ENVIRonMENTAL QUALITY STANDARDS: ENDPOINTS OR TRIGGERS FOR A TIERED ECOLOGICAL EFFECT ASSESSMENT APPROACH?

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(Received 7 November 2000; Accepted 30 March 2001)

Abstract—The recently derived Dutch Environmental Quality Standards (EQS) for water, soil, and sediment for approximately 170 substances have been evaluated. Three methods have been used to derive the Dutch EQS. Independent of how the EQS were derived, they are given equal weight in Dutch environmental policy. Scientifically, the three methods may deserve different weights. For example, for soil and sediment, the least reliable method had to be applied to derive most of the EQS. Ecological effects in these compartments may be either overestimated or underestimated. A multtiered approach is proposed, which is relevant for all parties involved, including other countries, and which may help improve ecological effect assessment.

Keywords—Environmental standards Environmental ecological effect assessment Multitiered approach

INTRODUCTION

In the last decade, the National Institute of Public Health and the Environment (RIVM) has derived environmental risk limits that served as a basis for the Dutch government to set environmental quality standards (EQS) [1,2]. These environmental risk limits are maximum permissible concentrations (MPCs) and negligible concentrations for water, sediment, and soil. The MPC is a scientifically derived environmental risk limit, while the negligible concentration is simply defined as 1% of the MPC, except for metals, for which a slightly different approach is taken. Dutch environmental policy does not take into account the possible interactions chemicals may have but does take into account that organisms are exposed to various substances in the environment. To take into account the latter, a factor 100 is introduced in deriving the negligible concentration from the MPC. For metals, the background concentration is taken into account in deriving environmental risk limits [2]. Both MPCs and negligible concentrations have been derived for a series of organic substances, pesticides, and metals. Here we evaluate the recently derived Dutch EQS. This evaluation is focused on the Dutch EQS, but the discussion will be applicable to other countries or forums as well. We would like to call attention of the scientific and ecological effect assessment community to start a dialogue on how to better derive or to more efficiently deal with EQS within ecological effect assessment. The latter is a topic that recently has been addressed by Chapman et al. [3].

METHODS

Substances, methodology, and sources

The approximately 170 substances for which EQS were derived and the methods that were used can be found in Crommentuijn et al. [1,2] and in the references therein. The substances were selected because they appeared high on the Dutch priority lists due to their widespread use and their occurrence in and potential risks to the environment.

Methods for deriving environmental risk limits

Three methods were used for deriving MPCs for each environmental compartment (Table 1); each of them is briefly explained below. (Currently, a log-normal distribution is used for the statistical extrapolation method as described by Aldenberg and Jaworska [4], which replaces the log-logistic-based approach as described by Aldenberg and Slob [5]. This change results in minor numerical differences. In addition, assessment factors as described by the Technical Guidance Documents [6] are currently used in addition to those from the modified U.S. Environmental Protection Agency [U.S. EPA] method [7,8].)

Statistical extrapolation (Aldenberg and Slob method). For substances for which at least four no-observed-effect concentrations (NOECs) for four different taxonomic groups were available, a statistical extrapolation method as described by Aldenberg and Slob [5] was used that results in a frequency distribution from which the MPC can be obtained. Other statistical extrapolation methods, such as those of Wagner and Lokke [7] and Erickson and Stephan [8] lead to approximately the same figures [9]. The main assumptions in using statistical extrapolation methods for deriving MPCs are that the taxa tested are a random selection of all taxa and thus are representative for all taxa and that the results are normally distributed. The second assumption was tested in deriving the MPCs [1,2]; the first assumption is more difficult to validate (see Results and Discussion).

Modified EPA method. For substances for which only medium lethal concentration (LC50) or median effective concentration (EC50) values or a few NOECs are available, the so-called modified EPA method was used to derive the MPC. The magnitude of the uncertainty factor depends on the number of available ecotoxicological data [9,10] and varies between 10 and 1000.

Equilibrium partitioning (EqP) method. When no ecotox-
EQS in a tiered ecological effect assessment approach

Summary

Three methods have been used to derive environmental risk limits for approximately 150 organic substances and 18 metals and metalloids [1,2]. These environmental risk limits started as the basis for setting the EQS in the Dutch environmental policy. Independent of how the environmental risk limits were derived, the EQS are given equal weight in environmental policy. From that policy point of view, it is easier to deal with one type of EQS no matter how it is derived. Once a value is given the status of an EQS, neither the way in which it is derived nor how the value is found is to be discussed from the policy point of view. We, however, find it our scientific responsibility to explicitly state that each of the three methods has different weights and that the resulting MPCs may be treated accordingly. We will first describe the relative uncertainties of the three methods, give some examples for the consequences of the varying basis for the EQS, and end with a proposal for improving environmental effects assessment.

Relative uncertainties

We would like to emphasize that the uncertainty of the MPCs generally increases in the order of statistical extrapolation (i.e., Aldenberg and Slob) method < the modified U.S. EPA method < the EqP method. This relative order in uncertainties is grossly corroborated by Chapman et al. [3]. Some studies have shown that the Aldenberg and Slob method leads to reasonable and reliable environmental risk limits. Recently, some field studies were performed within a large project, ‘Validation of Toxicity Data and Environmental Risk Limits for Soils,’ in The Netherlands on zinc. It was concluded that the environmental risk limit for zinc for soil as derived following the current Dutch methodology is a plausible instrument for generic use [13]. Earlier, Emans et al. [14] concluded that species tested in multiple-species experiments were as sensitive as similar or related species in single-species experiments based on the available, yet few, studies from the literature. Versteeg et al. [15] concluded that laboratory-generated single-species chronic studies can be used to establish concentrations protective of model ecosystem, and likely whole ecosystem, effects and that the use of the 5% of genera affected level is conservative relative to mean model ecosystem data but is a good predictor of the lower 95% confidence interval on the mean model ecosystem NOEC. Van de Plassche et al. [16] drew the same conclusion and found that the similarity was great between the MPCs based on single-species data and those based on field data for four major surfactants. Finally, the European Centre for Ecotoxicology and Toxicology of Chemicals, Brussels, Belgium (ECETOC) [17] compared model ecosystem results and results from field studies for three substances and showed that there was an almost one-to-one relationship.

However, for most of the approximately 170 substances for which we have derived environmental risk limits, the Aldenberg and Slob method could not be applied. For water, approximately half of the MPCs were derived with the Aldenberg and Slob method and half with the modified U.S. EPA method (Table 2, Fig. 1).

For soil and sediment, almost no ecotoxicological data are available, and MPCs for those compartments have, in many cases, been derived from MPCs for water applying the EqP

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Table 1. Methods used to derive the maximum permissible concentration (MPC) for different environmental compartments using different methods, based on the available ecotoxicological data

<table>
<thead>
<tr>
<th>First compartment</th>
<th>Second compartment</th>
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<tbody>
<tr>
<td>Statistical extrapolation</td>
<td>Statistical extrapolation</td>
</tr>
<tr>
<td>Modified U.S. EPA method</td>
<td>EqP method</td>
</tr>
<tr>
<td>EqP method</td>
<td>None</td>
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<tr>
<td>None</td>
<td>None</td>
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</tbody>
</table>

a Statistical extrapolation as described by Aldenberg and Slob [5]: the modified U.S. EPA method as described in [9,10]: the equilibrium partitioning method (EqP method) according to [e.g., 11,12,21]; U.S. EPA = U.S. Environmental Protection Agency.

b If no NOECs are available but one or more LC50s are available, then the modified U.S. EPA method will be applied; LC50 = lethal concentration for 50% of a population.

c Environmental compartments: water, sediment, or soil.

d Environmental compartments: sediment or soil.

NOEC = no-observed-effect concentration.
method (Table 2, Fig. 1). When we apply the categories of effect assessment of the Organization for Economic Cooperation and Development (OECD) [18], i.e., preliminary, refined, and comprehensive effect assessment (Table 3), most of the MPCs for soil and sediment are based on preliminary effect assessment.

In general, there is thus a great demand for ecotoxicological data. The lack of data currently limits reliable estimates of many MPCs since generally the uncertainty will decrease when more data are available. The substances for which MPCs were derived are high-priority substances for which relatively much information on ecotoxicological properties is available in the open literature. It is expected that, for other substances for which MPCs are to be derived, there will be less ecotoxicological information available, which would result in having to use more and more the least reliable methods in deriving MPCs. Furthermore, even if ecotoxicological data are available, their reliability may vary considerably.

Consequences of varying bases for EQS

We thus conclude that many of the environmental risk limits are scientifically weak because they are based on only one or two sets of ecotoxicity data or are calculated from environmental risk limits for another environmental compartment. The consequences of these weak environmental risk limits are diverse. (1) The use of uncertainty factors may greatly increase the possibility of overestimating ecological effect. This implies that useful chemicals will not be marketed or will not even be synthesized further because of their presumed environmental risk and the perception that governments, industries, or other parties will need to spend lots of money on cleaning contaminated sites or on preventing contamination of the environment from occurring [3]. (2) The use of uncertainty factors still may be insufficient to reduce the probability of causing harm to the environment, which thus will increase the possibility of underestimating ecological effect. Some of the cases below show examples of these consequences.

For many of the Dutch sediments, the concentrations of the sum of 10 polycyclic aromatic hydrocarbons (PAHs) exceed the EQS for sediment. The environmental risk limits for sediments for all those 10 PAHs were derived from those for water using the EqP method, while for deriving the environmental risk limits for water, 8 out of 10 used the modified U.S. EPA method. Also for DDT, actual concentrations exceed the EQS for sediment in many cases. The environmental risk limit for DDT in sediment is derived using the modified U.S. EPA method. These examples clearly show that there is a potentially nationwide problem due to high PAH or DDT concentrations in the Dutch sediments. Whether more in-depth site-specific ecological effect assessments or improved ecotoxicological data sets would lead to higher environmental risk limits and to a lower frequency of sites where PAH or DDT concentrations exceed their respective environmental risk limits is speculation. However, it may be worthwhile to further study either improving the environmental risk limit or better estimating site-specific ecological effects before large sums of money are spent on, e.g., sanitation measures such as dredging and disposal in large-scale controlled dump sites.

A second example is given within the framework of the admission of plant protection products and biocides. There are several examples of substances with few ecotoxicity data sets that call for further testing when these few data, accompanied with large extrapolation factors, result in a low environmental risk limit of the substance. Further testing increases the number of ecotoxicity tests and improves and usually increases the environmental risk limits.

Improving the basis for ecological effect assessment is the responsibility for many parties involved in ecological effect assessment. The government, which is usually the prime responsible party that derives and sets the EQS, will be responsible for the consequences of their policy. Industry is a second important party and is responsible for the industrial products that may pose a risk to the environment. There is thus a great need for reducing uncertainties for governments, industries, and other parties.

In the following section, a multiteried approach is proposed,
EQS in a tiered ecological effect assessment approach

Fig. 1. The relative distribution (%) of the use of the Aldenberg and Slob method (black bars), the modified U.S. EPA method (dashed bars), and the equilibrium partitioning method (horizontally striped bars) to derive maximum permissible concentrations for 150 organic substances and pesticides (A) and for 18 metals and metalloids (B) for each of the compartments water, soil, and sediment. Please note that, for water, the equilibrium partitioning method is not used.

Fig. 2. A proposed scheme for a multitiered ecological effect assessment approach. Trigger A calls for more or better ecotoxicological data to improve the quality of the generic environmental quality standards, and trigger B calls for more site-specific information to better determine the site-specific ecological effects. Either trigger may be used to improve ecological effect assessment.

Trigger A, which calls for further ecotoxicological tests, may be set by socioeconomic reasons by any of the involved parties, government, industry, or other. For example, when the costs of further testing, and the expected reduction in uncertainty with resulting higher EQS, outweighs the costs of cleaning contaminated site(s), financial implications will trigger further testing. When there is a social concern for environmental ecological effect, this will also trigger further testing.

When ecological effects are limited either to one environmental compartment or to specific sites, the generic EQS do not necessarily need to become more reliable since site-specific ecological effect assessment may give the appropriate information (trigger B) for further risk reduction measurements or remediation actions. However, further ecotoxicity testing may be an additional line of evidence for site-specific testing.

In some cases, a multitiered approach has been proposed earlier or is already being used. The ECETOC [19] has proposed generating further information on either the (eco) toxicologically and environmentally relevant properties or on the exposure patterns of substances when the ratio of the predicted exposure concentration to predicted no-effect concentration (PEC/PNEC ratio) exceeds one. For soil remediation in The Netherlands, a different type of multitiered approach is already being used. When the concentration of a substance at a specific site exceeds the environmental risk limit, site-specific information on the magnitude of pollution and on geological and hydrological information is included to evaluate the actual risk at that site for human health and the environment [20].

Often, in other countries, there is no generic ecological effect assessment, and only a site-specific ecological effect assessment comes into play. However, even site-specific ecological effect assessments are often based on literature data to evaluate the potential effects to, e.g., aquatic life. Also for site-specific ecological effect assessment, a multitiered approach may thus be useful, as illustrated above and shown in Figure 2.

Alternative ways of dealing with uncertainty may be the reduction of the uncertainty factors, including probabilistic information, that will provide a better estimate of the ecological effect of a substance to ecosystems when the EQS are exceeded. These solutions, however, are either difficult to include in deriving general EQS or call for expert judgment on a case-by-case basis.

Thus, the multitiered approach is not new in environmental ecological effect assessment and has a place already in several risk assessment schemes, but it may be used in even more cases. Additional remarks on how to better communicate is

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Table 3. Stages in risk assessment and required effects information [18]

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<tr>
<th>Tiers</th>
<th>Stages</th>
<th>Effects data</th>
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<tr>
<td>1</td>
<td>Preliminary or initial</td>
<td>Short-term toxicity</td>
</tr>
<tr>
<td>2</td>
<td>Refined</td>
<td>Chronic toxicity</td>
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<tr>
<td>3</td>
<td>Comprehensive</td>
<td>Field data</td>
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something that may need improvement as well. We would like to welcome reactions from the scientific community and regulators on how to improve ecological effect assessment on the basis of the available EQS and the proposed multitiered approach.

REFERENCES