Commentaries

From Risk Assessment to Sediment Management

An International Perspective *

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Abstract. Contaminated sediment management is complex and multivariate, involving a careful balance of science, politics and economics. As is true for most such complex issues, there is not a single correct way to address a problem, but rather the approach should be driven by the ecological, political and economic goals of all interested parties. However, because the choices made have far-reaching implications, it is useful for countries, regions or communities to develop standard approaches for sediment assessment and management to meet agreed-upon goals. This paper provides a brief review of a number of sediment assessment frameworks from around the world. Their main similarities and differences, and some of the reasons behind them, are addressed. Aspects of assessing and managing sediments are discussed, as well as why these are (or should be) driven by sediment management goals. Finally, suggestions are made to support the development of a European framework for sediment management and environmental quality.

Keywords: Assessment; conceptual site model (CSM); dredge disposal; ecological risk assessment; environmental quality; Europe; framework; in-place management; management; pathways; sediment; sediment policy; SedNet (demand-driven, European Sediment Research Network); sediment quality guidelines (SQGs)

1 Background

While there are exceptions to every rule, the field of contaminated sediment management can be divided into two general categories, largely defined by the purpose for which they are being examined. The first, construction or navigational dredging, generally involves the assessment and removal of large volumes of sediment. In many cases, these sediments have lower contaminant levels, or contaminants reside in areas considered to be of lower ecological significance than do 'hotspot' sediments, and thus they would not generally be the subjects of immediate environmental investigation if they were not the target of a dredging operation. Of course, in areas with high levels of historical contamination, or sites with significant ongoing contaminant input, these sites may have high levels of contamination that cannot be managed until sources are controlled or resources are available. Since removal is a given in this aspect of sediment management (unless environmental or economical problems bar it), assessment is carried out to address the risks of resuspension through dredging, disposal, beneficial uses and/or treatment options. The second type of sediment management, hotspot or environmental cleanup of contaminated sediments, generally addresses smaller volumes of sediment, though there are notable exceptions. The sediments addressed for this purpose may have much higher contaminant levels than do sediments managed for navigation and construction dredging, they may reside in areas of ecological significance or they may contain substances of particular concern (e.g., bioaccumulative substances), prompting immediate investigation and/or management. These sediments become the target of investigation when a spill, survey, toxic effect or historical record flags them as potentially posing a risk to human health, fisheries or the environment. Assessment of such sediments can focus on absolute and relative risk, as well as risks of in-place vs. removal options. The regulatory frameworks and technical communities that address these two sediment categories are often separate, with little or ineffective interaction. Assumptions, methods and frameworks designed to address one category may be inappropriate for the other.

Sediment management strategies fall into five broad categories, which are selected based upon an evaluation of site-specific risks and goals: 1) no action, which is only appropriately applied if it is determined that sediments pose no risk, 2) monitored natural recovery, based on the assumption that, while sediments pose some risk, it is low enough that natural processes can reduce risk over time in a reasonably safe manner, 3) in situ containment, in which sediment contaminants are in some manner isolated from target organisms, though the sediments are left in place, 4) in situ treatment, and 5) dredging or excavation (followed by ex situ treatment, disposal and/or reuse). The information required to evaluate or compare each of these options is fundamentally different, and any assessment should be designed to evaluate and support management goals and potential remedial options.

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For clarity a few terms will be defined, since they can have different meanings depending upon the background of the practitioner using them. As used in this paper, sediment assessment is defined as the process used to characterise sediment for a given purpose (e.g., evaluations for risks to environmental health, dredged disposal, land farming, habitat construction, etc.). Sediment management is defined as the process of making decisions and taking actions on sediments, taking into consideration a wide range of factors. A third important term which is used is Conceptual Site Model (CSM, see, e.g., ASTM 1995), which can be defined as a three-dimensional description (either qualitative or quantitative or a mixture of both) of a site and its environment, which defines what is known (or suspected) about the contaminant source area(s) and the physical, chemical, and biological processes that affect contaminant transport from the source(s) through environmental media to potential environmental receptors. The CSM is a tool to aid in the design of sediment assessment to inform management decisions.

2 Review of Sediment Assessment and Management Frameworks

Sediment assessment frameworks from various jurisdictions known to be active in sediment management were reviewed. We looked for similarities and differences between the frameworks, and, in particular, noted the role of sediment quality guidelines in sediment assessment approaches. Many of the management frameworks follow prescribed pathways, with detailed flowcharts and defined endpoints. Others are quite conceptual, describing a pathway or philosophy, but leave many aspects to the practitioner's discretion. When we organized the various frameworks by their management objectives, there were two main categories: dredged disposal and environmental assessment and management (e.g., general assessment of environmental quality and more focused assessment of contaminated sites with sediment issues). This review of sediment frameworks is our initial attempt at synthesizing elements of such frameworks. As we intend to follow up on this commentary article with a more in-depth analysis, the authors welcome identification of sediment assessment and/or management frameworks that have been overlooked in our review, below.

Examples of national/regional frameworks that were primarily for dredged disposal included those from England/Wales (CEFAS 2002), Australia/New Zealand (ANZECC and ARMCANZ 2000), Hong Kong (HKWB 2000, Nicholson 2000), Germany (Handlungsanweisung für den Umgang mit Baggergut im Küstenbereich HABAB-WSV; summarized in GKSS Research Centre 2001), Canada (Canadian Environmental Protection Act 1999, Schedules 5 and 6), USA (US EPA and ACOE 1991, 1998a), Puget Sound Dredged Disposal Analysis Program (PSDDA 1989, 1999), Great Lakes (US EPA and ACOE 1998b), the National Research Council (1997) report, and the Netherlands (in progress). Dredged disposal frameworks tend to be the most common type of sediment management framework. In addition, they are often more detailed and prescriptive than other sediment frameworks, as will be discussed below. As well as these national/regional frameworks for dredged disposal, there are international conventions such as the Convention for the Protection of the Marine Environment of the North-East Atlantic (Oslo and Paris Convention, OSPARCOM 1998) and the London Convention 1972, as well as guidance issued by pan-national organizations such as the International Maritime Organization (IMO), London Convention 1972, Permanent International Navigation Association (PIANC), Central Dredging Association (CEDA), and International Association of Ports and Harbors (IAPH). These bodies and their conventions tend to define general principles that national frameworks should adhere to.

In terms of understanding environmental quality, sediment guidance reviewed for this article included approaches used in the US EPA's draft National Sediment Inventory (US EPA 2001), New Zealand/Australia (ANZECC and ARMCANZ 2000, Batley 2001), and others which are in progress (e.g., The Netherlands). Specific frameworks for sediment assessment at contaminated sites included those from British Columbia, Canada (in progress), Superfund, USA (in progress), NRC (1997, 2001), Washington State, USA (Washington State Department of Ecology, Toxics Cleanup Program, Sediment Management Standards Regulations) and the Great Lakes Areas of Concern (USA/Canada, US EPA 1994). In addition to environmental assessment/management guidance tailored for sediments, which is very often risk-based, there are many generic ecological risk frameworks that are applied to sediment issues on a site-specific basis.

There were a number of differences and similarities between assessment frameworks – the primary dissimilarities could be categorized as being differences in: 1) the level of detail used to describe the framework and its elements (e.g., specificity of biological methods), 2) the degree to which criteria to move from one tier to the next are detailed, 3) the way the data are used to support decisions (i.e., independent vs. burden-of-evidence), and 4) the degree of professional judgement allowed. Similarities can be summarized as 1) virtually all frameworks are tiered, 2) virtually all frameworks use sediment quality guidelines in early tiers (with the exception of US EPA and ACOE 1991, 1998a), and 3) many frameworks, particularly those from North America, use biological assessment at higher tiers of evaluation.

Sediment assessment frameworks can be seen to exist on a continuum, from specific decision trees designed to select dredge disposal options to custom ecological risk assessments (EcoRAs) designed to assess risk and select an environmental management strategy. Due to their narrow focus, frameworks designed for assessing dredge disposal options are relatively inflexible, but are relatively simple to use because they provide specific guidance. The experience level required to carry out such an assessment can be less than that required for sediment assessments for other purposes. In contrast, sediment assessment frameworks designed to support environmental management strategies can be highly flexible and quite complex to carry out. As a result, they tend to either have elaborate guidance or to provide general, flexible guidance. In either case they usually require a high level of experience to carry out successfully, particularly where they are linked to sediment remediation planning.

An important tool in many sediment assessment frameworks is the use of sediment quality guidelines (SQGs), also known as action levels, criteria, standards, trigger values or screening values. 'Sediment numbers' have been developed in many jurisdictions for both categories of sediment management described in this paper (see compilations in EVS 1998, Chapman et al. 1999). However, in the vast majority of frameworks reviewed, they are not designed for use as disposal or cleanup criteria. While they are useful for flagging potentially toxic contaminant levels in sediments, and can thus indicate which sediments may be of no concern and those which merit a closer look, site-specific considerations and biological analyses should be used to develop remedial goals at a site. Significant efforts have gone into developing SQGs internationally. Leading efforts have been by the National Atmospheric and Oceanic Administration (Long and Morgan 1991, Long et al. 1995), Environment Canada (CCME 1999), Washington State (Washington State Department of Ecology, Toxics Cleanup Program, Sediment Management Standards Regulations), Florida State (MacDonald et al. 1995), The Netherlands (Min. V&W; cited in Peerbloom and van Hattum 2000), and some jurisdictions are in working on new guidelines (e.g., British Columbia Canada and The Netherlands). However, sediment guidelines and their derivation methods are still controversial, and the appropriateness of their use should be carefully evaluated in terms of site management goals, study questions and the CSM. To address and clarify some of these issues, sediment quality guidelines and sediment assessment frameworks will be one of the subjects of a Society of Environmental Toxicology and Chemistry (SETAC) workshop in the summer of 2002. Two recent documents that address the use of SQGs and weight-of-evidence frameworks are Chapman et al. (2001) and Batley et al. (2002).

Many factors, both scientific and non-scientific, must be addressed in sediment assessment and management. Science factors, which define and are guided by the CSM, include sediment type (grain size, percent and quality organic carbon (OC), mineralogy, etc.), receptors of concern, exposure routes, contaminant type(s), water type (marine, fresh, brackish), physical dynamics (deposition, erosion, tidal cycles, wave action), and the proportion of contaminated sediment to uncontaminated sediment. Non-science factors (which define and are guided by the management goals) include: management objectives, regulatory framework, protection goals, public interest(s), resources (financial and technical), economic implications of any action, perceived risk, 'cuteness coefficient' (whether or not charismatic animals are potentially at risk), and time factors. A summary of approaches for addressing many of these issues can be found in Apitz et al. (2002), and references therein.

A 'classical' ecologist's definition of ecological risk assessment (ecorisk) is the product of the magnitude of the adverse ecological effects (hazard) and the probability of adverse ecological risk (exposure). Put simply, even the most toxic material does not pose risk if there is no exposure pathway to an organism, but if an organism is likely to be exposed to toxics frequently or for an extended period of time, even relatively less toxic materials can pose significant risk. However, there are many types of risk, and what is evaluated depends upon the goals and the CSM. A few examples are absolute ecorisk (i.e. 'Does sediment x put species y at risk?'), site-specific risk (e.g., 'What is the risk of sediment x relative to regional or background risk?'), manageable risk (i.e., 'Can this risk be controlled?') and management option risk (e.g., 'What is the risk of leaving sediments in place vs. disturbing them?'). Sediment assessment and management frameworks (which are essentially risk-based) can be designed to address absolute risk to a specific target organism or community, to rank sediments within a region, to compare site-specific and regional or background risk, or to select and evaluate management strategies.

An important issue that must be resolved in a sediment management framework, and one that is addressed differently by various EU Member States is how one identifies reference sites and background contaminant levels. Reference areas can be used to make comparisons among biological, chemical or physical sediment data that might be collected from an area under study. Lack of appropriate criteria for selecting the reference areas may result in an inappropriate location being selected, and inappropriate sediment management actions being taken. Identification of the reference site may depend on the remedial goals and options, historical and existing conditions at the site, as well as the critical physical, chemical and biological parameters that are being evaluated. While absolute concentrations of contaminants in sediments are an important part of assessing site sediments, there are a number of reasons why this alone does not provide a full picture of what is happening at the site. Both organic and inorganic contaminants can exist in a region at background, ambient or natural levels, either because they have natural sources or because entire regions in urbanized, industrialized and other areas are exposed to ubiquitous levels of anthropogenic input. In many cases, since such contaminants have a tendency to associate with fine-grained sediments, there is a general regional tendency to have a 'mixing curve' of contaminated fines, and relatively uncontaminated coarse-grained sediments. Often, either ambient contaminant levels or background natural levels or a combination of both can be separated from site-specific levels by normalizing to or plotting against sediment characteristics which tend to indicate natural metal-rich particles (e.g., Fe, Al) or fine-grained particles (e.g., Fe, Al, %fines, %OC). While ambient or background levels of contaminants can be bioavailable, and may cause ecological impact, they are almost impossible to manage for on a site-specific basis – cost and logistics make it unlikely that an entire region will be remediated, and if specific sites are remediated to below ambient levels, those sediments are likely to be subject to recontamination by background sediments. Thus, it is important at a given site to examine contaminant distribution relative to regional, ambient or background levels, and to select reference sites with care (Apitz et al. 2002).

Primarily because of the large influence of the dredging community on the field of sediment assessment and management in North America (Power and Chapman 1992), until recently most of the sediment management approaches and research focused primarily on ex situ sediment treatment and disposal options, rather than on in-place management and risks. Essentially, we argue that the tools that were developed for environmental assessment and management of sediments were derived from the field of dredging and disposal. However, due to the large volumes of sediment to be managed, in recent years, many (though not all) groups predict or advocate that large volumes of contaminated sediment will be managed in place (unless dredging is the driver), largely because of the potential costs involved. Thus, sediment frameworks and research are evolving to match these specific objectives, resulting in improved approaches for site assessment to delineate contamination and better use of site data to frame management decisions.

A number of dynamic pathways may contribute to contaminant transport and exposure at contaminated sediment sites. These include the effects of bed transport, bioturbation, diffusion and advection, resuspension and deposition, and tranformation and degradation. The relative rates of these processes help define the potential risk of in-place sediments, pathways of exposure that must be controlled and, potentially, mechanisms of natural recovery of the sediment. A risk assessment that considers in-place management options must address all these factors. An understanding of the relative importance of these processes at sites will focus site conceptual models and help risk managers balance these processes to minimize risk and, ideally, optimize recovery (Apitz and Chadwick 1999, 2001). Such an evaluation should provide sufficient information to support decisions about which sediments can responsibly be managed in place, how aggressively they should be monitored or contained, or whether they should be removed and managed ex situ.

Sediment containment and disposal options which can be considered under appropriate circumstances include landfills, confined disposal facilities, in-place natural recovery, contained aquatic disposal, in situ capping, and deep ocean disposal. To evaluate these, sediment quality and risk must be compared to that of target environments. If removal is a given for dredging purposes, in-place risk is less important that it would be for a hotspot site (although it might need to be mitigated), and assessments may not focus on it. If removal is being evaluated, then risks of removal, transport, treatment and/or disposal in various environments must be evaluated.

The National Research Council, Marine Board – Committee on Contaminated Sediments released a report in 1997, in which they reviewed sediment management strategies and assessed technologies. Some of their conclusions, which may be relevant to the development of European strategies, were: 1) risk analysis is critical at all levels of decision making (systems engineering approach), 2) regulatory changes (in the USA) are necessary for optimum effectiveness, 3) consensus building is essential, 4) natural recovery is often a viable option, 5) volume minimization at every level is critical to cost control, and 6) the management process should seek to balance two parallel goals: (a) minimizing contaminant risk to the environment and human health and (b) minimizing cost (NRC 1997).

3 Recommendations for Sediment Assessment Frameworks of Environmental Quality in the European Union

The above discussion strongly argues that two separate frameworks (or a framework guidance that bifurcates early in the assessment or decision process) should be designed for the European Union (EU), one for the management of dredge material, and one for environmental management of sediments. These should be designed to address the economic, political and ecological goals of the EU, while leaving flexibility for country-specific goals. In the United States, there is considerable variability depending upon the jurisdiction within which sediments lie, but most practitioners desire greater compatibility. In the USA and Canada, a balance is being sought between Federal and State or Provincial frameworks and there is a continuing trend towards harmonisation.

Some keys to success which might be used to design a goal-oriented EU sediment framework (one in which data collection and assessment are designed to technically support management decisions which fulfill environmental, economic and political goals), are: 1) design sediment assessment to match short-listed sediment management options, 2) develop guidance as a series of building blocks, held together by an overall tiered framework, 3) assure that decision-making is transparent and somewhat standardized, but flexible enough to meet national/regional goals (i.e., which is in line with current international agreements and guidance), 4) build both natural and regional background concentrations, reference sites and site-specific bioavailability considerations into framework, 5) wherever possible, assure that source control is a primary requirement before other management strategies are applied (this may not always be possible on a watershed-wide basis), and 6) while sediment guidelines have an important role, they should not be used as pass/fail values – but rather as triggers for further investigation.

Because sediments are highly mobile, and do not respect national or ecological boundaries, wherever possible, frameworks should be applied on a watershed, or catchment, basis, with sediments which are hydrologically linked being assessed, ranked, prioritized and managed on a regional basis. Implicit in such an approach are source control and resource sharing issues that will require international cooperation. Although the charter of SedNet is specifically confined to freshwater sediments, it will be neither logical nor efficient to generate a sediment management framework that does not address that part of the sediment cycle that moves into the estuarine or marine environment. While the focus and driver may be rivers, it will ultimately be more cost-effective to consider together the entire lifecycle of sediments and their associated contaminants within a cathcment, from source to ultimate sink. Therefore SedNet places its sediment management framework(s) in the wider context of sustainable sediment management from cradle to grave.

To assure that the sediment frameworks will be appropriate for a particular set of management goals, it is important that any sediment management framework that is developed is consistent with all regulatory frameworks that may impact it. In the case of the EU, broad-based sediment management should be designed to consider all relevant EU Directives. The implementation of the European Water Framework Directive (WFD 2000/60/EC) results in a shift in the scope of water management: from local scale to watershed scale (often transboundary). As SedNet has recognised (Brils 2000), at this scale sediment is poorly covered by traditional water management approaches. The purpose of the WFD was to establish a framework for the protection of inland surface-, transitional-, coastal- and groundwaters that prevents further deterioration and protects and enhances the status of aquatic ecosystems and the water needs, terrestrial ecosystems and wetlands that depend on them. A catchment management approach is to be used, encompassing measures of ecological, hydrological and hydrogeological systems. The WFD is an ideal vehicle for addressing the important role of sediments in watershed quality (from headwaters to the sea), but it is uncertain to what extent sediment quality will explicitly play a role in assessing ecological quality under the WFD. The WFD directs member states to monitor macrobenthic invertebrates and develop sediment quality standards, so there is clearly scope for consideration of sediment quality as an integral part of river basin quality. A SedNet-developed sediment framework could be a catalyst that prompts Member States to consider sediment issues as important in development of their statutory regulations and guidance.

Another example of a relevant regulatory driver is the Council Directive 92/43/EEC (Habitats Directive), adopted by the EC to implement the Biodiversity Convention, which complements and amends the 1979 EC Wild Birds Directive (Directive 79/409/EEC). This directive is aimed at the conservation status of natural habitats and of wild fauna and flora. Conservation can be defined as a series of measures required to maintain or to restore natural habitats and populations of species of wild fauna and flora, and conservation status of a species means "the sum of influences acting on the species concerned that may affect the long-term distribution and abundance of its population within the European territory of the Member States to which the treaty applies" (Habitats Directive). Thus, for urbanised and industrialized areas bordering on waterways in Natura 2000 sites (the network of areas designed to conserve habitats and species of plants and animals which are rare, endangered or vulnerable in the EC), it is difficult to imagine that poor sediment quality will not affect the conservation status of listed species and habitats. However, the linkages between efforts to develop sediment frameworks and the Habitats Directive appear to be weak and should be strengthened within future development of European sediment frameworks. Lastly, another directive that will affect sediment management in the EU is Council Directive 1999/31/EC on the Landfill of Waste (better known as the Landfill Directive), which came into force in the EU on 16 July 1999.

Particularly for those Member States that are signatories to the North Sea conventions, sediment management approaches will have an impact on their ability to meet ecological quality objectives and elements (see, for example the Bergen Declaration 2002). This convention does not directly address sediment quality, but rather broad-based source control. However, since sediments can preserve contaminants long after sources have been controlled, and can ultimately be a source of those contaminants to the environment, sediment management is an important part of meeting ecological goals, and these goals may thus affect the management objectives of Member States throughout their catchments.

To design a European sediment framework, it is important that the EU defines its goals for contaminated sediment management. Is the goal to assure clean drinking water, to protect fisheries, ecosystems and human health, or eventually to reduce contaminant loads in waterways? What goals are chosen will profoundly affect how sediments are managed in European waterways.

4 Conclusions

The formation of SedNet provides an opportunity to define European goals for sediment management and to let these goals drive framework design, resulting in efficient sediment assessment and management. A review of worldwide sediment assessment and management frameworks and case studies makes it clear that any study that is not built around a Conceptual Site Model or is not focused on or defined by management goals runs the risk of being open-ended, iterative, expensive and inconclusive. In complex, multivariate natural systems, no amount of data can provide an answer unless a question has been defined. It will thus be important for SedNet to review and define European sediment practices, ecological priorities and objectives (at local and at higher levels) before designing sediment assessment and management frameworks and the tools used to support them. Consideration should be given to the Water Framework and Habitats Directives, particularly in sediment frameworks relating to environmental quality, since if all regulatory drivers are not satisfied in a sediment approach, the risk remains that sites will have to be revisited and evaluated or managed more than once, as management priorities shift. To maximize the applicability and effectiveness of the guidance developed by SedNet, two separate frameworks (or one that bifurcates early in the evaluation process) should be designed for the European Union (EU), one for the management of dredge material, and one for environmental management of sediments. This framework should address broad European goals, while retaining flexibility for Member States.

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