Feasibility of Decontaminating Dredged Material

C A Fletcher
T N Burt

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HR Wallingford

Address and Registered Office: **HR Wallingford Ltd.** Howbery Park, Wallingford, Oxon OX10 8BA
Tel: + 44 (0)1491 835381 Fax: + 44 (0)1491 832233

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Prepared by C A Fletcher (name) Scientist (Job title)

Approved by T. N. Burt Project Manager

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Summary

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Disposal options for contaminated dredged material are becoming more restricted as pressure for decreasing inputs of contaminants to sea increases, and as landfill space reduces. Decontamination technologies whihc alter contaminated dredged material properties, such that they are suitable for beneficial uses or sea disposal, are desirable. In this report the scale of the situation is described through examples of contaminated dredged material in the UK. A brief description of the international experience of decontamination technologies is given. The criteria which any prospective technology must satisfy in terms of practicality, effectiveness, economics and environmental acceptability, as well as meeting legislative requirements, are outlined. A review of the reported technologies for dredged material decontaminated is reported. This includes experience from a workshop titled "Decontamination of Dredged Material" which was held at HR Wallingford.

Decontamination technologies are likely to need to handle large volumes of material with high water content and often mixtures of contaminants. The suitability of each technology will be site specific. There are many potential treatment technologies which are broadly categorised as mechanical, physico-chemical, biological and thermal treatments. Decontamination technologies have the potential to become an integral part of the dredging and disposal operation. However, only some of these technologies are proven at full scale. Many which show potential are currrently underdeveloped and costly compared to alternative methods such as containment. There is no "cure-all" method and the end solution is likely to involve a combination of treatment technologies (treatment trains) and disposal options. Further research and development is required as decontamination technologies will be needed in the future in many countries. The export potential for developed technologies is high.

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1 Introduction

1.1 Background

The dredging of navigational channels and waterways in the UK is an economically essential activity. The majority of material generated in the UK through essential dredging operations is inert in nature. However, the contamination of sediments in some of our rivers, estuaries, ports and harbours, canals and marinas mean that the material dredged may have restricted disposal options under UK legislation and licensing systems. In addition, the likely increase in legislative pressure preventing the disposal of contaminated sediments to sea may have serious implications for current disposal practices for some dredged material. Alternative disposal options and beneficial uses will be increasingly sought for contaminated dredged material.

The majority of material from maintenance dredging is fine grained sediments (<63μm) which are cohesive in nature and thus, generally less appropriate for beneficial use projects. In addition, contaminants are often associated with the fine grained sediments reducing the usability of the dredged material further. Clearly, processes and techniques which alter the properties of contaminated dredged material are desirable if they can render the dredged sediment safe for disposal, or better still, suitable for beneficial use. Currently, the Port and Harbour Authorities are faced with the problem of having to dredge in order to maintain navigation channels for traffic but, additionally in some circumstances, having to deal with the disposal of contaminated dredged material. The dredging industry has to handle the material, local authorities have an interest in the disposal of contaminated dredged material on land, and the development and potential market to sell decontamination technologies lies with commercial organisations. At present, decontamination technologies, although recognised to be an expensive option, are receiving increasing attention. However, they need to be tested on a wide range of contaminant and sediment types so that their potential is realised and appropriately employed.

The perceived problem is the practicality and very high costs of processing the very large volumes of material associated with dredging, and handling their high water content. A further important issue is whether the important contaminants are sufficiently removed. The feasibility and requirement of decontamination technologies for contaminated sediments from UK sites with dredging requirements needs to be elucidated.

1.2 Objectives

The objectives of this study are:

i) To establish the feasibility of decontaminating dredged material and to identify the most promising technologies for the purpose.

ii) To define the scale of the problem (quantitative and geographical),

iii) To establish criteria which any prospective technology must satisfy and review technologies likely to be suitable for dredged material.

iv) Assess the practicality of decontaminating dredged material and write a specification for the work required to establish the feasibility and usefulness of the most promising technologies.

v) To hold a workshop to present initial findings to a target audience and to obtain the views of industry.

vi) To report findings of the study in an appropriate publication to promote industrial interest.

A workshop titled "Decontamination of Dredged Material" was held by HR Wallingford on 23rd January and was well represented by industry, users and researchers. A report of the workshop is given in Appendix 1. In addition, some of the findings have been published in a paper which was presented at CATS CONGRESS III held in Ostend in March 1996. A copy of the abstract is given in Appendix 3.

1.3 Report structure

The remainder of this report is in five chapters. Chapter 2 addresses the scale of the situation as regards dredged material contamination in the UK The criteria of importance for a successful decontamination technology are presented in Chapter 3. Chapter 4 gives a review of the decontamination technologies. For each type of technology the following information is given: basic principle, methods or processes under demonstration, environmental implications, estimated costs. Overall conclusions arising from this study are presented in Chapter 5 and recommendations for further study are detailed in Chapter 6.

The report finishes with a reference list for the literature cited throughout the text and three appendices outlining the HR Workshop, abstracts and the CATS III Congress.

2 The scale of the problem-quantitative and geographical

2.1 Dredged material contamination in the UK

Dredging is a fundamental and critical activity in fluvial and estuarine/ coastal areas. Large quantities of dredged material are generated in the UK every year through the essential dredging of navigation channels in ports and harbours and in estuaries of navigable rivers. The majority of dredged material (approximately 40,000,000 tonnes per annum) is disposed of to sea, while approximately 1,000,000 tonnes is disposed of to land per annum (MAFF, 1993).

Generally, during dredging operations, the large quantities of sediments collected are mostly inert in nature. However, in some areas high contaminants may exist and a small percentage of dredged material (less than 10%) is reported to be contaminated to the extent that disposal at sea is compromised. A wide suite of contaminants may be expected to be present at any one location from both historical and contemporary discharges made under licence, and accidental spillage which have led to the accumulation of contaminants in the sediments. Contaminants generally recognised to be of concern in aquatic sediments of dredging areas include metals (such as Hg, Pb, Cu, Cd and Zn), organobutyl tin (eg tributyltin (TBT)), organochlorinated pesticides (OCLs), organophosphorus insecticides (OPs), polychlorinated biphenyls (PCBs), herbicides, oil products, polyaromatic hydrocarbons (PAHs), dioxins and furans. The majority of these contaminants will be preferentially associated with the fines (<63µm) fraction and the organic matter of the sediments.

Although some release of contaminants will occur on dredging, contaminants will remain in the dredged material which will need to be disposed.

The London Convention 1972, Waste Assessment Framework is currently under discussion and, once annexed, will result in much closer scrutiny of both the disposal of waste at sea and the examination of alternative options. The disposal of contaminated dredged material is therefore likely to become increasingly problematic and expensive such that methods of decontaminating material will need to be considered.

2.2 Disposal options and constraints

2.2.1 Disposal to sea

The national framework on dredged material disposal in the UK involves the control of disposal to sea by MAFF using powers contained in Part II of the Food and Environmental Protection Act 1985 (FEPA), now modified under the Environmental Protection Bill. There are no statutory limits regarding levels of contaminants, however, under the principles of FEPA and the Environmental Protection Bill, regard to protecting the marine environment, living resources which it supports and human health must be undertaken. In addition regard to the practical availability of any alternative disposal methods are to be made. Other legislation which applies is the EC Directive on the Dumping of Waste at Sea (EC COM, 1985-directive 85/ 373/ EEC).

In addition the UK is obliged to meet criteria outlined under international conventions such as the London and OSPAR (Oslo and Paris combined) Conventions. The London Convention, otherwise known as the prevention of marine pollution by dumping of wastes and other matter, has guidelines whereby the disposal of wastes into the open sea are to be limited and controlled.

Other countries have separate systems governing dredged material management and disposal. The Dutch have more specific guidelines for the management and disposal of dredged material and aquatic sediments, with a 5 category classification system (0 to IV) according to metallic and organic contaminant concentrations. Highly contaminated material (Class IV) must be disposed of to land and contained. Hong Kong have also adopted a classification system based on metal concentrations. Canada has a screening guide for contaminated sediments. The system in the USA is based more on ecotoxicological assays.

Currently, MAFF are setting up action levels (not a set of standards) where the disposal to sea will be prohibited. These action levels are not anticipated to come into the public domain for the foreseeable future and decisions are very much based on chemical analysis of a suite of contaminants, dictated by national law and international conventions, and the wide experience and established procedures of MAFF staff.

2.2.2 Disposal to land

A recent publication gives guidance on the disposal of dredged material to land (CIRIA, 1995). This report highlights the following:

The position of dredged material with regard to disposal on land is not clearly defined in law, as recently changes in laws regarding waste management have occurred.

Dredged material for disposal to land is assessed by local authority Waste Regulatory Authorities (WRAs) which are now part of the recently formed Environment Agency.

Legislation of importance includes;

- L1 Waste Management Licensing Regulations 1994, SI 1994 No 1056
- L2 Environmental Protection Act part II-contains a Waste Management Licensing System which is detailed in the 1994 regulations above.
- L3 European Community Directives on Waste-(75/442/EEC; 91/156/EEC; 91/692/EEC)
- L4 Control of Pollution (Special Waste) Regulations 1980, SI 1980 No 1709- overrides exempt waste

Government guidelines include;

- G1 DoE Environment Circular 11/94-guidance on the concept of waste
- G2 Water Resources Act 1991- definition of "inland waters" for spreading of dredged material on agricultural land

- G3 Agricultural Act 1947- for the meaning of "agriculture"
- G4 Town and Country Planning Act- if the disposal of dredged material involves the development of land then planning permission is required
- G5 EC Environmental Assessment Directive
- G6 EC Directive on Landfill has recently been withdrawn, however, parts of it will continue to be implemented through UK legislation

Important points highlighted are:

i) The legislative position of dredged material as a waste is not clearly defined and activities should not be undertaken without communication and discussions with the relevant bodies ie WRAs, MAFF etc. It is expected that the position of dredged material will only become apparent with time, through the setting of precedent.

ii) That L1 has the phrase "directive waste", while L2 uses the phrase "controlled waste", but not all "directive waste" is "controlled waste", therefore not subject to L2.

iii) None of the categories of waste in L1 refer specifically to dredged material.

iv) Whether the waste has been "discarded" is of importance, and if it is to be used in a beneficial way, proof that other materials may have been sought (had the dredged material not existed) will be important. Also payment for the material may support applications for exemption from disposal licences.

v) Potential beneficial use options will need to be explored and where appropriate employed.

vi) Contaminant standards exist which are applicable to the disposal of dredged material to agricultural land.

vii) Standards for some contaminants exist for landfill/ containment eg. PCB concentrations up to 50ppm are acceptable. This is high compared to concentrations typically found even in contaminated dredged material meaning that few materials will be restricted from landfill sites.

viii) Disposal or use of dredged material on land will also be effected if the land carries a special designation, such as an SSSI (Site of Special Scientific Interest) or SPA (Special Protection Area) or SAC (Special Area of Conservation) outlined in the EC Habitats Directive and the EC Birds Directive.

2.3 Estuarine and coastal areas in the UK

As stated in Section 2.2.1 disposal of dredged material to sea requires a licence from MAFF. Granted licences have recently become open on a public register and contain some information on sediment properties and contaminant concentrations. Historically MAFF have not undertaken sediment particle size analysis, but are now starting to build this information up in a descriptive way (ie %sand, %silt, %clay). The percentage of total solids is given and contaminant concentrations given include most anthropogenic metals, polychlorinated biphenyls (PCBs) and organochlorine insecticides (eg DDT, dieldrin, lindane). These contaminants are routinely analysed for at sites of concern.

In the USA, dioxins, furans and polyaromatic hydrocarbons are occurring in dredged material from ports and harbours and are causing wide concern. These contaminants are currently not routinely analysed for in the UK sea disposal licence system, but may well be in the future and are considered to be of potential significance.

In UK marine areas it is generally considered that metal contamination is not a widespread problem and organic micro-contaminants such as PCBs, TBT, PAHs and oil products are of greater concern.

The quantities and level of contamination of monitored contaminants in dredged material from different estuarine and coastal locations can, therefore, be assessed from licence data where sea disposal is the desired disposal route. MAFF licence data indicates concentrations and volumes of dredged material (ie contaminant loads) approved for sea disposal. Refused licence applications, or licences granted on condition that some material goes to land disposal are therefore of great interest with regard to decontamination technologies.

Identification of sites which already, or which may in the future, present particular disposal problems include;

2.3.1 Devonport

Previously, Devonport displayed PCB contamination but the sediments were dredged and disposed of to land. In addition, licence data indicates previously high concentrations of Cd, with a low level of Hg and Cu enrichment relative to other dredged material data. Licences to dredge the Naval Wharf displayed the greatest concentrations for this location.

2.3.2 Blyth

Blyth is one site in the U.K where investigations into the use of decontaminating technologies were researched at pilot scale. At this site, the sediments over a small area of dock were highly contaminated with PCBs (ppm range). The tidal dock was also heavily contaminated with PAHs, Pb, Hg and Cd and heavy petroleum hydrocarbons (TPHs) and Asbestos. Concentrations of PCBs in the silt ranged from approximately 200 µg/kg to 75,000 µg/kg. However, the final disposal options undertaken were encapsulation and containment. Decontamination technologies, although investigated have not yet been employed due to economics and the risks associated with the unproven status of technologies at plant scale. However, heavily contaminated material is currently being temporarily stored and a solution is being sought.

2.3.3 Falmouth

In Falmouth Harbour there are high TBT concentrations at depth. These arose from the past dry dock activities of scraping boat hulls and flushing wastes into the water. Currently the contaminated area is being left alone, however, in the future if dredging occurs the contamination at this site will be an issue, especially because the existing disposal site is located near scallop beds.

A range of metal concentrations are indicated in licences which display very low/ background concentrations for the majority of metals to high Cu, Pb and Zn contamination in some locations. The inner harbour and yacht marina are particularly contaminated.

2.3.4 Portsmouth

Contaminated with PAHs. Clean-up is currently under consideration.

2.3.5 East Anglian Marina

There was a unique situation at this site arising from a very localised incident of extremely high TBT PCBs, DDT and dieldrin contamination confined to a very small area. The sources of these contaminants, to the extreme levels detected, are not known. This material was dredged and approximately 330m^3 of it was placed, at cost, to a commercial landfill site.

Sea disposal licence data from this general area, however, displayed no distinct metal contamination.

2.3.6 Newport

Some estuarine/coastal areas of South Wales have a recognised PCB contamination problem. PCB contamination arising from industrial activities in the area. In addition, licence data displayed relatively gross contamination of Cd, Cu, Pb and Zn.

2.3.7 Swansea

Cu, and other metals arising from the smelting industry in lower Swansea over the last century. Also Cu and sulphuric acid from local industrial activities. Licence data shows high sediment concentrations for Cd, Cu, Pb and Zn.

2.3.8 Maryport

The occurrence of trace radioactive contaminates at Maryport marina is possible. This area has no regular dredging program. However, licence data indicates sediment enrichment of Pb and Cd.

2.3.9 *Whitehaven*

This area is contaminated with Cd and Pu^{210}. A known source is the phosphate ores from local herbicide production.

2.3.10 *The Tees Estuary*

Metal contamination of the Tees estuary has been previously documented (Delo and Burt, 1991). High metal concentrations included Cu, Cd, Zn, Pb and Hg and these contaminants were monitored at the dredged material disposal ground.

2.3.11 *The Tyne Estuary*

Contaminated with metals and consistent requirement for large amounts of dredging. Metals occur naturally in the environment and marine sediments due to the weathering of rocks and determining metal enrichment due to anthropogenic sources can be difficult. There is no universally recognised or routinely undertaken procedure for defining metal contamination in sediments. MAFF have used a stretch of this river/estuary to examine different techniques to determine anthropogenic loads and investigate the best method from normalising and defining contamination.

2.4 Inland Waters in the UK

Increasingly UK environmental policy and legislation has been guided at cleaning inland waters and sediments up by reducing inputs. The situation is that control of point sources (sewage and industrial effluents) of contaminants in the UK is good and inputs have dropped dramatically since the 1970's/ 1980's to the extent that surface sediments in fluvial and inland waters are predominantly "clean". Even though diffuse (non-point) sources are still of concern and difficult to control (eg. atmospheric deposition, run-off from roads and nutrient/herbicide releases from farming), the need to treat and decontaminate dredged sediments in UK rivers and canals in the future is not predicted to be great.

However, there are areas of inland waters where metal contaminants are known to be of concern and where historic inputs have deposited contaminated sediments at depth. If dredged these sediments pose a disposal problem. Analysis of information as regards a few sites highlighted the following as having a dredging need and contaminant problem.

2.4.1 *North West Canal System*

Dredged material contaminated with metals (Hg, Pb) are collected from on-going dredging operations and stored in their own disposal ground. Contaminated dredged material is generated from regular maintenance dredging operations, however, here some crude separation occurs simply as a result of the pumping of dredged material from the dredger barges directly onto the site. At present, the contaminated fines are stored and the coarser fractions washed with the wastewaters being discharged directly back to the canal.

2.4.2 *Birmingham Canals*

The Birmingham canals are an example of where clean-contaminated sediment separation and washing treatments were employed in a clean-up operation. Heavily contaminated with metals (particularly Pb, Zn and Cu) and mineral oils, 5 km of canal were dredged for navigational and environmental (remediation dredging) reasons. The removal of approximately 30,000 m^3 of sediment was achieved. Of this 5,000 m^3 was treated by off-site washing and separation. Screening, followed by sieving and hydrocycloning were undertaken with subsequent use or disposal of various fractions of separated material. Waste water was treated to standards specified by the NRA and discharged back to the canal. Full process details, dredged material properties and contaminant concentrations are reported (Bromhead and Beckwith, 1994).

2.4.3 Norfolk Broads

Mercury contamination exists (from historical industrial discharges), and the mercury is actively methylated in sediments to methylmercury, an organometallic contaminant capable of bioaccumulating up the food chain with health implications for humans (NRA, 1994). The dredging and disposal of these areas is controlled and collected contaminated dredged material is currently disposed of to land.

In addition, very high nutrient sediment concentrations exist in the Broads coupled with a consistent dredging requirement for navigation and recreational boating purposes. There is concern over the effect of improving water quality in these areas, the sediments presently act as a nutrient sink. Improving water quality could become a problem as the anoxic sediments become oxic and release the nutrients.

2.4.4 Weaver Canal

Extremely high Hg concentrations have previously been reported.

2.5 Summary of UK Contamination

Contaminants of known concern in estuarine and coastal areas in the UK are TBT and PCBs. Metals are not generally causing a problem, with only a few estuaries showing metal contamination at significant levels.

It is recognised that there are a wide range of organic contaminants currently not monitored that may be of potential concern, such as the triazine herbicide, Irgarol 1051, currently being used in Cu/ Zn formulations as a replacement for TBT. Analysis for PAHs in dredged material is anticipated to be undertaken in the future, and these may also be of concern. In addition highly toxic dioxin and furan contaminants are currently not commonly analysed for in dredged material in the UK Once other contaminants, such as PAHs, dioxins and furans, are more routinely analysed for, they may also be of concern. The requirement for decontamination technologies may then become greater.

However, overall the contamination problem in the UK is piece-meal with localised "hot spots" which are often buried at depth and are only of concern when capital dredging is considered.

Where such "hot spots" exist, the feasibility of decontaminating dredged material is of interest. Although the costs are anticipated to be high and the technologies are not fully tested on a plant scale, for some sites where local contaminant "hot spots" occur treatment before disposal to land or sea may be a real option, and make both environmental and economic sense.

Generally the contaminants of concern in estuarine and coastal areas are the same for inland waters. Contamination by metals and nutrients are generally of more frequent and greater concern in these areas.

Therefore, currently in the UK decontamination technologies for sediments have not been employed to any great extent and are not yet entirely justifiable in terms of volumes of contaminated dredged material. Research is needed so that the risks, such as unpredictable costs and unknown effectiveness, presently associated with employing decontamination technologies can be properly addressed.

3 *Criteria for a successful decontamination technology*

There are many criteria a successful decontamination technology needs to satisfy which need to be highlighted to aid the development of promising technologies.

3.1 Appropriate technology

A first step, before any choices can be made, will be a sufficient assessment of dredged material properties and contaminant concentrations so that the problem which needs to be dealt with is clearly identified. Then the question "What are the appropriate technologies, if any, for this problem? can be asked.

3.2 Status and efficiency of technology

3.2.1 Development/ Availability

The availability and development of a technology will need to be known. The main question to be asked will be "Is the technology commercially available or what is its stage of development?"

3.2.2 Suitability

The technology will most likely have to remove a range of contaminants (removal or reduction). The percentage removal of contaminants from sediments will depend on the contaminant under investigation, the contaminant concentration of the feed sediment, the operation conditions (temperature, pressure and residence time). Final residual concentrations need to be determined. Sediment properties, such as percentage fines (<63μm) and organic matter will be important since the efficiency will be effected by the adsorption and strength of the bonds.

3.2.3 Practicality (eg process capacity and contact time)

The decontamination technology must be practical. Volumes of dredged material to be treated are likely to be high, therefore, process capacities will need to be high and the residence time of the process must agree with the projects overall timetable.

3.2.4 Effectiveness

The most recognised method for assessing decontamination technologies effectiveness is by using contaminant concentrations and removal efficiencies. However, it needs to be accepted/ recognised that sediment contaminant concentrations should not be the only criteria considered and the ecological significance of dredged material needs to be assessed. If the correct choices of decontamination technologies are to be achieved and employed at acceptable costs, the contaminants of importance and at what concentrations they are of environmental concern will need to be established.

Ultimately, the effectiveness will be measured by the ability of the decontamination technology to alter the material properties sufficiently to render it suitable for beneficial use and sea disposal.

3.3 Costs and benefits

The technology must be cost-effective compared to alternative options. A summary of the potential costs and benefits are provided in this section.

3.3.1 Comparing clean-up costs with alternative disposal options

It will be necessary to compare predicted treatment costs with costs of other options (open water capping, confined disposal facilities) and beneficial use projects. It is likely that controlled disposal of highly contaminated dredged material will involve the greatest costs and this may be a useful marker to compare against predicted costs of decontamination operations.

The clean-up costs which need to be considered are:

"Pioneering" costs of development

Costs that need to be considered include capital costs of installation, operational costs per tonne, possibly dismantling costs. Running costs include pre-treatment, land area, storage, transportation, fuel, additives, post treatment, final disposal route. Disposal costs of any resulting residues and effluents.

Costs of monitoring during and after work.

Cost of dewatering contaminated dredged material, transport and disposal may also be a marker for what could be afforded for any decontaminating process. Questions to be asked include; "will it be more cost-effective to transport the contaminated dredged material to the plant or to have a portable plant and take it to the contaminated dredged material?".

Overall the costs will depend on the technology, contaminant load reduction required, water content and operational conditions.

3.3.2 Environmental costs/ benefits

Environmental costs and benefits are typically more difficult to assess. However, they include:

Environmental costs involve the transfer of contaminants to other matrices (air, water) and the generation of other waste material with potentially acute levels of contaminants. There will be costs associated with the transfer of contaminants to other matrices

Environmental benefits are a solution to the problem, some technologies reduce contaminant loads permanently and beneficial use of the dredged material may be possible.

The environmental benefits will be case specific and will need to be demonstrated. The solution to the immediate problem can be measured in terms of an improved water/ marine environment, or the beneficial use of material. For example, some technologies reduce contaminant loads and, therefore, remove them permanently from the environment.

If decontamination technologies are to become a recognised option, their environmental advantages over other disposal options (eg. containment) need to be proven.

3.3.3 Changing legislation and emerging regulatory system

Decontamination technologies will have to treat dredged material such that legislative requirements, disposal options and beneficial use criteria are all met.

In addition, an unknown and legislatively undefined situation is "what disposal options will be open to the treated dredged material under legislation? (will they be considered as industrial waste, ie mine tailings)"

3.3.4 Acceptability and public perception

Public intervention is playing an increasing role in decision making and dredging activities are no exception. Dredged material needs to be seen as a resource not as a waste and the products will have to be acceptable and marketable.

Environmental acceptability and public perception are increasingly important. The location of decontamination plants at some sites may be unacceptable to the public (the NIMBY-Not In My Backyard syndrome). The transfer of contaminants into other environmental matrices during the clean-up process will be significant since controls will exist under legislation. Air emissions are controlled for certain contaminants. In addition, in removing the contaminants from the dredged material an effluent or waste cake may be generated and need to be dealt with. Process water must meet standards for effluent quality discharged into watercourses or the sewage network.

Therefore, an unacceptable loss of contaminants must be prevented. It is not acceptable that techniques create greater risks to environmental media than any other handling/ disposal options of the contaminated dredged material.

4 Review of technologies

4.1 Definition of treatment for this study

There are numerous methods of treatment of contaminated sediments of which decontamination technologies are only a part. Treatment processes include remediation, in-situ treatment, containment, sediment washing, separation techniques and decontamination technologies. Confined disposal (containment) facilities are a logical preparatory step for treatment processes or for storage prior to beneficial use. The suitability of a site for large areas of controlled storage will depend on the space available and the soil type. Storage, prior to treatment is occurring at the Marathon Battery Superfund site in New York and New Bedford Harbour Superfund Hot Spot in Massachusetts. However, the decontamination of sediments specifically are the treatment processes to be critically reviewed in this study and they are very much an emerging technology. Pre- or post- treatment methods that form an integral part of some of these decontamination methods will also be addressed.

Current technologies are often under utilised or are still being developed. Therefore the availability of technologies, likely future development, practicality, effectiveness and cost of technologies need reviewing before they can be established as viable options. Sediment decontamination technologies are very much an emerging technology and there is a general absence of information.

4.2 International situation on decontamination technologies

It is recognised that some other countries have more experience in this field then the U.K. Research or demonstration programmes focusing on treatment have been established in the U.S.A., Canada, the Netherlands, Germany, Belgium and Japan. Environment Canada's Contaminated Sediment Treatment Technology Program (CSTTP), Quebec Development and Demonstration of Site Remediation Technologies program (DESRT) and the U.S. Environmental Protection Agency's (USEPA) Assessment and Remediation of Contaminated Sediments (ARCS) program are both concerned with problems of the Great Lakes. In addition, sediment decontamination demonstrations for contaminated sediment from the New York/ New Jersey Harbour are reported (Tetra Tech Inc.and Averett (1994); Averett *et al.* (1994); Garbaciak, (1994); Garbaciak *et al.*, (1993)). Additional information and experience of treatment technologies is available from the USEPA's Superfund Innovative Technology Evaluation (SITE) Program and the site specific investigations. The Development Program Treatment Processes (DPTP) in the Netherlands is also actively investigating treatment technologies for sediments and has been running for several years. The Netherlands organisation for applied Scientific Research (TNO) have been carrying out research programmes since the 1980's.

Processes have mostly been evaluated on a laboratory scale and until recently little progress had been made toward field demonstrations of sediment treatment. In the USA treatment at production scale is completed or under way at three Superfund sites; Waukegan Harbour, Boyou Bonfouca and Marathon Battery. Full scale treatment in Europe has been primarily particle separation technologies (discussed in Section 4.3.1), although a number of innovative treatment technology demonstrations are scheduled to begin shortly (Schotel and Rienks, 1993).

Reviews of technologies include van Germert *et al.* (1994), St Lawrence Centre (1993) and PIANC (1995).

4.3 Review of decontamination technologies

4.3.1 Background

This section covers decontamination technologies reported in the literature. The cohesive nature of some dredged material and potential for such material to have high levels of associated contaminants reduce its usability. There are several potential ways to decontaminate dredged material, all costly, and all needing further research. At present the treatment of contaminated sediments exists on a laboratory or pilot scale and few operate on a large scale. Most are large scale hydrocyclones that separate sands from silts. The effective and treatment of sediments contaminated with a wide array of chemical species is not yet available. Such sediments would involve the use of a range of treatment technologies (treatment trains).

Therefore, there is no "cure-all" treatment. The treatment will depend on the contaminant species present in the dredged material which require removal and the properties of the dredged material itself, including the water content. No two sites are the same. It is likely that additional and specialised storage areas may be required as an integral part of the treatment process. In the Netherlands contaminated dredged material from the Port of Rotterdam is graded and is presently being stored in a large lake (the Slufter) where trials for treatment and beneficial uses are being conducted. The most heavily contaminated material is placed at a lined site called the "Parrots Beak". Both of these sites are shown in Plate 1.

Assessments of the costs of technologies have been undertaken in other studies. However, large uncertainties exist as costs have been extrapolated from pilot scale to full scale. In addition, the costs will depend on the contaminant to be treated, the quantity of material and the dredged material properties. Typically, the costs of decontamination operations are reported to be an order of magnitude greater than costs of sediment disposal (Keillor, 1993; Garbaciak, 1994). It is recognised that if costs can not be reduced, an alternative would be to find environmental benefits that justify these costs.

Treatment technologies for contaminated fractions being currently examined are outlined in Figure 1, where other factors related to the decontamination operation as a whole are also displayed.

Treatment technologies have primarily stemmed from innovative technologies from the hazardous waste/ mineral processing fields. While there have been a number of remediation technologies developed for the treatment of soils, there is a general absence of experience on how these technologies would perform with sediments.

Clearly the treatment will depend on the contaminant species present in the dredged material which require removal and the properties of the dredged material. However, no two sites are the same either in the contaminants present or in the potential for contaminating adjacent environments. This review deals with the treatment processes both individually and, where information is available, an assessment of individual contaminant groups, see Figure 2. Contaminants assessed will be those outlined in Chapter 2 as being a current problem within UK sites and contaminants anticipated to be of concern in the foreseeable future.

4.3.2 Mechanical separation

Principally, the techniques separate the fine fraction, where contaminants (especially metals) are generally concentrated, from the coarser fractions. Suitability will depend on the sediments properties. Their importance lies in their ability to reduce total volumes of contaminated material. This means that transport and storage coats are reduced. In addition, by concentrating contaminants into smaller volumes other decontamination technologies can be used more cost effectively.

Mechanical methods include separation basins, hydrocyclones, flotation, sieving, sediment washing and dewatering. These methods are typically pre- or post-treatment steps and are mostly proven technologies for sediments.

Separation basins This is a well established method which separates coarse material from fines by flushing with water jets, for example, and is applied on a large scale (Diebel and Zwakhals, 1993). This is relatively inexpensive technique, and with successful marketing, it may be possible to cover process costs by the sale of sand.

Hydrocyclones A hydrocyclone separates the sediment into sand particles and, fines and organic material. Due to the differences in sorption properties of these two fractions, the contaminants are generally concentrated in the fine fraction, while the sand is relatively clean. The removal efficiency of contaminants will be site specific and will depend on the contaminant distribution within the sediments. Where the dredged material is a >60% sand and the contaminants (such as metals) are predominantly in the fines, this physical separation method is well proven. Its use is increasing especially in the Netherlands and Germany.

An operational hydrocyclone is shown in Plate 1 where the contaminated dredged sediments from the Amsterdam Canals are being separated.

The efficiency of hydrocycloning is optimised by estimating the contaminant fraction and setting the separation factors accordingly. For the hydrocyclone method separation becomes increasingly poor for small particle sizes. The lower limit of separation is generally 10μm (van Gemert *et al.*, 1994).

Current examples of large scale hydrocycloning techniques which separate the sand fraction from the silts and clays in collected sandy dredged material include;

- Francop, Hamburg, Germany
  Boskalis Dolman bv environmental works (Mitra II) in Germany separate the sand from suitable (reasonably high sand content) material which can then be used. The dredged material is fed into the installation in dry form. The coarse particles are screened off and washed clean. The remaining dredged material is then turned into a slurry and, via hydrocyclones and sieving, the clean sand is separated from the silt. The process is efficient for sandy dredged material. The separated sand complies with quality criteria for unlimited general purpose use. The contaminated silt fraction is processed separately and dewatered to form a firm filter cake. The plant has a capacity of 400 tonnes of dredged material per hour, with at least 1,000,000 m^3 of dredged sandy material requiring processing over a 4 year period.

- (Elbe Estuary) Hamburg, Germany
  METHA (MEchanical Treatment of HArbour sediments), is a large scale separation and dewatering plant for the treatment of contaminated sediments from the Elbe estuary. The separated coarse grained sand fraction was found to have very low levels of contaminants and is reused, while the fine grained silt fraction is contaminated and mechanically dewatered and stockpiled on land at a contained disposal site meeting special environmental requirements for the Hamburg area. The plant is constructed to receive contaminated dredged material at a rate of 2,000,000 m^3 per year (Detzner, 1993; 1995). In practice the throughput of the solids fraction amounts to 600,000 tonnes per year, corresponding to 1.2 to 1.4 million m^3 per year (in situ) with 50% (by weight of the solid having grain size of <63μm (Kothe, 1995).

- Other examples where hydrocyclone separation of contaminated sediments has been, or is currently employed, include Ghent (Belgium), Amsterdam Canals (The Netherlands-see Plate 2)) and Birmingham Canals (UK).

Flotation Principally, particles are separated from the bulk liquid on the basis of differences in their physical and chemical properties. The applicability of flotation technologies to a wide range of dredged material types is uncertain and will clearly depend on water content. It is successfully used for the separation of oil and metal sulphides after flocculation in waste waters. Process capacity is reported to be 500 m^3 h^{-1} (van Germert *et al.*, 1994).

Sieving A simple method frequently employed before hydrocycloning to remove large objects.

Sediment washing Sediment washing techniques are incorporated into separation methods, such as hydrocyclones. Contaminants are concentrated into the silt fraction rather than destroyed during the sediment washing process. The volume of contaminated material represented by the silts and clays may, therefore, be smaller then the volume of originally contaminated sediment. The process is relatively inexpensive (Galloway, 1994). In addition, the "clean" sand fraction may be used beneficially.

No contaminants are destroyed during the sediment washing process, however, the volume of contaminated material represented by the silts and clays is smaller then the volume of originally contaminated sediment matrix and the sand fraction may additionally be used beneficially.

Dewatering This is mostly employed as a post treatment step after the initial separation, dewatering technologies are mainly undertaken to increase the cohesive nature of sediments and render them easier to handle and more usable. A reduction in volume of contaminated sediments can be advantageous to the overall disposal costs. Generally, the largest problems exist with fine grained materials as a long period and large areas for dewatering are required. Dewatering can be achieved by dewatering fields (eg. Antwerp and Rotterdam), filter presses and the use of thickeners (which will increase treatment costs). If the material is highly contaminated, problems can occur due to the uncontrolled oxidation of the material during dewatering (particularly in fields). There is subsequently potential for contaminant leakage and in the production of effluents which may need further treatment. The capacity of dewatering appliances are reported to be limiting (50 m^3h^{-1}) (van Gemert *et al.*, 1994).

Magnetic separation The use of large magnets to remove magnetic material is extensively employed for contaminated soil remediation.

4.3.3 Physico-chemical

A wide range of physico-chemical technologies exist which will remove or reduce contaminant loads from the sediment matrix. Contaminated dredged materials commonly display a wide range of contaminants. The situation is complex and the removal of metals is fundamentally different to the removal of organic contaminants.

Extraction techniques Extraction techniques involve the removal of contaminants from the solid matrix using the chemical and physical properties of a particular solvent or solvents. This technique does not destroy contaminants but concentrates them into a reduced volume and transfers them into an aqueous phase.

a) Acid extraction. Chemical treatments to remove metals involving acid/ alkaline leaching in a series of stages have been investigated (Muller, 1993). This method can remove heavy metals to below Dutch standards, however, the matrix of the material is destroyed with no usable products (Stokman and Bruggeman, 1995). In addition, the removal of Cd is not always sufficient by this technique (Schotel and Rienks, 1993). The extent of removal depends on the acid mixtures used. However, this treatment method is economically limited due to the quantities of acid and lime required. Also, there is uncertainty as to whether undesirable compounds are formed when organic matter is present. Aeration prior to acidification aids the process but will increase costs. Acid extractions which have been investigated in the Netherlands include hydrochloric acid, biochemically produced sulphuric acid and citric acid.

b) Complexation extraction; This procedure showed great promise at laboratory scale, however, due to regeneration difficulties and technical complications the use of this technology at plant scale is predicted to be limited (Stokman and Bruggeman, 1995).

c) A favoured method emerging in the USA is the solvent extraction technology, B.E.S.T. (Basic Extractive Sludge Treatment) Process. It is reported for bench and pilot scale and has had limited full scale application (Garbaciak, 1994). This method involves the stripping and removal of organic contaminants from a solid or liquid matrix using the chemical and physical properties of a particular solvent or solvents.

d) Supercritical fluid extraction; Laboratory scale tests are under investigation whereby supercritical fluid extraction (SFE) and supercritical water oxidation (SCWO) are being integrated so that heavy metal extraction and oxidation of organic components can be achieved in a combined unit operation. this is not demonstrated at full scale for dredged material, however, SFE is a proven technology for certain industrial processes.

The B.E.S.T. extraction techniques seems to be reported as the most appropriate technique for contaminated dredged material. However, extraction techniques are not likely to have a large scale application in the future as there seem to be a large number of more advanced competing technologies (microbiological, mechanical and thermal).

Immobilisation techniques This method employs the reverse principle to extraction, whereby here the material is chemically treated or fixed so that contaminants are associated with the solids such that they are immobile. Solids will then be either more usable or less of a problem for disposal. Examples include in-situ solidification, which is probably of limited use due to the large quantities of dredged material involved, the methods inability to conclusively remove or destroy contaminants in the long term (>5 to 10 years) and risk that it will eventually impact on bottom organisms.

Wet air oxidation This is a chemical oxidation process, which uses elevated temperature and pressure to oxidise organic constituents present in a liquid or slurried solid waste stream. No reports of its application at pilot scale have been found, however, laboratory experiments have been extended to a semi-practical scale. In theory, under high temperature and pressure, organic contaminants oxidise down to carbon dioxide and water, but in practice the actual composition depends on the material to be treated, pressure, temperature, availability of oxygen and the process duration. Degradation of organic compounds and reduction of contaminant loads is therefore expected, but may be incomplete.

Indeed, wet air oxidation has been shown not to be effective at destroying PCBs but it was, however, more effective at PAHs (Garbaciak, 1994). Application of this technology is established for municipal waste water treatment and sewage sludges. However, taking into account the wet nature of the process it has some preliminary advantages for dredged material as an initial dewatering pretreatment step is not required and it is reported to be applicable to slurries (eg from hydrocycloning) without dewatering. The predicted limited capacity of plant may reduce its usefulness for dredged material.

Base Catalysed Decomposition (BCD) The use of base catalysed decontamination of sediments from New York/New Jersey Harbour, where numerous contaminants occur in sediments and concentrations rank among the highest in the USA has been reported (Stern *et al.*, 1994). Assessed on a bench scale, this method proved to be fairly effective for destroying PCBs, chlorinated hydrocarbons, chlorinated pesticides, and dioxins. The method is reported to have strong capability of removing PAHs. The metal Hg is also removed but not other metals.

Ion exchange Technologies under consideration for the removal of metals include the use of flocculants to promote sedimentation. However, the selectivity of the tested resins in this study for different metals was roughly of the same order and metals such as Ca took up a large percentage of the exchange capacity due to it being present in far greater concentrations. Consequently large amounts of resin would be required to achieve the desired reductions of toxic metals, such as Cd and Hg, which are typically present at lower concentrations greatly limiting the effectiveness of this technology.

Technologies employing selective cation exchange, through existing complex forming ion exchangers, may be applicable to dredged material and would be mainly used for metal reduction (van Hoeck *et al.*, 1983). Alum and Ferric coagulants are considered to be unacceptable due to the high dosages required, while synthetic polymers are thought to have potential. However, techniques need to be selective with respect to heavy metals, preferably at dredged material pH levels (to keep costs, such as pH adjustment, down). Long contact times of up to one week are required making continuous processing difficult.

4.3.4 Biological

Biological degradation aims to enhance the natural breakdown of organic contaminants into harmless compounds by micro-organisms and can be undertaken ex situ by land farming (<60% water content) or using a bioreactor (>70% water content). The breakdown will depend on environmental conditions (temperature, humidity and nutrients) and in order to optimise the process, adequate ventilation and nutrients (N, P, K) at the required concentrations are needed. Toxic metals and other non-biodegradable substances will not be effected as they are recalcitrant, however, if present in high concentrations (>5000ppb (CEDA, 1994)) they cause problems by destroying the microbial population. In addition, the processes will have to be optimised to increase contaminant availability for degradation. The application for sediments typically requires oxygen. This increases costs and causes an engineering problem since such large quantities are involved. Consequently, processing is limited to a maximal layer thickness of 40cm (van Gemert *et al.*, 1994). Additional limitations arise from the low speed of the process. For certain contaminants, the final concentration is reached within an acceptable period (few months). For severely contaminated material it remains relatively high and a period of at least one year is likely.

Technologies for the in-situ implementation of enhanced degradation (aerobic biodegradation, anaerobic dechlorination) of organic contaminants exist (De Meyer *et al.*, 1993). In addition, in Hamilton Harbour, Toronto (Canada) such an in-situ project is in operation at the time of writing. However, generally , in-situ technologies are more likely to have a use in inland waters and not estuarine/ coastal areas due to greater variability in conditions and increased turbulence/ sediment mixing.

Additional limitations arise from the low speed of the process; for certain contaminants, the final concentration reached within an acceptable period (few months) for severely contaminated material remains relatively high and for purification purposes a period of at least 1 year will have to be reckoned on. The application for sediments, which are primarily anoxic requires oxygen increasing costs and causing an engineering problem for large quantities. Consequently processing is estimated to be limited to a maximal layer thickness of 40cm (van Gemert *et al.*, 1994).

Technologies for the in-situ implementation of enhanced degradation (aerobic biodegradation, anaerobic dechlorination) of organic contaminants exist. However, they may have a more likely use in inland waters and not estuarine/ coastal areas due to greater variability in conditions and increased turbulence/ sediment mixing.

4.3.5 Thermal

Typically dewatering and drying is required prior to thermal treatment. Thermal treatment can be applied at various temperatures such as to remove, destroy or immobilise contaminants. If thermal treatment is to be a realistic large scale option for contaminated sediment treatment, then cheap heat sources will be required.

<u>Thermal desorption</u> Thermal desorption is the application of heat to volatilise and remove the organic contaminants present in the solid matrix. This technology condenses the volatilised contaminants and collects them as an oily residue of substantially less volume than the original sediment mass. Therefore no net destruction of the contaminants is achieved by this method.

This method has an established application for hazardous wastes, sewage sludges and soils.

Garbaciak (1994) undertook pilot scale studies on sediments with PAH contamination being of primary concern. Conclusions about the effectiveness of this thermal desorption process were, however, difficult for low contaminant concentration levels in the feed sediment and confounded by the variation inherent in the analytical techniques for PAHs. More specific details of this technology are also given in a pilot study of two sites by Kenna *et al.* (1994).

This method has an established application for hazardous wastes, sludges and soils. Two technologies are relatively frequently reported for contaminated dredged material treatment;

a) Remediation Technologies, Inc (RETEC)
Garbaciak (1994) undertook pilot scale studies on sediments with PAH contamination being of primary concern. Conclusions about the effectiveness of this thermal desorption process were, however, difficult for low contaminant concentration levels in the feed sediment and confounded by the variation inherent in the analytical techniques for PAHs. More specific details of this technology are given in pilot study of two site by Kenna *et al.* (1994).

b) Soil Tech- Anaerobic Thermal Process (ATP)/ Taciuk Process

<u>Incineration</u> Rotary kiln incineration is tested and has a relatively short process time compared to physico-chemical and biological technologies. Operational conditions will vary depending on the target contaminant to be treated. High temperature (approximately 1200°C) and pressure incineration has demonstrated highly efficient contaminant removal even for PCBs and dioxins and is a technical option. This technology is commercially available, but at high costs (Stern *et al.*, 1994). In addition, concern about the concentration of metals in the waste ash has been expressed. It is only practical if sufficient organic matter is present and the contaminants are organic, otherwise the ash will contain most of the metals and require controlled disposal. The produced gases may need to be recombusted and a gas washer is required to prevent undesirable emissions occur to the atmosphere. However, the incineration technology is progressing at a rapid rate and may become more economic in the future.

<u>Thermal Immobilisation</u> At 1200°C some organic contaminants are completely incinerated, whereas non volatile metals are immobilised in the sintered product. An artificial product results which can be used in concrete or asphalt. At higher temperatures (1400°C) , smelting occurs where a liquid melt is produced. A variety of products can be achieved by controlling its rate of cooling. Under oxidised conditions a large proportion of the metals remains in the formed product, but despite this, a thorough flue gas treatment is still required. Such treatment processes have been successfully demonstrated and theoretically offer an option for sediments contaminated with a cocktail of contaminants or residues from separation processes such as hydrocycloning. However, obstacles to its successful application include the low scale acceptance of the products and the uncertainty with respect to environmental health aspects (Vellinga, 1995). In addition, it is an expensive technology.

Clearly the effectiveness of decontamination technologies with respect to individual contaminants is of key interest. The suitability of promising technologies for individual contaminant types is presented in Figure 2. It is however, dependant on sediment properties, operational conditions and the presence of other contaminant groups.

4.3.6 Costs of sediment decontamination technologies

The cost of sediment decontamination will depend on the quantity and properties of material to be treated (notably water content), the contaminant to be removed and level of removal required and the decontamination technology employed. Costs for full scale application of decontaminating dredged material are largely uncertain and estimates in the literature are based on extrapolation from bench or pilot scale. Therefore, costs reported are indicators only and caution is required in using them. Costs reported are generally in US $ and are reported as $ per unit volume or weight. To convert between weight and volume, knowledge of the density of the dredged material is required. As the quantity of material to be treated increases, generally, the cost per unit weight/ volume decreases.

	Costs US $ per tonne (wet weight)	£/m^3
Mechanical		
Separation	$5-44	£5-35
Sediment washing	$28	£25
Physico-chemical		
Extraction	$40-268	£30-210
Wet air oxidation, base catalysed decomposition	$34-945	£30-735
Biological		
Microbial degradation	$39-181	£30-140
Thermal		
Thermal desorption	$70-257	£55-200
Immobilisation	$33-158	£30-125
Incineration	-	£1000-2000

Conversion: Exchange rate $1.55:£
Bulk density 1200kg/m^3

For example, costs of sediment washing have been quoted to be $258/cy for 10,000 cy and $48/cy for 100,000 cy (Garbaciak, 1994). Clearly, there is a substantial difference in costs here. However, other techniques such as extraction (B.E.S.T.) and thermal treatment do not display such great reductions in cost as the quantity of material to be treated increases.

B.E.S.T. is reported as costing $174/cy for 25,000cy and $139/cy for 100,000cy. While thermal desorption (RETEC process) is reported as costing $535/cy for 10,000cy and $350/cy for 100,000cy (Garbaciak, 1994).

A good summary of estimated ranges of costs per metric tonne is given by Galloway (1992). A summary of these costs is given on page 20 and approximately converted into £/m^3.

Other estimates report decontamination costs to range from $5 to $300 per cubic yard or $6 to $200 per dry ton (St. Lawrence Centre, 1993).

If costs are compared using volume of in-situ sediment treatment, treatment costs (biological, extraction and immobilisation) range from $30 to $120 per m^3. Dredging and hydrocyclone separation range from $2 to $15 and $2 to $120 per m^3 of in-situ sediment respectively (van Dillen and Bruggeman, 1992).

5 Discussion and Conclusions

1. The demand for decontamination technologies is largely uncertain. An assessment of the geographical need (contaminant problems and dredged material properties), the requirements under legislation and licensing systems and alternative options are involved.

2. The geographical distribution of contaminated sediments in dredging areas in the U.K are as contaminated "hot spots". Decontamination technologies will need to handle large volumes, high water contents and often mixtures of contaminants. Each site will have its own specific contaminant problems and will therefore require potentially different decontamination technologies. As research on the most suitable decontamination technologies continues there is a need to have due regard to the site specific characteristics from where the material is coming and flexibility in choosing the appropriate technology is required.

3. For the decontamination of dredged material to be taken on board fully, then large scale, cost-effective technologies are needed to handle the millions of cubic meters of moderately contaminated dredged material generated by large port and harbour activities.

4. Much experience is being gained recently in Europe, Japan, Canada and USA with relatively large scale treatment of sediments.

5. There are several potential ways to decontaminate dredged material, many of which are presently costly and in need of further research. Their effectiveness needs to be established, their environmental benefits demonstrated and the costs more accurately estimated.

6. Appropriate technologies need further development and their effectiveness for large scale treatment needs to be tested.

7. Costs will be dependant on the decontamination technologies employed, quantity of material to be treated, the dredged material properties and the contaminant(s) to be removed and the cost of storage and transport. At present there are large uncertainties involved with assessing costs for full scale application.

8. While containment remains a legal and cheaper alternative, development of treatment technologies will continue to make only slow progress.

9. Public pressure may influence the solution to the problem of contaminated dredged material management. Increasingly severe standards are being made due to public pressure and the increasing recognition of contaminants toxicity's.

10. Some technologies may be preferred if an overall integrated pollution control assessment is considered. Technologies, such as Base Catalysed Decomposition (BCD) are preferred over extraction techniques in this respect, as BCD destroys chlorinated organic compounds rather than just remove them from the bulk material.

11. It is generally assumed, but not proven that the biological effect (human health and ecology) of contaminants present in dredged material is only found in the fine fraction. The separation of silt from sand is based on the observation that contaminates concentrate in this fraction and that the above assumption holds.

12. The initial concentration will affect the efficiency of removal, however, the final contaminant concentrations in the sediments against environmentally acceptable levels will be the key factor determining the success of a decontamination technology.

13. The environmental benefits of treatment may be economically justified for some of the most contaminated sites with relatively small sediment volumes. Appropriate sediment washing of dredged material can be cost effective as opposed to direct land filling of wet material. However, refinements to current sediment washing technologies may be required, particularly the loss contaminants to the atmosphere.

14. Decontamination technologies seem to be applicable either in combination with controlled disposal of residues or as alternatives to controlled disposal.

15. Public perception of dredged material is important and dredged material needs to be viewed as a resource rather than a waste to be disposed of. The environmental merits are clear and beneficial use is becoming a recognised option.

16. There is no "cure-all" method. The end solution is likely to involve a combination of treatment methods (treatment trains) and disposal options. There are many technologies. Some technologies are proven, while others have potential but are currently underdeveloped.

17. The lack of legislative initiatives prohibiting disposal of highly contaminated sediments to land and allowing 'trace' contaminated sediments to sea presently renders these technologies uneconomical and hinders their development. Other factors hindering their development include the uncertainty in costs, especially "pioneering" costs of development, the lack of funding, uncertain demand and market. In addition, previously land disposal has been a much cheaper option. There are also uncertainties regarding the final disposal/ beneficial use options for treated dredged material and public perception of the activities and products may be poor.

18. An integrated approach will be needed to handle contaminated dredged material, a requirement for storage areas is likely and, in addition, a heavy reliance on disposal to landfill/containment is likely to remain.

19. The likely increase in legislative pressure preventing the disposal of contaminants to sea, constraints on the capacities of landfill site and the continuing contamination in developing countries increase the need for decontamination technologies. The development and research of decontamination technologies, however, needs to be seen as less of a financial risk and their potential demonstrated with costs being outlined.

20. The export potential of developed decontamination technologies to other countries is high.

21. The findings of this study have been presented at a Seminar held at HR Wallingford (January 1996) and at the CATS III Congress (March 1996) which was an international conference covering the treatment of dredged material specifically. The work has stimulated a lot of interest. Both the HR Seminar and the CATS III congress are summarised in Appendix 1 and Appendix 3 respectively.

6 *Suggestions for further study*

Increasingly there are cases in the UK where dredged material is contaminated to the extent at which disposal options are restricted and costly containment at commercial landfill sites required. In other parts of the world, much greater contamination occurs and serious problems which can be addressed by the UK exist.

Examples of UK technologies are available in pilot surveys by private companies, frequently using a combination of techniques to deal with the cocktail of contaminants. It is anticipated that costs of such clean up operations at full scale are not necessarily prohibitive and can be competitive when compared to disposal at special sites on land.

Developing technologies and solutions to the increasingly recognised problem of the management of contaminated dredged material, which the UK can export abroad may also be of importance as other contaminants become included on the list of parameters tested in the licensing procedures.

The approach to such a study should be:

- Set up a framework to examine the results such that environmental, economic and social factors are also considered alongside the technical and scientific aspects

- Investigate the effectiveness and suitability of promising decontamination technologies over a range of sediment types and contaminant mixes by carrying out tests at bench and pilot plant scale with industrial partners.

- Identify potential markets based on available information

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Figures

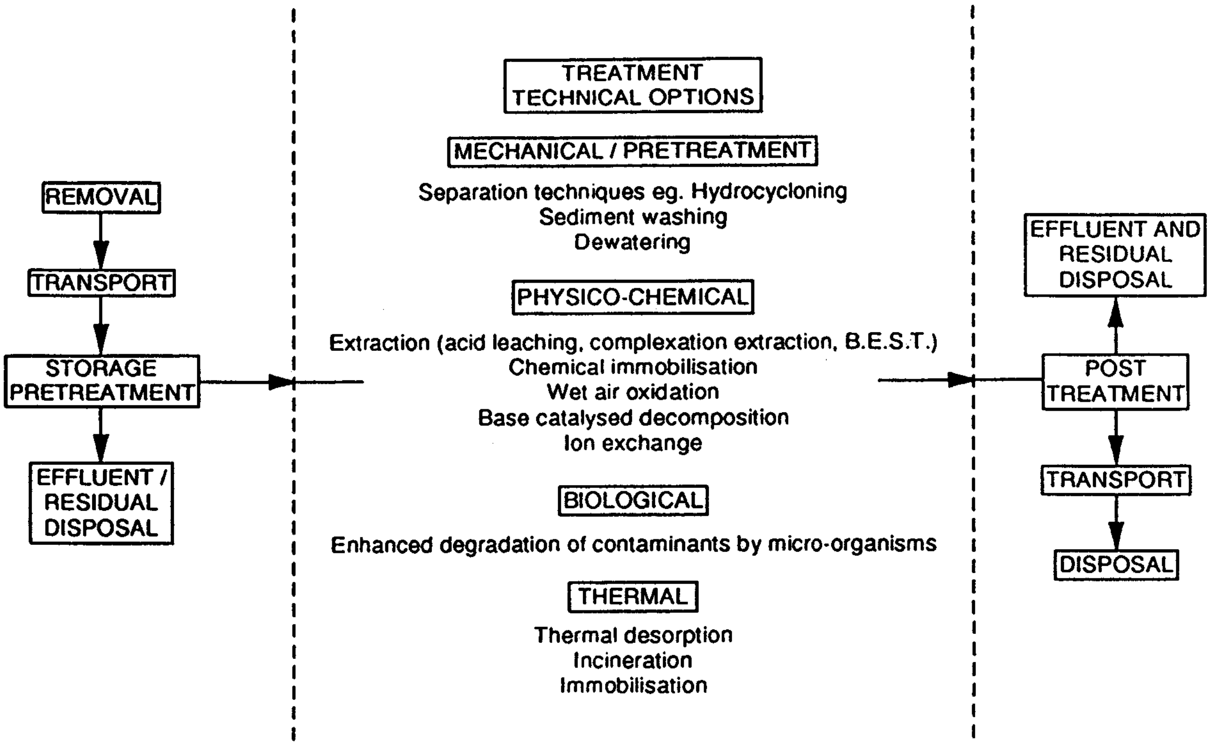

Figure 1 Decontamination Technologies

	Metals			TBT	PCBs	PAHs	Oils
	Cd	Hg	Others				
MECHANICAL							
Hydrocycloning	■	■	■	■	■	■	■
PHYSICO-CHEMICAL							
Extraction							
acid	●	●	●	*	-	-	-
B.E.S.T.	-	-	-	*	●	●	●
Immobilisation	●	●	●	*	*	*	*
Wet air oxidation	-	-	-	*	▲	●	●
Base catalysed decomposition	▲	●	▲	*	●	●	●
Ion exchange	▲	▲	●	*	-	-	-
BIOLOGICAL							
Degradation	-	-	-	*	●	●	●
THERMAL							
Desorption	●	●	●	*	▲	●	●
Incineration	●	●	●	*	●	●	●
Immobilisation	●	●	●	*	●	●	●

Key:
■ Reported success at plant scale
● Reported success at bench or pilot scale
▲ Reported failure
* Not demonstrated
- Not directed at this contaminant group

Figure 2 Suitability of technologies with respect to main contaminant chemical groups

Plates

Plate 1 The Slufter and "Parrots Beak", Rotterdam Harbour

Plate 2 Amsterdam Canal Clean-up using Hydrocyclone

Appendices

Appendix 1

Summary report on the Workshop

Appendix 1   Summary report on the Work Shop

As specified in the contract a work shop titled "The decontamination of Dredged Material" was held at HR Wallingford to bring together interested parties and open a discussion forum with industry. A list of participants, the workshop programme and abstracts of the presentations are presented in Appendix II. The presentation on decontamination technologies given by HR Wallingford reported the initial findings of this report to the target audience and obtained comments from researchers and practitioners on aspects of some of the treatment options. A list of speakers and abstracts of the presentations follow:

THE DECONTAMINATION OF DREDGED MATERIAL

Tuesday 23 January 1996

HR Wallingford Ltd
Wallingford, United Kingdom

Synopses

The UK Situation and the Future Role of Decontamination Technologies	Steve Warren Consultant
Review of Decontamination Technologies	Caroline Fletcher HR Wallingford
Market and Technology: will they match?	Martin Kroezen
Heijmans Milieutechniek BV	
Decontamination by using Supercritical Fluid Technology	Dr Mike Butcher and Chris Riley BHR Group Ltd
Netherlands Development Programme for Treatment Processes for Polluted Sediments (POSW)	Gerard Stokman Rijkswaterstaat
Pilot Scale Demonstrations of Decontamination Technologies	Dudley Gibbs Biolytic Systems Ltd
A Case Study North Blyth - Battleship Wharf Scheme	Colin Robson Northumberland County Council
The British Waterways Experience	Nick Smith British Waterways

The UK Situation and the Future Role of Decontamination Technologies

Steve Warren, Consultant

EU and UK waste regulations are being framed to reflect the fact that sacrificial disposal is now the last resort. The broad aim of legislation is to encourage the beneficial use of waste components and to avoid risk to health or to flora, fauna and the environment in general from contaminants that may be present in waste. The general result is to increase the cost of disposal.

Waste disposal to landfill, to sea, by incineration or by spreading on land are all governed by different regulations and conventions. EU Member States have stopped sea disposal of industrial wastes and will cease dumping sewage sludge by 31 December 1998 in accordance with the Urban Wastewater Treatment Directive. The disposal of dredged material is covered by the London Convention (1972) which permits the disposal of material containing specified toxic substances providing they are present only in "trace" amounts. Revisions to the Convention now under consideration would extend its scope to cover all dredging operations but a lack of toxicity data has prevented the development of quantitative criteria for contaminants in dredged material which could be used to determine its acceptability for sea disposal.

Spreading on land is now permissible only if there is a definable benefit to the soil and if contaminant levels are such that soil loading does not breach standards. Incineration is only practicable if the material is at least partly combustible and only worthwhile if its bulk is significantly reduced by combustion, which is unlikely to be the case for dredged material.

The classification of wastes and the regulations governing their disposal to landfill are currently being revised in both the EU and the UK. The containment requirements are least for inert wastes, intermediate for non-hazardous wastes and most stringent, and therefore most costly, for special wastes. Schedule 2 of the draft regulations lists sources of waste defined as special by virtue of their origin. It does not include dredged material but wastes not listed in Schedule 2 are defined as special if they are contaminated to the extent that they meet certain criteria, for example if they contain not less than 0.1% of substances defined as very toxic, or not less than 3% of toxic substances or a number of other conditions.

It is likely that only rather heavily contaminated dredged material would be classified as special waste on the basis of risk to human health but the last set of criteria relate to eco-toxicity. For this category the proposed criteria are not quantitative. The mere presence of any of the so-called class 'N' substances, with ecological effects (eg PCBs, TBT), is sufficient for the waste to be classified as special.

European pressure against the marine dumping of contaminated material is not likely to decrease and the cessation of sludge dumping in 1998 will leave dredging spoil in isolation. Whatever the UK view it will be difficult to resist this pressure. The cost of alternative disposal routes will be high (eg the price of disposing of special wastes can range from £40-£75/m^3) and decontamination may look like a cheaper option than it does at present. Even if we start now it will take at least until 2000 to make good our current lack of experience of decontamination technologies.

Review of Decontamination Technologies

Caroline A Fletcher, HR Wallingford

The dredging of navigational channels and waterways in the UK is an economically essential activity. However, contaminated sediments in some of our rivers, estuaries, ports and harbours, canals and marinas mean that the dredged material collected may have restricted disposal options under UK legislation and licensing systems. In addition, the likely increases in legislative pressure preventing the disposal of contaminated sediments to sea may have serious implications to current disposal practices for dredged material. Alternative disposal options and beneficial uses will be increasingly sought for contaminated dredged material.

Currently, the Ports and Harbours Authorities and Inland Waterways are faced with the problem of having to dredge in order to keep navigation channels clear for traffic but, in some circumstances, having to deal with the disposal of contaminated dredged material. The dredging industry have to actually handle the material, MAFF and local authorities have an interest in the disposal of contaminated dredged material, and the development and potential market to sell decontamination technologies lies with the commercial organisations.

Clearly, processes and techniques which alter the properties of contaminated dredged material are desirable if they can render the dredged sediment suitable for disposal, or better still, suitable for beneficial use. At present, decontamination technologies, although recognised to be an expensive option, are receiving increasing attention. However, in reviewing the decontamination technologies factors which need to be considered include:

1 Criteria for a successful decontamination technology
2 The situation in the UK and other countries
3 Current Decontamination Technologies
4 Factors hindering their development

1 Criteria for a successful decontamination technology

There are many criteria a successful decontamination technology needs to satisfy which need to be considered when reviewing decontamination technologies.

- Meeting legislative requirements

- Appropriate technology, practicality and suitability based on a site by site basis

- Status, efficiency, effectiveness and process capacity of technology

- Costs/ Benefits

- Environmental acceptability and public perception are increasingly important.

- Resultant material meets the disposal options/ beneficial use criteria

Basically is the technology available, effective, and is it economically and environmentally acceptable?

2 The situation in the UK and other countries

It is recognised that presently some other countries have more experience in this field then the UK Research or demonstration programmes focusing on treatment have been established in the USA, Canada, the Netherlands, Germany, Belgium and Japan. For example, the Development Program Treatment Processes (DPTP) in the Netherlands is actively investigating treatment technologies for sediments and has been running for several years. An overview of the research findings from the DPTP programme is being given later at this seminar.

Currently, in the UK there are few examples of research into decontamination technologies for sediments. The majority of dredged material generated in the UK, is inert in nature and disposed of at sea (approximately 40,000,000 tonnes per annum). However, in some areas contaminated sediments exist to the extent that, on dredging, their disposal to sea is compromised, and consequently disposal to land adopted. The actual quantities disposed to land are difficult to quantify.

The contamination of UK estuaries and waterways is generally localised "hot spots" which are often buried at depth and are of concern when dredging operations are considered or required. Where such "hot spots" exist, the feasibility of decontaminating dredged material is of interest. In UK marine areas it is generally considered that metal contamination is not a widespread problem and organic micro-contaminants such as PCBs, TBT, PAHs and oil products are of greater concern. There are, however, some examples of inland waterways where metal contaminants are of concern.

One estuarine site in the UK where investigations into the use of decontaminating technologies are currently under review is *Blyth*, Northumbria. Lessons learnt through pilot scale studies at this site will be given at this seminar.

3 Current decontamination technologies

There are numerous potential methods of treatment for contaminated sediments both in-situ and ex-situ of which decontamination technologies are only a part. At present most sediment decontamination technologies exist on a laboratory or pilot scale and few operate on a large scale and are, therefore, very much emerging technologies. Generally, there is a lack of information regarding their application with large volumes of contaminated dredged material. Pre- or post- treatment methods form an integral part of some of these decontamination methods and methods such as the large scale separation of silts and sands by hydrocyclones and dewatering techniques have been demonstrated for sediments.

Dredged sediments may have a range of contaminants of concern present. However, there is no "cure-all" decontamination technology. The technology/ technologies required will depend on the contaminant species present in the dredged material which require removal and the properties of the dredged material itself, including the water content. No two sites are the same.

Assessments of the costs of technologies have been undertaken in other studies. However, large uncertainties exist as costs have been extrapolated from pilot scale to full scale. In addition, the costs will depend on the contaminant to be treated, the quantity of material and the dredged material properties. Typically, the costs of decontamination operations are reported to be orders of magnitude greater than costs of sediment disposal.
The majority of treatment technologies for contaminated fractions currently examined are outlined in Figure 1, where other factors related to the decontamination operation as a whole are also displayed.

Mechanical
Principally, the techniques separate the fine fraction, where contaminants (especially metals) are generally concentrated, from the coarser fractions. Their importance lies in their ability to reduce total volumes of contaminated material and concentrate contaminants enabling decontamination technologies to be used more cost effectively.

These mechanical methods are separation techniques; Such techniques include separation basins, hydrocyclones, flotation and sieving. In addition sediment washing and dewatering. These methods are typically pre- or post-treatment steps and are proven technologies for sediments.

Physico-chemical
A wide range of physico-chemical technologies exist. Contaminated dredged materials commonly display a wide range of contaminants. The situation is complex and the removal of metals by physico-chemical processes is fundamentally different to the removal of organic contaminants.

Degradation of organic compounds and reduction of contaminant loads by some techniques will occur, but may be incomplete. Not all techniques, however, destroy contaminants but instead concentrate them into a reduced volume and transfer them into an aqueous phase. In addition, the final disposal option of the dredged material may be limited if solvents are used for example.

Biological
Biological degradation aims to enhance the natural breakdown of organic contaminants into harmless compounds by micro-organisms. The breakdown will depend on environmental conditions (temperature, humidity and nutrients) and in order to optimise the process, adequate ventilation and nutrients (N,P,K) at the required concentration are needed. Biological treatment is not very successful for all contaminants eg (PCBs, "heavy PAHs"). In addition, metals will not be effected as they are recalcitrant (eg Cd, Cu), however, if present in high enough concentrations metals may cause problems by destroying the microbial population.

Thermal
Typically dewatering and drying is required prior to thermal treatment. Thermal treatment can be applied at various temperatures such as to remove, destroy or immobilise contaminants. If thermal treatment is to be a realistic large scale option for contaminated sediment treatment, then cheap heat sources will be required.

4 Factors Hindering the Development of Decontamination Technologies

• Uncertain demand/ market for the technologies

• Requirement is strongly driven by changing legislation

• Costs; the risks involved in taking on "pioneering" costs

• Until recently, the much cheaper costs of land disposal prevented development

• Uncertainty of final disposal/ beneficial use options for treated sediments

• Public perception of products can prevent success

Key Points

Defining the situation

- The demand for decontamination technologies needs to be clarified based on the geographical need (contaminant problems and dredged material properties) and the requirements under changing legislation and licensing systems.

- The geographical distribution of contaminated sediments in dredging areas in the UK are as contaminated "hot spots". Each site will have its own specific contaminant problems and will, therefore, require potentially different decontamination technologies.

- Large scale, cost-effective decontamination technologies are needed to handle the millions of cubic metres of moderately contaminated dredged material generated by large port and harbour activities and inland waterways.

Decontamination technologies

- There are several potential ways to decontaminate dredged material many of which are innovative. However, currently most are costly, further research is needed so that their effectiveness for large scale treatment can be established, their environmental benefits demonstrated and the costs more accurately estimated.

- Costs will be dependant on the quantity of material to be treated, the dredged material properties and the contaminant(s) to be removed. At the moment there are large uncertainties involved with assessing costs for full scale application.

- The initial concentration will affect the efficiency of removal, however, the final contaminant concentrations in the sediments after treatment against "safe" levels will be the key factor determining the success of a decontamination technology.

- The environmental benefits of treatment may be economically justified for some of the most contaminated sites with relatively small sediment volumes.

- Currently decontamination technologies seem to be applicable either in combination with controlled disposal of residues or as alternatives to controlled disposal.

- Public perception needs to be changed so that dredged material is viewed as a resource rather than a waste to be disposed of. The environmental merits are clear and beneficial use is becoming a recognised option.

Are decontamination technologies feasible?

- Technically some decontamination methods are proven and others have great potential. Existing and innovative technologies are more likely to develop if legislatively driven and if a real future for their requirement, against alternative options, is demonstrated. Further research and development is required, and although in industrially developed countries the handling of contaminated sediments is becoming a decreasing problem as source inputs are controlled, in developing countries, who are even less able to afford clean-up technologies, contamination of navigable waterways is still occurring and decontamination technologies will be needed.

Market and Technology: will they match?

Martin Kroezen, Heijmans Milieutechniek BV

Decontamination by using Supercritical Fluid Technology

Dr Mike Butcher and Chris Riley

BHR Group Limited in conjunction with Leeds University's supercritical fluids group, have been developing a cost-effective solution for the clean, energy-efficient treatment of both the organic and metallic components of contaminated materials in one combined unit operation. By integrating supercritical fluid extraction (SFE) and supercritical water oxidation (SCWO) respectively, it is possible to extract heavy metal components, and to oxidise the remaining organic matter to relatively harmless oxidation products - namely, carbon dioxide and water. Moreover, it is possible to fuel the processes by harnessing the thermal energy that is generated from the incineration of municipal waste. Also, the recovery of valuable, high-purity heavy metals affords a potential means of capital repayment of the costs that are associated with the design and construction of new plant.

The presentation is divided into four parts: (I) properties and uses of supercritical fluids; (II) SFE; (III) SCWO; (IV) combined unit SFE-SCWO operation, fuelled by waste thermal energy.

A supercritical fluid (SCF) is a substance that above a certain critical temperature will not condense, but exists only as a single fluid. However, for the purpose of decontamination, supercritical carbon dioxide and supercritical water are of particular interest as they are widely available, cheap and harmless to the environment in comparison with the organic solvents that are used in conventional processes. For carbon dioxide, the critical temperature is only 31 °C. Moreover, the physical properties of SCFs, which are intermediate between those of a gas and a liquid, may be manipulated usefully by control of pressure and temperature.

For example, solvation power increases as the density of a SCF increases, thereby enabling SFE to be made selective for different solutes such as heavy metals. Subsequently, metals may be selectively precipitated by decreasing the density of the SCF, thus leading to high purity products with a market value. The high values of diffusion coefficients in SCFs make SFE processes generally faster relative to conventional extraction, and low viscosities give better penetration of the fluid into the matrices of the solid material. In short, SFE may be viewed as an intensified extraction process, that is clean and economically feasible. Moreover, SFE is a proven technology for the extraction of complex organics: on an industrial scale, it is used for the decaffeination of green coffee beans[1,2], extraction of different fractions from hops[3] and spices as well as for the extraction of essential oils[4]. Process-scale SFE is becoming widely used in Germany[5] and Japan, and hydrothermal processing of metallic complexes in the ceramics industry is well understood.

In order to explore the potential benefits of SFE's, BHR Group and Leeds University are linking the physical chemistry of SFE to the design of process-scale equipment by encoding the kinetics into computational fluid dynamics (CFD). This approach is generic in nature, and therefore also applicable to the treatment of industrial, municipal and dredged wastes.

Water above its critical temperature and pressure of 374 °C and 221 bar is able to dissolve many compounds, and can be used in the SFE of heavy metals and other contaminants from dredged waste. It may also prove possible to use SCWO in parallel or simultaneously (depending on reaction/extraction temperatures), to convert the organic matter, by reaction with dissolved molecular oxygen, to carbon dioxide and water[5] - as in the MODEC process[6]. In contrast to conventional incineration, the production of NO_x and SO_x is avoided, and complex scrubbing systems are not required. Instead, compounds containing nitrogen, sulphur and halogens produce relatively harmless nitrogen, and sulphate and halide ions respectively[7]. An additional benefit is that oxidation reactions are highly exothermic: therefore in SCWO the temperature can rise to ca. 6000 °C. And if the organic component is present in concentrations above 20%, the process can be run autothermically (i.e. self-sustaining in reaction temperature)[7]. The thermal energy may also be recycled to the inlet of the SCWO reactor, or used for the generation of electricity[6].

The fundamental reaction kinetics of SCWO of different substances are being widely studied[7-10]. At Leeds University, kinetic studies of the SCWO of model compounds such as phenol are being studied in tubular, plug flow reactors[11]. As a result, BHR Group will be able to combine the physical chemistry of the SCWO process with the fundamental fluid dynamics of process-scale oxidation reactors.

As EEC legislation comes into force, the trend for the disposal of municipal waste is towards incineration, which leads to the production of Fly and Grate ashes with a high heavy metal content. A significant number of large urban conurbations are located near harbours with dredging problems, and in an innovative approach to the decontamination of dredged sludge and ash, it is proposed to couple incineration with SFE and a SCWO reactor. Heat for the initiation of the oxidation reaction would come from the incinerator. Upon the attainment of an initial reaction temperature of ca. 1000 °C, and given sufficient organic matter, the process would become autothermic, and should provide high-grade thermal energy that will be recycled. BHR Group are currently developing the outlines of such a project.

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Netherlands Development Programme for Treatment Processes for Polluted Sediments (POSW)

Gerard Stokman, Rijkswaterstaat

Most sediments in the Netherlands are polluted with heavy metals and organic compounds. Approximately 10 million cubic metres of polluted sediments are removed annually for maintenance of harbours and waterways. In addition remediation is required for about 100 million cubic metres of sediment, mainly deposited in the years 1960 - 1980.
The sediment mostly contains various mixtures of oil, heavy metals, PAH's and organochlorine compounds in levels that imply a potential risk for human health and the environment.
Isolation or *in-situ* treatment of the polluted sediment has not yet proved to be applicable. Therefore confined disposal or *ex-situ* treatment of dredged material are the two main options in dealing with this huge problem in the Netherlands.
Since storage does not seem the best solution in the long term, because of the possible penetration of pollutants in surface and ground water and of the NIMBY (not in my backyard) - effect, it is better to clean the polluted sludge so that it can do service as sediment or be useful in civil engineering. Further more treatment reduces the dispersal of contaminants in the environment.

The Dutch policy on contaminated dredge material is to treat 20% in the year 2000. By this the necessary storage capacity will decrease and the re-use of raw materials will be stimulated.
To realize this commitment it is necessary to build and exploit treatment facilities and actual offer dredged material for treatment.
For the development of treatment processes a national programme, in Dutch called "Programma Ontwikkleing Saneringsprocessen Waterbodems" (POSW), in English "Development Programme for Treatment Processes for Polluted Sediments", is under execution which aims at environmentally sound technologies for dredging and treatment, and at testing chains of treatment technologies through pilot remediations.
In its second stage (1992 - 1997), the build up of the programme follows the logical order:

- site investigation
- environmental friendly dredging technologies
- classification of the sludge and polishing of fractions
- biological or chemical treatment technologies to clean (fractions of) the dredged material
- and finally thermal immobilization as zero waste option for severely contaminated sludges or residues from separation or chemical treatment.

POSW is currently focussing on a number of operational technologies. The applicability of such technologies as part of an integrated clean up chain has and will be proven in the field, in the framework of a financial and environmental assessment of the entire chain.

The Dutch Development Programme for Treatment Processes (POSW) for polluted sediments showed that determining the extent and composition of pollution is the first essential step in sediment remediation. Accurate site characterisation, in quantity and quality, optimises the amount of material to be dredged and the choice of treatment technologies to be applied. Effort and funds invested in this part of the process will be earned back later on.

Environmentally sound dredging depends strongly on precise and careful working methods to prevent spillage and dispersal. An adequate positioning system is a prerequisite. Complications with debris can be overcome with a two stroke dredging approach: first a rough stroke, followed by a precise second cleaning stroke. Environmental requirements will become more and more strict, with attention for a high accuracy, a minimal increase of the suspended solids concentration and minimal spillage.

The Dutch policy to recover and use 20% of the dredged material can be realised. Separation of clean sandy fractions is the first essential step, but additional treatment is necessary to realise this commitment.

Flotation of separate fractions has been tested on a semi-practical scale. Remaining contaminants in the sandy fraction can be removed and oil and PAH can be concentrated from fine fractions in a small part of the initial feed.

In addition, biological and chemical treatment technologies offer several options to deal with organic pollutants like oil and PAH.
The remaining problem of sediments contaminated by heavy metals or cocktails of pollutants and of residuals from separation can be dealt with by thermal immobilization. Immobilization offers a zero waste option resulting in products like artificial gravel or basalt that can be applied as a secondary raw material.

In the remaining period till the end of POSW-II (December 1996) various promising technologies will be tested in two forthcoming pilot remediations. The instruments that have been developed for assessment of costs and environmental effects will be improved and made available to water management, eg, in manuals.

POSW-II results will be used for policy development as well as for advice on future sediment remediation projects. This will include both preparation and execution of dredging and treatment of polluted sediments as well as the reuse of the treatment products.

The achievements up to now show that the separation of sand from dredged material is applicable at low costs. In addition further polishing of fractions (eg flotation) and biological and chemical remediation will be necessary and available to reach the national aim of 20%. Finally thermal immobilisation offers a zero waste option for contaminated sediments or residuals of treatment technologies.

Pilot Scale Demonstrations of Decontamination Technologies

Dudley Gibbs, Biolytic Systems Ltd

1. Introduction

The silt from the tidal dock area of Blyth Harbour and used in the study is contaminated with Polychlorinated Biphenyls (PCB's), Poly Aromatic Hydrocarbons (PAH's), Lead, Mercury, Cadmium, Heavy Petroleum Hydrocarbons and Asbestos. The concentration of PCB's in the silt ranges from below 200 µg / kilo up to 75,000 µg / kilo dependant on the place of sampling.

The main objectives of the study were as follows:

i) Set up semi-tech scale techniques and procedures for decontaminating silt from the seabed;

ii) Determine the optimal conditions for physical, chemical and microbiological treatment of silt;

iii) Establish a semi-tech scale biological plant and optimise the conditions needed to destroy PCB's, and alkane hydrocarbons in liquid effluents arising from treatment processes;

iv) Investigate the parameters for a process protocol that could be operated at full scale.

1. Outline trial procedures

A semi tech scale unit that could process $2m^3$ per day of contaminated liquid was constructed and set up on the site together with holding tanks and a screening / fractionating facility which could process 1 m^3 silt per day. A series of procedures were then executed to determine necessary parameters as follows:

i) Silt fractionation.

ii) Biological treatment of washings and liquid arisings.

iii) Particle size analysis.

iv) Chemical treatment of silt concentrate

v) Microbiological treatment of silt

Samples were taken at appropriate stages in the processes. Silts were air dried prior to being analysed for the relevant analytes using standard methods and the results reported on a dry weight basis. Supernatant liquids were analysed directly and the results reported on a weight volume basis.

Total petroleum hydrocarbons were determined by Soxhlet extraction and gravimetry. PCB content was determined by the NRA Exeter laboratory using NAMAS approved GC-MS protocols.

1. Results - summary

Biological treatment of PCB's in aqueous phase.		
PCB analytical results	Influent before treatment	Effluent after treatment
ng/litre	12771.6	17.5

Fractionation of the silt			PCB analytical results μg/kg		
Control	>2.5mm	Tb	Tc	Td	Te
28447.2	9737.0	50790.2	8550.8	64994.9	553996.9

Harbour silt PCB analysis by particle size

Fractionation of the silt showed that 83% of the PCB's were combined with the particles in the range 125 -500 microns

PCB's in silt before and after microbiological treatment		
Before treatment μg/kg	After treatment μg/kg	Cleanup
31891.1	3925.4	**87.70%**

1. Conclusions.

4.1 Fractionation of silt enabled concentration of PCB's into approximately one third of the volume where the remaining fraction was correspondingly reduced in PCB level such as to be suitable for disposal by landfill.

4.2 The trial demonstrated that silt that is contaminated with PCB's and other organic moieties can be successfully treated to a standard whence the final liquid effluent contains negligible levels of PCB's and can be discharged to the sea and the silt could be landfilled without significant detriment to the environment.

A Case Study
North Blyth - Battleship Wharf Scheme

Colin Robson, Northumberland County Council

REMEDIATION OF CONTAMINATED RIVER SILTS

DON'T PANIC!

The problem of Contaminated Land in Britain is a serious one, however, the title of this presentation is, I think, appropriately called Don't Panic.

When I became involved with the Battleship Wharf Scheme in Northumberland there was great clamour from the Press, the Public and most of all the various Regulatory Bodies over the problems associated with the site.

There certainly were plenty of problems, after 85 years of shipbreaking the site was contaminated with 60,000 cubic metres of asbestos laden soils, heavy metals including lead, mercury and cadmium and worst of all transformer oils containing PCB's. The latter had been discharged onto the site and into the adjacent tidal dock and river from dismantled Soviet Warships.

Having worked for 25 years on contaminated land sites, mostly on former colliery areas, I was fully aware of the regulatory framework within which I would have to operate.

Less expected was the initially negative approach taken by NRA and MAFF especially in response to the PCB problem.
Something I am pleased to say was quickly overcome.

The site is in the control of the Port of Blyth which is administered by a Board of Commissioners and a Chief Executive. When, following the discharge of oils, the Port were asked to deal with the problem they searched for a firm who could handle PCB's. A previous speaker at this symposium is an employee of a company who showed some knowledge of the problem and you have heard his approach. On my part, at that time, and still, I am not convinced that a cost effect treatment exists for this problem.

To understand what his company and later others were suggesting to me it was necessary to carry out a detailed trawl of the published literature on PCBs. This was done and has produced by purchase, borrowing and photocopying what is I guess one of the most comprehensive libraries on the topic available. That part was easy, reading it all, understanding it and trying to reconcile conflicting evidence and views was another matter.

One of the first lessons was that measurements of levels of PCBs, depending on the protocol used, could vary widely. Further, some of the levels of reduction required by MAFF were at the limits of detection technology.

The basic practical problem was that the MAFF would not issue a licence to tip dredged material at sea that contained PCBs at levels above 200 parts per billion. Such a licence is obviously vital to keep the Port operational. A chart of surveyed samples showed a contour of material above this level lying off the tidal dock, with a maximum of 50 parts per million in the dock. There was one plus factor here in that the River Blyth is a low energy system and silts do not move very far during the rise and fall of tides.

Following the initial stage of understanding the material we were dealing with , several things were evident and had to be agreed with the regulators:-

* The PCBs above the 200 parts per billion contour had to be brought ashore and treated.

* An environmentally safe method of dredging was necessary.

* A decision had to be taken regarding encapsulation or treatment.

* The sampling work had to be extended and refined.

At this point it was already obvious that there would have to be some encapsulation of contaminants on site. The site investigation had shown that the old quay was contaminated with a mix in the soil of asbestos, oils, heavy materials and PCBs. This mix meant that even if the technology for remediation was available, it would be very expensive. None of the contaminant levels on site could be classified as extremely high.

There is therefore still a solution to the problems of the dredged silts of including them in the stabilisation and encapsulation process.

The encapsulation was then considered and it was decide to construct a retaining bund across the old tidal dock behind which the contaminants could be encapsulated. This was later refined into a new quay wall with additional funds from the Port of Blyth.

At this construction was to be across open water it was decided to use a system of 13 metre diameter circular steel cells which required a level river bed as a formation. This design meant a sophisticated environmental and engineering dredging contract to first remove the contaminated silts and then allow clean silts and rock to be dredged and tipped to sea. This contract was prepared and put out to tender.

When the tenders were returned they were some £300,000 over estimate and the scheme was in jeopardy. The dredger however could never reach into the tidal dock so this was cleared by machine and dump trucks at low tide. A piece of good fortune at this time was exceptionally low tides which allowed clearance beyond the end of the tidal dock.

Simultaneously more refined results from sampling carried out by the NRA showed that 95% of total contamination was within the area that had been cleared. This threw into even greater relief the extra cost of “environmental dredging”.

In discussion with the Port of Blyth's Engineer he identified that he operated a river bed “plough” which could move the contaminated silts within reach of an extended reach excavator. It was estimated that this would reduce the remaining contamination to 1-2% of the original total.

Whilst the river silts contained the lowest amounts of PCBs, they were in a ratio of 4 to 1 by volume with the tidal dock extract. However in terms of their concentration of PCBs they were no worse than other materials found in industrial areas nationally, being in the range 0.2 to 1 part per million.

Both the NRA and MAFF agreed this procedure and over a three week period the contaminated silts were brought ashore and stored in a temporary lagoon.
It has been decided to dewater the river silts using a filter press system and the material will then be mixed with courser soils and used as general fill in non-developable areas of the site.

The jury is still out on the treatment of the tidal dock material. As I said earlier, I have yet to be convinced that a verifiable treatment for the reduction of PCBs to industrial background levels exists. In support of this I would sight a recent conference in Maastricht on contaminated land treatment which in out of 100 papers and 150 poster presentations hardly mentions PCBs at all.

At present my preferred option remains encapsulation although whilst awaiting the bund/dock walls construction, which will take 10 months, I remain open to offers.

However, I now feel confident that as a scientific layman, I can make a more considered judgement on those offers.

The British Waterways Experience

Nick Smith, British Waterways

Historical Perspective

The canal system of the UK dates from 1757 to the 1830s. The system was built to service the needs of the industrial revolution and transects many of the industrial heartlands of the UK.

In 1948, the majority of canals and waterways came under government control in the form of the British Transport Commission. The management of the canals and waterways passed to the successor body, British Waterways, in 1963.

Today the network of waterways under BW control is managed principally for leisure and tourism and as an environmental and heritage asset of national importance. Freight transport continues to be important on the broad river navigations and canals in the north east.

Dredging is an important part of the sustainable management of all canals and rivers navigations. It is necessary to provide for navigation and to maintain and enhance wildlife and fishery interest. Localised sections of waterway have sediments contaminated by historical industrial activity. Removal of this material is part of the on-going process of renewal which the waterways have enjoyed in recent years.

Development of Regulations

For most of the 200 years of canal history disposal of dredgings was an unregulated process. In 1988 dredgings lost their exempt status and were included within the definition of controlled waste. This change, together with additional regulations in 1992 and the obligations of the Duty of Care brought in the new requirements for the disposal of dredgings and the need to understand quality.

A further round of regulations implemented in 1994 brought in new requirements for the management of waste and its disposal and set out some specific exemptions applicable to inland dredging disposal.

Quantification of Liability

To establish an overview of the liability and determine disposal options it was important to obtain a qualitative of the material to be dredged.

Sediment Quality

Sediment sampling was carried out in the first months of 1992. Samples of sediment were taken every 2 km and submitted to an analytical laboratory.

The 30 parameters specified in the analytical suite were based on those previously requested by regulatory authorities.

The main parameters were interpreted against national codes of practice or guidance such as DoE Code of Practice for Agricultural Use of Sewage Sludge (DoE, 1989) and the ICRCL Guidance. In addition guidance derived from Kelly (1979) and the Netherlands guidance (Ministry of Housing, Physical Planning and Environment, 1987) was used to evaluate parameters not covered by the existing government issued guidance.

These guidance documents were used to construct a classification system that would provide guidance on the disposal options. The classification system focuses on contamination issues and their potential environmental significance in disposal.

Decontamination/Treatment Projects

Treatment plants have been used to screen and dewater dredgings principally because it is generally more difficult to dispose of wet dredgings than it is to dispose of contaminated material. As part of a process an element of decontamination may have been achieved by separating off the fines, which are usually associated with the higher levels of contamination, or by the inclusion of additives which bind in the contamination and reduce the potential for leaching at a future date.

A simple form of decontamination which BW has used, is to screen out the gross items, cans, bottles, traffic cones etc. from uncontaminated silt to allow it to be used for disposal on agricultural land.

Where we have identified silts which are heavily contaminated consideration is being given to processes which can remove the contaminating elements. These processes are:

(I) soil washing techniques using solvents or resins
(J) immobilisation
(K) bioremediation

Conclusions

Currently decontamination processes tend to be expensive when compared to the cost of landfill. This is exacerbated by the relatively small quantities generated during a BW dredging project and the problems associated with access for large equipment alongside the waterway network. As legislation tightens up, resulting in increased charges at landfill sites, plus the impending introduction of the Landfill Tax, decontamination will become more competitive.

Appendix 2

List of participants at Workshop

Appendix 2 List of participants

The Decontamination of Dredged Material

HR Wallingford

23 January 1996

Mr S J Bamford	ADAS	UK
Mr Steve Barber	AEA Technology	UK
Mr Neville Burt	HR Wallingford	UK
Mr Mike Butcher	BHR Group Ltd	UK
Mr Bill Coles	The Bristol Port Company	UK
Mr Tim Denton	Maunsell LRDC	UK
Ms Caroline Fletcher	HR Wallingford	UK
Mr Dudley Gibbs	Biolytic Systems Ltd	UK
Mr Alan Hunter	NRA Northumbria & Yorkshire	UK
Mr Martin Kroezen	Heijmans Milieutech Niek Bank	The Netherlands
Mr Peter Lucas	Mersey Docks & Harbour Co.	UK
MR James Maclean	Land & Water Services Ltd	UK
Mr Ian Marmont	British Waterways	UK
Mr Richard Melhuish	Land & Water Services Ltd	UK
Ms Eleni Paipai	HR Wallingford	UK
Mr Michael Pearson	Tees & Hartlepool Port Authority	UK
Dr John Rees	Celtic Technologies	UK
Mr Gavin Ridding	London Docklands Dev. Corp.	UK
Dr Chris Riley	BHR Group Ltd	UK
Mr Colin Robson	Northumberland County Council	UK
MR Eduard Slob	Ham Dredging	UK
Mr Nick Smith	British Waterways	UK
Mr Lode Speleer	Jan de Nul (UK) Ltd	UK
Mr Gerard Stokman	Ministry of Transport - Netherlands	The Netherlands
Mr David Tonks	EDGE Consultants UK Ltd	UK
Mr Steve Warren	HR Wallingford	UK
Dr Peter Wood	AEA Technology	UK
Mr Philip Woodgate	Port of Sheerness Ltd	UK

Appendix 3

CATS III Congress, Oostend, Belgium March 1996.

Appendix 3 *CATS III Congress, Oostend, Belgium March 1996*

A paper titled "Decontamination of dredged material-is it really feasible?" was presented at the CATS III conference held in Oostend, Belgium, 18-20 March 1996. An Abstract follows;

Decontamination technologies which alter contaminated dredged material properties such that they are suitable for sea disposal or beneficial use are desirable. However, the wide range of technologies researched are underdeveloped and relatively costly when compared to alternative options, such as disposal at landfill sites. In this paper examples of contaminated dredged material in the U.K are given and a brief description of the international situation for decontamination technologies. The criteria which any prospective technology must satisfy in terms of practicality, effectiveness, economics and environmental acceptability, as well as meeting legislative requirements, are also outlined. An assessment of promising technologies for dredged material decontamination against outlined criteria has been undertaken. Existing and innovative technologies are more likely to develop if legislatively driven and if a real future for their requirement, against alternative options, is demonstrated. Further research and development is required, and although in industrially developed countries the handling of contaminated sediments is becoming a decreasing problem as source inputs are controlled, in developing countries, who are even less able to afford clean-up technologies, contamination of navigable waterways is still occurring and decontamination technologies will be needed.

The CATS III Congress was an international conference specifically aimed at treatment technologies for contaminanted dredged material and sewage sludge. It was an excellent opportunity to update information on more recent (last 2 years or so) reasearch which has been undertaken in other countries. The conference included representatives from all of the major countries involved in this field (Holland, Germany, Belgium, USA, Canada). HR Wallingford was however the only representatives from the UK with an interest in dredged material decontamination. Severn Trent were the only other representatives and their interests were specifically directed at sewage sludge incineration and disposal on agricultural land.