Environment Canada Environnement Canada

Canada

INCORPORATING AN EFFECTS-BASED APPROACH INTO A CUMULATIVE EFFECTS ASSESSMENT (CEA) FRAMEWORK FOR AQUATIC ECOSYSTEMS

Munkittrick, K.R. and M.G. Dubé

NWRI Contribution No. 01-308

NATIONAL WATER RESEARCH INSTITUTE
INSTITUT NATIONAL DE RECHERCHE SUR LES EAUX

INCORPORATING AN EFFECTS-BASED APPROACH INTO A CUMULATIVE EFFECTS ASSESSMENT (CEA) FRAMEWORK FOR AQUATIC ECOSYSTEMS

K. R. Munkittrick[1] and M. G. Dubé[2]

[1] University of New Brunswick, P.O. Box 5050, Saint John, NB, Canada, E2L 4L5
[2] National Water Research Institute, Environment Canada, 11 Innovation Blvd., Saskatoon, SK, S7N 3H5

NWRI Cont #
01-308

March 31, 2000

[redacted]

Management Perspective

This manuscript was prepared under contract (by Dubé at the request of Munkittrick) to the Environmental Assessment Branch of Environment Canada (Mr. Robert St-Louis). The objective of the report was to summarize the key findings of the Moose River Basin Study (Munkittrick et al., 2000) and put into a context specific to the Canadian environmental assessment process. Some of the framework ideas have been submitted for publication in the Journal of Human and Ecological Risk Assessment (Dubé and Munkittrick 2001). The Environmental Assessment Branch has requested that this document be formalized as a NWRI Contribution so that it can be more widely distributed to audiences interested in cumulative effects assessment in the Canadian environmental assessment process. This research contributes information and understanding towards Environment Canada's initiatives on the development of frameworks for aquatic cumulative effects assessment.

This manuscript summarizes existing approaches to cumulative effects assessment including stressor-based and effects-based approaches. In stressor-based approaches, effluent sources are characterized and their effects on the environment predicted. This is the current approach practiced by project proponents under the Canadian Environmental Assessment Act (CEAA). In effect-based approaches, environment effects are first documented and then the cause of the effect is investigated. Effects-based approaches are currently used to assess impacts in the federally regulated Environmental Effects Monitoring (EEM) Program for the pulp and paper and mining industries and in large regional research programs such as the Moose River Basin Study. An example of implementation of an effects-based approach to assess the existing environmental state of fish performance is presented from the Moose River Basin study. Decision–making frameworks are also presented to illustrate how stressor and effects-based approaches can be integrated into environmental assessment and the management questions to be asked at key stages. A discussion is also presented on how the CEA framework can be expanded beyond assessment of fish populations.

Sommaire à l'intention de la direction

Ce manuscrit a été préparé à contrat (par Dubé à la demande de Munkittrick) pour la direction de l'Évaluation environnementale d'Environnement Canada (M. Robert St-Louis). L'objectif du rapport était de résumer les principales constatations de l'étude du bassin de la rivière Moose (Munkittrick *et al.*, 2000) et de les remettre dans le contexte spécifique du processus canadien d'évaluation environnementale. Certaines des idées concernant le cadre ont été proposées pour publication dans le *Journal of Human and Ecological Risk Assessment* (Dubé et Munkittrick, 2001). La direction de l'Évaluation environnementale a demandé que ce document prenne officiellement la forme d'une Contribution de l'INRE, de façon qu'il puisse être diffusé plus largement à des publics intéressés par l'évaluation des effets cumulatifs (EEC) dans le processus canadien d'évaluation environnementale. Cette recherche apporte des données et de l'information scientifique qui viennent appuyer les initiatives prises par Environnement Canada dans l'élaboration de cadres pour l'évaluation des effets cumulatifs dans le milieu aquatique.
Le manuscrit résume les approches actuelles de l'évaluation des effets cumulatifs, c'est-à-dire les approches basées sur les agents de stress et celles qui sont basées sur les effets. Dans les approches basées sur les agents de stress, on caractérise les sources d'effluents et on prédit leurs effets sur l'environnement. Il s'agit là de l'approche actuellement mise en œuvre par les promoteurs de projets aux termes de la *Loi canadienne sur l'évaluation environnementale* (LCEE). Dans les approches basées sur les effets, on commence par documenter les effets environnementaux, puis on en recherche la cause. Les approches basées sur les effets servent actuellement à évaluer les impacts dans le cadre du programme fédéral de suivi des effets environnementaux (SEE) pour le secteur des pâtes et papiers et celui des mines, et dans les grands programmes régionaux de recherche comme l'étude du bassin de la rivière Moose. Nous présentons un exemple de mise en œuvre de l'approche basée sur les effets pour l'évaluation de la performance des poissons dans les conditions environnementales actuelles, exemple tiré de l'étude du bassin de la rivière Moose. Les cadres décisionnels qui sont également présentés illustrent la façon dont les deux types d'approche peuvent être intégrés à l'évaluation environnementale, et suggèrent les questions touchant la gestion qui doivent être posées à certaines étapes clés. Nous présentons aussi une analyse de la façon dont le cadre de l'EEC peut être élargi au-delà de l'évaluation des populations de poissons.

Executive Summary

The cumulative effects assessment (CEA) component of an environmental assessment, which is required under the *Canadian Environmental Assessment Act*, is intended to assess or predict any potential effects of a proposed project relative to the existing "accumulated state" of the environment. Thus, any incremental effects arising from the combined influence of various projects on the environment are identified. Ideally then, CEA would involve two components, an evaluation of the existing environmental state or the existing cumulative response of the environment to existing stressors and, development of a predictive model to determine any potential impacts of additional stressors (*i.e.*, new development). As the density of development increases, there is a need to address the dual aspects of CEA in a more holistic and systematic manner using methods that incorporate site-specificity, an analysis of existing effects, a commitment to incorporate new science as it develops, an acknowledgement that predictions may not be accurate, and a commitment to follow-up monitoring to allow changes in management strategies as new data becomes available. The objective of this document was to propose a more holistic framework for assessing cumulative effects of existing and proposed project activities on aquatic ecosystems as required under the *Canadian Environmental Assessment Act*. Key framework components include:

- An effects-based assessment congruent with the design of the Canadian environmental effects monitoring (EEM) program (required by pulp and paper and mining industries under the *Fisheries Act*) to determine the existing accumulated environmental state prior to predicting the impacts of new development;
- A stressor-based assessment congruent with existing environmental assessment practices to predict potential impacts of new development relative to the existing environmental state;
- Incorporation of post-development or follow-up monitoring to assess the accuracy of impact predictions, study design, and to provide an avenue for adaptive management; and
- Incorporation of decision-making frameworks at each informational stage of the process to link scientific information to management decisions and action.

The goal of an effects-based approach to CEA is to determine the accumulated state of the existing environment prior to using existing stressor-based assessment tools to predict the potential for proposed project activities to cause environmental impacts. Critical components of the effects-based approach include system definition, developing key environmental indicators, developing a performance assessment, consistent and statistically sound data analysis, identification of significantly impaired environmental aspects, identification of stressors, follow-up and effects management. Traditional stressor-based approaches to CEA consist of documenting existing and potential stressors and valued ecosystem components (VECs) and using assumed pathways of potential interactions to predict impacts of a proposed project and develop mitigation strategies. Although it is very important to be able to examine the potential for known impacts of new stressors, it is very difficult to estimate the impact of future development on a system when the existing status and sensitivity of the system are unknown. The major advantages of an effects-based assessment for CEA are that it provides a site-specific focus for beginning to understand assimilative capacity and forms a basis for post-development monitoring. It also develops an understanding of ecological relevance prior to consideration of the significance and the

acceptability of any effects. Sentinel species that are monitored in an effects-based assessment are selected based on their ecological importance and ability to detect effects if they exist in a particular aquatic system. These species may or may not be the VECs typically selected based on human value in stressor-based assessment programs. The effects-based approach also incorporates powerful quantitative tools of effects size and statistical power to provide information required for managing ecosystem change. These tools can be employed to lessen the subjectivity of the CEA process by identifying existing thresholds that have been quantitatively exceeded and the confidence that that these exceedances are real. Thus, more scientifically based, quantitative information can be obtained and incorporated into the stakeholder process. Finally, the effects-based approach separates the definition of ecologically relevant changes from changes that are sustainable or acceptable. Changes that are ecologically relevant under existing conditions are in the need of careful monitoring and need to be considered when the effects of new development are assessed in the stressor-based component of the CEA. However, a change that is ecologically relevant may or may not be sustainable or acceptable depending upon stakeholder issues and management priorities. Decisions regarding sustainability or acceptability require information beyond ecological considerations.

Advantages of the proposed CEA framework include:

- Contributes to building consistency in the CEA process;
- Provides scientifically-based methodological direction for CEA;
- Integrates regional assessment information into a project-specific environmental assessment;
- Links environmental assessment to other forms of practiced environmental management and planning (*i.e.*, EEM Programs for the pulp and paper and mining industries);
- Incorporates site-specificity;
- Analyzes the effects of existing development;
- Acknowledges that predictions of development impacts may not be accurate and provides an avenue for re-assessment and adaptive management through follow-up monitoring;
- Provides quantification of ecologically relevant thresholds for environmental stress;
- Complements existing stressor-based approaches to CEA currently practiced by project proponents under the *Canadian Environmental Assessment Act*;
- Fits within the context of existing legislation (*Canadian Environmental Assessment Act*) and is consistent with post-development legislative requirements for effects assessment (*i.e.*, *Fisheries Act*);
- Provides Decision Management Frameworks (DMFs) for more consistent and directed information assessment at key CEA stages; and
- Provides a more holistic, systematic approach for incorporation of ecological information into a scientific and management framework.

There is a need to establish consistent baseline data collection and analysis procedures for CEA so that regional databases can be built and accumulated with each additional environmental assessment. Under the current stressor-based CEA practice, collection of large volumes of regional information by a project proponent may not seem realistic. However, if project proponents collect this information using the same effects-based model and scientific process, then the information gathered may serve to build regional databases. There is also a need to evaluate this proposed conceptual CEA framework in practice by integrating the effects-based approach with current stressor-based approaches in an environmental assessment trial.

- il fournit des cadres de gestion décisionnels permettant de mieux uniformiser et orienter l'évaluation de l'information à des étapes clés de l'EEC; et
- il fournit une approche plus globale et systématique permettant d'intégrer l'information écologique dans un cadre de données scientifiques et de gestion.

Il est nécessaire d'établir pour l'EEC des procédures uniformes de collecte et d'analyse des données de base, de façon à construire des bases de données régionales qu'on enrichira à chaque nouvelle évaluation environnementale. Dans la pratique actuelle d'EEC basée sur les agents de stress, il peut apparaître irréaliste de demander aux promoteurs de recueillir une grande quantité d'informations régionales. Toutefois, si les promoteurs recueillent cette information en utilisant le même modèle basé sur les effets et le même processus scientifique, l'information recueillie pourra aider à construire les bases de données régionales. Il est aussi nécessaire d'évaluer dans la pratique ce cadre conceptuel proposé pour l'EEC en intégrant l'approche basée sur les effets aux approches actuelles basées sur les agents de stress dans le cadre d'un essai d'évaluation environnementale.

Résumé

Le volet de l'évaluation des effets cumulatifs (EEC) d'une évaluation environnementale, nécessaire aux termes de la *Loi canadienne sur l'évaluation environnementale*, a pour objet d'évaluer ou de prédire les effets potentiels d'un projet proposé par rapport à l'état cumulatif existant de l'environnement. Tout effet supplémentaire provenant de l'influence combinée de divers projets sur l'environnement peut ainsi être identifié. L'évaluation des effets cumulatifs devrait donc idéalement avoir deux volets, une évaluation de l'état existant de l'environnement ou la réponse cumulative de l'environnement à des agents de stress existants, et l'élaboration d'un modèle de prédiction visant à déterminer l'impact potentiel des agents de stress additionnels (nouvel aménagement). À mesure que l'intensité de l'aménagement s'accroît, il est nécessaire d'aborder les deux aspects de l'EEC d'une façon plus globale et systématique à l'aide de méthodes qui intègrent la spécificité du site, une analyse des effets existants, un engagement à intégrer les nouvelles connaissances scientifiques qui apparaîtront, une reconnaissance du fait que les prédictions peuvent être inexactes, et un engagement à assurer un suivi pour apporter des changements aux stratégies de gestion en fonction des nouvelles données qui apparaissent. L'objectif du document est de proposer un cadre plus général pour évaluer les effets cumulatifs des activités existantes et des projets proposés sur les écosystèmes aquatiques, conformément aux exigences de la *Loi canadienne sur l'évaluation environnementale*. Les éléments clés de ce cadre sont notamment :

- une évaluation basée sur les effets qui concorde avec le programme de suivi des effets environnementaux (SEE) (imposé aux secteurs des pâtes et papiers et des mines par la *Loi sur les pêches*) visant à déterminer l'état cumulatif existant de l'environnement avant de prédire les impacts du nouvel aménagement;
- une évaluation basée sur les agents de stress qui concorde avec les pratiques existantes d'évaluation environnementale et qui visent à prédire les impacts potentiels du nouvel aménagement par rapport à l'état existant de l'environnement;
- l'intégration d'une surveillance post-aménagement ou d'un suivi visant à évaluer la valeur des prédictions des impacts et du plan d'étude, et à ouvrir la voie à une gestion adaptative; et
- l'intégration de cadres décisionnels à chaque étape informationnelle du processus pour lier l'information scientifique aux décisions de gestion et aux interventions.

Le but d'une approche de l'EEC basée sur les effets est de déterminer l'état cumulatif existant de l'environnement avant d'utiliser les outils d'évaluation basés sur les agents de stress pour prédire le potentiel d'impacts environnementaux des activités proposées. Les composantes critiques de l'approche basée sur les effets sont la définition du système, l'établissement des indicateurs environnementaux clés, le développement d'une évaluation de la performance, une analyse des données cohérente et solide sur le plan statistique, l'identification des aspects de l'environnement qui sont notablement altérés, l'identification des agents de stress, le suivi et la gestion des effets. Dans les approches classiques de l'EEC basées sur les agents de stress, on documente les agents de stress existants et potentiels et les composantes valorisées de l'écosystème (CVE) et on se sert des cheminements supposés des interactions potentielles pour

prédire les impacts d'un projet et élaborer des stratégies d'atténuation. Bien qu'il soit très important de pouvoir examiner le potentiel des impacts connus de nouveaux agents de stress, il est très difficile d'estimer l'impact d'un aménagement futur sur un système lorsqu'on ne connaît pas l'état existant et la vulnérabilité de ce système. Les grands avantages d'une évaluation basée sur les effets pour l'EEC sont le fait qu'elle fournit une démarche axée sur le site pour essayer de comprendre la capacité d'assimilation, et qu'elle constitue la base du suivi post-aménagement. Elle permet aussi de mieux connaître la pertinence écologique avant de considérer l'importance et l'acceptabilité des effets. Les espèces sentinelles qui sont surveillées dans une évaluation basée sur les effets sont choisies en fonction de leur importance écologique et de leur aptitude à signaler les effets qui peuvent se produire dans un système aquatique particulier. Ces espèces ne sont pas nécessairement les CVE qui sont généralement choisies en fonction des valeurs humaines dans les programmes d'évaluation basés sur les agents de stress. L'approche basée sur les effets intègre aussi les puissants outils quantitatifs que sont la taille de l'effet et la puissance statistique pour fournir l'information nécessaire à la gestion du changement écosystémique. Ces outils peuvent être employés pour affaiblir la subjectivité du processus d'EEC en signalant les seuils existants qui ont été quantitativement dépassés, et le degré de confiance à l'égard de la réalité de ce dépassement. Il est donc possible d'obtenir une information plus scientifique et de nature quantitative qui sera intégrée au processus de l'intervenant. Enfin, l'approche basée sur les effets fait la part entre les changements écologiquement pertinents et ceux qui sont durables ou acceptables. Les changements qui sont écologiquement pertinents dans les conditions existantes doivent faire l'objet d'un suivi attentif, et être envisagés dans l'évaluation des effets d'un nouvel aménagement dans le volet basé sur les agents de stress de l'EEC. Toutefois, un changement qui est écologiquement pertinent n'est pas nécessairement durable ou acceptable, selon les problèmes de l'intervenant et les priorités de la gestion. Les décisions concernant la durabilité ou l'acceptabilité demandent une information qui dépasse les considérations écologiques.

Les avantages du cadre proposé pour l'EEC sont les suivants :

- il contribue à l'uniformité dans le processus d'EEC;
- il fournit une orientation méthodologique scientifique pour l'EEC;
- il intègre l'information de l'évaluation régionale dans une évaluation environnementale spécifique à un projet;
- il lie l'évaluation environnementale à d'autres pratiques de gestion et de planification environnementales (programmes de SEE pour les secteurs des pâtes et papiers et des mines);
- il intègre la spécificité par rapport au site;
- il analyse les effets de l'aménagement existant;
- il reconnaît que les prédictions des impacts ne sont pas nécessairement exactes et ouvre la voie à une réévaluation et une gestion adaptative grâce à la surveillance et au suivi;
- il permet de quantifier les seuils écologiquement pertinents de stress environnemental;
- il complète les approches existantes de l'EEC basées sur les agents de stress, actuellement mises en œuvre par les promoteurs de projets aux termes de *Loi canadienne sur l'évaluation environnementale*;
- il cadre avec le contexte législatif actuel (*Loi canadienne sur l'évaluation environnementale*) et concorde avec les exigences législatives sur l'évaluation des effets post-aménagement (*Loi sur les pêches*);

Table of Contents

1 INTRODUCTION

1.1 Background

In 1995, the Canadian government included a requirement to address cumulative effects when an action or project is subject to a federal environmental assessment under the *Canadian Environmental Assessment Act* (CEAWG, 1999). The cumulative effects assessment (CEA) component of an environmental assessment is intended to assess or predict any potential effects of a proposed project relative to the existing "accumulated state" of the environment. Thus, any incremental effects arising from the combined influence of various projects on the environment are identified. In this context, although an environmental assessment may determine that an individual project may not cause significant environmental effects, its activities may have a significant environmental effect when assessed in conjunction with existing activities. Ideally then, CEA would involve two components, an evaluation of the existing environmental state or the existing cumulative response of the environment to existing stressors and, development of a predictive model to determine any potential impacts of additional stressors (*i.e.*, new development). Unfortunately, there are no established or widely accepted scientific methods that analyze and evaluate the dual aspect of CEA in a concise and manageable framework. Although, the Canadian Environmental Assessment Agency published a Practitioner's Guide for CEA in 1999 (CEAWG, 1999), this information is generic and discusses CEA as a geographically expanded form of an environmental impact assessment (EIA) which is predictive and exclusively stressor-based.

Traditional stressor-based approaches to CEA consist of documenting existing and potential stressors and valued ecosystem components (VECs) and using assumed pathways of potential interactions to predict impacts of a proposed project and develop mitigation strategies. This approach, which developed from EIA practice, has helped achieve sustainable development through the promotion of sound project planning and development, while reducing adverse environmental effects (CEAA, 1999). However, this approach has also helped to identify key deficiencies that need to be addressed to improve the strength of the environmental assessment process.

At the practitioner's level, stressor-based approaches are commonly a desk-top exercise that can be exacerbated by a lack of site-specific baseline data. The approach assumes that all stressors can be identified, all potential effects can be predicted, and in the case of stressor-based CEA, interactions between multiple effluent sources and multiple VECS are understood (CEAA, 1999). A lack of post-development monitoring and follow-up increases the risk associated with these gaps in knowledge because the accuracy of impact predictions are often not confirmed. This results in an absence of checks and balances characteristic of adaptive management.

Other deficiencies identified in the existing environmental assessment process include a lack of process consistency, methodological direction for CEA, integration of regional assessment information into a project-specific CEA, and a lack of linkages between environmental assessment and other forms of environmental management and planning (CEAA 1999). As the density of development increases, there is a need to address the dual aspects of CEA in a more holistic and systematic manner using methods that incorporate site-specificity, an analysis of existing effects, a commitment to incorporate new science as it develops, an acknowledgement that predictions may not be accurate, and a commitment to follow-up monitoring to allow changes in management strategies as new data becomes available.

1.2 Objectives

The objective of this document is to present an effects-based approach to CEA that can be integrated with the strengths of existing stressor-based approaches and the Canadian environmental effects monitoring (EEM) program to build a consistent and holistic CEA framework. The goal of an effects-based approach to CEA is to determine the accumulated state of the existing environment prior to using existing stressor-based assessment tools to predict the potential for proposed project activities to cause environmental impacts. To determine the accumulated environmental state, the effects-based approach determines if existing conditions differ from reference (*i.e.*, undeveloped) conditions for indicator environmental components, and assesses the magnitude of the difference with respect to threshold exceedances. Critical components of the effects-based approach include system definition, developing key environmental indicators, developing a performance assessment, consistent and statistically sound data analysis, identification of significantly impaired environmental aspects, identification of stressors, follow-up and effects management. Decision-making frameworks are incorporated into the holistic CEA framework for a progressive and iterative assessment evaluation that links the science of the process to management decisions. In addition, the post-development monitoring program is modeled after the effects-based performance assessment and the EEM program, which allows for a consistent and scientifically defensible approach to adaptive management.

The effects-based approach was developed for aquatic ecosystems, specifically to evaluate the cumulative effects of industrial development on fish in the Moose River Basin, Ontario, Canada (Munkittrick *et al.*, 2000). This document will describe the effects-based approach, compare it to the traditional stressor-based approach, and show how it can be integrated into a holistic CEA framework. This document also shows how the approach can be expanded to entire aquatic ecosystems.

2 APPROACHES TO CEA

There is no consistent methodology required for CEA resulting in a wide variety of approaches (reviewed by EIP, 1998). The absence of a consistent, widely-applied methodology relates to a variety of factors including the level of the environmental assessment, fragmentation of regulatory responsibility, the complexity of large drainage basins, transboundary confounding factors, the absence of historical data on systems under development, and tight timelines for assessment and approval processes (CEAA, 1999). This chapter outlines the commonly employed stressor-based approach, describes how it developed from EIA practices, outlines the effects-based approach, and presents the advantages of integrating both approaches into a CEA framework.

2.1 Stressor-Based Approach

To date, most CEAs have involved a traditional EIA conducted over an expanded geographic scale (CEAWG, 1999). Traditional impact assessments have focused on stressor-based predictive methods, which in general follow the United States Environmental Protection Agency risk assessment framework philosophy (US EPA, 1992, 1996). Stressor-based approaches employed in aquatic environmental assessments have been designed to predict the effects of single stressors, such as a single chemical within an effluent discharge or a single effluent, on aquatic system components (*i.e.*, sediment quality, water quality, benthic invertebrate community structure, fish community structure). The primary focus of aquatic EIAs has been related to the abundance of exploited or potentially exploited populations, the presence of rare, threatened, or endangered species, and the abundance and suitability of habitat. In many cases, stressor-based EIAs did not specifically recognize that sublethal impacts may already exist within the aquatic system, and that an incremental addition to the level of stress, due to proposed project activities, might have impacts beyond those that would have been predicted. The EIA framework usually involves five steps (EIP, 1998):

1. Scoping or Problem Definition
2. Description of Existing Conditions
3. Identification of Potential Impact
4. Development of Mitigation Strategies
5. Prediction of Impacts and Evaluation of Significance

Stressor-based approaches to CEA grew out of a need to expand the EIA process over a larger geographic scale to assess the potential impact of proposed project activities relative to other existing stressors and their associated effects. Key conceptual stages in the stressor-based approach to CEA are illustrated in Figure 1. The scoping stage of a stressor-based CEA includes question definition, selection of regional VECs, identification of spatial and temporal boundaries, identification of existing and potential project-related stressors, and development of a conceptual model to identify potential effects on VECs due to existing activities and proposed project activities (CEAWG, 1999). The analysis stage of the CEA approach involves collection of baseline data and analyzing stressor/VEC interactions. Residual effects are then defined after mitigative measures are identified and the significance of these effects are theoretically compared against thresholds or land use objectives. The final stage of the stressor-based approach to CEA involves regional follow-up monitoring to assess the accuracy of the impact predictions. The important differences between the procedures outlined for EIA and stressor-based CEA including identification of issues of concern and VECs over a regional scale, identification of temporal boundaries, an assumption that existing conditions may already be associated with effects, and monitoring on a regional and not a project-specific level.

The most significant data gaps associated with existing stressor-based approaches include a lack of understanding of all stressor/VEC interactions, and lack of site-specificity. In addition, many methods do not incorporate temporal and spatial aspects, multiple stressor interactions, and thresholds. In cases where interactions are incorporated, they can be poorly integrated and simplified, ignoring temporal and spatial aspects (EIP, 1998).

Stressor-based approaches to CEA are most effective when all stressors can be identified along with their associated effects. In the past, stressor-effect relationships have been established based primarily on gross inputs having acute effects. Over the last several decades, there has been a general decrease in the level of anthropogenic stress on aquatic systems as the acute toxicity of many industrial and municipal effluents has decreased due to improvements in effluent treatment. Improved effluent treatment has also led to reductions in toxicity, nutrient enrichment and biochemical oxygen demand associated with discharges. The discharge, release or application of persistent, lipophilic compounds has also decreased (*e.g.*, dioxins and furans, pesticides). As the intensity of environmental impacts has been reduced, previously unsuspected changes have been seen in aquatic environments exposed to effluents from pulp mills (Munkittrick *et al.*, 1998), sewage effluents (Jobling *et al.*, 1998; Servos *et al.*, 1998a), agricultural discharges (Servos *et al.*, 1998b), and other industrial sources (Matthiessen *et al.*, 1998) including textile effluents (Servos, 1999). In general, these impacts are associated with chemicals that are not identified or were previously unsuspected to be hazardous at the levels they are found in effluents. Chemical exposures have been associated with the occurrence of changes in fish maturity (Munkittrick *et al.*, 1991), appearance of intersex fish (Jobling *et al.*, 1998) and alterations in reproductive function (Colborn *et al.*, 1996; Matthiessen, 1998; Tattersfield *et al.*, 1998). These kinds of impacts would not have been considered during stressor-based predictions of potential impacts, as the existence of the changes, pathways of impacts, and the identity of the responsible chemicals were unknown ten years ago. Responses have been found at very low levels of exposure, and in some cases, at distances beyond those that would have been considered during traditional EIAs (*i.e.*, >90 km, Hodson *et al.*, 1992). Furthermore, the tools that were commonly used to look for single effects in the past were not designed to detect the subtle sublethal responses being detected today.

The lack of site specificity in stressor-based CEA approaches is also an important data gap which needs to be addressed to improve CEA methodology. Site specificity refers to an understanding of the aquatic system potentially affected by the proposed development. An understanding of site-specificity includes understanding the environmental components of the system, existing stressors, existing sensitivities to stressor exposure, and natural variability in the system over time and space. Under current stressor-based CEA practices, baseline data collection is often insufficient to address site-specificity. This information is important to understand the existing accumulated environmental state and capacity of that environment to assimilate additional stress. Without this information, predictions on the potential effects of proposed development can be underestimated or overestimated. For example, the potential of impacts of stressors can be buffered in aquatic systems where there is the potential for fish immigration, and exacerbated in systems that are closed to fish movement. In addition, stressor-based approaches do not address the reality that expected environmental impacts might be within the range of responses to natural stressors.

2.2 Effects-Based Approach

Ideally a CEA should initially determine whether there is an impact of existing development (effects-based approach) and subsequently determine or predict the extent of impact associated with future developments (stressor-based approach) (CEAA, 1999). Although it is very important to be able to examine the potential for known impacts of new stressors, it is very difficult to estimate the impact of future development on a system when the existing status and sensitivity of the system are unknown. Effects-based approaches to CEA attempt to define the accumulated environmental state with the ultimate goal of identifying and reducing impacts associated with existing developments. The sequential steps in the effects-based approach are to define the geographical limitations of the study, develop the key performance indicators of the system, develop the performance assessment, conduct data analysis to identify impaired aspects, determine the significance of the effects relative to thresholds, identify critical stressors including natural and anthropogenic stressors, and conduct follow-up monitoring and effect management (Figure 2).

An effects-based approach essentially works in reverse to a stressor-based approach. The existence of environmental effects are determined first, based upon a well design field program, where performance indicators at developed sites are compared to the same performance indicators measured at an undeveloped or reference sites (Figure 3). The magnitude of the difference between existing and reference conditions determines if ecologically relevant thresholds have been exceeded at developed sites for specific performance parameters. A decision-making framework can then be used to determine the significance of these exceedances and gives direction on how to proceed. Causal factors (stressors) can then be isolated and identified to develop predictive models on how this aquatic system responded to existing stressors or combinations of existing stressors.

The major advantages of an effects-based assessment for CEA are that it provides a site-specific focus for beginning to understand assimilative capacity and forms a basis for post-development monitoring (Munkittrick *et al.*, 2000). An effects-based assessment does not require an exhaustive documentation of stressor identities prior to evaluation, and initial analyses are independent of stressor identity. While there may be a large number of stressors involved, the "accumulated environmental state" is the summation of the impacts of all stressors (natural and anthropogenic). Organisms respond to a variety of natural and anthropogenic influences (Figure 4). In an effects-based CEA the integrated response of the organisms to these existing factors is measured although the factors themselves may not be identified until later in the process. Thus, if organisms are growing, reproducing and surviving at rates similar to reference sites, it can be assumed that existing conditions are not limiting the performance of resident organisms. If indicator or sentinel species are limited in their performance, in terms of growth, reproduction or survival, the environmental factors limiting performance can be used to focus the predictive, stressor-based component of the CEA framework.

One of the challenges facing development of a CEA framework is that many environmental responses associated with modern technology and waste treatment are subtle and can be within the range of the variability of natural performances that can be associated with natural environmental stressors. Subtle changes in the growth, size and reproductive performance of organisms can be associated with non-chemical stressors such as temperature, pH and dissolved oxygen that may not be directly related to anthropogenic inputs (Figure 4). Traditional approaches assume that the growth, reproduction and survival of fish are equivalent to a reference condition prior to development. The absence of pre-development assessments based on these parameters means that all changes found after development will be interpreted as a consequence of that particular development. Furthermore, any development-specific risk assessment would underestimate the potential consequences of changes in food availability, for example, without knowing that prior to development the receiving environment was already food limited.

In an effects-based approach to CEA, responses measured at developed sites are compared to responses measured at undeveloped sites. This provides an identification of the existing conditions prior to development. To determine if the effect is outside that associated with natural variability, the responses measured at all sites are compared to ecologically relevant thresholds. These thresholds are calculated based upon a magnitude of difference above natural variability observed at undeveloped sites. In an effects-based approach, the assimilative capacity of the system is defined to be the level of stress that can be imposed on a system until the growth, reproduction, or survival of resident fish is affected in an unacceptable manner. Thus, effects-based approaches provide a baseline assessment of the accumulated environmental state, as well as a target for assimilative capacity.

In addition to site-specificity, an effects-based approach to CEA forms a study design and a "bench-mark" for focusing post-development monitoring. Effects-based approaches require the collection of focused baseline data at developed and undeveloped sites prior to new development. This study design can form the basis of a post-development monitoring design for consistent and scientifically defensible comparisons before and after development. In addition, the effects-based approach produces baseline data on existing system performance that can be used as a bench-mark to determine if environmental performance deteriorated to unpredicted levels as a result of the new development.

In the proposed CEA framework, the design of an effects-based performance assessment and the post-development monitoring program are consistent and are based upon the extensive scientific expertise compiled during development of the Canadian EEM programs (Environment Canada 1995a, 1995b, 1997a, 1997b, 1997c, 2000). Recent regulations modified under the *Fisheries Act* (Pulp and Paper Effluent Regulations [1993], Metal Mining Liquid Effluent Regulations [In Progress]) require industries to conduct EEM programs. The pulp and paper industry completed its first three-year cycle of monitoring in 1996 and will submit the second cycle of information in April of 2000. The metal mining industry will commence its first field season, likely in 2001. These programs require the collection of information on the fisheries resources, benthic invertebrate communities, aquatic toxicity, and chemistry (water, effluent, and/or sediment) related to their effluent discharges. Design of the scientific component of the programs has resulted in an extensive review of field monitoring approaches, alternative monitoring approaches, statistical design, data analysis procedures and quality assurance and quality control procedures. Although the data interpretation process for the EEM program has not been completely designed, (*i.e.*, deciding whether a problem exists or not), the decision-making process should be compatible with any decision-making process designed for an effects-based CEA, since both programs have similar goals and objectives.

2.3 Integration of Stressor-Based and Effects-Based Approaches into a Conceptual CEA Framework

Stressor-based and effects-based approaches to CEA can be integrated into a holistic and complementary CEA framework as illustrated in Figure 5. The effects-based approach depends on developing an understanding of the system prior to new development that is critical for developing a CEA. This effects-driven approach involves measuring the "accumulated environmental state" of the system and trying to identify a) whether performance is below the level expected based on a comparison with undeveloped sites, and b) what factors are preventing the performance from being "normal" (Munkittrick *et al.*, 2000). The analysis depends on the resident organisms (in our case, fish) integrating the existing suite of environmental conditions and stressors.

The main output from an effects-based approach is an understanding of the existing carrying capacity or thresholds of the receiving environment for tolerating additional anthropogenic stress. This information then feeds into a decision-making framework (DMF) that determines the acceptability and sustainability of the changes (Figure 5). If the existing performance of the system is deemed to be unacceptable and/or unsustainable, then action must be taken to identify existing stressors and mitigate their impacts on the system prior to assessing impacts of new development. If there are no impacts observed in the existing system, or the impacts are deemed to be acceptable and sustainable, then the stressor-based component of the CEA framework proceeds where potential impacts of proposed project activities are predicted relative to the predetermined existing environmental state (Figure 5). Prediction can only be possible once a basic understanding of the system exists.

The stressor-based approach emphasizes the development of a conceptual model, based on the interaction of stressors with VECs. This tends to be based on large-scale integrators of biological responses (diversity, abundance), and performance parameters are based on available data or conducting workshops to develop a consensus on understanding the system among multiple stakeholders. Development proponents have been more supportive of stressor-based approaches than effects-based approaches because they are focused on predicting project-specific impacts related to proposed development. The disadvantage of focusing on a stressor-based approach is the inherent assumption that the potential impacts of the proposed development are understood and will be applicable to the receiving environment under development.

Natural and existing stressors may play a larger role in determining the potential impacts of development when changes are expected to be subtle and within the range of values normally seen in a receiving environment. However, when effects-based and stressor-based approaches are integrated into an overall framework for CEA, then the risks associated with these data gaps are overcome because the data collected from one approach off-sets the data gaps and disadvantages of the other approach. Once the existing accumulated environmental state is known then the prediction of potential impacts associated with new development becomes more focused. If existing impacts were observed for specific performance parameters, then the focus of the stressor-based assessment would be to determine if proposed project activities would deteriorate the performance of those parameters further. When the stressor-based assessment of potential project impacts has been completed this information feeds into a second DMF to determine if the predicted future state is acceptable and sustainable to warrant project development.

The final component of the proposed CEA framework is incorporation of post-development monitoring. The design of the follow-up monitoring program is based on, and comparable to the design of the effects-based performance assessment. It focuses on the performance parameters of concern and changes in those parameters are evaluated against the benchmarks established in the effects-based component of the assessment, prior to new development. Quantifying the level of existing stress and its consequences for performance provides loading goals for future development.

After completion of the post-development monitoring a third DMF is employed to determine if activities related to the new project resulted in impacts on environmental components beyond predicted levels, and if these impacts were significant (*i.e.*, unacceptable or unsustainable) and require mitigation. Incorporation of post-development monitoring in this regard results in a continued assessment and re-evaluation of project impacts over time and space.

Integrating effects-based and stressor-based CEA approaches into an overall CEA framework has several advantages (Munkittrick *et al.*, 2000) including:

- Contribution to building consistency in the CEA process;
- Incorporation of research design, scientific data analysis and effect quantification;
- Incorporation of regional information (effects-based approach) into a project-specific assessment (stressor-based approach);
- Consistency with other federal programs (the effects-based approach is based on and is consistent with environmental effects monitoring (EEM) programs conducted by large industries (currently pulp and paper and mining) as required under the federal *Fisheries Act*);
- Provision of a site-specific assessment to provide an understanding of the system for more focused prediction of impacts related to proposed project activities;
- Quantification of thresholds for environmental stress outlines clearer and more consistent lines of accountability;
- Incorporation of the existing stressor-based approach to project-specific environmental assessments currently practiced by proponents under the *Canadian Environmental Assessment Act*; and
- Provision of a directed, iterative and adaptive assessment due to incorporation of decision-making frameworks at key stages in the CEA framework and incorporation of post-development monitoring comparable to the effects-based performance assessment.

Application of this integrated CEA framework would be most relevant and advantageous for environmental assessments conducted beyond the screening level. These would include larger projects that have the potential for greater environmental effects, *i.e.*, those requiring assessments through a comprehensive study, panel reviews and mediations (CEAA, 1999).

3 CHANGES IN FISH PERFORMANCE - A MODEL FOR EFFECTS-BASED CEA

An aquatic ecosystem model for an effects-based approach to CEA was developed based upon studies conducted in the Moose River Basin, Ontario (Munkittrick *et al.*, 2000). In these studies, fish populations were evaluated to understand the cumulative effects of existing stressors (primarily hydroelectric facilities and pulp and paper industry) on key fish performance indicators. The objective of this chapter is to outline the different components, informational requirements, and main outputs associated with the different stages of the effects-based model. Application is restricted to fish performance indicators in aquatic systems. Chapter 5 describes how this approach should be expanded to include other ecosystem components.

3.1 Defining the System

The basic structure of the aquatic system needs to be understood to identify the key performance indicators to be used in the assessment. Guidance to the type of information which should be examined during study design can be found for the predesign or site characterization phases of the Canadian EEM program (Environment Canada, 1997a, 1997b, 1997c, 2000). The purpose of the system definition is to provide sufficient background information that the study design can be tailored to the specific characteristics of the site. Basic requirements include an understanding of geology, hydrogeology, local climate influences, industrial development, physical structure, water chemistry, and resident biota (Munkittrick *et al.*, 2000) (Figure 6). One of the key outputs of system definition is to select developed sites where fish performance indicators will be compared to undeveloped or reference sites. Ideally, these sites would be comparable in all aspects except level of development so the effects of development on existing fish performance could be accurately assessed. Geology, hydrology and climate affect water quality, fish habitat, and fish performance and need to be examined to help in site selection. Knowledge of the existing development within the study area is needed to understand the accumulation of stressors that the existing system may be responding to. This information is important for educated selection of reference and developed sampling sites, and for eventual identification of specific critical stressors if needed.

The physical structure of a system includes location of tributaries, dams and barriers (water falls and rapids), channel morphology (*e.g.*, meander profiles, riffle, run, pool ratios), substrate composition, and abundance and composition of aquatic vegetation. These structural components are important in terms of fish mobility, fish habitat, energy sources and energy flow.

Broad characterization of general water quality should be reflective of the geology and the inputs of the various effluents contributing flow to the system. Large differences in water chemistry will affect fish performance whether these differences are attributable to natural or anthropogenic influences. Large differences in water chemistry between developed and undeveloped sites will also confound result interpretation.

Finally, for an effects-based assessment it is important to have knowledge of the resident biota. This is often available from historical data collections and aids in the selection of the appropriate indicator species.

3.2 Developing Key Indicators

3.2.1 Selection of Monitoring Level

Stressor-based approaches commonly use multi-stakeholder workshops to develop a list of VECs early in the process of selecting assessment endpoints (CEAWG, 1999). These assessment endpoints are usually statements about the aspects of the ecological system that are valued for protection, but are often not directly measurable. In many cases, the VECs being studied tend to be variable (*i.e.*, population of walleye) and it is difficult to design an economical study to detect a statistical change. In those situations, changes to VECs are estimated through a surrogate indicator (*i.e.*, walleye catch by anglers). In effects-based assessments, selection of the most appropriate species and indicators focuses on the ecological characteristics of the system and the site-specific nature of the assessment requirements. An indicator in an effects-based approach may or may not be a VEC identified in a stressor-based approach. VECs may be difficult to relate to the performance of a system, and changes in other organisms may be more relevant to understanding the direct and indirect impacts associated with existing development.

In an effects-based assessment, development of key indicators refers to selection of the indicators that are most suitable to understanding the performance of the system. Considerations include the monitoring level (*i.e.*, food web position and level of biological organization), the type of measurement endpoints, and the level of understanding of the relevance of the endpoints to system performance (Munkittrick *et al.*, 2000). Changes in performance can be evident at all levels of organization, including the level of the individual, population or community. Some stakeholders prefer that there be no indications of any responses to exposure to stressors, and would prefer to have the most sensitive biochemical indicators free from abnormalities. Other stakeholders assume that as long as species are not eliminated, then there are no relevant impacts. Neither approach is ideal for an assessment program. Allowing any changes up to extinction to occur does not allow for a buffer zone for reaction if the system is to be managed adaptively. Furthermore, there could be many changes present at the population level, prior to extinction, which would be detrimental.

As the level of organization increases from individual to community, there is an increase in ecological relevance, an increase in the time lag for detecting changes, and a decrease in the specificity of the response (Munkittrick *et al.*, 2000). At the level of the individual, responses increase from short-term, neuroendocrine-based primary level stress responses to long-term, integrative responses in organ size and growth, in an attempt to adapt to the stress. At the population level, the first indicators of stress include changes in individual growth rates and other performance measures, long before changes in recruitment or abundance are noticed (Munkittrick and McCarty, 1995). At higher levels of organization, there is a concomitant increase in the time delay before detection of impacts, and a decrease in the ability to trace causality. If the focus of the assessment is to determine the sustainability of the system, and the acceptability of the changes, then a community-based assessment would have a time delay that could be inadequate for predicting changes in time for remediation of the system. The disappearance of species would be neither sustainable nor acceptable in most assessments, and monitoring the system at this level lacks the level of predictability offered by other levels.

At the other end of the biological organization spectrum, biochemical assessments within an individual are often too sensitive for selection as key performance indicators, with many changes occurring without whole organism consequences. While this level of monitoring may be suitable for defining responses and exposure, the inability to extrapolate changes to whole-organism and population level consequences limits its usefulness for determining the significance of changes and the consequences for determining acceptability. The main uncertainty of the biochemical indicators is that there is a need to know how big a change is important and what it is important for.

Determining the level for assessment depends on the level that provides the information required for making decisions. In this effects-based model we focused on individual integrators of responses, such as growth, reproduction and age distribution to assess the effects of existing development on fish performance (Table 1). Information at the interface between the individual level and the population level offers a compromise between the ecological relevance of community level changes and the sensitivity of individual level responses. This level is composed of integrators of performance which are directly relevant for population levels, have a relatively short time lag (weeks to months) and are linked closely enough to physiological indicators that there is some ability to trace cause-effect relationships. Changes in these measurements are relevant for evaluating sustainability and acceptability. In addition, by monitoring at the individual-population interface, some safety margin is built in so that fish communities are protected.

Table 1. Indicators of fish measurement endpoints at the individual level describing age structure, energy expenditure and energy storage.

Measurement Endpoint	Indicators
Age Structure	Mean age Age distribution
Energy Expenditure	Growth rate Gonad weight Fecundity Age at maturity
Energy Storage	Condition factor Tissue lipid levels Liver weight

3.2.2 *Selection of Measurements*

Individual-level performance characteristics integrate factors that are affecting fish, and key performance aspects include growth, reproduction and survival. The purpose of the effects-based assessment is to document the existing performance of key fish species within the community. Important performance aspects to define are growth rates, reproductive investments and age distribution. It can be assumed that fish populations that are growing, reproducing and surviving within ranges comparable to those seen at reference sites, are "normal" (Munkittrick and Dixon, 1989a, 1989b). In an undeveloped site, differences seen during the effects-based assessment would be an indication of a sub-optimal environment. It would be important to develop an understanding of why these populations did not fulfill their performance potential, prior to developing an assessment of the potential risks associated with new developments.

The measurement endpoints that are selected for an effects-based assessment should be relevant to a more holistic understanding of the basic biology of fish performance. Over the last decade, we have been developing an approach to examine the factors that limit the performance of fish populations (Munkittrick and Dixon, 1989a, 1989b; Munkittrick, 1992; Gibbons and Munkittrick, 1994; Munkittrick *et al.*, 1999a). In order to understand what is limiting the performance of the fish population, information is collected on whether the fish have enough food, whether they are utilizing it properly, and whether the population has an altered age structure. The analysis uses indicators of age distribution and measures of energy utilization and storage. Energy utilization measures include size and size-at-age indicators of growth rate, and gonadal size, fecundity, and egg size as indicators of reproductive potential. Energy storage measures include condition factor, liver size and lipid storage levels.

3.3 Developing Performance Assessment

Once the key indicators have been selected, the next step in an effects-based assessment is to develop an assessment of the performance of the system, *i.e.*, designing and implementing a field study program (Figure 6). The performance assessment involves developing a database on indicators of energy utilization, energy storage and age distributions collected on relevant fish species within the study area. Aspects of the study design to be considered include selection of sampling sites, the most appropriate species, sampling time, capture techniques, sample size and minimum data requirements. The EEM Program developed in Canada for monitoring pulp and paper effluents, and mining effluents offers extensive Technical Guidance Documents (Environment Canada, 1997b, 2000) and interpretation documents (Environment Canada, 1995a; 1995b) that contain information on an EEM program that has a similar design. Guidance is also available in relation to EEM programs developed in Sweden (Thoresson, 1993; Swedish EPA, 1997) and Australia (Keough and Mapstone, 1995, 1997; Mapstone, 1995; Terrens *et al.*, 1998).

3.3.1 Selection of Sampling Sites

In the effects-based component of a CEA the basic process includes background data collection, development of an understanding of natural variability, and monitoring of trends in sources of change. These components of the process all influence the selection of sampling sites for fish collection. Two categories of sampling sites are selected, reference or undeveloped sites, and developed sites. Background data collection is essential to define the system and to determine the comparability amongst the sites. Poorly selected reference sites are the most common criticism of ecological studies (Munkittrick *et al.*, 1999b). Local reference sites are essential for interpreting differences, and gradient designs and the use of multiple reference sites can strengthen interpretation of differences. While there is general agreement that there are no perfect reference sites, factors associated with site selection have to include similarity of sites, confounding factors that may affect interpretation, and the biology of the monitoring species (Environment Canada, 1997a). Because it can be very difficult to pick a good reference site, it is becoming more common to use multiple reference sites to get an indication of the variability between reference sites. All sites should be as similar as possible in all facets with the exception of level of development. Understanding natural variability can be determined by comparing indicators of fish performance amongst reference sites. Differences that are outside of the range of values seen at a number of reference sites are accepted to have more ecological relevance.

In order to monitor trends in sources of change, *i.e.,* assess the effects associated with existing development, comparisons are conducted at developed sites where samples collected downstream of developments are compared to both upstream reference sites, and to additional reference sites on other undeveloped tributaries.

The site selection process requires flexibility and an understanding that some of the results of the initial effects-based assessment may be difficult to determine because of inadequate information and hence, inadequate site selection. The benefit of post-development monitoring and adaptive management is that these deficiencies in site selection can be recognized, new information incorporated, and changes made in subsequent follow-up monitoring programs.

3.3.2 Species Selection

The purpose of an effects-based assessment is to define the factors limiting the performance of fish living in the system, and it is important that the species chosen as sentinels offer the most potential within the system for defining stressor influences. Stakeholder views, political agendas and the scientific needs for conducting an assessment can affect selection of the sentinel species. Local agendas can influence the selection of sentinel species. However, locally important species often exhibit life history characteristics that are not ideal for detecting stressor influences. For example, many species that are locally favored are sport fish, and most sport fish are predatory and highly mobile which reduces their ability to reflect local conditions. In addition, selection of sentinel species that are economically relevant can be a problem because a high level of human harvest can decrease the ability to detect responses associated with other stressors.

The priority factors for species selection should be exposure, abundance, and relevance to the study area and the study objectives (Environment Canada, 1997a). The ideal characteristics for a sentinel species are not the same for studies looking at point-source discharges, non-point discharges, and for understanding risks to human health. Obviously, rare species, or species not available at all sites are not ideal for sampling.

Exposure of fish to stressors is key to assessing their response to these stressors. Exposure requires residency in the area of stressor discharge especially for point-source dischargers. There have been some concerns related to using large-bodied fish species for monitoring and assessment programs in rivers due to their mobility. The significance of mobility issues will be site-specific; if there are barriers present preventing mixing of fish between reference and exposure areas, mobility issues can be less important. Some attention has been placed on small-bodied species and their potential for use in assessment programs (Environment Canada, 1997a; Gibbons, 1997). The main disadvantages to using small-bodied species relate to the lack of knowledge of the many life history characteristics for most of the species, and the reduced level of intuitive relevance for many stakeholders. Almost all stressor-based assessment programs use human value in selection of VECs. Because many of the small-bodied species are not widely recognized as important components of the system, their value is underestimated.

Although use of large, mobile predatory fish is an issue for some point-source discharges these species would be preferred if biomagnification of lipophillic chemical compounds is an issue. Large fish have greater longevity that may increase the lag time for detecting responses but, in the case of lipophilic contaminants and food chain biomagnification, a species with a prolonged life span would be preferred to maximize bioaccumulation.

Abundance is another issue to consider when selecting a sentinel species. It is important to ensure sufficient individuals are present to allow effects-based monitoring and post-development monitoring with adequate sample sizes and statistical power. Fish are also required that have life history characteristics that are easy to measure. Fish that are difficult to age will make data interpretation difficult. Spawning time is also consideration for species selection. In the case of prairie river systems in Canada, maximum exposure to most point-source dischargers can occur during overwinter periods due to low flow and ice cover. A species that spawns in the fall in the near-field area of an effluent source would have maximum exposure to their eggs and early life stages during the period of maximum effluent concentrations. However, a spring-spawning species would have maximum exposure during ovarian development during this same period.

3.3.3 Sampling Schedule

The selection of sample timing will depend on site-specific habitats, the species selected and the nature of the questions being asked. Most species show seasonal differences in habitat preferences and mobility. In extreme cases, a species may move seasonally among feeding areas, spawning areas, and overwintering areas, which can be very different habitats. In situations where there are no natural barriers to prevent movement in and out of the exposure areas, a basic understanding of the species' habitat preferences is needed to ensure that residency in the area of interest is maximized. The understanding required may be limited to ensuring that fish are sampled during the period of maximum residency. If there are doubts as to the duration of residency, alternative species should be investigated as to their suitability.

3.3.4 Capture Techniques

Capture techniques should be appropriate for the species selected as the sentinel. In many cases, sampling should be designed to avoid unintentional killing of non-target species, especially when sampling must be conducted in an area where there are limited numbers of sportfish, migratory species, or rare, threatened or endangered species. Guidance on sampling gear is available from the Technical Guidance Documents prepared for the EEM Programs in Canada (Environment Canada, 1997b, 2000) and Sweden (Thorreson, 1993; Swedish EPA, 1997).

3.3.5 Sample Size Requirements

One of the challenges of effective environmental assessment and subsequent management is in knowing if a difference in environmental performance exists among developed and reference sites, and if this difference is ecologically meaningful. Development of the Canadian EEM program for pulp and paper and mining industries has made a significant contribution to the understanding of how study design and sample size can be a powerful tool to provide information required for managing ecosystem change (Environment Canada 1995a; 1995b; 1997b; 2000). An understanding of the importance of study design and selection and collection of an appropriate number of samples results in data that can:

- Distinguish a difference in performance between developed and reference sites;
- Determine a specific magnitude of difference between sites that has been predetermined by stakeholders to be ecologically significant (*i.e.*, exceeds thresholds or a critical effect size) and requires subsequent management;
- Provide an estimate of confidence for the comparison (*i.e.*, statistical power); and
- Provide data that examines the significance of the difference between reference and developed sites relative to site-specific natural variability in performance indicators.

Ecological thresholds or critical effects sizes are one of the most significant informational outputs from an effects-based CEA. For each performance indicator an ecologically significant effect size can be pre-determined by stakeholders prior to implementation of the study design. This is the magnitude of difference between reference and developed sites that will indicate impaired performance for that performance indicator. There is considerable discussion around the issue of what constitutes an ecologically relevant threshold. Barnthouse et al. (1989) argue that a 10% change in variables would be societally and ecologically significant. However, in wild fish, differences as high as 20% have been observed in parameters at undeveloped reference sites. The pulp and paper EEM recommended a target effect size of 25% in terms of gonad size (Environment Canada, 1997a). There are a series of options for defining a target effect size that include:

- Using a predetermined difference, based on previous experience, that constitutes a change of sufficient magnitude to cause concern (e.g., 25% difference in gonad sizes; Environment Canada, 1997a);
- Selecting an arbitrary difference over reference conditions (+/- 2 standard deviations from the reference mean) (Kilgour *et al.*, 1998); and
- Selecting a difference that is outside the maximum or minimum range of normal variability observed at reference conditions.

A detailed discussion on effect size as it relates to an effects-based approach can be found in Environment Canada (1997b; 2000).

Power is the statistical strength of the study design or the ability to detect a difference in performance indicators between reference and developed sites when one truly exists. Power is an expression of the level of confidence in the comparison between sites and can be used in both study design and data analysis components of the effects-based approach. Understanding statistical power may seem overly technical for a management framework. However, it is included here to illustrate that tools currently exist to begin addressing management issues such as data uncertainty. These tools can be employed to lessen the subjectivity of the CEA process by identifying thresholds that have been quantitatively exceeded and the confidence that these exceedances are real. Thus, more scientifically based, quantitative information can be obtained and incorporated into the stakeholder process.

It is common for comparisons between developed and undeveloped sites to be conducted and the power level to be calculated *aposteriori* so that a level of confidence in the detection of the difference between sites can be stated. It is more valuable to establish power levels *a priori* (Keough and Mapstone, 1995, 1997; Mapstone, 1995; Terrens *et al.*, 1998). There are always potential errors associated with decisions but, with proper study design and collection of adequate numbers of samples, the level of error (*i.e.*, or inversely the power) that stakeholders are willing to accept for a particular analysis can be specified. This involves the manipulation of α and β during statistical analysis of the data, *i.e.*, controlling for Type I (α) and Type II (β) statistical errors. There is an increasing desire to set α (the probability of declaring an effect exists when one does not exist) and β (the probability of missing an effect when one exists) at equal levels (*i.e.*, 0.1) so that the chances of missing an effect or falsely declaring an effect are equal. Technical details on establishing power levels can be found in Environment Canada (1997b; 2000).

Effect sizes and statistical power targets are affected by sample size and the magnitude of natural variability (*i.e.*, variability measured at or over reference sites). In general, larger sample sizes result in greater power and an increased ability to detect smaller differences between sites (*i.e.*, smaller effect sizes). However, power and effect size are also affected by high natural variability. Systems with high natural variability will require larger sample sizes to achieve the same level of power and ability to detect specific effect sizes compared to sites with less variability. The most powerful approach to study design is to know the existing level of system-specific natural variability and use this information *a priori* to determine the number of samples required to meet system-specific targets for effect size and power level. Often adequate information is not available from baseline studies or historical data sets for design of an effects-based study. However, minimum sample sizes have been specified which can be used for initial effects-based programs where there is inadequate baseline data. In the EEM programs, minimum initial sample sizes have been set at 20 males and 20 females of 2 species (Environment Canada, 1997b; 2000). These sample sizes were selected because the variability in whole organism characteristics has been seen to stabilize after sampling 8 to 16 fish (Munkittrick, 1992).

One important aspect of the proposed CEA framework is the incorporation of follow-up monitoring of comparable study design to that conducted during the effects-based performance assessment. Follow-up allows for re-evaluation and the data can provide continuing estimates of site-specific natural variability to be incorporated into sample size estimates for future monitoring programs. In this context, stakeholders are assured that the amount of data collected is meeting their needs to make decisions and manage further development. It should be recognized that there are economical and practical limits to the number of samples that can be collected. However, collecting an inadequate number of samples provides little information for informed decision making.

3.4 Data Analyses

The data analysis component of an effects-based approach essentially involves two components, determining baseline or reference conditions and associated natural variability, and determining if responses to existing stressors are measured over time and space (Figure 6). The objective of the analysis is to summarize the data and provide information that is commensurate with the next phase of the effects-based approach, identifying impaired aspects of fish performance. The basics of data analysis include:

- Calculation of summary statistics (*e.g.*, mean, standard deviation) to show general patterns in the data as well as the presence of data anomalies (*i.e.*, outliers);
- Graphical presentation of the results to illustrate reference site variability, and differences between reference and developed sites for each performance indicator over time and space; and
- Statistical analysis including parametric (*e.g.*, regression analysis, analysis-of-variance, analysis-of-covariance) and non-parametric analysis to determine the statistical significance of differences. Statistical analysis also includes *aposteriori* power analysis.

It is beyond the scope of this chapter to review data analysis procedures. Extensive technical guidance is available in Environment Canada (1997b; 2000).

3.4.1 Analysis of Reference Sites for Fish Performance

Natural variability in fish performance indicators can be high. The importance of understanding and quantifying this variability inherent in each performance indicator should not be underestimated. As the performance of fish populations at developed sites is compared to reference sites to determine existing effects, a lack of understanding of the level of natural variability can lead to an overestimation or underestimation of effects. In our effects-based model, fish performance indicators are sampled at reference sites across systems (latitudinal comparisons) and at distances along a reference system (longitudinal comparisons). Latitudinal analysis should provide an indication of natural variability among closely related systems. Longitudinal analysis should indicate variability associated with downstream changes in river size, depth and flow. In addition to latitudinal and longitudinal analyses, seasonal variability and year-to-year variability among reference sites should be analyzed. This can be done either as part of the effects-based performance assessment or the post-development monitoring program.

Studies on the Moose River Basin have shown that performance indicators at reference sites are variable over space within a system, over seasons, and over years. This variability is not a problem but illustrates the need for data analysis to be conducted and interpreted carefully and within years with any differences confirmed with subsequent sampling (Hodson et al, 1996). It also illustrates that multiple reference sites should be used in an effort to capture all of the natural variability that occurs.

3.4.2 Comparison of Developed Sites to Reference Sites for Evaluation of Fish Performance

The identification of existing cumulative effects, which will determine the acceptability of future development on a system, is based on comparisons of fish performance indicators between reference and developed sites. Comparisons are conducted spatially, *e.g.*, upstream reference site is compared to a downstream developed site, and temporally, *e.g.*, at reference and developed sites over different seasons and over years. Results from the Moose River Basin studies illustrated that undeveloped/developed site comparisons were most relevant within a river, upstream and downstream, and within a given year. However, for an accurate representation of cumulative effects, comparisons are required over larger spatial and temporal scales. If a difference between sites is observed in a single year the consistency of the response between seasons and over years will help to determine its magnitude and extent. The Technical Guidance Documents for the EEM program should be consulted for more technical direction on site comparisons (Environment Canada 1997b; 2000).

3.5 Identifying Impaired Aspects

3.5.1 Ecologically Relevant Changes

Once the data analysis component of the effects-based assessment has been completed and differences among reference and developed sites measured, the ecological relevance of these changes is assessed (Figure 6). Ecological relevance is based on a comparison of the magnitude of the change relative to the variability measured at reference sites. The three common approaches to assessing whether the changes are ecologically relevant, *i.e.*, exceed pre-determined effect sizes or critical thresholds, are:

- Changes are more than two standard deviations from the reference condition (Kilgour *et al.*, 1998);
- Changes are outside the range of normal variability (maximum and minimum reference condition); and
- Changes are outside a maximum tolerable difference (*i.e.*, 25% for gonad size) (Environment Canada, 1997a).

The easiest method for compiling information on ecological relevance is to take the graphs developed in the data analysis phase and for each performance indicator draw horizontal lines on the graph (bar graph for example) which illustrate the critical thresholds. Bars for sites or times which fall outside of those lines are considered ecologically relevant changes.

It should be recognized that the effects-based approach separates the definition of ecologically relevant changes from changes that are sustainable or acceptable. Changes that are ecologically relevant under existing conditions are in the need of careful monitoring and need to be considered when the effects of new development are assessed in the stressor-based component of the CEA. However, a change that is ecologically relevant may or may not be sustainable or acceptable depending upon stakeholder issues and management priorities. Decisions regarding sustainability or acceptability require information beyond ecological considerations. These issues are considered in the decision-making framework component of the effects-based approach as described in chapter 4.

3.5.2 *Evaluation of Fish Performance and Limiting Factors*

Fish performance characteristics can be used to provide information on the factors limiting performance. Early development of this interpretation framework identified five possible response patterns (Munkittrick and Dixon, 1989a; 1989b); the response patterns are meant for developing hypotheses for focusing follow-up studies. They are ideally suited for adaptive management and iterative data collection.

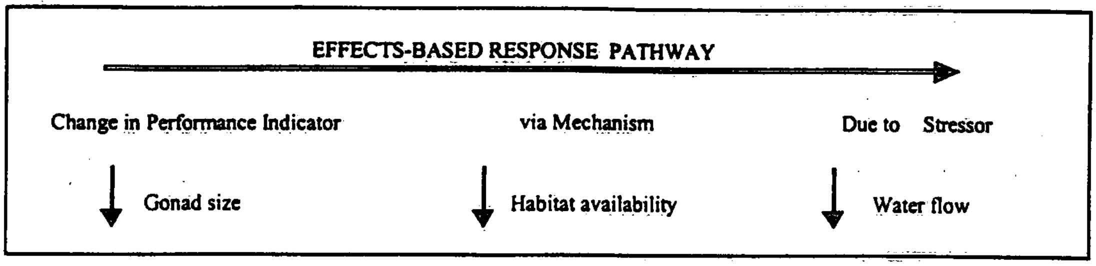
The original five response patterns included responses to adult mortality, juvenile mortality, early life stage mortality, food limitation, and a niche shift. Conceptually, it is easiest to understand the response patterns by envisioning a small lake with 1000 adult fish. A stressor (harvest, chemical spill, etc.) that preferentially removes half of the adult fish would result in a series of adaptive responses by the survivors. It would not be possible a year later to detect that the adults were missing, but it would be possible to detect that the remaining fish were younger than expected, were growing faster, maturing younger, storing more energy, etc.

Similar response patterns have been identified for the other standard impacts, and a literature review conducted in the late 1980s demonstrated that studies consistently fell into one of the five original response patterns (Munkittrick and Dixon, 1989b). The response patterns could be predicted given information on age structure, life history characteristics indicative of energy use (growth rates, age to maturity, fecundity, gonadal size) and energy storage (lipid levels, condition factor, liver size).

Studies on the responses of fish to pulp mills uncovered a new response pattern, where characteristics of energy use did not co-vary; fish could be growing faster and have higher energy storage, but show a reduced commitment to reproduction. This response pattern was interpreted to be reflective metabolic disruption (Munkittrick *et al.,* 1991). The discovery of additional response patterns led to a reformatting of the conceptual response pathways to incorporate additional response patterns reflecting chronic food limitation and the absence of significant impacts (Gibbons and Munkittrick, 1994).

In the performance assessment, indicators of age structure, energy expenditure, and energy storage were used to determine if fish were surviving, reproducing, and growing within ranges comparable to those seen at reference sites (Munkittrick *et al.,* 2000). If there were no differences between reference and developed sites it would indicate that existing stressors were not limiting fish performance or the ability of the fish to fulfill their performance potential. If ecologically relevant changes in performance indicators were observed between reference and developed sites this would indicate a sub-optimal environment for fish performance.

Identification of the mechanism is essential to link ecologically relevant changes in fish performance indicators to potential stressors via possible response pathways. For example, if ecologically relevant decreases in gonad size were detected for male fish at developed sites, this could indicate a reduction in energy expenditure. Unless conditions are critical, fish will allocate sufficient energy for maintenance and survival. Any remaining energy will be used for growth or reproduction, or will be stored. Decreased resource (*e.g.,* habitat) availability is a mechanism that can result in a reduction in energy expenditure. Stressors that decrease habitat availability include reduced water flow or the discharge of toxic chemicals. Therefore, the response pathway would be:



A model of fish population response patterns has been developed to assist with the understanding of the response pathways for fish exposed to stressors. Specifically the model outlines the progression and direction of fish responses to alterations in food/habitat availability, rates of mortality, and physiological impairment (Figure 7). Some of the response patterns may be stable and some may be transitional states (*i.e.*, unclear whether these will be observable in wild fish populations). Fish from a developed site exhibit an ecologically relevant increase [+], decrease [-], or no change [0] in characteristics relative to the reference fish. For presentation purposes, whole organism parameters were grouped into summary categories describing age structure, energy expenditure and energy storage (order of presentation of results within each box). For each of the fish response descriptions, the response pathway begins with fish unaffected by a stressor [fish show no change in age structure, energetic expenditure or energy storage: **000**]. The established patterns that have been identified in the literature are highlighted in Figure 7 by shaded boxes. An example of fish response patterns to changes in food/habitat availability is presented here. Additional explanation of the response patterns associated with mortality and physiological disruption are presented in Munkittrick et al (2000).

Decreased availability of resources - Resource availability may decrease for one of two reasons, either an increase in the population size or a decrease in the habitat or food base. Increased population size can result from a number of factors including increased migration, stocking of new fish, improved survival of young fish, or decreased predation rates. Decreased habitat availability can be associated with increased competition associated with improved survival of competing species or reduced water flows, as well as the discharge of toxic chemicals, solids, heat, or biochemical oxygen demand. The initial response of a population faced with diminishing resources is to reduce energy expenditures, resulting in a decrease in growth rate and reproductive output. There would be no initial impact on age distribution, since the same adult fish are present before and after the change in resources. Sampling the population at this point in time would result in detection of a pattern (based on age structure, energy expenditure and energy storage) which showed a difference only in terms of energy expenditure [0-0] (Figure 7). Further reduction in the food base would decrease the amount of energy available for storage, resulting in a change in response pattern to reflect decreasing energetic storage as well as decreased expenditures [0–]. Since the population has been producing fewer young, the average age of the population would begin to climb, resulting in an eventual increase in mean age [+–]. The change in resource availability has reduced the carrying capacity (the size of the population that can be supported by the environment). When the size of the resident population is reduced to a level consistent with the new carrying capacity, there will be sufficient resources for the remaining fish to reproduce, grow and store energy at a level consistent with their original rates of energy utilization and storage. However, the population would still be older than the original distribution, resulting in a pattern of [+00].

There are two possible outcomes from this pattern:

- If the age shift is moderate and the ability of the population to respond is high, the population may be able to rebound quickly. This should result in the detection of a population indistinguishable from the reference population [000], except for a change in population size (which should be readily apparent from the capture data).
- If the population has a substantially older age distribution (or additional external factors are associated with lethal conditions), the mortality rate will be higher. Increased mortality will result in a further decline in population size, which would result in an excess of food resources for the small population of individuals that remain. These fish will respond to the increased resources by increasing energy expenditures and storage [+++]. The increased reproductive output will result in an increase in younger fish, eventually leading to a decrease in the mean age of the sample population (when the fish reach sampling size) [0++]. The increased reproductive rate will result in an eventual further decrease in mean age, which may have two consequences:
  - The ability of the population to respond is high, and the differences slight, allowing the population to return quickly through an intermediate stage [-00] to reference levels [000].
  - The population responds slowly, requiring an intermediate [-++] pattern.

Incorporation of data collected in an effects-based assessment into the model for fish response is valuable because it:

- Integrates fish responses over different measurement endpoints (age structure, energy expenditure, energy storage);
- Determines a more holistic response (*i.e.*, status) of the fish population to existing stressors;
- Identifies potential limiting factors or mechanisms through which existing stressors might be acting (response pathway); and
- Identifies possible mechanisms that can provide direction as to the identification of existing stressors.

In addition, this information is valuable to:

- Focus the stressor-based component of CEA process and post-development monitoring programs on specific performance indicators and mechanisms which may be affected by new development; and
- To provide some predictive inference on the direction of response if particular performance indicators were exposed to additional stressors associated with new development.

3.6 Identifying Critical Stressors

The final stage of the effects-based approach to CEA is to identify existing stressors that are limiting fish performance via various mechanisms (Figure 6). A variety of approaches are suitable for investigating causality. A first priority is to first confirm that the changes are real, and to understand the magnitude and geographic extent of the changes. It is often possible to eliminate or prioritize stressors based on the geographic distribution of responses. However, it is important to understand the mobility of the sentinel species being used prior to making firm conclusions. The process of identification of the geographic extent can be streamlined if the mechanism of action can be identified enough to either reduce the amount of information needed at each site, or increase the efficiency of sampling. This is especially true if the changes (or the stressors) can be simplified into strictly a chemical or biochemical indicator, or a whole organism response specific to the indicator. Gradient designs (*e.g.*, improvement in environmental response with distance downstream of a point-source discharge) are especially suited when there is some geographic distance between stressors, or there is the ability to use caged fish/non-mobile fish or invertebrate sampling to isolate factors. On-site mesocosms or on-site artificial streams can be especially helpful to identify specific effluents as contributing factors (Courtenay *et al.*, 1998, Culp *et al.*, 2000; Dubé, 2000).

4 DECISION-MAKING FRAMEWORKS FOR CEA

Decision-making frameworks (DMF) provide the direction and focus for consistent environmental assessments where scientific information is linked to management decisions. Scientific information is produced in the effects-based assessment, the stressor-based assessment, and in the post-development monitoring component of the CEA framework (Figure 5). This information is fed into each DMF, which is then evaluated in conjunction with stakeholder issues of ecological, economic, sociological, and technological importance. In the proposed CEA framework, DMFs are used in three different stages:

- Effects-Based DMF:
  At the end of the effects-based assessment to determine if there is an impact of existing development;

- Stressor-Based DMF:
  A) At the end of the stressor-based assessment to determine if a developed system can tolerate additional development;
  B) At the end of the stressor-based assessment to determine if a pristine, undeveloped area will be impacted by new development; and

- Follow-Up Monitoring DMF:
  After each cycle of post-development monitoring to determine if the new development impacted an area beyond predicted levels.

Although the questions posed within each DMF are essentially the same, the direction given is specific to the stage of the CEA process with results from one framework feeding into the next. In the interest of clarity, we have simplified each DMF to focus only on fish issues. However, implementation of these DMFs mandates that decisions be made in a broader ecological context (*i.e.*, incorporating fish habitat issues) as described in chapter 5.

4.1 Effects-Based Decision-Making Framework

The effects-based DMF incorporates the information compiled from the effects-based performance assessment with information on sustainability and acceptability (Figure 8). The justification for the key questions posed in the DMF are presented below.

Are there existing effects with fish usability?

The first question in the framework relates to fish usability (Figure 8). Effects or changes in usability relate to potential human health concerns and are associated with contaminant burdens, odor or taste affecting consumption (tainting), or gross changes in external appearance of fish (lesions, tumors). Contaminant burdens that are above concentrations recognized as potentially harmful in fish consumption guidelines must be investigated further to identify the cause of the elevated contaminant levels. Changes in fish usability associated with tainting or fish appearance are also serious and require an investigation of causality. When effects on fish usability are documented for existing levels of development, then the project-specific stressor-based component of the CEA should not proceed until the source of the existing effects is identified and the effects mitigated. This is especially true if the proposed development has the potential to exacerbate issues with fish usability.

Are there existing changes in fish that exceed thresholds?

Regardless of whether there are concerns with fish usability, issues relating to environmental health must be examined in the DMFs. If there were no exceedances of ecologically relevance thresholds for the performance indicators measured in the performance assessment, then the sufficiency of the study design to detect these differences (*i.e.*, the statistical power) is determined (Figure 8). If sample sizes were sufficient to attain a specified power relative to inherent natural variability, then it can be concluded that there are no existing effects on fish within the receiving environment studied. Under this scenario, a project proponent would proceed with the stressor-based component of the CEA and evaluate the potential for proposed development to impact the receiving environment beyond existing conditions (Figure 5). If the study design was not of sufficient statistical power, then the study design requires improvement and the effects-based information re-evaluated (Figure 8).

Are the existing effects sustainable?

When critical effect sizes or ecologically relevant thresholds are exceeded for performance indicators measured at developed sites, an evaluation of the sustainability of those effects are required (Figure 8). To make this evaluation, information is required on the consistency of the exceedance (*i.e.*, were the changes confirmed in subsequent studies) and the extent and magnitude of the effect. The extent of the effect relates to the geographical distribution of responses and their relationship to the stressor (*i.e.*, does performance improve with distance downstream of the stressor). The magnitude of the effect includes a number of issues related to the size of the effect, the life stages affected, and the differences between species. To determine if existing effects are sustainable also requires information on the history of development at the site and temporal data on fish, which shows that the situation is getting better, worse or staying the same.

Issues of sustainability go beyond science, require stakeholder involvement, and require an understanding that not all effects are unsustainable. It is crucial not to confuse sustainability with an absence of impact. Obviously, individuals can survive numerous biochemical impacts, and populations can survive numerous individual impacts. The role of science should be limited to defining the existence of changes, the magnitude and extent of changes, and the trends of changes over time. Effects are deemed to be sustainable when *it can be insured that the environmental, economic and social aspects of the aquatic environment will be preserved with the same, or better quality, for future generations* (Environment Canada, 1995). If changes due to existing development are documented it must be decided if these changes have or will result in loss of the resource, in this case fish populations (*i.e.*, changes that are unsustainable). The priority has to be to ensure that populations and communities are preserved within a discharge or development area prior to considering effects of new development. If changes are determined to be unsustainable then the project-specific stressor-based component of the CEA should not proceed until the source of the existing effects is identified and the effects mitigated (Figure 8).

Are the existing effects acceptable?

If effects are documented and deemed to be sustainable then the acceptability of the changes needs to be determined (Figure 8). Decisions on acceptability of changes, like sustainability, require stakeholder involvement and go beyond the scientific process to include economic and societal issues (Swedish EPA, 1997, Greig *et al.* 1998). Changes in sexual maturity or fecundity of fish populations, which are ecologically relevant, may be considered to be sustainable once the extent and magnitude of the changes are assessed. However, after public consultation, stakeholders may decide that, although sustainable, these changes are unacceptable and the stressor-based CEA should not proceed until the cause of the reduced fecundity is identified and mitigated.

If ecologically relevant changes are evaluated to be sustainable and acceptable, then the stressor-based CEA should proceed but it should be focused on those performance indicators, which have been affected on an ecologically relevant level, to ensure the proposed development does not worsen the situation (Figure 8).

4.2 Stressor-Based Decision-Making Framework

The stressor-based DMF follows the same logic and progression as that described for the effects-based DMF although the evaluation is on *predicted* effects of proposed development (after mitigation is considered) as opposed to existing effects due to current development (Figure 9). The information used in the DMF is project specific using existing stressor-based predictive methods. If no effects of the proposed development are predicted, or the predicted effects are sustainable and acceptable, then development should proceed along with post-development monitoring. If there are predicted issues regarding fish usability, or the predicted effects are unsustainable or unacceptable, then development should not proceed for the current project description.

4.3 Follow-Up Monitoring Decision-Making Framework

One of the most advantageous aspects of the CEA framework presented here is the incorporation of post-development, follow-up monitoring. Currently under the *Canadian Environmental Assessment Act* a lack of follow-up monitoring in the environmental assessment process has been recognized as a weakness (CEAA, 1999). Any process that involves a component of prediction involves uncertainty and a possibility of error. Complete understanding of the aquatic system and the impacts of stressor on that system is seldom possible prior to approval of a new development. Follow-up monitoring provides an assessment of the accuracy of the predictions, the effectiveness of mitigation, and provides checks and balances for reassessment and adaptive management. The focus of an adaptive management strategy is to develop the information needed to manage the system in an iterative fashion, with enough of a response time to allow adaptation of the management strategy prior to irreversible damage occurring in a system. In adaptive management, current understanding is used to set initial operating conditions and these conditions are amended to preserve the health of the environment if dictated by new knowledge, improved technology or future developments (CEAA, 1999).

The key to follow-up monitoring is that the program employed is consistent with that used in the effects-based assessment. A comparison of post-development conditions (*i.e.*, conditions after the new development) to pre-development levels (*i.e.*, either pristine, undeveloped conditions or existing development prior to approval of the new development) does not provide the intended information if the design of the performance assessment differs between the programs.

Figure 10 illustrates a fish-only based follow-up monitoring DMF. A follow-up monitoring program is conducted with the same or similar design as that employed in the effects-based assessment and the accuracy of the predictions with respect to fish effects and fish usability are assessed. If there are no issues with fish usability, no effects on fish which exceed ecologically relevant thresholds, and the statistical power of the program is sufficient, there are no effects associated with the new development and follow-up monitoring should continue at the same or reduced frequency. If statistical power is not at the levels required, then the follow-up monitoring program requires re-design. One benefit of conducting follow-up monitoring is that the natural variability inherent at the site can be incorporated into sample size calculations for subsequent monitoring to achieve desired power and effect size levels.

If concerns with fish usability arise in the post-development monitoring program, or if unsustainable or unacceptable ecologically relevant effects are documented, then existing project activities require mitigation (Figure 10). It should be obvious that a new development that rapidly creates major changes in fish populations or communities can not be sustained and the underlying cause of the changes requires investigation and mitigation.

If ecologically relevant effects are documented but they are sustainable and acceptable then follow-up monitoring should continue with a focus on the performance indicators showing effects due to the new development (Figure 10).

5 EXPANSION OF THE CEA FRAMEWORK IN AQUATIC ECOSYSTEMS

5.1 Inclusion of Benthic Invertebrates as Indicators of Fish Habitat

The CEA framework proposed in this document focused on fish-specific issues to simplify presentation of the main concepts and ideas of the framework. However issues regarding sustainability, acceptability and legislative context require that CEA be applied in an expanded ecological framework involving other trophic levels and effect indicators. The main regulatory tools related to discharges and developments are the *Canadian Environmental Assessment Act* and the *Fisheries Act*, the *Canadian Environmental Protection Act (CEPA)*, and the *Pest Control Products Act (PCPA)*. For the purposes of impact assessment and CEA, most of the provisions requiring assessment are under *Canadian Environmental Assessment Act* or the *Fisheries Act*. The *Canadian Environmental Assessment Act* requires that development proponents identify any potential cumulative environmental effects, analyze them, determine their significance and identify possible mitigation measures. Identification of cumulative *'environmental"* effects requires that an assessment consider impacts to various trophic levels in addition to fish. Similarly, the objective of the *Fisheries Act* is to protect fish, fish habitat and man's use of fish (*i.e.*, fish usability). Since the *Fisheries Act* will eventually be involved in any post-development monitoring requirements for new development, a consideration of fish habitat impacts is essential.

Aquatic food webs include organisms at a wide variety of organizational levels, and assessments have been conducted focusing on lower trophic levels, as well as higher trophic levels. While there have been a variety of trophic levels used for assessment, current environmental assessments tend to use benthic invertebrate communities as indicators of habitat quality. When selecting benthic invertebrates exclusively as the monitoring level for fish habitat assessment an assumption is made that changes in the lower trophic levels (*e.g.*, macrophyte, algal, periphyton and zooplankton communities), which do not result in changes in fish or benthos, are sustainable and acceptable. If changes in lower levels of organization are large enough to have relevance for fish or benthos, they will be reflected in measurable changes in fish or benthos. Algal and zooplankton populations can be affected by developments, and in many cases are more sensitive than benthic invertebrate or fish species. There are a number of situations where it might be more relevant to monitor these groups for assessment programs, including where a situation is well enough understood that a cost-effective long-term surveillance program is needed, and these measurements can be used to indirectly indicate the health of the system. However, these changes must be translated into higher levels of organization to enable decisions about their importance to be made. Algae and zooplankton will work well as a warning signal, but only in systems where their role in the responses of higher levels is understood well enough to allow extrapolation. If changes at these levels are not relevant to higher levels of organization, then monitoring their status is not a cost-effective approach.

Considerable effort has been invested towards the development of assessment methods using benthic invertebrates, and community-based indices are widely available (Environment Canada, 1995a; Taylor and Bailey, 1997). Within the context of the CEA framework presented here, benthic data plays a key, supporting role in the determination of the ecologically relevant thresholds, and in evaluating sustainability and acceptability of change (Figure 11). For example, if changes in benthic communities exist but they do not affect the fish population, the situation is probably sustainable (fish will not disappear) at least within a relatively short time frame (years). An understanding of the size and extent of changes in benthic communities would provide key information on the amount of change in benthic communities that can be tolerated without a resulting change in fish performance in that system. Such information would be critical for understanding how close the existing situation may be to a threshold for change, what post-development monitoring requirements should be increased, and what the assimilative capacity of the system may be for tolerating changes associated with future developments. However, even if it is decided that changes in benthic invertebrates do not result in unsustainable effects, stakeholders may decide that these effects are still unacceptable.

5.2 Inclusion of Other Effect Indicators

Sublethal toxicity testing and monitoring of water and sediment chemistry can also provide invaluable information to assess the cumulative effects of development on aquatic ecosystems (Figure 11). For example, if after post-development monitoring it was decided that the development did not affect fish or fish habitat (*i.e.*, benthic invertebrates), then the proponent should be allowed to proceed to a minimal monitoring program. Monitoring of sublethal effluent toxicity or water or sediment quality could be used as a trigger to identify if risk had increased in the system and increased surveillance was required.

6 CONCLUSIONS, DATA GAPS AND RESEARCH NEEDS

6.1 Conclusions

The objective of this document was to propose a more holistic framework for assessing cumulative effects of existing and proposed project activities as required under the *Canadian Environmental Assessment Act*. Key framework components include:

- An effects-based assessment congruent with existing EEM program design to determine the existing accumulated environmental state prior to predicting the impacts of new development;
- A stressor-based assessment congruent with existing environmental assessment practices to predict potential impacts of new development relative to the existing environmental state;
- Incorporation of post-development or follow-up monitoring to assess the accuracy of impact predictions, study design, and to provide an avenue for adaptive management; and
- Incorporation of decision-making frameworks at each informational stage of the process to link scientific information to management decisions and action.

Advantages of the proposed CEA framework include:

- Contributes to building consistency in the CEA process;
- Provides scientifically-based methodological direction for CEA;
- Integrates regional assessment information into a project-specific environmental assessment;
- Links environmental assessment to other forms of practiced environmental management and planning (*i.e.*, EEM Programs for the pulp and paper and mining industries);
- Incorporates site-specificity;
- Analyzes the effects of existing development;
- Acknowledges that predictions of development impacts may not be accurate and provides an avenue for re-assessment and adaptive management through follow-up monitoring;
- Provides quantification of ecologically relevant thresholds for environmental stress;
- Complements existing stressor-based approaches to CEA currently practiced by project proponents under the *Canadian Environmental Assessment Act*;
- Fits within the context of existing legislation (*Canadian Environmental Assessment Act*) and is consistent with post-development legislative requirements for effects assessment (*i.e., Fisheries Act*);
- Provides DMFs for more consistent and directed information assessment at key CEA stages; and
- Provides a more holistic, systematic approach for incorporation of ecological information into a scientific and management framework.

The proposed CEA framework is founded upon good planning and information management. It is imperative that the focus for management decisions be established prior to conducting the performance assessment. For example, it is important to establish up front what will constitute

an ecologically relevant effect size, a significant effect, and what will be done if an effect is found.

6.2 Data Gaps and Research Needs

The expansion of methodologies for existing environmental assessments to address cumulative effects requires that a number of issues be carefully considered including:

- How can we determine what is sustainable?
- How do we define what will be considered an acceptable reference condition (background levels of performance)?
- What level of change is biologically significant (as opposed to statistically significant)?
- What process should be used for determining whether changes are acceptable?
- How do we attribute responsibility for existing changes within a system responding to multiple stressors?
- How do we predict the impacts of additional stressors when the existing performance is already adversely affected by pre-existing multiple stressors?

There is a need to establish consistent baseline data collection and analysis procedures for CEA so that regional databases can be built and accumulated with each additional environmental assessment. Cumulative effects assessment requires data collection, analysis and interpretation over regional scales. Regional databases for cumulative effects assessment are useful only if the data collected across the region is consistent. The necessity for consistent field collection protocols, data analysis, and quality assurance/quality control should not be underestimated. The Canadian EEM program for pulp and paper and mining industries is the basis of the effects-based approach and should serve as a model for baseline data collection and post-development monitoring. Under the current stressor-based CEA practice, collection of large volumes of regional information by a project proponent may not seem realistic. However, if project proponents collect this information using the same model and scientific process, then the information gathered may serve to build regional databases.

There is also a need to evaluate this proposed conceptual CEA framework in practice by integrating the effects-based approach with current stressor-based approaches in an environmental assessment trial. A gap exists between the effects-based research and EEM, and current environmental impact assessment practice. This gap needs to be recognized and the different approaches need to be integrated so the advantages and limitations of the integrated framework can be assessed.

7 REFERENCES

Barnthouse, L.W., G.W. Suter II and A.E. Rosen. 1989. Inferring population-level significance from individual-level effects: an extrapolation from fisheries science to ecotoxicology. pp. 289-300, In: (G.W. Suter II and M.A. Lewis, eds.) Aquatic toxicology and environmental fate: 11th volume, ASTM STP 1007. Amer. Soc. Test. Mat., Philadelphia, PA

CEAA (Canadian Environmental Assessment Agency). 1999. Review of Canadian environmental assessment act - A discussion paper for public consultation. Hull, Quebec, 68 pp.

CEAWG (Cumulative Effects Assessment Working Group). 1999. Cumulative effects assessment practitioner's guide. Hull, Quebec.

Colborn, T., D. Dumanoski and J.P. Myers. 1996. *Our Stolen Future: are we threatening our fertility, intelligence and survival? - A scientific detective story.* Penguin Books USA, New York. 306 p.

Courtenay, S.C., W.R. Parker and G.P. Rawn. 1998. Proceedings of a workshop to assess alternatives to the fish survey component of the environmental effects monitoring program for Canadian pulp and paper mills. Can. Tech. Rep. Fish. Aquat. Sci. 2233:viii + 108 p.

Culp, J.M., C.L. Podemski, K.J. Cash and R.B. Lowell. 2000. A research strategy for using stream microcosms in ecotoxicology: integrating single population and community experiments with field data. Journal of Aquatic Ecosystem Stress and Recovery. In press.

Dubé, M.G. 2000. Sources of Contaminants in the Bleached Kraft Pulping Process and Their Effect on the Mummichog (*Fundulus heteroclitus*). Ph.D. Thesis, University of New Brunswick, Fredericton, NB, Canada.

Environment Canada. 1995a. Further guidance for the invertebrate community survey for aquatic environmental effects monitoring related to Federal Fisheries Act Requirements. EEM 2, Ottawa, Canada

Environment Canada. 1995b. Further guidance for the adult fish survey for aquatic environmental effects monitoring related to Federal Fisheries Act Requirements. EEM 1, Ottawa, Canada

Environment Canada. 1997a. Fish Survey Expert Working Group: Recommendations from Cycle 1 review. EEM/1997/6. 262 p.

Environment Canada. 1997b. Fish Monitoring, Fish Survey Section 5.1 in Technical Guidance Document for Pulp and Paper Environmental Effects Monitoring. EEM/1997/7. 33 p.

Environment Canada. 1997c. Aquatic Environmental Effects Monitoring Requirements (revised EPS 1/RM/18). EEM/1997/1.

Environment Canada. 2000. Technical Guidance Documents for Metal Mining EEM Program. Environment Canada, Ottawa, ON.

Environmental Information Partnership (EIP). 1998. Cumulative effects assessment in the Moose Rive Basin - Background literature review. Prepared for the Environmental Information Partnership, South Porcupine, Ontario. Prepared by D.M. Abraham, ESSA Technologies Ltd., Richmond Hill, Ontario. 62 pp.

Gibbons, W.N. 1997. Suitability of small fish species for monitoring the effects of pulp mill effluent on fish populations. Ph.D. Thesis. University of Waterloo, Waterloo, ON, Canada

Gibbons, W.N. and K.R. Munkittrick. 1994. A sentinel monitoring framework for identifying fish population responses to industrial discharges. J. Aquatic Ecosystem Health 3: 227-237.

Greig, L.I., G.A. Duckworth, R. McCrea, and C. Daniel. 1998. Conceptual framework & considerations for cumulative effects assessment in the Moose River Basin: Workshop Report. Moose River Basin Environmental Partnership, Ontario Ministry of Natural Resources, South Porcupine, Ontario.

Hodson, P.V., M. McWhirther, K. Ralph, B. Gray, D. Thivierge, J. Carey, G. Van Der Kraak, D.M. Whittle, and M.C. Levesque. 1992. Effects of bleached kraft mill effluent on fish in the St. Maurice River, Quebec. Environ. Toxicol. Chem. 11: 1635-1651.

Hodson, P.V., K.R. Munkittrick, R. Stevens and A. Colodey. 1996. A tier-testing strategy for managing programs of environmental effects monitoring. Water Pollut. Res. J. Can. 31: 215-224.

Jobling, S., M. Nolan, C.R. Tyler, G. Brighty, and J.P. Sumpter. 1998. Widespread sexual disruption in wild fish. Environ. Sci. Technol. 32: 2498-2506.

Keough, M. J., and B. Mapstone. 1995. *Protocols for designing marine ecological monitoring programs associated with BEKM operations.* National Pulp Mills Research Program, Technical Report 11. CSIRO, Canberra, 177 pp. ISBN 0 643 05847 8

Keough, M. J., and B. D. Mapstone. 1997. Designing environmental monitoring for pulp mills in Australia. Water Science and Technology 35:397-404.

Kilgour, B.W., K.M. Somers and D.E. Matthews. 1998. Using the normal range as an ecological criterion for ecological significance in environmental monitoring and assessment. Ecoscience: In press.

Mapstone, B.D. 1995. Scalable decision rules for environmental impact studies: effect size, Type I, and Type II errors. Ecological Applications 4: 401-410.

Matthiessen, P. 1998. Effects on fish of estrogenic substances in English rivers. p. 239-247, In: *Principles and Processes for Evaluating Endocrine Disruption in Wildlife* (R.J. Kendall, R.L. Dickerson, W.A. Suk and J.P. Giesy, Eds.). SETAC Press, Pensacola, FL.

Matthiessen, P., Y.T. Allen, C.R. Allchin, S.W. Feist, M.F. Kirby, R.J. Law, A.P. Scott, J.E. Thain and K.V. Thomas. 1998. Oestrogenic endocrine disruption in flounder (*Platichthys flesus* L.) from United Kingdom estuarine and marine waters. Science Series Technical Report 107, Centre for Environment, Fisheries and Aquaculture Science, Lowestoft

Munkittrick, K.R. 1992. A review and evaluation of study design considerations for site-specifically assessing the health of fish populations. Journal of Aquatic Ecosystem Health 1: 283-293.

Munkittrick, K.R. and D.G. Dixon. 1989a. An holistic approach to ecosystem health assessment using fish population characteristics. Hydrobiologia 188/189: 122-135.

Munkittrick, K.R. and D.G. Dixon. 1989b. Use of white sucker (*Catostomus commersoni*) populations to assess the health of aquatic ecosystems exposed to low-level contaminant stress. Can. J. Fish. Aquat. Sci. 46: 1455-1462.

Munkittrick, K.R. and L.S. McCarty. 1995. An integrated approach to ecosystem health management: top-down, bottom-up or middle-out? J. Aquatic Ecosystem Health. 4:77-90.

Munkittrick, K.R., C.B. Portt, G.J. Van Der Kraak, I.R. Smith and D.A. Rokosh. 1991. Impact of bleached kraft mill effluent on population characteristics, liver MFO activity and serum steroid levels of a Lake Superior white sucker (*Catostomus commersoni*) population. Can. J. Fish. Aquat. Sci. 48: 1371-1380.

Munkittrick, K.R., M.E. McMaster, L.H. McCarthy, M.R. Servos and G.J. Van Der Kraak. 1998. An overview of recent studies on the potential of pulp mill effluents to impact reproductive function in fish. J. Toxicol. Environ. Health, Part B 1: 101-125.

Munkittrick, K.R., M.E. McMaster, C. Portt, W.N. Gibbons, A. Farwell, L. Ruemper, M.R. Servos, J. Nickle and G.J. Van Der Kraak. 1999a. The development of cumulative effects assessment tools using fish populations. In: Integrated Assessment of Ecosystem Health, K. Scow et al. (Eds), Ann Arbor Press, May, 1999 Publication

Munkittrick, K.R., O. Sandström, Å. Larsson, G.J. Van Der Kraak, L. Förlin, E. Lindesjöö, M.E. McMaster and M.R. Servos. 1999b. A reassessment of the original reviews of Norrsundet and Jackfish Bay field studies. 3rd Internat. Conf. Environmental Fate and Effects of Pulp and Paper Mill Effluents, Rotorua, NZ, November 9-13, 1997.

Munkittrick, K.R., M.E. McMaster, G.J. Van Der Kraak, C. B. Portt, W.N. Gibbons, A. Farwell, and M. Gray. 2000. Development of methods for effects-based cumulative effects assessment using fish populations: Moose River project. SETAC Press, in press.

Servos M.R. et al. 1998a. Impacts of alkylphenols, natural and synthetic estrogens in municipal effluents in Canada. Abstract PWA205, 19th Annual Meeting of the Society of Environmental Toxicology and Chemistry, Charlotte, NC

Servos, M.R. *et al.*, 1998b. Runoff of estrogens into small streams after the application of hog manure to agricultural fields in Southern Ontario. Abstract PWA206, 19th Annual Meeting of the Society of Environmental Toxicology and Chemistry, Charlotte, NC.

Swedish EPA (Environmental Protection Agency). 1997. Environmental impacts of pulp and paper mill effluents: a strategy for future environmental risk assessments. Report 4785. ISBN 91-620-4785-X.

Tattersfield, L., P. Matthiessen, P. Campbell, N. Grandy and R. Lange (Eds.) 1998. *SETAC-Europe/OECD/EC Expert Workshop on Endocrine Modulators and Wildlife: Assessment and Testing.* Veldhoven, The Netherlands, 10-13 April, 1997. SETAC-Europe Press, Brussels.

Taylor and Bailey, 1997. Technical evaluation on methods for benthic invertebrate data analysis and interpretation. AETE Report #2.1.3 CANMET (Natural Resources Canada)

Terrens, G. W., D. Gwyther, and M. J. Keough. 1998. Environmental assessment of synthetic-based drilling mud discharges to Bass Strait. APPEA Journal 1998:610-625.

Thoresson, G. 1993. Guidelines for coastal monitoring: Fishery Biology. Fiskeriverket Kustlaboratoriet, Kustrapport 1993:1, National Board of Fisheries, Öregrund, Sweden. (ISSN 1102-5670).

US EPA 1992. Framework for ecological risk assessment. EPA/630/R-92/001, Washington, DC

US EPA. 1996. Proposed guidelines for ecological risk assessment; notice. Federal Register 61 (175): 47552-47631.

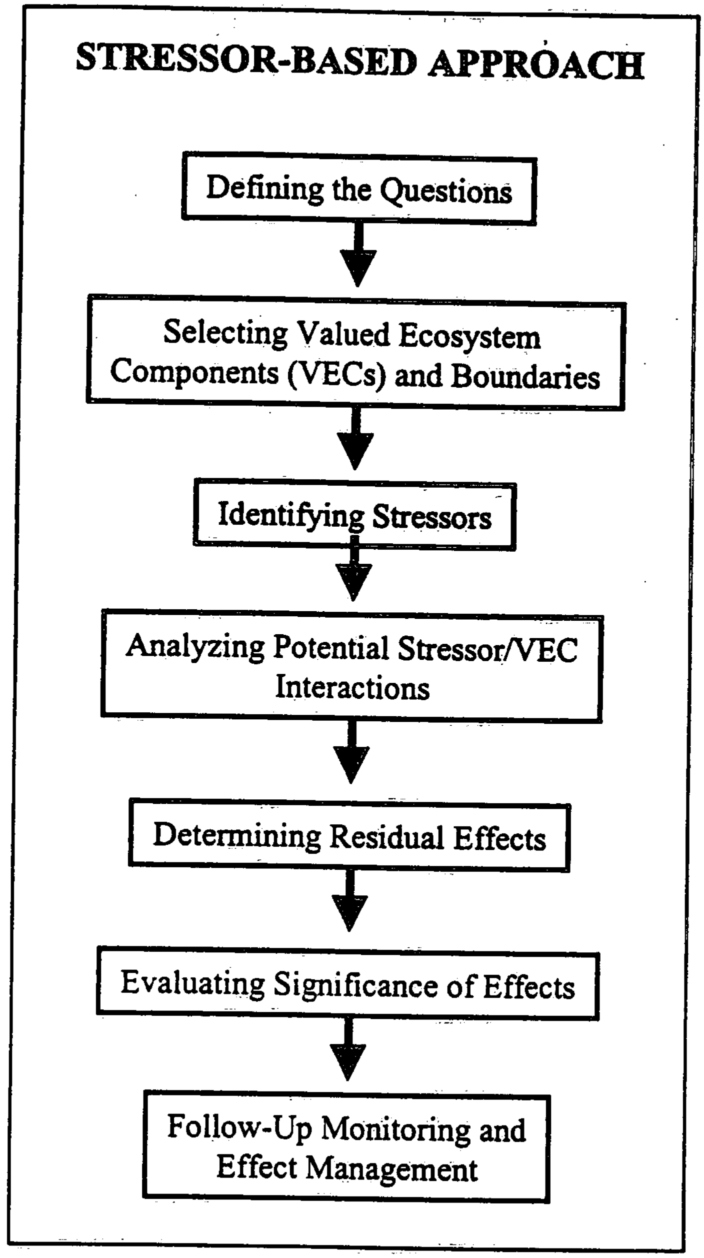


Figure 1. Components of a stressor-based approach to CEA (adapted from Munkittrick *et al.*, 2000).

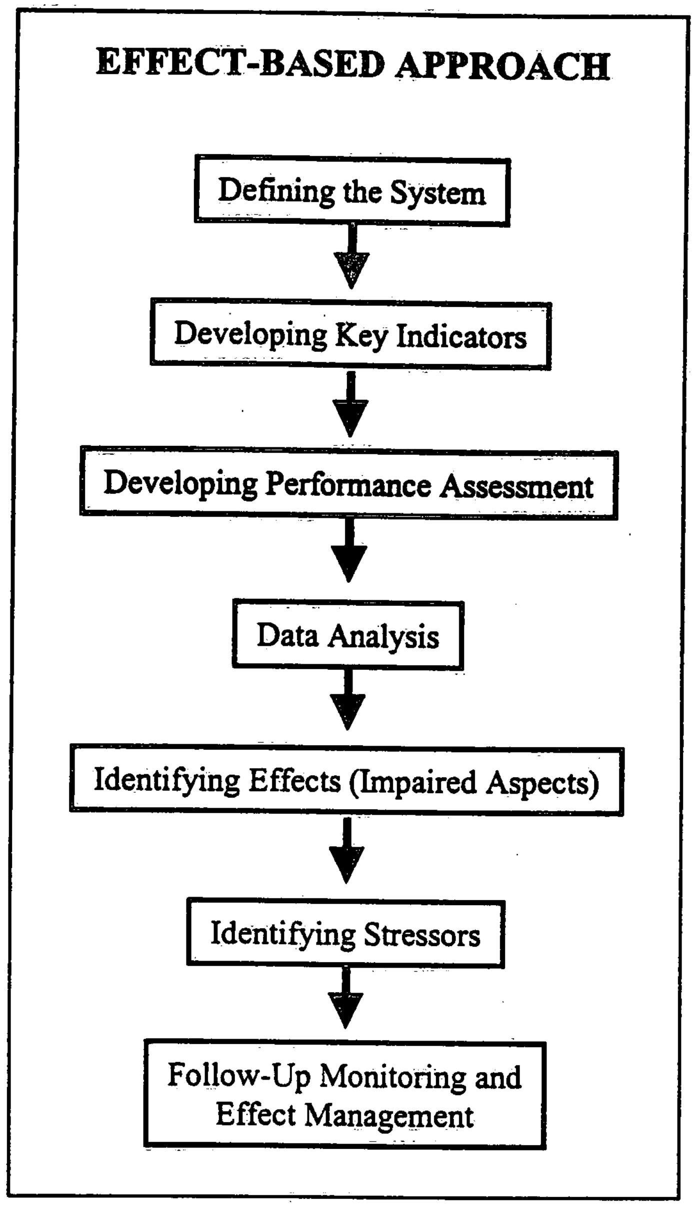


Figure 2. Components of an effects-based approach to CEA (adapted from Munkittrick *et al.*, 2000).

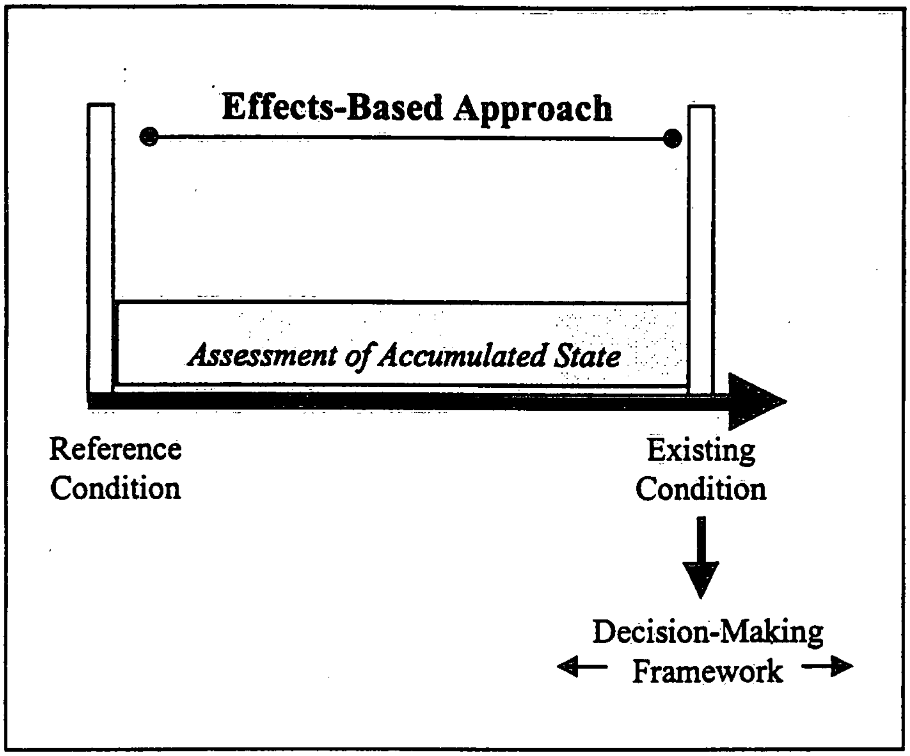


Figure 3. Basis of comparison for an effects-based CEA. Development within a system results in a change or progression from reference (undeveloped) conditions to existing conditions. Comparing performance indicators between developed and undeveloped sites provides an assessment of change or the accumulated environmental state. Once the comparisons are completed, this information feeds into a decision-making framework. If the changes are unacceptable the CEA does not proceed to predict the impacts of proposed development until the cause of the existing effects have been identified. If changes do not occur, or the changes are acceptable, then the CEA proceeds to the stressor-based predictive assessment.

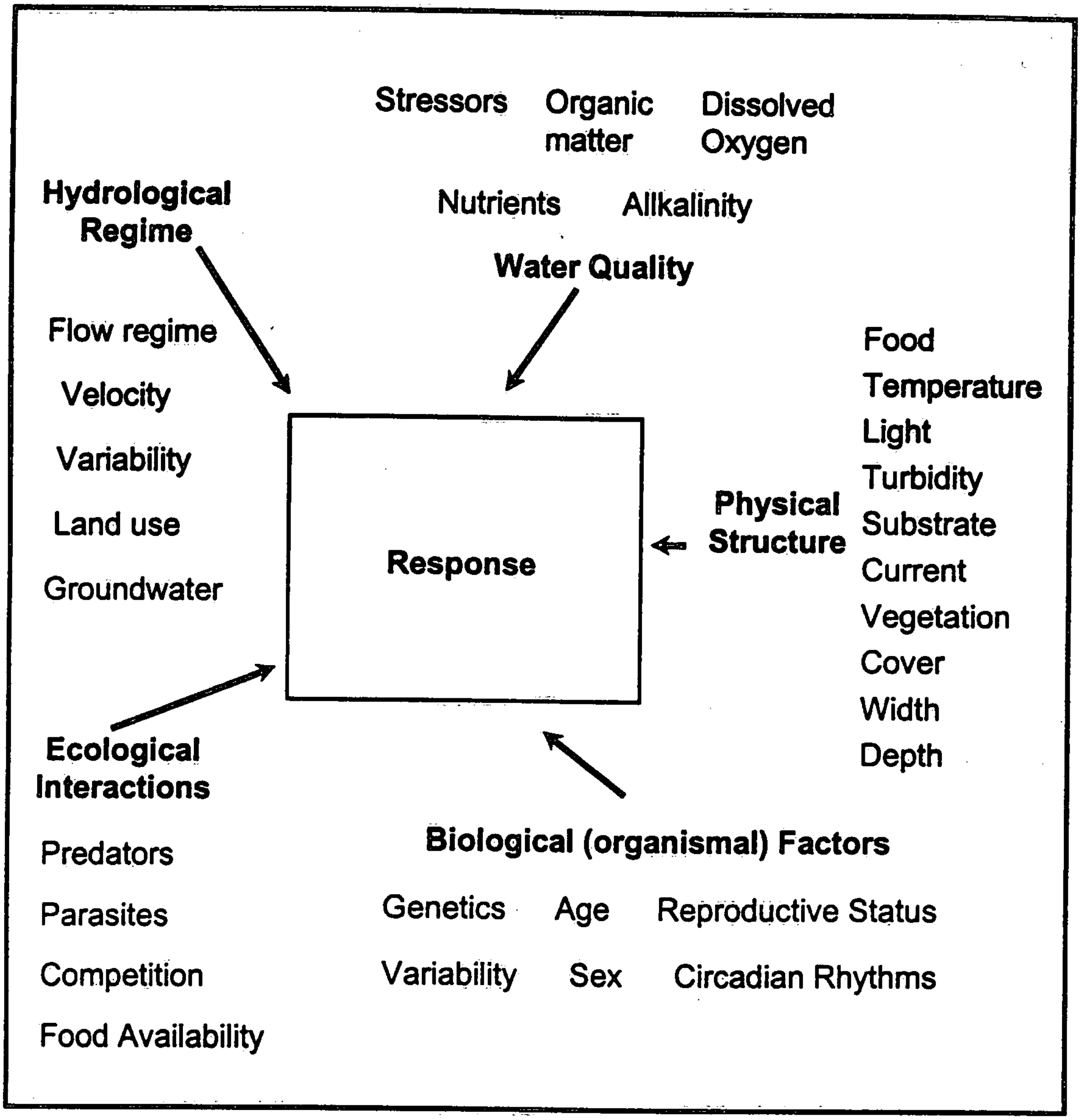


Figure 4. Factors affecting fish performance (adapted from Munkittrick *et al.*, 2000).

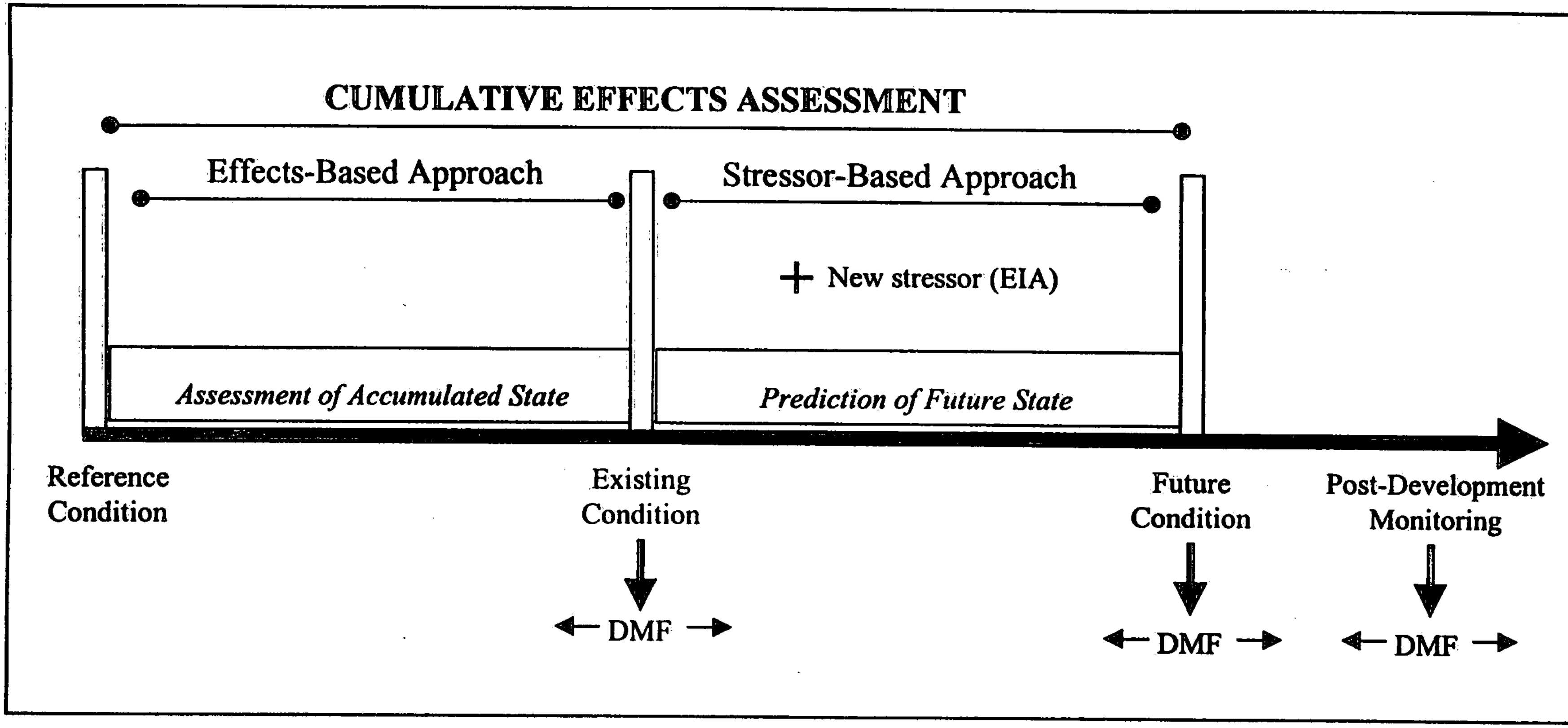


Figure 5. A proposed CEA incorporating effects-based and stressor-based assessments, decision-making frameworks (DMF), and post-development monitoring. The effects-based component of CEA evaluates the progression from reference (undeveloped) conditions to existing, developed conditions. If there are no changes or the changes are acceptable, the decision-making framework (DMF) guides the proponent to conduct an environmental assessment to predict the impacts of proposed project activities relative to the accumulated environmental state. A DMF at the completion of the stressor-based CEA determines if the predicted impacts are acceptable or not. If acceptable, development proceeds with post-development monitoring. If unacceptable, development does not proceed under the current project description.

COMPONENTS OF AN EFFECTS-BASED APPROACH

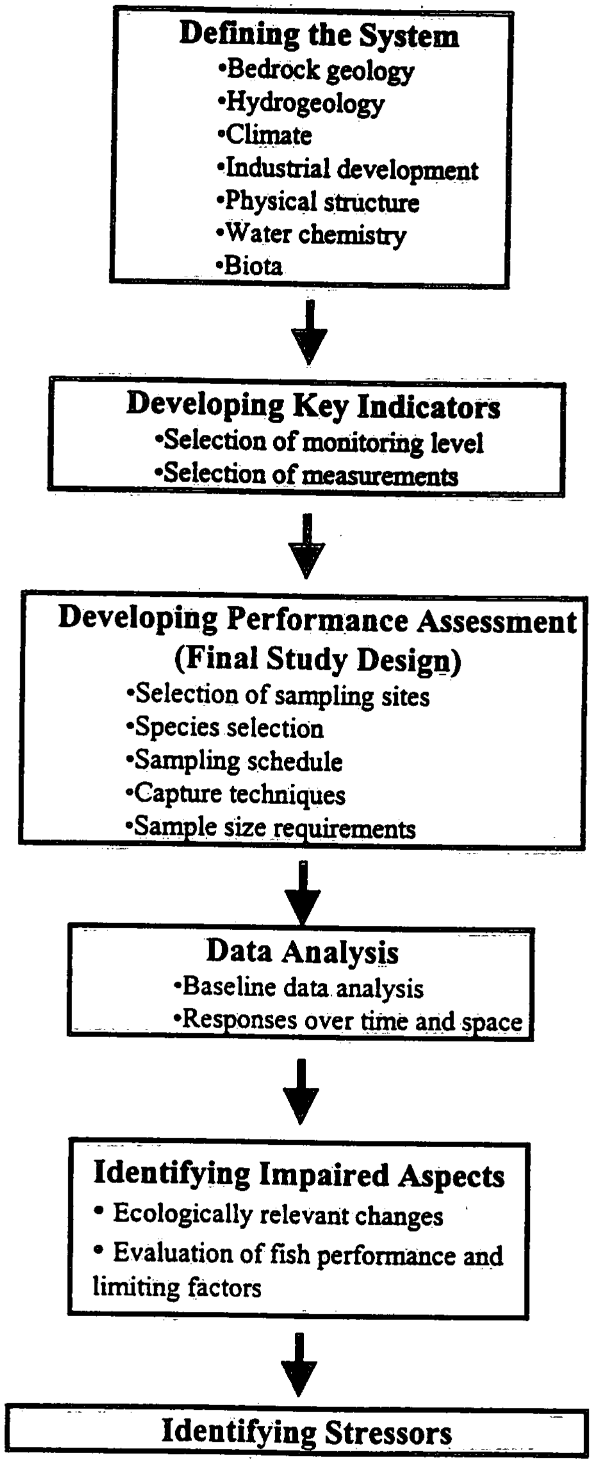


Figure 6. Key stages and associated components of an effects-based approach to CEA (adapted from Munkittrick *et al.*, 2000).

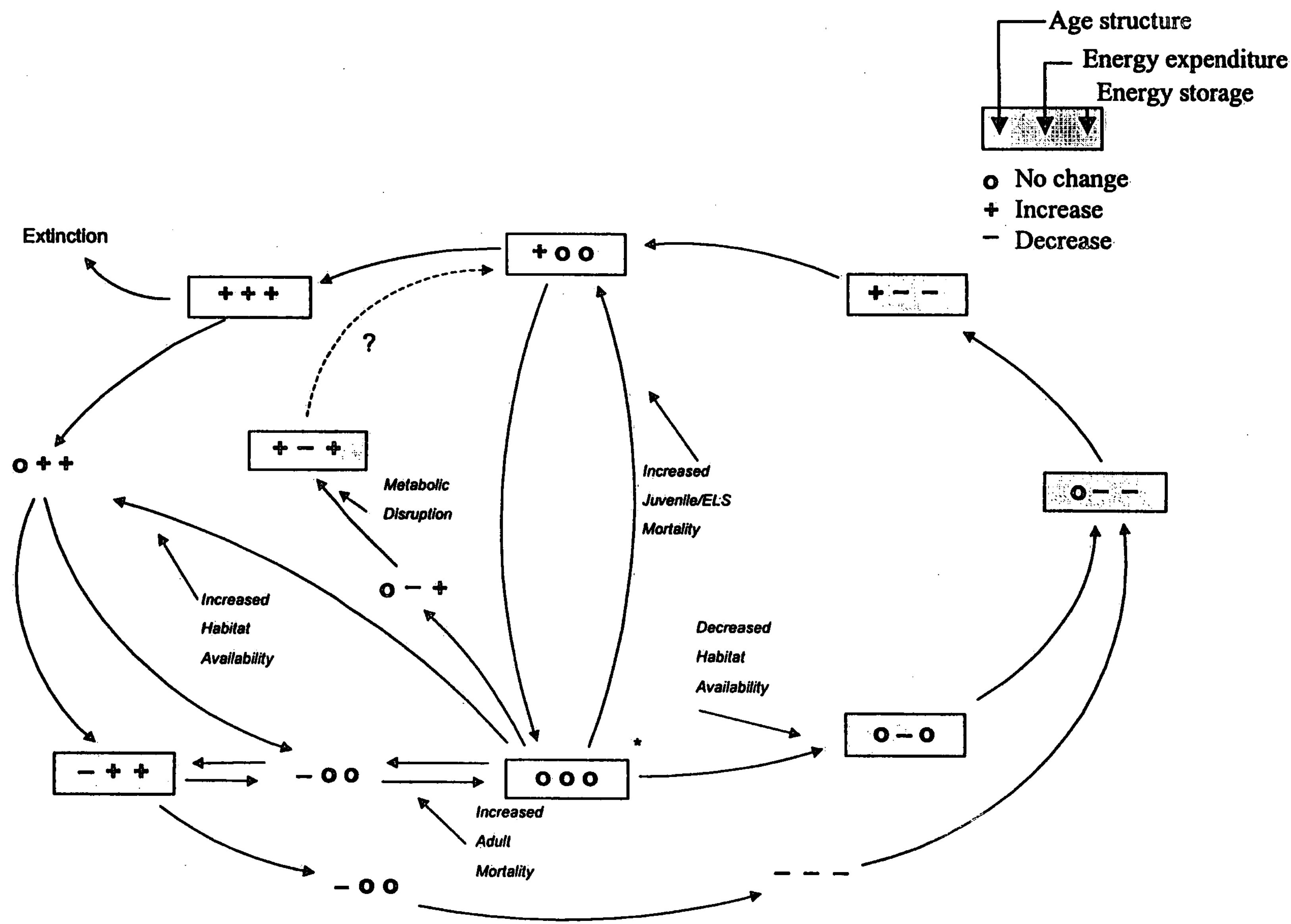


Figure 7. Effects-based model for fish performance illustrated response pathways and limiting factors (adapted from Munkittrick *et al.*, 2000).

EFFECTS-BASED DECISION-MAKING FRAMEWORK

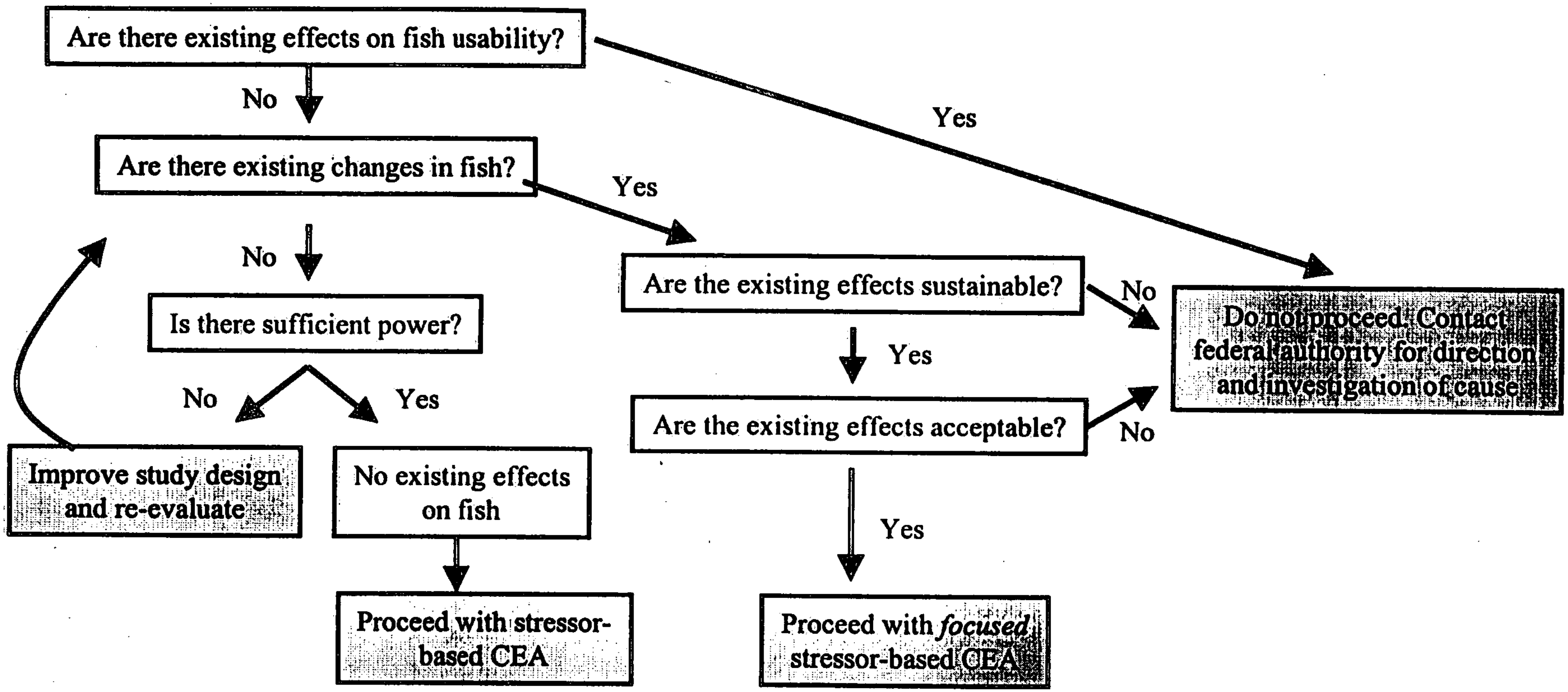


Figure 8. An effect-based decision-making framework for CEA

STRESSOR-BASED DECISION-MAKING FRAMEWORK

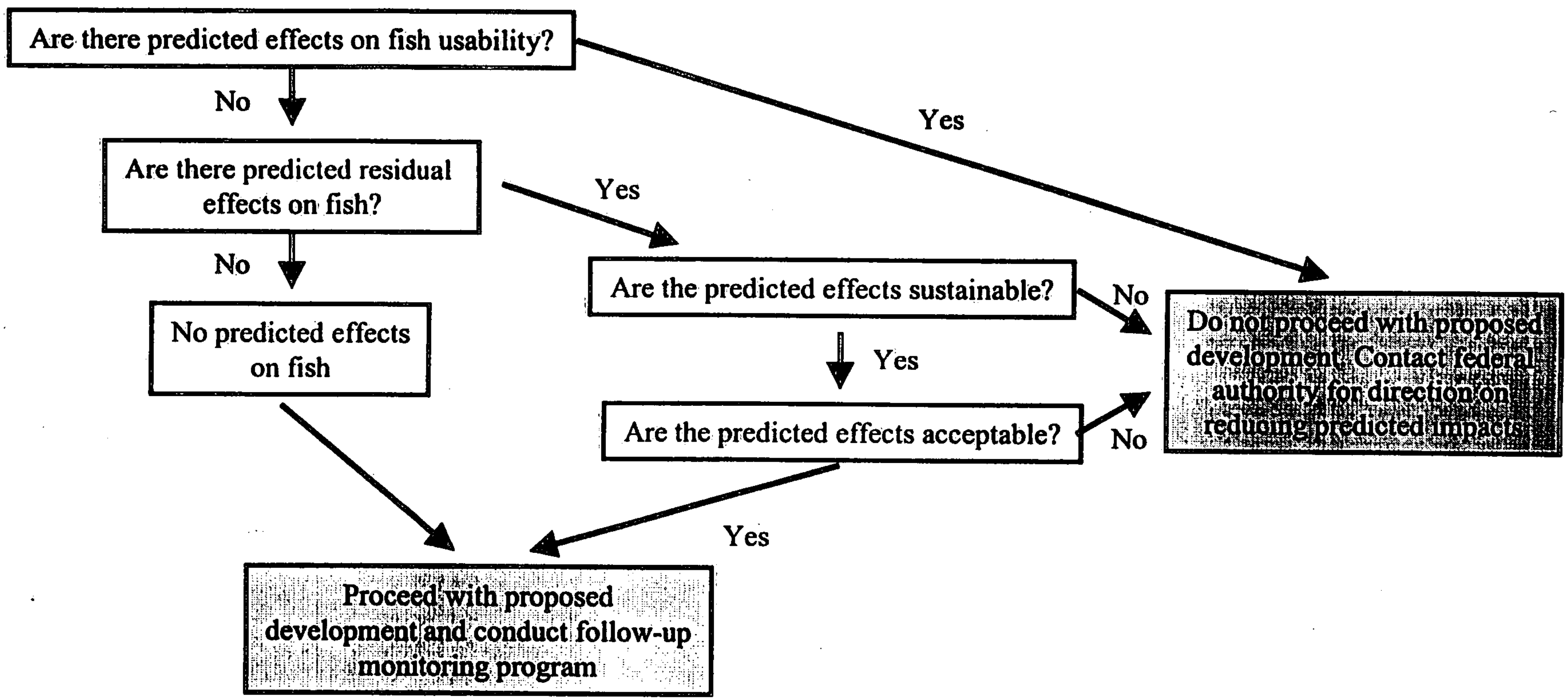


Figure 9. A stressor-based decision-making framework for CEA

FOLLOW-UP MONITORING DECISION-MAKING FRAMEWORK

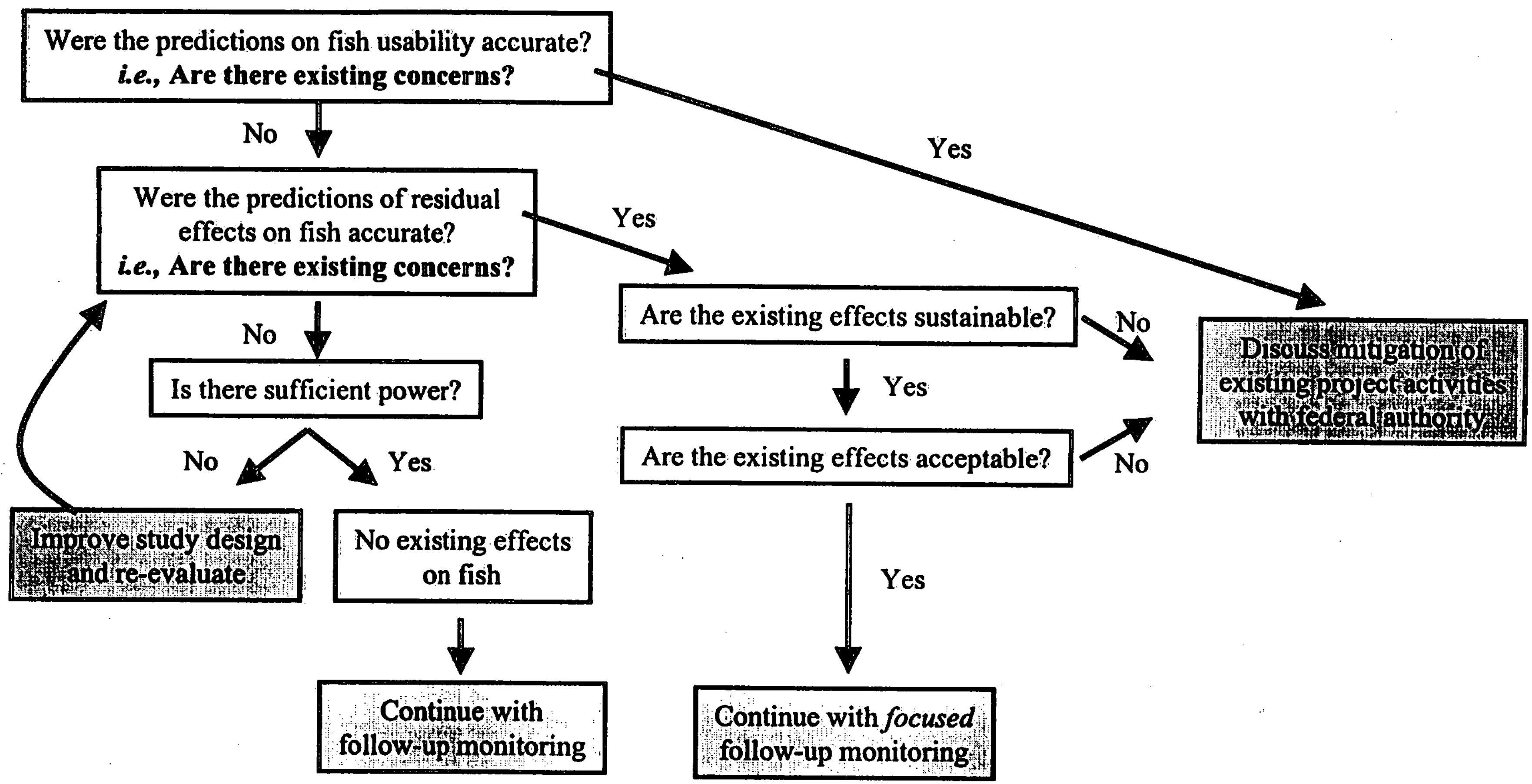


Figure 10. A post-development monitoring decision-making framework for CEA

EXPANDED CEA DECISION-MAKING FRAMEWORK

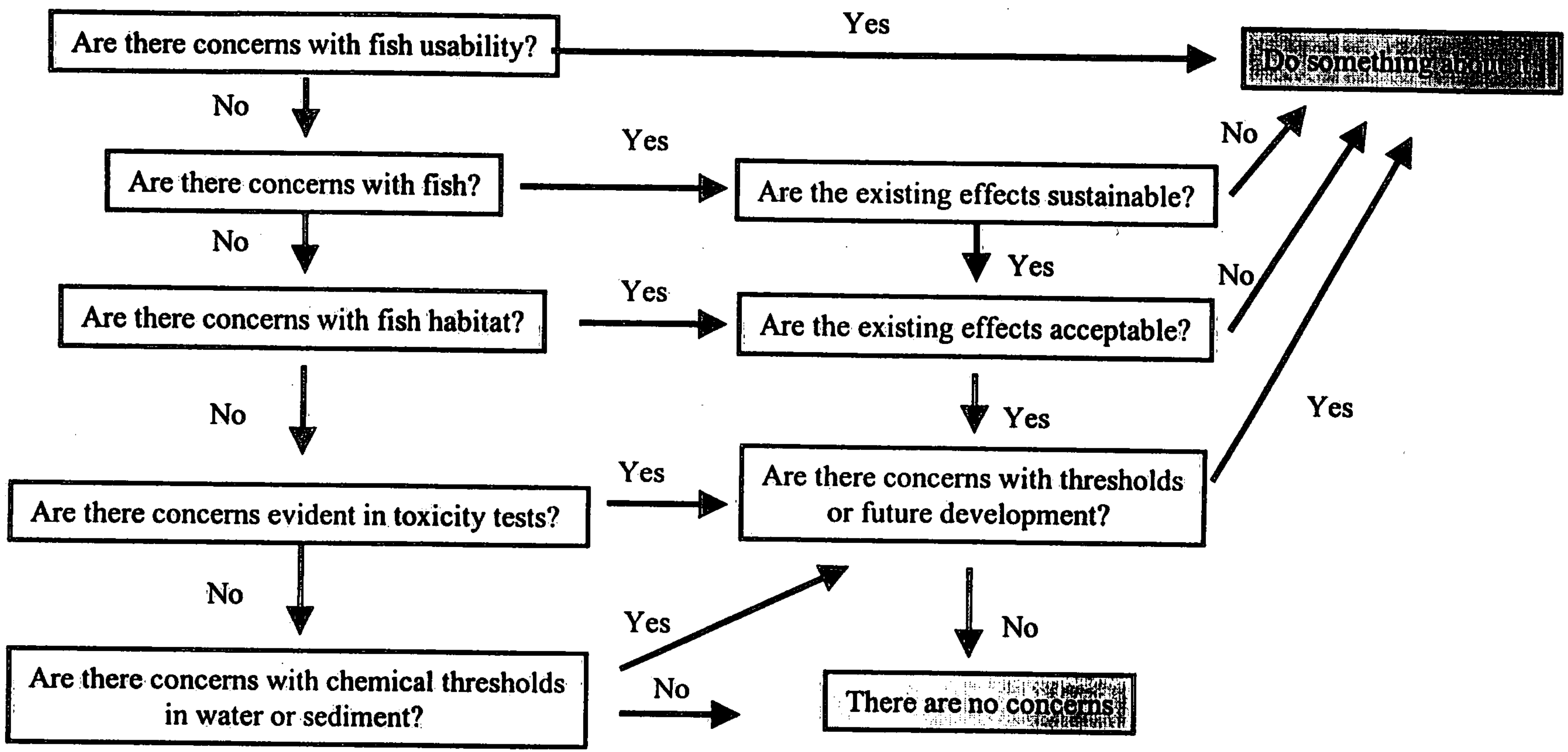


Figure 11. An expanded CEA decision-making framework

PRINTED IN CANADA ON RECYCLED PAPER
IMPRIMÉ AU CANADA SUR DU PAPIER RECYCLÉ

National Water Research Institute
Environment Canada
Canada Centre for Inland Waters
P.O. Box 5050
867 Lakeshore Road
Burlington, Ontario
L7R 4A6 Canada

National Hydrology Research Centre
11 Innovation Boulevard
Saskatoon, Saskatchewan
S7N 3H5 Canada

NATIONAL WATER RESEARCH INSTITUTE
INSTITUT NATIONAL DE RECHERCHE SUR LES EAUX

Institut national de recherche sur les eaux
Environnement Canada
Centre canadien des eaux intérieures
Case postale 5050
867, chemin Lakeshore
Burlington, Ontario
L7R 4A6 Canada

Centre national de recherche en hydrologie
11, boul. Innovation
Saskatoon, Saskatchewan
S7N 3H5 Canada

Environment Canada Environnement Canada

Canada