

State of the Art in the USA

Sediment Remediation: U.S. Focus on Capping and Monitored Natural Recovery Fourth International Battelle Conference on Remediation of Contaminated Sediments

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Abstract

The Battelle Conferences series represent the state-of-the-art of emerging technologies, science and management issues for contaminated sediment remediation. In the 2007 Conference held in Savannah, GA, two *in situ* technologies for cleanup sites were at the centre of interest: *Sediment capping*, a form of *in situ* containment, which involves the placement of a subaqueous covering of clean sediment and/or other materials to isolate contaminated sediments, and *monitored natural recovery* (MNR), where natural processes are used to mitigate the transfer of particle-bound contaminants into the water phase and/or biota. A third priority technology in the Superfund program, recommended by the U.S. Environmental Protection Agency (EPA), is *environmental dredging*, i.e., removing the sediments from the aquatic environment.

About 30 platform or poster presentations dealt with *in situ* capping as a technology, reflecting the rapid developments in this field, both in assessments and enhancements of 'classic' passive caps and the development and demonstration of active capping technologies. Issues relevant to monitored natural recovery were spread throughout many sessions; e.g., contaminant source identification, control, remediation strategies; innovative characterization and assessment, chemical/toxicological/biological measurements and characterization, bioavailability of contaminants, contaminant fate and transport and remediation effectiveness: defining, monitoring, and demonstrating success.

Presentations addressing the role of science and stakeholder input were complemented by discussions on the importance of data quality considerations, uncertainty analysis, and careful selection of reference sites highlighted the complex nature of these multidisciplinary assessments. Case studies, in which site-specific information was linked to regional management objectives, various approaches to watershed-scale assessment and management, and the role of ecosystem considerations, were all discussed in these sessions, as well as in a complementary panel discussion.

One compelling feature of the Savannah Conference 2007 (relative to the first couple of meetings) is that there were a much larger number of presentations that provided the tools, models, case studies, etc to fill in the lines of evidence that allow a fair comparison between removal and *in situ* management when appropriate, and evidence of a growing acceptance that the residuals and impacts of removal approaches can at times offset perceived benefits, so that *in situ* management can be considered if exposure risk can be properly assessed.

Keywords: Environmental dredging; monitored natural recovery (MNR); sediment capping; sediment remediation; USA

Introduction

The 310 platform and poster presentations of the 4th Conference on Remediation of Contaminated Sediments, held in Savannah, Georgia, January 22–25, 2007 represented the state-of-the-art of emerging technologies, science and management issues for contaminated sediment remediation. Extensive involvement of representatives of the US EPA, and the US Department of Defence ensured that current and emerging US policy and guidance on the subject was highlighted as well. Although the majority of presenters were from the United States, sediment experts in government, academia and industry throughout the world provided an international flavour, and allowed for some comparison of different approaches in different regions.

1 Treatment of Dredged Material vs. Remediation of Contaminated Sediments

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. 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 such as industrial megasites. 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. Site conditions are important in determining which remediation techniques (and combinations thereof) are appropriate (National Research Council 2007). Assessment of such sediments can focus on absolute and relative risk, as well as risks of in-place vs. removal options (Apitz and Power 2002).

2 Developments in Contaminated Sediment Management

Internationally, sediment management issues are highly politicized and often newsworthy. Not surprisingly, given the complex environmental issues and the enormous potential costs, in some cases, the decision process can be very adversarial. In the early 1990's, regulators (and most site owners) thought that removal and treatment of contami-

nated sediments would be the remedy of choice, most sediment-related research and development (R&D), in North America and Europe pursued technologies to support such an approach. However, based upon potential volumes and projected treatment costs, estimated potential costs of the indiscriminate use of such an approach are prohibitive. An increasing use of comparative risk assessments (CRA) that consider all risks of a remedial option, including those of removal, residuals, treatment, transport and disposal, provides a body of evidence which suggests that sediment removal can at times result in more human health risk and ecological damage (Wenning *et al.*), or, after great expense, not show measurable ecological improvement (Thibodeaux *et al.* 1999). Thus, there is growing acceptance that large volumes of contaminated sediments will be managed in place. There continue, however, to be gaps in our knowledge of the fate of contaminants in place, and the effects of in place and ex situ remedial strategies, which must be filled if management strategies are to be compared and chosen wisely (Apitz *et al.* 2005a).

3 U.S. EPA Priority Technologies for Remediation of Contaminated Sediments

The majority of contributions to this conference series related to sediment remediation technologies from U.S. companies and institutions reflect the development under the Environmental Protection Agency since 1991 (e.g., USEPA 1991, 1994, 1998, 2001a, 2001b). Based on the U.S. EPA's 'Contaminated Sediment Remediation Guidance for Hazardous Waste Sites' (USEPA 2005), the currently mature and available management strategies for contaminated sediments (not dredged material) are dredging, capping, and monitored natural recovery (MNR). In 2004, the US EPA decided to take action to clean up contaminated sediment at approximately 140 sites, including federal facilities, under the Com-

prehensive Environmental Response, Compensation, and Liability Act (CERCLA, commonly known as Superfund) and additional sites under the Resource and Recovery Act (RCRA). Many other sites are being cleaned up under state authorities, other federal authorities, or as voluntary actions (USEPA 2005). Capping, either alone or in combination with removal and/or MNR, is planned or has been implemented at about 40 sediment remediation projects in the United States, whereas MNR as a primary remedy, or in combination, is a component of about 28 projects in the United States. In spite of the above, however, both capping and MNR continue to be 'a harder sell' as the remedy of choice for regulatory agencies and the public because the contaminants are left in place (Zeller *et al.* 2005, Zeller & Cushing 2006; **Table 1**). As a result, greater emphasis is placed on demonstrating effectiveness than is typically done at a removal site, even if many of these actions may just move contaminants and their associated risks to other sites and systems.

This overview of the main meeting themes follows the order of major themes in the 2007 Proceedings (editors: Eric A. Foote and Gregory S. Durell, Battelle, Columbus/OH; ISBN 978-1-57477-159-6, compact disc format): A – Characterization, Assessment, and Monitoring; B – Sediment Processes and Modelling; C – Management and Policy; D – Remediation, Restoration, and Treatment; E – Regional Studies. In the following text, *author names of the 2007 conference papers are in italics* and are marked with * in the selected references.

A. Characterization, Assessment and Monitoring

The use of ecological risk assessment (ERA) to determine whether sites present a risk that requires remedial action is now well-established, in North America, and is increasingly used in Europe. A number of authors presented case studies on the evaluation of human and ecological risk assessment

Table 1: Some site characteristics and conditions especially conducive to particular innovative remedial approaches for contaminated sediment (after U.S.EPA Sediment Remediation Guidance 2005)

| Characteristics | Monitored Natural Recovery | <i>In situ</i> Capping |
|----------------------------------|---|---|
| General Site Characteristics | <ul style="list-style-type: none"> Anticipated land uses or new structures are not incompatible with natural recovery Natural recovery processes have a reasonable degree of certainty to continue at rates that will contain, destroy, or reduce the bioavailability or toxicity of contaminants with an acceptable time frame | <ul style="list-style-type: none"> Suitable types and quantities of cap material are available Anticipated infrastructure needs (e.g., piers, pilings, buried cables) are compatible with cap Water depth is adequate to accommodate cap with anticipated uses (e.g., navigation, flood control) |
| Human and Ecological Environment | <ul style="list-style-type: none"> Expected human exposure is low and/or reasonably controlled by institutional controls (ICs) Site includes sensitive, unique environments that could be irreversibly damaged by capping or dredging | <ul style="list-style-type: none"> Expected human exposure is substantial and not well-controlled by ICs Long-term risk reduction outweighs habitat disruption, and/or habitat improvements are provided by the cap |
| Hydrodynamic Conditions | <ul style="list-style-type: none"> Deposition of sediment is occurring in the areas of contamination Hydrodynamic conditions (e.g., floods, ice scour) are not likely to compromise natural recovery | <ul style="list-style-type: none"> Hydrodynamic conditions are not likely to compromise cap or can be accommodated in design Rates of ground water flow in cap area are low and not likely to increase unacceptable contaminant releases |
| Sediment Characteristics | <ul style="list-style-type: none"> Sediment is resistant to resuspension (e.g., cohesive or well-armoured sediment) | <ul style="list-style-type: none"> Sediment has sufficient strength to support cap (e.g. has high density/low water content) |
| Contaminant Characteristics | <ul style="list-style-type: none"> Contaminants readily biodegrade or transform to lower toxicity forms Contaminant concentrations are low and cover diffuse areas Contaminants have low ability to bioaccumulate | <ul style="list-style-type: none"> Contaminants have low rates of flux through cap Contamination covers contiguous areas (e.g., to simplify capping) |

Table 2: Lines of evidence useful in ecological risk assessment of contaminated sediments (from Apitz et al. 2005a, with permission)

| |
|---|
| Nature and extent of the contamination |
| Expected or acceptable indices of benthic diversity and abundance in the absence of contamination |
| Estimation of the potential for bioavailability, bioaccumulation, and adverse effects posed by chemicals and mixtures of chemicals (the potential for chronic and acute effects) on aquatic organisms |
| Stability (fate and transport) of the sediments and contaminants |
| Estimates of the potential risks posed by contamination to aquatic biota and associated resources |

and the use of Sediment Quality Guidelines (SQGs) and a number of innovative tools in its application. Furthermore, as various lines of evidence on contaminant risks, as well as those of non-contaminant stressors are developed, tools to integrate these LOEs within a risk assessment evolve as well (Table 2), and these were discussed in several sessions.

The use of quantitative risk assessment in the sediment remedy selection process, as well as during the design and implementation of the preferred remedy is becoming increasingly important as well. This approach seeks to predict net reductions in ecological and human health risks (primary to fish consumers) as a function of various remedial approaches and to quantify post-remedial risk reduction and the overall effectiveness of the remedy itself relative to remedial action objectives (RAOs).

A quantitative risk of remedy analysis was presented by *Wenning et al.* to compare different sediment remedial options, ranging from monitored natural recovery to capping and dredging, in the lower Hackensack River, New Jersey (see E – Regional Studies). Implementation risks to remedial workers and the local community associated with transportation, construction, and operation of the remedy were considered, as were short-term ecological risks during construction and operation such as habitat loss, water quality impact, recreational activities, and impacts on aquatic life.

Long-term risks after remedy implementation such as recontamination potential, sedimentation, and efficacy of ecological restoration were also assessed. These models are becoming more robust, as data are collected before and after remedial efforts, previously a large and controversial gap when remedial options were debated. Sessions discussed the long-term impacts and recovery of fish, shellfish, marine mammals and ecosystem services after both contaminant impacts and remedial efforts.

The hierarchy of criteria that may be used to demonstrate natural recovery processes is: (i) contaminant burial and natural deposition with clean sediments over time; (ii) reduced contaminant mobility from sorption, precipitation, and other binding processes; (iii) chemical or biological transformation to less toxic forms, and, under special conditions, (iv) dispersion of particle-bound contaminants that leads to contaminant concentration reductions (USEPA 2005, Zeller & Cushing 2006).

At all sites where sediment management strategies are considered, identification of the sources of contaminants is crucial. Removal strategies will only be a temporary solution if unresolved sources continue to contaminate sediments. Physical processes that support MNR by sequestration of contaminants deep in the sediment (e.g., burial with clean sedi-

ment), as well as the success or capping are dependent on developing a relatively contaminant-free physical barrier between contaminated sediments and sediments in contact with the sensitive receptors within the infaunal, benthic, and pelagic communities. These issues were discussed in detail in sessions addressing the identification and control of contaminant sources, as well as the role of such information in developing remedial strategies.

B. Sediment Processes and Modelling

Natural sediment and contaminant fate and transport processes, which are heavily influenced by site-specific characteristics, control the natural recovery of contaminated sediments, the effectiveness of *in situ* containment and remedial processes, and the amount and fate of any residual contamination after disturbance of the sediment (Reible et al. 1991, Apitz et al. 2005b), and thus these are the subject of considerable study in recent years.

Sediment physical parameters are critical to risk assessment from local, site-specific to the regional, or river basin scale. Aspects of sediment and contaminant stability should be considered in an overall risk-management framework, which is characterized by a progressive increase in complexity – e.g., definition of key elements at the site, regional geomorphology to understand the sensitivity of the site to flood, ice and storm-associated flows, and definition of needs for sediment sampling, acoustic surveying and current measurements (*Bohlen & Erickson 2005*, 3rd Battelle Conference Panel 1).

The quantification of flux rates including the transport of particle aggregates, microorganisms as well as dissolved and adsorbed substances requires an integration of various experimental techniques (e.g., flumes, flux chambers, current meters, sediment traps, turbulence columns, erosion chambers), to study the combined effects of sediment processes during resuspension, transport and deposition, and to describe these processes by models on different scales for the determination of hydrodynamic, chemical and biological parameters. Presentations in sessions described tools to examine the fate of sediments using measures of shear stress, track sediment dispersal and flow, examine sediment stability, and thus, the fate of associated or buried contaminants.

Generally, in order to give *in situ* remedial options such as *in situ* capping or MNR a real chance, a shift of emphasis is needed towards the use and communication of results from the analyses of multiple lines of evidence, e.g., by examining the potential impacts of large, low-probability events or combination of probabilities (e.g., the 100-year flood and the probability of erosion to a specific depth) on exposure and risk, and the associated uncertainties (*Bohlen & Erickson 2005*).

However, other pathways of contaminant transport, such as advection, diffusion, biologically-mediated transport, chemical transformation and gas ebullition can also be equally or more important at some sites, and these processes, and models to consider and compare them, were the subject of extensive discussion. Contaminant dynamics across the sediment/water interface, from land and groundwater, and from particles to the dissolved state were addressed. The role of biota, in controlling contaminant fate, and the factors influencing bioavailability of contaminants to various receptors, are all important subjects if site-specific characteristics are to inform risk-based assessment and management.

C. Management and Policy

The shift described above from presumptive, technology-based removal actions to CRAs seeking to balance the net risks of all aspects of the management process in order to maximise benefits to various objectives, whether they are to human or ecological health, ecosystem services, or some combination of these, requires a regulatory and policy framework in which RAO are based upon risk, rather than on mass removal of contaminants. If regulatory criteria are simply based upon the net removal of contaminants from a water body, or on absolute chemical criteria, rather than on minimizing pathways of contaminant exposure in the food chain (whether by removal, isolation, sequestration or other means), then much of the research described above is moot. Clearly, the science used to inform management decisions must be relevant and appropriate to local, regional, national and/or international policies (at the end of the present review we will have a look on similarities and differences in these policies).

(a) Defining, monitoring, and demonstrating success

Commonly used remedial effectiveness measures include contaminant levels in sediment, bathymetry, visual inspection of cores/grabs, mass of contaminant removed, volume of sediment removed, confirmation of cap placement, contaminant concentration in fish/shellfish, and ecological community surveys/toxicity testing (Evison *et al.*, Panel 2). Clearly, the criteria which are relevant depend upon the objectives of the project, as described above.

Because the objectives and RAOs of a management action can be very site-specific, case studies presented ranged from those examining triad-type criteria for sediment quality before and after remedial actions, to studies that looked at reductions in fish tissue concentrations, net removal of contaminants, reductions in contaminant seepage, improvements in benthic communities, or even control of resuspension during dredging. Both innovative approaches, and efforts to develop standard, web-based monitoring systems and guidance were addressed (e.g., Schaffer, Yanko *et al.*)

(b) Ecosystem- and watershed-based management

If a management strategy is to be focused on overall risk reduction, it is important that this is framed within a *conceptual site model* (CSM), a description what is known about the contaminant source area, as well as the physical, chemi-

cal, and biological processes that affect contaminant transport from the sources through environmental media to potential environmental receptors (ASTM 1995). This should be transparent and should guide data collection, processing and communication and thus should include an explicit discussion of heterogeneity, uncertainty, and scaling issues as well as the selection of reference sites and decision criteria (Apitz *et al.* 2005a, *Bridges & Apitz*, 3rd Battelle Conference 2005, Panel 2).

As sediment management shifts from the site-specific to the basin- or regional-scale, CSMs must be expanded to a basin scale. The description and inventory, whether conceptual or quantitative (involving chemical, sedimentological, hydrodynamic and modelling studies), of the mass flow of contaminants and particles within a river basin can be termed a *Conceptual Basin Model* (CBM, Apitz & White 2003), and can help inform risk assessment of a particular site (in terms of regional issues), and of basin-scale management as a whole. Inasmuch as it describes how materials move and interact between sites, CBMs provide insight into Cause (*Drivers-Pressures-State*) and Effect (*Impact*) relationships in a river basin. The more such relationships are understood and communicated, the easier it will be to manage the system (*Response*), with full participation of all stakeholders (Apitz and Barbanti, Panel 1).

Presentations addressing the role of science (and long-term, user-integrated research) and stakeholder input, complemented by discussions on the importance of data quality considerations, uncertainty analysis, and careful selection of reference sites, highlighted the complex nature of these larger-scale, multidisciplinary assessments. Case studies, in which site-specific information was linked to regional management objectives, various approaches to watershed-scale assessment and management, and the role of ecosystem considerations, were all discussed in these sessions, as well as in a complementary panel discussion. Whilst there were calls for more uniform approaches to sediment management in general, presentations on emerging and unusual contaminants, the impacts of rare events such as extreme storms and sunken submarines, and the special and site-specific concerns and needs of ports and harbours internationally highlighted the need for flexible tools (informed by the CSMs and CBMs described above), stakeholder involvement, cost-benefit analysis and adaptive management, all of which were addressed in discussions and case studies.

The system can be a site, an ecosystem (Apitz & Parker), or a river basin. For example, instead of addressing the CERCLA (Superfund) remediation of contaminated sediments on a site-by-site basis (USEPA 2005), the Navy and Marine Corps have grouped all sediments at the Marine Corps Base Quantico into upper basin-level areas (Gutberlet & Garrity); the result of the watershed approach led to regulator concurrence in the closure of 17 terrestrial sites. In Europe, the holistic view on the river-groundwater-sediment-soil system brings in a variety of related issues, like nature conservation, the use of space, economic and social issues, and stakeholders with interests ranging from nature conservation to entrepreneurial interests, who want to be involved in river basin management (Slob & Ellen).

D. Remediation, Restoration and Treatment

Not surprisingly, given the title of the conference, this topic area was the most extensive of the conference, and reflected both the breadth of management options, and the evolving nature of sediment management. Whilst there were many presentations on ex situ sediment management approaches, the proportion of these talks relative to those on *in situ* management strategies has declined over the history of the conference, with innovative capping technologies and advances in *in situ* treatment showing increasing prominence (along with habitat restoration studies).

(a) Monitored natural recovery; habitat and wetlands mitigation and restoration

Issues relevant to MNR, a management category of increasing interest, were spread throughout many sessions; e.g., contaminant source identification, control, remediation strategies; innovative characterization and assessment, chemical/toxicological/biological measurements and characterization, bioavailability of contaminants, contaminant fate and transport and remediation effectiveness: defining, monitoring, and demonstrating success, and were thus described in other sections. MNR can be combined with other engineering approaches to increase success of remedial action (enhanced MNR, eMNR), e.g., in the form of thin-layer capping, installation of flow control structures to encourage natural sediment deposition, or the use of additives like activated carbon (Zimmerman et al. 2004, Millward et al. 2005) to enhance sorption or to reduce bioavailability. In Panel 2, Greenberg and Magar (in *Evison et al.*), presented three case studies, describing sites where MNR and eMNR have been demonstrated and have helped to reduce risks.

A large session addressed the risks and benefits of habitat and wetlands mitigation and restoration. These approaches can be stand-alone restoration of habitats to replace or enhance their ecosystem services, or they can be a part of larger remediation strategies, providing enhancements, mitigation or beneficial use opportunities. In many cases, habitat restoration can enhance public acceptance of a remedial strategy, but contaminant risks to wildlife either *in situ* or which are drawn to the site, must be considered in an overall risk assessment. This session was followed by a session on the special concerns and issues of shoreline remediation, which can include challenges such as erosion control, technological barriers and concerns over infrastructure.

(b) *In situ* capping

In the 2007 Battelle Conference, about 30 platform or poster presentations dealt with *in situ* capping as a technology, reflecting the rapid developments in this field, both in assessments and enhancements of 'classic' passive caps and the development and demonstration of active capping technologies (including discussion of three large-scale demonstrations of active capping technologies in the U.S.). Whilst many issues were addressed in the case studies and research presented, some main points were studies on the migration and fate of contaminants such as mercury, modelling and control of gas ebullition in capped sediments, the development and testing of reactive cap materials such as organoclays,

activated carbon and apatite to bind or degrade contaminants; the development scour-resistant sediment caps; and the combination of active capping with other management approaches such as wetland enhancement and beneficial use.

(c) Advances in navigational and remedial dredging

As sediment removal is still an important part of the sediment manager's toolbox, aspects of both navigational and remedial dredging were subject to extensive discussion. Presentations discussed improvements in the dredging process, including better monitoring, precision dredging, resuspension control, and extensive discussion on the assessment and importance of dredging residuals. Beneficial reuse of DM, for habitat restoration, construction, containment and other purposes, either before or after some ex situ treatment was discussed in a long session. Ex situ treatment technologies, ranging from volume minimization to more complex treatment trains designed to remove, destroy or immobilize contaminants were the topic of another session.

Panel Discussion on U.S. EPA (2005) Priority Technologies

As in 2005, a panel discussion was arranged in the 4th Conference on "What worked and what didn't" in the three U.S. EPA (2005) priority technologies (*Evison et al.*):

- 1) Dredging effectiveness should be evaluated on a site-specific basis in the context of 'net risk reduction' rather than the often used, but generally inappropriate measure: the quantity or mass of sediment removed.
- 2) When evaluating cap effectiveness, both remedy performance and risk reduction goals must be considered. At some sites, cleanup levels have been maintained in caps over highly contaminated sediment. Benthic community recovery starts shortly after cap construction and full recovery has been seen within five to seven years at a large capped site.
- 3) As with dredging and capping remedies, MNR relies on contaminant source control; monitoring programs should include multiple lines of evidence that include chemical, physical, geotechnical, and biological metrics, and modelling in order to evaluate, with adequate certainty, the effectiveness of MNR at a site.

According to the panel discussion, concerns remain for both *in situ* remedies: for (a) *monitored natural recovery*, concern that for some contaminants recovery mechanisms may not be sufficient to reduce risk to acceptable levels, and for (b) *capping*, concern for mechanisms that might increase contaminant flux through caps, such as ground water advection, gas ebullition, or NAPL movement.

E. Regional Studies: Lower Passaic River, NJ; Great Lakes

(a) Hackensack River/Lower Passaic River/Newark Bay, New Jersey (E-001 to E-008)

The Lower Passaic River is a 27 km tidally influenced river located in northeastern New Jersey, and represents the major freshwater contributor to Newark Bay. By the 20th century, urban and industrial developments surrounding Newark Bay and the Lower Passaic River have resulted in poor water quality, contaminated sediments, bans on fish and shellfish consumption, lost wetlands, and degraded habitats. Since the 1980s the wider Newark Bay area is one of the major targets for soil and sediment remediation under EPA's CERCLA and other funding organizations; this is demon-

strated by the number and quality of contributions to the 4th Battelle Conference dealing with different aspects of sediment research and management in this region.

The Newark Bay complex has long been associated with dioxin contamination and this chemical was used as a tracer for mass balances of sediment inputs from various sources (*Garvey et al.*). Mass-per-unit (MPA) estimates for Lower Passaic suggest 4–5 million m³ of contaminated sediments containing nearly 30 kg of 2,3,7,8-TCDD and these solids currently are responsible for ~80% of 2,3,7,8-TCDD in Newark Bay.

In the same area, a high-resolution three-dimensional hydrodynamic model was developed by *Kim et al.* and, for the closer area at the Hackensack/Passaic River/Upper Newark Bay confluence, sediment stability studies were performed by *Dekker et al.* This information is essential to predict the movement and concentration of various chemicals of concern with the study area as well as its interactions with other regions of the New York harbor system under different management and/or remediation scenarios.

A special monitored natural recovery approach has been reported from the Hackensack River at the Panel 2 by Greenberg & Magar (in *Evison et al.*): Sediment along the eastern shore of the river near the confluence with Newark Bay are contaminated by chromium, which is attributable, in part, to a former waterfront commercial property that was used for disposal of approximately 800,000 m³ of chromite ore processing residue from 1905 to 1954. In this example, monitored natural recovery is based on the well-known fact, that, once reduced, Cr(III) is stable in aquatic environments and unlikely to oxidize to Cr(VI), even in the presence of dissolved oxygen (Martello et al. 2007).

(b) Great Lakes (E-009 to E-014)

Finally, an overview of more traditional sediment remediation technologies was given on the Great Lakes Legacy Act (GLLA) program, specifically aimed at accelerating the pace of contaminated sediment remediation in sites within the 31 U.S. Great Lakes' Areas of Concern (*Tuchman & Boehme*). The Act authorizes up to \$ 50 million for projects that remediate contaminated sediments or lead to their remediation. The program has a cost share requirement, with a minimum of 35% required from the non-federal sponsor; \$ 3 million will be spent for research on the development of innovative technologies, \$ 1 million for a public information program on contaminated sediment.

4 European Perspectives in the Field of Sediment Remediation Technologies

The Battelle Conference series on 'Remediation of Contaminated Sediments' presents the developments of the leading technology market, United States, and the recent advances are typically reflected in the contributions to Theme D on techniques for both dredged material treatment and sediment remediation. The (few) presentations from European companies and institutions in Theme D fall under the former category, i.e., the treatment of sediment material that is removed (see Introduction):

- Construction of subaquatic confined disposal facility 'Hollandsch Diep' (Paper D-057, Rijkswaterstaat, Utrecht, The Netherlands)
- Beneficial use through optimized sediment processing centres (Abstract D-071, Bokalis Dolman bv, Rotterdam, The Netherlands)
- Dredged material substituting for clay in dike constructions for flood protection: Modeling the release of pollutants via seepage water (Abstract D-086, University of Bremen, Germany)
- Confined aquatic disposal facility in a deep fjord basin: The Oslo Harbour remediation project (Paper D-091, Norwegian Geotechnical Institute, Oslo, Norway)
- Floating bioreactor for on-site sediment treatment (Paper D-105, URS Deutschland GmbH, Dreieich, Germany)

Technologies for dredged material treatment in Europe followed similar trends, as communicated by world-wide operating harbour organisations CEDA (Central Dredging Association) and PIANC (International Navigation Association; formerly Permanent International Association of Navigation Congresses). A specific European initiative was that of the harbour authorities from Bremen, Hamburg and Rotterdam in forming the Dutch-German Exchange (DGE) on dredged material, which is now broadening to incorporate neighbouring countries like Belgium, the U.K., France and the Czech Republic. The emphasis for decisions in this management category is on cost-effectiveness; this implies facilitation of the cheapest approaches such as relocation, placement on banks and confined disposal, especially in pits (Hakstege 2005). To date, the focus of the EU-funded Sediment Research Network SedNet is on dredged material treatment (Bortone 2007).

Sediment management under the EU Water Framework Directive will need a wider scope with *in situ* technologies embedded in a modern system of risk assessment and communication on the river basin scale. Alongside the WFD, several regulatory frameworks such as EU Landfill Directive, EU Waste Catalogue, EU Soil Strategy (or Framework Directive) and Marine Strategy Directive are being implemented. One of the consequences of this complexity seems to be that in Europe there is less regulatory acceptance of risk-based (rather than mass-based or chemical threshold-based) decisions, and thus more resistance to some of the technologies favoured by the U.S. Environmental Agency.

A new initiative for Europe-wide activities in the field of sediment management technology could start in the course of the forthcoming strategies against chemical pollution of surface waters (WFD article 16), i.e. establishment of a program of measures until 2009 for sources of priority substances including the specific source/pathway "historical pollution from sediment" (EAF 2004). In view of the size of the problems in Europe (ConSoil 2000, SedNet 2004), the guidance for innovative remedial measures and the experience from successful problem solutions in the United States, both presented at this conference, cannot be ignored. Good reasons to follow these examples are the role of the US National Academy of Sciences and the list of Committee members chosen by the National Research Council to evaluate the effectiveness of dredging as a remedial option on contaminated sediments at Superfund Megsites (National Research Council 2007; <http://www.nap.edu/catalog/11968.html>).

European scientists and policy makers should work together to ensure that RAOs are driven by regional risk reduction with an aim towards basin-scale good ecological status, rather than by simple chemical thresholds that may result in moving risks from one area or set of receptors to another. This will require a focused effort to ensure that decision frameworks are underlain by models and measures that clearly and explicitly link sound science to well-thought out, Europe-specific policy and objectives.

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