Criteria and Guidance for Determination of Pronounced Eutrophication

National Environmental Effects Monitoring Office

April 10, 2007

Introduction

This discussion paper describes the different levels of eutrophic responses in the aquatic environment and, based on these levels, defines the criteria developed for identifying areas of pronounced eutrophication. These criteria have been developed using three cycles of existing Environmental Effects Monitoring (EEM) data. Levels of variation of data from exposure versus reference areas were associated to varying degrees of eutrophication based on relevant scientific literature. Presented criteria are intended to be used by mills to provide guidance for identifying sites with pronounced eutrophication.

Historical overview

Historically, in Canada, mill effluents contained many substances able to cause deleterious effects in receiving waters. While the effects at individual sites varied according to the quantity of discharges and the dilution capacity of the receiving waters, problems seen at some sites included large areas of rotting fibre mats combined with large reaches of water with little or no dissolved oxygen, and concentrations of effluent constituents toxic to fish, even after dilution.

The *Pulp and Paper Effluent Regulations* (PPER), which were passed in 1992, set strict limits for BOD (biochemical oxygen demand) and TSS (total suspended solids), based on the performance of Canadian mills using secondary treatment and prohibited the discharge of acutely lethal effluent. The PPER are effluent quality based regulations and thus the performance expectation was that each mill would achieve the minimum national standards for effluent quality. However, it was recognised that the level of protection needed could vary depending on the type of ecosystem into which the regulated facility discharged its effluent. As a result, the EEM program was introduced, which assesses the impacts of the effluent on the receiving environment and helps to assess if these effluent quality based regulations are achieving adequate protection.

Over the past three decades, vast improvements in pulp and paper effluent quality have occurred as a result of mills installing pollution prevention measures and, in most cases, secondary treatment, to meet federal and provincial requirements. The pulp and paper industry has taken action and made major capital and human resource investments to achieve these improvements. Between 1970 and 2003, BOD deposits per tonne of output fell by 98%, TSS deposits by 92% and effluent discharges per tonne of output by 59%. The toxicity of effluents also changed from being acutely lethal to fish at low concentrations to being essentially non acutely lethal in whole effluents. In 2003, over 96% of effluent samples tested passed the non acutely lethal requirements.

Smart Regulation Initiative

In the Speech from the Throne in September 2002, the Government of Canada made a commitment to move forward with a “Smart” Regulation Strategy, which would contribute to innovation and economic growth, improve the Government of Canada’s regulatory performance and reduce the administrative burden on business. "Smart" is an acronym for: Specific, Measurable, Attainable, Realistic, and Timely. The Smart Regulation initiative involves a series of government-wide projects aimed at strengthening the policy, processes, tools, and regulatory communities that are needed to sustain the federal government’s high levels of regulatory performance and to facilitate continuous improvement (Government of Canada, 2005).

Environment Canada launched the *Smart Regulation Project on Improving the Effectiveness and Efficiency of Pulp and Paper Environmental Effects Monitoring* in December 2004, bringing together policy experts from the federal government (Environment Canada, Department of Fisheries and Oceans, and Privy Council Office), industry, and the Aboriginal and environment communities. The mandate of the group was to review the key scientific findings and operational experience gained to date through implementation of the EEM program, work collaboratively to develop ways to improve the future effectiveness and efficiency of the program and to improve environmental performance where environmental effects have been identified. The group was tasked with providing external advice to Environment Canada, which will inform discussions within the federal government and consultations with interested parties on future proposals to improve the EEM program.

In December 2005, the policy expert group completed a report entitled *Improving the Effectiveness and Efficiency of Pulp and Paper Environmental Effects Monitoring*. The report includes eight recommendations to Environment Canada (EC) and the pulp and paper industry on how to improve the effectiveness and efficiency of the pulp and paper EEM program. One of the recommendations (recommendation number 6) suggested that mills showing pronounced eutrophication adopt best management practices, develop a “best practices” guide, and track effectiveness of undertaken measures. It was also recommended that Environment Canada develop criteria and guidance for identifying areas of pronounced eutrophication.

Environment Canada, in its response to the report published on EC’s website (http://greenlanedev3/eem/English/Publications/web_publication/smart_reg_response/index.cfm), has reiterated its strong support for industry’s commitment to address the problem of pronounced eutrophication. To help industry implement best management practices to address this eutrophication issue, EC committed to developing criteria for identifying areas of pronounced eutrophication by 2007, by using existing endpoints employed in the EEM-based field monitoring studies.

Eutrophication process

Eutrophication, or nutrient enrichment, is a process of overfertilization of a water body by nutrients that results in the production of more organic matter than the self-purification reactions of that water body can overcome (Chambers *et al.* 2001). Often, pulp and paper mill effluents can be significant external sources of both dissolved and particulate organic matter in aquatic systems, and can lead to increased eutrophication in the receiving environment.

In the case of mild and moderate eutrophication, the typical response is an increase in the abundance and number of benthic invertebrate taxa (taxon richness) relative to the reference conditions. With pronounced eutrophication numbers of opportunistic fauna increase significantly, while a decrease in dissolved oxygen concentrations in the sediments or overlying water produces a gradual disappearance of more sensitive fauna (including larger taxa) (Hellawell, 1986).

Hyper- or severe eutrophication is observed when the abundance and taxon richness of benthic organisms decline; at this stage negative impacts on fish stocks and plant life are usually observed. Hypoxic or anoxic conditions can develop when oxygen is consumed by decomposing organic matter. If currents are weak and the organic matter is not being flushed from the area, these conditions may generate potentially toxic reduced compounds such as methane, ammonia and hydrogen sulphide (Pearson and Rosenberg, 1978).

Eutrophication Criteria

The general criteria for eutrophication usually found in the published scientific literature tend to reflect the potential risks to the aquatic environment and do not necessarily predict the presence of negative impacts. Usually, common water quality indicators are used to define the degree of eutrophication. The most commonly used are: total phosphorus, chlorophyll *a* and Secchi disc depth (Gray *et al.*, 2002).

Published scientific literature based on benthic studies indicates that the level of eutrophication can be reflected by variations in benthic invertebrate abundance (number of animals per unit area, or density) and taxon richness (number of distinct family level taxa per sample) (Grall and Chauvaux, 2002; Nixon, 1995). Such endpoints have been calculated for most of the sites during the EEM program and are readily available.

Figure 1, based on Lowell *et al.* (2003), summarizes gradual variations in abundance and taxon richness along a gradient of nutrient enrichment, toxicity or smothering and generalizes the particular benthic response patterns stated in the Pulp and Paper Guidance Document (Chapter 12, Figure 12-2 in Environment Canada, 2005a). Based on this widely accepted response pattern, pronounced eutrophication is characterized in benthic invertebrate communities by elevated abundance of individuals from so-called opportunistic species (e.g. freshwater tubificid worms and chironomids) and localized extirpation of sensitive fauna, normally larger taxa (e.g. mollusks). Hyper eutrophication, on the other hand, is usually characterized by a decline in the abundance or biomass of benthic organisms; heavy sedimentation of organic matter can smother zoobenthos making the habitat available for opportunistic colonizers (e.g. polychaetes) (Gray *et al.*, 2002).

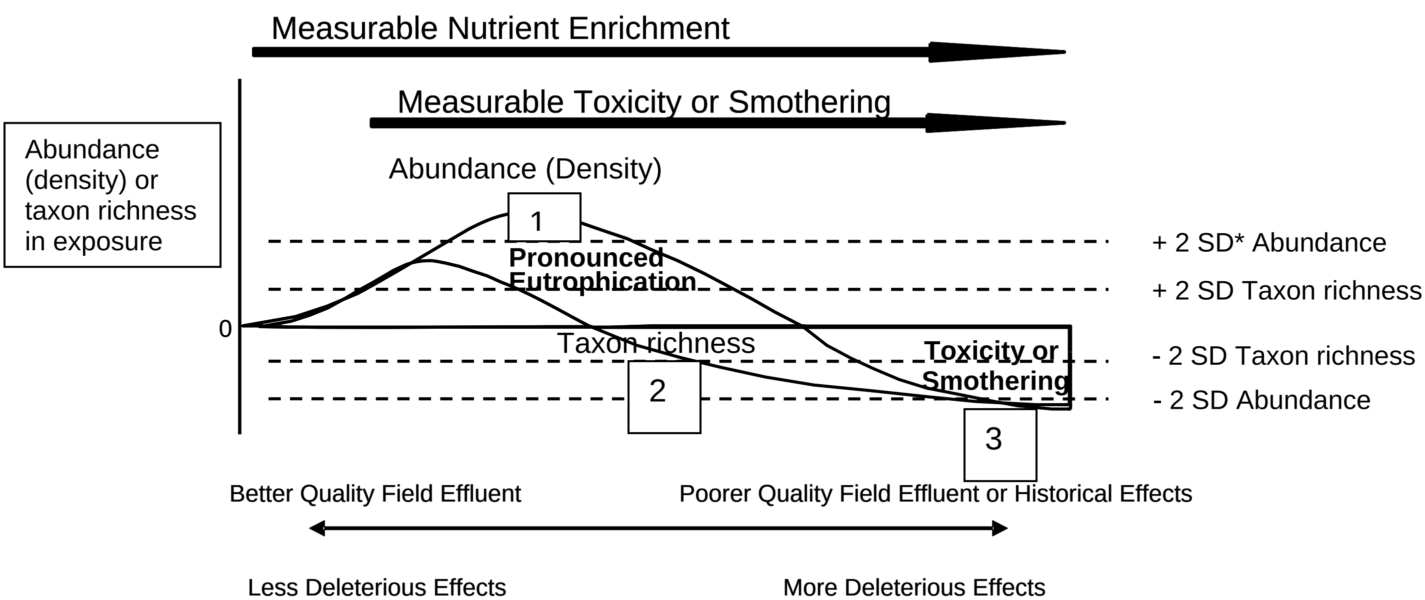

Figure 1. Variations in benthic invertebrate abundance (density) and taxon richness in an exposure site relative to a reference site along a gradient of increasing nutrient enrichment, producing either a toxicity or a smothering effect. This graph is based on a figure from Lowell *et al.*, 2003. Note: the lines illustrating + and – 2SD for abundance and taxon richness are theoretical. For the significance of cases 1, 2 and 3: see text.
*SD – standard deviations

For the purposes of EEM, based on scientific information collected during the program and analysis of Figure 1, the following criteria have been developed and are proposed for use in defining pronounced and hyper eutrophication (Table 1):

Table 1. Definitions of pronounced and hyper-eutrophication applied to benthic invertebrate community EEM data*.

Level of Eutrophication	Definition		
	Abundance		**Richness**
Pronounced	+ 2 SD	and/or	- 2 SD
Hyper	- 2 SD	and	- 2 SD

Notes: + infers a statistically significant increase of at least 2 standard deviations relative to mean of the reference area.
- infers a statistically significant decrease of at least 2 standard deviations relative to mean of the reference area.
* applicable for control-impact, artificial substrate and mesocosm studies. For gradient designs, the pronounced eutrophication criterion is a statistically significant decrease in abundance and/or increase in taxon richness with increasing distance from the outfall (i.e., equivalent to increased abundance and/or decreased richness in more effluent-exposed areas close to the outfall). The hyper-eutrophication criterion is a statistically significant increase in abundance and taxon richness with increasing distance from the outfall (i.e., equivalent to decreased abundance and richness in more effluent-exposed areas close to the outfall).

Data from EEM studies showed that most mills reported statistically significant effects in at least one of the core endpoints for benthic invertebrate and fish population studies. Since it was recognized that statistically significant differences are not necessarily considered to be serious, a concept of Critical Effect Sizes (CES) was developed to identify differences that could lead to ecologically significant effects. CES for benthic invertebrate community endpoints are based on whether the change in the endpoints falls out of the natural range of variability using a statistical basis of two standard deviations ($\pm$2 SD). The same concept has been retained to develop the eutrophication criteria: 1) statistical significance and 2) an effect size exceeding two standard deviations.

Many mills use gradient designs rather than control/impact designs and, for those mills, reported increases or decreases are based on statistically significant correlations (value of endpoint versus distance of station from outfall). Some mills have opted for benthic studies based on artificial substrates or mesocosm studies. For those kinds of studies the same CES were applied.

Based on Figure 1 and Table 1, benthic survey data defines <u>pronounced eutrophication</u> when mean exposure abundance (density) is significantly greater than the reference abundance mean, and the difference is greater than +2 SD of the reference mean (Case number 1 in Figure 1).

Another scenario indicative of pronounced eutrophication is defined when the mean exposure taxon richness is significantly lower than the mean reference taxon richness, and the reduction exceeds 2 SD of the reference mean (Case number 2 in Figure 1).

A scenario reflective of conditions worse than pronounced eutrophication, called hyper-eutrophication (Table 1) has been defined in cases where both exposure abundance and taxon richness means are significantly smaller than reference mean values and the difference exceeds 2 SD of the corresponding reference value (Case 3 in Figure 1).

Hyper-eutrophic conditions can occur in cases where an extensive loading of organic matter is combined with low dissolved oxygen levels. Such a situation can also take place during extensive particle deposition, thus "smothering" benthic habitats. Alternatively, it is possible that sediment-associated toxicity generates a response pattern for the benthos in the exposure area that is not attributable to nutrient loading but comparable to case number 3 of Figure 1 ("Toxicity or smothering"). However, each of these scenarios requires additional information to confirm which mechanism is the principal cause of effects in question. Regardless of the cause, mills falling into this latter category (Table 1) are showing serious effects and deserve further studies.

Site specificity and confounding factors (Historical Effects)

For mills showing possible eutrophication, more information/consultation could be needed before it can be decided if benthic studies at these locations indicate pronounced eutrophication. Cycle 4 results may help to classify mills with effects shown in one cycle. Mills may also possess information other than EEM study results, which demonstrate eutrophic responses in the receiving environment. Furthermore, certain site-specific, confounding factors may influence the identification of eutrophication at a mill. Final decisions will be made based on consultation with regional offices and the stakeholders.

Some mills have experienced significant accumulations of organic matter in the form of fibre mats. In such circumstances, although the present EEM surveys are showing changes to the benthic invertebrate community, what is actually measured is the recovery from more or less pronounced historical effects. In such cases, EEM results may reflect the recovery from a historical deposition, not the effects of current effluent and therefore future EEM surveys should continue to consider the impact of historical deposits. This should also be taken into consideration during the design and review of EEM studies and methods developed to differentiate between these two situations. Since the causes of eutrophication effects may be very site-specific, investigation of causes and solutions could also be site-specific.

Next steps

The results of this exercise are a starting point for discussions with the stakeholders. Mills which think that their benthic study results, in two successive cycles, meet the criteria as recommended by Environment Canada should contact their regional authorisation officer to discuss and plan the next steps to be taken.

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