Feature

The Need for New Concepts in Risk Management of Sediments

Historical Developments, Future Perspectives and New Approaches

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Abstract. Being part of a highly dynamic system, contaminated sediments are especially in need of an integrated management approach. Due to change in importance from source to diffuse pollution and the variety of chemical substances in the environment, different scientific fields need to cooperate and incorporate their data in a common risk assessment scheme.

Public perception of risk that is associated with sediments and with chemical data is low while the acceptance of ecotoxicological data with decision makers is often missing. A growing demand of the public to be involved in decision processes and informed about environmental problems demands a change of methods and concepts in the future. Necessity of an integration of risk assessment and management procedures has been suggested in order to increase the efficiency of the process and the early involvement of public concern. As the confidence in experts' opinions decreases, a strong need for communication with and transparency for all involved parties arises.

Keywords: Integrated approach; perception of risk; quality criteria, ecotoxicological; quality criteria, chemical; risk assessment; risk management; SedNet (EU sediment research network)

Introduction: Specifics of the Sediment Compartment

The issue of environmental contamination in Europe was first recognized only for the water and soil compartment. In the consequence, European networks and research centres were founded that developed strategies and concepts for risk assessment. The more recently recognized need also to deal with contaminated sediments initiated the formation of the European Demand-Driven Sediment Research Network 'SedNet', which addresses issues related to the management of sediments and dredged material.

Sediments differ from soil in a number of aspects, which should be attended to in risk assessment and management procedures: Most sediments belong to a highly dynamic, transboundary system in which the solid phase is in contact with a constantly changing and moving medium – the water phase. But sediment itself is also transported along rivers, exposed to changing environmental conditions such as pH, redox conditions, salinities – all of which may influence the properties of bound chemicals, their interaction with organisms and the particles' adhesive capacities. Soil, however – compared to sediments – is a rather stable environment, the problems of which are much more easily perceived by the public. Easier access and handling facilitates control and monitoring of management options. Understanding of these properties influences possibilities for risk assessment:

The 'Fitness for use' concept for soil (Ferguson 1999), for example, that is favoured by most EU Member States can not be an option for sediment that is still part of the dynamic system. Only a confinement that limits transport and distribution would allow for an assessment associated with a specific use – therewith taking the sediment out of the ecological system.

Over time, river sediments accumulate a 'cocktail' of contaminants, that may show synergistic or additive effects. Different substances are most likely to be in different stages of ageing and residual formation, hence being differently bioavailable for organisms (Alexander 2000, Reid et al. 2000).

While the control of source pollution, with increasing control of industrial processes and municipal waste treatment has been the major concern for a long time, attention has shifted in Northern Europe towards diffuse pollution due to the input from surface runoff, groundwater, erosion, etc. For example, 80% of the heavy metal transport in the Rhine basin nowadays originates from diffuse sources (Vink and Behrend 2001). Immission of undefined origin together with historical pollution produce an unpredictable load of contaminants that accumulate in the sediments over time. Most chemical substances, that are produced by industrial processes and released to the environment, finally end up in the sediments. Whether they show additive or synergistic effects on organisms or are in different stages of ageing and residual formation can't be determined by routine chemical measurements. Most are not even detected, which potentially results in false negative errors if only chemical analyses are considered for risk assessment.

This paper stresses the need for an integrated risk assessment as being especially important when sediments are concerned. It points out historical developments and future perspectives, indicating new approaches for risk management that may become part of the discussion in the 'risk management and communication' working group of SedNet.

This discussion will be reflected by a series of articles on 'Risk Management' in the forthcoming three issues of JSS through 2002.

1 Developments in Risk Assessment

Rapid industrialization in Europe and its direct consequences on humans initiated a public perception of human health risk from the exposure to chemicals. During the last decades, with the growing realization that human health and environmental health are entwined in many aspects such as recreation, food production, and climate change, public awareness of environmental problems has been increasing, assisted by the occurrence of human-made fatal incidences. Examples of these are the reduction in the population of birds of prey due to DDT in the 60s, foam on surface waters due to nondegradable detergents, calamities in Seveso because of dioxin release, and massive fish reduction in the Rhine river. This, consistently, led to the development of legislation on pesticides, end-of-pipe emission standards, requirements for the rapid primary degradation of detergents, and international environmental treaties (Van Leeuwen 1997).

So, in the early 1980s, the water-pollution problem was well known. The severity of contaminated land, however, caught politicians and the general public by surprise. Instead of an estimated 350 sites that were thought to be contaminated in the Netherlands in 1981, the actual number rose to 300,000 sites in 1995 (Ferguson and Kasamas 1999). Nowadays, some 750,000 sites across Europe are suspected to introduce contaminants into soil and groundwater, endangering water resources, ecosystems and/or human health (Ferguson et al. 1998). Acknowledging these problems, international initiatives were established within the European Union (networks like CARACAS, NICOLE, and CLARINET, and centres like the ETC/S and RACE), concerned with risk assessment and/or remediation of soil and groundwater, and aiming at the coordination and concentration of Member States' activities. From discussions between the chemical industry, member states, and the European Commission, ecological risk assessment procedures have evolved for new chemicals (the seventh amendment to Directive 67/548/EEC), existing chemicals (EC Council Regulation 793/93) and agricultural biocides (914/414/EEC) (Van Leeuwen 1997). EU guidance documents for risk assessment indicate that the generic ERA practice is based on a standardized minimum data set that contains short-term ecotoxicity data, basic physicochemical data, use information, and import/production data. For risk assessment of contaminated sites, chemical concentrations are measured or predicted and compared to those concentrations that are considered as no effect concentrations based on single species test data. Environmental protection is considered to be guaranteed due to the application of arbitrary uncertainty factors to the lowest observed effect concentrations (to gain the predicted no-effect concentrations [PNEC]) and worst-case assumptions. The risk involved is considered to be smaller, the lower the environmental concentration is as compared to the PNEC values.

Where solid phases are involved, as in soil or sediments, the Technical Guidance Documents (TGD) of the EU have been using the equilibrium partitioning method (EPM) described by Di Toro et al. (1991). This approach presumes that the partitioning of a chemical between surface bound organic carbon, porewater and benthic organisms is at equilibrium. Studies that indicated a similar sensitivity of benthic and pelagic organisms led to the use of quality criteria for water to calculate the PNEC.

As Riedhammer and Schwarz-Schulz pointed out, a revision of the TGD is currently taking place at the EU level, initiated by the understanding that the EPM is based on assumptions that can not be generally applicable, especially when highly sorptive substances are concerned. The concept that presents the basis of the revision of the sediment compartment, which has been developed by the German Federal Environmental Agency (UBA), improves the current practice in the following aspects: Chemicals are tested by long term sediment tests with benthic organisms, considering species with different habitats, feeding strategies and different exposure routes (Riedhammer and Schwarz-Schulz 2001).

These technical guidelines are supposed to become applied within the framework of the EU Existing Chemicals Regulation from 1993 (793/93/EEC), where priority substances are tested for the risk that they present once released to the environment. Considering this aim, the concept will be a major improvement in direction to a more ecologically oriented risk assessment for chemicals. As these studies still aim at the establishment of PNEC values which are compared with results of chemical analysis of environmental samples, it should be differentiated from and not confused with a risk assessment of contaminated sediments.

2 The Shortcomings of Risk Assessment for Sediments

The concepts for risk assessment of chemicals in sediments have often been transferred to the risk assessment of contaminated sediments. This is accomplished by performing chemical analyses in the sediment and fitting the measured concentrations in the PEC/PNEC concept or to a similarly derived list of guideline values as in the classification model of the ARGE-Elbe in Germany (ARGE-Elbe 1996). If some substances exceed the quality criteria, a risk is assumed. The shortcomings of this have been recognized for a long time: A large number of substances with concentrations just below the given limit values are valued as less dramatic than the concentration of just one substance that is elevated slightly beyond the limit. This will probably lead to a false estimate of the actual risk, as additive or synergistic effects of chemicals are not considered. However, other shortcomings of this concept are worse: The European Inventory of Existing Commercial Chemical Substances (EINECS) lists 100,000 chemicals, 75% of which are not toxicologically tested (Gandrass and Eberhardt 2001). Most of these will sooner or later end up in sediments. If they are not detected because their presence is not expected or because no analytical methods are available , any risk assessment may give false negative errors: An indication of 'no effect', although there is one. These are the most dreaded mistakes, although scientists are trained to avoid false positive errors, and a reduction of the probability to overlook a possible hazard is ecologically of uttermost importance.

Sediments much more so than soils are transported in the ecosystem, carrying with them contaminants and taking up new substances along their way. Since source pollution has become less severe compared with the effects of diffuse pollution, they present to the risk assessor a cocktail of chemicals in different stages of ageing and residual formation. The bioavailability of substances that had been attached to sediments for different times is currently impossible to estimate with chemical methods and will likely be overestimated (Alexander 2000). Substances which are not detected, however, are not estimated at all, although they may be toxic and persistent.

Another limitation of the chemical assessment concepts, if transferred to sediment risk assessment, is the disregard of the potential of autochthonous organisms. Microorganisms have been known to actively increase bioavailability of bound chemicals by different methods, such as adhesion to substrate sources, secretion of surfactants and change of the affinity of their uptake systems (Wick, Springael et al. 2001). In addition, interactivity of different species, that not only reflects itself in biomagnification processes, may also raise bioavailability of bound substances. Largely increased biodegradation potentials that have been described for biofilms are also possible for autochthonic (microbial) communities in soils or sediments which usually go unobserved by chemical analyses. It is these microbial communities, however, that control and steer the biogeochemical cycles in the sediments that the other organisms depend upon.

3 Integrated Sediment Risk Assessment, Management and Perception

Although ecotoxicological test systems have been integrated in the assessment of sediments in the United States since the 70s, and although their integration has been advised in the OSPAR Guidelines for the management of dredged materials (OSPARCOM 1998), implementation in national risk assessment concepts has been slow. Emphasis in the reality of most states is given to substance-oriented approaches, based on chemical analyses. The risk-based approach, being a central issue in environmental policy in The Netherlands, consists of 3 risk limits and 5 operationally defined sediment contamination classes. All are based on ecotoxicological chemical-effect studies and chemical analyses of sediment material (Peerboom and van Hattum 2001).

Management of sediment along the Federal Inland and Coastal Waterways in Germany is done according to two directives: HABAK-WSV (BfG 1999) and HABAB-WSV (BfG 2000). Although chemical, ecotoxicological and ecological criteria can add to the overall assessment process, emphasis is given to chemical data.

In The Netherlands, a development of an integrative assessment system has been suggested due the inefficiency of chemical analysis in the assessment of complex pollution. The new concept is supposed to comprise biotests and effect-integrated measurements in addition to chemical data. A classification system is currently under revision and a limited set of bioassays is evaluated and scheduled for implementation in 2002. Also Belgium, Great Britain and Germany show tendencies to strengthen the importance of bioassays in their assessment concepts (Peerboom and van Hattum 2001). However, the acceptance of ecotoxicological tests is often limited – in ministries, with risk assessors and managers – and here appears to be a conflict that needs being analysed – with consideration of the public and managers' perception.

3.1 Perception of risks

Risks that are involved with contaminated sediments are much more difficult to communicate than those connected with soils for obvious reasons. However, the acceptance of biotest application to determine a possible hazard seems to be higher among the general public than with fellow scientists and risk managers – although for different reasons. To the public, toxicity of sediment is easier to understand if adverse impacts on test organisms are shown, rather than if concentrations of never-heard-of chemicals are reported or statements are made about the degree of chemical contamination of the material in a river bed. As the confidence in high-level scientific reports has been shaken in recent years, due to a number of controversies such as bovine spongiform encephalopathy and genetically modified organisms (Ludwig 2001), the attitude to openly question the opinion of 'experts' is shared with an increasing expectation to become informed about environmental problems. In The Netherlands, this has been recognized already for some time and large efforts had been taken up to win the public approval for the construction of the slufter, a confined disposal site for contaminated, dredged material in Rotterdam. But according to Haerlin and Parr (1999), "...., most companies and governments still treat public acceptance as just an additional challenge to be overcome by asserting the safety of the technology. They are out of touch with the values of society, and that cannot be overcome by means of any scientific risk assessment." Aspects that increase public perception should already be considered in the risk assessment process and not be left to the risk management step alone. This has been one of the major outcomes of the CARACAS network: They questioned the strict separation of risk assessment and management (which has been an important part of the US EPA policy) and rather opted for a dynamic interplay between both concepts. They conclude: "Nevertheless, if risk assessment and risk management cannot be separated (as these arguments suggest) an improvement in the scientific basis for risk assessment is of the utmost importance for a whole decision making process." (Ferguson et al. 1998).

We believe that an integrated procedure with a strong emphasis on the ecological and ecotoxicological aspects would improve the current practice for risk assessment and increase the public perception.

Why then is the acceptance of ecotoxicological test systems with governmental and ministerial bodies still low – especially in Germany?

1) Direct sediment tests are considered as being too expensive and too time consuming. Indeed, there is a need for short-term, inexpensive, but chronic test systems. Tests with microorganisms and invertebrates with a short generation time and high reproduction fulfil these demands and a direct sediment contact assay with *Arthrobacter globiformis* is in the last phase of standardisation in Germany. However, more development and experience is required in this respect.

2) A misfit between sediment toxicity and concentration of chemicals leads to uncertainties concerning the relevance of ecotoxicological data: high contaminations can still result in low toxic effects and small concentrations of contaminants might lead to high effects in biotests. Even worse: Although monitoring of chemical contaminants might not detect large changes in quality and quantity, ecotoxicological tests might show a large fluctuation of toxic effects between sampling surveys (O'Connor and Paul 2000). Although often used as an argument against ecotoxicological assays, this misfit rather supports the idea of an integrative assessment as biotests show, which neither chemical data nor model assumptions can: the effect of those substances that are bioavailable.
3) There is no assent between ecotoxicologists regarding the composition of a biotest battery for sediments. There will have to be an agreement upon at least general criteria of a minimal test combination before non-scientists will be persuaded of the usefulness of these methods. But it should not be forgotten that some time was needed before harmonization regarding the chemical analyses of sediments had been achieved. However, attempts are made for harmonized approaches. In our working group, a project that is funded by the German Federal Environmental Agency (UBA), and resulted in a close cooperation with federal, private and public institutions, aims at the development and harmonization of a minimal test combination for marine sediments in Germany.
4) Interpretation of biotest data along an absolute scale, resulting in single numbers to indicate the risk of the environment, is difficult and usually left to experts. This results in a lack of transparency and sometimes in the accusation that any interpretation and classification was performed solely subjectively. The complexity of biological effects leaves us with an ecotoxicological response pattern that is interpreted on the basis of ecological knowledge. Deciding upon limit values for environmental protection on the basis of chemical concentrations in sediments is a similar process – in the respect that scientific knowledge has to be involved. Whether chemical or ecotoxicological data, one always has to define the criteria and assumptions on which interpretation is done.

The nature of ecotoxicological testing is in contrast with the long lasting efforts to simplify natural systems and to look for numbers that ensure environmental quality. Ecotoxicology is a young field and much less straight forward than chemical analysis. Together with ecological data, it reflects effects on the living environment. The degree of uncertainty that is connected with the interpretation and the deduction of risk from biotest results is more obvious than with chemical quality criteria, where the process of estimating a risk is a stringent procedure with no place for individual decisions. Therewith, an objectivity is feigned and reliability is confused with reproducibility.

Chapman already stated in 1991 that, "we need to return to common sense and basics (i.e. a recognition of complexity rather than further efforts to oversimplify) in order to avoid the increasing use of bad science as a basis for regulation and management" (Chapman 1991). There has to be a change in the conscience of politicians, as they will have to face the complicated reality of the environment instead of getting yes/no answers on which to base decisions. And it also involves a change in the scientific minds, as the belief that all systems are too complex to permit any statements about prediction, legislation or professional endorsement will impede scientists in their progress (Cairns 1991). Funtowicz et al. (1999) pointed out that the environmental problems represent 'post-normal science' where "typically facts are uncertain, values in dispute, stakes high, and decisions urgent". It is a management task that needs the strong cooperation of scientists and experts in environmental decision making. This "new paradigm relies crucially on a better understanding of environmental and biological processes and on greater sophistication, transparency and rigour in the application of science, but within a collaborative and consensual decision making framework" (Eduljee 2000).

An integrated scientific approach, which has become known as the sediment quality triad (Chapman et al. 1992, Chapman et al. 1996), improves description and analyses of environmental and biological processes, but it still presents a challenge to scientists in this respect, as it demands the integrative assessment of ecotoxicological, chemical and biological data (**Fig. 1**).

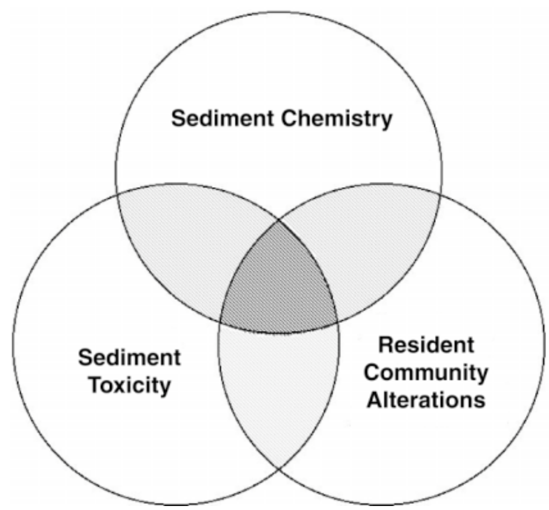

Fig. 1: Conceptual model of the Sediment Quality Triad, combining data from chemistry, toxicity, and in-situ studies (from Chapman et al. 1992)

Ecotoxicological data indicate possible adverse effects, but without identifying the causes. This can currently only be done by chemical analyses. In order to identify the bio-effective substances, methods like whole sediment 'toxicity identification evaluations' (TIEs) or solid phase extractions can be applied (Kosian et al. 1999, Lebo et al. 2001). These combine chemical extractions with ecotoxicological testing. However, these methods still have to be optimised and are currently too expensive to be integrated into routine measurements. Quantitative analyses of chemical contamination that are momentarily performed for risk assessment are needed to indicate sources of pollution, where biotests may not have detected a certain contamination and what – if any – methods should be applied for sediment treatment.

Both ecotoxicological and chemical data leave us with circumstantial proof of an adverse impact on the living environment. Ecological evidence should be sought to verify the assumptions. Generally, determination of benthic species abundance and diversity is time-consuming and work intensive, and a disturbance can also be due to natural changes in the environmental parameters. So, methods are currently looked for that can serve as an indicator of adverse effects and which are easier to quantify, as for example activity of autochthonous microbial community or diversity of invertebrate key species.

A method to integrate the information from the different fields, that is favoured by our working group, is the application of fuzzy expert systems (Heise et al. 2000, Heise and Ahlf in prep), as the fuzzy set theory (Zadeh 1965) is best suited to reflect natural variability, ambiguity and lack of quantitative data in environmental prediction (Silvert 1997). It presents an interesting alternative to stochastic analysis since fuzzy logic models reflect pretty well how humans think and take decisions (Mohamed and Côté 1999), facilitating perception by non-experts. Although this is still an unusual basis for official decision making, it may provide a tool to be integrated into new approaches of environmental risk management. As Einstein may have said, "We cannot solve the problems we have created with the same thinking that created them" (Ludwig 2001).

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