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SEDIMENT QUALITY OBJECTIVES AND CRITERIA DEVELOPMENT IN GERMANY

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ABSTRACT

New objectives regarding the improvement of water quality as well as problems with the resuspension and land deposition of dredged materials require a standardized assessment of sediment quality. Numerical approaches are based on the accumulation, pore water concentrations, solid/liquid partition and elution properties of contaminants; these non-biological schemes can be extended and completed by additional biological criteria. Specific biological approaches have been combined with chemical surveys (for example Sediment Quality Triad). In Germany, numerical criteria are based on the background approach. Biological criteria approaches include bioassays on sediment, porewater and elutriates; recent developments are directed towards microbial solid phase bioassays. Special emphasis is placed on the characteristics of the mineral and organic solid substrate, in particular, buffer capacity against pH-depression; these components should be classified on the basis of the carbonate and sulfide inventories.

KEYWORDS

Sediment quality; chemical-numerical criteria, biological criteria, Germany

INTRODUCTION

Reasons for the development of sediment quality criteria have been in the mid-eighties:

- ♦ that, in contrast to the strong temporal variability in the water phase, sediments *integrate contaminant concentrations over time* (spatial variability in sediments, however, is considerably greater than in the water column);
- ♦ secondly, that long-term perspectives in water management need "*integrated strategies*", in which sediment-associated pollutants have to be considered as well;
- ♦ management plans have increasingly been based on the *assimilative capacity* of a certain receiving system, and this requires knowledge of the properties of sedimentary components as the major sink;
- ♦ in this respect, it soon became clear that contaminants are not fixed permanently by the sediment, but may be *recycled via biological and chemical agents*. Therefore, the contaminant level in the sediment may have greater impact on the survival of benthic organisms than do aqueous concentrations.

Finally, there is the wide spectrum of problems with dredged sediment: permissions for *dredging activities* and *deposition of dredged material* have to be based on standardized sampling protocols and test procedures. In this context, the conventions for the marine environment - Oslo and London - should be mentioned (Förstner, 1989).

Efforts have first been undertaken by the United States Environmental Protection Agency to develop standard procedures and criteria for the assessment of environmental impact of sediment-associated pollutants. Initial review papers provided by JRB-Consultants (1984) and Battelle (1985) indicated five approaches for closer consideration. Further discussions led to the differentiation of biological and chemical-numerical approaches (Chapman *et al.*, 1987). Numerical approaches, are based on (1) accumulation, (2) pore water concentrations, (3) solid/liquid equilibrium partition (both sediment/water and organism/water) and (4) elution properties of contaminants (Shea, 1988). The second component in an assessment scheme would include characteristics of the solid substrate, in particular, buffer capacity against pH-depression (Förstner *et al.*, 1990). Biological criteria can be subdivided into data derived from *field observations*, tests on *original sediments* and toxicity tests on *spiked sediments*.

Chemical-Numerical Criteria

- ♦ "Background"-Approach
- ♦ Pore Water Composition
- ♦ Sediment/Water-Equilibrium
- ♦ Remobilisation (Short-, Medium- and Long-Term)
- ♦ Substrate Composition (Acid Producing and Buffer Capacity)

Biological Criteria

- ♦ Field Observations
- ♦ Bioassays with Original Sediments
- ♦ Bioassays on Spiked Sediments

Biological criteria integrate sediment characteristics and pollutant loads, but they do generally not indicate the cause of effects. With respect to chemical-numerical criteria, there is no immediate indication on biological effects; their major advantages lie in their easy application and amendment to modeling approaches.

CHEMICAL-NUMERICAL APPROACHES

A few remarks on the possibilities and limitations of chemical-numerical criteria approaches.

Background Approach: Compares the actual data with sites comprising natural or insignificant pollutant concentrations. Particularly useful are samples from deeper layers of the sediment sequence at a given site, for example, from drill holes, since this material is derived from the same catchment area and usually is similar in its substrate composition. Nonetheless, standardization with respect to grain size distribution is indispensable.

Porewater Approach: Based on the experience that the composition of interstitial waters is the most sensitive indicator of the reactions that take place between pollutants on particles and the aqueous phase which contacts them. There is the advantage of a direct recovery and analysis of water-borne constituents. But there are several disadvantages, mainly arising from the sampling and sample preparation, which need considerable precaution, such as for exclusion of oxygen.

Equilibrium Approaches: These approaches are related to the broad toxicological basis of food and water quality data - a very important advantage. On the other hand, there are the effects of sample preparation, e.g., the drying procedures; the separation techniques, for example, filtration or centrifugation; there are the before-mentioned strong effects of grain size composition, the influence of suspended matter concentration in the aquatic system, which is even more important, if the kinetics of sorption and desorption are too slow for reaching equilibrium in a given time of interactions - with the extreme situation of non-reversibility of these processes, as observed for metals, PCB and chlorophenols.

U.S. EPA is currently proposing the equilibrium partitioning approach for deriving sediment quality criteria for non-ionic organic chemicals (Anonymous, 1990; Adams et al., 1992). In fact, for compounds such as PCB, DDT, and PAH, the equilibrium approach may be acceptable, in comparison to the problems still present with other methods. K_D -values of *metals* are not only correlated to organic substances but also with other sorption-active surfaces; therefore, the equilibrium partition approach exhibits strong limitations for metallic elements. For polar organic substances, which are widely unexperienced with respect to their "sorption" behaviour, the K_D -approach at present cannot be taken into consideration.

Remobilization: Short-term effects may be studied from water/sediment-suspensions, medium-term effects from experiments using tanks. Field observations, often do not show clear effects. This is valid, in particular, to the effect of metal mobilization from anoxic sediments during oxidation. This point - which is very important for dredging activities - should be discussed in more detail with new experience.

Sensitivity to Redox Variations

Direct assessment of the pH-changes resulting from the oxidation of anoxic sediment constituents can be performed by ventilation of sediment suspensions with air or oxygen. In practice, sediment substrates should be characterized with respect to their acid-producing potential and their buffer capacity. From such data, a prognosis can be made of middle- and long-term mobilization, in particular, of toxic metals. The acid-producing potential mainly depends on the oxidation of sulfides and organic matter, the buffer capacity is predominantly represented by the carbonate content of the sediment. Results from titration experiments using 1 molar nitric acid on sediment suspensions of 100 g/L are presented in figure 1. The titration curve of the Rhine River sediment exhibits a small plateau in the pH-range of 5.5 and 6, probably due to a certain fraction of carbonate, which is consumed by addition of 80 mmol of acidity. On the contrary, the titration curves of both Elbe River sediments are continuously decreasing as a result of the low content of carbonate in these samples. The sediment from the inland harbour basin of Harburg, originally sulfide-rich material which has been stored for 1 year in a closed bottle, has already reached an initial pH of 4.3; this is probably due to the consumption of the low residual buffer capacity by oxidation of parts of the sulfide fraction.

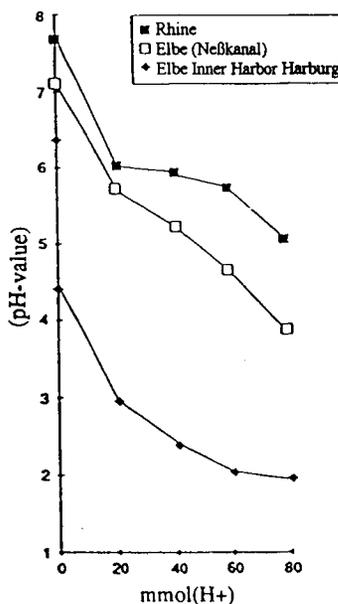


Figure 1

Variation of pH-Values from Titration Curves of Suspensions (100 g L^{-1}) of Sediment Samples from Rhine and Elbe Rivers after Addition of 1 M Nitric Acid (Förstner et al., 1992)

Additional biological criteria

The chemical-numerical approaches can be extended and completed by additional biological criteria. This normally implies a considerable gain of information. Two examples were selected:

An "ecological risk index" was introduced by Hakanson (1980) and tested on 15 Swedish lakes representing a wide range in terms of size, pollution status, trophic status, etc. Enrichment factors were multiplied by a "toxic response factor" for individual compounds, and the element lead, for example, is taken as factor 5, cadmium as factor 30, and mercury and PCB are multiplied by 40. The "toxic response factor" is formulated from a complex set of assumptions. It can possibly be defined much easier from direct measurements of the relative toxicity of typical pollutants, e.g., from bioassays on water samples. We propose a toxicity factor based on the standardized Microtox Test System, where the individual multiplicants are determined from comparable EC_{50} -values.

The effect of bioconcentration provides important perspectives for sediment criteria development (Lake *et al.*, 1987) and, therefore, deserves closer consideration. Bioconcentration of organic components seems well correlated to lipophilicity (Mackay, 1982). However, the correlation to $K_{Octanol/Water}$ must be used with discretion. Oliver (1984) has found characteristic linear dependencies of bioconcentration of oligochaete worms in sediments for chemicals with K_{OW} 's less than 10^5 . At very high partition coefficients of chemicals ($>10^6$), there is a rapid decrease in bioconcentration. The decrease may be caused by difficulties in chemical transport across membranes due to large molecular size or may be affected by strong binding of these chemicals to the sediment particles making them less bioavailable.

Chemical-numerical criteria include the widely discussed approach by DiToro (1992) called "metal-AVS-normation". The idea behind this method is that at a surplus of sulfide, the metals in the system should not be biologically available. If this would be valid, the analytical efforts could be reduced considerably. However, there is increasing evidence that metal availability to organisms cannot generally be deduced from this parameter. For example, aquatic plants have adapted to reduced sediments and by oxidizing the rhizosphere they make both essential elements and toxic metals more bioavailable (Klaine *et al.*, 1993). With respect to criteria development, AVS-normation can only reflect short-term conditions within homogenized sediment. Sooner or later - if no provision is made for keeping permanent anoxic conditions, e.g., by capping these materials - resuspension of the sediment will induce oxygenation and by this process remobilization of metals will take place (Kersten and Förstner, 1991).

NUMERICAL SEDIMENT QUALITY CRITERIA USED IN GERMANY

In the following section, several examples will be given of proposals to introduce sediment quality criteria for German surface waters.

Index of Geoaccumulation (Müller, 1979)

A first quantitative measure of metal pollution in aquatic sediments has been proposed by Müller, which is called the "Index of Geoaccumulation", that is: the enrichment on geological substrates:

$$I_{geo} = \log_2 C_n / 1.5 \times B_n$$

The I_{geo} compares the the measured concentration of the element in the fine-grained sediment fraction (C_n) with geochemical background value (B_n) in fossil clay and silt sediments. The Index of Geoaccumulation consists of 7 grades, whereby the highest grade (6) reflects 100-fold enrichment above background values. Table 1 presents examples for the River Rhine catchment; and a comparison of these sediment indices with the water quality classification of the International Association of Waterworks in the Rhine Catchment has been made. Highest rates of accumulation - at different levels for the Upper and Lower Rhine sections - have been found for cadmium, lead, zinc, and mercury, whereas copper, chromium and cobalt are less concentrated in these sediments. No further consideration is given to the ecological relevance of the values.

Table 1 Comparison of IAWR (International Association of Waterworks in the Rhine Catchment) Water Quality Indices (Based on Biochemical Data) and Index of Geoaccumulation (I_{geo} ; Müller, 1979) of Trace Metals in Sediments of River Rhine

$$I_{geo} = \log_2 C_n / 1.5 \times B_n$$

IAWR Index	IAWR Water Quality (Pollution Intensity)	Sediment Accumulation Index (I_{geo})	I_{geo} - Class	Metal Examples	
				Upper Rhine	Lower Rhine
4	Very strong pollution	>5	6		Cd
3-4	Strong to very strong	>4-5	5		
3	Strongly polluted	>3-4	4		Pb, Zn
2-3	Moderately to strongly	>2-3	3	Cd, Pb	Hg
2	Moderately polluted	>1-2	2	Zn, Hg	Cu
1-2	Unpolluted to moderate	>0-1	1	Cu	Cr, Co
1	Practically unpolluted	<0	0	Cr, Co	

We have used the Index of Geoaccumulation for a comparison of five river systems in Germany. Of these examples the sediment sample from lower Rhine River (collected from the deeper part of the sediment pile) exhibits highest overall metal accumulation, followed by the sample from the Elbe River; in both examples, mercury and cadmium are typically influencing the average factor of enrichment. The sediment samples from the rivers Weser, Main, and Neckar are by far less contaminated than the aforementioned materials; however, there is still considerable enrichment of cadmium in sediments of both the Weser and Neckar Rivers.

Table 2 Index of Geoaccumulation (after Müller, 1979) for Sediments from Five Examples of Rivers in Germany ($I_{geo} = \log_2 A_n / B_n \times 1.5$)

	Neckar R.	Main R.	Rhine R.	Elbe R.	Weser R.
Copper	0	1	2	2	0
Lead	1	2	2	2	2
Zinc	1	2	3	4	2
Cadmium	3	2	6	4	4
Mercury	0	1	4	6	1
Average	1.0	1.6	3.4	3.3	1.8

Incorporation of "Toxic Effects" into Accumulation Data

The major deficiency of this method is that it does not take into account the biological effects of the different pollutants. This situation can partly be overcome by introducing a factor for the relative toxicity. Such factor can point more clearly to the critical compounds, and may therefore stimulate setting priorities for control and rehabilitation measures. In the present Table, a factor of toxicity has been used which is derived from the Microtox Test System. In the case of the extreme mercury pollution of the Elbe River, reduction of a specific source - emissions from chlorine alkali plants - could contribute to the improvement of the overall sediment quality. For example, with available technology and reasonable costs the concentrations of mercury in the Elbe River could be reduced to such an extent that the overall sediment quality would be at least comparable to the sample from the Weser River.

Table 3 Factor of Enrichment x Toxicity Factor (Standardized "Microtox" Values, after Walker, 1988)

		<i>Neckar R.</i>	<i>Main R.</i>	<i>Rhine R.</i>	<i>Elbe R.</i>	<i>Weser R.</i>
Copper	(x 5)	7	10	17	22	6
Lead	(x 1)	2	4	4	6	4
Zinc	(x 5)	10	15	35	70	30
Cadmium	(x 10)	62	53	500	340	360
Mercury	(x 35)	46	98	805	2520	81
<i>Total</i>		<i>127</i>	<i>180</i>	<i>1381</i>	<i>2958</i>	<i>481</i>

Numerical Evaluation of the Factor "Element Mobility"

A last example refers to the elution properties of sediment samples. Here, an "elution index" is based on the metal concentrations which are exchangeable with 1 N ammonium acetate at pH 7; this fraction should be mobilized under more saline conditions, for example, in the estuarine mixing zone. Comparison of the release rates from oxic and anoxic sediments clearly indicates that oxidation of samples affects a very significant increase of the metal mobility; this effect is particularly important for cadmium.

Table 4 Elution-Index for Selected River Sediments, as Determined from Exchangeable Proportions (1 M Ammonium-Acetate). Calculated Relative to Background Data from Elbe River Sediments. These Values are Multiplied by a Factor of 100

	<i>Neckar R.</i>	<i>Main R.</i>	<i>Rhine R.</i>	<i>Elbe R.</i>	<i>Weser R.</i>
Copper	0.2	-	1	1	-
Lead	1	1	2	1	1
Zinc	7	9	28	36	9
Cadmium	30	30	230	30	-
<i>Total Oxic</i>	<i>38</i>	<i>40</i>	<i>261</i>	<i>68</i>	<i>10</i>
<i>(Anoxic)</i>	<i>0.5</i>	<i>0.3</i>	<i>8</i>	<i>> 4</i>	<i>4</i>

Proposal for Reference Values for Sediment Resuspension in the Elbe River Estuary

In the river mouths to the southern coast of the North Sea, approximately 20 million m³ sediments have to be dredged from Rhine/Meuse (Rotterdam harbour) and ~10 million m³ from the rivers Scheldt (Antwerp), Weser (Bremerhaven) and Elbe (Hamburg). Total quantity of sediment to be dredged in The Netherlands, Belgium and Germany amount to about twelve times the total suspended matter supply from the Rhine. The possibilities of disposal of these enormous quantities of material are severely limited because of the pollutants present in the dredged material.

In Germany, the critical area, for which "orientation values" for priority pollutants have been designed, is the Elbe River estuary. During the last ten years, the harbour authorities - in addition to land disposal - used the method of "sludge-harrowing" for resuspension of part of the dredged material deposited in harbour basins and shipping channels. During ebb-stream, the suspended particles should be exported to the North Sea. The effect can be seen from recent data (Förstner, 1990): in the upper reaches of the Elbe estuary, mercury, cadmium and zinc are enriched by factors of 100 to 10 compared to natural background. Meanwhile, however, there is already a significant increase of mercury and cadmium in the outer estuary, close to the North Sea.

We have proposed relatively simple reference values for decisions on active resuspension. A ten-fold enrichment was considered as an undisputed significant pollution effect, and sediments above this limit should not be resuspended. For cadmium and mercury, both elements from the black list, a five-fold increase in the sediment was considered critical. Our proposal (Förstner, 1990) is similar to the Dutch sediment draft (Van Veen and Stortelder, 1988), designed for the management of Rotterdam harbour sludge subsequent to the filling of the artificial peninsula off Rotterdam (Table 5).

Table 5 Proposal for Reference Values of Pollutant Concentrations on the Basis of a 10-Fold Enrichment (Exception: Cadmium and Mercury - 5-Fold Enrichment) Compared to Background Values of Elbe River Sediments (Fraction <63 μm)

	<i>Reference Rotterdam Harbour</i>		<i>Background Conc.</i>	<i>Proposal for LAWA</i>
	<i>Target Value</i>	<i>Standard Value</i>	<i>Elbe River Sediment</i>	<i>Reference Values*</i>
Mercury	0.3	1	0.2 - 0.4	1 mg/kg
Cadmium	0.8	4	0.3 - 0.5	2 mg/kg
Arsenic	25	40	3 - 5	40 mg/kg
Lead	50	125	25 - 30	250 mg/kg
Copper	25	70	20 - 30	250 mg/kg
Zinc	180	750	90 - 110	1000 mg/kg
PCB*	1	10		10 $\mu\text{g}/\text{kg}$
PAH*	50	500		500 $\mu\text{g}/\text{kg}$

* for each individual PCB or PAH * Förstner (1990)

BIOLOGICAL CRITERIA DEVELOPMENT IN GERMANY

In spite of the limited acceptance of the available information by official policy, active administrators initiated an even wider and more ambitious programme on quality objectives of fresh waters. Sediments should form a major aspect in this programme of the Federation-States Working Group, and emphasis is given to the protection of organisms living on or within the sediment including microflora and microfauna of the interstitial system in addition to the quality objectives for aquatic communities. It is stressed that these communities are significantly supporting the transport, fixation and degradation of hazardous substances in sediments. Such quality objectives need criteria based on biological investigation:

- ♦ the large variety of substances in sediments may produce synergisms, which do not permit *a priori* consideration on individual substances, and
- ♦ matrix effect at the actual state of knowledge does not permit interpretations according to the dose-response relationship.

Biological sediment quality criteria

The available biological sediment quality criteria have now to be checked, if they respect the requirements to be generally applicable (to different sites and all exposition pathways) and comprehensive (to different trophic levels and a wide spectrum of contaminants):

Bioassay approach: Directly measures the toxicity of a contaminated sediment, respecting all exposure pathways. Needs standardized procedures and a test battery for the assessment of different contaminants. Can be generalized if the problem of control and reference sediments is solved. Comparable concentration-effect relations can be established in aquatic bioassays by stepwise dilution. Due to the variety of sediment types this procedure can at present not be used for sediment toxicity tests. As with all bioassays, there is no clear answer to the question of their ecological relevance.

Apparent Effects Threshold Approach: Uses empirical data and can be improved by additional data. The interpretation is not unequivocal, since it depends on the applied effect indicators. In Germany, the procedure cannot be used for freshwater systems, since there are not enough data available from such environments. Data from United States cannot be used, since they were mainly related to marine sediments.

Screening Level Concentration Approach: Is based on actual field data, which indicate the effects of contaminated sediments; however, influences other than pollutants can be reflected in the sediments as well. Ecologically descriptive data are inherently site specific, and therefore their applicability to other sites is limited.

Equilibrium Partitioning Approach: Includes all exposition pathways. It requires definition of acceptable concentrations of contaminants in the organisms. As already mentioned, equilibrium sediment-biota partition is applicable for hydrophobic organic pollutants; it is, therefore, not comprehensive. Possibly, the approach can be generalized, if the assumption is valid of constant bioaccumulation factors for different contaminants and organisms.

Sediment Quality Triad (Chapman, 1986): A combination of biological laboratory and field data in comparison with chemical analyses, which compensates the limitations of the individual approaches. Interpretation of data is not always possible. Not standardized at present, may nonetheless lead to general sediment quality criteria, however, at relatively high costs. The sediment triad is an integrated procedure, which uses empirical evidence, that is observation, not being based on theories. Such procedures seem to be particularly promising, since each component of the system is contributing to the interpretation of the other components.

In Europe, two integrated procedures have been proposed during recent years. The one by Van de Guchte *et al.* (1991) is directly based on the sediment triad, and it is aimed for the site-specific assessment of highly contaminated sediments - "hot-spots" - in the Netherlands. The triad parameters include:

- ♦ Chemical analyses of 49 substances, such as heavy metals, PCB, PAH, chloro-pesticides;
- ♦ biological analysis of field parameters for site-specific assessment of bioavailability of characteristic pollutants and their adverse effects (by benthic organisms). Investigations on accumulation processes, for example on molluscs, will be included;
- ♦ the third component is a toxicological analysis using bioassays (*Chironomus* sediment toxicity test, *Daphnia* elutriate test). The objective is to answer the question if the effects found in the field studies are caused by the sediment-associated pollutants.

This concept has been applied on Rhine sediments. At given chemically based sediment quality, two contamination levels can be derived from the studied parameters: "Safety Level" and "Warning Level". If the three groups of measured parameters (chemical, field-biological, ecotoxicological) congruently deviate from the reference values, then the "Warning Level" is reached. This could mean that this proportion of dredged material cannot be resuspended or that special precautions have to be applied during dredging.

The concept of Ahlf and collaborators for the assessment of sediment-bound pollutants exclusively relates to toxicological data. It is mainly based on microbial toxicity tests, using bacteria and algae. An overall biological assessment scheme includes: (1) Field description of benthic communities; (2) benthos bioassay on total sediment; (3) porewater bioassay (bacteria, Chromotest); and elutriate bioassay (algae, bacteria, Chromotest). In addition, tests can be performed on fractions of the sediment which have been extracted or treated with a co-solvent. For example, a non-polar surfactant has been applied, which is commercially used to solubilize hydrocarbons from contaminated soil. On the other hand, the concept can be modified according to users requests, in that only parts of this structure may be needed for a site-specific problem.

The sediment study in the Hamburg harbour area was carried out on the basis of 50 sediment cores. A portion of the sediments was extracted with the addition of a non-polar surfactant. Factor analysis has been performed for 64 samples with chemical characterization. The bulk concentrations of cadmium, copper, mercury, hydrocarbons, extractable organic chloride, and Lindane were selected as relevant variables.

Table 6 Representation of the Four Main Factor Loadings Resulting from a Factor Analysis of 64 Sediment Samples (Ahlf *et al.*, 1991)

	<i>Factor 1</i>	<i>Factor 2</i>	<i>Factor 3</i>	<i>Factor 4</i>
Algae Assay			0.91	
Bacteria Assay		0.89		
Bacteria/Detergent		0.86		
Cadmium	0.90			
Copper	0.91			
Mercury	0.67		0.51	
Hydrocarbons				0.94
EOX	0.86			
Lindane		0.54		

The first factor joins the main contaminants and indicates the same contamination source and/or the same sedimentary behaviour. The second factor suggests a relationship of Lindane to bacterial toxicity. The third factor represents the high phytotoxicity of Hg and its assessment in the algae assay. Finally, separation of the hydrocarbons in factor 4 indicates that the distribution of hydrocarbons is affected by distinct inputs.

An integrated concept of sediment toxicity evaluation, which is presently designed for the surface waters in Germany, will consist of the two components "bulk sediment" and "elutriate". The bulk sediment bioassay, which also includes pore water, involves analyses of effects on microorganisms, plants, benthos organisms and on genotoxicity. New developments refer to "solid phase" bioassays using microorganisms. For soils, plants are important indicators of pollutants in dredged material on land. Elutriate tests comprise standardized procedures on bacteria, algae, daphnia and DNA. Both compartments can be compared and further interpretation on extrapolation from laboratory to nature is mainly derived from description of microflora. Its major advantage lies in the fact that it reflects complex ecological responses in the sediment below a square centimetre scale. A new solid phase bioassay is presently developed on the basis of studies on artificial sediment in comparison with elutriates; the bacteria were more sensitive in contact with the spiked sediments.

SUMMARY AND OUTLOOK

From the present experience, including a recent evaluation of about one thousand literature references, we come to the following conclusions.

- ♦ As far as equilibrium conditions can be assumed for sorption and desorption processes, one should restrict toxicological investigations to the water phase
- ♦ Biological effects, which are suspected to be caused by sediment-bound contaminants should preferably be assessed by laboratory experiments
- ♦ On the other hand, if the effect of "in place" pollutants on the abundance and distribution of benthic organisms have to be studied, this should be done from field data
- ♦ We should emphasize the merits of microbial bioassays, which are rapid, inexpensive and sensitive to toxicants. In many cases microbiotests are adequate substitutes for expensive macro-biotests

We can conclude that the tools for biological investigations are basically available, especially in the area of bioassays. What is still missing, are the agreements on standardized concepts and procedures. Optimization of procedures will remain one of the major objectives of future research, in particular for a better assessment and understanding of ecological effects from moderately polluted sediments.

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