A framework for incorporating the science of impact, risk and state of resource assessments into management decisions for flowing waters

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1.0 INTRODUCTION

A number of federal, provincial, tribal and municipal governments share in the responsibility for managing habitat in the province of Ontario. The Department of Fisheries and Oceans (DFO), has a mandate under the Fisheries Act (Section 35(2)) to ensure that fish habitat is not harmfully altered, disrupted or destroyed (HADD). The Ontario Ministry of Natural Resources (OMNR) has a mandate to manage the aquatic ecosystems and the fisheries they support for long term sustainability. Municipalities and tribal governments manage local landuses under the Planning Act to ensure their compliance with Federal and Provincial Policies and laws. Each agency contributes to habitat management differently.

As part of its mandate, DFO evaluates "projects" submitted to it for approval. Projects may be as simple as a culvert installation on a small intermittent stream, or as complex as a new hydro dam on a large river. DFO examines information about the biophysical condition of the site, as well as information about proposed developments to determine the likelihood that a HADD will result. Where a HADD is likely to occur, DFO will either recommend mitigation or deny the project. In some cases, DFOs decisions require site-specific biological, physical or chemical data to assist in the estimating the likelihood of a HADD. DFO has also recently identified culverts, stream realignments and shoreline hardening as three types of developments for which there are information gaps, that are difficult to screen the environmental risks of, and that thus require science to fill those gaps (Gillespie et al., 2002). DFO, therefore, periodically requires field studies to address the information needs of referrals, either generically (as in culvert assessments) or site-specifically. The studies that DFO requires can vary widely in the attributes measured and statistical design (Gillespie et al., 2002).

Municipalities and Conservation Authorities carry out subwatershed studies that require the characterization of biophysical conditions in stream systems. On the basis of existing or historical conditions, subwatershed studies (and plans) determine the future developments that can occur in a system while minimizing environmental damage. Subwatershed studies often rely on historical data (aquatic resource inventories), but can incorporate new data from field studies.

Conservation Authorities also carry out routine biomonitoring that may be part of larger environmental monitoring programs (e.g., CVC, TRCA). The design of those monitoring programs is challenging because of fiscal restraints and an underlying desire to sample as much as possible in as many places as possible. Sampling is, however, limited to specific

biophysical or chemical variables at specific key locations. Though monitoring is carried out annually, sampling locations may be visited only once in every three to five years.

Finally, industry and Municipalities are often required to carry out site-specific monitoring to address permit requirements or certificates of approval to operate. Monitoring is usually intended to determine the effects of point-source discharges on aquatic receiving environment biology, chemistry or physical attributes. Pulp mill effluents, mines and municipal wastewaters are example discharges that may require monitoring. Monitoring requirements often dictate rigorous study designs to document effects, including high levels of statistical replication and the characterization of attributes (e.g., sentinel fish populations) that may require considerable effort in the field.

Each of the above examples are assessments. Those that characterize existing conditions can be termed state of the resource assessments are may or may not require new data. Studies that examine the effects of existing developments can be called impact assessments, while those that predict future impacts are typically called risk assessments or environmental assessments. Though the goals and objectives of each of these types of assessment differ, they should all follow a generalized thought process beginning with problem formulation, followed by identification and characterization of the stressor being evaluated (or not), definition of physical and temporal boundaries on the assessment, existing information assessment, and design of field studies if required. Where field studies are carried out, the challenge is in selecting measurement variables, protocols for measurement, timing, locations, etc., i.e., all those factors that comprise the study design. Those designing the studies need assistance to determine if and when data need to be collected; if so, what type, where, when, and how intensively.

The principal objective of this document is to provide a generalized but flexible framework for assessing the biophysical condition of stream systems. The framework will provide general guidance on how to determine when new field studies are required, the design of those studies, and follow-up actions. Further, this framework formalizes a flexible process for developing study designs that satisfy individual objectives. It is anticipated that this document will be a useful frame of reference for DFO Habitat managers, referral biologists, and Conservation Authority biologists, among others, in assessing existing conditions, or to justify studies that are designed to predict or document effects associated with development.

This document describes a generic framework that summarizes a thought process for carrying out assessments and designing studies. The underlying principles of the document follow from approaches used in site-specific risk assessments (EPA, 1993; CCME, 1996; MOE, 1996). While the original purpose for this document is to provide

assistance to those working on streams, the concepts and process are applicable to any environmental question. The document cannot stand alone, and does require companion documents that (1) describe individual measurement protocols (e.g., Ontario Stream Assessment Protocol), (2) provide guidance on statistical aspects of study design (e.g., Gillespie et al., 2002), and (3) recommend measurement precision.

Apart from this introduction, this document has two main sections. Section 2.0 overviews the framework and provides general background. Section 3.0 provides examples of how the framework might be applied.

2.0 FRAMEWORK

In support of a workshop on riverine management held in 1998, Boyd et. al. (2000) developed a management framework for ecosystems (Figure 1). In this framework, overall ecosystem goals and objectives are specified on the basis of human values. Where development activities threaten those values, issues emerge. The political environment determines which issues become priority and require management. Where there is sufficient knowledge on which to immediately base a management decision, management can be carried out. The success of a management action may or may not be monitored over time (as part of Adaptive Experimental Management) to feed back to Issue Analysis and provide additional knowledge against which to propose management actions for future issues. Where there is not enough knowledge on which to propose a management action, the framework anticipates that science will be carried out to address the knowledge gap. Where science addresses the gaps, that new knowledge can be used to inform the Issue Analysis stage.

The 1998 workshop confirmed the need for an overall framework that would guide managers through the science analysis (McGuinness et. al., 2000). The assessment framework presented here (Figure 2) is intended to address that gap and to assist in the development of study designs. This framework broadens the Issues Analysis Stage into six discrete steps, the Science Analysis Stage into two discrete steps and Management into two discrete steps. As such, the framework described here provides further guidance towards the issue assessment.

The proposed framework (Figure 2) for carrying out stream assessments has the following 11 fundamental steps:

1. **Question Definition**: Development of a clear question that the assessment is intended to answer. The construction and interpretation of Hypothesis of Effect diagrams or their equivalent should aid this step.

2. **Assessment Typing**: Clear articulation of the type of assessment that is intended. That is, is the study intended to characterize existing conditions as part of a state of teh resource assessment, predict future environmental effects (i.e., risk assessment) or evaluate the present-day effects of specific stressors (i.e., impact assessment).

3. **Stressor characterization:** Description of the development pressure, proposed project, chemical stressor, etc., that is under evaluation.

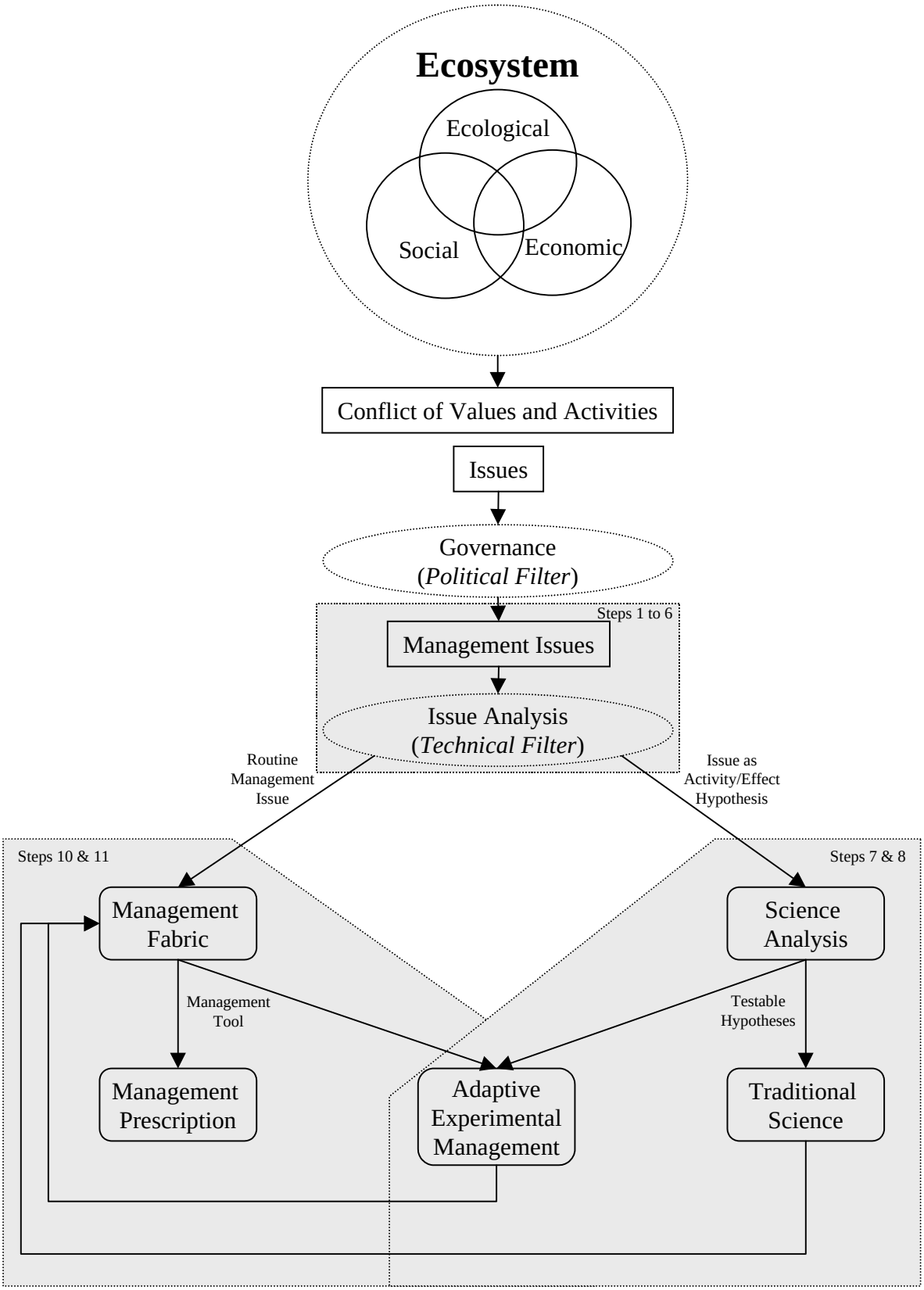

Figure 1. Management framework for stream systems (from Boyd et al., 1998).

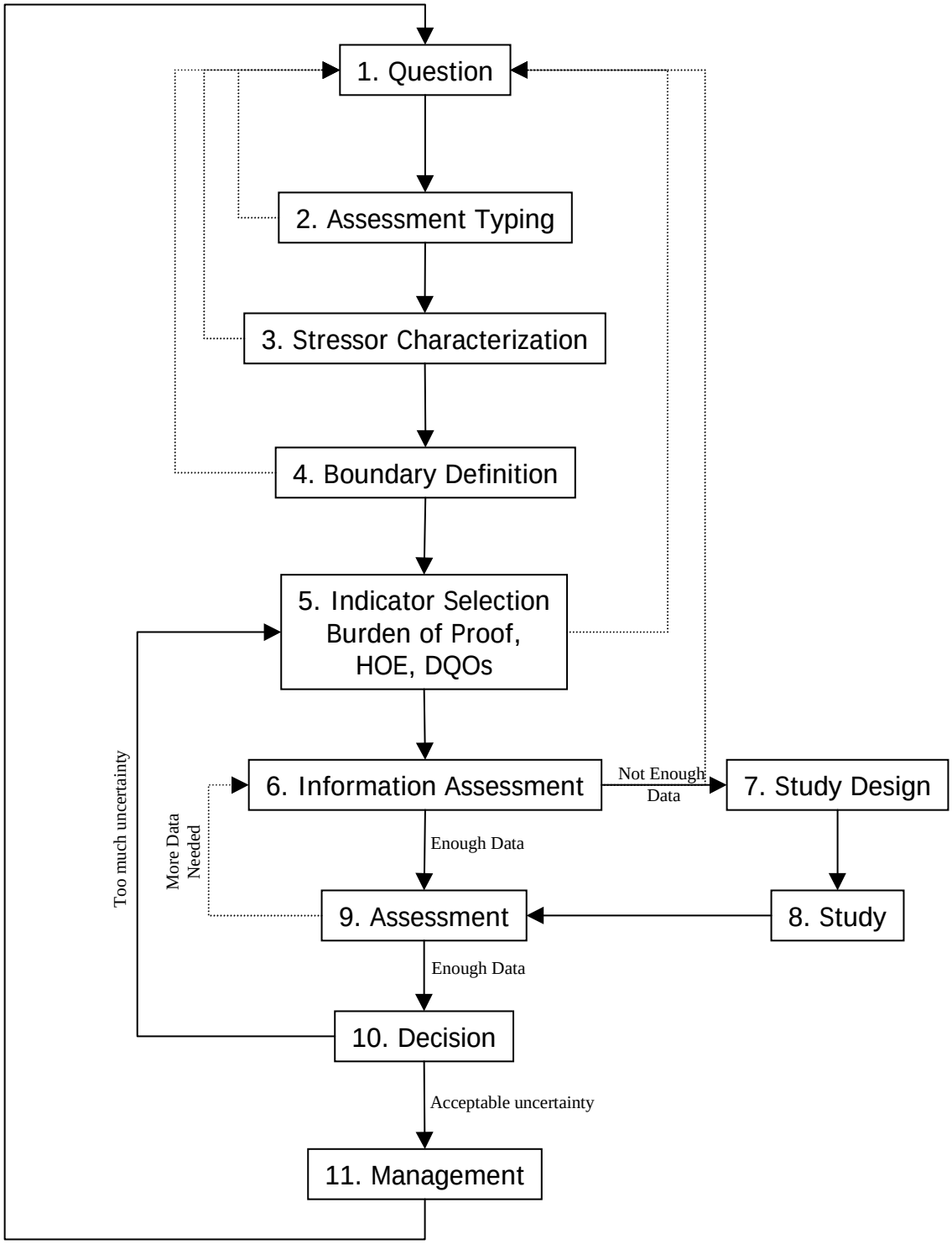

Figure 2. Schematic illustration of the process for carrying out a stream assessment.

4. **Boundary definition**: Description of the spatial and temporal bounds of the assessment.

5. **Indicator selection**: Justified selection of environmental indicators that will be used in the assessment.

6. **Information Assessment**: This step determines whether the existing available information and knowledge are sufficient for making the assessment.

7. **Study Design (if necessary)**: This step details the attributes of fields studies. Measurement variables and protocols, timing, locations are incorporated into a studies' design.

8. **Study (if necessary)**: Conduct of the field study.

9. **Assessment**: Carry out the assessment with existing or new field data.

10. **Decision**: On the basis of the assessment, decide a course of follow-up action. Regardless of the nature of the assessment, each assessment should lead to a decision regarding follow up activity.

11. **Management Action**: Carry out the recommended management action

Each of these steps is described fully below. Management Issues or questions "trigger" the use of the framework. The framework then guides the assessment to answer the question either through the use of existing information and knowledge, or through the development of new knowledge obtained through studies specifically designed to address knowledge gaps. This framework builds upon some of the basic "risk" assessment frameworks developed in Canada (CCME, 1996; OMOE, 1996; FCEMS, 2000), the US (USEPA, 1989), and elsewhere (e.g., Denmark, Pedersen et al., 1995). The process of evaluating effects is intended to be logical, and to initially incorporate a screening-level exercise that may build to larger, more comprehensive assessments where there are more gaps in the understanding of the relationship between the development pressure (stressor) and valued environmental components.

2.1 Level of Detail

Following from CCME (1996), a tiered approach to assessment is recommended. Here, it is recommended that screening and comprehensive assessments be carried out iteratively. If an initial screening-level assessment cannot adequately address the question posed with an acceptable degree of uncertainty, an additional level of detail is required for the assessment (see loop from Step 10 to Step 5, Figure 2). Thus, assessments may be carried out iteratively until uncertainties are at an acceptable level. The impetus for carrying out additional iterations is the uncertainty associated with a decision (Stage 10). Sources of uncertainty include:

- normal variation in environmental conditions;
- imperfect or incomplete knowledge; and,
- human error in carrying out the assessment.

CCME (1996) recommends that the uncertainty considered acceptable for terminating an assessment must be determined by the individual assessor, while financial and regulatory considerations may also come into play. According to CCME (1996), we should also recognize that there is no single best approach to an assessment, and that multiple lines of evidence are better than single approaches.

2.2 Step 1: Question Definition

The most important task in any assessment is articulating the question that the assessment is to address. It is recommended that the underlying objective of the assessment be articulated in a few sentences. See Appendix 1 for example questions. Questions need not be detailed in this step since Steps 2 through 5 will increase the detail of the overall question. A well articulated question will assist in defining the information requirements of the next 4 steps. When carrying out Steps 2 through 5, it may become evident that the initial question did not adequately capture the underlying objectives, or was not a question that could be feasibly answered and should be revised. Thus the feedback loops from Steps 2 and 5 to Step 1.

2.3 Step 2: Assessment Typing

The framework is considered appropriate for a variety of assessment types including:

1. **Impact**;
2. **State of the Resource**; and,
3. **Risk Assessment**.

Project objectives often combine aspects of each of these assessments. In these cases, assessments should be carried out for each specific question, with the results combined at the end where warranted. Assessments with combined objectives run the risk of compromising one or all of the multiple objectives, though they can be done with careful planning (Section 3.4).

Definitions for each of these categories vary. Here, impact assessments are considered studies carried out after an activity (development or natural event) has occurred with the objective of determining the nature of the effect on biophysical conditions. These impact assessments are also called environmental effects monitoring (EEM) studies (e.g., Environment Canada, 1998). Impact assessments are generally site-specific and document the effects of a particular development on environmental characteristics. See Environment Canada (1998, 2001) and Gillespie et al. (2002) and references therein for considerable guidance on the design of these types of studies for aquatic environments. These studies generally compare biological responses in "affected" locations with biological responses from "unaffected" locations. Differences in response between affected and unaffected locations are used as evidence of effects. Guidance on optimal and practical statistical designs is provided in Gillespie et al. (2002)

Conservation Authorities, among others, often conduct studies that are designed to characterize existing biophysical conditions, and may or may not test for spatial or temporal trends. Here, these types of studies are termed state-of-the-resource assessments. Data from state-of-the-resource assessments can be used as baseline studies against which to judge future development. In those cases, state-of-the-resource assessments become the initial stages of comprehensive impact assessments. If there is no stressor[1] or modifier (see definition below), the assessment is a state-of-the-resource assessment. Stressors should not be confused with strata[2] which are incorporated into studies to account for natural sources of variation in biophysical responses.

Classically, risk assessments are defined as those studies that evaluate the likelihood that adverse effects will occur, are occurring, or have occurred as the result of development (U.S. EPA, 1992). Risk assessments are typically carried out to determine the likelihood that chemical contaminants will have adverse effects on terrestrial or aquatic animals (CCME, 1996). In the context of fish habitat assessment, however, risk assessments represent evaluations of the likelihood that habitat alterations will affect the productive

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[1] *A stressor is an activity (natural or anthropogenic) that is predicted to have an effect on a valued ecosystem component.*
[2] *Strata are natural features such as catchment area, slope, and surficial geology that cause variation in biological condition. From a statistical point of view, they can be used to stratify study designs and account for natural variation in biological endpoints.*

potential of fish and/or fish habitat (i.e., cause HADD). There is considerable overlap in the classic definition of risk assessment and the definition of impact assessment presented here. Where there is a new development, risk assessment will rely on existing data from other facilities to derive the burden of proof that an environmental impact (HADD) may result. Where the development is existing, the risk assessment will require at least some site-specific data to characterize physical and chemical condition, which would be used to estimate the likelihood of a biological impact. Where biological responses are measured as part of a site-specific risk assessment, the assessment becomes an impact assessment as described above.

2.4 Step 3: Stressor Characterization

The stressor characterization stage should identify the major stressors that have potential to affect selected responses (Step 5). Variables that reflect the degree of human activity are modifiers, because they reflect the degree of modification imposed on the natural biophysical environment (Figure 3). Modifiers generally refer to the human activity or development (e.g., mill, mine, urban area, culvert). It may be possible to quantify the modifier, for example the area of a catchment that is under urban area.

2.5 Step 4: Boundary Definition

In this step, the physical/spatial and temporal bounds for the assessment are identified. Spatial bounds require consideration of the physical extent of potential effects and/or the scale at which effects might be manifest. Boundary definition includes an understanding of the primary landscape variables that might influence the assessment endpoint (Figure 3).

Primary variables are those characteristics of the landscape that provide the underlying foundation for biophysical conditions. Primary variables are also difficult to modify by human activity. Kilgour and Stanfield (2001) listed the following general features that can be considered primary variables, and that are particularly important to the distributions of fish:

- **Upstream drainage area**, because it reflects/determines flows and discharge, and is a strong determinant for fish community composition and species richness.

- **Position** which is a measure of how close to a large river a stream site is. Being in close proximity to a large river influences species richness.

- **Connectivity** which reflects connections of a stream site to other types of water bodies including inland lakes, great lakes, salt water and wetlands.

- **Bedrock geology** because it determines deep acquifer flow patterns and basic water chemistry.

- **Surficial geology** because it determines soil permeability and is associated with the likelihood of there being significant groundwater resources.

- **Slope** because it is associated with flow velocities, substrate particle size, and thus the kinds of animals found at a site.

- **Climate**

Primary variables represent the template against which natural variations in biological responses (compliance indicators) are often set (Kilgour and Stanfield, 2001). Thus, their potential influence on biological responses should be considered in any assessment. For example, biological responses in stream systems vary greatly with catchment area. Small streams with small upstream catchments tend to be cooler with a limited diversity of cold-water fauna. In contrast, larger streams/rivers with larger upstream catchment areas tend to be warmer with larger diversity of fauna (Vannote et al., 1987). Catchment area may be a very important factor to consider in the design for state-of-the-resource assessments covering catchments or watersheds, but might not be an important factor for the assessment of a point-source discharge on a large river. Where these factors are expected to be important, they would be used to stratify study designs.

2.6 Step 5: Indicator Selection

This step involves the selection of indicators on which to make the assessment. The assessment endpoints should be selected on the basis of Hypothesis of Effects models, and the approach that will be taken to develop the burden-of-proof in the assessment. Data quality objectives determine the protocols under which data should have been or should be collected. In selecting indicators, it is assumed that managers have already established valued ecosystem components (VECs) through other activities (Figure 1). In classical risk assessment frameworks, identification of VECs is a critical component of the overall assessment. The indicator should provide a direct measure of the VEC, or if surrogates are selected, the managers must ensure that the relationship between the VEC and the surrogate are well understood. The best indicator should be capable of being measured to the same degree of precision necessary to answer the question emerging from the issue analysis.

In stream assessments, several possible indicators are possible. At the site level, Cairns et al. (1993) recognized three general kinds of indicators: (1) compliance (i.e., VECs); (2) surrogate; and (3) diagnostic. Early-warning indicators can be a fourth type of indicator (Kilgour and Barton, 1999). Each of these kinds of indicators can be used to address one of four general questions relating to ecosystem management (Cairns et al., 1993): (1) are stated ecosystem objectives being met, i.e., are the VECs in an acceptable condition? (2) if VECs are not in an acceptable condition, why not? (3) how can impending impacts on VECs be predicted before they are actually observed? (4) are there indications that VECs may be in jeopardy of being impacted in the future.

The first part of this section describes some types of indicators that are typically used in environmental assessments, and their uses and limitations (Section 2.6.1). Then, the importance of defining criteria to be used for decision making and the level of precision required for a state-of-the-environment assessment is described (Section 2.6.2). The third part of this section introduces the use of hypothesis of effect diagrams (Section 2.6.3), while burden-of-proof approaches are described in Section 2.6.4. Both are integral in risk and impact assessments.

2.6.1 Indicator Types

2.6.1.1 Compliance Indicators

As defined by Cairns et al. (1993), compliance indicators are those environmental attributes (like valued ecosystem components, VECs) that we are trying to protect, enhance, and otherwise prevent impacts to. Thus, if we know what it is we are protecting, defining the compliance indicator for any assessment should be relatively easy. That is rarely the case. Cairns et al. (1993) suggest that compliance indicators (VECs) should be the most obvious part of any monitoring effort, and thus their significance should be communicable to the public and policy makers. Compliance indicators should have biological and social significance, be measurable with standard approaches, be interpretable, have historical data against which to judge trends and be measurable at scales that are relevant to management issues. Compliance indicators are typically aspects of ecosystem structure or composition (Figure 3) that are chosen because they integrate conditions within the ecosystem. Because they are integrators, they can take longer to respond to changes in chemical and physical habitat conditions. Thus the detection of effects on compliance endpoints is often a signal that the whole ecosystem has been altered and that the effects may be irreversible. For routine monitoring, compliance indicators are not preferred because they do not detect effects until after it may be too late to manage the problem.

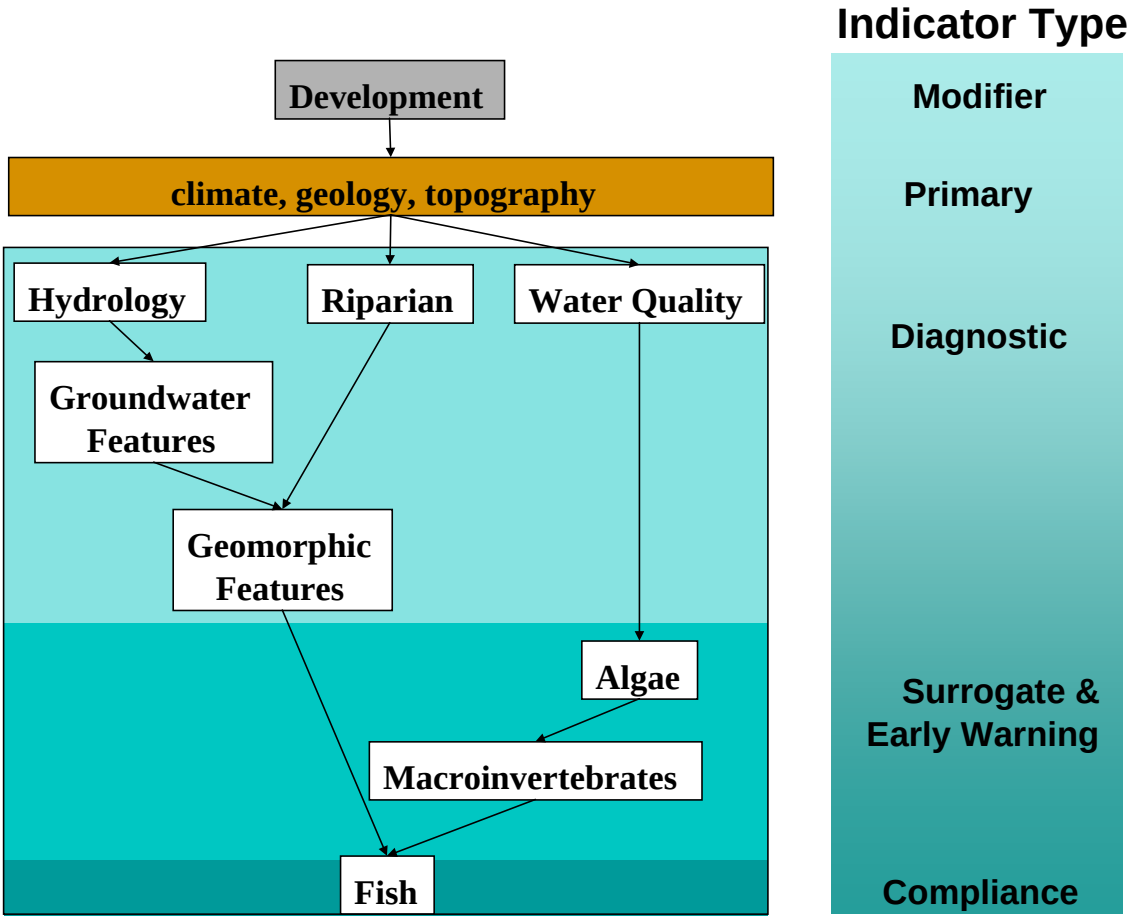

Figure 3. Schematic showing the relationship between a hypothesized effect and measurable assessment endpoints.

The Fisheries Act has the underlying objective of having *no net loss of fish and/or fish habitat*. In the context of that Act, a logical compliance indicator would be some measure of actual or potential fish production. Not only is production difficult to measure (quantify), but it also does not tend to respond to environmental stress as rapidly as do changes in species assemblages (Schindler, 1987). Thus, though the Act may imply one or more measures worth assessing, common sense should also be used when making the final selection. In Canada, there is no common VEC used in the assessment of stream resources, but species assemblages and the biomass of key species have been put forward in numerous cases.

2.6.1.2 Surrogate Indicators

Surrogate indicators are those indicators that are measured, not because they have a direct ecosystem value, but because they actually or theoretically reflect the condition of a compliance indicator (VEC). Some reasons for incorporating surrogates into an assessment include:

- they are easier to sample in a quantitative fashion;
- when sampling of the compliance indicator would be too destructive;
- when there is a defined relationship with the compliance indicator;
- when the surrogate indicator is measurable at a more appropriate temporal or spatial scale; and,
- when the surrogate indicator has lower natural variability and can be measured more precisely
- when data for the surrogate indicator can be produced in a more timely fashion.

In Canada, the Pulp and Paper Effluent Regulations (PPER) require proponents (mills) to monitor the condition of sentinel fish species (typically white sucker in freshwater environments) and benthic macroinvertebrates. Sentinel-species surveys are proposed because pulp mills discharge into large receiving environments where it is difficult to characterize effects on a fish community or assemblage. The sentinel-species surveys are thus a surrogate for potential effects on fish communities. Similarly, benthic community surveys are conducted, not because they are considered a VEC (though some agencies treat them as such), but because they are considered a surrogate measure of potential effects on fish habitat (Environment Canada, 1998). Kilgour and Barton (1998) have demonstrated that the composition of benthic invertebrate communities can to some degree predict the composition of fish communities. In part, that demonstration supports the idea that benthic communities could be used as surrogate indicators of potential effects on fish communities.

2.6.1.3 Early-Warning Indicators

Early warning indicators are used to detect trends in environmental conditions that may affect the compliance indicator at some point in the future (Cairns et al., 1993). They should have a well-defined relationship with the compliance indicator, have standardized measurement protocols that are cost effective and result in defensible data, and should be able to integrate effects of various kinds of stressors in a manner that is similar to the compliance indicator. Sampling should be non-destructive to the compliance indicator, and there should be potential for continuity in measurement over time so that trends can be detected. Finally, it should be possible to obtain the data relatively quickly without time lags so that effects, if present, can be managed in a timely fashion.

In aquatic environments, early-warning indicators have included the following kinds of indicators:

- behavioural;
- physiological; and,
- morphological.

Early-warning indicators are generally biological because VECs are typically biological endpoints, and they are a direct measure of a VECs initial responses to stress. Indicators of physical and chemical habitat features are not considered early-warning indicators because changes in the chemical or physical makeup of a stream do not guarantee that biological effects will occur.

2.6.1.4 Diagnostic Indicators (Drivers)

Diagnostic indicators are those indicators that provide insight into the cause of non-compliance. Diagnostic indicators should have known linkages to the biological attributes of interest (i.e., compliance indicator or VEC), and may be identified through hypotheses-of-effects models (Section 2.6.3). As with other indicators, there should be standardized measurement protocols, with the potential to make measurements at appropriate spatial and temporal scales. Physical and chemical habitat descriptors measured in the field can also be thought of as *drivers* because they are the fundamental features that drive biological responses (Figure 3).

2.6.2 Criteria for Assessment Endpoints

Regardless of the assessment endpoint, criteria must be established *a priori* to define acceptable and unacceptable conditions for the compliance, surrogate, early-warning and diagnostic indicators. Criteria for compliance or VEC endpoints crystallize the anticipated or expected biological condition. Where the VEC has a condition other than

the expected condition, one should conclude that an undesirable impact or HADD has occurred. Criteria for surrogate, early-warning and diagnostic indicators are values that correspond with unacceptable effects on the compliance indicator (Figure 4). Thus, when surrogate, early-warning or diagnostic indicators have conditions outside of the establish criteria, there is good evidence of existing or potential future impacts to the VEC (which may also be considered a HADD).

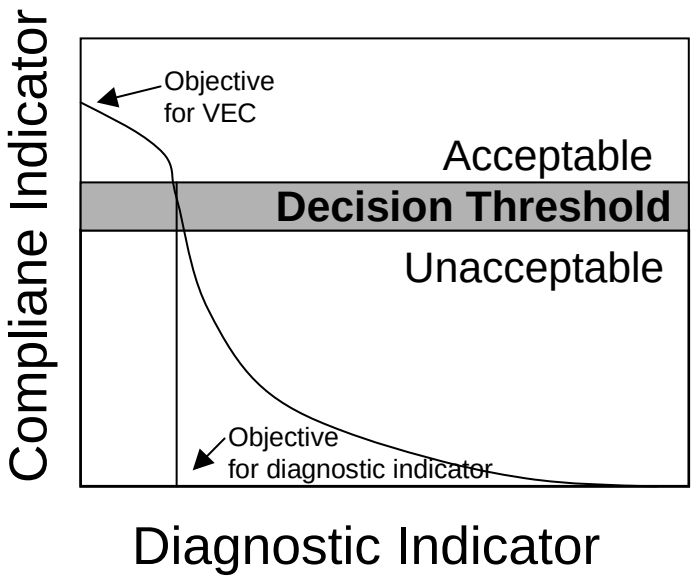

Figure 4. Possible relationship between a compliance indicator (VEC) and a diagnostic indicator showing potential criteria/objectives for both.

Criteria are also required in order to specify data quality standards. In screening-level assessments and depending on the assessment endpoint, criteria may already be established in published literature. Generic water and sediment quality objectives (CCME, 1999) define critical concentrations above or below which there may be a risk of biological impairment. In more comprehensive assessments, criteria may have to be developed through field programs that characterize acceptable natural background conditions, and or through consultative processes (Environment Canada, 2001). Criteria may be as simple as "*brook trout should be present*", or as complex as "*indices of fish community composition shall not exceed natural background conditions for these specific kinds of habitats, where natural background is defined as the mean plus 2 standard deviations*".

The intended uses of data (e.g., hypotheses to be tested, summary statistics involved and total uncertainty that can be tolerated) influence the required quality of the data. Data quality objectives should specify sensitivity, accuracy and precision. These

characteristics will in turn affect the selection of specific assessment endpoints. Take for example a proposed impact assessment with benthic invertebrates as one assessment endpoint. If the criterion for declaring an undue impact was a loss of a major taxonomic group such as mayflies, stoneflies, gastropods, etc., then coarse taxonomy might be all that would be required. Generally, the criteria against which judgements are to made often dictate the quality of data, and thus the measurement protocols.

These two important steps are combined in an iterative process to define the assessment endpoints. An integral step in this process is an evaluation of existing data that could be used to answer the question. Note that different data sets are likely to be used depending on whether the assessment is a screening or comprehensive assessment. From the above example, a manager may choose to simply use numbers of water quality infractions in an area for the screening tool. For the more comprehensive assessment they may choose the rapid bioassessment methods of the kick and sweep technique would be appropriate to answer this question (Module 3, Stanfield et. al., 2000).

2.6.3 Hypothesis of Effects Models

It is highly recommended that hypothesis-of-effect (HOE) models be developed as part of the early stages of an assessment to clarify the pathways through which a stressor will interact with the proposed VECs. These models identify modes of action of stressors on assessment endpoints. HOE models should be structured to clearly illustrate the current understanding of how management or development activities are linked to VECs through important physical, chemical, biological, economic and social processes (Greig et al., 1992; Gillespie et al., 2002).

On the basis that VECs have been identified, that the stressor has been well characterized, and the spatial and temporal boundaries have been established, HOE models effectively summarize in a visual format, the expected mode of action of the stressor. By doing so, HOE models clearly identify measurable indicators.

2.6.4 Burden of Proof

On the basis of HOE diagrams, an approach to a burden-of-proof as to whether an impact is likely (i.e., risk assessment) or whether an impact can be attributed to a specific stressor can be developed. For example, the burden-of-proof that mining effluents cause effects on aquatic organisms is derived from demonstrating concordance between environmental chemistry, bioavailability (i.e., elevated tissue contaminant concentrations or toxicity) and biological effects (Chapman, 1991; Green et al., 1993; ESG International, 1998). The specific burden-of-evidence will depend on the question, but will be key to selecting indicators.

2.7 Step 6: Information Assessment

On the basis of the hypotheses to be tested, the burden-of-proof approach taken, and the data quality objectives, the data required to carry out the assessment should be apparent. If the data are available, the assessment can be carried out. If the data are not available, the data need to be developed (Steps 7 and 8). For impact assessments, site-specific data that are up to date are usually required. Where the data are outdated or were collected using inappropriate methods, or did not demonstrate a cause-effect relationship, more data may be required. At the screening stage, risk assessments usually rely on data from other sites or studies. If the screening-level assessment does not produce a decision with a high degree of confidence, more data may be required. In risk assessments, the requirement to have more data usually infers that more site-specific data are necessary to take into account site-specific factors. For state-of-the-resource studies, there are an increasing number of datasets (or data layers) available that may enable a screening-level assessment to be carried out, or with minimal effort conduct more rigorous assessments.

2.8 Steps 7 and 8: Study Design and Study

Where there are inadequate existing data to carry out an assessment with sufficient confidence, it is necessary to obtain more data that will produce a more confident assessment. The specific study design employed will vary with the hypothesis, and resources available. Study designs generally specify the following attributes of a study:

- statistical design;
- study area boundaries (temporal and spatial); and,
- sampling methods

Study area boundaries should be evident from Step 4 (Boundary Definition). Common and powerful statistical designs are well documented elsewhere (e.g., Gillespie et al., 2001, and references therein). Impact and risk assessments often incorporate elements of what are referred to as Before-After, Control-Impact (BACI) designs that have been well described by Green (1979), Underwood (1991, 1993, 1994) and others. BACI designs compare data from impaired (exposed) sites to data from reference or control sites. Recognizing that two locations can naturally differ in biological responses at any given time, Green (1979) and others have recommended that the principal evidence of an effect is a difference in changes from before to after development, between control and impacted sites.

Specific sampling methodologies need to be identified (Appendix 1) and defended. Typically, impact and risk assessments rely on the most rigorous methods available. For

example, the environmental effects monitoring program for the pulp and paper sector incorporates benthic invertebrate surveys with identifications to the lowest practical level, principally genus and species (Environment Canada, 1998). The mining EEM program is proposing family-level identifications on the basis that they are as statistically rigorous, but much less costly to produce (Environment Canada, 2001).

Finally, requiring more data does not necessarily imply that more field work is required. Existing data sets often contain data that are useful to an assessment. Examples include:

- Ontario Ministry of Natural Resources (OMNR) FISHNET database that is used to store fisheries-related data;
- OMNRs NRVIS databases that is used to store natural resource information such as topography, forest cover, wetlands, and fish and wildlife habitats;
- OMNR/ROM inventory database;
- OMNR's HabProgs which warehouses data collected under the Ontario Stream Assessment Protocol (Stanfield et al., 2001); and,
- Environment Canada's BEAST database that warehouses benthic invertebrate and physical habitat data major systems in Ontario.

2.9 Step 9: Assessment

The assessment step has one primary objective, that is to determine whether there is enough information to make a management decision. For state-of-the-resource assessments, it is necessary to know whether enough information is available to characterize environmental conditions. As part of the characterization in a state-of-the-resource assessment, new questions may emerge, forcing the assessment back to Step 1 (Question).

For risk and impact assessment this Step requires:

- Understanding the relationship between the development (stressor) and the assessment endpoint (often termed Hazard Assessment, e.g., CCME, 1996); and,

- On the basis of expected relationships between the development (stressor) and endpoint, predict the extent and nature of impacts; and

- Evaluate the level of uncertainty that the development has had or will have effects (often termed risk characterization, CCME, 1996).

By their nature, screening-level risk assessments can rely on published data and models. Where data and models do not exist for a specific question, new data and models would have to be developed through Steps 7 and 8.

For impact and risk assessments, CCME (1996) describe both qualitative and quotient methods for characterizing the likelihood that effects are associated with a given stressor. Qualitative methods rely on professional judgement of the likelihood of effects in terms of high, moderate, or low (similar to approaches used in most habitat suitability models). Quantitative methods can be used in situations where the stressor is measurable, and are typically applied where concentrations of chemicals are of concern. Where environment concentrations of chemicals exceed objectives, there is a potential risk of biological impacts.

To quantify risk associated with environmental impacts (due to chemicals), CCME (1996) recommend calculating quotients, which are the ratio between the expected environmental condition (concentration), and the chemical objective. Quotients < 1 imply a slight risk with little or no required action (Burns, 1991). Quotients > 1 imply that risk is greater and that management action may be required. Quotients are commonly used in ecotoxicological assessments involving chemicals, but could easily be applied to other stressors for which there are quantitative relationships with relevant biological endpoints (Figure 5). Where there are multiple stressors, individual quotients can be summed to produce an overall hazard index (CCME, 1996).

2.10 Step 10: Decision Matrix

Every assessment should lead to a decision and recommendation regarding management action. The decision matrix (Table 2) should be visited at the end of each assessment iteration, whether it is a screening assessment or a comprehensive assessment. Where the risk that the stressor(s) has or will affect the assessment endpoint is high, and that assessment has a high confidence, then the logical resulting decision should be a recommendation to manage the stressor. If risk is high but confidence is low, more data may be required as part of a more comprehensive assessment. Where there is high confidence of low risk, then the defensible decision may be to recommend maintenance of that level of risk. Clearly, many of these decisions are subjective and require professional judgement.

Table 2. Decision matrix

Confidence	Recommended Action	
	High Risk of Biological Impact or HADD	Low Risk of Biological Impact or HADD
High	Manage or improve existing development. Dissallow or re-design new or proposed development.	Maintain existing development. Allow new or proposed development.
Low	Increase comprehensiveness of assessment	Increase comprehensiveness of assessment

With state-of-the-resource assessments, this step should be used to evaluate whether the assessment was sufficient and no additional questions emerge, or whether the assessment creates new questions that initiate a new assessment.

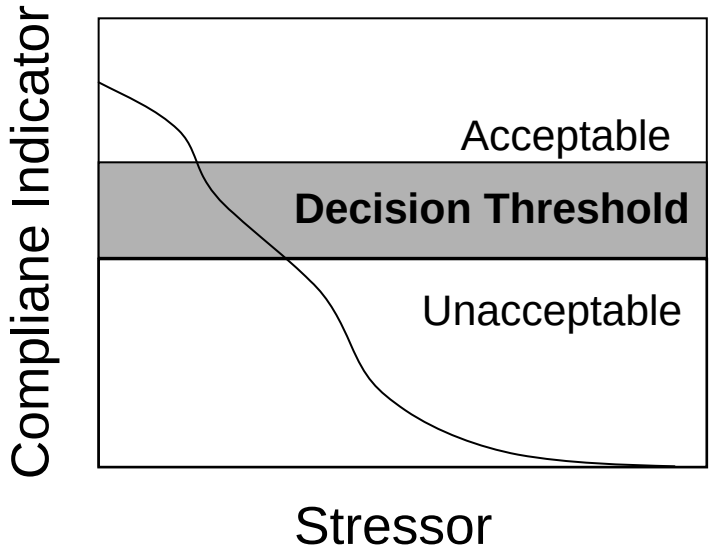

Figure 5. Potential relationship between a stressor and compliance indicator (VEC).

2.11 Step 11: Management Action

All decisions should lead to action following from the decisions in Step 10. Where the burden of evidence indicates existing effects (impact assessment) or potential for effects (risk assessment), some action to mitigate or prevent those effects should be taken.

Management of a stressor may lead to different questions or issues arising. The framework may, therefore, loop back to Step 1 (Question Definition).

Action from state-of-the-resource assessments may include evaluation of new hypothesis or *no action*.

3.0 APPLICATION OF THE FRAMEWORK

In this section, four examples are worked through representing the three assessment types: impact, state of the resource, and risk. A fourth study that combines elements of all three is also provided as an example.

3.1 Impact Assessment

Impact Assessment	
Step	**Approach/Result**
1. Question Definition	Have brook trout declined in the Humber R. watershed with development, since 1970?
2. Assessment Type	Impact
3. Stressor Characterization	Converted lands (lands characterized in non-natural states within the watershed)
4. Boundaries	Spatial: Humber R. watershed Temporal: Assessment should compare the present (2002) condition to an expected pre-1970 condition.
5. Indicator Selection	Compliance Indicator (VEC): brook trout biomass Surrogate Indicator: fish community composition, benthic community Early-Warning Indicator: not applicable Diagnostic Indicator: physical in-stream habitat, temperature Modifier Variable: % impervious area because it summarizes the principle mode of action of urban areas on stream hydraulics and a large component of the development in this watershed is classed as urban. Burden of evidence: The best burden of evidence that development has had an effect on brook trout biomass requires data on brook trout biomass both before and after urbanization in both the Humber R. watershed and a non-urbanized watershed. Those data are not achievable.

Impact Assessment	
Step	**Approach/Result**
	Therefore, a secondary burden of evidence would involve spatial comparisons of developed and less developed streams. Where compliance, surrogate and diagnostic indicators are correlated in their responses to urbanization, there would be good evidence of a development-related effect. For the screening level assessment, data could be taken from other watersheds.
6. Information Assessment	It is perceived that there is adequate information on effects of development on fish communities from other catchments.
7. Study Design	not necessary at the screening stage
8. Study	not necessary at the screening stage
9. Assessment	Data from the U.S. show the relationship between % imperviousness and impacts on fish communities. Data on imperviousness within the Humber R. catchment indicate that imperviousness is > level that would cause impairment of fish communities.
10. Decision	Conclusion is that urbanization in the Humber River watershed is at a level that would likely cause impairments to fish communities. Further studies may be warranted to quantify the observed effect at which point the assessment proceeds back to step 5 for re-evaluation of indicators, information assessment, and possible study design.
11. Management	This assessment has already concluded that the Humber R. is at high risk to loss of brook trout production as a result of past landuse activities. One management action would be to develop an action plan to reverse the impacts from these stressors. Another management action might be to initiate a study to quantify the effect that landuse has had on this species and to protect remaining habitats. After 1 or more iterations of the assessment process, it will be determined whether development in the Humber R. catchment has significantly affected brook trout biomass. If it has, then mitigation would be recommended. If not, maintenance would be recommended.

3.2 State of the Resource Assessment

State of the Resource Assessment	
Step	**Approach**
1. Question Definition	What is the condition of brook trout in the Humber R. watershed in 2002?
2. Assessment Type	State of the resource
3. Stressor Characterization	none identified
4. Boundaries	Spatial: Humber River watershed Temporal: present day (2002) condition
5. Indicator Selection	Compliance: brook trout biomass Surrogate: not required Early warning: not required Diagnostic: water temperature might be measured because it is so critical to determining the presence/absence of brook trout.
6. Information Assessment	Because there are no present-day data, new data would be required. Study design is then required.
7. Study Design	Study design would potentially stratify for major landscape features including catchment area, slope and surficial geology.
8. Study	Would be carried out.
9. Assessment	Would characterize spatial variations in brook trout biomass and the diagnostic indicator.
10. Decision	The spatial characterization of brook trout biomass may produce new questions of interest to the project manager. Otherwise, the assessment has fulfilled its objective.
11. Management	The management action here would involve the evaluation of new hypotheses, or may require no action at all.

3.3 Risk Assessment

Risk Assessment	
Step	**Approach**
1.	Will brook trout biomass be affected by further development in the Humber R. watershed?
2. Assessment Type	Risk
3. Stressor Characterization	Urbanization
4. Boundaries	Spatial: Humber R. watershed Temporal: Assessment should compare the present (2002) condition to an expected pre-development condition.
5. Indicator Selection	Compliance: brook trout biomass Surrogate: fish community, benthic community Early-warning: not applicable Diagnostic: physical in-stream habitat Modifier Variable: % impervious area because it summarizes the principle mode of action of urban areas on stream hydraulics. Burden of evidence: The best burden of evidence that urbanization could have an effect on brook trout biomass requires data on brook trout biomass both before and after urbanization in both a developed and non-urbanized watershed. Those data are not available. Therefore, a secondary burden of evidence would involve spatial comparisons of urbanized and non-urbanized streams. Where compliance, surrogate and diagnostic indicators are correlated in their responses to urbanization, there would be good evidence of an urbanization-related effect. For the screening level assessment, data could be taken from other watersheds.
6. Information Assessment	It is perceived that there is adequate information

Risk Assessment	
Step	**Approach**
	on effects of urbanization on fish communities from other catchments to carry out a screening-level assessment.
7. Study Design	Not necessary at the screening stage.
8. Study	Not necessary at the screening stage
9. Assessment	Data from the U.S. show the relationship between % imperviousness and impacts on fish communities. Our intention is to develop models that could relate the percent of imperviousness in Lake Ontario tributaries with species biomass. Once these are developed we could use the relationship to predict the degree of change expected from a prescribed increase in imperviousness.
10. Decision	Conclusion is that further urbanization in the Humber River watershed would negatively affect fish communities and brook trout biomass by x%. It may be recommended that the growth of urban areas be minimized or that mitigative measures be incorporated into future growth.
11. Management	Management would either ensure limited growth, or ensure that mitigative measures are put in place to eliminate effects.

3.4 Combining Study Designs

The following has been extracted and modified from (Stanfield et. al., 2000). As is common with most field surveys, there are often competing objectives among the partners/managers. The Bowmanville - Soper's watershed study was no exception. In the summer of 1998, the project team began to design a study to assess the current state of the stream resources in these two watersheds. The team chose to use the stream protocol as one of the tools for collecting field data and began by working through a process similar to the framework presented here. As the team articulated the study design, the project steering committee identified three seemingly conflicting study designs.

- a state of the resource survey stratified by physical features such as physiography and adjacent landuse;

- a state of the resource survey stratified by management zones (catchments with varying long term planning strategies); and,

- an impact assessment study testing study intended to identify changes in conditions over time.

The challenge was to design a study that could satisfy all of these objectives while recognizing that funds were limited. A balanced stratified random design was applied to satisfy the project requirements. The watershed was divided into 4 physiographic zones. Each would receive 25 % of the sites. Next, each of 3 landuse types (forested, agricultural and settlement) would be divided among the 4 physiographic zones, allocating equal numbers of sites to each landuse type. Finally, the eight management zones were not treated as strata per se, but acted as modifiers for the randomisation. Site selection was done such that the sites were approximately equally distributed among the management zones. This design permitted the study team to ask a number of questions relating to the various strata.

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Appendix 1

Partial Listing of Available Stream Sampling Protocols

Protocol Element	Protocol	Source
Fish Community	1-pass electrofishing (biomass)	Stanfield et al. (2000)*
	3-pass removal electrofishing (population estimate)	Stanfield et al. (2000)* Zippen 1958
	qualitative electrofishing	Stoneman MTO
Benthic Community	rapid bioassessment[3]	Stanfield et al. (2000)*
	rapid bioassessment[3]	Barbour et al. (1999)
	rapid bioassessment[3]	David et al. (1998)*
	Point-source EEM programs	Environment Canada (1998, 2001)
	Travelling kick methodologies	Reynoldson et al. (1999)*
	misc	Klemm et al. (1990)
	Point transect kick and sweep	
Habitat	point-transect	Stanfield et al. (2000)* Simonson et. al., (1994)*
	Visual	Dodge et al. (1984)
		Barbour et al. (1999)
	Calibrated visual based	Stanfield et al. (2000)* Dolloff et. al., (1993) Watershed Report Card (1999)
Geomorphic assessments	Natural Channel Design Manual	Jack has reference?
	Diagnostic indicators of channel stability	Stanfield et al. (2000)
	Stream habitat and fish habitat design	Newbury and Gaboury (1993)

Note: Protocols with an * are accompanied by a data management system

[3] These protocols are designed to evaluate the same indicator and are virtually the same except for minor differences in specific habitats sampled, and taxonomic effort.