5**. The issue, impact to be addressed, and the data required have been identified. Specific methods have not been identified, recognizing the lack of formally defined methods for these investigations. Proponents should rely on the guidance of qualified professionals.

The potential shortcomings of the reductionist approach can be offset by considering synergistic effects between components within a synthesis of potential impacts. For example, the impacts of reduced channel cross-sectional area resulting from increased aggradation in response to reduced flow magnitude and duration can be integrated into the assessment of useable habitat for fish by altering the shape of stream cross-sections used in habitat simulations.

Table 5. Ecological considerations to be addressed in detailed studies.

Issue	Potential Impact	Significance Assessment	Data required
Flushing flow	Increased sedimentation in habitats leading to lower egg-fry survival and invertebrate production.	Will the hydrology post project provide flushing flows of adequate timing and magnitude?	Hydrology: change in flow frequency. Sediment: existing and expected change in sediment transport.
Channel maintenance	Increased erosion and channel change or encroachment of vegetation into channel.	Will the hydrology post-project maintain the channel by providing adequate channel forming flows at similar frequency?	Hydrology: existing and predicted change in frequency of channel forming flows. Geomorphology: channel analysis and interpretation of impacts from channel change.
Flood pulse	Reduction in frequency or duration of wetting of riparian areas.	Will the hydrology post-project wet riparian areas with similar frequency and duration?	Floodplain inundation method (Instream Flow Council 2002).
Habitat connectivity	Isolation of productive off-channel habitats: loss of access to habitats during key life history windows.	Will off-channel habitats (if any) be accessible post project during appropriate times? Will the quantity and quality of habitats remain similar?	Habitat: 1:5000 mapping of riparian and off-channel habitats with habitat quality assessment. Link to habitat-flow model to estimate change in access, and quantity and quality of habitat.
Source of behavioural cues	Loss of cue to migration and other life history events.	Will hydrology retain peak events of the same magnitude and timing?	Life history: document major life history events and link timing to hydrograph. Assess alteration in cue timing and magnitude (calculate as percentage change from median magnitude of existing regime). See the Migration Cue Method of the Instream Flow Council (2002).

4.1.8 Cumulative Effects

The term cumulative effects has been used in different ways. The Canadian Environmental Assessment 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."

In this document, cumulative effects refers specifically to the combined effects on the environment from separate activities, including activities that are not associated with the proposed water use project. The emphasis of a cumulative effects assessment (CEA) is the interaction of multiple activities to produce an environmental impact. CEA has been promoted as a necessary part of impact assessments because the effects of unrelated activities (say for example, fishing and forestry) when assessed individually may be considered insignificant, but the incremental effects when measured together may be considered significant.

Assessment of cumulative effects is now required by federal legislation when a project is subject to a federal environmental assessment under the *Canadian Environmental Assessment Act*. Despite the importance of cumulative effects, current assessment and management techniques are not fully developed with respect to these, and as a result they are not always effective. Proponents should consult the reference guides provided by the Canadian Environmental Assessment Agency to obtain recent guidance on the appropriate methods for analysis (CEAA 2002).

For projects proposing to withdraw water from a stream, the ways in which land and water has been and is used in a watershed can influence the impact on fish and fish habitat. For example, logging and agriculture can affect water temperature and runoff rates, dykes affect flow patterns and sediment movement in a stream channel, and other water uses affect available surface water volumes. Harvest pressure can affect the resilience of fish stocks to additional perturbations, increasing the importance of small incremental effects on habitat caused by water withdrawal. For example, a population in at low numbers may be particular vulnerable to natural mortality from predators at barriers, and this predation may be unsustainable if flow reductions increase the difficulty of upstream passage. In contrast, a robust population has more resilience when faced with an increase in mortality from natural predators.

Proponents must consider potential interactions between existing resource uses and the proposed project. This includes existing and requested water licences and water licence applications (both upstream and downstream), and land uses that may significantly affect instream processes (forestry, mining, linear development, agriculture, urbanization, recreation). Mortality from recreational and commercial fishing should also be considered in the cumulative effects assessment.

4.1.9 Other Studies

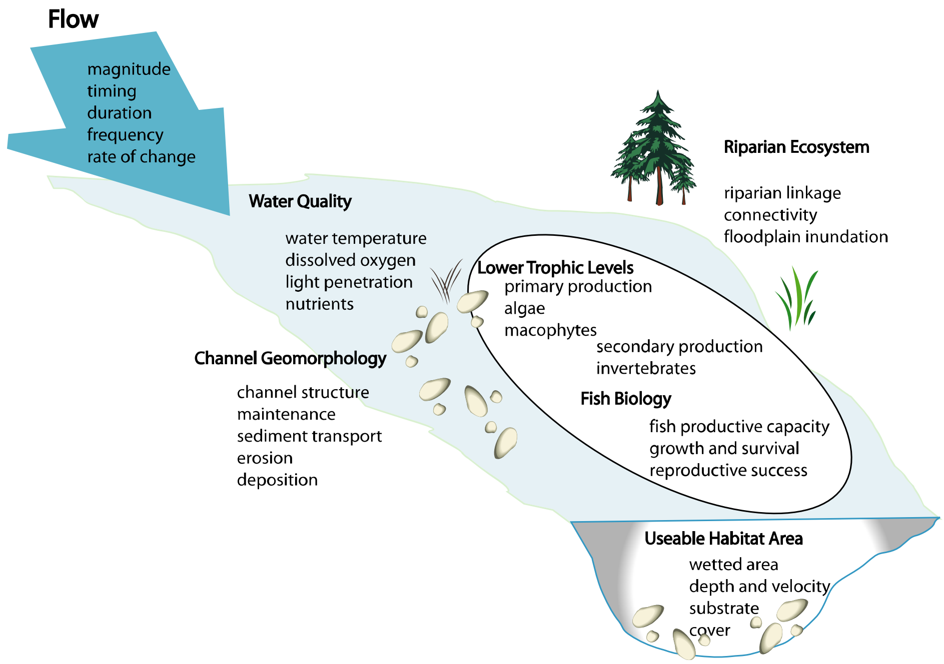
Water licence applicants often undertake economic, physical, or biological studies in an effort to understand potential effects of different operating scenarios on the viability of their project. These studies may also be useful during the review of applications. Although there is no need to include copies of these studies with the water licence application, applicants may wish to submit a reference list of available relevant studies. Applicants should note that there are preferred methodologies for some assessments, so the presence of an earlier study conducted with a methodology not recommended here does not guarantee its utility.

4.1.10 Data Analysis and Interpretation

The objective of instream flow assessment is to identify, characterize, and quantify the effects of specific instream flow regimes on aquatic resources. The analysis of effects is complex because fluvial systems and the ecology of aquatic organisms is complex. The analysis can be facilitated by structuring potential impacts in a hierarchy that reflects potential causal linkages. Common impact mechanisms are listed in **Table 2**.

The core activity of impact assessment is the characterization of baseline flow and habitat conditions, prediction of post-project conditions, and comparison of baseline and post-project conditions. To make this potentially intractable analysis workable the analysis can be structured into components that isolate physical and biological attributes. Organizing fluvial physical and ecological processes into component parts facilitates analysis and has the secondary benefit of clarifying the effects of the project on specific environmental values. **Figure 5** shows the key information supporting an instream flow analysis, organized by the information headings in this document; flow, water quality, geomorphology, habitat, fish biology and ecology, and ecosystem. This information can be organized in different ways. This section provides an example of how this information can be assembled and integrated to provide an impact assessment of flow change.

Figure 5. Diagram of the key information used in an instream flow analysis: flow, water quality, geomorphology, ecosystem, useable habitat area, and aquatic ecology. Processes linking information can be characterized by correlating information sources. Other factors that can affect fish population ecology should also be considered.



4.1.10.1 Steps in Impact Analysis

Impact assessment is essentially prediction. The goal is to describe pre-project flow and habitat conditions, and then describe anticipated changes. Pre- and post-project conditions should be described using the same variables to facilitate the comparison. The method of instream flow assessment promoted here uses a quantitative approach, comparing the mean and variance of stream flow and habitat characteristics. There are many subjective judgements required during data analysis. The most important features of the assessment however are transparency and repeatability; a different practitioner should be able to understand how a study is designed and conducted, and to repeat the study and obtain similar results.

The impact analysis can be conceptualized as a 3D matrix of time, space, and effect. Time is organized into distinct periods of relevance to aquatic habitat (e.g., the growing season versus the non-growing season) as is space (e.g., stream reaches). The central tendency (mean, median, or percentile of interest) and variance (standard deviation, confidence interval, or probability distribution) can be calculated for each environmental variable within each combination of time and space. Alternatively the variance explained by time and space can be included as factors in an analysis of variance where baseline and post-project conditions are compared.

A matrix analysis can create a large number of comparisons that may unnecessarily complicate the analysis and impair interpretation. Prior to analysis, practitioners should use site-specific information, the scientific literature, and professional judgment to identify key environmental variables, time periods, and locations that will be the focus of analysis and interpretation. This would be first undertaken during the design of detailed studies, then revisited and confirmed after the data have been collected and summarized, to refine the focus of the study.

Impact assessment can be simplified if critical life history periods or production bottlenecks can be identified. For example, low flow conditions during the growing season are considered to often result in habitat limitations for juvenile salmonids and create habitat bottlenecks that limit productive capacity. In such cases instream flow study studies should focus on defining habitat conditions during the low flow period for those species and life stages of interest.

We have broken the impact assessment process down into ten steps:

1. Identify the species of concern. Typically this is more than a single species. The analysis should focus on those species most sensitive to flow change, which can effectively act as an indicator of the effects of flow change on fish and habitat.
2. Identify the limiting life stage for the species of concern. There may be co-limiting life stages.
3. Identify the habitat parameters most important to the species of interest. If physical habitat is the key concern, then the analysis would focus on this. Other parameters such as water quality, temperature, sediment, and long term channel changes may also require analysis.
4. Identify the most important habitats for the species of concern. This can be done on one or more spatial scales. There may be a critical reach that should be selected for analysis: this would typically be the reach immediately downstream of the POD. There may also be one or more critical mesohabitats for the species of interest.
5. Identify the critical time period for the species and life history of interest. If more than one life stage limits the population, there may be more than one critical period.

6. Calculate habitat quantity for the life stage/species of concern within the reaches/mesohabitats of importance during the critical period. This may have to be repeated for multiple species and life stages.
    a. In the case of physical habitat this can be expressed as mean weighted usable area, providing the area in m^2 of habitat during baseline and post-project conditions.
    b. For water temperature, this may be expressed as degree days, if growth rate or incubation rate is of interest, or degree days above a temperature threshold, if critical temperature is of concern.
    c. For other environmental variables of concern (nutrients, oxygen, habitat for invertebrates, etc.), emphasis may be placed on the particular statistic of interest (e.g., minimum, mean, median, maximum, a probability frequency distribution, cumulative score, etc.)
7. Calculate the duration and magnitude of low flows by season under baseline and post-project conditions.
8. Calculate physical habitat as a function of daily flow for each day within the critical period, using the historic flow record under baseline and post-project conditions. Other environmental variables may not require such a detailed calculation. For example, assessment of channel change may calculate and present only peak flow frequency or the return period of a flow of a particular magnitude.
9. Compare baseline and post-project conditions in tabular and graphic formats. Where the data permit, use estimates of variance to generate measures of statistical significance or probability of change.
10. Use site-specific information, the scientific literature, and professional judgement to interpret the biological significance of the estimated changes in habitat.

The certainty of predictions should be properly described using confidence limits calculated with classical parametric estimators for normally distributed data or with non-parametric estimators for non-normally distributed data. Typically, more than one post-project condition will be described because proponents will examine the impacts of alternative project designs. By describing multiple scenarios the sensitivity of fish habitat to flow change can be evaluated, which will increase our understanding of the risk to fish production from flow withdrawal.

4.1.10.2 ‘Falls Creek’: Example of a Habitat Analysis

An example of the analysis of instream flow information is provided here using a hypothetical stream ‘Falls Creek’ from south coastal BC. We assume here that a screening assessment has been completed for the proposed project, and those data needs have been met. Furthermore, we assume that the project proponent has decided to undertake a detailed instream flow assessment.

The stream has a MAD of 3.42 cms with peak flows driven by high rainfall during the fall and winter, and moderate freshet from April through June, followed by steadily decreasing flows to a critical stream flow period in August and September. Pre-project hydrologic characteristics are summarized in **Table 6** showing a) key hydrologic statistics and b) flow thresholds as per Hatfield *et al.* (2003).

The proposed project is run-of-river with the powerhouse located upstream of the anadromous zone. Rainbow trout and Dolly Varden char are found in the diversion section, as well as in the upstream and downstream sections. The project will divert flow around 5 km of stream.

If designed to meet the threshold flows provided in the Guidelines, the project would reduce MAD to 1.97 cms (a 30% reduction in flow), but have no effect on median flows during the CPSF or on annual low flows (10^{th} %tile, 20^{th} %tile, **Table 7**, **Figure 6**). However, for reasons of economic feasibility, the proponent has proposed a minimum flow release of 10% MAD (0.34 cms) year-round, well below the monthly thresholds in the Guidelines, and a maximum diversion rate of 5.2 cms, which exceeds the Guideline of the 80^{th} %tile annual flow of 4.4 cms for this stream. This proposed scenario will reduce MAD to 1.39 cms (a 59% reduction in flow, **Figure 7**, **Table 8**). Median flows during the CPSF will be reduced by 4%, and the 20^{th} %tile flow will decrease by 41%. Furthermore, there will be an 82% decrease in the spring freshet, which creates the potential for substantial impacts to fish habitat and stream and riparian ecology. Given the presence of two species of sport fish and the desire to divert water at rates greater than the Guideline's flow thresholds, the proponent is required to undertaken detailed studies on fish presence, habitat, geomorphology, water quality, and stream and riparian ecology.

The results of detailed studies would be extensive, requiring dozens of pages to properly present. To provide some guidance on how to analyze and present data, we will provide a condensed analysis of the fish habitat data. This presentation omits much of the detail that will be required to allow regulatory agencies to properly review the project.

The detailed study consists of three parts, a fish reconnaissance inventory to identify and quantify fish distribution in the upstream, diversion, and downstream sections, an FHAP to quantify and categorize fish habitat in the diversion section into mesohabitats, and an instream flow study to define the relationship between fish habitat and flow. The reconnaissance inventory identifies rainbow trout and Dolly Varden char throughout the upstream, diversion, and downstream sections, with rainbow trout dominating the diversion section by two fold in terms of abundance and biomass.

Table 6. Hydrologic characteristics for 'Falls Creek' showing a) key hydrologic statistics and b) median monthly flows and flow thresholds as per Hatfield *et al.* (2003).

a)

Statistic	Baseline Flow (cms)	Baseline Flow (%MAD)
MAD	3.42	100.0%
Median	1.97	57.7%
Min daily	0.11	3.3%
Max daily	92.6	2700%
10^{th} %tile	0.33	9.6%
20^{th} %tile	0.58	16.9%
Freshet Median (April-June)	3.01	87.9%
CPSF Median (Aug-Sept)	0.35	10.4%

b)

Month	Median Flow (cms)	Fish-bearing Threshold (%tile)	Fish-bearing Threshold Flow (cms)
January	3.30	27	1.95
February	3.02	32	2.12
March	2.51	43	2.31
April	2.83	37	2.40
May	2.80	37	2.38
June	2.05	53	2.11
July	0.90	78	1.37
August	0.39	89	0.91
September	0.32	90	0.86
October	0.57	85	4.93
November	3.61	20	1.27
December	3.32	26	1.61
Annual	1.97	51	2.02

Table 7. Hydrologic parameters on 'Falls Creek' showing the hydrologic effects of a project meeting the Guideline monthly flow thresholds provided in Hatfield *et al.* (2003).

Statistic	Baseline Flow (cms)	Post-project Flow (cms)	% Change	Post-project % MAD
MAD	3.42	2.41	-30%	70%
Median	1.97	1.61	-18%	47%
Min daily	0.11	0	0%	3%
Max daily	92.6	88.2	-5%	2500%
10^{th} %tile	0.33	0.33	0%	10%
20^{th} %tile	0.58	0.58	0%	17%
Freshet Median (April-June)	3.01	2.17	-28%	64%
CPSF Median (Aug-Sept)	0.35	0.35	0%	10%

Figure 6. Hydrograph of 'Falls Creek' showing daily flows averaged over the period of record for a project scenario that meets the Guidelines. The blue solid line shows the baseline flow, the solid red line the post-project scenario (flows calculated based on flow thresholds in Hatfield *et al.* 2003). Pink columns indicate flows diverted down the penstock (powerflows) and the solid green line shows the monthly flow thresholds.

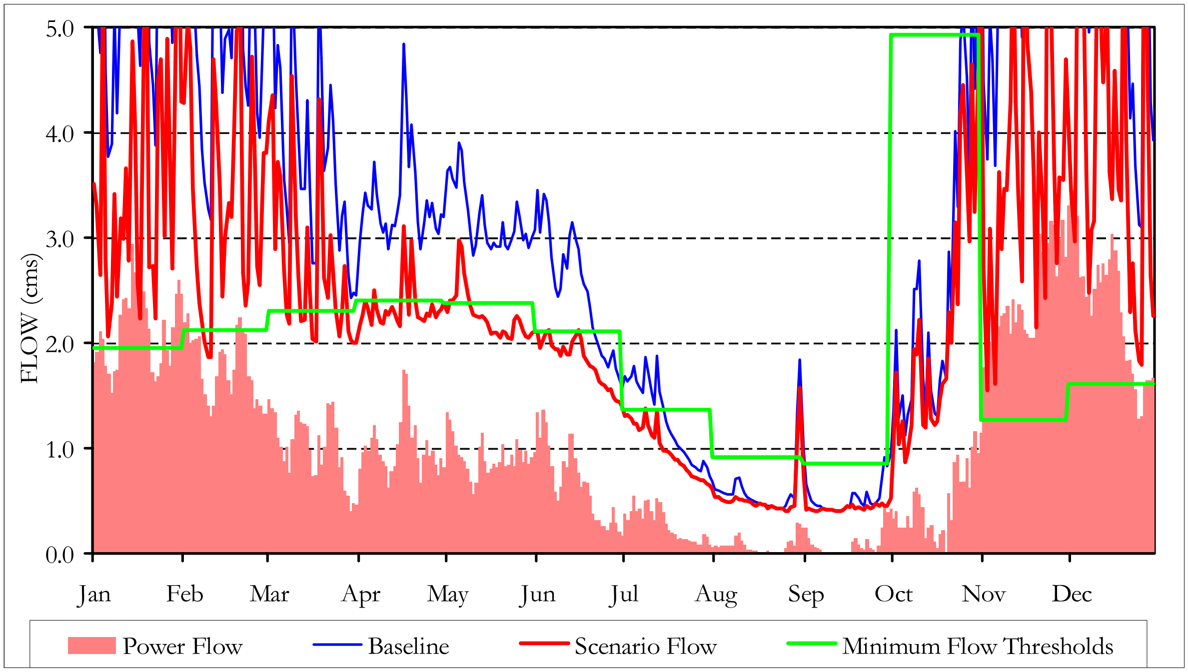


Figure 7. Hydrograph of 'Falls Creek' showing daily flows averaged over the period of record under the proposed operating scenario (10% MAD minimum instream flow release). The blue solid line shows the baseline flow, the solid red line the post-project flow (scenario follows flow thresholds in Hatfield *et al.* 2003). Pink columns indicate flows diverted down the penstock (powerflows) and the solid green line shows the minimum flow release.

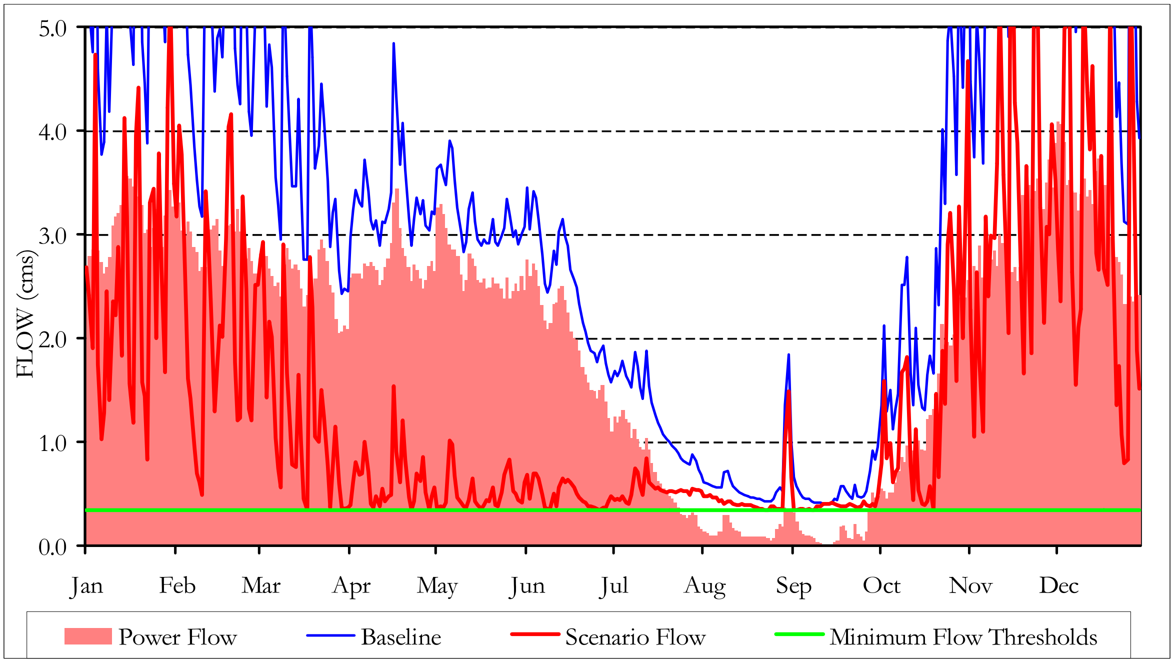


Table 8. Hydrologic parameters for 'Falls Creek' showing the hydrologic effects of the proposed project, with a minimum flow of 10% MAD and a maximum diversion threshold of 5.2 cms.

Statistic	Baseline Flow (cms)	Post-project Flow (cms)	% Change	Post-project %MAD
MAD	3.42	1.39	-59%	40.5%
Median	1.97	0.34	-83%	10.0%
Min daily	0.11	0.11	0%	3.3%
Max daily	92.6	87.4	-6%	2550%
10^{th} %tile	0.33	0.33	0%	9.6%
20^{th} %tile	0.58	0.34	-41%	10.0%
Freshet Median (April-June)	3.01	0.54	-82%	15.8%
CPSF Median (Aug-Sept)	0.35	0.34	-4%	9.9%

Both species are found in low densities, with combined biomass densities of <500 g • 100 m^{-2}. Adults of both species are small in size, typically < 150 mm fork length, however, no rainbow trout fry and few Dolly Varden fry are found in the diversion section. Rainbow trout and Dolly Varden occupy similar habitats and are clumped in distribution, occupying pools immediately downstream of cascade-riffle sections where they exhibit active feeding behaviour as they feed on invertebrate drift. Neither species is abundant in runs or glides. Mesohabitats are divided equally between fast and slow habitats as follows: 10% cascades, 20% riffles, 20% runs, 30% glides and 20% pools. Spawning habitat is scarce in the diversion section: high gradient causes heavy scour, limiting the deposition of small substrate.

Once the reconnaissance and FHAP data have been collected, the limiting species and life stage can be identified by considering the information on size and distribution concurrent with the habitat information. The numerically dominant species is rainbow trout. This species has higher velocity preferences than Dolly Varden char and so is considered more sensitivity to flow change. Given these two factors, rainbow trout are selected as the species of most interest for the assessment. Juvenile rainbow trout HSI curves are selected because the small size of the adult fish does not warrant use of adult HSI curves. The analysis will focus on the rearing habitat requirements of rainbow trout. Spawning habitat is unlikely to be a limiting factor, though the study should calculate losses for spawning habitat and present these for the review of regulators.

To define the habitat-flow relationship, 24 transects are established in the diversion reach and measured at three flow levels equal to 10%, 50% and 100% MAD. Estimates of WUW are calculated for each transect, and a line is fitted through the relationship of

WUW vs. flow. The shape of the fitted curve is critical to estimating the flows that maximize WUW. A number of models, differing in both form and parameter values, may fit the data with similar likelihood. Habitat flow relationships tend to be non-normal and have a log-normal form: this prior knowledge can be used when selecting a regression model for habitat prediction. Furthermore, habitat-flow relationships can be predicted with different models to provide a sensitivity analysis of model form.

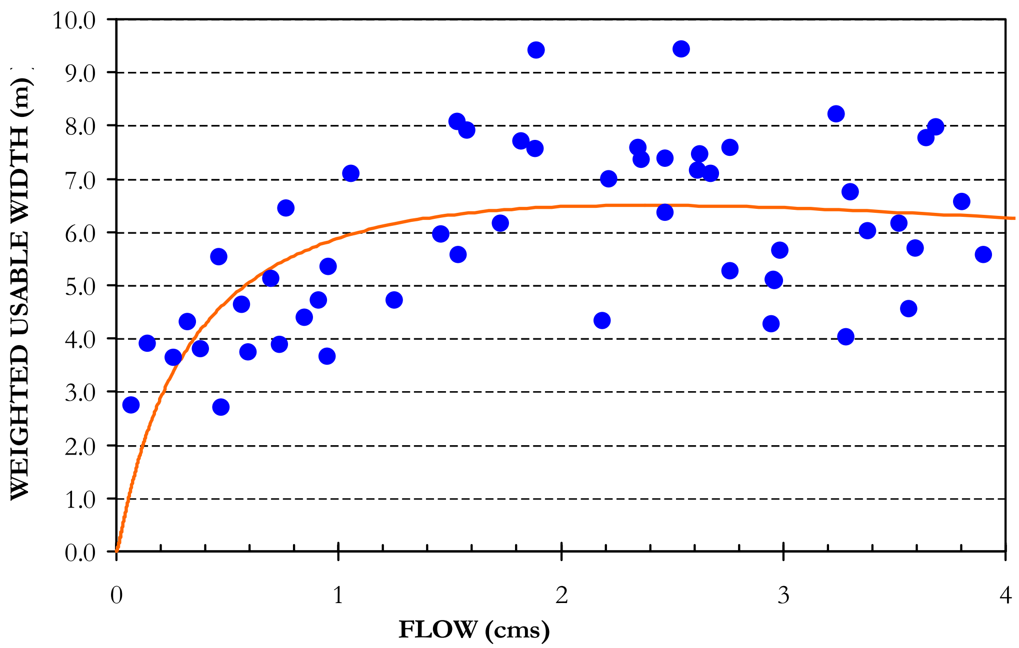
The habitat-flow relationship shown in **Figure 8** can be used to calculate the quantity of habitat in the reach of interest by multiplying the weighted usable width by the length of the reach, either directly or by calculating separate habitat-flow relationships for each mesohabitat and multiplying this by the respective length of mesohabitat unit in the reach. This quantity can be calculated each day over the period of record to create a habitat time series, for both the baseline and post-project periods. The habitat time series shows differences between the two regimes that can be quantified and expressed as a statistic (mean, average, probability distribution, etc.) during the critical flow period.

The influence of local inflow should be considered in the analysis of habitat change. Local inflow will reduce the effects of water withdrawal by adding additional flow into the diversion section and increasing habitat. The calculations should be made for each diversion segment where flow increases by 15% or more.

The data can be rolled up into summary statistics to reflect the quantity of habitat under baseline and post-project conditions. In 'Falls Creek', habitat for rainbow trout rearing during August and September (the critical period stream flow) decreased from 28,400 m^2 to 24,300 m^2 (a decrease of 14%) under the proposed operating scenario. Spawning habitat for rainbow trout decreased from 6,300 m^2 under baseline conditions to 4,800 m^2, a 24% decrease in habitat. The mean may not be the most appropriate statistic with which to aggregate habitat: the median or a particular percentile may be more appropriate, depending on how flow is thought to limit the life stage of interest. Once these calculations have been made for each environmental parameter, the significance of the predicted changes in habitat must be assessed.

For spawning and other discrete life history events, the number of consecutive days of suitable flow within a period of interest can be an informative statistic for describing changes in instream flow. Fish adapt to the natural variability in stream flows by waiting until flows are suitable. For example, they may delay upstream migration and reproduction to coincide with appropriate flow levels (Muhlfeld 2002). To describe the availability of suitable windows for discrete life history events, the frequency and duration of flow events within a particular flow range can be calculated and compared between baseline and post-project conditions.

Figure 8. A habitat-flow relationship calculated for steelhead trout juveniles in the diversion section of 'Falls Creek', showing the individual transect values for each transect across all mesohabitats. A curve is fitted to the data, following a log-normal form that is typically found in habitat-flow relationships.



4.1.10.3 Analysis of Impact Significance

A comparison of baseline and post-project conditions will likely identify differences in both physical and biological variables; differences that can arise from a variety of causes. Assessing the significance of these differences is a daunting challenge for the instream flow practitioner. Statistical tests provide a means to assess whether predicted changes arise solely by chance. But different sources of uncertainty are often compounded to the extent that confidence intervals extend well beyond any predicted difference in baseline and post-project condition, which limits the utility of strict adherence to a statistical approach. Statistical confidence can be accurately calculated for some components of the analysis, such as the empirical relationship between habitat and flow, and this can be brought forward when comparing pre- and post-project conditions to a gauge of how meaningful the predicted change will be.

Biological significance must also be considered. It may be possible to calculate statistically significant differences in water temperature between baseline and post-project conditions even if these differences may have no biological significance. Likewise, project flows may change substantially during one season, but the change may be of no biological significance if the species of interest is limited by flow during a subsequent season. At the other end of the spectrum are differences that are not statistically significant, but may indeed be biologically important. For example, mean flow during a particular month may be similar between pre- and post-project conditions, but if instantaneous flow is highly variable in one situation this may have adverse effects on instream biota. Clearly, some professional judgement is required when discussing biological significance.

Differences between baseline and post-project conditions can arise from a variety of causes. One source of difference, measurement error, should have been minimized by carefully collecting the baseline information with the best methods available and using this as input to generate estimates of post-project conditions. Another source of variability, interannual variation, should be incorporated into the analysis by simulating changes in habitat over 20 or more years of flow records. Other sources of variability, such as in fish growth rates, which can be affected by temperature, nutrients and other factors, will affect simulations of fish production. This is typically beyond the scope of an instream flow assessment, since we rely primarily on habitat measures. There are many sources of variation: practitioners should identify these and quantify them if possible.

4.1.10.4 Synergistic Effects

In the incremental approach advocated here, the component parts of a stream are analyzed independently: the stream is reduced to individual components (hydrology, water quality etc.) and each is studied in isolation. When these individual studies are complete, the overall impact of flow changes on stream productive capacity is 'constructed' by considering the results of the individual analyses. Although this approach is typical of environmental impact assessments in general, it lacks realism and may overlook poorly understood but important ecosystem functions. For example, the historic practise of setting flows based on a minimum flow consideration that meets the habitat needs of a valuable species and life history may radically alter the hydrograph, even prescribing low flows during historic high flow periods.

An alternative approach is to consider the stream as a single, indivisible unit with emergent properties that cannot be fully understood nor fully analyzed by examining the individual parts. There is growing interest and focus on a holistic approach to instream flow setting, and the Guidelines reflect this by setting flows with reference to the natural flow regime. The Natural Flow Paradigm, which advocates setting flows using the natural regime as a template, is the dominant theory of the holistic approach to instream flow setting.

These concerns resulted in the Guideline Flow Thresholds being designed with historic flows as the key reference point (Hatfield *et al.* 2003). The Guidelines calculate flow thresholds with reference to historic, natural flows, thereby incorporating the ecological concerns of the natural flow paradigm. Given this, it may seem incongruous that the detailed Assessment Methods take a reductionist approach, but this is merely pragmatic since we are limited by the existing science and methodologies. We are hopeful that a more holistic understanding of river ecology will develop from the results of the types of monitoring studies recommended under the Guidelines, leading to the development of more holistic detailed assessment methods. In the meantime, proponents can partly address holistic ecology issues by considering each of the potential benefits of the natural flow regime. These benefits can be assessed by undertaking the studies identified in Section 4.1.7.

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6.0 APPENDICES

Appendix A: The BC Instream Flow Methodology

This Appendix is provided to help environmental professionals comply with *British Columbia Instream Flow Guidelines* (Hatfield *et al.* 2003) in the design and implementation of flow studies relating to water use projects. The information presented within will also help professionals develop project-specific environmental management strategies that meet or exceed agency resource management objectives.

The purpose of the British Columbia Instream Flow Methodology (BCIFM) is to provide a standardized approach to the collection of instream flow information in relation to fish and fish habitat. This will provide a basis for the evaluation of applications to dam, divert, or extract waters from streams throughout the province. The BCIFM is complementary to other existing provincial methods and relies in part on data collection standards outlined in the following documents:

- Fish Habitat Assessment Procedure (Johnston and Slaney 1996)
- Manual of Standard Operating Procedures for Hydrometric Surveys in British Columbia (RISC 1998)
- Reconnaissance Fish and Fish Habitat Inventory Standards and Procedures – RLFFHI (RISC 2001a)
- A Guide to Photodocumentation for Aquatic Inventory (RISC 1996a)
- Automated Water Quality Monitoring (RISC 1999)
- Fish-stream Identification Guidebook (FPC 1998)

To provide continuity with existing data collected on fish habitat in the Province and consistency in methodologies, some the methods defined in the Fish Habitat Assessment Procedure (Johnston and Slaney 1996) will be undertaken as part of the BCIFM. The FHAP is focussed on identifying opportunities for effective fish habitat rehabilitation in habitats impacted by forest harvesting, rather than on the assessment of the potential effects of water withdrawal. Accordingly, proponents are not required to complete a FHAP, but must use a select set of the methods and techniques defined in the FHAP, as described below. Existing FHAPs will be valuable sources of information that will cover off many of the information needs for the BCIFM.

The FHAP is structured into overview summary, reconnaissance Level I field surveys, and detailed Level II field surveys. In the BCIFM, the screening provides the data equivalent to the FHAP overview summary. The detailed assessment in the BCIFM requires information similar in detail to both a Level I and Level II FHAP field survey.

6.1.1 Study Design

The BCIFM is a *stratified-random* approach to fish habitat measurement. Within stream reaches (as defined in the Reconnaissance Fish and Fish Habitat Inventory: Standards and Procedures, RISC 2001a), sites are selected at random or from individual habitat units within a given reach. The reach may be partitioned into segments that reflect project issues. For example, within a reach, concerns may be limited to the lower portion where a fish species and life-stage are present. Although primarily based on physical and biological criteria, accessibility considerations may dominate transect selection.

The process of describing a stream reach and collecting information from it mirrors the methods in the FHAP.

Under the BCIFM, a FHAP Level I field survey (as per Johnston and Slaney 1996, pp. 33-60) will be completed for each study reach, with the following modifications:

1. Objectives: The objectives on p. 33 are not the focus of the BCIFM. The objective is to describe and quantify habitat, as the Level I FHAP allows. The objective is not to identify impacts from forest harvesting or opportunities for restoration, though these can be noted in the assessment, as they may be relevant to the determination of cumulative effects.
2. Discharge: A flow gauging station must be established in each study reach (downstream, diversion, upstream), metering as per the BCIFM document. The methods for discharge measurement defined in the Level 1 FHAP (p. 42) must not be followed.
3. Stream Temperature: Stream temperature must be recorded continuously under the BCIFM. The methods for temperature measurement under the Level 1 FHAP (p. 43) must not be used.
4. Gradient (%): Gradient must be measured with a surveyor's rod and level. The Abney level or clinometer methods must not be used.
5. Mean water depth: Mean water depth will be measured in detail under the BCIFM, therefore, the method defined in the Level 1 FHAP (p. 46) can be ignored.
6. Mean bankfull depth: Bankfull depths will be measured in detail under the BCIFM, therefore, the method defined in the Level 1 FHAP (p. 48) can be ignored.
7. Large Woody Debris Tally: This information is not essential to the BCIFM. However, it has value for other resource users and proponents are asked to collect it as defined in the Level 1 FHAP (p. 49).
8. Habitat Evaluation: A habitat evaluation is required under the BCIFM, however, the focus should be on limitations to production, rather than on impacts from forestry. Forestry impacts should be considered as one of many factors that may be controlling fish production. The focus should be lifted from identifying

potential restoration opportunities to the assessment of how productive capacity will change with alterations in flow.

9. Initial Planning for Fish Habitat Restoration Projects: pp. 59-60 in the Level 1 FHAP – this is not required under the BCIFM.
10. Reporting: A fish restoration plan is not required. The focus on the report should be on existing conditions and limiting factors to fish production.

The objectives of the Level 2 FHAP are not appropriate for the BCIFM. Although detailed information will be collected at a level similar to the Level 2 FHAP, the objectives, focus, and methods will be different. The following describes the information to be collected for the BCIFM.

The BCIFM requires the collection of data at three or more flow levels to provide the empirical data around which a habitat-flow relationship can be predicted. Data will be collected at a minimum of three flows ranging from 5% to 40% *naturalized MAD* (NMAD), with a preference of five flows over this range. This requirement may vary based on the geographical location of a given stream, the fish species present, and site-specific ecological considerations. For example, empirical data collection at 40% NMAD in a certain reach may not be possible based on safety considerations alone. In such cases, data collected over lower flow ranges may be extrapolated upwards to estimate habitat at higher flows. In some streams, the use of computer-based modelling techniques will be required to infer habitat-flow relationships in lieu of empirical data.

The steps involved in the BCIFM are outlined below.

1. Quantify the habitat unit composition of each reach by delineating the reach into pool (slow), riffle (fast, turbulent), and glide/run (fast, non-turbulent) habitats, expressed in linear distance (m) of channel occupied by the mesohabitat within the reach. This is completed under the FHAP Level 1 assessment described above.
2. Identify an adequate number of *transect* sites per reach. The number required will depend on heterogeneity of habitats within the reach. A minimum of five transects will be required per mesohabitat unit type. The number and location of transects sites should be guided by professional judgment and can be discussed with agency representatives prior to the study.
3. At each transect, measure *microhabitat* characteristics (depth, velocity, substrate, and cover) at three flow levels spanning the range of 5% to 40% NMAD. A greater number of flow levels may be required, dependent on the range of flows to be examined. Again, professional judgement and agency input may be required.
4. Calculate the *weighted usable width* (WUW) over the range of flows measured.

6.1.2 Transect Site Selection

The selection of transect sites is critical. Improperly located sites may not provide adequate data for assessing the effects of flow change on fish habitat. Although random transect selection is appropriate in many cases, specific study issues may demand a more focussed approach. For example, if the primary interest in the study was habitat for rearing steelhead parr, it would be appropriate to locate study transects on riffles, the habitats preferred by these species. For juvenile steelhead, pools often show limited change in wetted width, depth, or velocity with flow change, so focussing sampling efforts there may provide little information on how flow change affects fish habitat. Such non-random transect placement would not provide an estimate of habitat change with flow withdrawal, except for steelhead parr. Such a focussed study is efficient because it targets the key issue, and avoids spreading sampling effort across less important sites. However, regulators must agree with such a focussed sampling plan in advance.

The location of transects for discharge measurement is different than the location for habitat measurement. Sites for discharge measurement should be selected following the guidelines presented in the RIC Standard Method for Hydrometric Surveys (RISC 1998). The results of the two methods should not be interchanged because most habitat transects cannot provide accurate estimates of flow, and most flow transects do not provide areas of specific interest for fish.

Transect sites should be located in habitats important to the fish stock(s) of interest. These habitats can be located by using existing information that will help focus transects on key areas. For example, records may indicate that a species of interest spawns in the uppermost section of a stream reach upstream of a proposed powerhouse, guiding proponents to focus sampling there.

Proponents are encouraged to consult existing agency records and information sources (e.g., FISS, Fish Wizard - Ministry of Water, Land and Air Protection and B.C. Fisheries 2003) to determine area-specific fish habitat use. Additional fish information sources may include:

- BC16’s
- Consultant reports and other grey literature
- DFO Special Reports
- Provincial and Federal enhancement facilities personnel
- MWLAP Resource Analysis Branch (RAB) surveys and maps
- MWLAP Special Reports
- Salmon Escapement Database System (SEDS)
- Steelhead Harvest Analysis Reports
- Stewardship groups
- Stream Inventory Summary System (SISS) files

- Aerial video-documentation
- Watershed Restoration Program (WRP) studies

Other resource users (e.g., streamkeeper groups, local anglers, First Nation, etc.) may also provide important anecdotal information on species-specific particulars (e.g., known spawning or rearing areas for a given species).

Accessibility is an important economic and safety consideration. Canyons on the Mamquam River near Squamish, the Jordan River on Vancouver Island, and the Kettle River in the interior have been sampled with whole river habitat transects. Access to these sites is dangerous, and personnel must have formal training in roped climbing techniques. Where loose rock cannot be avoided, safe access may be impossible. Although biological and sampling considerations are important, some habitats are too dangerous to sample. Many habitats are so difficult to sample that proponents may wish to limit their sampling, but this can rarely be justified unless there is a critical safety concern. Proponents arguing that safety concerns prevent access must have the supporting opinion of a climbing or other access expert.

Road access points can be identified on TRIM maps and aerial photos during the screening assessment. At the detailed screening level, a low level overflight will assist in the site selection process. These overflights should be videotaped to allow viewing by agency personnel. The overflight surveys must be timed to capture flow levels of interest (5% to 40% NMAD). The methods for overflight methodologies are described in the RIC Aerial Photography and Videography Standards for Fish Habitat Channel Assessment (RISC 1996b).

Once potential points of access by road, water, and air have been identified, an access plan can be prepared. Access during high and low flow stages will differ and should be considered in the access plan. Sites accessible at 10% NMAD by wading upstream may be inaccessible at 40% NMAD. Where access appears impossible at higher flow levels, proponents may have to select alternative sites on other reaches or streams. Alternative sites must be agreed to by agency personnel prior to sampling.

6.1.3 Transect Setup

Prior to conducting field measurements, transects must be properly setup, marked, and geo-referenced to allow identification in the field. They should be marked such that one can return and easily relocate them in the future. This will simplify the post-construction monitoring task, and will facilitate a comparative evaluation of predicted and post-project effects.

6.1.4 Marking Transects and Locations

Upon having identified suitable transect locations, the end of each transect should be marked using pins made of any of the following types of materials (other similar materials may also be used):

- 8”-10” galvanized spikes
- 5/8” diameter rebar
- Galvanized t-posts
- Angle iron
- Rock climbing anchors

The selection of one type of pin over another depends largely on the type of stream bank found at a given location. However, wherever possible the use of non-corrosive materials is preferred (e.g., galvanized spikes or t-posts). If using galvanized spikes, they should be placed in the base of a tree or into stable woody debris along the bank, above the point of rooted vegetation. It is essential that all pins be located above this point such that depth and velocity measurements capture the wetted width over the range of metered flows. Pins should also be located considering logistical and technical issues surrounding the collection of elevation data using the level and rod.

Transects and pins must be marked with flagging tape on both sides of the river. They should be properly identified using a simple alphabetical and sequential numerical system (e.g., a first transect on the Campbell River would be marked CT01, and identified as Campbell Transect 01, a second transect would be CT02, etc.). Whenever a transect crosses an island, it may be divided and named as two, with each part identified as part ‘a’ and ‘b’ (e.g., CT01a and CT01b). Transects should be number starting at the downstream end of a surveyed reach or watercourse. Consistency in the naming system will facilitate stream-specific data management and organization.

Each transect should be geo-referenced using a handheld GPS receiver. Geo-reference data should be collected in UTM format using the NAD83 map datum. If using an industrial-grade GPS receiver refer to the British Columbia Standards, Specifications and Guidelines for Resource Surveys Using Global Positioning System (GPS) Technology, Release 3.0, section on High Significance Point Features (RISC 2001b). Where local topography prevents GPS data collection, sites should be identified on 1:20,000 topographic maps and UTM’s should be inferred from marked locations using map coordinates.

Within each reach it will probably be necessary to establish a stage-discharge relationship. This can be achieved by establishing a permanent staff gauge and correlating stage readings to discharge measurements. This document does not discuss the characteristics of staff gauge sites or the procedures for installing staff gauges. For information on staff gauge installation procedures refer to the Standard Operating Procedures for Hydrometric Surveys in British Columbia (RISC 1998) (Section B, pages 9-32).

6.1.5 High Flow Considerations

The sampling of transects during high flow may require the use of specialized equipment such as static lines, angled safety lines, and boats. Static and angled safety lines require stable anchor points on each side of the stream immediately upstream from the transect location. Static lines should have a tensile breaking strength of 800 lbs (e.g., 1/2" high quality poly-propylene or ¼" Spectra® line) and should be made of highly visible material (Aaron Conway, International Rescue Instructors Alliance, pers. comm.).

Static and safety line setup may require swimming or boating across the stream. A lightweight, buoyant line can be used during the first crossing and replaced later on with the working line.

Boats are usually used in larger streams and rivers. Boaters should be experienced with river operations. For details on the use of boats and depth and velocity data collection refer to RIC Standard Operating Procedures for Hydrometric Surveys in British Columbia (RISC 1998) (Section D, pages 110-123).

6.1.6 Hydrometric Survey Equipment

Types of hydrometric survey equipment are described in detail in the Standard Operating Procedures for Hydrometric Surveys in British Columbia (RISC 1998) (Section C4-C5, pages 60-93).

Horizontal axis current meters are the most common meters used to collect depth and velocity data. Two of these meters have increased in popularity over the past years because of their smaller sizes. Their size is ideal for the collection of data in more confined and restrictive spaces. These meters are manufactured by Swoffer (model 2100, single propeller) and Marsh McBirney (model Flo-Mate 2000, electromagnetic sensor).

If a propeller-type meter is chosen, it is important to ensure that the best size propeller be selected for the size of the project stream. Further, consistency in using the same propeller with the same meter must be assured. Particularly with Swoffer meters, alternating propellers and meters during the course of a study will affect the data collected. Meters are calibrated to a particular propeller, and therefore changing propellers requires proper mode selection and/or recalibration.

In some cases, data collected with one propeller may be adjusted to those collected using another one based on the differences in calibration values between the propellers used.

Calibration is essential prior to any study. Proponents must provide written confirmation of meter calibration:

1. By the manufacturer prior to the study; and
2. By the protocol defined by the manufacturer prior to each field trip.

Proponents should include in an appendix to the study report documentation of each calibration performed, initialled by the technician responsible for the calibration.

6.1.7 Habitat Data Collection

The following section provides details on the data collection requirements involved in the BCIFM.

The BCIFM requires collecting general physical habitat characteristics and depth and velocity data at each transect site. General procedures describing the setup and position of a tagline (i.e., measuring tape) and the collection of depth and velocity data are provided in RISC 1998, Section D, pages 106-109. Details on depth and velocity collection requirements specific to this methodology are provided in Section 6.1.8 of this manual.

6.1.7.1 General Physical Habitat Information

For each transect site, information on the following habitat characteristics must be collected:

a. Mesohabitat type
b. Channel type
c. Particle diameter - D95
d. Gradient/slope
e. Roughness
f. Cover

Collection procedures are provided in the User Notes for the IFS Field Data Card – Section 6.1.14.

6.1.7.2 Habitat Unit Type

Streams display distinct units of habitat that can be differentiated based on mean water velocity, width, width/depth ratio, and other microhabitat attributes. Mesohabitats (also known as channel geomorphic units and as habitat units) provide convenient strata for the partitioning of study effort. Moreover, ecological values differ between mesohabitats, creating the opportunity to focus study efforts on the most important unit given a particular study objective.

Each study reach should be delineated into habitat units based on the definitions provided in the Fish Habitat Assessment Procedure (Johnston and Slaney 1996). There are several hierarchies available in the literature, though Hawkins *et al.* (1993) has emerged as a standard and should be used unless there are good reasons to adopt an alternative. Habitat unit composition changes with flow (Hogan and Church 1989, Hilderbrand *et al.* 1999) with slow moving habitats (pools) being more abundant at low flows and fast moving habitats (riffles), being more abundant at higher flows. Given this, it is important that habitats be sequenced under a low flow when microhabitat measurements are made.

6.1.7.3 Channel Type

Channel type should be recorded as per Johnston and Slaney (1996). For instream flow modelling, it is important to distinguish cross-sections with multiple channels from those with a single channel. Where a transect spans one channel, the channel type is single. Where a transect crosses an island (as defined in the RISC Stream Inventory Standards and Procedures 2001a), the channel is considered multiple. Gravels bars do not define a multiple channel. Channel classification as defined in the FHAP can be used to provide further detail,

6.1.7.4 Particle Diameter - D95

For a definition of D95 refer to Stream Inventory Standards and Procedures (RISC 2001a).

6.1.7.5 Gradient/Slope

During transect data collection, accurate gradient information should be collected with a surveyor's rod and level.

6.1.7.6 Roughness

Roughness pertains to the irregularity of a substrate surface (Armantrout 1998). Roughness data is collected in metres (m) at each transect site, and is measured as the height of the average substrate particle protruding from the streambed.

6.1.7.7 Substrate Data

Substrate is quantified visually by expressing the percentage of each size class to the nearest 5%. The proportion of each type is quantified at vertical along a transect, based on the substrate present in a 1 m^2 patch centered on the vertical. Take note of the following change in substrate size distribution: **fines are not sub-categorized into two size classes** (refer to **Table 9**).

Table 9. Summary of substrate classification.

Substrate Categories	Size Range
Fines	< 2 mm
Small Gravels	2-16 mm
Large Gravels	16-64 mm
Small Cobble	64-128 mm
Large Cobble	128-256 mm
Boulders	256-4000 mm
Bedrock	>4000 mm

6.1.7.8 Cover Data

Cover elements are identified by visual observation. In some cases, the collection of cover data may not be possible (e.g., areas where water depth is too great, fish passage transects upstream from falls or large cascades, in canyon sections). Cases where there are no cover elements in a depth and velocity cell or where the collection of cover data is impossible should be noted (refer to the Used Notes for the IFS Field Data Card). Information on cover types is provided in the Stream Inventory Standards and Procedures (RISC 2001a) Section 4.2.4.

6.1.8 Collecting Depth and Velocity Data

This section relies greatly on data collection methods described in Standard Operating Procedures for Hydrometric Surveys in BC (RISC 1998) (see Section D, pages 99-130). References to RISC 1998 are made where applicable.

The information provided here differs from RISC 1998 in that it focuses on the measurement of habitat conditions, rather than on measuring discharge. At transects intended for discharge data collection the procedures outlined in RISC 1998 should be followed.

6.1.8.1 Verticals

The spacing requirements of *verticals* are described in Standard Operating Procedures for Hydrometric Surveys in BC (RISC 1998) (see Section B.2.4, page 32).

Positioning

Transects must accommodate a minimum of 20 verticals. The positioning of each vertical depends entirely on streambed topography, and must take into account changes in water surface elevation over the range of metered flows. Some study designs may require verticals to be repeated in the same locations during each outing: this depends on the software used to calculate weighted useable width. **Figure 9** provides an example of where to position verticals to accurately capture the streambed topography.

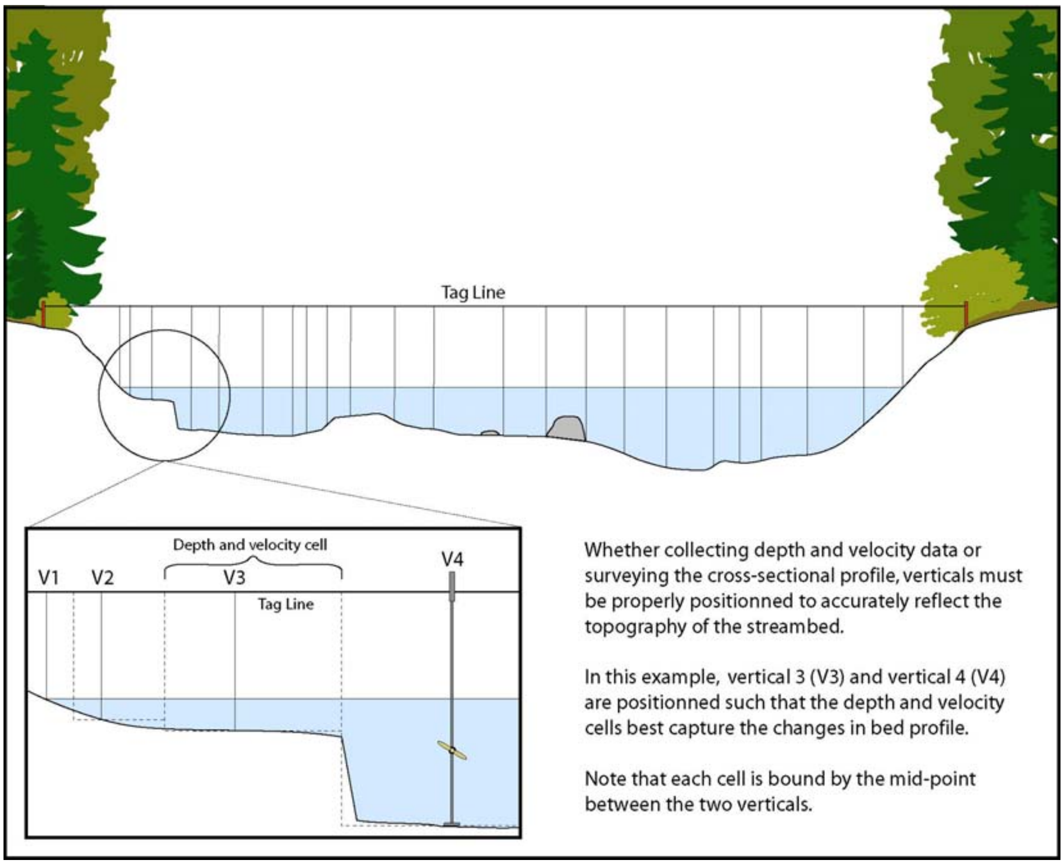

Figure 9. Example of appropriate vertical positioning to capture changes in streambed topography.

Direction of Flow

When measuring depth and velocity, the sensor (e.g., propeller, bulb, wheel) must be oriented properly to the flow. If the sensor is not aligned with the flow, the divergence (i.e., from not facing directly upstream) should be expressed in ^{o}. When measurements are taken at 180^{o}, velocity data should be recorded as a negative value.

Large Boulders and Protruding Bedrock

Verticals should capture water edges along large embedded D95 and protruding bedrock outcrops. Typically ‘large’ is defined as 1 m along the transect line, however, what qualifies as large will vary between transects and will depend on transect width.

Figure 10 illustrates the positioning of the metering rod in these cases.

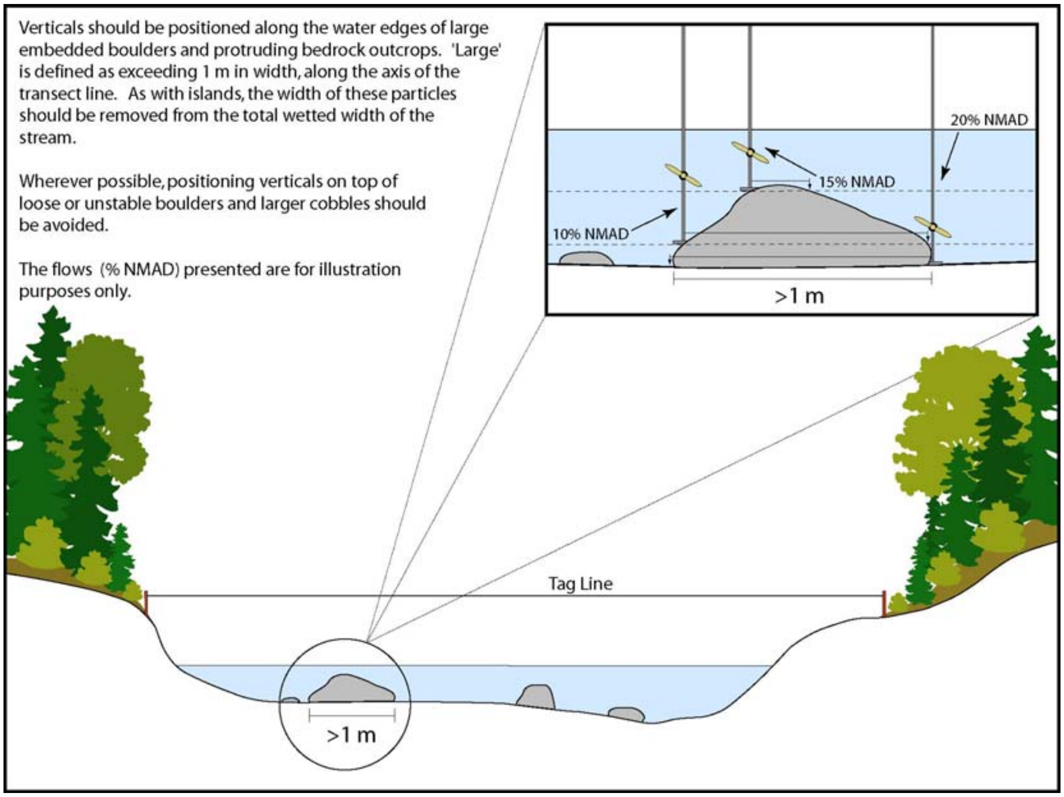

Figure 10. Example of appropriate rod positioning when encountering large embedded boulders and protruding bedrock outcrops.

Undercut Banks and Confined Spaces

At undercut banks, an attempt should be made to position the rod in the confined area to obtain a velocity measurement. This generally requires to rod to be positioned at an angle. In addition to depth and velocity, the depth of the undercut bank should also be measured.

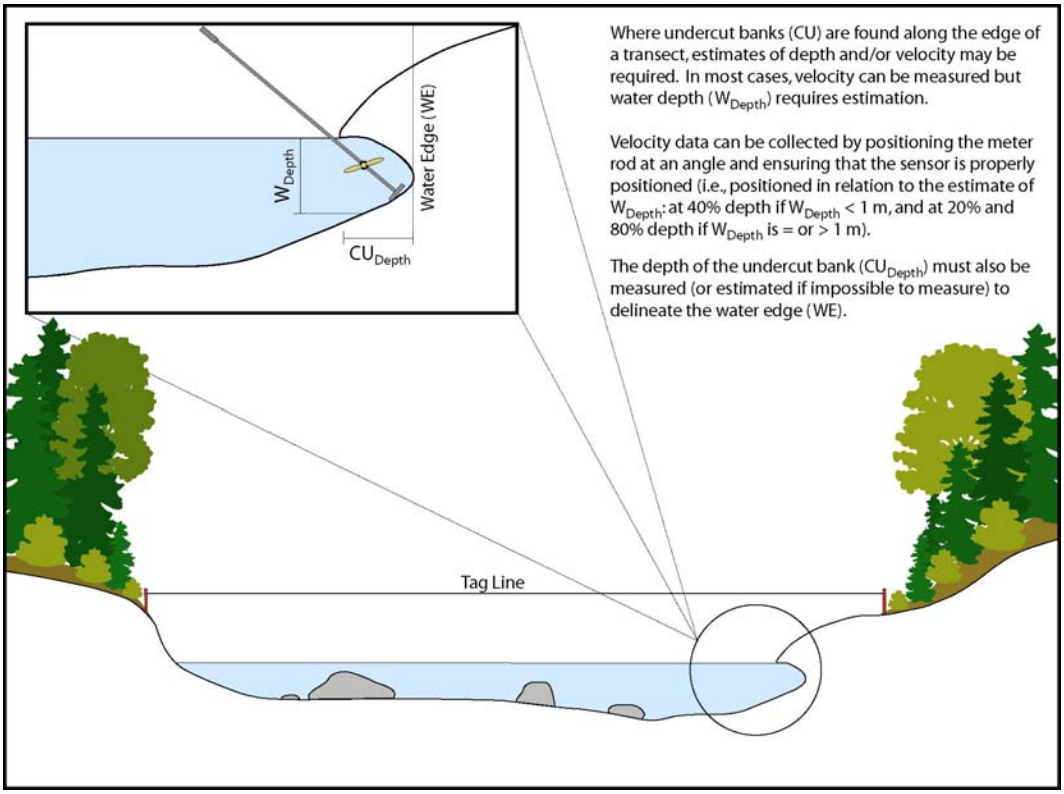

Figure 11 illustrates how to collect these data. Similar procedures may be required in cases where LWD are obstructing the bank.

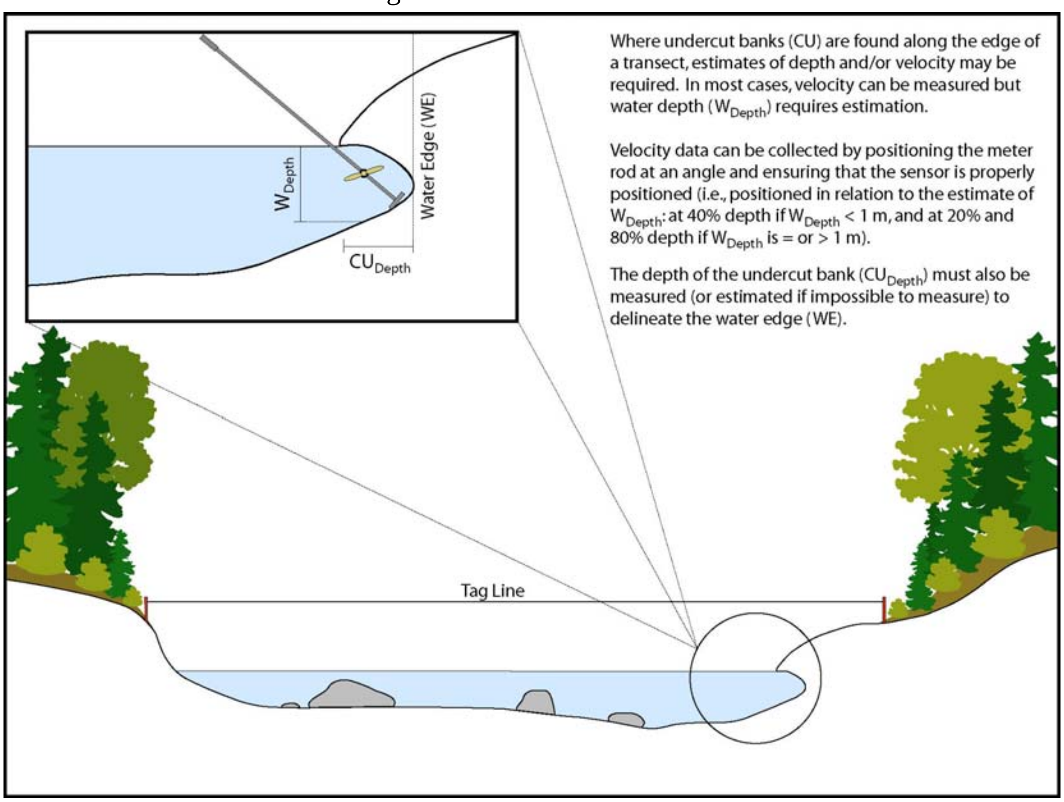

Figure 11. Example of procedures involved in the collection of depth and velocity

data at undercut banks. Similar procedures apply when encountering LWD at water edges.

Low Velocity Conditions

In areas were water velocities are too low to be captured by a meter, but velocity is evident, an estimate of velocity may be required. These situations are commonly encountered in shallow rearing habitats along stream margins where at some verticals, depth is too shallow to obtain a velocity reading (i.e., the sensor can not be submerged). In some instances, when using a propeller-type meter, velocities can be measured by partly submerging the propeller. When velocity cannot be measured it should be estimated by comparison to a vertical of known velocity.

6.1.8.2 Drawing the Site

A detailed drawing of each transect site is required to facilitate the re-location of important features in future outings (e.g., photo locations, benchmark location, etc.). Drawings also prove useful in providing a sound understanding of site conditions to those who have not seen the sites. The drawing must include the following items:

- Transect name/number, location, and length
- Types of pins on both sides of the river
- Types of trees in which pins are anchored
- Location of the benchmark
- Location of the tripod during the elevation survey
- Locations where gradient elevations were measured
- Location of photo-points and their distances from the transect, including directional arrows and photo numbers
- Areas of turbulent and laminar flow
- Large protruding boulders and bedrock, islands
- Undercut banks and LWD
- Direction of flow and northern arrow
- Habitat unit(s), side channels, spawning areas
- Important landmarks, features, and observations
- UTM Coordinates along the transect line

Figure 12 is an example site drawing that incorporates this information.

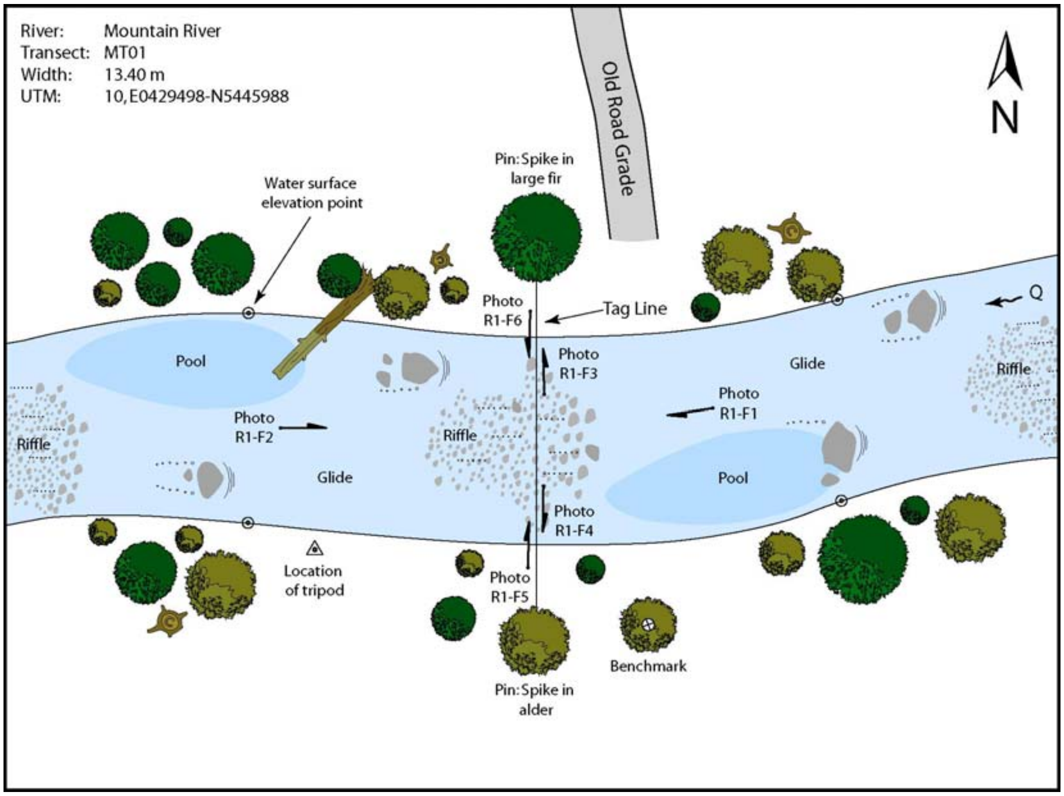

Figure 12. Example site drawing including all data requirements.

6.1.9 Calculating Weighted Usable Area

Weighted usable width (WUW) can be calculated at each station by applying habitat suitability index values for depth, mean velocity (at 0.4 of depth), the dominant substrate within a radius of 0.5 m from the station (for adult spawning), and dominant cover within a radius of 0.5 m from the station (for juveniles).

$$WUW_{dvs} = \Sigma_i^n (W_i*D_i*V_i*S_i);$$

where W_i is the width of cell *i* on the transect, D_i is the suitability of depth at cell *i*, V_i is the suitability of velocity at cell *i*, S_i is the suitability of substrate at cell *i*,. Cover or another habitat parameter can be substituted for substrate in this model. The model assumes that habitat is determined by the habitat variables in the multiplicative fashion, representing a specific hypothesis about habitat. Other models reflective of other hypotheses may be used instead, providing that their use can be rationalized and is documented.

WUW should be aggregated for each habitat unit within the reach. Wide variations in habitat-flow relationships between transects demand that the variability between transects be accounted for explicitly, expressed as confidence intervals around habitat-flow relationships (Williams 1996). Typically WUW is negatively skewed, with a few very large values representing a high proportion of the habitat. Given this, mean statistics may not accurately predict the central tendency of the data, and standard deviation may not properly describe the confidence intervals. To address this, the data may be transformed, or non-parametric statistics may be used. Bootstrapping (Efron and Tibshirani, 1991) is a useful way to calculate confidence limits with non-normal habitat data (Williams 1996).

6.1.10 Collecting Elevation Data

If modelling of habitat at different flows is necessary, then elevation data will have to be collected to facilitate modelling. Elevation data should be collected by standard surveying techniques. This information provided here relies greatly on data collection methods described in Standard Operating Procedures for Hydrometric Surveys in BC (RISC 1998) (see Section E, pages 131-149).

The information provided here differs, in part, from that presented in RISC 1998: it relates to the collection of elevation data in relation to depth and velocity transects rather than to gauging stations. In essence, differences between methodologies lie in data collection requirements rather than the procedures themselves. Elevation data may be collected using either a standard surveyor's level and rod or using more sophisticated digital surveying equipment (e.g., total station).

6.1.10.1 Establishing a Benchmark

Prior to initiating the elevation survey, a permanent local benchmark must be established. The benchmark should be established by placing a standard survey pin into the base of a large, secure tree. Further, it must also be properly and clearly identified to facilitate relocating it in future outings. If multiple transects are located in close proximity, the benchmark should be established such that all transects can be surveyed from the same location. Minimizing movement of the tripod will reduce the introduction of error in data collection, and will accelerate the survey itself.

6.1.10.2 Surveying the Cross-Sectional Profile

If modelling techniques are required to infer between or extrapolate beyond unmeasured flows, a detailed survey of the channel cross-section must be completed at each transect. The survey must be tied into the benchmark, and must capture most changes in streambed profile. The number of rod readings depends on the study-design and type of model used, as well as on streambed characteristics. Some studies may require the cross-sectional profile be tied in with the exact position of each depth and velocity vertical. Others may simply require surveying the bed profile and correlating the changes in water surface elevation over the range of metered flows with the water surface elevation collected during the profile survey.

In either case, it is important to note that sufficient readings must be collected to accurately reflect the topography of the streambed. **Figure 9** provides an example of the number of rod readings (23 readings for the given transect) required to adequately capture the streambed topography at a given transect site.

6.1.10.3 Local Stream Gradient

The local stream gradient must be determined at each transect site. Gradient is measured by surveying water surface elevation in six locations surrounding the transect site. These locations are listed below. Elevation data is measured on the right and left wetted edges of the stream.

- 20 m upstream from the transect (both banks)
- At the transect itself (both banks)
- 20 m downstream from the transect (both banks)

6.1.11 Photodocumentation

Photographic methods should follow procedures described in A Guide to Photodocumentation for Aquatic Inventory (RISC 1996a). Date-stamped photos are preferred.

Good quality photographs will illustrate channel features and changes in wetted area and turbulence at different flows. These photos will be used by reviewers to help assess the effects of flow change on fish habitat.

6.1.11.1 Requirements

A series of transect-specific colour photographs must be taken at the same location over the range of metered flows. With the exception of pin photos, all photos must be replicated at each flow level. Each set of photos (shot over the range of flows) should be consistent in format (portrait or landscape). Where pans are required to capture the entire channel width, photos should always be taken from left to right regardless of whether facing upstream or downstream. The tag line should be visible in all photos taken. The photo requirements for each transect are as follows:

- Looking upstream at the transect
- Looking downstream at the transect
- Looking at the transect from the left bank towards the right bank
- Looking at the transect from the right bank towards the left bank

- Looking at the right bank pin
- Looking at the left bank pin

Photos looking from bank to bank should be taken from a position that captures the substrate. Photos taken facing either upstream or downstream must include the entire transect width. Due to obstructions caused by overhanging vegetation, pins may be excluded from the pictures. Whenever possible, replicate photos should be taken at the same time of day (or close) as the first set was taken. A crewmember should be included in the picture to provide a size reference. Examples of photographs that capture these requirements are given in **Figure 13** through **Figure 18**.

Figure 13. Example photo looking upstream.

Figure 14. Example photo looking downstream.

Figure 15. Example photo looking at the left bank from the right bank.

Figure 16. Example photo looking at the right bank from the left bank.

Figure 17. Example photo looking at the right bank pin (rebar).

Figure 18. Example photo looking at the left bank pin (spike).

6.1.11.2 Cataloguing

The BCIFM requires the collection of many photos. Photos for a single project could exceed 400 (i.e., 25 transects with 6 photos per transect, of which 4 are replicated over a range of 5 metered flows). Effective presentations of these photos require proper management of the images. To facilitate photo management and review, a simple classification and organizational system should be used.

Descriptors

Each photo should be accompanied by a detailed, yet concise descriptor. For example, if a photo is taken looking in an upstream direction at transect CT01, a simple and effective descriptor could be ‘Looking upstream at transect CT01’. Or, in the case of a pan, a descriptor could be ‘Pan looking upstream at transect CT01 (river right - RR)’ and ‘Pan looking upstream at transect CT01 (RL)’. Some digital cameras are capable of recording audio descriptions of each photo, which can improve the ease of cataloguing large numbers of photos.

Cataloguing and Archiving Hard Copies

Photos should be catalogued in both hard and digital copy for ease of review. Hard copies are usually for indexing and reference purposes, and can be catalogued in a binder with a descriptive label assigned to each photo. Regulatory agencies and the public may require that photographic images be provided in digital format. All project photos should be archived in a systematic way following the standard hierarchal root folder-subfolder system used on most popular desktops. For each photo, the following information should be documented:

- Transect name
- Roll number
- Photo number (as per negatives)
- Discharge at the time photo was taken
- Date
- Watercourse
- Reach Number
- Time at which the photo was taken
- The initials of the photographer

6.1.12 Field Safety Considerations

The collection of instream flow data can be hazardous. The Workman’s Compensation Board of B.C. identifies mandatory training requirements for work environments in B.C. Those undertaking the work must be certified with the appropriate training.

6.1.12.1 Safety Equipment

The task of collecting data at high flows requires the use of several safety accessories to ensure safe working. The following safety accessories are required when working in streams.

- Throw bag (minimum length 20 m)
- Personal Floatation Device (PFD)
- Wading belt (optional)
- Whistle attached to PFD, waders, or dry suit
- Cutting tool
- Buoyant safety line
- Light weight dry suit (optional, but often necessary)
- Non-slip footwear appropriate for the substrate (optional)
- VHF radios (or other means of communication acceptable to the WCB)

6.1.12.2 Courses and Certifications

Several courses in BC provide training with respect to working in and around flowing waters. Some of these courses provide a sound background for working in flowing water, particularly under high flow conditions. Courses are offered at different training levels to accommodate the need of any one trainee. Of these, the following are recommended:

- Swiftwater Safety Operations (Level I, II, or III) (Level II is most recommended);
- Wilderness First Aid

Additionally, WCB Level 1 First Aid and Transportation Endorsement are mandatory, and electrofishing certification is required for use of electrofishers.

6.1.13 Data Collection Forms

IFS Field Data card (Front)

IFS FIELD DATA CARD							
STREAM NAME		(LOCAL)		PAGE	of		
WATERSHED CODE				ACCESS			
ILP MAP #		ILP #		NID MAP #		NID #	
REACH #		FIELD UTM	MTD	DATE		TIME		CREW	
TRANSECT		WIDTH (m)	MTD	TRANSECT TYPE		AGENCY	

CHANNEL				FLOW METER		PHOTO-DOCUMENTATION		
HYDRAULIC UNIT TYPE				TYPE		ROLL	FRAME	DESCRIPTION
CHANNEL TYPE				MAKE		ROLL	FRAME	DESCRIPTION
ROUGHNESS (m)		D95 (m)		MODEL #		ROLL	FRAME	DESCRIPTION
CHANNEL SLOPE			MTD	PROP SIZE		ROLL	FRAME	DESCRIPTION
BANKFULL WIDTH (m)			MTD	CALIB #		ROLL	FRAME	DESCRIPTION
WETTED WIDTH (m)			MTD	ROD LG		ROLL	FRAME	DESCRIPTION
PIN INFORMATION				WATER		ROLL	FRAME	DESCRIPTION
TYPE (RR)		LOCATION		TEMPERATURE	MTD	ROLL	FRAME	DESCRIPTION
TYPE (RL)		LOCATION		FLOW (cms)		ROLL	FRAME	DESCRIPTION

STATION		ELEVATION SURVEY				SUBSTRATE							COVER	DEPTH - VELOCITY					
						% SUBSTRATE									VELOCITY (ms⁻¹)				
STATION	DISTANCE (m)	NORTHING (m)	EASTING (m)	OBS ELEV (m)	ELEV (m)	R	B	LC	SC	LG	SG	F	COVER	DEPTH (m)	0.2d	0.4d	0.8d	FLOW ANGLE (°)	COMMENTS
BM																			
PIN	0.00					-	-	-	-	-	-	-	-	-	-	-	-	-	
LWE														0.00		0.00			

- SAMPLE -

IFS Field Data card (Back)

STATION		ELEVATION SURVEY				SUBSTRATE							COVER	DEPTH - VELOCITY					
STATION	DISTANCE (m)	NORTHING (m)	EASTING (m)	OBS ELEV (m)	ELEV (m)	% SUBSTRATE							COVER	DEPTH (m)	VELOCITY (ms^{-1})			FLOW ANGLE (°)	COMMENTS
						R	B	LC	SC	LG	SG	F			0.2d	0.4d	0.8d		
RWE														0.00		0.00			
PIN	0.00					-	-	-	-	-	-	-	-	-	-	-	-	-	

HIGH FLOW INFORMATION		FISH OBSERVATIONS			COMMENTS
STATIC LINE	Y N	METHOD	S V EF A N		
ANGLE SAFETY LINE	Y N	SPECIES			
BOAT	Y N	LF STAGE	E A F P Ad S		
SWIMMING	Y N	BHVR	F R H S		
DIF LVL	1 2 3 4 5	DENSITY	H M L F		
ACCESS	G M F P I	LOC	P S T Us Ds		

SITE DRAWING

- SAMPLE -

6.1.14 User Notes for the IFS Field Data Card

Referencing Information

User notes for the following fields are described in the Reconnaissance (1:20,000) Fish and Fish Habitat Inventory: Standards and Procedures, Chapter 4 (RISC 2001a):

- Stream name
- Local Name
- Watershed Code
- Access
- IL Map Number
- ILP Number
- NID Map Number
- NID Number
- Reach Number
- Field UTM and method
- Date, time, crew, and agency

Transect Name:

Definition: Name given to a transect using a simple alphabetical and sequential numerical system. For example, a first transect on the Campbell River would be marked CT01, and identified as Campbell Transect 01, a second transect would be CT02, etc.
Method: Identified by the project head/supervisor/proponent. Transects should be identified in a sequential order starting at the mouth and progressing upstream.
Recording procedure: Record the name of the transect in the appropriate cell.

Width (m):

Definition: Measured width of the transect.
Method: Measure the transect width from pin to pin using a standard field tape (e.g., tag line). Other recognized measurement methods may be used (refer to RISC 2001a, Site Card User Notes, Chapter 4, page 53, section on W_b).
Recording procedure: Record the width of the transect in meters (m) to the nearest centimeter (0.01 m). Record the method code as per page 53 in RISC 2001a.

Transect Type:

Definition: The type of transect used in an instream flow study.
Method: Identify the type of transect from the following list.
Recording procedure: Record the type of transect in the appropriate cell using the following codes.

Transect Type	Code
Discharge	**D**
Habitat	**H**

Channel Information

Mesohabitat Type:

Definition: The type of mesohabitat that best describes the location at which the transect is located.
Method: Identify the mesohabitat type from the following list.

- Cascade
- Fall
- Glide
- Plunge pool
- Rapid
- Riffle
- Run
- Scour pool

Recording procedure: Record the mesohabitat type in the appropriate cell.

Channel Type:

Definition: The type of channel that best describes the location at which the transect is located.
Method: Identify the type of channel either as being single or multiple (multiple channels are separated by islands).
Recording procedure: Record the type of channel in the appropriate cell.

Roughness (m):

Definition: Roughness pertains to the irregularity of a substrate surface.
Method: Measured as the height of the average substrate particle protruding from the streambed.
Recording procedure: Roughness is measured using a standard ruler and recorded in metres (m) to the nearest centimetre (0.01 m).

D95 (m): Refer to the Reconnaissance (1:20,000) Fish and Fish Habitat Inventory: Standards and Procedures, Chapter 4, page 61 (RISC 2001a).

Channel Slope:

Definition: The measured slope of the channel using surveying equipment (e.g., level and rod).
Method: Calculate the slope of the water surface using the data collected with the surveying equipment.
Recording procedure: Record the slope as the ratio of rise over run to the nearest 0.001.

Bankfull Width (m): Refer to the Reconnaissance (1:20,000) Fish and Fish Habitat Inventory: Standards and Procedures, Chapter 4, page 53 (RISC 2001a). Provide the width at the transect location.

Wetted Width (m): Refer to the Reconnaissance (1:20,000) Fish and Fish Habitat Inventory: Standards and Procedures, Chapter 4, page 51 (RISC 2001a). Provide the width at the transect location.

Flow Meter Information

Type:

Definition: The type of flow meter used to collect the depth and velocity data.
Method: Types include propeller meters, single or multiple impeller type meters, electromagnetic sensor meters, etc.
Recording procedure: Record the type of flow meter in the appropriate cell.

Make:

Definition: The brand name/make of the flow meter used to collect the depth and velocity data.
Method: n/a.
Recording procedure: Record the brand name/make of the flow meter in the appropriate cell.

Model Number:

Definition: The model number of the flow meter used to collect the depth and velocity data.

Method: n/a.

Recording procedure: Record the model number of the flow meter in the appropriate cell.

Propeller Size (applicable to propeller type meters only):

Definition: The size of the propeller used to collect the depth and velocity data.

Method: n/a.

Recording procedure: Record the propeller size in the appropriate cell.

Calibration Number:

Definition: The brand name/make of the flow meter used to collect the depth and velocity data.

Method: n/a.

Recording procedure: Record the brand name/make of flow meter in the appropriate cell.

Rod Length:

Definition: The length of the metering rod used to collect the depth and velocity data.

Method: n/a.

Recording procedure: Record the length of the metering rod in the appropriate cell.

Photo-Documentation Information

Roll Number and Frame Number: Refer to the Reconnaissance (1:20,000) Fish and Fish Habitat Inventory: Standards and Procedures, Chapter 4, page 68 (RISC 2001a).

Descriptor:

Definition: The description of a photo.

Method: Record a detailed, yet concise descriptor. For example, 'Looking upstream at transect CT01'. Or, in the case of a pan, a descriptor could be 'Pan looking upstream at transect CT01 (river right-RR)' and 'Pan looking upstream at transect CT01 (RL)'. Avoid ambiguous descriptors such as 'downstream shot of transect CT01'.

. **Recording procedure:** Record the photo description in the appropriate cell.

Pin Information

Pin Type (River Right – RR and River Left – RL):

Definition: The type of pin used to hook up the tag line on each bank.

Method: Types include galvanized spikes, rebar, galvanized t-posts, angle iron, and rock climbing anchors.

Recording procedure: Record the type of pins used in the appropriate cell.

Pin Location (River Right – RR and River Left – RL):

Definition: The location in which the pin is anchored.

Method: Indicate whether the pin is anchored in the bank, in a deciduous or coniferous tree (species preferred), or whether the pin is anchored in any other type of material (e.g., concrete abutment, rip rap, etc.).

Recording procedure: Record the pin location in the appropriate cell.

Water Information

Water Temperature: Refer to the Reconnaissance (1:20,000) Fish and Fish Habitat Inventory: Standards and Procedures, Chapter 4, page 59 (RISC 2001a).

Flow (cms):

Definition: The water flow at the time of survey.

Method: Indicate flow of the watercourse either expressed in cubic meters per second (cms) or as a % value of NMAD.

Recording procedure: Record the pin location in the appropriate cell.

Station Information

Station (m):

Definition: The type of stations identified along the tag line.

Method: Identify the type of station (LWE, RWE, or PIN) starting with 0.0 on the left bank (0.0 at the left bank pin). LWE denotes the Left Wetted Edge and RWE denotes the Right Wetted Edge.

Recording procedure: Record the station type in the appropriate cell. LWE and RWE must be recorded for islands, and for boulders and bedrock outcrops that are > 1 m in width along the axis of the tag line.

Distance (m):

Definition: The location (or distance from the left pin) of stations and depth and velocity verticals along the tag line.
Method: Identify the location of stations and verticals along the tag line by using the metering rod.
Recording procedure: Record the distance of stations and verticals in (m) in the appropriate cell. All distances are recorded to the nearest 0.01 m.

Elevation Survey

Elevation Survey: These data requirements are specific to analysis models and vary between models. Methods for collecting elevation data are presented in Standard Operating Procedures for Hydrometric Surveys in BC, Section E, pages 131-149 (RISC 1998).

Substrate Information

% Substrate:

Definition: The sediment that covers the channel bed.
Method: Visual estimation of bed material composition classified as per categories outlined below.
Recording procedure: Estimates are expressed in percentages, to the nearest 5%. The proportion of each type must be quantified at every depth and velocity cell.

Code	Class	Size
F	Fines	< 2 mm
SG	Small Gravel	2-16 mm
LG	Large Gravel	16-64 mm
SC	Small Cobble	64-128 mm
LC	Large Cobble	12-256 mm
B	Boulders	256-4000 mm
R	Bedrock	> 4000 mm

Cover Information

Cover:

Definition: Any structure in the wetted channel or within 1 m above the water surface that provides a hiding, resting, or feeding place for fish. The various cover types are:

Code	Description
SWD	Small Woody Debris
LWD	Large Woody Debris
B	Boulder or cobble
C	Undercut banks
DP	Deep Pool
OV	Overhanging vegetation within 1 m of the water surface
IV	Instream vegetation
IC	Ice
N	No cover present

Method: Visual estimation of cover types present in each depth and velocity cell.
Recording procedure: Record all the cover types present in each depth and velocity cell.

Depth and Velocity Data

Depth (m):

Definition: The depth of the water at each vertical location.
Method: Measure the depth of the water using the metering rod.
Recording procedure: Record the depth in (m) to the nearest 0.01 m in the appropriate cell.

Velocity ($m \cdot sec^{-1}$):

Definition: The velocity of the water at each vertical location.
Method: Measure the water velocity at each vertical using a meter. Velocity measurements must be taken at 0.4 depth if the water depth is < 1 m, and at 0.2 and 0.8 depth if the water depth is greater than 1 m.
Recording procedure: Record the water velocity in $m \cdot sec^{-1}$ in the appropriate cell. Measurements should be recorded to the nearest 0.01 $m \cdot sec^{-1}$.

Flow Angle (^{o}):

Definition: The angle of flow in relation to an axis perpendicular to the tag line.
Method: Estimate the angle of flow by comparing the angle of the sensor with an imaginary axis perpendicular to the tag line.
Recording procedure: Record the angle in degrees (^{o}), clockwise in relation to the imaginary axis, and to the nearest 10^o.

Comments:

Definition: Comments to aid in interpretation of information. Comments may include presence of fish or redds at a given depth and velocity cell.
Method: n/s
Recording procedure: Record a number in the light shaded area under the comment header, and reference this number and elaborate on the nature of the comment(s) in the comment section on the back of the IFS Field Data Card.

High Flow Information

Static Line:

Definition: Indicates whether a static line was used to collect the depth and velocity data at the metered flow.
Method: n/s
Recording procedure: Circle the appropriate letter code: y = yes and n = no.

Angle Safety Line:

Definition: Indicates whether angle safety lines were used to collect the depth and velocity data at the metered flow.
Method: n/s
Recording procedure: Circle the appropriate letter code: y = yes and n = no.

Boat:

Definition: Indicates whether a boat was used to collect the depth and velocity data at the metered flow.
Method: n/s
Recording procedure: Circle the appropriate letter code: y = yes and n = no.

Swimming:

Definition: Indicates whether swimming was required to access a given transect at the metered flow.
Method: n/s
Recording procedure: Circle the appropriate letter code: y = yes and n = no.

Difficulty Level:

Definition: A subjective evaluation of the level of difficulty involved in collecting the depth and velocity data. This information can be used for reference purposes when having to return to a transect location at higher flows. It can also help in determining high flow considerations for future outings.

Method: n/s

Recording procedure: Circle the appropriate number code as per descriptions provided below:

Difficulty Level	Description
1	Very easy
2	Easy, but flows can make you loose footing
3	Difficult, but feasible without safety accessories
4	Very difficult, requires safety accessories
5	Impossible, life threatening

Access:

Definition: A subjective evaluation of the accessibility of a transect. This is particularly useful when having to swim, drift, or cross a side channel to access the transect.

Method: n/s

Recording procedure: Circle the appropriate letter code as per descriptions provided below:

Access	Description
G	Good access
M	Moderately good access
F	Fair access
P	Poor access
I	Impossible access due to high flow and danger

Fish Observations

Method:

Definition: Method used to observe fish at the transect site.

Method: Select the applicable method as per that outlined in the following table.

Letter Code	Method
S	Snorkelling
V	Visual observation from water surface
EF	Electrofishing
A	Angling
N	No fish observed

Recording procedure: Circle the appropriate letter code.

Species:

Definition: The species of the fish observed at the transect site.

Method: Professional judgment and knowledge.

Recording procedure: Record the species code as per RIC standards.

Life Stage:

Definition: The life stage(s) of the fish species observed at the transect site.

Method: Select the appropriate life stage(s) as per that outlined in the following table.

Letter Code	Life Stage
E	Egg(s)
A	Alevin(s)
F	Fry
P	Parr
Ad	Adults
S	Spawning adult

Recording procedure: Circle the appropriate letter code.

Behaviour:

Definition: The behaviour(s) of the fish observed at the transect site.
Method: Select the appropriate behaviour(s) as per that outlined in the following table.

Letter Code	Behaviour
F	Actively feeding
R	Young fish rearing
H	Adult holding
S	Adults spawning

Recording procedure: Circle the appropriate letter code.

Density:

Definition: A subjective evaluation of fish densities observed at the transect site.
Method: Select the appropriate density indicator as per that outlined in the following table.

Letter Code	Density Indicator
H	High number of fish (> 50 fish)
M	Moderately high numbers of fish (15-50 fish)
L	Low numbers of fish (5-15 fish)
F	Single or few fish (1-5 fish)

Recording procedure: Circle the appropriate letter code.

Location:

Definition: The location where fish were observed in relation to the tag line.
Method: Select the applicable locations as per that outlined in the following table.
Recording procedure: Circle the appropriate letter code.

Letter Code	Location
P	In the primary channel
S	In a secondary channel
T	At the tag line
Us	Upstream from the tag line
Ds	Downstream from the tag line

Appendix B: Background Information

The following is a list of selected references grouped by subject which provide additional background information on instream flow, geomorphology, and fish life history and habitat. There is also a section listing various Resource Inventory Standards Committee manuals. The citations in Appendix A: The BC Instream Flow Methodology are also included within the appropriate section.

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