NUCLEAR GENERATING STATIONS: BIOPHYSICAL ENVIRONMENTAL EFFECTS, MONITORING, SCOPING & DESIGN

D. A. Wismer

NWESD - Environment
Ontario Hydro

CONCEPTION DE PROGRAMMES DE SURVEILLANCE ENVIRONNEMENTALE D'EFFETS BIOPHYSIQUES POUR LES CENTRALES NUCLÉAIRES

RÉSUMÉ

Lors d'études d'impact écologique de facteurs conventionnels (non radiologiques), il n'est pas toujours possible d'obtenir, par surveillance de routine sur le terrain, des résultats, avec indicateurs de tendances, qui puissent être défendus avec assurance sur la place publique. Un programme bien conçu de surveillance d'effets environnementaux (SEE) doit inclure une stratégie statistique, à la base de toute recherche. Il doit, pour être efficace, à un coût raisonnable, tenir compte de la difficulté de mesurer des effets prenant place dans des systèmes naturels très variables, que les facteurs de stress soient radiologiques ou non. Une étude d'impacts conventionnels (non radiologiques) a l'avantage de pouvoir déceler de gros changements physiques qui mènent à une réaction biologique. Malgré cet avantage, il est encore très difficile de voir un effet. La difficulté sera d'autant plus grande lorsqu'il s'agira de déceler, à partir de données d'émission et de doses estimées, un effet radiologique qui ne peut être que minime.

Cet exposé identifie sept éléments clés qui doivent faire partie de la conception et de la définition du champ de tout programme de SSE, si l'on veut avoir une probabilité raisonnable (80%) de déceler un impact : le design statistique de relevés; les stations témoins; les composantes à préserver dans l'écosystème; les hypothèses d'effets; définition du champ d'activité; les modèles quantitatifs; et une base de données informatisée. Des exemples de ces facteurs de design, pour des programmes de surveillance environnementale de facteurs non radiologiques, sont tirés des 25 ans d'expérience de ces programmes pour les cinq centrales nucléaire d'Ontario Hydro sur les Grands Lacs.

ABSTRACT

Routine field surveillance monitoring for trend detection has proven inadequate for defensible results in conventional (non-radiological) ecological impact assessment studies. Sound environmental effects monitoring (EEM) design must include a statistical research-based strategy to cope cost-effectively with the difficulty of impact detection in highly variable natural systems regardless of the type of stressor (radiological or non-radiological). In conventional effects studies (non-radiological), we had the advantage of large physical changes to trigger biological responses, and it was still difficult. Detecting what must be a small radioecological effect, based upon emissions data and estimated doses, will be much more difficult. This paper identifies seven key factors that must be included in any EEM scoping and design to have a reasonable (80%) chance of detecting an impact: statistical survey design, field controls, valued ecosystem components, effects hypotheses, scoping workshops, quantitative models and a computer database. Practical applications of these EEM design factors are illustrated from 25 years of learning from experience with non-radiological monitoring at Ontario Hydro's five nuclear generating stations located on the Great Lakes.

1.0 INTRODUCTION

This paper describes the concept and application of environmental effects monitoring as it has evolved over 25 years of study of ecological impacts primarily at Ontario Hydro's five nuclear generat ing stations located on the Great Lakes. The value to you will be the focus on key factors that can "make or break" any environmental effects monitoring program, regardless of the type of effect in question — conventional or radionuclide. The focus of our effects monitoring was on thermal and habitat changes. We had the impact detection "advantage" of large cooling water system interventions like a huge hot water flow into the lake or intake mortalities of tonnes of fish. It was still difficult to detect ecological change. Detecting what must be small radioecological effects, based upon the small magnitude of the physical intervention from emissions data and estimated doses, will be much more difficult. Attention to these ecological impact design aspects will be even more important in future radioecological monitoring than it was in the past for non-radiological effects.

Environmental effects monitoring (EEM) is becoming more common as either a provincial or federal regulatory requirement with each passing year (see section 2.1). Most recently, both Environment Canada and the Atomic Energy Control Board have publicly stated that an assessment is underway (Environment Canada 1995) for radiological effects on non-human species from nuclear generating stations and the future will involve EEM (Maloney 1996). The requirement is also accompanied by increasing expectations for technical quality (see section 3.0). Experience has shown that EEM is expensive and unless it is well-designed, it typically delivers inconclusive findings on impact. Inconclusive findings themselves can be costly. The regulatory agencies can exercise the U.N. Rio Summit "precautionary principle" to require compensation or mitigation in the absence of conclusive evidence on impact (Peterman and M'Gonigle 1992; Keating 1993).

What does environmental effects monitoring cost? Our Great Lakes environmental effects monitoring, across a range of bio-physical parameters, have typically cost us 0.5M$/y per generating station per year for 10 years of field sampling, followed by about 0.3M$/y for 3 years of reporting. This was expensive compliance, especially when the studies could not provide conclusive evidence on the magnitude of localized station impacts (Ontario Hydro 1992a, 1992b). More focused effects monitoring on a single biological indicator, bottom-living aquatic invertebrates (Sheehan 1995) cost 50k$/y for four years at Lambton TGS on the St. Clair River.

2.0 ENVIRONMENTAL EFFECTS MONITORING

2.1 Why Undertake Environmental Effects Monitoring (EEM)?

Federal and provincial regulatory agencies now require EEM in follow-up to environmental assess ments (EAs) and in permits for industrial wastewater direct discharges. It is also required by the federal liquid effluent regulations for metals mining and pulp & paper industrial sectors (Environment Canada 1992). Federal and provin cial laws require effects monitoring for new projects or modifi cations adjacent to a wetland (CCG 1993; MNR 1992).

Sound environmental management also requires EEM to understand the ecological effects of our activities as a basis for rational and environmentally defensible decision-making. A complete environmental management system needs to take into account the ecological effects on the receiving environment of the facility. This is the ultimate performance effectiveness test of environmental protection systems.

2.2 What is Environmental Effects Monitoring?

We monitored to detect (and quantify) *changes* in the *bio-physical* natural environment due to station construction and operations. Our monitoring programs would have been broader in scope if the purpose have been to verify the socio-economic predictions of the submitted environmental proposals for the developments (Ontario Hydro 1975). The projects were EA-exempt since they pre-dated the provincial EA Act of 1976 and were not appropriate to the federal EA process existing at the time. The *bio-physical* environment was specified by the regulatory permitting basis for our programs. The field survey programs were two-pronged and simultaneous, one to measure physical changes due to cooling water intake and discharge, and the other to measure the biological responses. The first effects studies in the 1970's measured *change* as a trend through time in the mean abundance of a particular aquatic species population (eg. bass) or a biological community of populations (eg. bottom-living invertebrates).

Our five generating stations were situated at three Great Lakes sites, one on Lake Huron and two on Lake Ontario. Bruce A and B shared a single site located about half way up the eastern shore of Lake Huron. Pickering (A and B) was situated on the north shore of Lake Ontario 30 km east of Toronto and Darlington is another 35 km west of Pickering. The effects monitoring programs first started in 1970 at Pickering A and are now ongoing only at Darlington (Table 1). The three Great Lakes impact study sites all shared a common problem for ecological impact assessment — a constantly shifting baseline. This was due partly to the shoreline locations which fronted a huge expanse of open water and were exposed to wind-driven storms. The effects of wind on the lake forced natural variability into the distribution and abundance of nearshore zone biota in response to high amplitude changes in water temperatures and lake currents. Also, the prime monitoring target, the fish community, was going through major changes in relative species composition and abundance, every 5-10 years, due to background interventions of invading species (sea lamprey, alewife, zebra mussels, spiny water flea) and dramatic increases in predators (salmonid stocking). These factors combined to create a very "noisy" background environment. This noise often masked the relatively weak "signal" created by local station impacts.

Table 1. Schedule of Nuclear Generating Station Operations and Effects Monitoring (EEM)

ACTIVITY	STATION NAME, CAPACITY AND COOLING WATER FLOW				
	BRUCE A 3076 MW 178 m^3/sec	BRUCE B 3440 MW 198 m^3/sec	PICKERING A 2060 MW 132 m^3/sec	PICKERING B 2064 MW 138 m^3/sec	DARLINGTON 3524 MW 150 m^3/sec
Beginning of Construction	1969	1976	1964	1974	1977
Units In-Service	1977-79	1984-87	1971-73	1983-86	1990-93
EEM	1973-81	1979-89	1970-79	1979-88	1984-96
Hypothesis Scoping	None	1986	None	1985	1984, 1990

3.0 KEY MONITORING PROGRAM DESIGN FACTORS

Seven key monitoring program design factors were selected from past experience and judgement on future regulatory requirements. These are listed by subsection: 3.1 effects hypotheses, 3.2 scoping workshops, 3.3 valued ecosystem components, 3.4 statistical trend detection, 3.5 field survey controls, 3.6 quantitative models, and 3.7 computer databases. A final subsection 3.8 comments on the state of the applied science.

3.1 Effects Hypotheses

Monitoring depends upon both preoperational baseline studies to set the temporal control (null hypothesis of no impact environment) and on impact predictions to set the specific alternative hypotheses of what changes should be able to be detected (Fairweather 1993). Predictions are necessary as the basis for design. Sample size calculations depend on magnitude of predicted effect as much as they depend upon the variability of the population parameter. It is now a general expectation that there should be site-specific hypotheses and underlying conceptual cause-effect models for any ecological effects assessment (Waters and Erman 1990; Environment Canada 1990).

For our 5 nuclear stations only the newer "B" stations and Darlington benefitted from scientific hypotheses to drive the programs, and only Darlington had that right from the start in 1984 (Table 1). Most of the issues were about fishes, thermal and physical habitat effects as well as intake fish loss. Radionuclides were included but it was solely human pathway based upon the existing compliance monitoring. The exception was Bruce B where there was a non-human pathway hypothesis, but the regulatory workshop recommendation in 1986 was for literature review on suitable monitoring assessment endpoints then partnering with other nuclear agencies to develop practical measurement endpoints. Since that time, the recommended literature reviews have largely been done by other international agencies (IAEA 1992; UNSCEAR 1996). The partnering has just begun, 10 years later, with this symposium.

An hypothesis of effect is an explicit statement of a set of cause-effect relationships whereby one or more project action is hypothesized to change the status of a valued ecosystem component or VEC (ESSA 1986). Station actions (grey boxes) are differentiated from background (stippled boxes) natural and non-station human influences, habitat and biological responses (basic boxes) combining to influence the VEC (bottom box) (Figure 1). A predicted decrease in local forage fish populations is shown in the example. Each prediction outlines cause-effect linkages of station actions and other natural or human disturbances culminating in an impact on a valued ecosystem component. We had from 11 to 20 of these predictions for each station depending upon the local issues (Table 2).

The new federal guidelines require more detail than represented in our example (Environment Canada 1992). They state that predictions of effects on a VEC should actually be field-testable hypotheses including: type and magnitude; spatial and temporal extent (including multiple stations combined effects). Other key aspects to ensure a useful and cost-effective monitoring program based upon Environment Canada (1990) and supported by our direct experience are: probability of occurrence; potential ecological and social value; level of (scientific) uncertainty; cost-effectiveness "reasonableness" of sampling; final end-use of data collected.

Figure 1. Effects Hypothesis Causal Linkage Diagram from Bruce B Environmental Effects Scoping Workshop, 1986

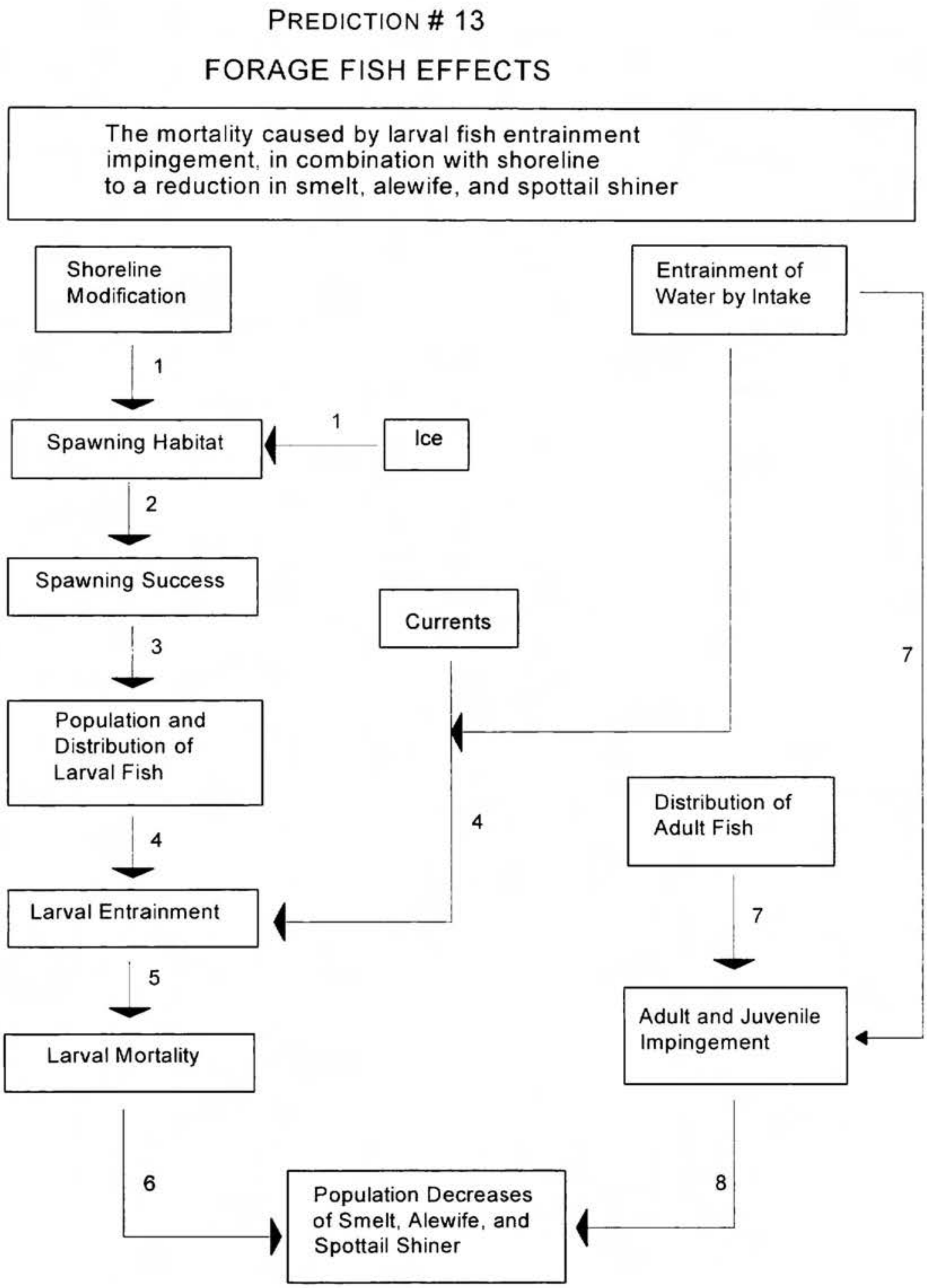


Table 2. Frequency Distribution of Number of Effects Hypotheses by Type

EFFECT	PICKERING	BRUCE B	DARLINGTON
Water Quality	1	2	1
Erosion	2		
Fishes	11	8	4
Gulls	1	1	1
Waterfowl	1	2	1
Rooted Algae	1		
Plankton	1		1
Benthic Invertebrates	1		1
Vegetation		2	
Deer		1	1
Radionuclides	1	2	1
TOTALS	**20**	**18**	**11**

3.2 Scoping Workshops

We started to use stakeholder workshops in 1984 to define the effects hypotheses and cause-effect linkages to scope out the studies (Table 1). The key impact issues were summarized at workshops held for each generating station in a series of hypotheses of effects specific to each site. These included bio-physical effects on aquatic, terrestrial and atmospheric components of the local ecosystem in a regional context. The rationale for initiating these scoping workshops was technical and budgetary. The technical reason was that the key survey design questions were judgemental and inappropriate for decision-making solely by our own scientists. For example, who decides what VECs? Who decides what size and type of change is acceptable? The answers to these questions are critical in determining the number of samples and programs costs (section 3.4). Cost-effectiveness was improved by dropping the programs that had little chance of yielding useful impact results (algae, larval fish and plankton tows) or were not of interest to stakeholders (benthic organisms) and focusing on magnitudes of known or most probable effects (intake fish entrainment and thermal discharge effects on spawning and fishing mortality).

The original workshop conclusions on potential key impacts and cause-effect linkages usually changed with time as new EEM data and regulatory agency staff came along. We coped with this problem by having annual review meetings where results were presented, original hypotheses were reviewed for continued validity or revision, inferences and opinions exchanged and the conceptual model and EEM program adjusted.

3.3 Valued Ecosystem Components

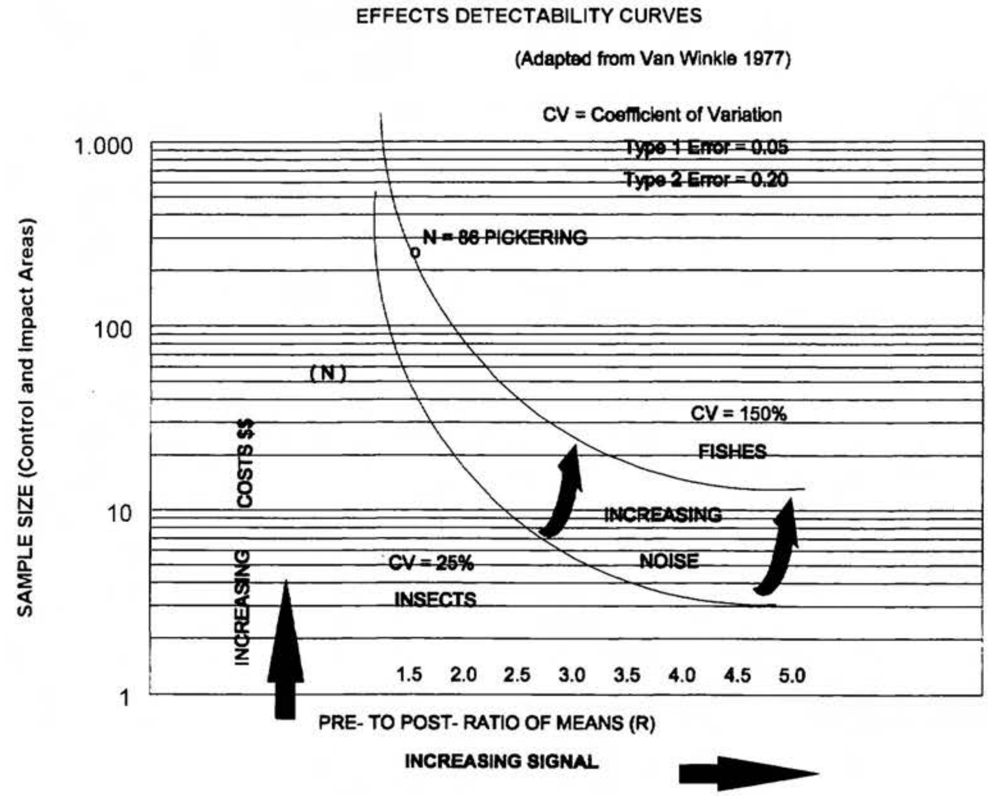
The choice of biological impact indicators is recognized by both regulators and academics as crucial to the success of effects monitoring (Environment Canada 1992; Cairns and McCormick 1992). These are termed valued ecosystem components (VEC) (Environment Canada 1990; ESSA 1984). Some biological indicators are typically more variable than others and therefore less sensitive for impact detection (Figure 2). For example, the coefficients of variation of fish in our studies were larger (98-174%) than values reported elsewhere for alternative indicators such as shellfish (30-50%) and bottom living insects (20-78%) (Eberhardt 1978). The wrong choices can make the monitoring program inconclusive, expensive, and even ecologically damaging. Choices include what type of organism (microbe, plankton, algae, aquatic plant, invertebrate, bird, fish, amphibian) and life stage as well as what level of biological organization (tissue, organ, individual, species population, community, ecosystem) (Kelly and Harwell 1988; Environment Canada 1992) (Figure 3). The choice of biological response indicator should be the result of scoring based upon published optimization criteria (Environment Canada 1992; Cairns and McCormick 1992). A selection of the most important eight criteria are listed in Table 3.

Once you have made those choices based on the earlier criteria then you need to decide what to test for and measure. Examples are the bullets in Figure 3. Radionuclides indicators would most likely be at sub-organism level of biomarkers for any VEC. As as you move up the hierarchy you trade off increased biological relevance and decreased extrapolating error against a weaker linkage of cause-effect to a specific toxic agent (radionuclides, organics etc) and decreased detectability due to more natural variability. For example, a sub-organism level radionuclide effect biomarker would be easier to detect and assign to a specific cause but less ecologically relevant than a population-level indicator. Conversely a population-level indicator is quite relevant but difficult to detect (takes decades) and combines responses to stresses.

Table 3. Ecological Indicator Selection Criteria (Adapted from Cairns and McCormick 1992; Kelly and Harwell 1988)

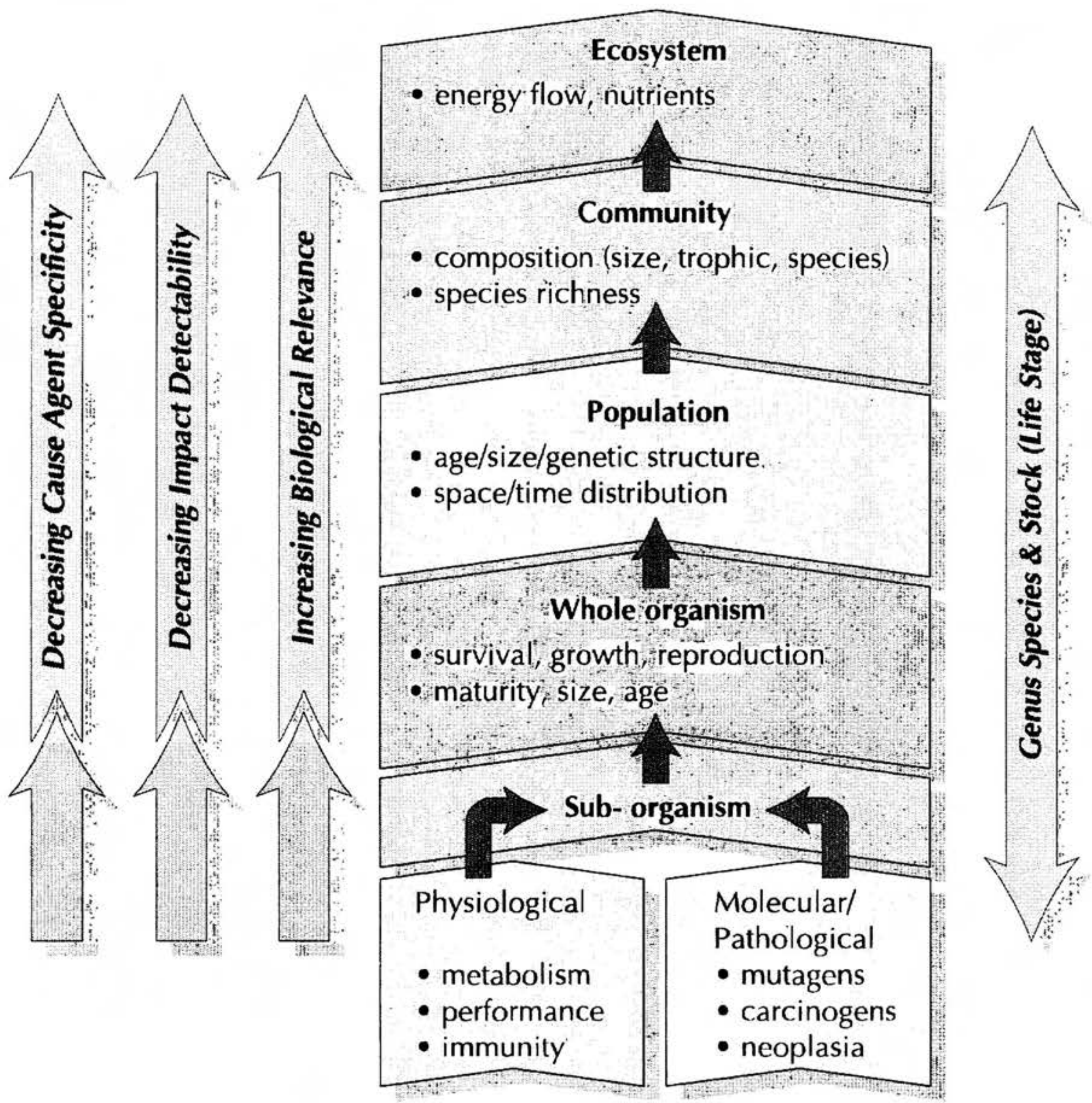
INDICATOR CRITERION	DESCRIPTION
#1. Impact Sensitive	Responsive to station-induced stressors.
#2. Cost-Effective	Maximizes the amount of useful information gained per unit of sampling effort.
#3. Historical Data Series	Has existing data series of sufficient length to define variabil ity and natural cycles.
#4. Background Literature	Biology and impact response published for other sites.
#5. Non-Destructive Sampling	No irreversible harm to sample population or ecosystem from sampling.
#6. Signal-to-noise	Low natural variability (noise) which otherwise could con found detection of impact (signal).
#7. Confirmatory Test	Definitive data (statistical) test possible to prove pres ence or absence of station impact.
#8. Locally Relevant -Social -Ecological	Obvious information value to regulatory agencies and stakeho lders; important to maintaining the normal appearance of the local ecological community and unimpaired ecosystem oper ation (structure, composi tion and function).

Figure 2. Effects Detectability Curves



Number of sampling stations required in each of control and impact areas to detect statistically significant differences between two means expressed as a ratio for each of two levels of coefficient of variation (CV). Type 1 Error = 0.05, Type, Type 2 Error = 0.20

Figure 3. Many Choices Of Impact Indicators At Different Levels Of Biological Organization



3.4 Statistical Trend Detection

At the outset of our programs in the 1970s, the objective of field sampling was to simply "characterize the environment" with the implicit assumption that any detected trend for change would be an effect and any important change would be detectable. Statistical analyses were applied as the final task rather than at the beginning for experimental design. These non-statistical designs could not supply confident conclusions on impact, no matter how sophisticated the final statistical analysis (Ontario Hydro 1992a, 1992b). Regulatory agencies are now demanding that calculations of sensitivity be done for final effects reports that purportedly show no effect and to prove there was a reasonable chance (eg. 80%) of detecting an important size of impact (Environment Canada 1992). The regulatory standard for acceptable risk of missing an important impact will likely be 20% or less (CEARC 1992). In our Pickering and Bruce studies, the risk was higher, about 40%, of missing a real difference. We discovered that "no effect" monitoring results were misleading if sampling was too infrequent or at the wrong time relative to the natural population cycles of abundance.

There are two types of common sampling errors (Environment Canada 1992). A Type 1 statistical error which represents a "false alarm", the risk to the station of falsely detecting an impact that is not really there, or being blamed for an impact that does not exist. The result to the utility (developer) could be unnecessary costs for mitigation or compensation. A Type 2 statistical error represents the risk to biological populations of missing a real impact. This represents potentially unsustainable effects, beyond the carrying capacity of the ecosystem, a cost to society especially those sharing the renewable resource. What we can do to avoid these errors is to calculate the sample size needed to guarantee a reasonable, or 80% chance of detecting an important size of impact (20% Type 2 error) at low risk to the utility (5% Type 1 error) by way of PC-based software (Goldstein 1989) or tables in statistical texts (Zar 1984). The software and tables assume the curves shown in Figure 2 and the following equation:

$$(1) \quad \textbf{Impact Detectability} = \frac{\textbf{Magnitude Of Impact}}{\textbf{Variability}} \approx \frac{\textbf{"Signal"}}{\textbf{"Noise"}}$$

Impact detectability is directly related to the size of the impact (numerator above) and the variability in the population parameter measured (denominator above). The necessary sample size goes up on a log scale related to coefficient of variation and the magnitude of the difference between before and after mean values. This is a "signal-to-noise" ratio where a weaker signal (smaller impact) gets obscured by strong noise (variability) (Figure 2).

In the denominator of the relationship shown above, choice of parameter to be measured can really limit the detectability of impact. For example, impact sensitivity calculations for our studies at Pickering showed the combination of sample size (n=96) and a high coefficient of variation for fish (150%) required a large difference from preoperational to operational periods (50%) for impact detection (Figure 2: CV= 150%, R=1.5). The same difference would have been detectable for a smaller and less costly sample size if a less variable alternative indicator, such as lake bottom-living insects, had been chosen (Figure 2: CV= 25%, N=20)

One way to improve detectability is to pick indicators that have a *high signal- to- noise ratio*. The signal-to-noise ratio is higher for transplanted individuals relative to population-level measures or measures of physical or chemical parameters (Osenberg et al 1996). These transplants could be clams in cages relocated from a clean source area to the reference site and the impact site (Pellerin 1995). Individual-based field measures can be coupled with individual-based PC models (Osenberg et al 1996) to maximize detection power and minimize extrapolation errors as noted by Barnthouse (these proceedings).

3.5 Field Survey Controls

Detectability is not just a matter of sample numbers and adroit choices of indicators but also how the sampling is arranged in time and space. Trend data without some spatial and temporal control information cannot prove or disprove impact. In any impact assessment situation, we are trying to decide whether measured differences between control and impact sites have changed from the Before period (preop) to the After period (operational) (Stewart-Oaten et al 1992; Environment Canada 1992). Ideally we would want repeated sampling before and after impact and at two control sites (Underwood 1996).

In the temporal dimension, sampling many times before and after impact accounts for random differences between the sites, and also tests for a sustained pattern of difference baseline to impact. In the spatial dimension, sampling at least two reference sites, accounts for the usual naturally-occurring spatial differences in ambient conditions (patchiness). This is the "controls" design factor in time (before and after) and space (control versus impact).

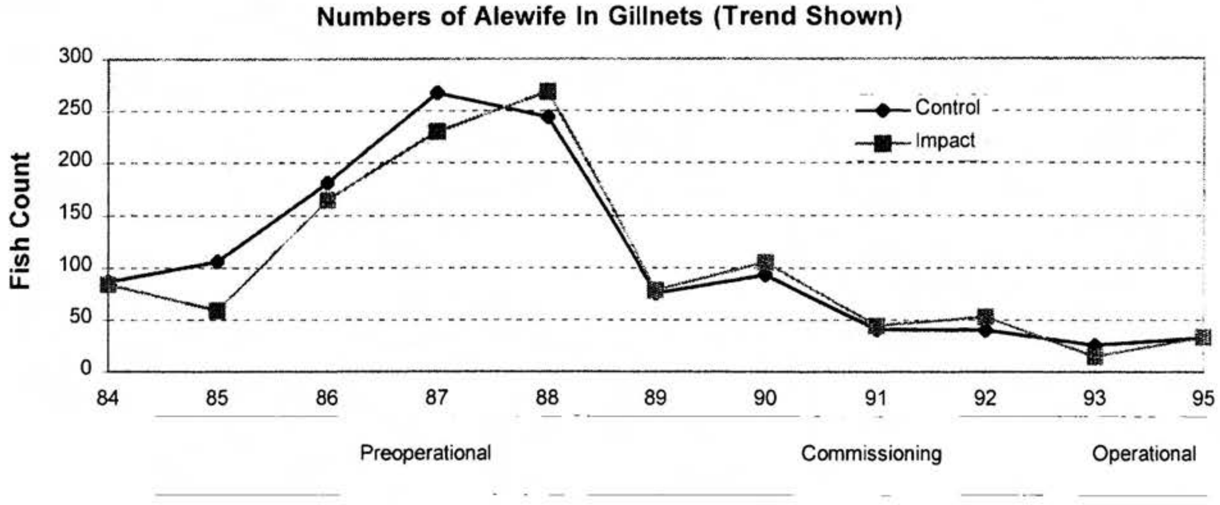
An example is given from Darlington in Figure 4. The upper panel was a test using only temporal controls. It showed a statistically significant decline in alewife ($p<0.10$). There was no attempt to test for a change in the difference between impact and control sites from preoperational (Before) to operational (After) periods. The lower panel was the more definitive test for local impact using differences between spatial and temporal controls. It showed that there was no local impact since there was no trend in the difference between impact and control sites with time. The point here is, you cannot just rely on analysis of simple time trend plots (the top panel) to show real local effects. You need replicated spatial controls to test for local impacts.

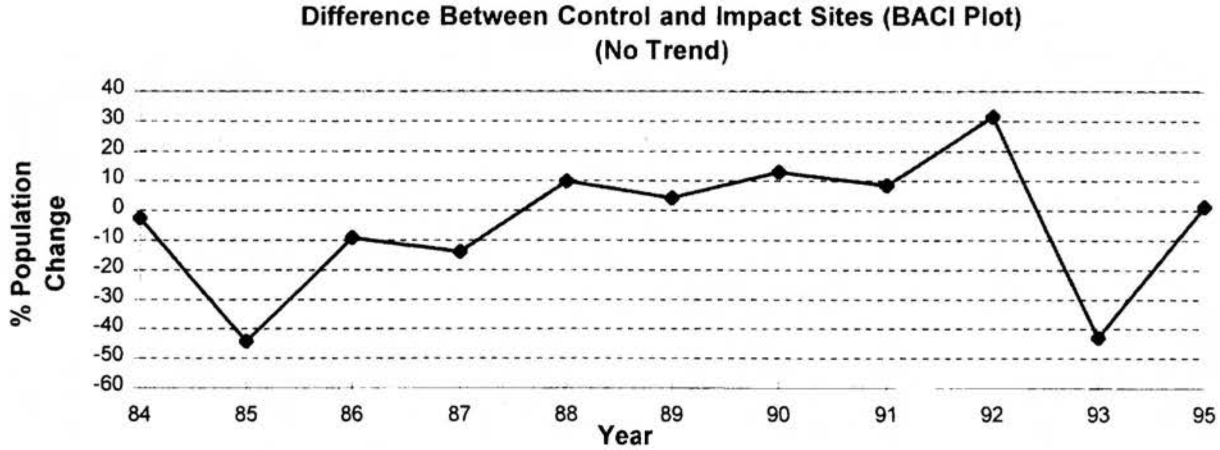
3.6 Quantitative Models

Another basic tool for effects monitoring design, analysis and interpretation is quantitative modelling (Environment Canada 1990; Shuter et al 1985; Thompson 1996). The permit requirements for our generating stations required physical modelling of thermal plumes supported by field verification (Ontario Hydro 1992a). These physical models were then coupled with biological models of key species to generate predictions of effects on fishes (ESSA 1989). The biological modelling, although not required by regulatory permit, was necessary in our judgement, to support the final inferences that were made from often insufficient field data. Model supported inferences were reproducible, defensible and explicit.

A cumulative effects example was our simulation of combined intake alewife fish losses from twelve generating stations on the U.S. and Canadian sides of Lake Ontario (ESSA 1989). This work was conducted in partnership with natural resource and regulatory agencies to better manage the lake-wide stock of alewife. The government agencies were concerned about combined effects of their own predator stocking (salmonid) and station effects. The annual average losses at station intakes were relatively small and insignificant (2% of alewife population) compared to the amount eaten by salmonid predators (24% of alewife population).

Figure 4. Impact Detection With Before/After — Control/Impact (BACI) Survey Designs. Upper Panel Shows Temporal Trend Plot. Lower Panel Shows Difference Plot.





This modelling result helped us to make a defensible case against the need for costly intake mitigation to reduce fish losses.

Modelling is especially important to support monitoring for radionuclide effects. This is because if effects are detectable, it will most likely be at the sub-organism level which will then require defensible and explicit extrapolation to the whole organism, individual and population level to determine biological significance. This need has been recognized by AECB (Thompson 1996). Models also have a role to play in field survey design. Physical models of contaminant fate and dispersion will be needed to determine specific sampling locations for ecological responses.

3.7 Computer Databases

Quantitative effects model development and testing is only possible if field effects monitoring data has first been organized and captured within a computer PC-based data base. If effects monitoring is of the long duration typically required to detect ecological effects (greater than 10 years), involves several VECs and physical surveys it is worthwhile to enter the field data straight into a computer database. This forces logical organization, data checking and management. The ease of access to the data fosters incremental knowledge-based changes to improve the conceptual scientific model and adjust the survey design to important but unexpected biological responses. The PC database also allows a quick turn-around on results so that low value monitoring programs can be either terminated or improved to yield information of use for problem-solving.

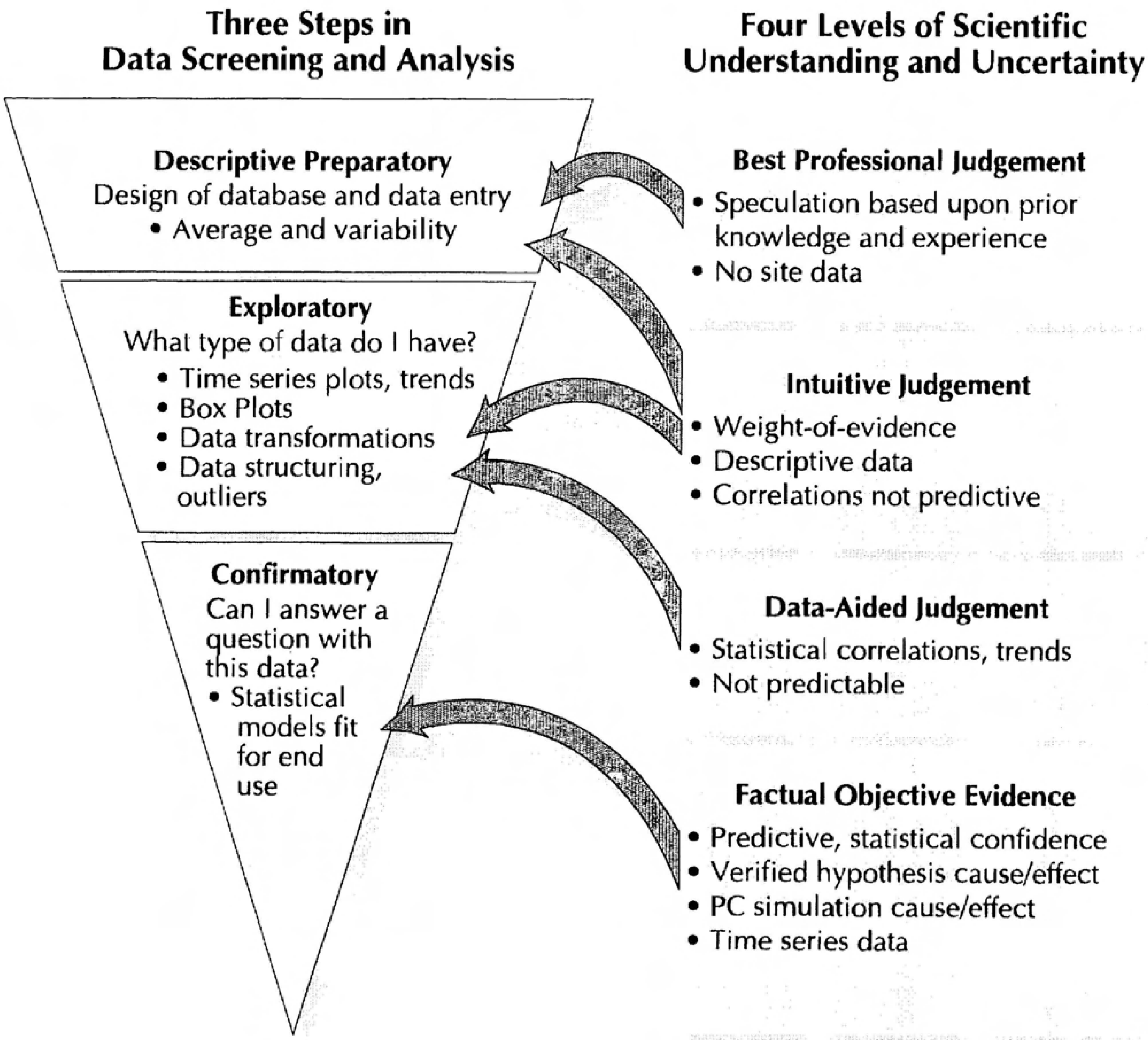
3.8 Ecological Risk and Uncertainty

In the foregoing sections 3.1 to 3.7, I have described the seven design factors that work together to yield high quality scientific information of the type needed to support decision-making. Environmental decision-makers also need an appreciation of the limits of the scientific approach and level of uncertainty associated with any assessment of ecological risk before they can responsibly use the results. The use of numbers, computer models and statistical-based surveys does not guarantee conclusive results or avoid the need for scientists to make judgements (Figure 5). Our scientific goal is almost always confirmatory statistical analysis (bottom inverted triangle) and factual objective understanding (bottom box) but lack of attention to the seven design factors or simply uncontrollable natural factors can often make us fall short of the ideal.

4.0 CONCLUSION

Prior to this decade, environmental effects monitoring was rarely a requirement for project approval. In the last few years effects monitoring regulations and guidelines have begun to influence approvals for utilities and other industrial sectors. Ontario Hydro had an early start on the bio-physical application of effects monitoring because of discharge permit requirements in the 1970s which reflected regulatory concerns about cooling water system impacts on the Great Lakes. More recently, we have realized a new value for the site-specific effects monitoring data in support of our need to begin to directly address the key sustainable development questions of relative ecological risk of adverse effects on habitat (carrying capacity) and self-sustaining populations raised at the UN Rio Earth Summit's Agenda 21 (Wilcox 1992). This value has been recognized in the Corporate Biodiversity Strategy (Hounsell 1996), and the new Darlington site environment policy and environmental management system (DNGD 1996). An effective environmental management system needs some performance measures of ecological effects for the receiving environment, in addition to the traditional end-of-pipe focus on environmental protection (Ontario Hydro 1993).

Figure 5. Ecological Science Levels of Analysis and Uncertainty



This paper concludes with a checklist for use in EEM survey design:

1. Design for variability and a specific statistical test.
2. Replicate your samples in space and time.
3. Predictions and endpoints come from stakeholder workshops to assure that the results will be fit for use.
4. Use detectability tests to optimize design both before and after sampling.
5. Bound the study in space using measures of the physical/chemical changes in habitat.
6. Individual-based measures and models are the most powerful and representative. Some kind of iological model driven by real physical data inputs is needed to fill in the holes that always exist in ecological impact assessments.
7. The significance of extrapolated or measured population-level effects will depend upon knowledge or guess-work about vulnerability based upon both the geographic range and local stock structure.
8. Use a PC-database to get the numbers in and get the results out in a quick turnaround to check how well your design is performing, then make improvements.

5.0 DISCUSSION

There were no questions following this presentation.

6.0 REFERENCES

Cairns, J., Jr. and P.V. McCormick. 1992. Developing An Ecosystem-Based Capability For Ecological Risk Assessments. The Environmental Professional 14:186-196.

CCG 1993. Canada Gazette Part I. Ottawa, Saturday. September 18, 1993. Canadian Environmental Assessment Act. Queen's Printer For Canada. Minister of Supply and Services Canada, Ottawa.

CEARC 1992. Impact Assessment and Environmental Monitoring: The Role of Statistical Power Analysis. June 1992. Canadian Environmental Assessment Research Council, Ottawa.

Culhane, P.J. 1987. The Precision and Accuracy of U.S. Environmental Impact Statements.Environmental Monitoring and Assessment 8(3):217-238.

DNGD 1996. Darlington Nuclear Generation Division Manual NK38-MAN-07002.1-001-R01-P. Classification Public. Environmental Management System Manual. December 20, 1996. Darlington Nuclear Generation Division, Bowmanville ON.

Eberhardt, L.L. 1978. Appraising Variability In Population Studies. J. Wildl. Manage. 42(2):207-238.

Environment Canada 1995. Report of the Ministers' Expert Advisory Panel on the second Priority Substances List Under the Canadian Environmental Protection Act (CEPA). October 1995. PSL2 Secretariat, Environment Canada, Hull, Quebec.

Environment Canada 1992. Aquatic Environmental Effects Monitoring Requirements. Report EPS 1/RM/18. May 20, 1992. Annex 1 and 2. Environment Canada. Department of Fisheries and Oceans.

Environment Canada 1990. Post-project Analysis and The Improvement Of Guidelines For Environmental Monitoring and Audit. Environment Canada Report EPS 6/FA/1. Environmental Assessment Division. August 1990. ISBN 0-662-57752-3.

ESSA. 1989. Simulation Analysis Of The Aquatic Effects Of Pickering and Darlington NGS Using the DARPICK Model. Prepared By ESSA Environmental and Social Systems Analysts Limited for Ontario Hydro Environmental Studies and Assessments Department, Toronto.

ESSA 1986. Report Of A Project To Develop Post-Operational Monitoring Recommendations For The Bruce B Nuclear Generating Station. December 1986. Final Report Prepared for Ontario Hydro By ESSA Environmental and Social Systems Analysts Ltd.

ESSA 1984. Environmental Effects And Monitoring Options For The Darlington NGS. April 1984. Final Report Prepared for Ontario Hydro By ESSA Environmental and Social Systems Analysts Ltd.

Fairweather, P.G. 1993. Links Between Ecology and Ecophilosophy, Ethics And The Requirements Of Environmental Management. Australian Journal of Ecology 18:3-19.

Goldstein, R. 1989. Power and Sample Size via MS/PC-DOS Computers. Amer. Stat. 43(4):253-260.

IAEA 1992. Effects of Ionizing Radiation on Plants and Animals at Levels Implied by Current Radiation Protection Standards. Technical Report Series No. 332. International Atomic Energy Agency, Vienna.

Keating, M. 1993. The Earth Summit's Agenda For Change. Centre for Our Common Future. ISBN: 2-940070-00-8.

Kelly, J.R. and M.A. Harwell. 1988. Indicators Of Ecosystem Response and Recovery, Pages 10-35 In Ecotoxicology: Problems and Approaches. Springer-Verlag NY.

Maloney, R.J. 1996. An Approach to Environmental Protection for Nuclear Facilities. Paper Presented International Symposium Of Ionizing Radiation: Protection Of The Natural Environment. Stockholm, Sweden, 1996 May 20-24. Atomic Energy Control Board, Ottawa, ON.

MNR 1992. Policy Statement Wetlands. A Statement of Ontario Government Policy Issued Under The Authority Of Section 3 of the Planning Act 1983. Approved by Order in Council No. 1448/92. May 14, 1992.

Ontario Hydro 1993. Report Of The Task Force On Sustainable Energy Development. October 18, 1993. Co-chairmen Jim MacNeill/David Runnalls. Ontario Hydro, Toronto, Ontario.

Ontario Hydro 1992a. Pickering NGS "B" Environmental Effects Report. September 1992. Prepared by LGL Limited for Ontario Hydro, Toronto, Ontario.

Ontario Hydro 1992b. Atikokan Thermal Generating Station Environmental Effects Report. June 1992. Prepared by Ecological Services for Planning Limited for Ontario Hydro, Toronto, Ontario.

Ontario Hydro 1975. Proposal For Bruce Generating Station B. February 1975. Ontario Hydro Public Reference Library, Toronto.

Osenberg, C.W., R.J. Schmitt, S.J. Holbrook, K.E. Abu-Saba, and A.R. Flegal. 1996. Detection Of Environmental Impacts: Natural Variability, Effect Size, and Power Analysis. Pages 83-108 In R.J. Schmitt and C.W. Osenberg [eds] Detecting Ecological Impacts: Concepts and Applications in Coastal Habitats. Academic Press. New York NY.

Pellerin, J. 1995. Use Of Biomarkers In Estimation Of Exposure To Contaminants And Resultant Effects On Biota And Ecosystems. Paper presented By J. Pellerin, Universite du Quebec a Rimouski At Atomic Energy Control Board, February 7, 1995 Environmental Research Seminar. Ottawa ON.

Peterman, R.M. and M. M'Gonigle. 1992. Statistical Power Analysis and the Precautionary Principle. Marine Pollution Bulletin 24(5):231-234.

Sheehan, R.W. 1995. Effects Monitoring For The Flue Gas Desulphurization Waste Treatment System At Lambton TGS Operational Studies December 1994 - April 1995. Ontario Hydro Technologies Report No. A-F-95-133-CON. September 28, 1995. Ontario Hydro, Toronto ON.

Shuter, B.J., D.A. Wismer, H.A. Regier, and J.E. Matuszek. 1985. An Application Of Ecological Modelling:Impact Of Thermal Effluent On A Smallmouth Bass Population. Transactions of the American Fisheries Society 114(5):631-651.

Stewart-Oaten, A., J.R. Bence, and C.W. Osenberg. 1992. Assessing Effects Of Unreplicated Perturbations: No Simple Solutions. Ecology 73(4):1396-1404.

Thompson, P. 1996. Protection Of The Environment From The Operation Of Nuclear Facilities: Proposed Canadian Approach To The Development Of Guidelines. Paper Presented International Symposium Of Ionizing Radiation: Protection Of The Natural Environment, Stockholm, Sweden, 1996 May 20-24.Atomic Energy Control Board, Ottawa, ON.

Underwood, A.J. 1996. On Beyond BACI: Sampling Designs That Might Reliably Detect Environmental Disturbances. Pages 151-178 In R.J. Schmitt and C.W. Osenberg [eds] Detecting Ecological Impacts: Concepts and Applications in Coastal Habitats. Academic Press. New York NY.

UNSCEAR 1996. Effects Of Radiation On The Environment. United Nations Scientific Committee on the Effects of Atomic Radiation, United Nations, New York. NY.

Van Winkle, W. 1977. Assessing The Effects Of Power-Plant-Induced Mortality On Fish Populations. Pergamon Press. New York NY.

Waters, W.E. and D.C. Erman. 1990. Research Methods: Concept and Design, Pages 1-34 In C.B. Shreck [ed] Methods for Fish Biology. American Fisheries Society. Bethesda MD.

Wilcox, B.A. 1992. Defining Sustainable Development. Environ. Sci. Technol. 26(10):1902.

Zar, J.H. 1984. Biostatistical Analysis. 2nd Edition. Prentice-Hall. Englewood Cliffs, NJ.