

ABSTRACTS
for the
CONFERENCE
ON THE
REMEDIATION
OF SEDIMENTS
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OVERVIEW OF SEDIMENT DYNAMICS IN NEW YORK HARBOR

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New York Harbor is a complex series of large embayments, tidal straits, and rivers with many diverse hydrodynamic environments. The textural distribution of bottom sediments reflects this diversity. Sediments range from sands near the entrance to the Harbor in the Lower Bay, to fine-grained muds in channels, mud flats and other quiescent parts of the estuary. Most of the approximately one million metric tons of fine-grained sediments that enter the Harbor each year are brought there by several tributaries, including the Hudson, Passaic and Raritan Rivers. Municipal wastewater treatment plants and CSOs, along with biological production of phytoplankton are significant contributors to the total suspended sediment load to the Harbor. Based upon dredging records and estimates of off-channel sedimentation rates coupled with sediment input data, the total fine-grained sediment load to the Harbor from landward sources can easily account for over 90% of the Harbor's annual sedimentation rate. Estuarine circulation is responsible for the trapping of large quantities of sediment entering the Harbor. This is particularly true in Newark Bay and the lower Hudson River where the estuarine circulation also promotes resuspension of sediments and the formation of turbidity maxima.

**BENCH-SCALE TESTING OF SELECTED REMEDIATION ALTERNATIVES
FOR CONTAMINATED SEDIMENTS**

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The Assessment and Remediation of Contaminated Sediments Program within the U.S. Environmental Protection Agency's Great Lakes National program Office contains a component for the demonstration and evaluation of sediment remediation technologies. Towards this end, bench-scale tests of solvent extraction, thermal desorption, and wet-air oxidation technologies were conducted. Contaminated sediments from Indiana Harbor, Indiana; Buffalo River, New York; and Saginaw Bay, Michigan were tested. The primary contaminants of concern in these sediments were polychlorinated biphenyls and polynuclear aromatic hydrocarbons. The solvent extraction tests were conducted with sediments from all three sites. The thermal desorption studies were conducted with Indiana Harbor and Buffalo River sediments. The wet-air oxidation testing was performed with Indiana Harbor sediment. This paper will present the results of the bench-scale testing for each technology and will present a comparison of the effectiveness of the various technologies.

MINERAL PROCESSING PRETREATMENT OF CONTAMINATED SEDIMENT

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Savings in the overall cost of environmental remediation can be expected when low-cost mineral processing techniques are used to reduce the volume of contaminated material requiring expensive contaminant destruction or controlled disposal. Mineral processing methods do not destroy contaminants, but they can concentrate the pollutants in a smaller volume of materials. This volume reduction can make a subsequent destruction technology more efficient or economical, or reduce the cost of disposing of the sediment in a controlled facility.

The Bureau of Mines, U.S. Department of the Interior, in cooperation with the Great Lakes National Program Office, U.S. Environmental Protection Agency, has conducted a study of mineral processing methods for remediation of contaminated sediment. The sediments, from rivers and harbors on the Great Lakes in the United States, contained varying, but relatively low, levels of heavy metal contamination, along with organic contamination such as polychlorinated biphenyls (PCB's). The Bureau conducted investigations in size classification, magnetic separation, gravity separation, and froth flotation to concentrate contaminants. The most effective application of mineral processing technology on Saginaw River sediment, was the use of size classification to isolate metal and organic contaminants. Froth flotation was also found to be effective on organic contaminants.

TREATMENT TECHNOLOGIES FOR CONTAMINATED SEDIMENTS

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The Coleraine Minerals Research Laboratory (CMRL) of the National Resources Research Institute (NRRI) is applying mineral processing techniques to the treatment of Great Lakes contaminated sediments. The partition of fine sediments by combinations of various size and density classification techniques and extractive mineral processing unit operations has the potential to isolate the most heavily contaminated fractions from the bulk of the material and in some cases detoxify selected fractions. The ultimate objective is to reduce the cost of remediation by isolating materials which can be returned to the environment and to decrease the volume of material that would require either rigorous treatment for detoxification or permanent impoundment.

This research program encompasses three phases: progressing though, (1) the initial characterization of selected sediment samples and small-scale laboratory beneficiation tests, Phase I; (2) continuous integrated pilot-plant operations to generate basic engineering design data, Phase II; and (3) providing the final flowsheet and equipment specifications for a full-scale on-site field demonstration unit, Phase III. The research program is being carried out under a Cooperative Agreement between NRRI and the U.S. EPA Environmental Research laboratory in Duluth, Minnesota.

Sediment samples utilized in the first phase of the project were obtained from seven of the Areas of Concern (AOC) identified by the U.S./Canada International Joint Commission's Great Lakes Water Quality Board. These AOC sites included:

Indiana Harbor
Saginaw Bay
Buffalo River
Manistique River

Duluth-Superior Harbor
Rouge River
Presque Isle Bay

The major contaminants in these sediments are heavy metals, polycyclic aromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs).

In the first phase of the project chemical, physical and mineralogical characterization work has been conducted on sized and unsized samples of sediment. Bench-scale treatment tests involving physical separation based on size, specific gravity, normal magnetic separation, high-intensity matrix magnetic separation, selective flocculation, and flotation were conducted. The project is currently beginning the second phase pilot-scale testing.

THE REMOVAL OF HEAVY METALS AND ORGANIC COMPOUNDS FROM ANAEROBIC SLUDGES

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Immobilization of metal ions from solution by the anaerobic microorganism *Desulphovibrio* has been studied recently by Watson and Ellwood. In this work it was found that heavy metal ions with insoluble sulphides are removed from solution to residual levels of less than 1 ppb. Further each bacterium can take on a considerable fraction of its own weight in many cases 3 to 4 times its own wet weight. This has been done with a variety of strains of the anaerobic microorganism *Desulphovibrio*. The work reveals that the magnetic moment developed after 2 hours is approximately half the magnetic moment developed in a 24 hour period when the microorganism is grown in a solution containing the metal ions. A large number of metal ions have been studied namely, U, Ru, Sr, Co, Pu, Am, Ce, Cs and Zr of interest to the nuclear industry, Pt, Pd, Rh, Ru, Ir, Au, Ag, Fe, Co, Ni, and Cu of interest to the precious metals industry and a number of pollutant metals such as Hg and Cd. With exception of iridium and Cs, it has been possible to reduce the above metal ion concentrations from 10 ppm to 1-2 ppb and in many cases less than 1 ppb.

Hamilton has found that radioactive 'hot' spots are formed in anaerobic estuarine muds and marshes near the Sellafield nuclear reprocessing plant. The presence of these 'hot' spots are strong evidence that concentrating processes are present. We will present results which show that we are able to remove a substantial fraction (> 80%-80%) of these 'hot' particles using High Gradient Magnetic Separation (HGMS). This indicates that the immobilization and localization of magnetic ions has taken place in the 'hot' spots. We suggest that one powerful mechanism by which this can occur is the immobilization of the radioactive heavy metals and other heavy metals such as Fe and Mn by colonies of sulphate reducing bacteria (SRB) such as *Desulphovibrio* which occur in anaerobic regions of the mud. Most of the radioactive metals which find their way into the anaerobic muds are paramagnetic so when

they are immobilized in the SRB cluster, the cluster becomes paramagnetic and therefore may be removed by magnetic separation.

Based on this work, a method of decontaminating anaerobic muds and sludge from heavy metals and perhaps fluoro- and chloro- carbon compounds and PCBs can be suggested. If a compound such as iron sulphate is introduced into the mud as it builds up over a period of time, the population of SRB colonies will increase and the iron and other heavy metals precipitated and immobilized in the colonies. We have found that the iron sulphide precipitates produced by the SRB have a large specific surface area and will strongly adsorb chloro- and fluoro- carbon compounds. After the mud is dredged the application of high gradient magnetic separation will concentrate a substantial fraction of the heavy metals and perhaps the chloro- and fluoro- carbon compounds into a small fraction of the throughput which greatly reduces the disposal and treatment problem.

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SANITATION AND REVALORIZATION OF DREDGING SILT,
A RESEARCH PROJECT ON THE RIVER LYS/FLANDERS

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A dredging contract involving 30.000 m³ of slightly polluted silt on the river Lys in Menen has turned into a full-scale research project on sanitation and revalorization of polluted dredged materials.

The aims of the project are the following:

- studying the behavior of polluted dredged materials on the dredging site,
- studying the behavior of polluted dredged materials on a dumping site,
- studying the possibilities of flotation as a decontamination technique for fine-grained dredged materials,
- developing an afforestation technology for dredged material deposits as a way for landscape restoration.

The site consists of 6 large and 13 small basins. The large basins are filled hydraulically and are dewatered by means of overflow weirs. The small basins are lined with a geomembrane and dewatered by means of drainage systems. These small basins are suited to control the water, nutrient and pollutant flows in a semi-contained system. The concentrate of the flotation is stored in some of these small basins.

The particle segregation of the dredged materials in a hydraulically filled deposit seems to offer a viable treatment solution for dredged materials and the processed water that leaves the deposit can easily be kept within allowable quality limits.

Some species of the genus "Salix", in combination with newly developed plant techniques make it possible to grow tall, dense wood-coverage on the dumping site within a few months after filling.

The heavy metal intake by the plant species is not strictly proportional where it is related to the heavy metal content of the area under review.

Flotation is very useful for the cleaning of coarse fractions after the grain-size separation of dredged sediments. Laboratory-scale testing proves that, within certain limits, it can be useful

for the removal of organic pollutants from fine-grained sediments. In full-scale operations it is possible to isolate more than 60% of the oil in dredged silt in a concentrate of only 25% of the solid mass.

However, the following parameters are of great importance during full-scale operations:

- the residence time in the flotation cells,
- the solids concentration of the feed,
- the removal of coarse particles, including clay balls (selective dredging is extremely important),
- correct dosage of flotation chemicals.

In following years research will hopefully answer the following questions:

- what is the effect of afforestation going to be on the leachability of heavy metals,
- how will the natural breakdown of organic pollutants evolve in different types of rooted and unrooted, soils in dredged materials.

FACILITIES FOR THE TREATMENT AND DEPOSIT OF DREDGED MATERIAL FROM THE HAMBURG HARBOR

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Harbors and waterways can only fulfill their commercial task if there is always sufficient water depth for navigation. In many regions, constant dredging is required to keep clearing new sediments - deposit, sand, silt - which are laid down through natural processes.

Hamburg, as a logical consequence of its policy giving high priority to environmental protection, introduced wide ranging research in 1980 in order to investigate the contamination problem of the Elbe silt and has developed procedures to utilize the dredged mud which is inevitably accumulating in the harbor or at least accommodate it taking care of the environment.

The costs of the research work and the analyses to answer the technical questions of a large-scale new technology have amounted, since the beginning of the 80's, to more than 25 million DM. After more than 10 years the results of these internationally acknowledged efforts with the main points of the Hamburg dredged mud concept are:

1. Construction of a large scale plant to mechanically separate harbor silt (METHA) with an investment cost of 137 million DM. The contaminated fraction - clay, slate and organic substances - is separated from the dredged mud so that the quantity of the polluted material is reduced. The practically uncontaminated sand can be utilized. With its starting phase plant, Hamburg contributes considerably to the protection of the environment and to the cleaning of the North Sea. In the middle term, the surface intensive spreading and drying operation will be set up (about 250 ha of Hamburg Basins). The METHA has only a surface need of about 26 ha compared to the actually required areas for the processing of the dredged mud.
2. A 1985 Senate decision has allowed the construction of two silt hills with a total volume of 12 million m³ in Francop and Feldhofe at a cost of approximately 435 million DM without taking

into account the amount devoted to staff, research and inspection. The contaminated and drained silt is layered according to safe technical dumping methods into silt hill with exemplary landscaping and shaping.

3. Construction of depositing site purification plant (SARA) with an investment value of 9 million DM. The harmfully contaminated water accumulated during the dredging, transport and draining is purified and eventually discharged into the Elbe.

4. Research of further use possibilities of the silt produced as an alternative or addition to the hill construction. As a first step, in 1980/91, a collection of possible utilization applications has been set up. At the 2nd stage, 10 selected solution proposals were closely examined in 1981 - 1985. Besides questions concerning the large scale technical complexity of production, an important factor was the evaluation of the procedures from the point of view of the ecological and economic aspects. Apart from the fact that the proposed procedures have up to now only been completed in the laboratory or the technical trials, they have also excluded numerous procedures because they could take into account the whole extent of the Hamburg dredged mud questions.

In addition to the technical aspects alternatives to the METHA, SARA and hill technique have so far not been taken far enough to be able to solve the Hamburg dredged mud question. The silt fraction that can be reasonably recycled will remain the urgent task of Hamburg. The technical procedures for the treatment of the dredged mud should not be considered as the only promising possibilities to reach this objective but the efforts of all Elbe residents are necessary to attain the common objective:

The Elbe must become a clean river again!

From a general ecological viewpoint, this is the only long term solution for a worthwhile use of dredged mud falling in Hamburg Harbor.

SEDIMENT REMEDIATION - DEVELOPMENTS IN THE NETHERLANDS

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Forty years of water pollution in Western Europe have resulted in the accumulation of heavy metals and toxic organic chemicals in the bottom of reservoirs, lakes, estuaries and coastal waters.

In the Netherlands, more than 30 million tons of polluted sediments have been deposited by the rivers Rhine, Maase and Scheldt. These pollutants include the metals mercury and cadmium and persistent organic chemicals such as PCBs (polychlorinated biphenyls), PAHs (polynuclear aromatic hydrocarbons), mainly from industrial sources.

Nowadays, the original point-sources of pollutants have been largely reduced, but diffuse emissions remain. At the same time, top layers of down-stream sediments are now releasing the accumulated pollutants, until they are completely covered by a layer of clean silt freshly brought down by the unpolluted rivers. This release may continue for decades, thereby hindering the ecological improvement of many surface waters, even after complete elimination of the original sources of pollution. Furthermore, land and sea disposal of dredged material from harbors and canals (millions of tons, annually) must be reduced. For the next few years, environmental isolation of the contaminated sludge in special large scale dump sites seems the only solution.

In addition, a development program for sediment treatment processes has started up in 1989.

In the first phase (1989-1990), research was focused on testing and development of techniques for environmentally friendly dredging, particle separation, cleaning and immobilization of pollutants.

The program in the second phase (1991-1996) is aimed at the further development and practical full-scale demonstration of the most promising methods. Depending on the type of sediment and the pollutants present, a selection will be made from physical, biological or chemical cleaning techniques. Mixtures of chemicals

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may require a combination of these techniques, or complete immobilization of the pollutants in the particles.

To assess the applicability, special attention is given to the net environmental gain in relation to the costs of the treatment processes. It is expected that in the near future roughly 10 to 20 percent of the polluted dredged material could be considered for cleaning, as an alternative against direct disposal.

THE EFFECTIVENESS OF GRAIN SIZE SEPARATION/SOIL WASHING
AS A VOLUME REDUCTION TECHNIQUE FOR MILDLY
CONTAMINATED SAGINAW RIVER SEDIMENTS

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As part of two U.S. Environmental Protection Agency programs, a pilot scale demonstration of volume reduction techniques was carried out in the spring of 1992 at the U.S. Army Corps of Engineers Saginaw Bay Confined Disposal Facility using Saginaw River, MI, sediments. Approximately 300 cubic yards of sediments containing about 25% fine material (<45 microns), and 75% coarse material having an average of 1.5 ppm PCB were processed through a grain size separation/soil washing system developed by Bergmann USA. The system consisted of a rotary trommel screen, three hydrocyclones, a dense media separator, an attrition scrubber, various screens and a clarifier. Under the Assessment and Remediation of Contaminated Sediments (ARCS) program, composite samples were generated for up to 23 locations throughout the plant using grab samples collected at approximately one hour intervals. Following the ARCS demonstration, a more intense monitoring of all input and output streams was conducted under the Superfund Innovative Technology Evaluation (SITE) program.

The process screened oversize material and produced three fairly uniform discharge streams. The majority of the feed material was recovered as washed sand with an average PCB concentration of 0.2 ppm. The fine fraction was about 22% of the feed and had an average PCB concentration of about 5 ppm. The particulate organic fraction contained about 11 ppm PCBs.

The process demonstrated could be used to significantly reduce the volume of material requiring confinement or further treatment whenever the dredged material is primarily sand. The plant used for this demonstration was not specifically designed for Saginaw River sediments and was constrained by the small scale of the demonstration. Design of a system specifically oriented towards a particular sediment type could result in a simplified process and a cleaner sand fraction. One potential problem associated with the

use of this and other grain size separation techniques is that significant volumes of material more contaminated than the feed are generated and would require confinement or treatment using a second process. The economics of handling this enriched product will play a major role in determining if a grain size separation/soil washing technique is feasible at a particular site.

PILOT SCALE DEMONSTRATION OF A SOLVENT EXTRACTION PROCESS
AT THE GRAND CALUMET RIVER, INDIANA

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This paper describes the Basic Extraction Sludge Treatment (B.E.S.T.) process (a patented solvent-extraction treatment technology) and its application to the treatment of contaminated sediments. The process design and the properties of the solvent triethylamine are described. Results of bench-scale and pilot-scale tests conducted at the Grand Calumet River in Gary, Indiana as part of the Assessment and Remediation of Contaminated Sediments (ARCS) program are presented. Cost estimates were developed for a large-scale treatment of Grand Calumet River sediment using the B.E.S.T. process.

USE OF FLUORESCENT TRACERS TO STUDY THE TRANSPORT
AND DEPOSITION OF CONTAMINATED SEDIMENTS

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We have used fluorescent tracers to identify mechanisms and quantify rates associated with the transport and deposition of contaminated particles in coastal water bodies. A slurry of fluorescent pigment particles was injected through a sewage outfall into Salem harbor. The settling and coagulation characteristics of these particles were determined by laboratory studies. Flow cytometry was used to detect, count, and size individual tracer particles in samples of bottom sediments and from sediment traps, leading to estimates of the relative rates of flushing and deposition of particles of different size. A key result of this study was the observation that the smallest tracer particles (less than 1 mm) were deposited at effective rates much greater than could be explained by settling or coagulation with larger particles in the water column.

The residence time of water and suspended particles in Fort Point Channel, a sub-region of Boston Harbor containing a major combined sewer overflow and sediments with high concentrations of contaminants, was determined by measuring the disappearance of fluorescent tracers from the water column. Flushing by tidal water movements was quantified using Rhodamine WT dye and the fate of suspended particles was inferred from measure concentration of fluorescent pigment particles initially mixed with the dye. The results indicate that particle removal was about twice as fast as could be accounted for by flushing, reflecting deposition in the channel. However, as was the case with the Salem study, the absolute rate of particle deposition was an order of magnitude greater than observed in laboratory settling columns designed to measure both the settling of unaggregated particles and the aggregation of pigment particles with larger, faster-sinking particles in the water column.

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We have concluded from these studies that deposition of fine suspended particles may be significantly augmented by scavenging in a bottom "fluff" layer. According to this hypothesis particles are transported by vertical mixing to the sediment-water interface where they are circulated through the highly porous interfacial sediments by fluid motions induced by near-bottom currents or the activities of benthic organisms. Removal from suspension occurs when a particle collides with and sticks to the interfacial material. The potential importance of this mechanism for particle deposition has been confirmed by controlled laboratory studies of particle aggregation at the sediment-water interface.

RELOCATION OF DREDGED MATERIAL IN THE PORT OF ROTTERDAM

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About 23 million m³ of dredged material must be removed from the port of Rotterdam yearly. Thirteen million m³ of this, mainly of marine origin, is relocated in the sea. The remaining 10 million m³, is contaminated to such a degree, that disposal into the sea or relocation on land sites is not permitted, unless special measures are taken.

The long term strategy of the port is that the dredged material should be clean. This will entail an improvement in quality of between 70% and 90%. In the meantime (until 2002 A.D.) the contaminated dredged material will be disposed into 2 specially constructed disposal sites.

The construction and use of these disposal sites is subject to environmental regulations, based upon the national environmental policy. Permits for the disposal sites are based on an environmental impact statement (E.I.S.).

The strategy of the port for the existing disposal sites is an efficient and sound use of the precious disposal capacity. Therefore research and experiments have been carried out to examine the possibilities for separation of fractions (contaminated versus non-contaminated) dewatering and re-use.

Next to that the alternative solutions for relocation into the North Sea are being investigated. Together with the State Department of Public Works and E.I.S. is in preparation on the possibilities for optimization of the off-shore disposal site, including the possibilities for the use of off-shore pits in combination with sand extraction.

Preliminary feasibility-studies have shown that this last solution is a very promising alternative for the disposal of contaminated dredged material.

USGS STUDIES ON THE COMPOSITION, DISTRIBUTION, AND
TRANSPORT OF CONTAMINATED SEDIMENTS IN MASSACHUSETTS BAY

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The coastal regions off Massachusetts are sites of active concern regarding pollutant transport. Boston Harbor has some of the most contaminated bottom sediments in coastal regions around the U.S. and is the site of one of the nation's most expensive pollution remediation programs. The new sewage treatment system under construction will discharge effluent via a subsea-floor outfall pipe 10 miles offshore. The location of the outfall and its effluent are raising concerns in many neighboring coastal areas about transport of excess nutrients and contaminants. In addition, the harbor requires dredging for navigational purposes; dredged sediments may need disposal in an offshore dumpsite and innovative technologies for this purpose are being sought. The newly authorized Stellwagen Bank marine sanctuary abuts the historical offshore dumpsite, and there is concern about contaminants affecting biological systems on the bank.

The USGS is conducting a 5-year study of contamination and sediment transport in Boston Harbor and Massachusetts Bay. The study is designed to answer questions such as: How are water and material transported throughout the bay? Where do sediments, accumulate and at what rate? What are the present contaminant levels in sediments and how will they change? The study includes (1) geologic mapping of sedimentary environments, (2) studies of circulation in Massachusetts and Cape Cod Bays, (3) Long-term current and sediment-transport observations, (4) contaminant inventories and rates of sediment mixing and accumulation, (5) circulation modeling, (6) development of a contaminated-sediments data base, and (7) information exchange.

Remote-sensing geophysical surveys, including digital mosaics of sidescan sonar, sediment samples, and bathymetric data, show the extremely varied sea floor in Massachusetts Bay. Areas of coarse sand, gravel, and boulders commonly lie immediately adjacent to areas of finer sediments. These fine-grained sediments are

preferred hosts for contaminants such as arsenic, silver, cadmium, chromium, copper, lead, mercury, nickel, antimony, thallium, selenium, and zinc in amounts ranging to more than 100 times background values, as well as organochlorine and aromatic hydrocarbon compounds. In cooperation with the Massachusetts Water Resources Authority and other Federal and state agencies, more than 1,600 sediment samples have been incorporated in a scientifically edited data base that includes chemical and geological parameters. In addition, sampling for *Clostridium perfringens*, a bacterium spore known to be a sewage indicator, has yielded information on the distribution of sewage-derived products. Rates of accumulation and (or) reworking of sediments have been derived from ^{210}Pb analyses.

For the past 3 years an instrumented mooring has been maintained continuously at one location in western Massachusetts Bay to document the effect of infrequent catastrophic events, such as winter storms and hurricanes, and to define seasonal and interannual variability. The instruments measure currents, temperature, salinity, turbidity, and waves. Photographs of the bottom and suspended sediments are taken periodically by the instruments. These long-term observations, supplemented by other shorter term instrument deployments throughout the region, reveal that fine-grained, organic-rich sediments are deposited mainly in the summer period. Sediment traps record sediment flux more than 100 times the normal during periods of storms, primarily because of sediments resuspension. Current observations suggest southerly and offshore transport during the storms and onshore transport during tranquil periods.

Three-dimensional modeling of the circulation in Massachusetts Bays aids in the interpretation of field observations, provides insight into key physical processes, and forms the basis for regional water quality and sediment transport models. Data-verified computer modeling of near-bottom tidal currents demonstrates maximum currents at inflow-outflow areas for Boston Harbor and off the outer hook of Cape Cod. Models of transport applicable to finely dispersed particulates from present-day and projected effluent-pipe sources indicate that the dominant transport in winter is southeastward along the coast from the

Boston area and the zone where effluent has been diluted to 200-fold or less is not likely to reach Cape Cod Bay. Modeling efforts for the summer period, which may be more critical for contaminant transport, are in progress.

SHAPING PITS FOR DISPOSAL SITES IN NEW YORK HARBOR

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For over 15 years, the use of subaqueous borrow pits in New York Harbor has been recognized as a possible disposal alternative for isolating and containing dredged sediment. If existing pits were to be used, a sand cap would restore the bay floor to its premined condition. If new pits are to be created, the size and shape of suitable pits depends upon both the physical limitation of the equipment and the fate of dredged sediment released at open water disposal sites. An area greater than 260 m in diameter must be designated. The side slopes of the pit should be as steep as possible to provide the greatest volume while minimizing the area committed to this use. During the pit's use as a disposal site, the top of the deposit of dredged material in it must be more than at least 1.5 m below the ambient sea floor at the margins in order to contain material during the discharge, and approximately 7 m below sea level to enhance containment during the active lifetime of the site. Strict control of the disposal operation is essential, and an allowance should be made for a final sand cap about 1 m thick.

PHYSICAL FACTORS AFFECTING THE DISPERSAL OF DREDGED MATERIALS
IN COASTAL WATERS: MANAGEMENT CONSIDERATIONS

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Over twenty years of field and laboratory study have provided a reasonable basis for the evaluation of the primary factors governing the transport of sediments dredged in coastal and estuarine waters and the ultimate bio-availability of particulate associated contaminants. At the dredging site, materials are placed in suspension by mechanical agitation of the sediment column, produced by the operating dredge, and discharge and/or drainage from the associated barge or shoreside containment area. Concentrations vary as a function of sediment characteristics, dredging method, mechanical or hydraulic, and required production rates. Observations at a variety of sites in New England indicate that for deposits of relatively fine-grained sandy silts and clays the typical clam-shell dredge will lose approximately 2-4% of its contained mass during each vertical pass of the dredge bucket. Continuing improvements in dredge design indicate that this loss figure can be significantly reduced by the use of closed or shuttered buckets. Materials placed in suspension form a coherent plume and are advected downstream and progressively settle to the sediment water interface. The spatial extent of the impact zone is governed primarily by particulate settling velocities which are often difficult to accurately specify. Values are best obtained by the use of in-situ bulk sampling using modified Own tubes or the equivalent. At offshore disposal sites, materials are placed in suspension by entrainment of portions of the mass settling from the barge and/or resuspension associated with bottom impacts. Short-term dispersal of these materials is governed by operational protocols, material characteristics, and local hydrography including depth, current velocities, and water column temperature-salinity structure. Protocols can be established that result in the precise placement of materials and the formation of reasonably coherent disposal mounds permitting close monitoring of a variety of mound physical characteristics including bathymetric contours

and the texture of the surficial sediments. Precise placement also permits subsequent capping of the disposal mound by less contaminated materials, if required. The spatial distribution of sediments suspended during discharge is governed by the same factors affecting dispersal of the dredge induced plume. Field observations and numerical modeling techniques, indicate that these materials typically settle rapidly and affect relatively small areas beyond the limits of the disposal site. On the longer term, in-situ field observations indicate that fine grained disposal mounds are stable. Compaction and consolidation of the mound are responsible for the major alterations in mound contours with surface erosion affecting only very thin near-surface layers. These data establish some particular constraints on future monitoring programs.

MONITORING DEPOSIT CONDITIONS

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Not only contaminated dredged sediments from harbors and estuaries but also all kinds of industrial wastes are and still will be stored in ponds, in order to separate the sediments 'temporary' from the environment. Basic problems in design of such ponds are the prediction of storage volume, long term diffusion of contaminations to the environment and remediation. In order to be able to cope with these problems the mechanical behavior of the sediment during deposition and consolidation in the ponds and extraction from the ponds must be understood. The most important involved processes will be discussed. Although theoretical and experimental knowledge is available with respect to these processes it is important to do field measurements with respect to sediment conditions for evaluation and possible adjustment of predictions. Some practical and technical feasible measuring systems will be presented.

FLOW FIELD OBSERVATIONS IN A ROTATING ANNULAR FLUME

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Since about 25 years rotating annular flumes have been used for studying erosion and/or deposition of cohesive sediments in the laboratory. These flumes have advantages over straight recirculating flumes in that effects of inflow and outflow conditions are avoided and that there are no pumps to break down the suspended flocculated sediment. However, a disadvantage of annular flumes is that secondary flow velocities are generated in the flowing water, yielding a complex 3-D flow field instead of a 1-D one as assumed in many erosion/deposition conceptions. These secondary flow velocities can be counteracted by rotating not only the top lid but also (in opposite direction) the flume itself.

The present investigation has been aimed at the optimization of the flow field in an annular flume with a rotating top lid as well as a rotating bottom. The measurements were done in the 4 m in diameter carousel of the Civil Engineering Department of the Delft University of Technology. The velocity field was measured with a 2-D fibre-optics backscatter Laser-Doppler Anemometer system. The tangential velocity, the water depth and the ratio of rotational speeds of top lid and flume were varied.

Uniform distributions in cross-sectional direction of near bottom shear stresses are found to be accompanied with minimal secondary flow circulations near the bottom. The investigation shows also that in situations where the secondary flow circulations are minimal, the remaining secondary flow velocities are generally not small compared with the sediment fall velocities. It is clear that this has implications for future studies of erosion, flocculation and deposition of cohesive sediments in a rotating annular flume.

The program of the paper presentation is: 1. Introduction, 2. Previous investigations, 3. Rotating annular flume, 4. Laser Doppler Anemometer equipment, 5. Measuring program, 6. Measuring results, 7. Conclusions and implications for future research.

**GEOTECHNICAL ANALYSIS AND CONSOLIDATION SETTLEMENT OF
DREDGE-SEDIMENT MOUNDS**

**by Armand J. Silva
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As part of the U.S. Army Corps of Engineers, Dredge Area Monitoring System (DAMOS) project, three coherent dredge disposal mounds in the Central Long Island Sound (CLIS) site were sampled and analyzed for geotechnical properties to predict self-weight consolidation behavior. Two mounds were capped with sandy materials and the third capped with silty sediments. Although some mixing of contaminated and capping dredge materials was observed, several cores showed a distinct boundary between the two materials. Bathymetric surveys were conducted shortly after disposal and at periodic intervals over seven to eleven year period after the initial disposal events. The average vertical strain experienced at each mound was approximately 62%, based on available bathymetric data. Properties obtained from geotechnical testing were used in one-dimensional consolidation computer models to predict the settlement and compare results with those derived from bathymetric surveys. The critical parameters in the settlement calculation are the determination of the initial stress condition and initial void ratio at the time of disposal at each site, and compression of the base material. Settlement predictions using the traditional consolidation theory were essentially identical (within 3 cm) to the observed bathymetric changes, whereas the finite strain consolidation computer code accounted for 76% of the observed change in mound height at one site. The analyses showed that compression of the underlying base material can be a major contributor to overall settlement of mounds.

MECHANICAL BEHAVIOR OF COHESIVE SEDIMENTS

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Because cohesive sediments in estuaries and rivers are the predecessors of clays it is obvious to use classification and identification systems with respect to clays known from soil mechanics. It will be shown that the fundamental mechanical behavior of clays can easily be extended to cohesive sediments ranging from soft clay to mud up to fluid mud. The regarded mechanical behavior will not only include the stress-strain behavior in the solid state but also the failure mechanisms like ductile, shear plane and cracking, and the post failure behavior into a liquid state i.e. the rheological behavior. Special attention will be paid to the influence of the porewater on the mechanical behavior and the drained and undrained condition. The influence of partly saturation due to gas production, osmotic effects on the mechanical behavior will be discussed. Some applications to practical processes like consolidation, erosion and shearing (vane test) will be presented.

ROLE OF COASTAL BOTTOM MUD IN WAVE ENERGY ABSORPTION

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The wave dissipative nature of soft bottom muds in the shallow coastal seas is a phenomenon that is well known to many mariners and fishermen globally, and in recent years has attracted attention as a result of ecological concerns and engineering possibilities. Coastal areas with muddy bottoms often are inherently important to fisheries due to the presence of a nutrient-rich substrate, hence there is a natural concern for its continued role in that context, especially in the event of human actions that might unduly disturb or deplete the mud. Likewise, beach protection against wave action provided by mud is a natural benefit, and currently the use of underwater nearshore berms composed of fine-grained sediments is being explored as a means for artificial beach protection.

This paper focusses on the behavior and role of bottom mud as a medium for wave energy absorption. The utility of a recently developed hydrodynamic model in predicting the degree to which wave height attenuation occurs is demonstrated through the use of laboratory as well as prototype data. A noteworthy characteristic of wave-mud interaction is the ability of waves to horizontally transport the bottom mud, which is highlighted through model prediction and comparison with laboratory data. In the prototype, e.g. along the southwestern coast of India, this mechanism leads to transient, episodic occurrences of mudbanks in otherwise sandy nearshore waters.

Unquestionably, the most important property of mud in these contexts is its rheology, hence it is most essential to use accurate constitutive models in conjunction with the hydrodynamic model to predict wave height attenuation and mud mass transport. A new, representative rheological model is described.

MONITORING OF CAPPED DREDGED MATERIAL DISPOSAL SITES

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Monitoring of capped dredged material disposal sites is necessary to assure both successful placement of materials and the long-term integrity of the cap. Monitoring during placement defines the size and shape of the contaminated sediment deposit so that capping sediments can be directed to specific disposal points. This is accomplished using a combination of precision bathymetry and sediment profile camera surveys. Interim and post-cap placement surveys are used to determine if the specified cap thickness was attained.

Long-term monitoring is used to assure that the cap is performing the function of isolating the contaminants from the environment. Long-term monitoring should be structured using a tiered design. The first tier of the monitoring program keys on the expected biological recovery response and continued assessment of physical stability. Higher tiers of the monitoring program are necessary only when biological recovery is abnormal. Experience at cap sites in New England has shown this approach to be both effective and sensitive so that problems can be identified and remediated when necessary.

A DECADE OF CAPPING: GEOCHEMICAL PERSPECTIVES

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Design of capped disposal projects rests on the assumption that a sufficient thickness of suitable dredged material can effectively isolate dredged material unsuitable for open water disposal. Regardless of the type of construction, this capping layer must prevent biological and physical disturbance of the underlying material and insure that contaminants are not remobilized through the processes of consolidation and dewatering. Evidence collected under the Disposal Area Monitoring System (DAMOS) from capped disposal mounds in Long Island Sound indicates that no detectable mobilization of trace metals has occurred over a seven to eleven year period. Despite consolidation of the mounds and underlying sediments, cap sediments remained geochemically distinct from mound sediments. I will present a geochemical model for capping of contaminated sediments, compare the model with results from coring studies, and address how results might effect pit design and construction.

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