

Discussion Articles

Biological Effects-based Sediment Quality in Ecological Risk Assessment for European Waters

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Abstract

An overview is given of decision making frameworks for Ecological Risk Assessment (ERA) used for sediment in a number of European countries. These frameworks fall into two categories:

- Biological Effects-Based Assessment of *in situ* risks (referred to as *in situ* BEBA);
- Biological Effects-Based Assessment of the *ex situ* quality of dredged sediments (referred to as *ex situ* BEBA).

The first approach is usually part of an evaluation of whether remediation is needed in order to control or reduce the ecological risks of sediment pollution in a given location. The purpose of the second approach is to evaluate the risks of possible (unconfined) disposal options for dredged sediment (including sediment that is dredged for navigational reasons).

Important aspects are:

- Objectives for sediment management;
- The level of integration of BEBA in legal frameworks;
- The use of chemical (numeric) SQG's in BEBA and their integration with biological information;
- The criteria used to infer effects and to classify sediment quality.

Between EU countries the basis for deriving SQG's as well as the level of implementation of SQG's varies considerably. For use of SQG's in river basins, clearly there is a need for harmonisation of SQG's. Also, there is a large variation between EU countries with regard to the role BEBA plays in decision making frameworks. With respect to the implementation of the EU Water Framework Directive, possibilities arise for harmonization of BEBA on a river basin level, especially for *ex situ* BEBA.

1 Introduction

Since the mid sixties, national governments in a number of countries of Europe have become active in their attempts to monitor and control environmental pollution. Most efforts have focused on the development of environmental quality guidelines and their implementation in policies and regulations. After 35 years, guidelines have been still derived for

less than one percent of the compounds known to be present in the environment due to human activities (Van Wezel 1999). Therefore, although much knowledge has been gained concerning the risks of this relatively small group of chemicals, it is clear that there is insufficient information about the risks caused by the majority of the other compounds that are released in the environment.

Special concern has been given to compounds that can bind strongly to particulate matter (especially clays and organic matter) and eventually are deposited in the sediment. Often in depositional areas historical pollution can be found that represents the sometimes unforeseen consequences of human activities. Historically, sediment quality has been assessed by making comparisons between concentrations of contaminants with (numerical) sediment quality guidelines (SQGs). Based on such a comparison, the potential risks, or hazard of (groups of) sediment-bound contaminants can be estimated. A recent overview of the use of SQGs in Europe has been given by Babut et al. (2003). An important aspect in the risks caused by sediment-bound chemicals is the degree of exposure encountered by sediment-dwelling organisms. It is well documented that often only a fraction of the contaminants bound to sediments are biologically available, in part because desorption can be slow. Thus, actual exposure levels are lower than would be expected on the basis of the total concentrations of compounds in sediment (Hamelink et al. 1994; Kraaij 2001). However, it is also known that mixtures of contaminants can have additive or synergistic effects (Hermens et al. 1984; De March 1987; Von Danwitz 1992), which may not be well addressed by single SQGs. For these reasons, and because of the large number of unknown contaminants as explained above, ecological risk assessment of sediment quality has received much attention in the past decades. The advantages of biological endpoints, such as effect bioassays, over chemical quality assessment are that biological testing integrates the effects of all contaminants present at their actual bioavailability (and detect possible combination or synergistic effects).

Most so-called ecological risk assessment (ERA) frameworks deploy biological effects-based sediment quality assessments (BEBA). The basic principle of most of ERA is the use of multiple lines of evidence (Burton et al. 2002). Important lines of evidence are: 1) Assessment of the condition of the benthic zoomacroinvertebrate community; 2) Assessment of sediment toxicity by using bioassays (BEBA); and 3) Assessment of the potential effect occurring through foodchain poisoning (evaluation of bioaccumulation and biomagnification). The present paper is intended to give an overview of ecological risk assessment frameworks that are used in Europe, including the use of SQGs within those frameworks. One of the important points that needs to be addressed is that in this paper the term 'decision' will mean different things for the different countries. The information available will vary, as will the 'depth' of environmental policies. Therefore, an important question is what the purpose for ERA is in the different countries.

Two main goals for sediment quality assessment in Europe are distinguished:

- Biological Effects-Based Assessment of *in situ* risks (*in situ* BEBA) at sites where sediment quality and potentially sediment management is to be considered;
- Biological Effects-Based Assessment of the *ex situ* quality of dredged sediments (*ex situ* BEBA) in order to select sediment management options (e.g., free or confined disposal or treatment options).

The two objectives for carrying out a risk assessment procedure are different in nature and therefore are structured differently, as described herein:

1.1 *In situ* BEBA

The biological effects-based assessment of the *in situ* risks in sediment (*in situ* BEBA) focuses on location-specific conditions with respect to the bioavailability of contaminants and the assessment of the damage to the ecosystem. The assessment of damage to the ecosystem can be either predictive or retrospective. *In situ* BEBA can be considered as one of the lines of evidence in an ERA (Burton et al. 2002). ERA can be combined with studies focusing on the risks related to transportation of contaminants to the surface water and to biota, or to deeper sediment layers, and subsequently to the ground water.

With the growing concern for the potential problems caused by sediment pollution, ecological risk assessment approaches have been proposed as decision support tools or instruments for prioritisation. These approaches generally rely upon a tiered process, to allocate limited technical and financial resources.

In general, three main purposes can be identified for which *in situ* BEBA frameworks have been developed (Ingersoll et al. 1997):

- Integration of information from large numbers of parameters that use different lines of evidence (e.g., sediment chemical concentrations, sediment toxicity, benthic community measures, tissue concentrations, etc.);
- Proof of causality between environmental effects and sediment contamination;
- Tiered approach for increasing confidence in a cost-effective manner.

1.2 *Ex situ* BEBA

Ex situ BEBA is a *hazard assessment*, in which biological/toxicological endpoints are used as predictors of possible effects that may occur when the sediment is disposed of in the environment (aquatic or on land). In this BEBA, bioassays are often included in the sediment quality assessment or added as a second Tier. The approach is more prognostic, i.e. based on the outcome of the assessment, predictions are made of the consequences of free disposal of dredged sediments in the environment. In that respect this approach, using sediment toxicity assessment bears resemblance with total effluent risk assessments (see e.g. Grothe et al. 1996, Tonkes et al. 1999).

Comparing *in situ* and *ex situ* BEBA, it is likely that the assessments lie at very different levels in a decision making process (see also Aplitz and White in this issue). *In situ* BEBA is usually a front-end investigation necessary to evaluate whether sediments are a risk, before any decision about some action would be needed. *Ex situ* BEBA is something that is carried out after it has already been proposed to dredge (e.g. dredging for nautical reasons), but when disposal options have to be considered.

Apart from the ecological risk assessment approaches explained above, there may be different concepts that use risk information for other questions, such as prioritising. These concepts will also be discussed in the present paper. From a number of countries we were able to obtain information on current practice with regard to sediment quality assessment. The present paper describes the stage of implementation of *in situ* and *ex situ* BEBA in national monitoring programs or in legal frameworks. The focus is on freshwater sediments, but for some countries there is more experience with *in situ* sediment quality assessment in estuarine or marine waters, or the evaluation of *ex situ* quality is more important for marine sediments, with regard to disposal of sediment at sea. Subsequently, BEBA applications for estuarine and marine waters will also be described. Selected BEBA approaches are described in more detail, such as the *in situ* BEBA used in The Netherlands, and a number of *ex situ* BEBA approaches in other countries.

2 Description of Integrative Sediment Quality Assessment (BEBA) Approaches in EU Member Countries

2.1 *In situ* BEBA approaches

2.1.1 Belgium

Sediment quality assessment in Flanders has been incorporated in a monitoring network by the Flemish Environment Agency since 2000. The focus is on freshwaters. Every year 150 locations are sampled, with specific locations resampled every four years, so in total 600 locations are included in the monitoring program. The assessment is based on a Triad approach (Long and Chapman 1985, Chapman 1996). Physical-chemical, biological and ecotoxicological assessment methodologies are used, and an identical weight is assigned to each of the three assessments. The principle behind the classification of the watercourse sediments rests on an evaluation of the abnormality compared to a reference condition,

so for each methodology a reference condition must be defined. This creates the possibility of classifying watercourse sediments in the absence of existing biological standards.

- **Physical-chemical assessment.** The chemical parameters that are included in the assessment are: nonpolar hydrocarbons (NPHCs), extractable organohalogenes (EOX), sum of the chlorinated pesticides (SOCP), sum of 7 PCBs (PCB7), sum of 6 Borneff PAHs (PAH6), heavy metals Cd, Cr, Cu, Ni, Pb, Hg, Zn and As. The concentrations are normalised to values for sediment with a standard granular composition and organic carbon content (see description of normalisation in section on The Netherlands). The site is classified based on the ratio to reference values. The sediments are ranked in classes based on the concentrations of the various contaminants. The sediment then receives an overall ranking based on the highest contaminant class ranking.
- **Ecotoxicological assessment.** A battery of three tests is used for the ecotoxicological assessment. The battery consists of two pore water tests, namely a growth inhibition test with *Raphidocelis subcapitata* and an acute mortality test with *Thamnocephalus platyurus*, and one solid phase test, namely an acute test with *Hyalella azteca*. The results are compared to results obtained with a reference sediment (with similar characteristics for grain size distribution etc). Based on the ratio, a classification is assigned. The ultimate ecotoxicological class is determined by the highest class of the two assessments (interstitial water and bulk sediment). The result is used as an estimate of the acute impact determined on aquatic life forms.
- **Biological assessment.** Two indexes are used for the biological quality of watercourse sediments, namely a Biotic Sediment Index (De Pauw and Heylen 2001) and the percentage of mouth deformities of *Chironomus* sp (De Deckere et al. 2000).

Finally, the results are integrated based on the three classifications (Table 1). This assessment method results in a rough indication of the sediment quality. To date, the results of this approach have not been used directly in sediment management.

Table 1: Overall class assignments for sediments in Belgium using the TRIAD approach^a

Chemical class	Ecotoxicological class	Biological class	Overall class
3 or 4	2, 3 or 4	2, 3 or 4	4
1 or 2	2, 3 or 4	2, 3 or 4	3
3 or 4	2, 3 or 4	1	3
3 or 4	1	2, 3 or 4	3
1 or 2	1	2, 3 or 4	2
1 or 2	2, 3 or 4	1	2
3 or 4	1	1	2
1 or 2	1	1	1

^a Class 1 is good quality, class 2 is moderate quality, class 3 is poor quality and class 4 is very poor quality. See for other criteria (De Deckere et al. 2000)

For prioritisation of sediment locations, a method is proposed in Belgium that was previously developed for the prioritisation of pesticides in Flanders (Callebaut and Vanhaecke 1999). Apart from the information described above, some additional factors were added from the methodology for the risk assessment of existing chemicals (Van der Zandt and Van Leeuwen 1992). Each chemical parameter that assesses the exposure and the risk is categorised, resulting in a score for both the exposure and the risk. The scores are multiplied, which gives a final score that can be used for ranking the chemicals. However, some changes had to be made for sediments. The exposure of organisms to chemicals in sediments will also be assessed by the sediment-water exchange. Both the equilibrium between the solid phase and the interstitial water as well as the release of contaminants to the surface water will affect the sediment-water exchange. The human risk of chemicals in sediments is less important, because the direct exposure to sediments is negligible for humans. The most important pathway of human exposure is the risk of bioaccumulation throughout the food chain. These evaluations have yet to be incorporated in a legal framework.

2.1.2 France

There is currently no framework applied in France which could be definitely attributed to this kind of risk assessment. *In situ* assessments are mainly related to (i) monitoring, (ii) ecosystem restoration or (iii) flood management.

- Monitoring:* Until now, sediment quality monitoring for the protection of water bodies was done on the basis of analyses of 'priority' pollutants and comparison to numerical SQGs. The use of toxicity bioassays is now seriously envisaged, following several demonstrative studies (Garric 1998). Two bioassays have been selected, i.e. *Chironomus riparius* (10 days, survival and growth) and *Hyalella azteca* (14 days, survival and growth) and will be applied after the formal adoption of a standard. Observations of invertebrate communities are also carried out at almost all the stations of the monitoring network, but their results are usually not matched with measurements of sediment contaminants. An attempt was made in 2001 to identify sensitive benthic organisms and reliable descriptive variables, and possibly underline contamination / biological responses patterns (Garric et al. 2002). This first study appears interesting, but should be extended with more powerful multivariate methods, and a more selective approach, as it appears that the impacts of contaminants are stronger in low current sections¹. Ultimately, either the use of bioassays or matching benthic observations with sediment chemistry should help to consolidate or refine the existing SQGs.
- Ecosystem restoration:* there may be many reasons leading a local institution (municipality or group of municipalities) or a water manager to envisage a restoration of

¹ The standard method for invertebrates communities assessment is based on sampling of various habitats; the above mentioned approach looking for relationship between richness or abundance and sediment contamination did not discriminate between the habitats.

a degraded ecosystem, or some functionalities of that ecosystem. Dredging in this case appears as a technical solution among others, or as a part of the overall restoration process. In any case, the dredging project will be subject to authorisation by the relevant authority or, depending of the volume, to a simple declaration. In the latter case, the project manager will have to describe all aspects of the project, while in the former he will have to provide a so called 'impact study' encompassing a broad range of issues.

- (iii) *Flood management*: dredging may be proposed as a solution for managing floods in urbanised areas, or in the vicinity of dams. Again, the dredging project will be subject to authorisation by the relevant authority or, depending of the volume, to a simple declaration.

The current guidance for these 'impact studies' is rather open if not vague, and does not require the inclusion of ecotoxicological aspects. It is recommended that one considers various management options, not only dredging (Imbert et al. 1998). The relevant authority would generally ask for a focus on toxicological or ecological impacts if it knows beforehand, or suspects, that chemicals are present at the site of concern. A specific guidance for 'in-place' sediments risk assessment is currently under development on behalf of the French Ministry of Transportation.

2.1.3 Germany

Sediment quality assessment to determine *in situ* risks in Germany is mainly based on chemical quality criteria. Three main systems are used: The assessment systems of the Joint Water Commission of the Federal States 'LAWA' (Länderarbeitsgemeinschaft Wasser), of the ElbeRiver Water Quality Board 'ARGE ELBE' (Arbeitsgemeinschaft für die Reinhaltung der Elbe) and the "index of geoaccumulation" (Müller 1979). Whereby the LAWA and ARGE ELBE classifications are based on ecotoxicological effect levels of heavy metals, organic substances (industrial chemicals) and biocides, the index of geoaccumulation exclusively considers geochemical data, and does not take into account, that heavy metals have different effects on organisms. Nevertheless it is still widely used.

The LAWA-System: The classification of LAWA for sediment quality consists of 4 main and 3 sub classes based on data for 7 heavy metals, 28 organic chemicals, nutrients, salts and 11 sum parameters (ATV-DVWK 2000). Quality class I reflects a natural or potentially natural environment with no xenobiotic substances measured in the sediment and with average geogenic (natural) background levels of heavy metals. Class II includes target values that are expected to guarantee a high ecological protection. Target values for the water

phase are based on ecotoxicological No Observed Effect Concentrations (NOEC), measured with four different test systems (Table 2) whereby the lowest measured concentration of the most sensitive species used is multiplied with a compensation factor of 0.1. According to the Federal Environment Agency, it is not yet possible to designate target criteria for the protection of sediment-dwelling organisms, due to the lack of generally acknowledged methods. Therefore soil limit values in force under the Sewage Sludge Ordinance are adopted as water quality targets for the asset of "Suspended solids and sediments" (Federal Environment Agency 2001). These quality targets, which make up class II of the LAWA system are considered to correspond to the "good environmental quality" of the European Water Framework Directive. The limits between the higher classes (II – IV) are derived from a multiplication of the target values by a factor of 2.

The ARGE-ELBE-System: the classification according to the ARGE ELBE is structured similarly to the LAWA system but uses target values that have been decided upon by the International Commission for the Protection of the Elbe. It uses 27 priority substances and includes arsenic because of its special importance for the Elbe (ATV-DVWK 2000).

The 'Index of Geoaccumulation' consists of a 7 tiered classification system, whereby the different classes derive from continued doubling of a background level. No biological considerations are involved.

Constructive criticism of the existing guidelines has increased in recent years, main points being the chemical based nature of the classifications, the doubtful transfer from sewage sludge to sediments for quality target levels, the high uncertainty due to the limited number of chemical substances measured, the resulting high potential for either underestimating or overestimating risk (Heise and Ahlf 2002). Several research groups have recommended application of a Triad approach, integrating chemical measurements, biological investigations and ecotoxicological measurements (Neumann-Hensel et al. 2000, Ahlf and Förstner 2001, Ahlf et al. 2002a, Hollert et al. 2002). An investigation of suitability of bioassays and biological classification methods has been prepared in Germany for the Federal Environment Agency in order to form a basis for a revision of Sediment Quality Criteria (Ahlf and Gratzner 1999). However, discussions are still ongoing.

Recently, recommendations were made for the use of an integrated stepwise approach combining toxicological, chemical and ecological information to assess and evaluate the quality of sediments (Ahlf et al. 2002b). A difference from approaches followed in most other countries is that bioassays are used as a trigger for further research steps, instead of the

Table 2: Data basis for the protection level 'Aquatic communities' used in Germany (Calmano 2001)

Primary producer: Green algae, e.g. <i>Scenedesmus subspicatus</i>	Growth within 72 hours
Primary consumer: Crustaceans, e.g. <i>Daphnia magna</i>	Reproduction within 21 days
Secondary consumer: Fish, e.g. <i>Brachydanio rerio</i>	Toxicity within 28 days (or 14 days), can be replaced by toxicity in early life stages
Degraders: Bacteria, e.g. <i>Pseudomonas putida</i>	Growth within 16 hours

chemical data that are more commonly used. In Henschel et al. (2002) a stepwise approach is described for an integrated assessment of ecosystem health effects and the consequences of sediment contamination for human health.

2.1.4 Italy

Presently, an *in situ* BEBA is not regulated in Italy and only recently some recent research and monitoring programmes have combined toxicological, chemical and ecological information. To assess the risks to biota, the Italian Dec. Leg. 152/99 (to implement 91/271/CEE and 91/676/CEE Directives) fixes Water Quality Objectives, and sediment quality assessment is considered supplementary. In freshwaters, two procedures are foreseen:

1. Basic analyses of water quality: anthropogenic impacts on biota are evaluated using the Extended Biotic Index (IBE), a biological species diversity index;
2. Additional analyses: not obliged by law, but suggested to investigate short or long term effects in particular cases. Toxicity test of concentrated water samples in *Daphnia magna*; mutagenicity and teratogenicity tests of concentrated water samples; algal development test; tests of concentrated water samples in bioluminescent bacteria.

In addition, bioaccumulation analyses of priority pollutants (PCBs, DDTs and Cd) on muscle tissues of fish or on macrobenthos are suggested.

As for sediments, analysis of a number of metals and organic micropollutants are considered as supplementary and performed in particular cases to determine causes of environmental degradation of the water body. In case it is necessary to highlight short or long-term toxic effects the Decree indicates to perform the following types of bioassays:

- Bioassay on sediment extracts;
- Bioassay on sediment as it is;
- Bioassay on interstitial water.

The following organisms are suggested for the bioassay tests: *Oncorhynchus mykiss*, *Daphnia magna*, *Ceriodaphnia dubia*, *Chironomus tentans* and *C. riparius*, *Selenastrum capricornutum* and luminescent bacteria.

As for coastal and marine environments, the Decree recommends a preliminary classification of the water quality based on dissolved pollutant concentrations. To finally define the quality of the coastal/marine environment, analyses on sediments and biota should also be performed. To assess the sediment quality the following analyses should be performed:

- Granulometric analyses;
- Heavy metals;
- Bioassay in different taxonomic group and with standardised protocols;
- Organic Carbon;
- PCBs and pesticides;
- TBTs (in the proximity of harbours).

To assess the state of the coastal/marine environment, bioaccumulation analyses of metals and organic pollutants (PAHs, PCBs, pesticides) in Mytilidae (*Mytilus galloprovincialis*) and Ostreoida (*Ostrea edulis*, *Crassostrea gigas*) are of importance. If the indicator species are not present in

the environment the following should be alternatively used: Tellinoidea (*Donax trunculus*) and Veneroidea (*Tapes decussates*, *Tapes philippinarum*). Additional analysis could be performed a) on key communities (phanerogame, reefs) to more completely characterise the ecological state of the environments, b) by the use of bioassay to test short and long term effects of pollutants in different taxonomic groups (favoring autochthonous species for which standardised protocols exist).

To classify the coastal/estuarine environment there are no existing integrated approaches assigning ranks. The environmental classification will therefore be based on existing trophic indices of species diversity.

2.1.5 Netherlands

In the Netherlands, sediment quality assessment has become part of routine monitoring programs, both in fresh- and marine waters. Different sets of SQGs have been implemented for a chemical classification of sediment quality on a scale from 0 to 4. These SQGs were to some extent based on ecotoxicological effect data (Van der Gaag et al. 1991; Van der Kooij et al. 1991). More recently, SQGs have been developed for sediment quality assessment using species sensitivity distributions (SSDs) for specific chemicals (Van de Guchte et al. 2000). Chemicals below their SQG value reflecting protection of $\geq 95\%$ of the theoretically present species are considered to cause a tolerable degree of risk; chemicals higher than their SQG value reflecting protection of $\leq 50\%$ of the species indicate potential high risk. The latter SQGs form, together with SQGs that have been derived specifically for assessment of potential human risk, the basis for the Dutch intervention value (see below).

Location-specific assessments of the *in situ* risks of sediment pollution in the Netherlands are carried out mainly in fresh water systems. The *in situ* BEBA is then part of a broader evaluation of the risks caused by sediment pollution, aimed at the question whether the risks make sediment remediation necessary. For this evaluation, a tiered approach is followed:

1. *1st tier assessment: Comparison of levels of priority pollutants with national standards/guidelines.* Chemicals measured routinely are mineral oil, chlorobenzenes, organochlorine pesticides, PCBs (standard group of 7 congeners), PAHs (16 of EPA) and the heavy metals Cd, Cr, Cu, Ni, Pb, Hg, Zn and As. Contaminant levels are normalised according to the approach described by CUWVO (1990), in order to compensate for differences in sorption characteristics between sediments². Normalised contaminant levels are then compared with the Dutch sediment quality criteria (developed for first tier assessment of risks for human health and ecosystems). According to the resulting classification, most polluted sediments (exceeding intervention value(s): class 4 on a scale from 0 to 4) require a risk assessment (2nd tier).

² Standard sediment is defined as having a 25% particle fraction $< 2 \mu\text{m}$ and 10% organic matter on a dry weight basis.

2. *2nd tier assessment*: The primary statement for this second line assessment is as follows: if a priority pollutant exceeds the intervention value (indicating potential high risks, e.g. in the case of ecological risks: species-sensitivity distribution for the pollutant indicates that > 50% of the theoretically present species might be affected), the site needs to be remediated urgently, unless it is shown that there are actually no high risks at that particular site. Thus, there is an assumption of risk, until it is disproved. If the data supplied from the second tier show that there is actually no high risk at a site where a priority pollutant exceeds the intervention value, the need for remediation is no longer considered as urgent. Conversely, if actual (high) risk were confirmed, the next step would review different remedial options, that are to be compared for the expected risk reduction. Three main pathways are considered within this tier for achieving a complete risk assessment, the third being an *in situ* BEBA approach:

1. Human exposure: model calculations are carried out in order to quantify the extent to which humans (adults/children) can be exposed to contaminant via food consumption or via recreation activities in water. When the exposure exceeds maximum permissible risk criteria, actual risk is concluded. The model is based on general assumptions with regard to behaviour and diet of human populations.
2. Investigation of the risk of transport of contaminants from the sediment to groundwater, or to surface water. Model calculations are carried out in order to quantify the extent to which these processes occur. When contaminant fluxes (preferably calculated from field data) exceed high risk criteria, actual risk is concluded.
3. *In situ* BEBA (see Fig. 1): The evaluation of risks for the ecosystem is done by using the TRIAD assessment. In the Dutch version of the TRIAD, bioaccumu-

lation measurements are also considered, using the results of laboratory tests, or preferably by measurements using indigenous organisms (Den Besten et al. 1995). Based on the *most sensitive* parameter, sediments are classified for the categories 'field observations' and 'bioassays' (Table 3) as either '-' (no effect/risk), '±' (moderate effect/risk) or '+' (strong effect/high risk). The goal is to elucidate the relationship between effects on macrozoobenthos and responses of bioassays which, in turn, can be related to levels of chemical pollution. For that purpose, chemical concentrations are converted into 'toxic units' (TU): these are the ratio between the chemical's normalised concentration and the lowest NOEC³ reported in the literature, among the bioassays included in the battery (Den Besten 1995). High risk is inferred when strong effects are observed in field surveys and/or bioassays that can be related to chemicals present in the sediment (Table 4).

3. *Prioritisation*: When the supplied data from the second tier show that there are actually no high risks at a site where a priority pollutant exceeds the intervention value, the need for remediation is no longer considered urgent. In the case where actual high risks were confirmed, a next step is possible in which different remedial options are considered for the risk reduction that can be achieved. The information from the sediment quality assessment can be used again in setting priorities within the group of locations that urgently need to be remediated. In the Netherlands, some experience exists with the use of multi criteria analysis (MCA; also called Analytic Hierarchy Process – AHP; Saaty 1980) for this purpose. MCA enables a ranking of sites based on risks for the ecosystem.

³ If sufficient data are available, the median value would be preferable.

Table 3: Classification of effects in bioassays in the Triad approach used in The Netherlands^a

Daphnia	Parameters (equal, take most sensitive)			
	NOEC-mortality (in % dilution of pore water)	Mortality in undiluted pore water	NOEC-reproduction	Inhibition of reproduction in undiluted pore water
Criterion 1	NOEC < 100% NOEC > 10%	–	NOEC < 100% NOEC > 10%	Inhibition > 10% Inhibition < 50%
Criterion 2	NOEC ≤ 10%	mortality ≥ 50% within 48h	NOEC ≤ 10%	Inhibition ≥ 50%
Chironomus	Parameters (equal, take most sensitive)			
	Mortality eggs, prior to start sediment bioassay (incubation of eggs in elutriate)	Mortality larvae	Inhibition of development	Effect on weight (negative effects are scored only)
Criterion 1	mortality > 25%	mortality > 10% mortality < 50%	inhibition > 10% inhibition < 50%	effect > 10% effect < 25%
Criterion 2	mortality ≥ 50%	mortality ≥ 50%	inhibition ≥ 50%	effect ≥ 25%
Microtox	Parameter: 1/EC20 (5, 15, 30 min: equal, take most sensitive)			
Criterion 1	1/EC20 > 2			
Criterion 2	1/EC20 ≥ 10			

^a NOECs are expressed as the % pore water dilution showing no effect; exceedance of criterion 1 results in class 2 toxicity (moderate effects); exceedance of criterion 2 results in class 3 toxicity (strong effects); otherwise, class 1 (no toxicity).

Classification of sediment can be done on each of the bioassays independently (i.e., most sensitive bioassay determines the toxicity score).

Effects on which the toxicity score depends should be significant at $p < 0.05$

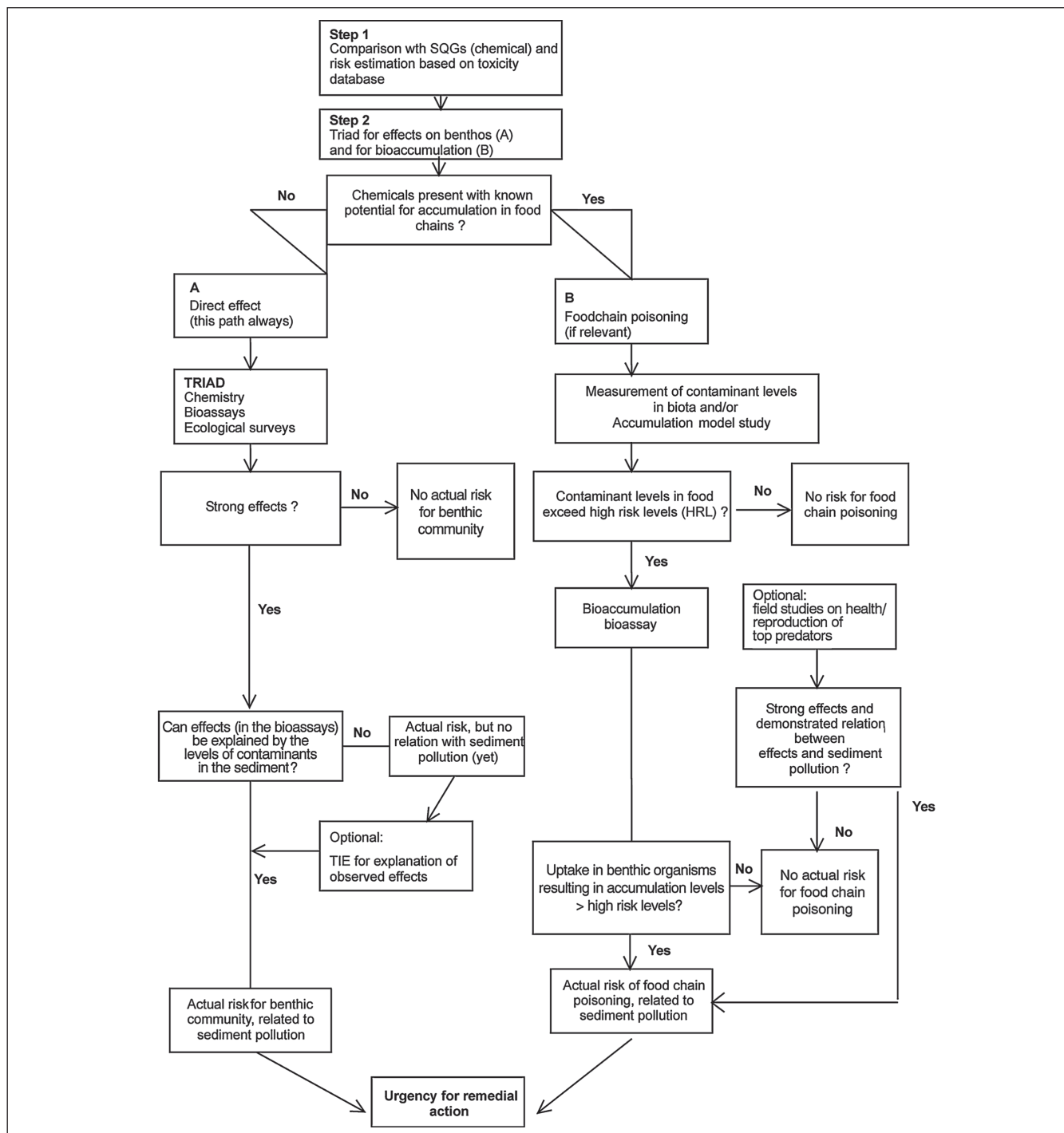


Fig. 1: Ecological risk assessment in NL for the decision yes/no urgency for remedial action

This method (described by Den Besten et al. 1995) is based on the same classification of results as described above. For each criterion (= parameter), standard numerical values (scores) were assigned to the effect/risk classes, from the value 1 for the class representing the strongest effect or highest risk, to for example 0.5 and 0.25 for the classes representing moderate risk and no risk, respectively. Then the criteria are given a specific place and weight in a hierarchy. The scores are multi-

plied by the weight of the corresponding criterion and subsequently totalised bottom-up using a computer program, resulting in a final score between 0 and 1. The difference between the final score and the theoretical score 1 (the score for a site with strong effects / high risk for all parameters) gives an indication of the risks for ecosystem health at each of the sites. For this method all available information from the field surveys can be used, including site-specific information from bioaccumulation

Table 4: TRIAD: Interpretation and Consequence for Remedial Action (after van Elswijk et al. 2001)

Effects on ecology (field studies) or Bioaccumulation levels in biota *	Effects measured in bio-assays (toxicity) or Bioaccumulation measured in bioassays *	Explained toxicity: TU _{bioassay} ** or Comparison of levels of bio-accumulating contaminants in the sediment with 10xMPC or the PEL	Triad conclusion: actual ecological risk ?	Additional research needed ?	Decision based on Triad research with respect to urgency*** of remedial action and if applicable, recommendations for additional research
+	+	+	Yes	No	Actual risk demonstrated, urgency for remedial action.
+	±	+	Yes	No	Actual risk demonstrated, urgency for remedial action.
±	+	+	Yes	No	Actual risk demonstrated, urgency for remedial action.
-	+	+	Yes	Yes	Actual risk demonstrated, but urgency cannot be concluded yet. Additional research should be aimed at field surveys (other season, more parameters).
+	-	+	Yes	Yes	The serious effect(s) observed in the field were not confirmed by the outcome of bioassays. Additional research is recommended before remedial action is considered urgent. Possibly a low bioavailability of contaminants, or too short exposure in the bioassays.
+	+	-	Yes	Yes	Actual risk demonstrated, but urgency cannot be concluded yet (no relation between contaminants and observed effects). Additional research needed to identify cause of the effects.
+	±	-	Yes	Yes	Actual risk demonstrated, but urgency cannot be concluded yet (no relation between contaminants and observed effects). Additional research needed to identify cause of the effects.
±	+	-	Yes	Yes	Actual risk demonstrated, but urgency cannot be concluded yet (no relation between contaminants and observed effects). Additional research needed to identify cause of the effects.
±	±	+	indications only	Yes	Moderate effects, but they can be explained. Additional research necessary to confirm that risks are acceptable (repeat bioassays and/or use more parameters). No urgency
±	±	-	No	optional	Moderate effects, and no causal relationships between effects and sediment contamination. No urgency
+	-	-	No	optional	Effect seems not to be caused by contaminants. Possibly other factors have caused effects in field. No urgency
-	+	-	No	optional	Research needed in order to explain the results of bioassay(s). No urgency
±	-	+	No	optional	Moderate effects in field, but not in bioassays, although they would have been explainable on the basis of sediment contamination. Possibly low availability of contaminants. Additional research could focus on other bioassays (possibly more representative of benthic community in the field) or on other contaminants. No urgency
-	±	+	No	optional	Moderate effect, explainable. Additional research should be aimed at field surveys (other season, more parameters). No urgency
±	-	-	No	no	No urgency
-	±	-	No	no	No urgency
-	-	+	No	no	Contaminants cause no effects and seem to have low availability. No urgency
-	-	-	No	no	No urgency

* + = strong effect/risk; ± = moderate effect/risk; - = no effect/risk

** TU_{bioassay}: calculation of toxic units for explanation of effects observed in bioassays; + = TU for groups of contaminants or individual contaminants > 1

*** Criteria for urgency:

1. Category field or bioassays showing a strong effect (+); the other category at minimum moderate effect (±)
2. Effect in at least 1 bioassay should be explainable (either by calculating TU for a group of contaminants or for individual contaminants: TU > 1)
3. If criterion 1 is not met because a strong effect is observed in one category and no effect in the other, and effects could be explained, then actual ecological risk still is indicated, but no urgency for remedial action until additional research has been carried out to provide more effect data

studies. At a higher level of a decision hierarchy, information from human risk studies, ecological risk assessment, and estimates of contaminant mobility (transport) can be integrated. In the MCA, specific weights can be attributed to the different criteria (=parameters) and higher in the hierarchy, at branch points. This makes the method

useful for decision makers, who have to deal with all these aspects at the same time and therefore need integrated information. In the near future, estimates of the expected beneficial effects of remedial action will also be integrated in the step of prioritisation of dredging locations.

2.1.6 Norway

Fresh and marine waters. In Norway a classification system for sediment quality has been developed to evaluate the environmental quality in freshwater and fjord/coastal water systems (SFT 1997a; 1997b). The classification of sediment quality is based on chemical concentrations and ranges from class I (insignificantly polluted) to class V (extremely polluted). The chemical parameters that are included in the assessment are TBT, hexachlorobenzene, sum of DTT derivatives, sum of 7 PCBs, sum of toxic equivalents of dioxins and dibenzofurans, sum of 16 PAHs and the heavy metals Cd, Cr, Cu, Ni, Pb, Hg, Zn and As for fjord/coastal sediments and only heavy metals for freshwater sediments. The specific values used in each classification range are based on diffuse background levels for pollutants from a large data set and statistical methods. The criterion that distinguishes class I and II is this diffuse background level, with the criteria for the remaining classes based on a statistic scaling up of the background level value. The difference between class IV and V takes the pollutants' bioavailability into consideration.

There is currently no Norwegian national framework for conducting a biological effects based sediment quality assessment for *in situ* risks of sediment contamination. However, studies have been carried out in order to facilitate the development of such a system (Källqvist 1993). Test organisms included were algae (*Skeletonema costatum*) and crustaceans (*Acartia tonsa*, *Nitocra spinipes* and *Tisbe furcata*). A classification system was proposed for each test system independently, but not for an overall classification of sediment quality. Recent attempts to carry out risk assessment of contaminated sediments focus on bioavailability and bioaccumulation (utilising a test with a polychaete, *Nereis diversicolor* and a test with the snail *Hinia (Nassarius) reticulata*) (Hylland 1996). Furthermore, ecological effects on soft bottom fauna, as well as fluxes of contaminants and the relative importance of sediments as a source of contamination are considered (Skei et al. 2002).

The Norwegian Pollution Authorities (SFT) in cooperation with the Norwegian Institute for Water Research (NIVA) and the Norwegian Geotechnical Institute (NGI) are currently developing a national framework for conducting risk assessments of contaminated sediments. The experience and knowledge that has been gained through national projects as well as internationally are integral in the development of this framework. The structure and main components of the framework are to be completed by the end of 2003.

2.1.7 United Kingdom

There has been considerable research and development in the field of sediment risk assessment in the UK, but not much uptake in a regulatory sense, particularly for freshwater sediments. The UK had a very active period of sediment research in the mid-1990s, resulting in broad reviews of approaches to risk assessment (e.g., NRA 1995, SNIFFER 1995) as well as establishment of the National Marine Monitoring Programme (MPMMG 1998).

In the UK, *in situ* freshwater sediments are only routinely assessed for environmental quality within the framework of the EC Dangerous Substances Directive (76/464/EEC), together with the Water Resources Act 1991, both of which require control over inputs of dangerous substances into water. Specifically for sediments, List 1 Dangerous Substances are monitored in sediment or biota at sites proximate to dischargers that discharge those substances, under a standstill provision. Under this provision, it is necessary to demonstrate that the levels of a particular substance, present in either sediments and/or biota, do not increase significantly with time (Environment Agency 1997). In addition, *ad hoc* investigations of freshwater sediment quality are conducted, related to site-specific issues such as contaminated land, navigable waterways management, water quality problems and academic interest. Aside from draft sediment quality standards for dioxins and furans in England and Wales (Environment Agency 2000), there are no freshwater standards for sediment assessment at this point in any part of the UK.

In the past few years, the Environment Agency has been reviewing the situation and is re-examining their policies related to sediment assessment and management. They commissioned two reviews to advise them. Environment Agency (2002a) reviewed the use of sediment quality guidelines and Environment Agency (2002b) reviewed the nature and extent of sediment issues, encompassing both ARPS and BEBA.

The authors of a recent document by the Environment Agency (2002a) stress that SQGs are insufficiently reliable to support automatic regulatory action should guideline concentrations in sediments be exceeded. Exceedance of SQGs should always trigger investigatory actions that seek to confirm or deny the predicted risk. It was argued that SQGs could be useful in the UK, provided (i) they minimise 'false negatives' (type II error) and (ii) their exceedance must not be the sole reason for regulatory action Environment Agency (2002a). They should rather be used as a first screening, along with considerations of background concentrations, which is consistent with the conclusions drawn in another document by the Environment Agency (2002b).

Although the Environment Agency (2002a,b) supports tiered approaches to sediment assessment, they do not propose a definite framework at the moment, but recommend developing and validating an approach for the UK. The Environment Agency (Harris et al. 2002) has identified the need for an increased focus on sediment assessment and management issues (in partnership with other stakeholders) and intends to develop an overall strategy, within which ARPS would sit.

In marine and estuarine waters, the UK's National Marine Monitoring Programme (NMMP) is a well-developed programme that monitors sediment quality, essentially using a triad approach. The Marine Pollution Monitoring Management Group (MPMMG) is a management group for the programme, with representation from all government organisations with statutory marine environmental protection monitoring obligations.

The NMMP was developed in response to OSPAR as well as several EC Directives. The NMMP Phase 2 focuses on

stable depositional sediment sites (approximately 110 sites) and evaluates: sediment chemistry, benthic communities, bioaccumulation, and ecological effects methods. It is also anticipated that NMMP data will be used to fulfil some of the monitoring requirements of the Water Framework Directive⁴. Initially, the main objective of the programme was to describe marine quality around the UK through spatial surveys (phase 1), but it has now shifted to detecting with appropriate accuracy long-term trends in physical, biological and chemical variables at selected estuarine and coastal sites (phase 2). Other objectives include support for consistent standards in national and international monitoring programmes for marine environmental quality (for example: EC Directives, OSPAR) and making recommendations on how new analyses and techniques are best implemented in the United Kingdom. Overall, the aim is to produce reports providing overviews of the spatial (NMP holistic report 1998) and temporal distributions (every three years from 2002) of these variables and their inter-relationships.

2.1.8 Spain

Freshwaters. No sediment quality assessment other than the use of chemical measurements is recommended for the management of sediment polluted in fresh water from Spain. However, no SQGs are recommended to evaluate chemical measurements in sediments. Most of the assessments carried out in these areas are based on the geochemistry of sediments. Some research includes the use of biological assays such as the commercial Microtox[®], but only as complementary information. Most of the studies that have used both chemical and biological data were forced by the Spanish legislation related to hazardous material, but were not part of an integrated approach for sediment quality monitoring in these environments. The biological assays used for the assessment of hazardous material (mammalian tests, no fresh water organisms) are inappropriate for determining the quality of sediments.

Estuarine and marine waters. Most of the regulatory agencies both from the Central and Autonomous Governments follow a typical Triad schema to determine sediment quality in these areas. It is important to note that it is not a weight of evidence approach (e.g. the Triad as described by Chapman 2000), but a general monitoring using the main idea from the Triad: quantification of pollution based on the assessments of the contamination (enrichment of anthropogenic substances) and the effects associated with those polluted sediments. It is not mandated by any law but has been adapted by most regulatory agencies. The Triad approach has been used in Spain since about 1992–1993 (DelValls et al. 1998). From the results obtained, different sediment quality values (guidelines) were derived by comparing them to those obtained in a similar Triad application carried out in San Francisco Bay (USA) and reported by DelValls and Chapman (1998). These Sediment quality guidelines have been used following a tiered approach for the monitoring of

the impact provoked by a mining spill (Aznalcóllar, April 1998) in some coastal areas located in the Gulf of Cádiz (Riba et al. 2002, Riba 2003).

The SQGs reported by DelValls & Chapman (1998) were used to evaluate the concentrations of certain heavy metals from the mining spill in different areas of an impacted estuarine and coastal environment (DelValls et al. 2002). Briefly, an ecological risk factor was derived by calculating the ratio of the measured concentration of the metals to their respective SQGs (Tier I). Those areas with ratios higher than 1 in some metals from the mining spill were considered as potentially impacted (polluted) and then tested using a battery of toxicity tests (both sediments and waters) and compared to other clean stations in the area with ratios clearly below 1 (Tier II). Based on the results of Tier II, stations were selected for application of TIER III, the sediment quality Triad. The Triad results were compared to those of an area known for its contamination by mining activities (e.g. Huelva). Such use of SQGs and integrated BEBA type of approaches is under consideration by different regulatory agencies and is being discussed by expert commissions for the monitoring of the impact in the Galician coasts after the oil spill provoked by the tanker 'Prestige'.

2.2 *Ex situ* BEBA

2.2.1 Belgium

No *ex situ* BEBA approaches exist in Belgium.

2.2.2 France

The political framework for dredged materials is still under discussion for freshwaters. From a legal point of view, these materials are classified as wastes, but not necessarily as hazardous. Another confusing issue is the destination of the materials – a deposit on soils is subject to a different set of regulations than those applying to a deposit in waters. There is thus a need for guidance at various levels of the management process; some pieces of guidance, e.g. for the overall management process, has been introduced (Imbert 1998), and should now be completed by more specific frameworks for the evaluation of the dredged materials. On behalf of the Ministry of Equipment and Transportation, such a framework was recently proposed for the ecological side of the assessment (Babut 2001).

*Tier 1: Chemistry based screening risk assessment*⁵. In this proposed framework (Fig. 2), SQGs are used in Tier 1 in order to determine a 'risk score', which may trigger three decisions: (a) below a given value, the materials can be disposed of without specific requirements; (b) above another given value, the intended disposal should be further assessed through a detailed ERA; (c) between these values, complementary tests should be done.

⁴ Full details of all sites together with methodologies, sampling schedules and frequencies are provided in the NMMP2 monitoring manual – 'The Green Book' at www.marlab.ac.uk/nmpr/nmp.htm.

⁵ Note that although this step was designed as a part of the risk assessment framework for dredged materials, i.e. for *ex situ* BEBA, it could also, and would probably, be applied as part of any sediment quality assessment, including *in situ* BEBA.

