Great Lakes Sediments:
Contamination, Toxicity and Beneficial Re-Use

(Courtesy: U.S. Army Corps of Engineers)

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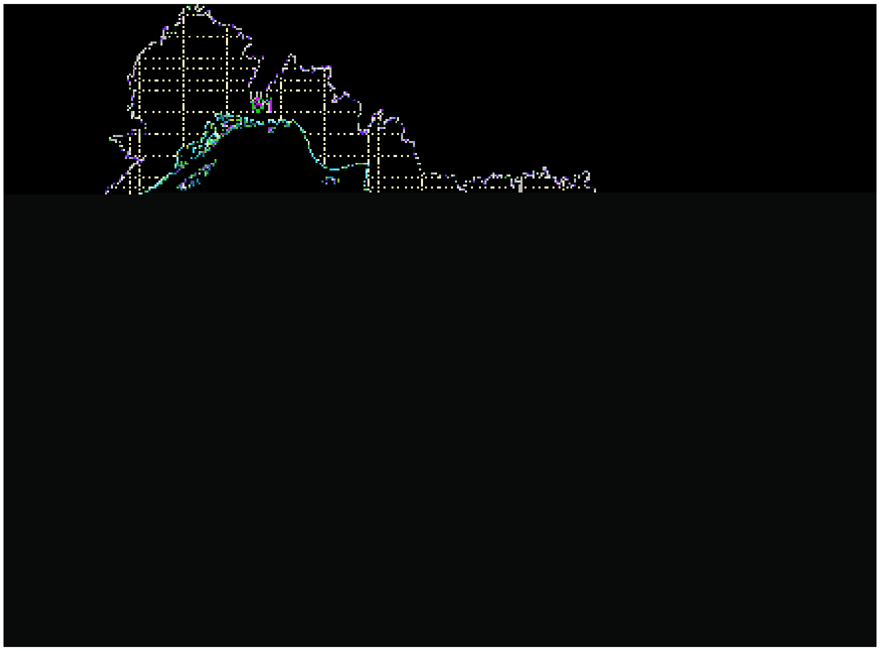
1. INTRODUCTION AND LEGAL FRAMEWORK

The Great Lakes are an extraordinary natural resource, holding 95% of the surface freshwater found in the United States, and represent 18% of the world's supply of surface freshwater. This wealth of freshwater sustains abundant and diverse populations of plants and animals, many recreational activities, and the five lakes are a readily available waterway system for economic activity and fisheries.

Years of point and non-point source discharges from industrial and municipal facilities, and urban and agricultural runoff to the Great lakes and its tributaries have contributed toxic substances into the ecosystem, resulting in major contamination issues. In most cases, the contamination is introduced in the tributaries which, via sediment transport and erosion mechanisms, contribute to contamination of the Great Lakes proper. Because of their vast size and volume, less than 1% of the lake waters (averaged across the basin) are flushed annually, resulting in settling out and accumulation of suspended particle-associated contaminants in the water column. Hence, the sediments serve as repositories for and on-going sources of organic and inorganic contaminants, exposing and impacting aquatic organisms, wildlife and humans through the development of cancerous tumors, loss of suitable habitats and toxicity, fish consumption advisories, closed commercial fisheries, and restrictions on navigational dredging.

The programs and policies to restore and protect the chemical, physical and biological integrity of the Great Lakes have been covered under the 1978 joint binational Great Lakes Water Quality Agreement (section 118(c)(3) of the Clean Water Act) between the US and Canada. In 1987, a protocol (Annex 14 – Water Quality Act) was added to the GLWQA to jointly address concerns about persistent toxic contaminants, with specific objectives to: (i) identify the nature and extent of sediment pollution, (ii) to develop methods to evaluate both the impact of polluted sediment on the Great lakes System, and (iii) to evaluate navigation are impaired by anthropogenic pollution or perturbation”; 42 out of 43 AOCs were determined to be impaired by sediment contamination. The AOCs (Figure 1) involve 2,000 miles (20%) of the shoreline considered impaired because of sediment contamination and fish consumption advisories remain in place throughout the Great Lakes and many inland lakes.



1. St. Louis River
2. Torch Lake
3. Deer Lake
13. Muskegon Lake
14. White Lake
15. Saginaw River and Bay
16. St. Clair River
17. Clinton River
19. Detroit River
23. Cuyahoga River
24. Ashtabula River
28. Eighteen Mile Creek
29. Oswego River

4. St. Marys River
5. Manistique River
6. Menominee River
7. Fox River
8. Sheboygan River
9. Milwaukee estuary
10. Waukegan Harbor
11. Grand Calumet River
12. Kalamazoo River
18. Rouge River
20. River Raisin
21. Maumee River
22. Black River
26. Buffalo River
27. Niagara River
31. St. Lawrence River

25. Presque Isle Bay

contamination (e.g. PCBs, mercury) as well as a sink for volatilized contaminants from the water column , and (d) agricultural runoff (e.g. pesticides, nutrients).

result of prevailing flows or tidal effects. Displacement of sediment beyond the “fluff layer” requires boundary shear stresses that occur only during major storms, or shipping. The variety of factors affecting sediment erodibility present a major challenge to predict the response of a given deposit to a specified range of forces. Hence, any information on tributary contributions to the Great Lakes contaminant burden is site-specific, and order-of-magnitude range. Recent innovations such as acoustic profiling can provide high resolution characterization of surficial and sub-bottom sediments (McGee et al., 1995), and help define the thickness and distribution of disparate sediment types (Caulfield et al., 1995). In the overall quantitative mass balancing of sediment transport, resuspension and transport are computed using the output of a hydrodynamic model, and the measured characteristics of sediments (e.g. Buffalo River, Saginaw River, Fox River/Green Bay, Lake Michigan) (USEPA, 1994).

Atmospheric transport has indicated a significant regional environmental impact resulting from re-emission of the sediment burden of PCBs, toxaphene, and organohalogen pesticides into the water column and across the air-water interface. For example, air mass back-trajectory data for organochlorine insecticides and PCBs over the Great Lakes, indicated local or regional volatilization, rather than long range transport (e.g. McConnell et al., 1998). Moreover, significant temperature-dependent air-water exchange of toxaphene (polychlorinated bornanes and bornenes) in the Great Lakes was demonstrated, whereby the colder temperatures and lower sedimentation rates in Lake Superior are responsible for its higher aqueous concentrations (Swackhamer et al., 1999). Further evidence for re-emission of the PCB sediment burden via the water column to the atmosphere was obtained by Jeremiasson et al. (1994) in a mass balance study in Lake Superior.

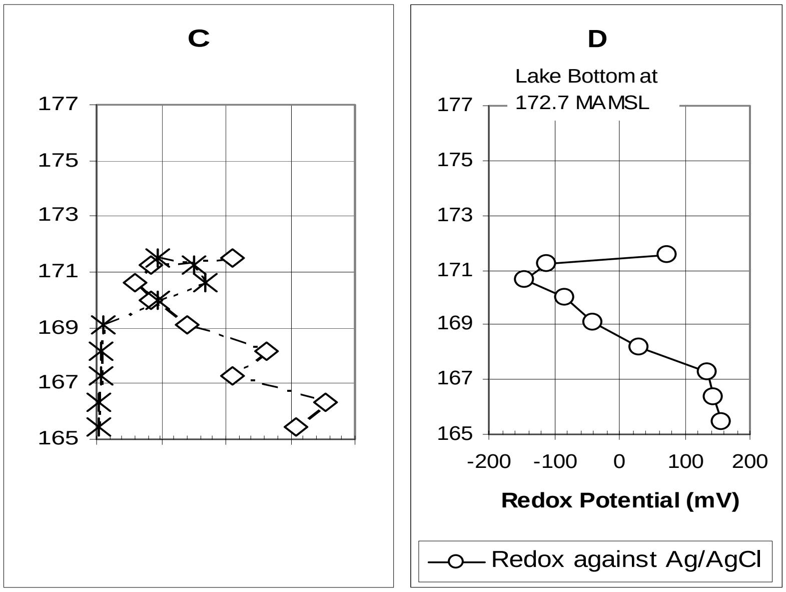
As an example, The Lake Michigan Mass Balance study (1994-95) was commissioned to provide a coherent, ecosystem based evaluation of toxics in Lake Michigan, with the goal to develop a sound scientific base of information to guide future toxic load reduction efforts. Hence, tributary and atmospheric sources of four pollutants (PCBs, Trans-nonachlor, mercury, and atrazine) were investigated to identify and quantify sources, as well as to develop cause-effect relationships for contaminant loads and bioaccumulation. Eleven tributaries were monitored, and 20 atmospheric monitoring stations were deployed. Examples of results for PCBs and mercury indicate that atmospheric loadings exceed tributary loadings for both pollutants by a factor of 4-5. Trans-nonachlor exhibited a net export from the Lake.

This study has now been expanded into the Great Lakes Environmental Database (GLENDA), to integrate data entry, storage, and access for mass balance modeling efforts in the future.

3. SEDIMENT BIOGEOCHEMISTRY

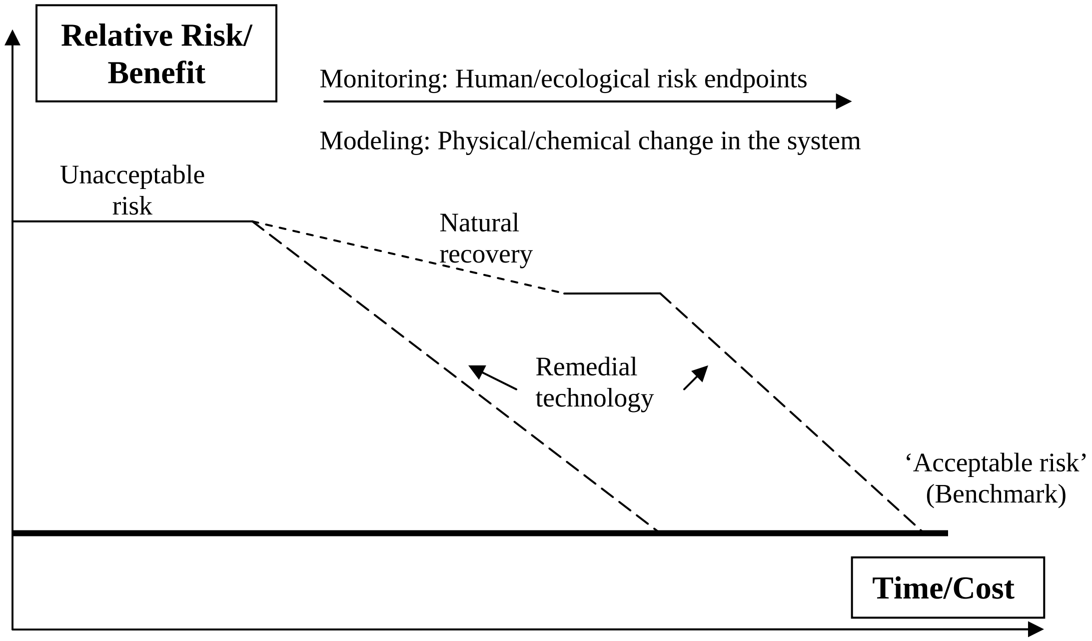
The deposition of natural and anthropogenic organic matter, as well as heavy metals in the Great Lakes basin has resulted in a complex interaction between sediment hydrodynamics, contaminant chemical manufacturing plants. Organic contaminant profiles for polychlorinated biphenyls (PCBs), polychlorinated dibenzo-p-dioxins, pesticides (e.g. atrazine), and polycyclic aromatic hydrocarbons (PAH) in sediments are often reflective of a combination of known point sources (e.g. insulators, transformers, paper plants,…) and diffuse sources (atmospheric deposition, agricultural runoff). In undisturbed core samples (evaluated by radioisotopes such as ^{132}Cs), sediment contaminant burdens (concentrations), and isomer- or congener-specific signatures are capable of revealing temporal occurrences of specific source contributions, using statistical tools in the realm of environmental forensics. Since most important point source contributions (often in Great Lakes tributaries) have been identified and closed over the last two decades, the depth concentration profiles of organic and inorganic contamination in the Great Lakes, which had steadily increased for the last 200 years and peaked 20-30 years ago, have started to decrease (Figure 4). Hence, more recent sediments are less contaminated, which renders them more amenable to beneficial re-use after dredging and disposal (section 6).

concentrations ranging from < 1 mg/kg to > 100 mg/kg. Whereas total concentrations of heavy metals in freshwater sediment environments can be determined with common analytical techniques, the issue of metal toxicity as a component of sediment risk assessment is complex, since the speciation of metals determines their bioavailability to benthic organisms and fish. Various operationally defined fractions of metals in rivers and freshwater catchments for the of dissolved oxygen from the overlying water column, and the respiratory consumption within the sediments. Up to 60-70% of natural organic matter incorporated in anoxic sediments ultimately becomes degraded via fermentation, and other anaerobic respiration mechanisms. Freshwater sediments tend to be predominantly methanogenic due to the limited input of sulfate.



Organic carbon respiration fluxes under these various terminal electron accepting processes are on the order of 10^{-2}-10^{2} mmol C (as CH_2O)/kg/yr (Murphy and Schramke, 1998). The organic carbon turnover fluxes are dependent on temperature, seasonal impacts, and depth, as reflected by oxygen and microbial respiration index profiles (Carlton and Klug, 1990). Under the prevailing respiratory conditions in freshwater sediments, aerobic and anaerobic degradation of sediment-associated contaminants will occur as well, to various extents, depending on the chemical characteristics of the contaminants and the metabolic capability of the sediment microbial populations and communities (Adriaens et al., 1999; Adriaens and Barkovskii, 2002; Adriaens et al., 2002). These natural bioattenuation processes may impact sediment toxicity from contaminants through contaminant degradation, solubilization, or sequestration, depending on the pathways used, and the distri toxic chemicals, more complex ecological structures (populations, communities, ecosystems) and different endpoints (e.g. survival, growth, and reproduction). Furthermore, the ability of the ecosystem to recover from the stress may also be considered.

Hence, the selection of ecological assessment techniques to be applied at a given AOC in the Great Lakes Basin includes: (i) chemical analysis of samples of sediment, surface water, and organism tissues from the site; (ii) toxicity testing of sediments; (iii) community analysis based on measurements of the types and number of benthic macroinvertebrates at the site; (iv) exposure models to predict chemical concentrations and bioavailability in environmental media, and to estimate uptake by key-receptors; (v) ecological models to extrapolate from measurement endpoints to assessment endpoints in receptor groups for which community analysis is not a primary tool. These assessment techniques can then be used to evaluate remedial alternatives at contaminated sediment sites, using a comprehensive mass balance modeling approach, to describe each of the underlying mechanisms causing change in the system (Figure 6).



From a risk assessment perspective, bioavailability of sediment-associated contaminants can be defined as "the fraction of the total contaminant in the interstitial water and on the sediment particles that is available for bioaccumulation", whereas bioaccumulation is "the accumulation of contaminant concentration via all routes available to the organism" (Landrum and Robbins, 1992). Bioavailability is generally affected by (i) contaminant characteristics (e.g. octanol-water partition coefficient, K_{ow}), (ii) the composition and characteristics of the sediments (e.g. organic carbon content, particle size distribution, clay type and content, cation exchange capacity, and pH), and (iii) the behavior and physiological characteristics of the organisms (e.g. organism behavior and size, mode and rates of feeding, source of water – interstitial vs. overlying – for respiration).

Bioavailability of sediment-associated contaminants is generally assessed either by comparison of sediment and organism concentrations (steady state ratios or accumulation factors), or by determining the uptake clearance (in units of g sediment/g organism.hr). Mass balance box models (sediment solids, interstitial water, unavailable contaminant), which include aqueous uptake, feeding, and excretion, as well as adsorption/desorption functions are commonly used to quantify accumulation of contaminants in the species under consideration.

Effects-based testing is currently the primary means of sediment quality evaluation, and is a basic tool for estimating the risk of various sediment management techniques to the aquatic environment (NRC, 1997; Giesy and Hoke, 1990). Organisms used for freshwater toxicity assessment include bacteria (Microtox), algae ( ), (e.g. Daphnia), insects ( ), and fish (e.g.). Several of these indicator species have been used to map toxicity in the Lower Detroit River, Western Lake Erie and Toledo Harbor, and the Trenton Channel (e.g. Giesy and Hoke, 1990). To supplement effects-based testing, the EPA has published sediment quality criteria (SQC), based on day amphipod ( ) and chironomid ( ) produced 8-52% false positives and 10-23% false negatives when exposed to contaminated sediments (Becker et al., 2002). Of all sediment quality tests (5) used, the apparent effects threshold (AET; USEPA, 1989) exhibited the greatest accuracy when compared to biomass and survival endpoints determined for both species. Nevertheless, the outcome of species-specific toxicity testing on sediment interstitial waters can then be used to create maps of vertical and horizontal sediment toxicity, and to help guide the selection of remedial technologies, or to calculate the sediment volumes which would have to be removed to improve the quality of the benthic habitat to a specified level.

In 2001, the NRC published a report titled “Risk Management Strategy for PCB-Contaminated Sediments”, much of which is applicable to other contaminants. This report resulted in a recent guidance document (OSWER Directive 9285.6-08) which highlights 11 principles for managing contaminated sediment risks at hazardous waste sites. These broad management principles are: 1. Early source control; 2. Early and frequent community involvement; 3. Coordination with states, local governments and natural resource trustees; 4. Develop and refine a conceptual site model that considers sediment stability; 5. Use an iterative approach in risk-based framework; 6. Carefully evaluate the assumptions and uncertainties associated with site characterization data and site models; 7. Select site-specific, project-specific, and sediment specific risk management approaches that will achieve risk based goals; 8. Ensure that sediment cleanup levels are clearly tied to risk management goals; 9. Maximize the effectiveness of institutional controls and recognize their limitations; 10. Design remedies to minimize short term risks while achieving long-term protection; 11. Monitor during and after sediment remediation to assess and document remedy effectiveness.

Sediment removal, natural recovery, and disposal technologies each exhibit associated risk characteristics. For example, (e.g. in situ capping, containment or treatment) are governed by the potential loss of contaminants in situ and thus their enhanced bioavailability to benthic macroinvertebrates and fish. For example, resuspension and advection during cap placement, and long term diffusion, advection, bioturbation, and erosion are the dominant loss mechanisms during in situ capping. Hence, information on cap integrity and sediment bed stability will be required as primary monitoring variables for this technology application. Similar processes will impact both other non-removal technologies. Particulate, dissolved and volatile contaminant releases represent the major loss mechanisms during , and thus the risk associated with this activity has to be compared relative to leaving the contaminated sediments in place.

Lastly, have more mechanisms for contaminant loss than most other remediation components, due to volatilization, plant uptake, dispersion of dust, bioturbation, leaching and seepage (Figure 7). The potential for the various loss mechanisms should be evaluated in the laboratory or using model predictions, and appropriate design modification put in place. Particularly pathways involving movement of large volumes of water (e.g. effluent during hydraulic filling) have the greatest potential of releasing significant quantities of contaminants from confined disposal facilities (CDFs).

Even though no formal guidelines are available to measure emission losses from CDFs and other remedial approaches, modeling approaches to estimate volatile losses from chemical vapor equilibrium concepts and fundamental transport phenomena, lysimeter testing protocols (surface runoff), and column settling tests (effluent losses) have been developed for this purpose.

5. SEDIMENT CONTAMINANT MITIGATION

During the last 30 years, navigational and remedial dredging in the Great Lakes Basin have generated in excess of 70 M. cubic yards of contaminated sediment in need of sustainable management practices. These contaminated sediments require high volume management approaches, which can be broadly classified in removal and non-removal ( ) strategies. Any decision to leave sediments in place is highly dependent on an evaluation of the relative risks posed by the sediments left untreated on the bottom, the risks of performing a treatment operation on in situ sediments, and the risks associate with the removal and subsequent disposal or treatment of the contaminated dredged material (NRC, 1997). Considering the extent of Great Lakes sediment contamination, open water disposal became impossible by the early 1970s, and hence, confined disposal and treatment technologies have to be considered. Between 1993-96, open water disposal was applied with 32% of uncontaminated Great Lakes sediment, and 12% was used for beach/littoral nourishment. Currently, dredging and confined disposal is chosen in >90% of all contaminated sediment management options, the remainder being in situ capping, and natural recovery. No full scale in situ treatment strategy is considered, and two sites apply some form of ex situ destruction or immobilization technologies. The various dredged material management alternatives applicable for Great Lakes contaminated sediments will be briefly discussed below.

Non-removal technologies are those that involve the remediation of contaminated sediments in situ (i.e. in place), and include capping, containment, and treatment (Figure 8, A). These alternatives do not require sediment removal, transport, or pretreatment.

<u>In situ capping</u> is the placement of a cap or covering over a deposit of contaminated sediment, The cap may be constructed of clean sediments, sand, gravel, or may involve a more complex design using geotextiles, liners and multiple layers (Zeman et al., 1992; Palermo and Miller, 1995; Palermo, 1998). Capping has become one of the few accepted management techniques, despite a dearth of knowledge on long-term chemical fluxes into the overlying water column,

Confined disposal

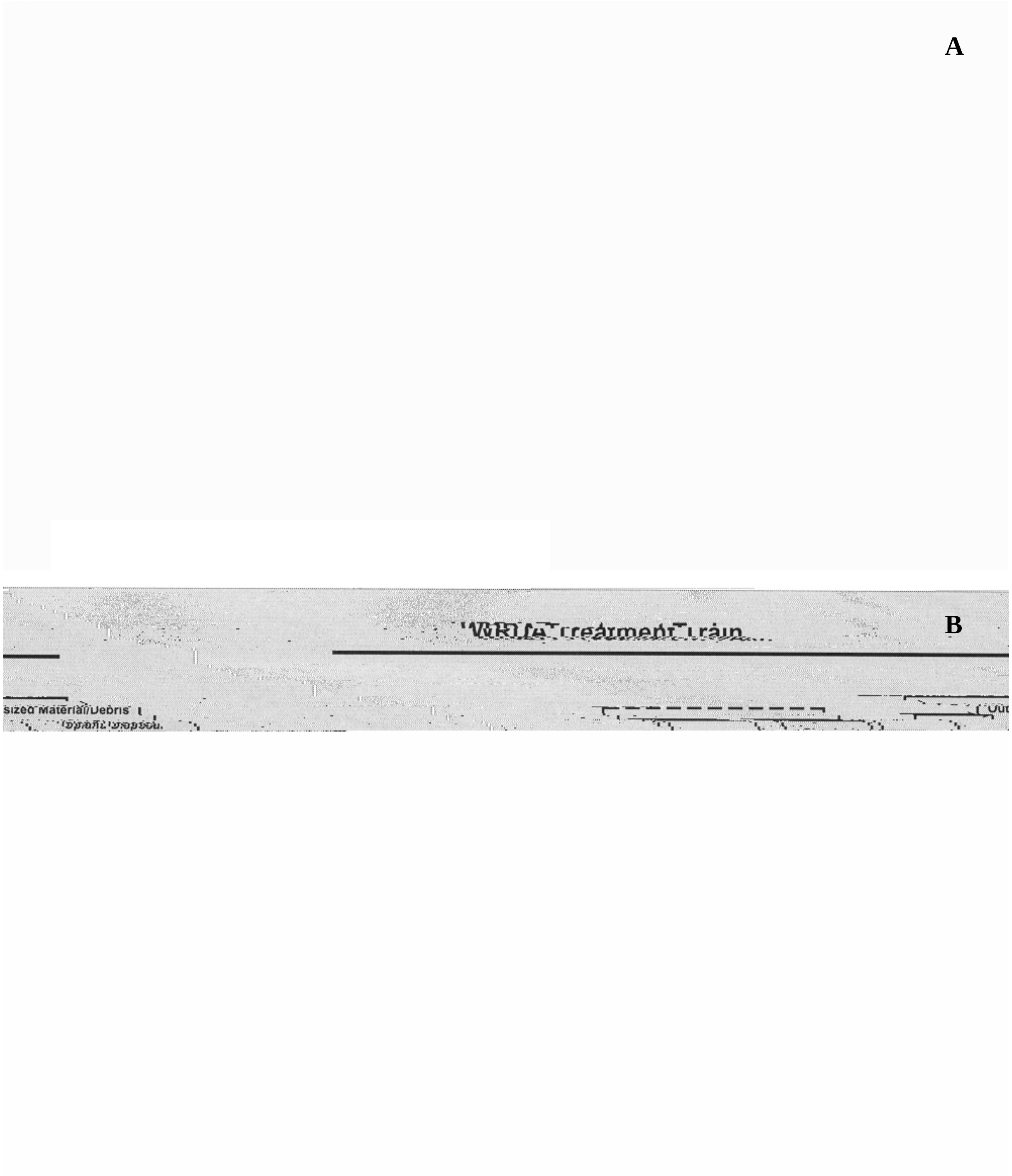
Over the last 30 years, twenty three of the 44 Great Lakes CDFs have been filled or have less than 10% of their capacity remaining. At the same time, there is (are):

(i) Continued demand for CDFs to manage contaminated dredged material for navigation
(ii) Increased demand to manage contaminated material from remedial dredging
(iii) More stringent environmental requirements for new CDFs, raising their cost
(iv) Fewer ports and local governments are capable of sponsoring new CDFs

Several options are being considered or have been implemented to increase the capacity of CDFs: raising the dikes, increase consolidation through aggressive dewatering, particle separation (contamination is mainly associated with fine grained material), and remove material from the CDF. The latter option has been one of the main driving forces behind innovative technology development for beneficial re-use of the stored dewatered sediments.

6. BENEFICIAL RE-USE CONCEPTS AND APPLICATION TO GREAT LAKES SEDIMENTS

Methods for the handling and disposal of dredged material have been studied and developed for many years, and several literature reviews are available to help select the successful complete treatment trains (e.g. http://www.bnl.gov/wrdadcon/publications/reports; Kraus and McDonnell, 2000). The former reference pertains to the Water Resources Development Acts (WRDA), which set forth a program consisting of a series of progressive steps to lead to a full-scale demonstration of one or more decontamination technologies with a processing capacity of at least 500,000 cubic yards per year (WRDA 1990; 1992; 1996). The WRDA Decontamination Program draws on many disciplines, ranging from [illegible] onae-0.0017 T1(hTD0.5.3(acity of)]TJog



cement, fly ash, lime, and cement kiln dust. After blending, the material is allowed to set into a hardened granular soil-like condition with a lower water content and improved structural/ geotechnical properties. The contaminants become more tightly bound to the sediment matrix by chemical and mechanical means, thus preventing leaching and minimizing bioavailability.

Beneficial end-products include construction-grade cement for cement blocks and paving material, glass aggregates and tile products.

A number of technology demonstrations for treatment of Great Lakes contaminated sediments have indicated the application of WRDA technologies in freshwater environments. An early application was the Contaminated Sediment Treatment Technology Program (CoSTTeP), a sub-program of the Canadian Great Lakes Cleanup Fund (GLCF), which has evaluated six technology categories at 5 sites in Canada (Hamilton Harbor, Thunder Bay, St. Marys River, Welland River-Niagara, Toronto Harbor), including: (i) pre/post treatment; (ii) non-incineration thermal treatment; (iii) chemical treatment; (iv) metal removal; (v) biological treatment; and (vi) solidification/stabilization (1990-97). All sites considered were non-PCB sites, and were contaminated with creosote, polycyclic aromatic hydrocarbons (PAH), and metals. The results, reported in http://www. REMEDIATION.com, have indicated that the technologies have difficulty competing with landfill options, on a cost basis. No assumptions were made with respect to cost recovery due to beneficial re-use, marketing and commercialization.

The State of Michigan-Department of Environmental Quality (M-DEQ) has been working with the GLNPO to investigate the application of beneficial treatment technologies for treatment of contaminated Black Lagoon sediments in the Trenton Channel of the Detroit River. Following favorable reviews of bench-scale studies (Cement-Lock, Biogenesis Soil Washing, and plasma vitrification), a pilot scale demonstration of the Cement Lock technology using 2,000-5,000 cubic yards of sediment will be conducted, with the objective of delivering a marketable final product for beneficial use. The sediments are contaminated with oils and grease (18,000 mg/kg), PAH (51 mg/kg), PCBs (11 mg/kg), and heavy metals (As: 7.8 mg/kg; Cd: 9.5 mg/kg; Cr: 138 mg/kg; Cu: 180 mg/kg; Pb: 218 mg/kkg, and Hg:

with the U.S. Army COE, the University of Wisconsin – Center for Byproducts Utilization is evaluating the applicability of commercial top soil products from dredged materials from Milwaukee and Green Bay, with the objective to grow corn, sunflower, sorghum, ryegrass, and clover. The sediments are contaminated with PCBs and PAH.

Industrial, municipal, and commercial users make up the majority of end-users of dredged material as a beneficial resource. Industrial users represent the largest sector in terms of numbers of potential users (POAK, 1999), while municipal users are the largest on a per cubic yard basis (USACE, 1999). Commercial users have embraced dredge material on a much smaller basis, and have generally used pilot projects to determine marketability of products. A recent study of the end-user communities in the San Francisco Bay area, which included a detailed survey of the construction and redevelopment community, indicated very little enthusiasm to utilize dredged material as a resource. Perception of re-used dredged material as hazardous or a health hazard after contaminant destruction and stabilization is a major issue that needs to be addressed via a concerted outreach effort (EPA 000-0-9000).

One major effort to address these issues is a proposed framework for evaluating beneficial uses of dredged material in NY/NJ harbor (Bonnevie et al., 2001). This framework is consistent with the current US Army COE Dredged Material Management Plan (DMMP), to provide economically cost-effective, and environmentally sound management practice to satisfy the need for safe navigation. Since the DMMP presents a strong preference for management options that result in beneficial use of dredged material, the framework is intended to incorporate economic, environmental and policy-related information that would be supplemental to a standard cost-benefit analysis. To encompass the diverse array of potential benefit types, a wide range of assessment endpoints related to potential for environmental risk (economics, human health, ecological health, and resource management) are included. Considering that all stakeholders, including citizen groups, are involved, it is hoped that a normalized weight-of-evidence approach to beneficial reuse may address real and perceived impacts.

7. SUMMARY

Even though most sources of organic and inorganic contamination impacting the Great Lakes Basin have been identified and addressed, historic contamination and continuing contributions from tributaries and atmospheric deposition indicate that sediment management strategies for navigational and remedial reasons are here to stay. On-going work to develop contaminant mass balances for the Great Lakes, and improved integr the boundary conditions of the problem, and linkages/correlations between total sediment toxicity and contaminant-specific toxicity are needed, to quantify the importance of bioaccumulation under varying conditions and scenarios. Considering the high volume/low contamination scenario typically encountered in contaminated sediments, rapid throughput contaminant and microbial screening technologies are required to process large numbers of samples. In the area of sediment toxicity, suitable endpoints need to be refined, to enable proper comparisons between ‘before’ and ‘after’ remediation scenarios, as well as to aid in priority ship wakes,…) impact sediment stability. These issues have to be considered in conjunction with the chemical stability of contaminants in sediments, e.g.. what is the impact of sequestration and natural destructive (microbial or abiotic) processes on the state of the contaminant and its association within the sediment matrix? The required expertise, to address sediment transport, stability and chemical stability is well represented between the Engineering College's CEE and NAME departments, and the Geology department.

Risk reduction strategies have meaning only if the baseline risk can be properly evaluated and quantified, and if predictive assessments can be incorporated. Since the approaches to quantify risk, and to help provide a scientific basis for making remedial response decisions, often rely on complex series of mass balance models, there is a need to quantify and propagate the associated uncertainty with contaminant mass and loss pathway estimates. Within this context, and for economic purposes, uncertainty analysis can also aid in defining the minimum amount of data that will be required to achieve acceptable levels of uncertainty, or aid in future sampling plans. Further, since risk is based on exposure and loss pathways, there is a great need to help establish scientific methods for measuring sediment bed stability (and thus contaminant transport), and contaminant bioavailability (i.e. organic and inorganic speciation). Finally, the use of mass balance models requires highly skilled personnel, and this need is likely to continue, unless more readily useable models can be developed. Some attempts have been made to develop Excel-based models which are more accessible to less experienced individuals. Again, the expertise in these various topical areas is well represented between the previously mentioned schools and departments.

A large variety of contaminants from industrial, agricultural, urban, and maritime activities are associated with sediment particulates, including bottom sediments. Of particular interest are (1) synthetic organic chemicals (chlorinated pesticides, polychlorinated biphenyls (PCBs), and industrial chemicals); (2) polycyclic aromatic hydrocarbons (PAHs), that are typically components of petroleum, coal, and pyrogenic residues, as well as biogenic and naturally occurring substances; and (3) toxic elements (e.g., arsenic, cadmium, copper, lead, mercury, zinc), all of which can be toxic at sufficiently high concentrations. Toxic chemicals cause a wide range of direct and/or indirect adverse effects on biological systems, ranging from cells to ecosystems. The severity of these effects depends on the types and properties of the chemicals and the "dosage" or duration of exposure to ambient concentrations. Numerous bioassays at different trophic levels are available to investigate the adverse effects of contaminants, including mortality, impaired physiology, biochemical abnormalities, and behavioral aberrations.

Whereas statistically significant endpoints for various bioassays and chemicals have been developed, the scientific literature provides conflicting evidence for toxicity test responses to contaminant mixtures in sediments, as synergistic and antagonistic effects between the chemicals confound the causal relationships developed for individual toxics. Moreover, the sediment biogeochemistry (e.g. oxidant and reductants for respiration) and physical-chemical characteristics (e.g. grain size distribution) impact the test responses as well. Further emphasis on the development of empirical correlations between sediment geochemistry factors controlling bioassay responses and sensitivity, and predictive models for complex mixtures is needed. Whereas some of the expertise in this area is available in SPH, it is unclear whether the complexity of toxicity evaluation can be addressed with current expertise at UM.

The current evaluation of effectiveness, feasibility and cost of innovative treatment technologies indicated that most were feasible, all technologies exhibited some degree of contaminant-specific effectiveness, and most cost more than traditional confined disposal. Also, technologies for the treatment of contaminated sediment in situ are less developed than those applicable to dredged material. The following research needs were identified by the NRC for selected technologies:

Natural recovery: scientific underpinnings, protocols for in situ flux measurements and to quantify relative chemical release measurements
In place capping: data analysis of current efforts, controls for chemical release, simulation of temporal disturbances

Technology	Process	Advantages	Disadvantages	Cost
Contaminant Separation				
Thermal Desorption/ Cement-Lock	Heat (up to 1400 ºC) to remove contaminants from the sediment matrix, which is then added to cement mix. The process takes place in a rotary kiln.	Beneficial uses include construction fill and habitat restoration. Existing cement plants may be able to handle large volumes of dredged material Process can remove all organic and most metals	Site waste stream that requires disposal at a hazardous waste treatment facility	Processing cost of $ 50 per cubic yard Value of construction-grade product $50-70 per cubic yard. Disposal costs of waste stream depends on level of contamination
Fluidized Bed Treatment	High temperature heating unit (not oxidation or incineration) that converts all organic materials to carbon monoxide, hydrogen and methane	Material is 99.9% free of organic material and,		

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