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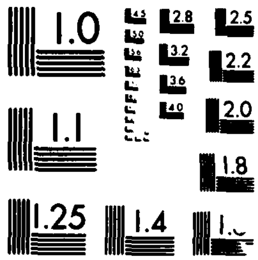
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TNO-rapport

Report no. : R 87/266

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APPLICATION AND INTERPRETATION OF BIOASSAY AND BIOMONITORING: A PLANNING DOCUMENT

Research Requirements for Development
of Predictive Capabilities
First interim report

Date: 1987-10-13

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TNO

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PREFACE

John W. Simmers (Waterways Experiment Station)

Historically, the concepts of peer guidance and peer review by working groups or workshops of experts have been a major feature of some research programs conducted by the U.S. Army Engineer Waterways Experiment Station (WES). Working groups have been convened for all research programs pursued by the Contaminant Mobility and Regulatory Criteria Group as appropriate. The current Contaminant Mobility Workshop is an evolution of the working group process initiated to provide guidance and review for the upland and wetland bioassay research under several programs. As research programs and sponsor requirements have changed, reflecting the results of the research to date, the perspective of the workshop has changed from the application of upland and wetland animal bioassays to the evaluation of contaminant movement through the ecosystem. Simultaneously, the realization by the WES that a large data base existed in Europe has led to various research contracts with the Institute for Soil Fertility, the Delta Institute for Hydrobiological Research (DIHO), the University College of Wales, Rothamsted Experimental Station, and an extensive program of joint research with the Netherlands Organization for Applied Scientific Research (TNO). This, the fifth workshop, has been coordinated by TNO Laboratories and represents a partnership of the WES, TNO and DIHO.

The following proceedings of this workshop are presented as a summary of the discussions which took place. They do not represent a position statement of any organization represented, but are intended to clarify the direction of future research and pose the questions that now must be addressed in the continuing research. A workshop such as this could not take place without the enthousiastic support of all the participants, both research scientists and decision makers. However, special mention must be made of some of the people responsible for the organization. Drs. Joop Marquenie (TNO) assumed the role of workshop coordinator and deserves special thanks for his extensive efforts in planning all parts of the workshop. Dr. Albert Holland (RWS/DGW) and Dr. Jos Kuipers (RWS-lower rivers) coordinated all field visits in the Netherlands delta. Dr. Martin Hemminga (DIHO) conducted the DIHO portions of the workshop. Ir. Yolanda Kreps-Hendrikx, Ministerie van Openbare Werken (Belgium) made possible the briefings of the dredging and disposal situations at Ghent. Additionally, special thanks are extended to Dr. Hans Nijssen of the Port of Rotterdam for conducting field trips and providing a briefing on the Europort dredging and disposal activities.

1. INTRODUCTION

John W. Simmers and C.R. Lee (Waterways Experiment Station)

1.1 BACKGROUND AND GENERAL AIMS

The need to predict the extent and degree of contamination in waterways, dredged material, sediment, and soils is truly international in scope. As technology has developed at different rates and in response to different levels of needs or problems, a large suite of bioassay and biomonitoring techniques now exists. Similarly, useful data bases exist that may be mutually beneficial when more closely interrelated.

1.2 SCOPE OF THE FIFTH MEETING

The following proceedings of the Fifth International Workshop on Contaminant Mobility relate to three critical areas of contaminant mobility research: the fate and effects of contaminants in ecosystems; physical and chemical assessment and approaches; and decisionmaking strategies. Through exploration of these topics, it was anticipated that the current projects evaluating the extent of contamination and contaminant mobility at existing study sites in both the United States and Europe might lead to the understanding necessary for long-term prediction of contaminant movement into the biota and, most significantly, the effects of contamination on the biota.

1.3 BIOASSAY APPROACH

These proceedings represent a dramatic turn in thinking concerning bioassay and biomonitoring research that is somewhat like a maturation process. While the bioassay and biomonitoring are dependable, the need to consider biological effects and to make long-term predictions has been recognized. Measurements of tissue levels of many contaminants also may be as overly simplistic and questionable as using bulk analysis of sediments for predictive purposes.

1.4 DRAWBACKS IN LONG-TERM PREDICTION

The need for long-term predictive capabilities has been recognized by the workshop participants and some sponsors/decisionmakers. However, the most graphic demonstration has been the changes in contaminant bioaccumulation and sediment toxicity which occur as dredged material ages in upland and wetland disposal conditions. As the task groups have indicated in this report, there are significant questions concerning long-term prediction, expecially in reference to the less persistent contaminants and the short-term and long-term biological effects.

At this time, research projects involving the WES, TNO, DIHO, Rothamsted Experimental Station, and other institutes have indicated that a laboratory test can predict potential bioaccumulation or toxicity at a single point in time. A laboratory test also may be related to field results, as indicated in the Field Verification Program (FVP), Times Beach studies, and the Ottawa (Illinois) mine spoil restoration project. Laboratory tests also may be used to relate results from laboratory tests species to field species or to ecosystem compartments. Through the existing projects and research programs at the FVP field site (Bridgeport, CT), Times Beach, Ottawa (Illinois), Indiana Harbor, and the Broekpolder, the suggestions of the task group will be tested and implemented as appropriate.

2. FATE AND EFFECTS OF CONTAMINANTS IN ECOSYSTEMS

2.1 ECOSYSTEMS AND DREDGED MATERIAL DISPOSAL

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Members of the task group: J.M. Marquenie, S.H. Kay, E.A. Stafford and M. Scholten

2.1.1 Community structures

In a well developed ecosystem, several levels in the community can be recognised. These together form the structure, and most of the levels are inter-dependent. Generally, sunlight energy is trapped and stored by the plant community and microbial and animal communities are dependant upon this energy. The functioning of ecosystems is entirely dependant upon this sole input of energy (sunlight) and the cycling of nutrients. Energy fixed and stored in this primary cycle is then available for use in secondary cycles within the ecosystem.

An example of this cycling of energy and nutrients can be seen in the woodland ecosystem: most of the sunlight energy is trapped by the trees. For their growth they need energy, carbon dioxide and nutrients, supplied through the roots. Together with the nutrients, contaminants within the ecosystem may follow one of a number of pathways: some, for example cadmium, may enter the root and be translocated to the leaves, where they are concentrated; others may be carried to the roots with the nutrients and accumulate along the root surface, for example PCBs and PAHs. At the end of the growing season, leaves are shed and fall to the forest floor.

With the growth of plant material, numerous food chains will develop. Two types of food chain may be identified as important in the mobility of contaminants in the ecosystem:
The first food chain is a grazing one. Animals grazing or mining the plants, for example aphids and grasshoppers, feed on live plant material and are then preyed upon by insects, birds and small mammals. Another example is the muskrat grazing plant roots. This animal also will be exposed to organic contaminants in the rhizosphere, which do not enter the plant. A lack of grazers generally results in lower diversity in the plant community and a decrease in predators.

The other food chain is the 'decomposer' food chain. This starts with the activity of soil microflora and fauna, resulting in microbial decomposition and fragmentation of leaves. Decaying plant material is then consumed by detritivorous species of soil invertebrates, for example earthworms and woodlice. A wide variety of other organisms including insects, birds and small mammals will feed on these detritivores.

Through the 'decomposer' food chain, nutrients concentrated in the leaves are mobilized, and become available again for plant growth. Disturbance of this cycle may result in excessive accumulation in the litter layer and nutritional problems in the plants.

2.1.2 Critical pathways for contaminants

From the preceeding discussion, it is evident that two critical pathways for contaminant mobility exist, resulting in the build up of contaminants to levels exceeding those in the surrounding soil.

i) Contaminants accumulating along the root surfaces. These high levels will affect root grazers and decomposers.
ii) Contaminants translocated to other plant parts (e.g., stems and leaves). These levels will affect grazers of live plant material but also will directly affect the litter layer as it forms with annual leaf fall. As decomposition of organic matter proceeds, an enrichment of some contaminants (e.g., Cd) has been observed under the cottonwood trees at both the Times Beach Confined Disposal Site (Buffalo, N.Y.) and the Broekpolder (Rotterdam, The Netherlands).

Both pathways suggest that the humus layer will be the point of concentration of plant-mobile contaminants within the community. Concentrations of contaminants in this layer initially may be similar to those in the leaves, but may gradually increase with time as the result of leaf fall and litter breakdown. Additionally, plant roots may accumulate high concentrations of organic contaminants, probably along their surfaces.
Detritivorous organisms feeding in the humus layer and on decomposing roots are likely to pose a greater risk to their predators than are the grazers feeding on live plant material (except possibly root grazers).

Ecosystem development at dredged material disposal sites could be envisaged as follows:
Dredged material disposal sites will show a succession in the community structure, in which floral and faunal components are involved (Figure 1). At first, pioneer species will establish themselves. Although insects, such as fly larvae, may be among the first to appear, weedy plants will dominate the site. With the weeds, grazers, sap-feeders, seed-eaters, and their predators will form the frame of the initial community. With time, a fine litter layer will be formed, enabling surface dwellers such as woodlice to enter. Shrubs and young trees begin to dominate the landscape. The continuous interaction between soil fertility, plant life, grazing animals and their predators may lead to an envolved ecosystem containing a wide variety of plant species, including trees, and a grazer food web. On the surface, an extensive humus layer develops, containing a rich decomposer fauna with their specific predators. At the top of the food chain, more or less specific predators will occur, feeding from the ends of one or both of the other food chains.

Deterioration and breakdown of this system may occur in two ways and be evident at the following critical levels:

i) Contaminants with high octanol/water partitioning coefficients have been demonstrated to accumulate along food chains and have maximum influence on the top predators. Organisms most at risk are those with fat deposits which are mobilised rapidly in short time spans.
Examples are: . root feeding vertebrates (muskrat)
. vertebrate predators of soil invertebrates (shrews, hedgehogs, blackbirds etc.)
Several cases have been reported indicating that top predators are affected mainly by organic contaminants.

ii) At severe concentrations grazers feeding on live plant material can be directly at risk. However, because most dredged material is only moderately contaminated, the impact is more likely to occur as a result of contaminant concentration (enrichment) in the top-soils. This may lead to a reduced soil microflora and invertebrate fauna. The result may be the disturbance of nutrient cycles and consequent reduction of plant productivity. Other effects are secondary. Due to the reduced number of soil invertebrates, the number of predators upon them also will be reduced. Cases of excessive litter accumulation due to reduced soil mi-

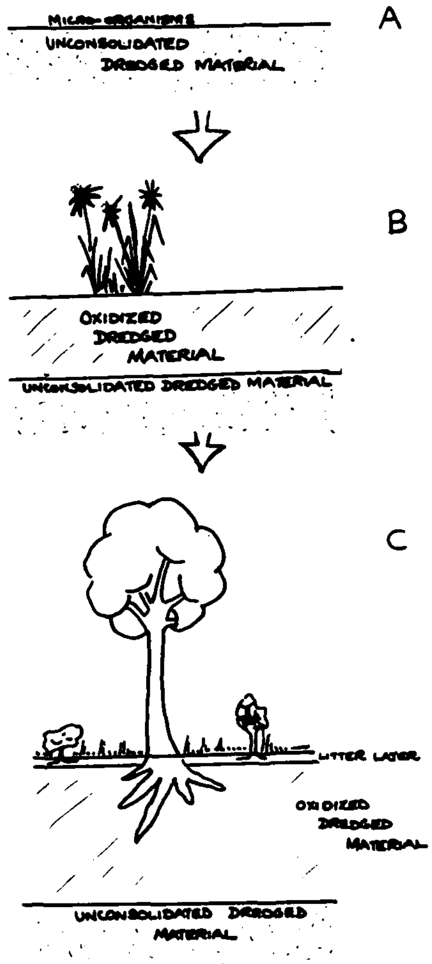

Figure 1 Potential pathways for the evolution of upland disposal sites containing contaminated dredged material:

A Initial conditions in newly-disposed dredged material;
B Drying, oxidation of surface layers, and colonization by pioneer species;
C Development of the litter layer, trees and shrubs;

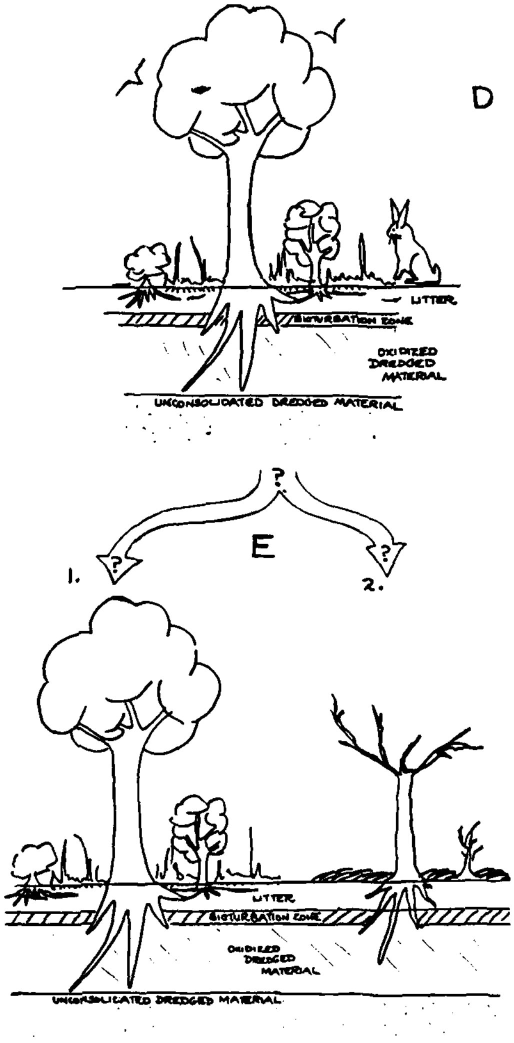

Figure 1 (cont'd).

- D Advanced successional stage with well-developed forest, understory vegetation, and litter-zone vegetation; complete food chain present;
- E Possible pathways for ecosystem dysfunction:
  1. loss of predators as the result of organic contaminants
  2. loss of soil microflora and fauna due to contaminant enrichment and toxicity; litter accumulation and inhibition of nutrient cycling; death of dominant vegetation and secondary loss of predators resulting from diminished food supply.

crofloral and faunal activity are known from orchards and metal polluted sites, but no cases of food chain poisoning have been reported.

The absence of grazers will result in an absence of predators and, potentially, decreased diversity in plant species. Lack of decomposers will result in the absence of their specific predators, increased litter, disturbance of nutrient cycles, and potentially may cause the destabilization of the ecosystem with resultant outbreaks of pests or overgrazing. Early warnings of ecosystem disfunction may be indicated by the absence or reduced numbers of typical soil infaunal predators.

2.1.3 Changes in bioavailability

Accompanying the succession of communities, changes in bioavailability of contaminants may occur. Chemical. changes (oxidation) directly after disposal may result in an increased (cadmium) or decreased (arsenic) bioavailability of metals.

The plant bioassay is expected to be useful in the prediction of metal uptake by trees and other plants rooting in the mineral soil. Furthermore, the results of the plant bioassay are the key factors for predicting concentrations in the primary litter layer. In a climax state, the well-developed litter layer is expected to support most of the soil invertebrates and many of the shallow-rooted (weedy) plants. Concentrations and availability of contaminants in this layer therefore will be the key factors for estimating environmental risks.

Earthworm bioassays conducted on dredged material from Times Beach, Ottawa and the Broekpolder demonstrated that Cd concentrations were increased in the topsoil and that bioavailability of this cadmium to the earthworm also increased toward the surface of the soil. Direct measurements of contaminants in the litter layer may be sufficient to suggest potential problems due to contaminants (such as Cd) which are translocated and concentrated in the above-ground plant parts. The key question, however, is how any build up of contaminants in the litter layer will affect the soil flora and fauna involved in the processes of litter breakdown, decomposition, and nutrient cycling.

It is expected that the concentrations of persistent organic contaminants in the litter layer will be lower than those in the mineral layer. Soil invertebrates living at the interface between these layers or in the mixing zone, however, will be able to bioaccumulate them. Root-feeding invertebrates are likely to be the most affected due to the increased concentrations on the roots. Possible mobility of these contaminants within the ecosystem can be best predicted using a direct earthworm bioassay. Mobility of these contaminants will occur through the predatory food chains. Bioavailability of organic contaminants to a predator are not expected to differ among faunal food sources but may differ among floral food sources. Extrapolation from the earthworm bioassay should take into account that the lower molecular weight PCBs and the PAHs were not found in significant concentrations in vertebrates. Predators on vertebrates therefore are likely to be exposed to different mixtures of these compounds than would be found in the soil invertebrates. The effects on the predators may differ due to differences in life strategies (e.g., life span, reproduction rate, and fat metabolism).

2.2 PLANT COMMUNITIES

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Members of task group: G. Wilhelm, W.H.D. Ernst, A. Mudroch, F. Reboredo, J.W. Simmers and M. Hemminga

2.2.1 Introduction

There are some critical aspects of the plant bioassay protocols that give us pause as currently used. The persistent idea that such protocols can be used to predict the future availability of contaminants on an abandoned dredged material site, it seems to us, is spurious unless one also can predict the species of rhizosphere which will develop. Currently, the only context in which the bioassay organism's behavior is studied is the initial physicochemical context as described by extraction protocols, the results of which remain an item of debate. Until the concomitant influences of developing biological activity are included in the context, we suspect that reliance on purely physicochemical data will continue to frustrate conceptual progress.

Another troublesome aspect of the bioassay is the notion that the ecological principles which are applied to maritime estuarine systems can be applied to inland wetlands and upland sites. The ecology of an inland wetland is quite unlike that of the estuarine marsh. The latter is under influence of the mathematically predictable ebb and flow of water, which is of relatively constant composition and physicochemical quality. Such marshes usually are marked by zones, and these zones are dominated usually by but one species in equilibrium with the system for an indefinite period. Succession to woody plants along most of our coast line is rare. The inland wetland is under the influence of disparate rainfalls, ever-changing edaphics, succesional pressures, and the susceptibility to inhabitancy by literally hundreds of plant species of various physiognomies, which can manifest themselves in vegetational matrices of nearly infinite sets of floristic composition. Inland marshes and upland areas are usually more vulnerable to oxidation and the related vagaries of physicochemical variations.

We will suggest that bioassay protocols be designed to integrate with developing rhizospheres and that the pattern of rhizosphere development on dredged materials be studied with respect to probable succession routes.

Having done so, then we can learn to design plant communities which will provide rhizospheres that are compatible with contaminated substrates.

2.2.2 Discussion

It is now abundantly recognized that physicochemical factors such as heavy metal contaminant content, and sulfide, carbonate, macronutrient, and pH levels are important in assessing the potential availability of heavy metal contaminants. Immense discussion has addressed itself to the various effects of these factors on dredged material "aging", but these same discussions have proceeded with the idea in mind that such factors are the principal and overriding ones insofar as the prediction of potential bioavailability is concerned. Organic contaminants and their influence on substrate chemistry, however, are all but ignored.

We would like to suggest that developing biological activity on an exposed, oxidized, dredged material has a tremendous potential impact on contaminat mobility. Consider, for example, the following biological factors which are inevitable on any developing or "aging" site:

- Biological activity plays a role in pedogenic processes.
- Plant species may facilitate Mn and Fe oxide formation.
- Plant tissues translocate, store, and recycle contaminants.
- Roots provide a milieu for mycorrhizal fungi and other soil-dwelling microbes.
- Roots can mediate their own ambient pH.
- Transpiration processes and root penetration affect soil moisture.
- Decaying plant material forms humic acid, fulvic acid, and other chemical species which may transform available metals into non-available forms.
- Root growth promotes segregation of parent material and enhances weathering processes.

- Plants provide a suitable substrate and food source for animals, particularly soil invertebrates.
- Plants consolidate erodible surface, intercept rainfall, and conserve nocturnal moisture.

These factors, we feel, must be included in the context of our discussion. Then it must be realized that plant species composition and community physiognomy will change from year to year as the rhizosphere develops, pedogenesis progresses, and succession takes place.

Essentially, we feel that a rhizosphere consists of a physicochemical milieu which is whilly and completely apart from what can be measured or indexed from simple extractions made on the "soil" itself. Additionally, it is evident that new, freshly deposited dredged material and sludges are - like yearly stirred (tilled) agricultural "soils" - more akin to growth media and ecologically unrelated to chemically stratified, biologically-mediated, weathered soils. Analysis of contaminant mobility data derived from chemically homogeneous sources must be viewed only as interesting until it can be placed in a more fundamental context.

Another important, influential factor is that most disturbed ground (including dredged material) is destined to inhabitancy by a species-poor cadre of low-order plants, these essentially seral in nature. It is an artifact of post-settlement North America today that scarcely 2% of our native flora is available in sufficient quantity to revegetate spontaneously ground which is laid bare and open; these species are comprised of mostly ruderal, ubiquitous, non-conservative floristic elements. The other 98% are virtually excluded from most contemporary plant successions; a classic "climax" is impossible to obtain in as much as the critical species are unable to participate in the process. Rather, the resulting system is a species-poor, forever unstable "community", often consisting of homogeneous stands of but one species. Our confidence that contaminant mobility relationships could stabilize under such circumstances is low. If species-rich, native plant communities, with ultimately stable rhizospheres are to be established, the seeds and diaspores of conservative floristic elements will have to be installed and appropriate management protocols established. The genetic potential and root/soil chemistry relationships are all but unknown insofar as they relate to contaminant mobility. Until we have analyzed the significance of contaminant movement in plant communities which are rich in autochthonous elements, which have "learned" genetically how to sustain themselves in relative equilibrium with each other and within their particular habitat, we will not understand contamination in the field.

2.2.3 Research needs

- Define criteria for contamination of sediments to be exploited and disposed in confined areas;
- Locate and survey old and new disposal sites;
- Select sites of comparable character for ecosystem evaluation;
- Use the bioassay procedures to test already-developing pedogenic horizons, and index changes from original material at the old disposal sites;
- Locate and survey contaminated industrial sites for study, and select plants already adapted to such situations;
- Examine regional biomes and their array of potential plant communities;
- At several disposal sites, study the effects of management strategies (burning, mowing, grazing etc.) on plant succession and community development;
- Study effects of plant succession on contaminant mobility.

2.3 ANIMAL COMMUNITIES

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2.3.1 Validation of bioassay tests in assessment of suitability of dredged material for upland/wetland disposal

Good plant and earthworm bioassay methodology have now been developed and well tested. These procedures may be applied to evaluate contaminant mobility at currently-used and old dredged material disposal sites. A good range of old disposal sites of documented age and nature are available for study. About ten or more of these sites could be selected and the following procedure followed:

a. Assess levels of persistent contaminants in the soils;
b. Run earthworm and plant bioassays on the unconsolidated anaerobic material collected from below the water table. This can be assumed to be relatively similar to the original dredged material in terms of persistent contaminants. It should give a reasonable estimate of what would have occurred if bioassays had been conducted on the original material. However, it should be recognized that processes occurring in upland disposal sites, such as leaching and degradation, may have altered the concentrations somewhat. Therefore the results of these bioassays should not be misrepresented as being identical to what would have occurred on the original dredged material.
c. Select a short range of key indicator invertebrates and vertebrates to sample on site and assess residues of persistent contaminants in their tissues.

   Suggested animals include:

   i soil/litter - earthworms, woodlice
   ii plant-feeding invertebrates - grasshopper
   iii carnivorous invertebrates - spiders, centipedes
   iv vertebrates that feed on soil invertebrates - robins, woodcock, mice, shrew
   v plant-feeding vertebrates - pigeons, rabbits
   vi carnivorous vertebrates - hawks

Optionally, these data could be improved by selecting a similar number of reference sites adjacent to the contaminated sites and censusing populations of the key indicator species.

From the extensive literature on environmental effects of PCB's, mercury, and organochlorine insecticides, the vertebrates most likely to be at risk are well known. These include eagles, hawks and fish-eating birds (e.g., pelicans). These persistent chemicals are those most likely to cause long-term hazards on disposal sites. Less is known, however, about effects on many invertebrate species.

From the data collected in this way, regressions can be plotted relating residues in worms and plants from the bioassays against residues in key indicator species, to validate bioaccumulation predictions of the bioassays. Levels of contaminants in test plants from the plant bioassay also could be related to those in climax or available vegetation on older sites, and also to amounts in the litter layer and the thickness of the litter layer. This could be supported by studies on rate of organic matter breakdown in the litter layer. Other "overall" effect parameters (e.g., respiration or biomass) might indicate functional disturbances as well. The conclusions reached in the survey of key indicator organisms could be supported at a later stage by detailed food chain feeding studies on relevant key organisms. Compound- and species-specific research is needed to distinguish bioavailability and to establish acceptable levels of contamination at a particular site. There is also a need for a detailed study of one whole ecosystem (e.g., Times Beach) to assess the kinds of organisms that concentrate contaminants. These studies should place some emphasis on the dynamics of several "fate" processes, which determine the mobility and bioavailability of contaminants under different and fluctuating environmental conditions. Bioassays used in a specific situation should be chosen carefully. Ecotoxicological effects should be studied both in the field and laboratory. Bioaccumulations should not be the primary goal of these studies, but should be used as a tool to relate environmental contamination to the observed ecotoxicological effects.

2.3.2 Colonization

The extent of colonization might possibly be used as an index of unacceptability of dredged material for landfill as a warning of potential long-term hazards.

2.3.2.1 Assessment

By using soil cores, pitfall traps and suction traps, the extent of colonization of a site may be assessed.

2.3.2.2 Routes of recolonization

- Surface-living invertebrates: across surface of the dredged material (e.g.. ants, Diptera);
- Soil-inhabiting invertebrates: from aerial routes (e.g., by the wind or on the feet of birds);
- Plant-dependent invertebrates: aerial insects.

2.3.2.3 Rate of colonization

- Dependent upon disappearance of adverse chemicals: salt;
- Transient chemicals (aromatic);
- Persistent contaminants (organochlorines, PCB's, heavy metals).

2.3.3 Key organisms in contaminant transfer

Key organisms could indicate serious ecosystem effects. These could be indicator organisms, essential/important organisms, or very sensitive organisms.

2.3.3.1 Types of key organisms

a. invertebrates
   - soil/litter consumers - woodlice, earthworms
   - plant feeders - grasshoppers
   - carnivores (localized) - spiders

b. vertebrates
   - invertebrates feeders - robins, woodcock
   - plant feeders - pigeons, mice
   - carnivores - hawks.

2.3.3.2 Identification of best key organisms

This could be based on a thorough survey of residues in and the abundance of the predominant organisms from at least one site. This should be compared with a comparable control site, and might be supported by data from the literature.

2.3.4 Fate and effects of contaminants

2.3.4.1 Fate

a. Short term - breakdown or volatilization
b. Long term - persistence

2.3.4.2 Mode

a. Direct - acute/chronic toxicity
b. Indirect - affects food supply

2.3.4.3 Targets

a. Humans - through water, air, or food (if agricultural crops are grown on contaminated material)
b. Wildlife: - carnivores
   - detritivores
c. Systems: - Organic matter breakdown
   - Mineral cycling.

2.3.4.4 Assessment

- Sediment residue analyses and sediment characterization (particle size, organic matter, etc.);
- Modelling bioavailability;

- Bioassays;
- Analysis of key indicator organisms;
- Food chain studies;
- System studies (e.g., litter bag, organic matter breakdown).

3. PHYSICAL AND CHEMICAL ASSESSMENT

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Members of task group: J. van Veen, J.W.J. Gielen, P. Kelsey, A. Janssen and W. Goosens

3.1 INTRODUCTION

The physical and chemical characterization of dredged materials, sediments and soils often contributes towards a substantial part of the total research costs. In numerous cases, governmental or industrial authorities simply ask the analyst to execute the analysis and to produce figures. After receiving these figures, the "thinking process" begins, and the authorities consider what to do with these figures. This "afterwards" process often results in the conclusion that the wrong parameters were determined. It seems worthwhile to change the sequence and to ask for chemical analysis only if it is known initially what to do with the figures. If it is not possible to decide, then no money should be spent on chemical and physical analysis.

3.1.1 Sampling and storages

Sampling and storage of samples is a major concern in each project. The way sampling and storage is performed strongly depends on the aim of the research project. The major question in the management strategy for dredged material is the bioavailability of the contaminants. Several bioassays are applied on the materials to determine bioavailability. Bio- and chemical assay samples are taken from sediments to be dredged material or from already deposited dredged material. The sediments are heavily stirred by the dredging device. At that point, chemical changes begin, converting, oxidizing and releasing contaminants. The material in the bioassay containers may be mixed with sand or manure, again allowing the above process to occur. One should bear in mind that the bioavailability of contaminants in the dredged material at this point in time reflects only the availability of contaminants in a substantially changed material.
If the aim of the research is to assess the availability of contaminants in the virgin sediments, extreme care should be taken to preserve the integrity of the sample (see paper by Dr. Reynders presented on 27 September).

Similar problems arise in the classification of dredged materials in the Netherlands (class 1 to 4). This is done by removing the organics and carbonates prior to the actual particle size determination. Does this procedure maintain the integrity of the collected sample? Because the actual state of the dredged material to be studied is not established, it is very difficult to give guidelines on sampling and storage.

3.1.2 Analysis of real samples and standards

3.1.2.1 Toxic metals

The metal analysis of dredged materials is performed after total digestion of the sediments. The analysis yields the total amount of metals in the sample. This value is then compared with the bioassay uptake. The above described problems of chemical conversion during sampling and bioassay preparation undoubtedly will influence the bioavailability of the toxic metals. If the bioassay is used only to warn for possible problems it is assumed that the assay then describes a worst case situation. This assumption may not always be true, however. The bioassay generally is conducted after toxic metal analysis by the total digestion method. If the analysis yields high values, the bioassay is applied. If only low values are found, the bioassay may not be done. It still is possible that the low values are accompanied by high bioavailability. The bioassay is implemented in the decision making strategy and therefore should be applied on all materials to be examined. One should also consider the possibility of omitting the toxic metal analysis of the sediment and only applying the bioassay for describing the possible risks associated with different uses of dredged materials.

3.1.2.2 Organics

The total number of organic contaminants adsorbed on dredged material undoubtedly will include thousands of different substances. So far, consideration has been given only to the relatively easy to analyze groups, including PCB's, chlorinated insecticides and PAH's. It is very clear that these groups form only a minor part of the total number of contaminants. However, they all have proved to be very persistent chemicals. These groups should be regarded only as guide chemicals to describe the "total" degree of contamination with organic pollutants.

3.1.2.3 Reference materials

Toxic metal and organic contaminant analysis is accompanied by the analysis of blank and certified reference samples. Although all this care is taken, interlaboratory differences are always encountered. A long and very time consuming process is to organize ring tests among different laboratories. All participants will gladly cooperate to test their own quality control. The question, however, is whether or not the WES should conduct ring tests. NBS and other organizations supply reference materials which primarily are easy to maintain and to store. It will take some time before they will sell certified wet worm tissue or wet dredged material. In order to control and to test the laboratories WES uses for their analysis, WES should prepare homogeneous amounts of worm and plant tissue. These reference samples should be added in a blind way to each sample series to be analysed. This method has been applied by TNO for approximately 5 years with mussel tissue and has resulted in a quick recognition of analytical problems, deviations, and errors. It is not necessary to establish the absolute concentrations of metal and organic contaminants in these reference samples. However, the stability of these contaminants in this reference material over the project time should be determined.

3.1.3 Needs for standardization

Standardization can be applied both on chemical analysis and bioassay methods. In view of the chemical conversion of dredged materials, it seems advisable first to standardize the bioassay and to find and determine the key parameters that describe the established state of the dredged material to be tested. As long as the outcome of different analytical methods applied by the contract laboratories vary within acceptable limits, it seems advisable to allow each laboratory to apply the methods they commonly use.

3.2 TREATMENT OF CONTAMINATED SEDIMENTS

3.2.1 Introduction

Based on a decisionmaking strategy, a decision is made whether or not a sediment is to be dredged. In the case it is to be dredged, a disposal environment must be found for the dredged material. The destination depends strongly on the quality of the sediment and the quantity of the sediment.

a. Quality

The choice of the disposal site can be in surface water, in a landfill, or in a confined disposal site. In some cases the quality of the sediment is sufficiently bad that national or regional standards do not allow disposal. Disposal can also be impossible because it is socially not accepted.

b. Quantity

Confined disposal sites sometimes are not available or their size is limited, so the reduction of the volume of the contaminated sediment for disposal is necessary.

In both cases (a and b), the result is that the contaminated sediment may not just be taken to a disposal site, but first has to be treated.

3.2.2 Treatment

3.2.2.1 Volume reduction

Contaminants in sediment mainly are attracted to organic material and the fine fraction. Separation of the sand from the organic material and fine fraction results in a part which is relatively clean and a part in which the contaminants are concentrated. The separation is called classification. With regard to sediment, the hydrocyclone process is a suitable classifier. Hydrocyclone classification separates the sand from the other part, which contains the fine fraction and organics, together with most of the water (the overflow of the hydrocyclone). This means that dewatering of the overflow results in the reduction of its volume. Summarized, classification and dewatering results in a reduction of the contaminated sediment volume requiring disposal. This treatment process (classifying/dewatering) has full-scale application in Germany and the Netherlands.

3.2.2.2 Contaminant reduction

Improvement with regard to the quality depends on the quality assessment method. Here only two assessment methods are considered: those based on contaminant availability and those based on contaminant content. Remedial action in the first case involves immobilization and decontamination; the second case involves only decontamination.
Immobilization techniques have been investigated in Germany, while decontamination techniques have been investigated in both the Netherlands and Germany. Decontamination does not mean the movement of the contaminant to another compartment of the environment (e.g., the evaporation of contaminants into the air). Remedial actions have not been applied on a full-scale basis with regard to sediment. Decontamination of soil has been applied in the Netherlands, however.

4. DECISIONMAKING

Authors: C.R. Lee, L. Tent and A. Holland
Members of the task group: L. Tent, P. Worthington, M. Mensink, A. Holland and C.R. Lee

4.1 GUIDELINES AND CRITERIA

4.1.1 Needs for guidelines

a. Determination of how to manage a dredged material must consider:
   - Site of dredging operation
   - Characteristic of the disposal site.

b. Evaluation of fixed concentrations (threshold levels) needs to be reworked in a technically sound manner with more scientific knowledge for:
   - Emission limits
   - Current dredging activities.

c. Fixed concentration criteria should be related to contaminant pathways and the "consequences" of contaminant mobility and bioaccumulation. Pathways should include:
   - sediment/soil into air
   - sediment/soil into groundwater
   - sediment/soil into surface waters discharged into
     i estuarine environments
     ii freshwater environments: hard water and soft water
     : geographic distribution
   - sediment/soil into biota such as plants, soil invertebrates and aquatic organisms.

d. Evaluation of the consequences of contaminant mobility and bioaccumulation on the food chain.

e. Several limit values already exist, such as EC directives, ANNEX, FDA and EPA water quality criteria.

f. Establishment of environmental goals are required, such as:
   - Keeping clean sites clean
   - No multiplication of contaminated sites
   - No further degradation (stand-still principle)
   - Sanitize (clean up) problem sites

g. Evaluation of surface area exposure to the environment of contaminated sediments needs to be incorporated into a decisionmaking framework.
   It's the problem of dealing with probability. What risk does an animal have when it "visits" a 100 km^2 area with 1 ppm (Cd) instead of 10 km^2 with 10 ppm? The animal lives longer in a less polluted area (e.g., time effect relationship"). What will be the concentration (e.g., of Cd) in the water in the case of 100 km^2 with 1 ppm, instead of 10 km^2 with 10 ppm (e.g., concentration-effect relationship)?

4.1.2 Quality assurance

Decision making processes should indicate an accuracy of determination and a reproducability of results which would be reasonable and render the decisions meaningful (e.g., accuracy ± 30% true value; reproducibility ±20%. If these values cannot be met, the research/investigation should concentrate its efforts on improving the method of analysis, in preference to continued experimentation in obtaining results. In-lab and inter-lab quality control is necessary. National and international comparisons of laboratories should be done. Biological tissue standards are required for contaminant analyses, especially organic contaminants.

4.2 SEDIMENT VERSUS BIOLOGICAL CRITERIA

Sediment-based criteria, such as bulk analysis should be used as an inventory of contaminant content and the potential long term contamination. These criteria need to be related to the ultimate fate and effect of sediment contamination in the environment. The evaluation of fixed,(limiting) concentrations should take into account additional parameters such as grain size, organic matter, etc., because of their influence on contaminant availability.

For example: A Cd content of 3 mg/kg is set for agricultural soils. If this value is exceeded, one is not allowed to apply sewage sludge on the field.

This Cd content was established after consideration of many soil chemical analyses, related Cd contents of plants, and the accepted daily intake concentrations. However, it has become evident that "3 mg/kg Cd" applies to "normal" soils with a given grain size (for example: 20% sand content). As the sand content increases, Cd availability increases also. Consequently, the established value should be lowered accordingly. This can be accomplished either by a general reduction to 1 mg/kg, for example, or by the introduction of factors developed from bioassay tests such as:

Sand content (%)	20	30	50	70
Sediment Cd content (mg/kg)	3	3	3	3
Factor	1	0.9	0.7	0.5
Resulting Cd content (mg/kg)	3	2.7	2.1	1.5

Biological criteria could be used as screening tools to set priorities on sanitization (clean up) measures. Biological criteria are necessary to ensure that contaminant levels in biota stay or become low and that unacceptable adverse consequences in the food chain do not occur. Biological criteria can serve as controls or a balancing system for sediment criteria. Biological criteria must relate to "effects" and consequences in the field environment.

4.3 DECISIONMAKING FRAMEWORK

Author: C.R. Lee

Any framework developed to make decisions on the management of contaminated sediment should consider the following issues:

a. Must be based on both chemistry and biological effects
b. Must have established environmental goals
c. Must be achievable
d. Must be quantifiable
e. Must be usable and be of value
f. Must relate test procedures to environmental consequences
g. Must integrate test data into a quantifiable entity that can be used to determine "good" or "bad" situations

h. Must define and quantify the decision point (i.e., Bioassay: 50% mortality on bioassay organisms exposed to the contaminated sediment = restrict; bioaccumulation > statistical increase = restrict; or bioaccumulation > criteria = restrict)
i. At some point, the decisionmaking framework needs a risk assessment component incorporated
j. The final decision will require the incorporation of economic and social factors.

5. SUMMARY AND CONCLUSIONS

Author: S.H. Kay

The need for long-term predictive capabilities regarding contamination in waterways, dredged material, sediments, and soils is well recognized and is international in scope. The Proceedings of the Fifth International Workshop on Contaminant Mobility focus on three critical areas: the fate and effect of contaminants in the environment; physical, biological, and chemical assessment procedures; and regulatory decisionmaking criteria.

The prediction of the environmental effects and fate of contaminants in dredged material has been based primarily upon bulk chemical analyses and bioassays of sediments collected prior to dredging and disposal operations. Dredged material changes greatly with time through physicochemical weathering (i.e., ageing) processes such as drying, oxidation, photodecomposition, and leaching, especially when placed into an upland disposal environment. These processes are influenced further by the activities (i.e., bioturbation) of microorganisms, plants, and animals. The fate and effects of contaminants in disposal sites are greatly influenced by these physicochemical and biological processes. The currently-used approaches (laboratory tests which do not allow for the effects of ageing of dredged material following disposal) for evaluating sediments prior to dredging are inadequate for predicting the long-term fate and effects of contaminants in the disposal environment.

Many of the problems encountered when predicting the environmental effects and fate of contaminants are associated with the changes occurring in the surficial (i.e., leaf litter and the underlying humic layer) layers. With the exception of the deep-rooting species (i.e., trees and shrubs) which penetrate the oxidized mineral layer (i.e., beneath the humic layer), the major portion of the ecological risk is associated with those organisms living in the surface litter and humic layers and the predators of those organisms. Plant bioassays conducted on sediments collected prior to dredging and disposal are useful to predict both contaminant (metal) uptake by shallow and deep-rooting species in the early stages of succession and the potential build-up of contaminants in the leaf litter. For the later stages of succession, however, it will predict bioaccumulation only in those plants which are rooted primarily in the oxidized mineral layer.

The most realistic predictions of the mobility of persistent organics must be based on a direct bioassay of the dredged material with a soil-feeding invertebrate, such as the earthworm, *Eisenia foetida.* The most consequential environmental effects of persistent contaminants are expected to be found at the level of the soil-dwelling invertebrates and their predators. A data base is needed to determine the interrelationships between contaminant bioavailability in dredged material and the concentrations and effects in the organisms which comprise the food chain. The needed studies should be field oriented and should include an analysis of the structure of existing food chains and the contaminant burdens in representative food-chain components at existing mature disposal sites.

The physical and chemical characterization of dredged material, sediments, and soils consumes a large proportion of the available research funds, yet frequently is done without consideration for how the data will be used. Routine chemical analyses appear to be of limited value (for inventory purposes only) because they do not address bioavailability. Bioassays always must be conducted to determine potential toxicity and bioaccumulation of contaminants, even when sediment contamination appears to be low.

Quality control in the laboratory also is of prime importance. Generally speaking, standard reference materials are not readily available for the types of chemicals and/or substances involved in research on contaminant mobility from dredged material. The materials used as reference standards must be qualitatively similar to those of concern (i.e. worm tissue should be used as the reference standard for worm analyses, fish muscle or livers for fish tissues, etc.). Consequently, a large quantity of homogeneous worm or plant tissues, etc., should be prepared for use as reference materials to recognize analytical problems and detect errors in analyses.

Because of the large quantities of sediments that must be dredged and the limited size of confined disposal sites suitable for disposal of highly contaminated material, methods must be used to reduce the volume of contaminated sediment to a manageable size. A method in use in the Netherlands and Germany is the hydrocyclone, which separates the fine fraction containing most of the contaminants from the coarse fraction. The dewatering of the fine fraction results in further volume reduction. Water from the hydrocyclone and from dewatering process sometimes must be treated. Further treatment of the sediment may be necessary to either immobilize (e.g. liming) or remove contaminants.

The decisionmaking process is one which weighs the environmental hazards of contamination against economic, social, and other considerations and is both partly scientific and partly administrative and political. Local input to dredged material management should be related to the local environmental goals which have been established (e.g., either cleanup or no further degradation). Quality assurance is of great importance to the decisionmaking process. Intra- and interlaboratory quality control is necessary, and all decisionmaking processes should indicate both accuracy and reproducibility of test results. Biological criteria possibly could be used as screening tools to set priorities for sanitation (cleanup) measures. Biological criteria also are necessary to insure that unacceptable adverse effects do not occur in the food chain.

Consequently, criteria for contaminated dredged material must consider the fate and effects of contaminants in the food chain. Bulk chemical analyses alone are of limited value and should be used for inventory purpose only, and not as regulatory criteria for evaluating sediment quality. Bulk chemistry, however, may provide useful information regarding potential sediment chemical changes that may occur with time and, hence, affect bioavailability. Consequently, both sediment chemistry and bioassays are needed in the evaluation of sediment contamination.

6. RECOMMENDATIONS

a. Bulk chemical analysis alone should not be used as the criterion for making decisions on the disposal of dredged material. The evaluation of sediment contamination should be based on biological effects and fate in the food chain. Consequently, bioassays must be conducted on all soils, sediments, or dredged material to assess bioavailability and allow prediction of environmental impacts.

b. Plant (*Cyperus esculentus*) bioassays should be conducted on dredged material to evaluate the potential movement of metals into deep-rooted species and to predict the potential for enrichment of the surface litter layer as the result of plant uptake and deposition through leaf fall.

c. Plant roots should be analyzed for both metals and organics because of the tendency toward accumulation around the roots and potential movement into the food chain via root-feeding animals.

d. The earthworm (*Eisenia foetida*) bioassay should be conducted on the air-dried dredged material or sediment to allow for the evaluation of the effects of persistent organic contaminants and mercury in the food chain. This bioassay, however, has been shown to significantly underestimate Cd uptake in soil invertebrates living in mature disposal sites, because of Cd enrichment of the surficial layers due to leaf fall. This also may apply to other elements that are readily translocated by plants. Thus caution is advised in the interpretation of earthworm bioassay results for metals.

e. To insure quality control within and among laboratories, a substantial sample of homogeneous tissue should be prepared for each bioassay species to be used as reference standard on subsequent chemical analyses. Samples of this reference standard should be included in a "blind" manner with all experimental samples for analysis.

g. In order to relate the results of chemical analyses of dredged material and bioassays to real environmental effects, studies are needed on a range of existing disposal sites which have developed into apparently healthy ecosystems. The studies should be directed toward each of the major components of the food web, including decomposers, grazers, and carnivores. Plant and earthworm bioassays should be conducted on materials from the deep, reduced layer, the oxidized mineral layer, and on the litter layer. From this data base, models can be developed to allow prediction of future ecosystem effects from the results of plant and animal bioassays. A predictive model, based on the plant bioassay for accumulation and enrichment of metals (for instance cadmium) in the litter layer and the subsequent accumulation and effects in earthworms is of specific interest in this respect. Potential candidate sites might include the Broekpolder near Rotterdam, and Times Beach at Buffalo, NY.

APPENDIX 1

WORKSHOP PROGRAM

Information leaflet on the
FIFTH INTERNATIONAL WORKSHOP ON CONTAMINANT MOBILITY

GENERAL AIMS

- Stimulate the interaction between international experts on contaminant (bio)mobility.
- Provide guidance to USCE-WES projects in relation to dredging and disposal of contaminated sediments.

AIMS OF THE FIFTH MEETING

Based on active visits to contaminated disposal sites with evolved ecosystems and long-term contaminated wetlands:

- Evaluate the importance of sediment-based criteria versus effect-based criteria in the management of contaminated sediments.
- Evaluate the use of bioassays as a tool for the long-term prediction of bioavailability of contaminants.
- Delineate the major effects and critical pathways for contaminant transfer along food-chains in relation to dredged material disposal.
- Coordinate research efforts in these respects between European and American scientists.

SPONSOR

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Martin Hemminga (DIHO)
Albert Holland (RWS-DGW)
Joop Nieuwenhuize (DIHO)
Hans Nijssen (Municipality of Rotterdam)

Programme design and coordination

Joop M. Marquenie (TNO)

DATES AND PLACES

September 26: Field trip Western Scheldt
September 27: Motel Wouwse Tol
September 28: Excursion Eastern Scheldt and Broekpolder
September 29: Field trip to Sassenplaat and Rotterdam
September 30: TNO headquarters, The Hague
October 1: TNO laboratories, Delft

ACCOMODATION

September 25 ------------------- September 27 -------------------- October 2

Motel Wouwse Tol	Motel Hoornwijk
Bergsebaan 85	J. Thijssenweg 2
Bergen op Zoom	Rijswijk
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REMARKS

A passport is needed in order to cross the Dutch-Belgium border on our way to the Callemansputten disposal site.

It is advised to bring suitable clothing and shoes or boots for entering wetlands and disposal sites in rain and wind.

PROGRAM

WORKSHOP CONTAMINANT MOBILITY 1986

<u>Thursday September 25</u>

17.00 Departure from Amsterdam RAI Congres Centre by touringcar
Welcome aboard.
19.00 Dinner at Willemstad
23.00 Arrival at Bergen op Zoom (motel Wouwse Tol)

<u>Friday September 26</u>

8.00 Breakfast
9.00 Departure for Western Scheldt
10.00 - Callemansputten (disposal site)
12.00-13.15
Lunch with introduction to RWS - (dr. Speksnijder)
Hotel Royal-Sas van Gent
13.45 - Land van Saeftinge (natural wetlands)
Guidance will be provided by
RWS- DGW (dredging and disposal)
DIHO (estuarine communities)
17.00 Return to motel

<u>Saturday September 27</u>

7.00 Breakfast
8.00 Conference room Wouwse Tol
8.30 Introduction to RWS (DGW/DBW) (dr. A. Holland)
- organization and historical background
- overview of sediment related tasks
- the problems we are facing
- anticipated research and solutions

8.45 Introduction to DIHO (dr. M. Hemminga)
- organization and historical background
- research topics
- sediment related projects
- contaminants in ecosystems

9.00 Introduction to WES (dr. C.R. Lee)
- organization and historical background
- sediment related projects
- longterm development and processes

9.30 Coffee break
10.00 Scientific program (20 minute lectures and one hour lunch break)
- dr. Ma (small mammals)
- dr. Nijssen (Broekpolder)
- dr. Nienhuis (estuarine ecology)
- dr. Janssen (criteria for sediments)
- dr. Reynders (contaminant mobility)
- dr. Lee (FVP)
- dr. Simmers (ageing of disposal sites)

15.00-17.30
Discussion in task groups

<u>Sunday September 28</u>

8.00 Breakfast
9.00 Departure
10.00 Visit to the Eastern Scheldt storm-surge barrier, including boat-trip
11.00 Departure for Rotterdam Broekpolder
11.45 Lunch Grevelingendam
12.45 Short stop at the Hellegatsplaten (reference area)
14.30 Visit to Broekpolder disposal site
16.30 Arrival at Rijswijk (motel Hoornwijk)

<u>Monday September 29</u>

7.00 Breakfast
8.00 Introduction to the Sassenplaat and the Haringvliet (dr. Kuipers)
9.00 Visit to Sassenplaat dredged material restoration island
12.00 Lunch and introduction to Rotterdam disposal sites (dr. Nijssen)
14.00 Visit to Rotterdam disposal site
17.00 Departure for motel

<u>Tuesday September 30</u>

7.00 Breakfast
8.00 Conference room TNO (The Hague)
9.00 Ecotoxicological risks (drs. Marquenie)
9.20 Hamburg (dr. Tent)
- development of dredging and disposal
- problems and solutions

9.40 Coffee break
10.00 Discussion in task groups
12.00 Lunch
13.00-17.30
Discussion in task groups and report preparation

<u>Wednesday October 1</u>

7.00 Breakfast
8.30 Introduction to TNO (dr. Langerwerf)
- organization
- aims

9.00 Report preparation
12.00 Lunch
13.00 Report presentations
15.00 Final remarks
15.30 End of workshop
16.00 Guided tour around TNO laboratories
17.30 Departure

<u>October 20</u>

Mailing of draft proceedings to participants

<u>November 20</u>

Deadline for comments

<u>December 20</u>

Mailing of final proceedings

APPENDIX 2

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APPENDIX 3

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The Marine Biological Association
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Dr. Ir. G. Pichot
IHE
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Dr. Fritz Prosi
Zoological Institute
Federal Republic of Germany

Dr. Fernando Reboredo
The New University of Lisbon
Portugal

Dr. Ir. J.J. Reynders
University of Utrecht
The Netherlands

Mr. R. Glenn Rhett
U.S. Army Engineer Waterways Experiment Station
U.S.

Mr. Norman Rubenstein
U.S. Environmental Protection Agency
U.S.

Dhr. H. Reurich
Hydronamic
The Netherlands

Dr. John Simmers
WES
U.S.

Mr. Jens Skei and/or
Mr. Kristoffer Naes
Norwegian Institute for Water Research
Norway

Dr. Elizabeth A. Stratford
Rothamsted Experimental Station
United Kingdom

Dr. Ludwig Tent
Port Authority of Hamburg
Federal Republic of Germany

Dr. Eelke Turkstra
DBW
The Netherlands

Dr. Dick Lee
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U.S.

Dr. Ir. Wim Ma
Institute for Nature Management
The Netherlands

Ir. Bernard P.M.A. Malherbe
Harbor and Engineering Consultants
Belgium

Dr. Joop Marquenie
MT-TNO
The Netherlands

Dr. Mart Mensink
NMF
The Netherlands

Dr. Alena Mudroch
National Water Research Institute
Canada

Mr. Peter Lewis Nowicky
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Dr. Piet Nienhuis
DIHO
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Dr. J.P.J. Nijssen
Department of Public Works
Municipality of Rotterdam
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Dr. H.J. Peperstraete
Center for Nuclear Energy Research
Belgium

Dr. G. Persoone
Rijksuniversiteit Gent
The Netherlands

Ing. Johan van Veen
MT - TNO
The Netherlands

Dr. Joop Veghter
VROM
The Netherlands

Mr. J. de Vries
AVECO
The Netherlands

Dr. Barbara T. Walton
Oak Ridge National Laboratory
U.S.

Dr. Gerould S. Wilhelm
The Morton Arboretum
U.S.

Dr. P. Worthington
Commision of the European Communities
Belgium

APPENDIX 4

ABSTRACTS OF PRESENTATIONS

INFORMATION ABOUT THE
HOST ORGANIZATION, TNO

organization for applied scientific research

TNO

TNO, the Netherlands Organization for Applied Scientific Research, was established by law in 1930 with the aim of ensuring that applied scientific research is put at the service of the community in the most efficient manner possible. TNO is a fully independent, nonprofit applied research organization with a staff of about 5000 and an annual research volume of approximately Dfl. 550 million.

In 1982 TNO executed some 20.000 contract R&D projects, commissioned by about 6000 Dutch and foreign clients. TNO's major target group is trade and industry, the small and medium-sized firms in particular. Other important target groups are: central and local authorities, private organizations, societies, foundations and individuals. In some cases collective research is carried out for specific branches of industry.

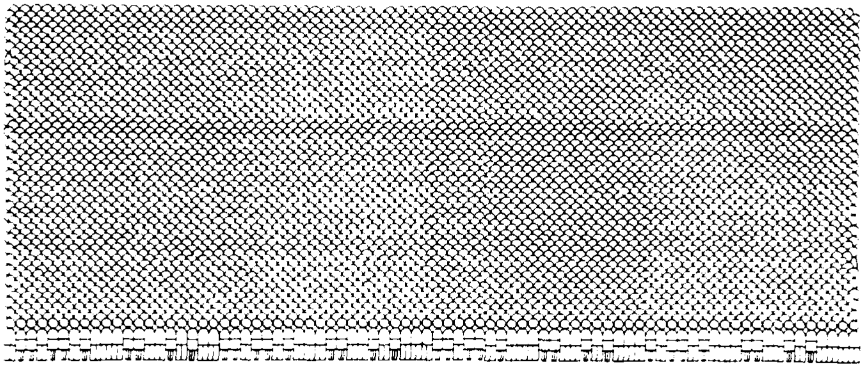
TNO's main fields of interest are: industrial technology, energy, the environment, food and nutrition, health, defence and infrastructure (including building and living). In this connection three main service categories are distinguished, viz.: explorative research, applied research and the transfer of know-how.

TNO consists of eight divisions, each with its own specific field of research, viz.: Building and Metal Research, Industrial Products and Services, Technology for Society, Technical Scientific Services, Nutrition and Food Research, Health Research, National Defence Research, and Policy Research and Information. The divisions comprise about 35 institutes in total, which are either branch or discipline-oriented. It is common practice for TNO to form teams of experts drawn from various institutes for the execution of projects which require a multi-disciplinary approach.

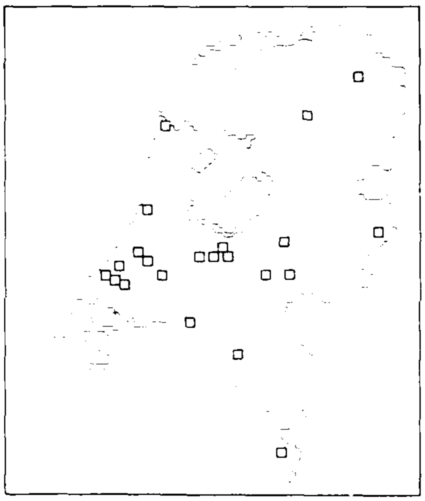
Some examples of important research topics or branch-related research are:

- Applied Biology
- Applied Chemistry
- Applied Mathematics
- Applied Physics
- Biomedical Sciences
- Biotechnology
- Breeding of Laboratory Animals
- Building Materials and Structures
- CAD/CAM
- Chemical Analysis
- Chemical and Biological Testing
- Consumer Investigations
- Defence Research
- DNA-recombinant Research
- Energy-related Research
- Environmental (Pollution) Research
- Ergonomics
- Experimental Gerontology
- Fibre Research
- Food and Nutrition Research
- Forest Products Research
- Groundwater Survey
- Heating and Refrigeration Research
- Industrial Trouble Shooting
- Leather and Shoe Research
- Mechanical, Physical and Chemical Engineering
- Medical Technology
- Metal Research
- Microelectronics
- Offshore Technology
- Operations Research
- Packaging Research
- Paint Research
- Physical Testing
- Pilot Plant Studies
- Plastics and Rubber Research
- Product and Process Innovation and Development
- Productivity Studies
- Quality Control
- Radiobiological Research
- Risk Analysis
- Road Vehicles Research
- Robotics
- Sensory Perception Research
- Socio-technology
- Standards and Performance Testing of Materials and Products
- Technical Information
- Techno-economic Studies
- Toxicologie
- Training

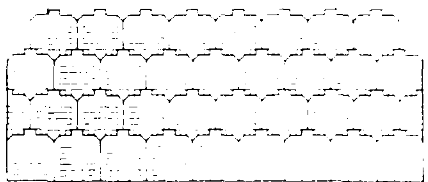
TNO issues its own periodicals 'TNO Project' and 'Innovation' in Dutch, and regularly publishes informative newsletters on research and innovation in English. Results of TNO contract research are confidential. Other work is publicized in reports, journals, annual reports, and so on.



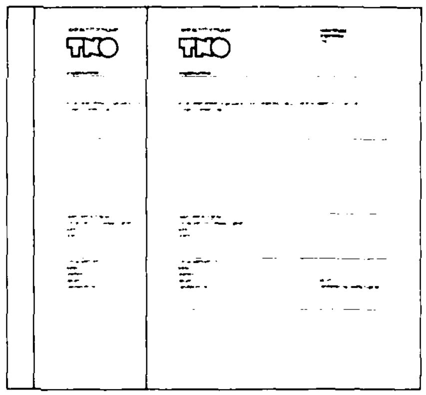
5000 employees



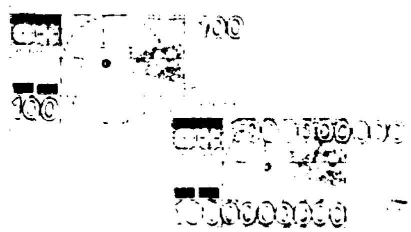
TNO-locations in the Netherlands



35 institutes



20000 R & D projects, commissioned by about 6000 Dutch and foreign clients...



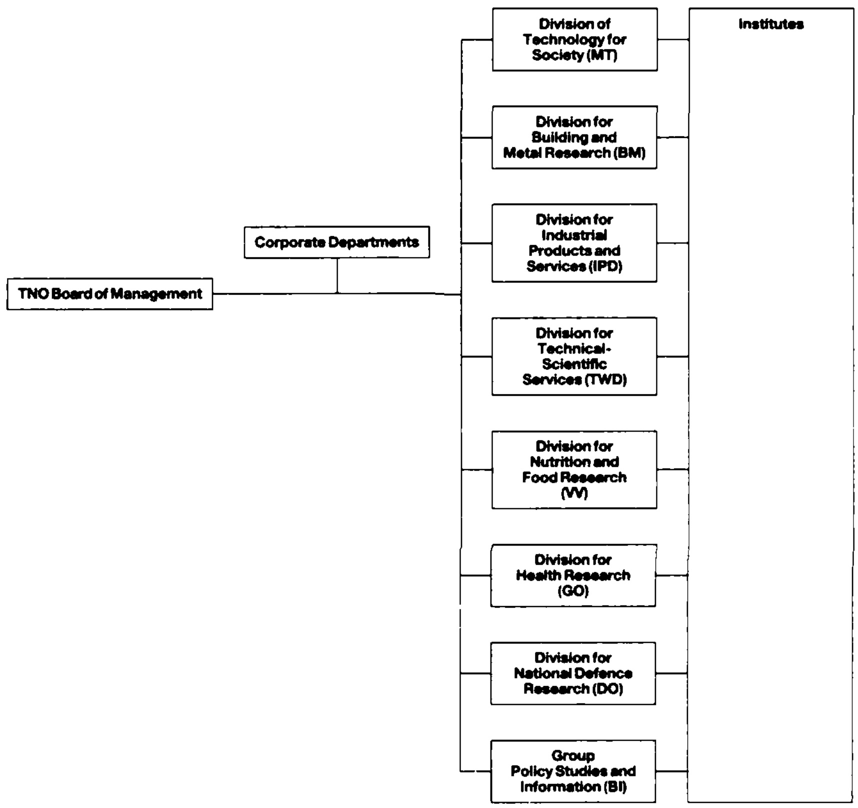
...amounting to Dfl. 140 million

More detailed information and/or a complete list of all TNO institutes and their specific fields of research can be obtained from:

TNO Guide for Trade and Industry
Mr. A. C. Lakwijk
Schoemakerstraat 97
2628 VK Delft
Telex 38071 zptno
Tel. (0)15 - 56 93 30 ext. 2041

TNO Corporate Communication Department
P.O. Box 297
2501 BD The Hague
Netherlands
Telephone 070 - 81 44 81
Telex 31660 tnogv nl

Organizational Structure TNO



INTRODUCTORY PRESENTATIONS

INTRODUCTION TO THE RIJKSWATERSTAAT

Mr. Albert Holland (Tidal Waters Division, Rijkswaterstaat, Middelburg, NL)

The Rijkswaterstaat (RWS) is the Public Works Department within the Ministry of Transport and Public Works. Within the RWS, the responsibilities for water and sediment pollution fall under the Inland Waters and Tidal Waters Divisions. These agencies have the jurisdiction over matters pertaining to the inland waters and estuaries of the Netherlands. The RWS conducts research into problems associated with the pollution of water and sediments including the extent of contamination, variation in space and time, and environmental effects. Various projects include studies of metal and organic contamination throughout the rivers, harbors, canals, sea arms, and estuaries in the Netherlands, and a Netherlands-wide project to classify sediment according to the level of contamination.

INTRODUCTION TO THE DELTA INSTITUTE FOR HYDROBIOLOGICAL RESEARCH

Dr. Marten Hemminga (DIHO, Yerseke, NL)

The Delta Institute (DIHO) was organized following the flooding in 1953, which resulted in severe loss of life in the delta areas near Rotterdam. DIHO addresses all aspects of hydrobiological research in the delta area, including pollution. The institute conducts multidisciplinary, long-term, field-oriented studies in aquatic and salt marsh systems. Three research groups address element cycling in food chains, estuarine ecophysiology, and salt marsh structure and function. Pollution research since the 1970's has been oriented towards radionuclides, heavy metals, and organics.
A major portion of recent research efforts has been in the Eastern Scheldt with projected future work to begin in the contaminated Western Scheldt.

INTRODUCTION TO THE WATERWAYS EXPERIMENT STATION

Dr. C.R. Lee (Environmental Laboratory, WES, Vicksburg, MS, USA)

The Waterways Experiment Station (WES) was organized following the flood of 1927 to address hydrological problems related to flood control in the lower Mississippi Valley. The WES today is comprised of six research laboratories: Hydraulics, Structures, Geotechnical, Weapons Effects, Environmental, and the Coastal Engineering Research Center. WES scientists conduct research in the areas of navigation, flood control, and water resources to support the needs of Corps of Engineer (CE) Districts, Divisions, the Water Resources Support Center, and the Office of the Chief of Engineers. The CE conducts a large portion of the maintenance dredging and has the responsibility for the permitting of all dredging and disposal operations in the United States.

Following the passage of the Clean Water Act of 1971, the Environmental Laboratory (EL) was created to address problems concerning the environmental impacts of waterway construction and maintenance, including dredging and disposal operations. Within the Environmental Laboratory, the Contaminant Mobility and Regulatory Criteria Group (CMRCG) evaluates the movement of sediment-bound contaminants and provides guidance on the potential effects of contaminated dredged material disposal in upland, intertidal, and open-water disposal environments. CMRCG scientists develop bioassays and models to predict the behavior of contaminants in dredged material and participate in the development of decisionmaking strategies and regulatory criteria for dredged material.

SITE VISITS

CALLEMANSPUTTEN DISPOSAL SITE

Ir. Y. Kreps-Heyndrikx (Ministry of Public Works, Ghent, Belgium)
Mr. R. Roman (Ministry of Public Works, Ghent, Belgium)
Ir. Bernard Malherbe (Harbour and Engineering Consultants, Ghent, Belgium)

The Callemansputten is a dredged material disposal site containing hazardous sediments from the Maritime Canal connecting Ghent with Terneuzen in the Western Scheldt. The site is a landfill occupying approximately 14 ha at a depth of 18 m. Because of the hazardous nature of the contaminants, the site is surrounded by a bentonite clay wall 80 cm thick extending down to the clay layer beneath the disposal pit. Mobility of pollutants to the surrounding is prevented mainly by groundwater flow management (inversion). (See paper by Kreps-Heyndrikx et al. for further information).

MARITIME CANAL GHENT-TERNEUZEN

RESEARCH PROGRAM FOR DREDGING, TREATMENT AND DISPOSAL OF CONTAMINATED MUD

Y. KREPS-HEYNDRIKX [1], R. ROMAN [2], B. MALHERBE [3], D. VANDENBOSSCHE [4]

ABSTRACT

Dredging and disposal of chemically contaminated mud out of the maritime Canal Ghent-Terneuzen, implies special care in order to limit or prohibit diffusion of pollutants to the surroundings.

A first research stage has lead to a realised isolated spoil dumping pit where diffusion of pollutants to ground water has been limited according to the results of a pre-investigation research program.

The second research stage, yet in execution has to study the possibilities of combining treatment of spoil to the dredging of it and see if no alternatives exist taking into account the criteria of technological and economical feasibility and ecological repercussion.

RESUME

Le dragage et le dépôt de boues polluées du canal maritime Gand-Terneuzen nécessitent des mesures spéciales afin de limiter ou d'empêcher la diffusion des polluants dans l'environnement.

Une première étape, déjà réalisée, comprend un puits de dépôt étanchéifié où la diffusion des polluants a été étudiée par un programme de recherche approprié.

La seconde étape qui vient de débuter, a pour but l'étude d'une combinaison possible d'unités de traitement au système de dragage et l'évaluation d'alternatives possibles en ayant des critères de faisabilité technique et économique et de répercussion écologique.

SAMENVATTING

De uitbaggering en de opberging van verontrinigde modders van het maritiem kanaal Gent-Terneuzen vragen bijzondere maatregelen om de diffusie van het verontreiningd materiaal naar te omgeving te vermijden.

Een eerste faze werd reeds tot stand gebracht: De diffusie van verontreinigd materiaal in een waterdichte afzettingsput werd bestudeerd door een aangepast studieprogramma.

Een tweede faze die zopas werd aangevat, heeft tot doel: de studie van een mogelijke eenheidskombinatie van de behandeling van een uitbaggeringsysteem en de evaluatie van mogelijke alternatieven mits technische, ekonomische en ekologische mogelijkheidscriteria.

[1] Chief Engineer-Director, Ministry of Public Works, Administration of Waterways, First Directorate of the Scheldt River Basin - Ghent.

[2] Principal Engineer, Head of Service, Ministry of Public Works, Administration of Waterways, First Directorate of the Scheldt River Basin - Ghent.

[3] Project Manager, N.V. Haecon, Consulting Engineers, Ghent.

[4] Technical Director, N.V. Haecon, Consulting Engineers, Ghent.

1. INTRODUCTION

The maritime canal between the Belgian inland port of Ghent and the sea channel of the Western Schelde at the Dutch city of Terneuzen is a key component in the prosperity of the region. The canal is capable of taking ships of up to 60,000 tons d.w. and is maintained at a depth of 13.5 m by dredging.

The maintenance of the canal requires the dredging of about 250,000 to 300,000 cubic meter of mud anually.

The catchment area and the banks of the canal are highly industrialised with a variety of heavy, chemical and petro-chemical facilities and both the canal water and the dredging spoil are contaminated with toxic chemicals.

Since the dredging and the disposal of the spoil is concerned by contaminated mud special care has to be taken for preventing the contamination of the surroundings.

This article presents the problem of the contaminated mud of the maritime canal Ghent-Terneuzen, the global research program and the already realised solutions for the disposal of the mud.

2. PROBLEM STATEMENT AND PRE-INVESTIGATION

Because of the need of dredging works, a set of 29 bottom-samples were taken in september 1977. The sampling sites were distributed regularly between the Dutch border and the town of Ghent (see figure 1 for general lay-out of the canal).

To determine the pollution degree of the canal-mud quantitative analyses were performed on the samples for:

a. anionic detergents
b. phenols
c. cyanids
d. hydro-carbons
e. metals (Fe, Mn, Cd, Cr, Cu, Pb, Ni, Hg, Zn, Na en Ca)
f. water content and density

On figure 2 the mean composition of the spoil to be dredged is illustrated, showing that :

1. ca. 8% of the dry material of the spoil are contaminated.
2. ca. 71% of these contaminations are caused by Fe.
3. ca. 20% of these contaminations are caused by Na.
4. ca. 8% of these contaminations are caused by heavy metals.

The table 1 below gives some comparitive analytical results between the canal-mud and the canal water.

Element	Analysed spoil-concentration milligram/liter	Analysed canal-water-concentration microgram/liter
Cadmium	0.06 - 10.9	0.4
Chromium	4.0 - 1273.0	3
Iron	3,000.0 - 61,000.0	462
Mercury		0.2
Manganese	52.0 - 3,583.0	650
Nickel	4.6 - 86.0	14
Zinc	15.0 - 4,633.0	64

Table 1 : Comparitive analytical results between Canal-mud and Canal water.

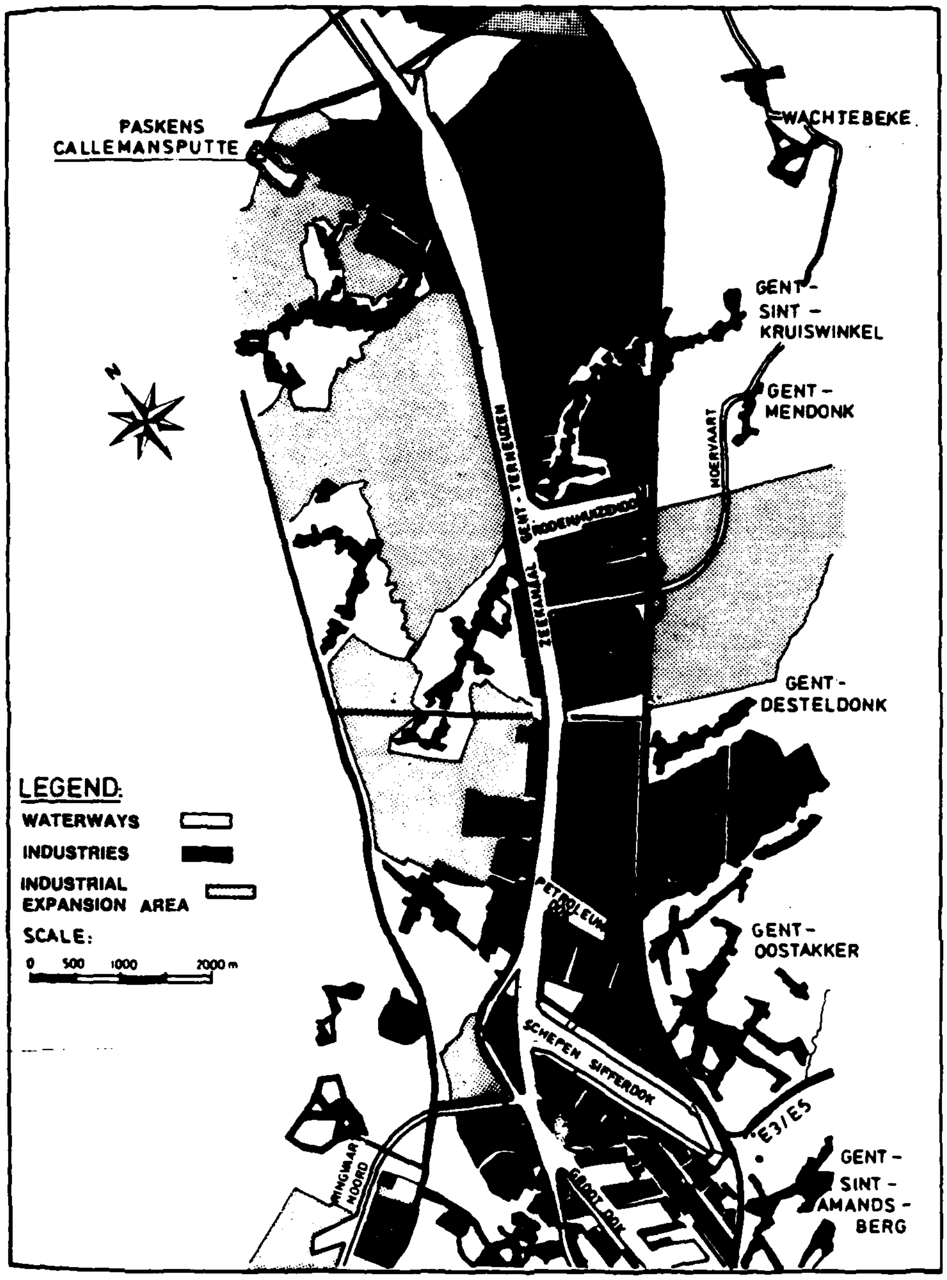


Figure 1 : General lay-out of the Maritime Canal Ghent-Terneuzen

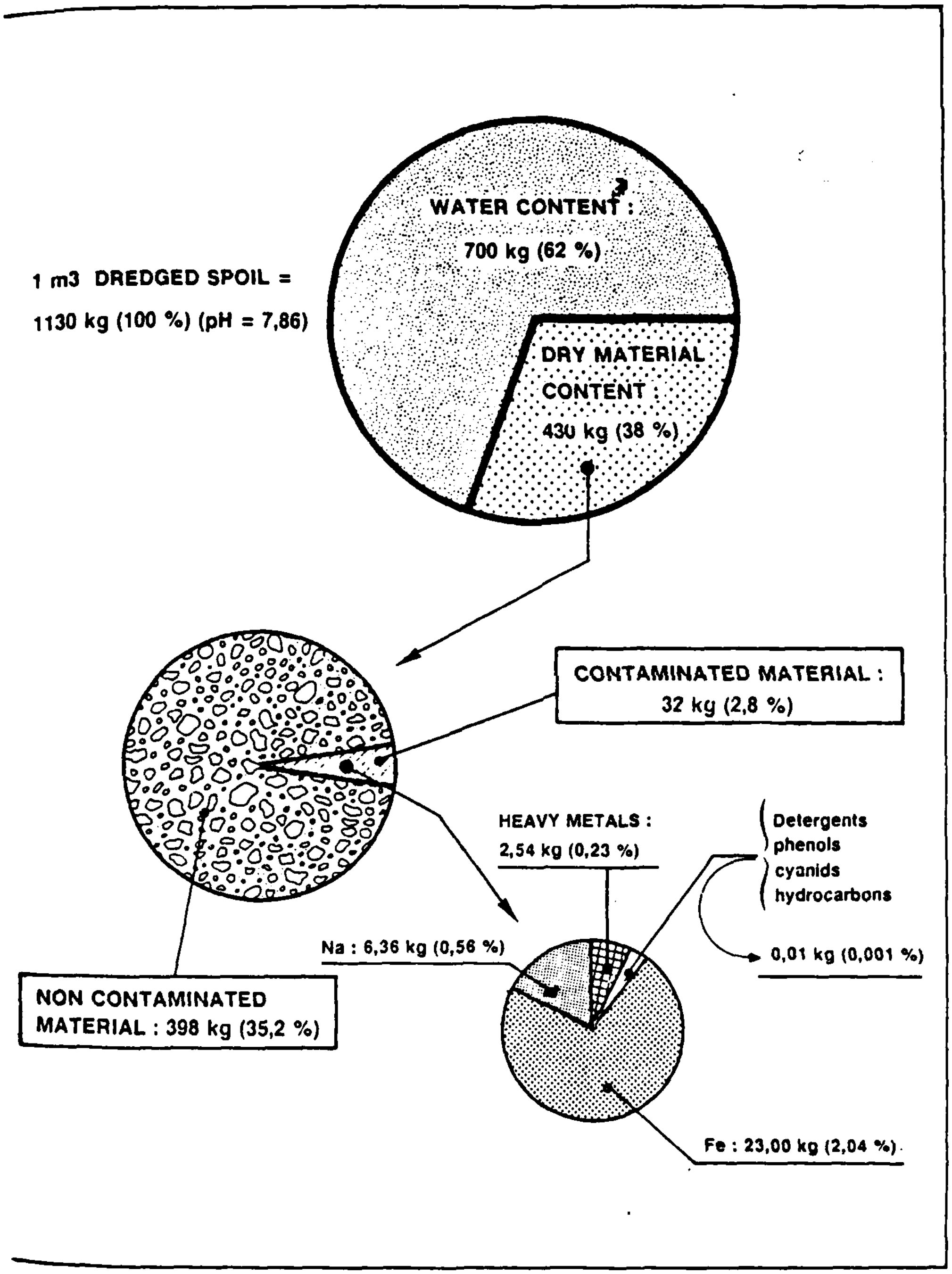


Figure 2 : Mean composition of dredged spoil

The results shown in table 1 show the very high distribution coefficients (ratio of spoil concentration to water concentration) of the pollutants; this means a relative preferential concentration of these contaminants in the Canal-mud itself.

A disposal of the dredged spoil on land by landfilling must take into account the fact that some of the contaminants may be transported via the porewater into the surroundings. In the development of the porewater chemistry in the depot three phases can be distinguished. These are an initial stage directly after filling where free oxygen might be present after being introduced by the pumping processes, a second phase where oxidising agents such as sulphates are still present and a final phase which is charactarised by a low red-ox potential and dominated by the presence of sulphides. Specially the long-term porewater composition is a a-priory unknown and has to be calculated. The calculation of this long-term porewater composition is rather difficult because of the complexity of the composition of an eventual depot or landfilling.

In this research stage it was decided to evaluate the distribution coefficients of the pollutants between solid material concentrations and pore-water concentration for the long-term phase by a chemically undisturbed sampling of a previously exploited landfill (the Sidmar site) containing similar spoil from the Canal. The results of these analyses are shown in table 2.

Element	Solid concentration mg/kg (dry)	Porewater concentration microgm/lt
Cadmium	10	0.4
Chromium	173	17
Iron	25020	1400
Mercury	3	0.3
Manganese	455	1040
Nickel	40	16
Zinc	1960	7

Table 2 : Analytical results of landfill spoil at the Sidmar site.

As can be seen by comparing the analytical results of canal-water (table 1) and pore-water (table 2) the concentrations are similar, although the sampling didn't occur at the same moment. One possible reason for this similarity could be that the canal is essentially a closed system, anaerobe and where the sludge and the water is continually mixed by the passage of large ships.

3. RESEARCH PROGRAM

The research program to develop a solution for the dredging and the disposal of this contaminated mud out of the Canal must be seen in 2 stages :

1. first stage for short-term solution whereby an isolated spoil dumping pit is realised.
2. second stage for long-term solution whereby the disposal of this contaminated spoil and the navigable depth in the Canal can be assured for the future.

Actually, the first stage is already realised at the site "Paskens-Callemansputte" in Zelzate; this will be described in more detail in the chapter 4 of this publication.

The second research stage has just begon as a study-contract since 1st July 1985. Some approach-concepts of this part of the research will be briefly exposed in the chapter 5 of this publication.

. FIRST RESEARCH STAGE : REALIZATION OF AN ISOLATED SPOIL DUMPING PIT

A combination of economic and environmental considerations lead to the decision by the Belgian authorities (Kreps-Heyndrikx & Roman 1981) to landfill the spoil at a specially excavated site located close to the canal near the town of Zelzate.

The site is indicated on the map of figure 1.

For geohydrological reasons a coring was performed on the site of "Paskens-Callemansputte"; the results of this are :

- from 0 m to 18 m below ground level : fine sand with some silty and shelly layers.
- from 18 m to 21 m below ground level : clayey sand.
- from 21 m to more than 40 m below ground level : clay.

The permeability coefficient of the clay layer was measured and reveals a value of 5×10^{-8} cm/sec. The fine sand is extracted and a disposal volume of 1,200,000 m^3 is realised; the surface area of the spoil dumping pit reaches so 14 ha.

A typical cross-section of the spoil dumping pit is illustrated on figure 3, where all the countermeasures are shown to prevent the migration of the contaminants from the landfill into the surroundings. These countermeasures are :

1. the construction of a cement-bentonite screen all around the excavation pit (screen : 0.6 m wide and 1.7 km long) reaching into the clay layer (screen-depth : 22 to 25 m); this construction realises in this way an isolated watertight pit (minimal permeability of the screen : 10^{-6} cm/sec.).

2. the cement-bentonite screen allows a certain degree of deformation without fissuration.

3. an open drainage or "ditch" collects the surface water between the screen and the pit to prevent surface water pollution; the water of the ditch is pumped via a closed pipe to the canal.

4. the dumping of the spoil is done below the water level in the pit to prevent air-pollution.

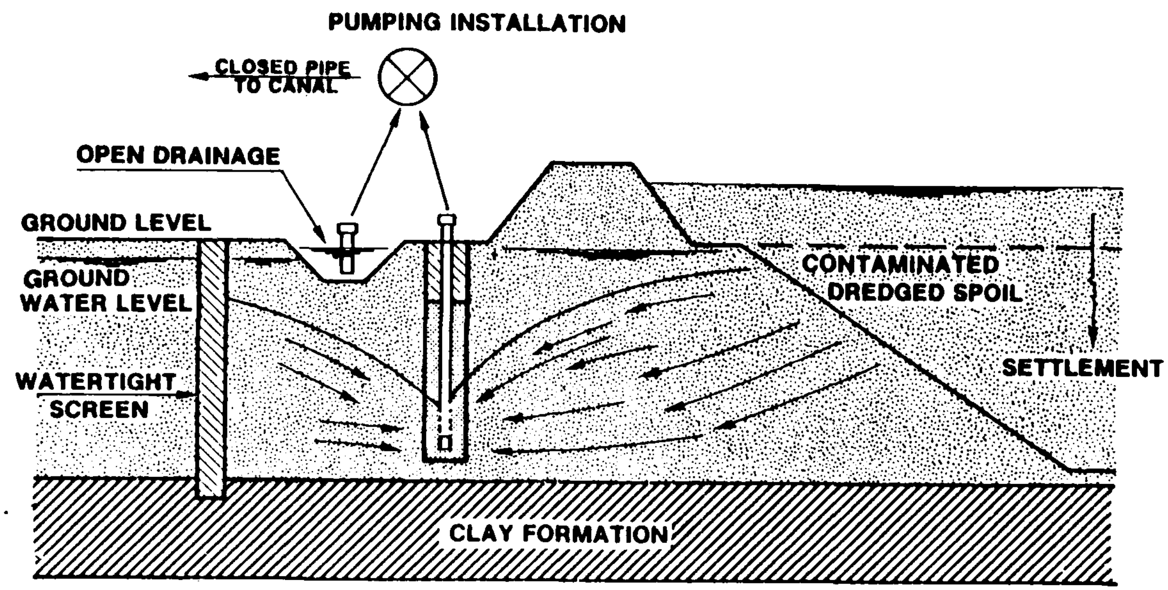


Figure 3 : Cross-sectional view of spoil dumping pit "Paskens-Callemansputte"

5. a pumping installation lowers the phreatic groundwater level down below the surrounding one between the ditch and the pit; this ensures a groundwater flow to the inside of the pit and helps to prevent convective-diffusive flow through the cement-bentonite screen.

6. a control program during which groundwater samples are taken after the spoil disposal; the sampling wells are both inside and outside the watertight screen and sample-analysis is done for pH, Cl^-, F^-, NH_3-N, As, Cd, Ca, Cr, Co, Fe, Cu, Hg, Pb, Mn, Mg, Mo, Na, Ni, Ag, Zn, K, nitrates, sulfates, ...

Although it was expected that these and other proposed measures would avoid any pollution problems arising from the site, responsible project management requires that this be quantitatively demonstrated.

The site is not capped and in the long term it is intended to incorporate it into the green-belt around Ghent (figure 4). Rain water will therefore enter the site throughout its entire existence. Some of this rainfall will evaporate, some will be taken up by the plant cover, and the balance will either have to be pumped off or will penetrate the screen and the deep clay layer to the surrounding or deeper aquifers. It is the volume and chemical quality of this water that has to be calculated in the safety assessment of the site.

The water flow pattern was calculated using a finite difference computer model (Loxham et al, 1984) and results of calculations are illustrated in fig. 5. As can be seen the major flux is to the overflow ditch. The water balance gives (in cubic meters/year) :

Rainfall on site	=	65350	100%
Evaporation and Plants	=	37350	57%
Input to site	=	28000	43%
Output to ditch	=	26040	40%
Output through clay	=	190	0.3%
Output through screen	=	1770	2.7%

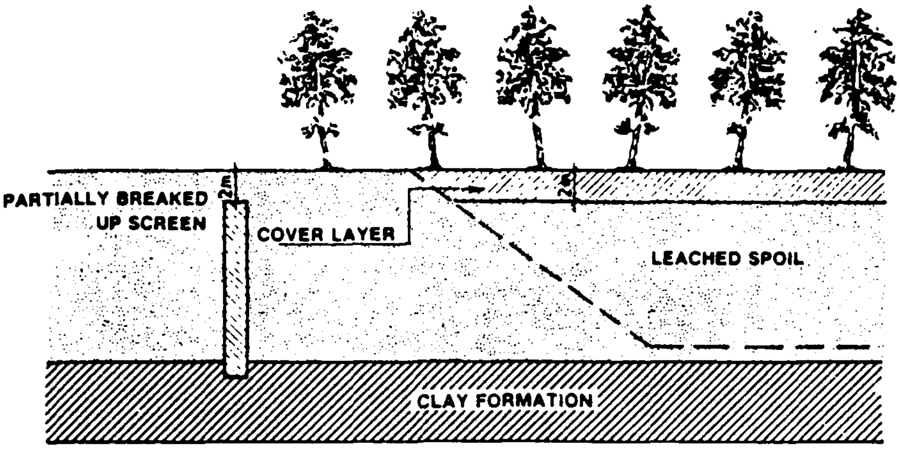


Figure 4 : Final destination of Paskens-Callemansputte

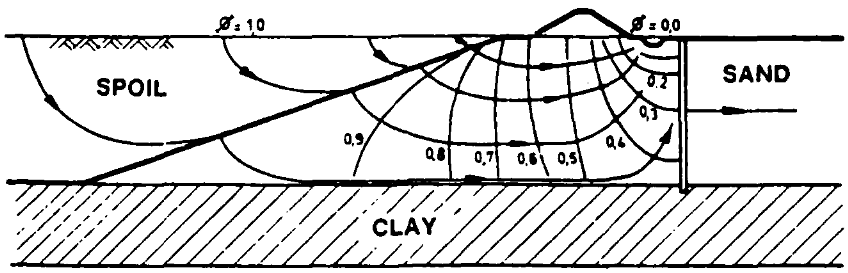


Figure 5 : Calculated water flow pattern
(after Loxham, Kreps-Heyndrikx et al, 1984)

The transport mechanisms considered in the analysis are :

1. Penetration of 300 mm of rainwater through the spoil to the overflow ditch.

2. Convective-diffusive flow through the cement-bentonite screen under the hydraulic head differential of a meter into the surroundings.

3. Convective-diffusive flow through the clay under the expected differential head of 2.2 meter.

Two situations can be distinguished. In the short term the spoil will be relatively permeable and the rainfall can penetrate deep into it and become itself contaminated. However in this phase it can also be assumed that the screen is intact and active control strategies such as holding the water level inside the depot lower than outside can and will be maintained. In the long term however this is less certain and worst case assumptions have to be made in the assessment.

In the event the calculations were made under the assumptions that although control of the water level in the depot would be lost almost immediately and would give rise to a convective driven flux to the surroundings, credit could still be taken for the action of the screen. The very long term situation in which the screen has deteriorated but the sludge itself consolidated has been discussed by Loxham en Weststrate (1983).

Because of the complexity of the composition of the depot considered, 2 methods are chosen to evaluate the long-term porewater composition (Loxham, Kreps-Heyndrikx et al, 1984).

1. The heavy metal concentrations in the porewater of the Zelzate site where then estimated assuming the same distribution coefficients as found in the Sidmar site. The results of this procedure are shown in table 3.

2. A second approach was chosen for the organics and the halogens chloride and fluoride. The values measured in the samples from the Sidmar site could not be extrapolated to the Zelzate landfill because it is unclear how much of these mobile ions have already been leached out. It has been assumed that all the chloride is dissolved in the porewater and that all the hydrocarbons are

dissolved to the maximun possible amount indicated by laboratory leaching studies. In this context it should be noted that there are at least three tons of detergents in the landfill.
The estimation of the concentration of fluoride in the porewater presented special difficulties. On the one hand fluoride is a highly mobile anion which can dissolve easily in water. If this were to be the case then the fluoride anion would be the critical species in the safety analysis. However there is a large amount of calcium in the dredged spoil so that not all of the 260 tons of fluoride in the depot need be in the dissolved form. The calculation is complicated in that the available calcium can be distributed over a wide range of other components.

Contaminant	Solid conc. mg/kg (dry)	Porewater microgm/lt	Toxicity
Cadmium	6	0.2	0.04
Chromium	590	59	1.2
Iron	46030	2560	12.8
Mercury	2	0.2	0.2
Manganese	1100	2600	2.4
Nickel	70	16	0.3
Zinc	2630	100	1.0
Chloride	1220	860 (mg/lt)	34.4
Fluoride	521	1500	2.1
Organics	17	(1000)	(100)

Table 3 : Contents of selected contaminants.

The spoil was pumped from a transfer point on the canal to the site using canal water. The excess water was returned to the canal. Once in the site the spoil settles out and consolidates. During this process the contaminants come to equilibrium with the porewater. For many pollutants such as heavy metals, phenols and pesticides for example the distribution between the solid phase and the porewater is such that almost all of the contaminant is associated the solid phase. The distribution coefficient, (ratio of solid concentration to porewater concentration, gm/gm:gm/ml) is often in the order of 10,000.

In the final column the so-called toxicity index is given (Haug 1976). This is the volume of clean water required to dilute one volume of contaminated solution to drinking water standards. As can be seen problems are to be expected with (dissolved) organics, manganese, iron, chromium, and the halogens fluoride and chloride. As these last two are the most mobile of the list and as the surrounding groundwater can only be polluted once, attention will be focused on these anions (second evaluation method).

In the second evaluation method (calculation of contaminant fluxes) the porewater compositions as given in table 3, are used as the starting values to calculate the contaminant fluxes of the halogens fluoride and chloride, using a 2-dimensional finite difference approximation to the classical convection-dispersion equation (see for example Bear 1972 for a presentation of this equation).

As is to be expected considering the dominant water flow to the drainage ditch most of the contaminant leaving the site does so via this route. Approximately 90% of the chloride is washed out of the site by rainfall to the ditch. A similar figure is found for the dissolved fluoride and organics. However where as the chloride is more or less leached out in 50 years the other components continue to dissolve into the incoming porewater and reduce the quality of the ditch water for long periods of time.

From an environmental stand point however, it is the flux to the surrounding soils through the screen and through the clay layer that are of importance. In fig. 6 the fluxes of chloride, fluoride and organics from the whole site are shown. The results in fig. 6 are based upon calculations in which the porewater initially in the embankments is assumed to be clean. The contaminant must first of all displace this water before it can come to the screen to start its transport to the surroundings. This however takes time and whilst this is happening the contaminants can disperse into the water on the more dominant flow patch to the ditch. This combination of mechanisms leads to the results shown; i.e. a developing period followed by a steady state period.

However for chloride the steady state period never fully develops because the inventory of chloride in the site becomes depleted on approximately the same time scale. For the other components the inventory is so large that this effect does not occur.

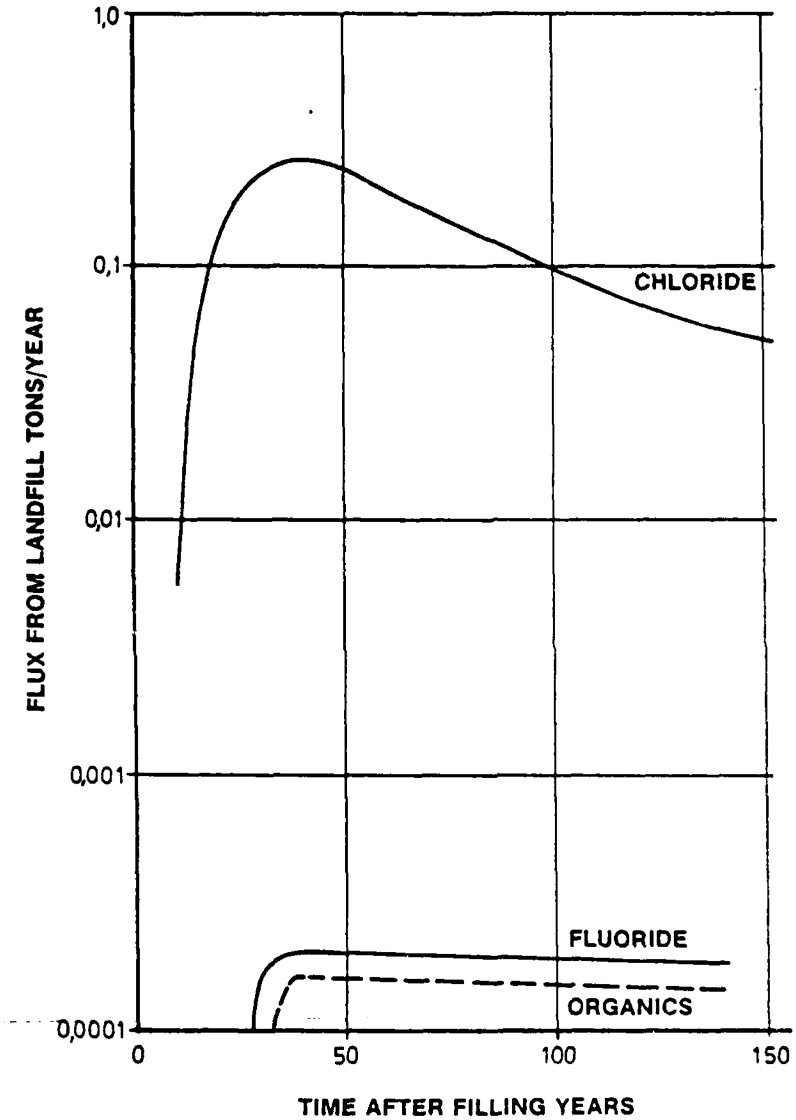


Figure 6 : Calculated emissions from landfill

Larger emissions are found for the case where the depot is first drained and then filled with spoil. In this case the porewater can be found immediately in the vicinity of the screen and the process of diffusion and convection can start at once.

In both cases however the fluxes are small compared to those that would have occured if the screen had not been installed. This is illustrated :

Total chloride in landfill = 600 tons.
Lost to surroundings :
a. without screen = 600 tons.
b. with screen = 8 tons.

For the other components a similiar picture emerges.

The emission through the clay layer shows a similar pattern although the fluxes are much smaller.

It can be concluded that on the basis of this study even the most contaminated spoils can be safely landfilled whithout endangering the surrounding soil and groundwater quality.

5. SECOND RESEARCH STAGE : LONG-TERM SOLUTION FOR THE DISPOSAL OF CONTAMINATED MUD

Since this part of the research program has just started, results can't yet be presented. However, in this chapter a short general idea will be described which is the guideline for this second research stage.

The purpose of the research is to look for a combined system for dredging, treatment and disposal of contaminated mud. This system will be analysed with criteria of :

a. technical feasibility
b. economical feasibility
c. ecological and environmental repercussion

Every system of combination of systems has to be taken into account in this evaluation, since it seems that the mud pollution in the Canal may be very different from place to place.

Furthermore the isolated spoil dumping pit "Paskens-Callemansputte" has a disposal capacity for some maintenance years left, and must therefore be optimised for the future.

Two types of systems can be considered :

a. systems where the mud is dredged and where a pollution-monitoring pilots the contaminated spoil to a treatment plant; the treatment residu and the uncontaminated mud can then be dumped on their respective disposal areas.

b. systems where the mud is treated in-situ to enhance the fixation of the contaminants to the mud itself, followed by an disposal of this conditioned mud.

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INTRODUCTION TO THE WESTERN SCHELDT

Dr. Speksnijder (Rijkswaterstaat)

The Western Scheldt is a tidal marshland extending from the River Scheldt to the North Sea. The estuary has been polluted by domestic and industrial discharges flowing into the River Scheldt and the streams and canals bordering the upper portion of the estuary. Monitoring studies indicated a range of contaminants, especially metals, from the river to the mouth of the estuary and crossing international borders. The contamination is thought to be responsible for the decline in productivity (especially shellfish) throughout the Land van Saeftinge.

Mr. van de Wiel ("Landscape of Zeeuws-Vlaanderen")

The workshop participants visited the "Drowned Lands of Saeftinge", a natural estuary of the Western Scheldt, which was diked to protect the surrounding lands from tidal innundation during very severe storms in the North Sea. In this estuary are numerous natural dikes formed by overflow from the channels onto the higher areas, where the sands are deposited. The channels winding throughout the estuary contain contaminated sediments. The Land van Saeftinge now is a protected nature preserve.

SASSENPLAAT DREDGED MATERIAL RESTORATION ISLAND

Dr. Jos Kuijpers (Rijkswaterstaat, Dordrecht, NL)

The Sassenplaat (at Moerdijk) had existed since 1944 as a sandbar and was a freshwater estuary until 1970. The original sandbar was excavated to provide room for a ship canal. A small portion of the original sandbar remains in a natural state, whereas the remaining portion created with dredged material has been managed to prevent being overtaken by the willow trees. Today the site contains Class 3 dredged material of a sandy nature with 3 to 5 ppm Cd. Egyptian geese, mallards, and mute swans are abundant here. An experiment to establish bulrushes (*Scirpus lacustris*) failed due to grazing by the geese and swans until wire was put down to prevent feeding on the roots.

Storm-surge barrier information centre

1985/1986 season exhibition

1 The 1953 flood disaster

For centuries the people of the Netherlands have been fighting to keep out the sea. During the night of 1 February 1953 the battle erupted once again in all its fury. Large areas in the south-west were flooded; 1835 people were drowned and others lost all they possessed. The shading on the map indicates the flooded areas.
Major breaches in the dykes are also shown.

2 The original Delta Project

The disaster called for immediate and decisive action. Once the dykes had been resealed and their weakest points reinforced, all efforts were directed to carrying out the Delta Project. With the exception of the Western Scheldt and the New Waterway, which have to be kept open for shipping, the inlets were all to be sealed off. Modern technology and dam construction methods made the project a success. Roads were constructed across the new barriers to link the Delta area with the rest of the Netherlands, while lakes of salt and fresh water formed on the landward side of the dams. Now, over thirty years after the disaster, the entire project is nearing completion.

3 Implementation of the original Delta Project

The first stage was the construction of a storm surge barrier made up of two sliding steel gates in the Hollandse IJssel. Large sluices were installed in the Haringvliet Dam to improve water management in the northern part of the Delta region. But before the Veerse Gat, the Haringvliet and the Brouwershavense Gat inlets could be finally sealed, dams had to be built inland in the Zandkreek, the Volkerak and the Grevelingen so as to prevent strong currents causing damage further inland.

4 The debate on the Eastern Scheldt

In the original Delta plan the Eastern Scheldt was to be sealed off by means of a solid dam. Work was begun in 1968, but the idea encountered growing resistance, particularly from environmental groups and the fishing industry. In 1974 the Government decided to commission studies to find an alternative solution to the problem of the Eastern Scheldt.

5 The final decision taken in 1976

In 1976 the Government took the final decision on the Eastern Scheldt problem. This involved:

- constructing a storm surge barrier in the mouth of the Eastern Scheldt;
- constructing two compartmentation dams, the Philips dam and the Oester dam (with the Marquisate dyke);
  freshwater lakes will be formed on the landward side of these;
- excavating the Bath discharge channel to carry fresh water from the more easterly of these lakes into the Western Scheldt;
- improving the South Beveland canal. The locks at Wemeldinge will then be abandoned and new locks will be constructed at Hansweert;
- raising the dykes on the banks of the Eastern Scheldt to provide flood protection while work is in progress. The latter works have now been completed.

6 The final stage

The mouth of the Eastern Scheldt, showing the channels, the construction islands and the storm surge barrier.

[illegible] Deltadienst
[illegible] Rijksvoorlichtingsdienst
[illegible] Bruns
[illegible]
[illegible]
[illegible] Reprografie

7 **The principle of the storm surge barrier**
65 pre-fabricated concrete piers were placed on foundation mattresses in the three channels in the mouth of the Eastern Scheldt. Steel gates will be suspended between them, which can be closed at dangerously high tides. Under normal circumstances the gates will be kept raised, maintaining the difference between high and low tide at roughly three quarters of its former range.

8 **Longitudinal sections of the three channels**
The horizontal scale has been made much smaller than the vertical scale for the sake of clarity. The drawing clearly shows that the piers and gates in the centre of the channels are higher than those near the banks. The smallest gates are 5.90 m in height while those in the middle of the Roompot channel measure 11.90 m. This follows the natural contours of the channel bed.

9 **The cost of the Eastern Scheldt project and its benefits**
The original estimate for the entire project (the storm surge barrier and additional construction work) amounted to Fl. 5.0 billion at 1976 prices. Adjusted for inflation, this had risen to Fl. 6.7 billion by 1-1-'85. However, various circumstances have led to increased costs, which could not be entirely offset by economising on the project, and these have, as of brought the total estimate up to Fl. 7.6 billion, which exceeds the index-linked estimate by approximatel 13%.
About 95% of this sum has now been spent.
On the credit side, the project has benefits, of course, although these cannot be expressed in monetary terms.
They include:
a. protection against flooding
b. preservation of a salt water tidal environment in the Eastern Scheldt
c. the survival of the oyster and mussel farming industry
d. employment for large numbers of people in carrying out the project
e. the development of new engineering techniques which will benefit exports.

10 **Construction stages**
1. The foundation is compacted and accurately dredged to the correct level after which the foundation mattresses are laid.
2. The piers are positioned by the lifting vessel.
3. The base of the pier is firmly embedded in several layers of stones.
4. The road bridge box girders are positioned.
5. The front of the piers is lengthened to take the gate suspension. The gates are then placed in position.
6. The concrete transverse beams complete the storm surge barrier.
7. The storm surge barrier is operational (date 1986).

11 **Use and management of the storm surge barrier**
The gates will be lowered to close the barrier at exceptionally high tides. A number of important questions will be taken into account in deciding whether to close the barrier: How severe is the storm and how high will the tide be? How long should the gates remain closed? What should the water level be inside the gates if the effects are to be least harmful to the dykes and the environment?

It also has to be borne in mind that closing the barrier creates a constant water level in the Eastern Scheldt accompanied by high waves which could damage the edges of sandbanks and mud flats. However, this situation would not usually last longer than one tide. During longer periods of stormy weather the barrier may be partly opened to ensure continued tidal movement with low high-water levels in the estuary.

The barrier could also be used, for example, if the dykes were breached or oil were discharged into the sea.
Extensive studies are being conducted to work out strategies for opening and closing the barrier.

12 **Sand deposits in the seabed**
The strength of the current varies. There is a period of about an hour around the turn of the tide when the force of the current is at its lowest, and this time has to be used to carry out certain operations such as the positioning of foundation mattresses or piers. In slack water, however, the sand that is normally carried along by the sea may be deposited, and it had to be syphoned off before mattresses or piers can be put in position, as layers of sand must not be allowed to collect between the component parts of the dam.

13 **Compacting the seabed**
As the storm surge barrier required a firm foundation, the first step was to remove poor soil strata, replacing them with sand. In order to prevent loosely packed sand from shifting, it was compacted by a specially built vibrator vessel, the „Mytilus". This packed the grains of sand more closely together, thus reducing the space for water between them and increasing the bearing capacity of the seabed.

14 **Foundation mattresses prevent the sand being washed away from under the piers**
To stop the sand being washed away from under the piers the seabed under the axis of the barrier was covered with a double layer of foundation mattresses. The lower one acts as a filter and consists of layers of sand, coarse gravel and fine gravel within a polypropylene cover. The mattresses are 200m long and 42m wide, and are protected from possible damage by smaller mats measuring 30m by 60m which are filled with gravel. All the mattresses were manufactured at a factory on the construction island and were lowered into position by the pontoon „Cardium".

15 **Tile mats**
Any unevenness in the foundation mattresses could be levelled out by mattresses consisting of concrete slabs varying in thickness from 15cm to 60cm. They were laid on the seabed by the pontoon „Donax". The foundation mattresses are positioned so accurately that it has very seldom been necessary to employ this method of correction. Once the piers are in position the current begins to accelerate. To ensure that the stone filling in the seams joining the foundation mattresses is not washed away the seams are protected by gravel mats which were manufactured on shore and unrolled on the seabed by the „Sepia".

16 **Polypropylene scour protection mats**
Once the barrier is completed the maximum speed of the current in the axis of the channels will increase from 1.5 metres per second to 4.5 metres per second. To prevent erosion, a section of the seabed 650m wide on both sides is covered by scour protection mattresses. These used to be made solely of osiers and reeds with loose stone dumped on top. However, since 5 km² of the bed of the Eastern Scheldt had to be covered, a new method was devised. The new scour protection mats are made of synthetic woven polypropylene with solid concrete ballast and were manufactured in a factory on North Beveland. They are 30m wide and have a maximum length of 260m. Similar techniques have also been used elsewhere in the Eastern Scheldt but with asphalt as the ballast.

17 **Closing the barrier**
When an extremely high tide is expected the 3 channels in the mouth of the Eastern Scheldt will be closed by means of the 62 steel gates in the barrier. There are 15 gates in the Hammen, 16 in the Schaar van Roggenplaat and 31 in the Roompot. Each gate is raised and lowered by means of two hydraulic cylinders. The 124 cylinders enable the 62 steel gates to close the mouth of the Eastern Scheldt completely within about one hour (approx. 18 cm/min.). Re-opening the channels takes the same length of time. To move the gates oil is pumped to the hydraulic cylinders by electrically driven pumps housed inside the box girders of the road bridge. When oil is forced above the piston, the gates are lowered; to raise the gates oil is pumped in below the piston.

18 **Structure of gates and hydraulic cylinders**
The gates are approx 41 metres wide and 5.40 metres thick and their heigt varies according to the bed profile, ranging from 5.90 to 11.90 metres. The weight of the gates varies from 260 to 480 tonnes.
The principal elements of the gates are a bearing structure of steel tubes, ranging from 5 to 81 cm in diameter, and plating 1 cm thick. The gates are assembled in Zwijndrecht.

The main elements of each hydraulic cylinder are a cylinder casing (diameter 5 to 90 cm) and a piston rod with piston. The smallest cylinders weigh 45 tonnes, the largest 100 tonnes. Fully extended they vary in length from 21.9 m to 34.6 m. To allow for any irregulations in the positioning of the piers the cylinders are hinged to the gates and attached to the piers.

The cylinders are assembled in Rotterdam and Hengelo. Both the gates and the cylinders are transported to the Eastern Scheldt by means of pontoons and tugs.

19 **The stone sills between the piers**
A sill of graded layers of stone, increasing in size as they work upwards, is constructed at the base of the piers. Each layer thus keeps the one below in its place. The largest stones are placed under water very carefully using a specially built crane. The stone was imported from Scandinavia and Germany.

20 **1:1000 scale model of work in progress**

21 **Seabed improvement**
The bed of the Eastern Scheldt under the storm surge barrier has to have an enormous bearing capacity, and poor foundation layers have therefore been dredged and replaced by better quality sand.

22 **The seabed compacting rig „Mytilus" (mussel)**
The bed has been further strengthened by compacting it to a depth of about eighteen metres to ensure that the sand has sufficient bearing capacity. This was done using a specially built vessel fitted with four steel vibration tubes. The tubes were inserted into the ground and then slowly withdrawn (over a period of several hours), vibrating all the time; this increases the density of the loose sand and thus its bearing capacity.

23 **The mattress positioning pontoon „Cardium" (cockle)**
The seabed has been protected from erosion by filter mattresses made up of layers of sand, fine gravel and coarse gravel, packed in polypropylene covers. A second mat was laid on top, filled with gravel. The seabed was first levelled by the „Cardium's" extra wide suction nozzle before the vessel rolled the mats into position.

24 **The asphalt laying barge/stone dumper „Jan Heymans"**
Gravel and stone were deposited in the seams between the mattresses. The asphalt laying barge „Jan Heijmans" was fitted with stone dumping equipment for this purpose. These deposits were then covered with steel cable mats weighted by gravel ballast.

25 **The block mattress pontoon „Donax"**
If the foundation mattresses proved to be uneven, this could be corrected by laying mats of concrete slabs, varying in thickness from 0.15 to 0.60 m. These were positioned by the "Donax". However, the foundation mattresses were usually positioned so accurately that the use of the block mattresses turned out to be a rare exception.

26 **The lifting, transporting and positioning vessel „Ostrea" (oyster) and the mooring and cleaning pontoon „Macoma" (a type of mollusc).**
A special lifting vessel was built to transport and position the piers, each of which weighs approximately 18.000 tonnes. It was shaped like a horse shoe, and was fitted with heavy grabs and tackles to lift a pier a few metres from the bed of the construction dock. Assisted by tugs and the tide, the „Ostrea" then sailed to one of the channels, where it was secured to the „Macoma" which had been manoeuvred accurately into position in advance. Once any sand had been removed from the foundation mattresses by the suction equipment on the Macoma, the pier was positioned on the mattress at low water.

27 **The top layer dumper „Trias"**
At the base the piers are secured in a number of layers of stone. The smallest stones in the lower layers are dumped by dumpers and grabs. The largest stones, each of which weighs several tonnes are positioned by a specially adapted crane on board the pontoon „Trias".

28 **The floating derek „Taklift 4"**
The remaining sections of the barrier, such as road bridge box girders, pier abutments, gates and sill beams, are positioned using huge sheerlegs.

29 **Construction, transport and positioning of the piers**
The concrete piers were built in construction docks on the construction island. Once all the piers in a dock were completed, the dock was flooded and the ring dyke partially dredged away. The Ostrea could be floated in to lift the piers one by one and take them to their final destination in the channels. Once it had arrived the Ostrea was moored to the Macoma which had already been manoeuvred into position.
The suction nozzle of the Macoma removed the sand and had settled on the foundation mattresses whereupon the pier was lowered on to the seabed.

30 **Construction of piers**
The piers were built in three construction docks on the artificial island Neeltje Jans. The floor of these docks lies 15 metres below sea level. Construction started in March 1979, the last pier was completed in March 1983. Meanwhile the water was readmitted to the docks and a channel was dug to the Oosterschelde so that piers could be transported to their final destinations. The average weight of a pier is 17.000 tons and it contains about 7.000 cubic metres of concrete and in total 450.000 cubic metres for all piers. The base slab of a pier measures 25 x 50 metres, the height varies from 34 to 40 metres depending on the pier's position in the channel.

31 **Construction of other concrete components**
Besides gates and piers the storm-surge barrier consists of capping units (1), road box girders (2), sill beams (3) and upper beams (4).
The sill beams were built in a construction dock on the artificial island. The other components were manufactured at Kats on North-Beveland, where the elements of theZeeland bridge were built between 1962 and 1965.

32 **Finishing the storm-surge barrier**
With the large floating derek, Taklift IV, the components were put into their place.
First the piers are heightened with the capping units varying in height between 4.30 and 10 metres.
The cylinders of the lifting mechanism will be attached to the capping units. Then the road box girders will be placed, followed by sill beams and upper beams.
The sill beam with a height of 8 metres, a width of 9 metres and a weight of 2800 tons determine the size of the opening between the piers and serve as a base for the closed gates.
The upperbeam is 4.80 metres high, 6.30 metres wide and weighs 1200 tonnes. The top of the beam is 5.80 metres above Amsterdam Ordnance Datum which is therefore the highest water level against which the barrier provides protection.
When all components have been placed, the road box girders will be widened 5 metres on both sides, so that a two-lane road and a road for service-purposes can be made. The road will be opened in the summer of 1987.

33 **Lock for shipping**
Now that work is in progress in all three channels of the Oosterschelde the passage to and from the Oosterschelde is blocked.
A shipping lock (Roompot lock) has been built at the southern tip of the artificial island to allow shipping necessary for the work to get through. The lock is 100 metres long (net length 95 metres) and 16 metres wide and has a sill depth of 5.70 metres below Amsterdam Ordnance Datum. The locks will be closed by means of rolling lockgates.
In February 1984 the lock was opened and it is the only open passage between the Oosterschelde and the North Sea. All other shipping has to use it as well. Traffic will cross the lock over a fixed bridge at a height of 21 metres above Amsterdam Ordnance Datum.

34 **The service building for control and maintenance of the storm surge barrier**
On the north western tip of the artificial island Neeltje Jans the service building has been built which houses, offices, control rooms, workshops and storage required to operate and maintain the barrier. The building will also contain 10 diesel generators able to generate all the electricity needed to close all the gates at the same time.
The two upper floors will accommodate a permanent information centre, where an exhibition will illustrate the Delta Project and its significance for the south western part of the Netherlands. This centre will open in 1986. The present information centre and the information centre of the Haringvlietsluices will be accommodated here.

35 **Measuring and inspecting work on the seabed**
The work vessels are directed into position from measuring vehicles on shore using laser position fixing equipment. It is difficult for divers to inspect work on the seabed because of turbid water (reducing visibility to 30 cm) and fast currents. The underwater inspection vessel „Portunus" was therefore developed. It used special equipment to trace imperfections under the piers that are already in position. Work on the seabed could also be carried out in an oxygen-filled submersible chamber.

36 **The weather forecast for 31 January 1953**
Meteorological office weather forecast as broadcasted by radio on Saturday, 31 January 1953, preceeding the floods.
08.15 hrs: all areas: wind force 7; westerly
09.30 hrs: all areas: gale warning; west-northwest
17.00 hrs: all areas: strong gales; west-northwest
17.15 hrs: the weather forecast:
„Northern and Western North Sea: strong westerly-northwesterly gales imminent, spreading to south and east later, persisting all night. Dangerously high tides at Rotterdam, Willemstad and Bergen op Zoom".

37 **A special office of the Royal Netherlands Meteorological Institute provides weather reports for the project 24 hours a day.**

38 **Data on wind and currents**
A close network of wind and tide measuring posts, wave measuring buoys and current direction and speed measuring instruments ensure a constant flow of data.

39 **Monitoring sea conditions during construction of the storm surge barrier**
A special division of the Delta Project department is responsible for hydraulic monitoring while the barrier is under construction. The movement of sand and the velocity of currents are measured from ships using the most modern precision equipment. The direction and speed of currents are recorded by anchored buoys fitted with measuring apparatus and echo sounders are used to determine the depth of the seabed.

40 **Future functions of the artificial islands**
One opted for a plan in which recreation, fishery, nature as well as informative expositions are represented.
Only daytime recreation is taken into consideration.

41 **Policy plan for the Eastern Scheldt**
The Eastern Scheldt Study Group was set up in 1977 to hold consultations and issue advice on the design and management of the Eastern Scheldt area while work was in progress and after the project had been completed. The Group consists of representatives of central government, provincial and municipal authorities and water boards. Its policy plan for the period until 1990 was approved by central government in 1982 and adopted by the Zeeland provincial executive. A copy of the plan is for sale at the desk.

42 **The principal functions of the Eastern Scheldt area**
The Eastern Scheldt is regarded as a nature conservation area, parts of which may also be used - with proper care - for other purposes. Nature is given the highest priority, followed by fishing, recreation and shipping. Policy may be adjusted annually on the basis of research and developments in society.

43 **The Environment**
Life in the Eastern Scheldt is an illustration of the natural process of eating and being eaten.

A knowledge of the tides, temperatures and salt content is just as important as a knowledge of the feeding patterns of living creatures.

44 **The salt water tidal system**
The Eastern Scheldt will continue to be one of the two salt water tidal systems in the Delta area with its own unique flora and fauna which have adapted to the ebb and flow of the tides. The highest parts consist of saltmarshes covered by vegatation and criss-crossed by a dense network of creeks. Mud from which the water recedes at low tide is found between the high and low water line and shelters vast numbers of creatures such as lug-worms and shellfish.

They are an important source of food for birds at low tide and fish at high tide. Mussel banks, which accommodate a rich variety of animal life, occur on the borderline between mudflats and channels.

Many species of fish are to be found in the deep channels, and organisms such as sea anemones and sponges, which thrive on rocky coasts, live on the stone-faced slopes along the dykes and breakwaters.

45 **Fishing**
One tenth of the Dutch fishing industry is concentrated in the Eastern Scheldt. Closure of the Eatste-n Scheldt would have meant the end of the mussel and oyster industry and of the lobster trade, resulting in the loss of hundreds of millions of guilders and a rise in unemployment.

The Eastern Scheldt is also an important breeding ground for many other species of fish which live in the North Sea such as sole, plaice and shrimps.

46 **Changes brought about by the Eastern Scheldt project**
The storm-surge barrier now under construction in the mouth of the Eastern Scheldt will reduce the difference between high and low tide to three-quarters of its present level (2.70 m instead of 3.40 m). As a result water will no longer wash over the highest parts of the saltmarshes and the vegetation will therefore change. The lowest levels of mud will no longer be exposed at low tide, thus reducing the feeding grounds for birds.

The construction of the compartmentation dams will also lead to a reduction in the area of saltmarshes and mudflats, since 20% of it is situated on the landward side of the dams. Plant and animal life will change completely in this sector.

Surface area now and after 1987

	Eastern Scheldt now	Eastern Scheldt + freshwater lake after 1987
saltmarsh	1 440 ha	600 ha
mudflats	16 800 ha	9 600 ha
water	26 760 ha	25 100 ha
reclaimed land	—	9 700 l.a
	45 000 ha	45 000 ha

47 **Water quality control**
Measuring vessels and helicopters take water samples which are laboratory tested to ascertain their oxygen, salt and nutrient content. The results will help us to understand how life in the Eastern Scheldt is likely to develop in the future and will enable measures to be taken to ensure that a healthy environment is preserved.

48 **Environmental research/seabed fauna**
Because of the reduction in the current velocity in the Eastern Scheldt suspended particles will sink to the bottom, making the water clearer but at the same time depositing additional sludge here and there on the estuary bed. How will the organisms living in the water react to this change? Research into seabed conditions and seabed fauna will help to answer this question.

49 **Environmental research/saltmarshes**
The change in tidal movement will also affect plant life on the saltmarshed. Higher-lying parts will be flooded less frequently by salt water from the estuary but will be more exposed to rainwater. Plants which require a saline environment will therefore be confined to the lower-lying parts and freshwater species will become established higher up.
Research will help to understand changes in the processes of growth and erosion.

50 **Enviromental research/bird life**
Birds are attracted to areas with plentiful supplies of food. As the Eastern Scheldt is rich feeding ground it is also an area of international significance for birds: various species spend the winter there and migrants use it as a staging post. The low-lying meadows between the two lines of dykes along the estuary are particularly popular as breeding grounds.

ROTTERDAM DISPOSAL SITE (SLUFTERDAM)

Drs. Hans Nijssen (Public Works of Rotterdam, NL)

Contaminated (Class 2 and 3) dredged material from the Rotterdam harbor area currently is being placed into a temporary disposal area. The Slufterdam disposal site is now under construction and will extend to approximately 28 m below sea level and will be surrounded by a dike extending to about 20 m above sea level. Because of the expense of designing such sites as this, no more are planned for construction. Future disposal will have to be in the sea or in upland areas. Consequently, there are needs to both clean up the silts in the harbor and to develop proper guidelines for disposal. Future contamination of the sediments must be avoided by limiting discharges.

ABSTRACTS OF SCIENTIFIC PRESENTATIONS

Observations on soil fauna return and metal mobility at an afforested area of a disposal site of harbor-dredged sediment (Broekpolder)

Dr. Wei-chun Ma

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Studies are presently in progress at RIN to investigate the degree of soil fauna return at an existing site (Broekpolder) containing harbor-dredged material over an area of about 450 ha. Since almost 20 years of its establishment this site now has a surface layer of ripened sediment of about 5 to 7 m thickness belonging to the so-called Class 3 type of polluted sediment. The Broekpolder is ultimately destined for afforestation and recreational purposes.

The soil fauna colonizing an afforested subsite of about 2 ha was investigated. This subsite has been planted in 1970 with five main tree species, including ash, maple, oak, elm and poplar, together with alder and several shrub species. Sampling of the surface-active soil fauna was done using pitfall trapping while soil-inhabiting species were sampled by hand-sorting of soil cores. In addition, vertebrates were sampled using both snap-traps and pitfalls. The surface-active soil macrofauna included Diplopods, Isopods, Collemboles, Coleoptera, Opiliones and Gastropods. Among the soil-inhabiting species Lumbricids and Dipteran larvae (Tipulids) were abundant. However, the species composition of the soil invertebrate fauna in general showed a still poor species diversity. Chilopods, for example, and several common species of collemboles and isopods were found lacking in the samples. Among vertebrates woodmice (*Apodemus sylvaticus*) and toads (*Bufo bufo*) were common. Other species such as shrews, however, were rare or absent both inside as well as outside at the edges of the subsite. The regular outbreaks of Tipulids suggested that the soil ecosystem is still rather unstable, possibly due to a relative lack of predatory species.

Metal analyses in earthworms (*L. rubellus, L. castaneus* and *Dendrobaena octaedra*) sampled at the subsite showed elevated concentrations of cadmium but not of lead. Both metals were found at highly elevated concentrations in the soil, however. A similar difference in metal accumulation was observed in kidney and liver organs of woodmice suggesting a low bioavailability of lead at the subsite. It is intended to continue these investigations in a long-term monitoring program to study soil ecology and metal mobility at afforested sites established on contaminated harbor-dredged sediment.

The Broekpolder - Rotterdam

Drs. Hans Nijssen (Public Works Department, Rotterdam, NL)

The Broekpolder was used as a dredged material disposal site to the City of Rotterdam from 1959 to 1976. The polder was divided into sections with canals to provide drainage. The initial thickness of the dredged material was about 1 to 1.5 m. The density has increased with time, however. To encourage drainage and consolidation, drains were installed. After about 1 to 2.5 years of ageing, a 1.5 m thick layer of dredged material consolidates to about 0.1 m. In 1970, local anthorities became aware of the contaminant problem in the Broekpolder. Under the present system of sediment classification, Broekpolder dredged material is largely Class 3, and, to a lesser extent, Class 4 waste, due to the high content of metals, organochlorines, and pesticides. Forestry and vegetable crop production studies have been conducted on Broekpolder soils. Studies completed by the Institute for Soil Fertility indicated that Cd availability was very high and that crops grown on the site would greatly exceed the ADI for Cd (55-75 μg/person/day). Consequently, the Broekpolder can not be used for agricultural crops. Disposal sites containing contaminated dredged materials are now required to be covered by a 1 m layer of sand because of the potential for contaminant mobility to plants, animals and man. Also, dredged material now is kept anoxic to restrict oxidation and consequent mobilization of contaminants. Class 4 sediments, no longer are placed into polder disposal sites

Contamination of the sediment in aquatic systems

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1. Introduction

Holland is situated at the lower course of some important European rivers. The western part of Holland was formed for a greater part from sediment carried along by these rivers. After the construction of dikes, started already in the Middle Ages, the deposition of sediment has been restricted to the riverbeds and the outer marches.
As a result of spills from industries, urban areas and diffuse sources upstream these rivers and the strong affinity of many of the contaminants to the suspended matter, the quality of the river sediment has been deteriorating constantly until the seventies. From then on improvement has been noted for a number of micro-pollutants (see Fig. 1).

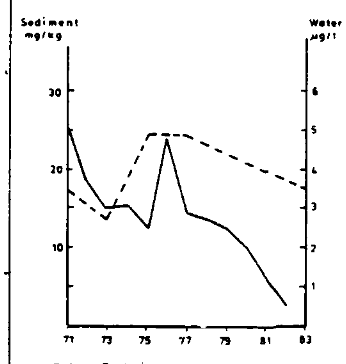


FIG.1: Cadmium content of :
——— Rhinewater (Lobith) and
- - - bottomsediment (Haringvliet)
from 1971 - 1983

Important infra-structural works, as the closure of the Haringvliet-estuary in 1970, have radically changed the sedimentation pattern. While a mixture of fluvial and marine sediment used to be disposited in the Haringvliet-estuary this nowadays is restricted to fluvial sediment only.
In general two kinds of polluted riverbed can be distinguished:

1. the "normally" polluted riverbed, in which the sediment is in geochemical balance with the water phase;
2. the "extra" polluted riverbed in which this balance does not exist due to local discharges, and here a re-delivery of contaminants to the water phase is possible.

2. Research strategy

The research strategy is fixed on the assessment of the ecological functioning of the northern deltabasin, since this is considered of fundamental importance for the (potential) use as fishing-, production or drinkingwater, recreation- and nature preservation-areas.
For this an ecological system-analysis is essential, for which the energy- and materialstreams in the various environmental compartments (surfacewater riverbeds, groundwater and organisms) have to be studied.
Next the effects of pollution on separate organisms and on the total environment must be researched, whereupon the steps to be taken to further a desired development have to be considered.

3. Research program in the northern delta basin

In 1984 drillings have been executed at 14 locations in the northern Deltabasin to a depth of several meters. Of the drillings the composition of the sediment was established as well as the degree of pollution of the separate strata. In 1985 similar drillings will be executed at 60 locations and 600 samples of the toplayer will be taken. The choice of the drilling locations is based on the physiography of the riverbed, since there is a connection between the character c.q. the quality of the sediment and the sedimentological/morphological development of the riverbed. Considering the occurrence of organisms a number of characteristic depths can be fixed (2 m, 2-8 m, 8 m water depth).
In marshes along the banks samples have been taken of soil, interstitial water and vegetation. Quantitative inventories are being made of the most important groups of organisms of which the degree of contamination will be established too.

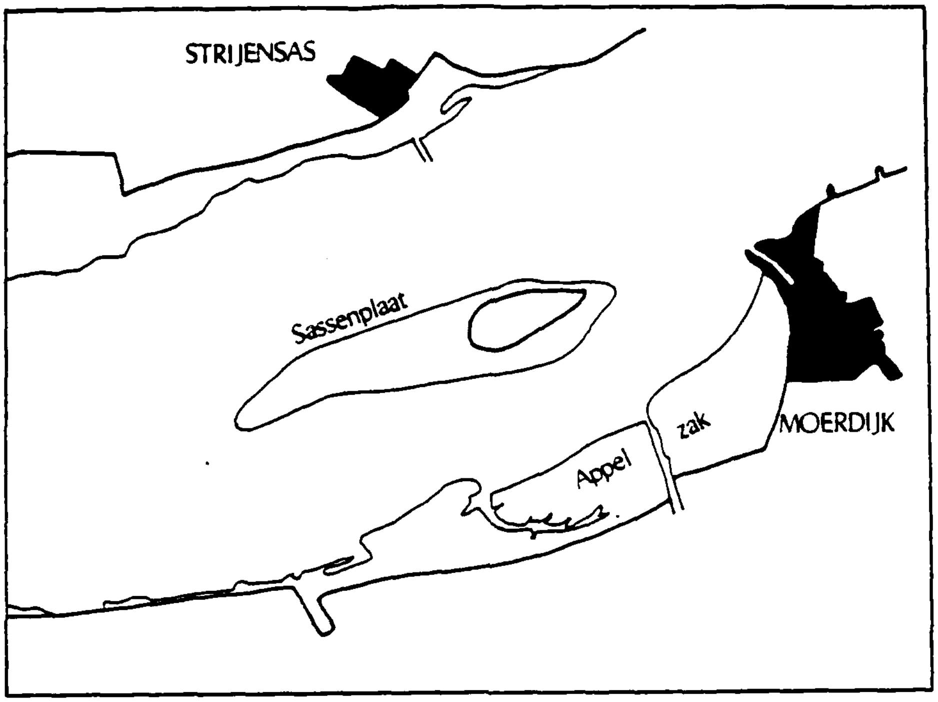


Figure 1.

4. Results

As a result of the closure of the Haringvliet in 1970 by means of a dam, with outlet-sluices the velocity of the water in the northern deltabasin has been strongly reduced. Consequently the deposition of fluvial sediment in the basin has increased strongly. The sedimentation of 4-5 million cubic meters per annum now occurs mainly in the eastern part of the basin (Fig. 2). When this area reaches a new equilibrium the main sedimentation area will be shifting westward.

Preliminary results of the drillings show a distinct boundary between the estuarial sediments of before 1970 and the more recent sediments. There also is a great difference between the pollution of the various strata (Fig. 3).

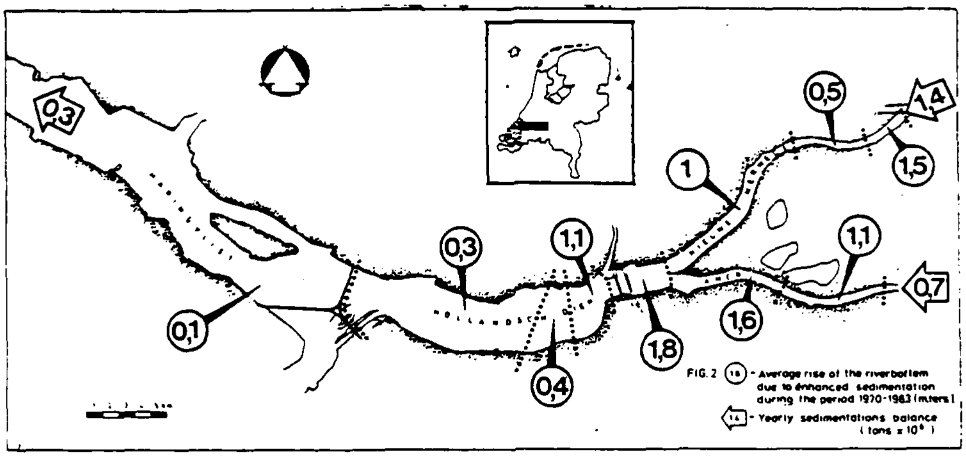


Figure 2

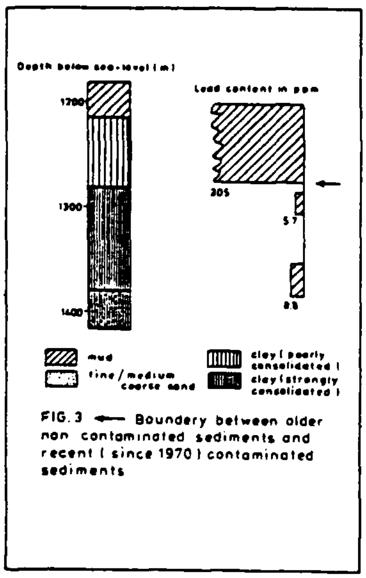


Figure 3

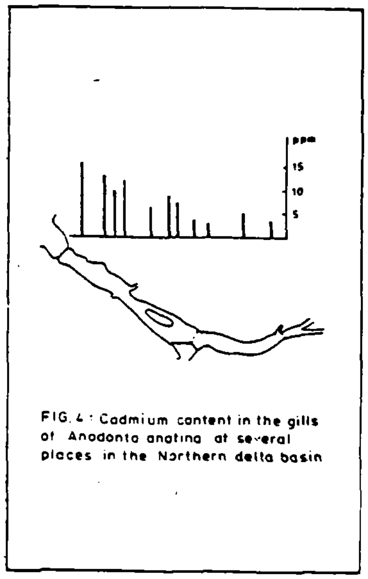


Figure 4

The presence of heavy metals and organic micropollutants in benthic organisms appears to be clearly higher than in less polluted areas. Remarkably the concentration of some contaminants in organisms from the Haringvliet (where relatively litte polluted sediment was deposited) appears to be evidently higher than that found in organisms from the Hollandsch Diep (Fig. 4).
In chironomid larvae in the northern deltabasin, there seems to be a connection between the existence of deviations in the chitine-structure of the head and the degree of pollution of the sediment.
The concentration of PCB's found in eel is so high that consumption is not advised. Since 1982 a certain improvement can be noted. Furthermore some indications show that the reproduction of birds that feed on fish and benthic organisms has been affected in this area.

5. Control-instruments

In areas with polluted sediments basically four control-instruments are to be considered.

5.1 Remedial action at the source

Discharge on surfacewater is the main cause of pollution of the riverbed. When the quality of the surface water is improved, the quality of the suspended matter will also improve and consequently older and polluted sediments will be covered with a less contaminated layer.
In the policy on water quality the ecological relations between the surface water and the riverbed will have to play an important role.

5.2 Water-quantity control

Since water is the transport medium for the suspended matter, the sedimentation process can be influenced by water quantity control.

5.3 Civil-engineering projects

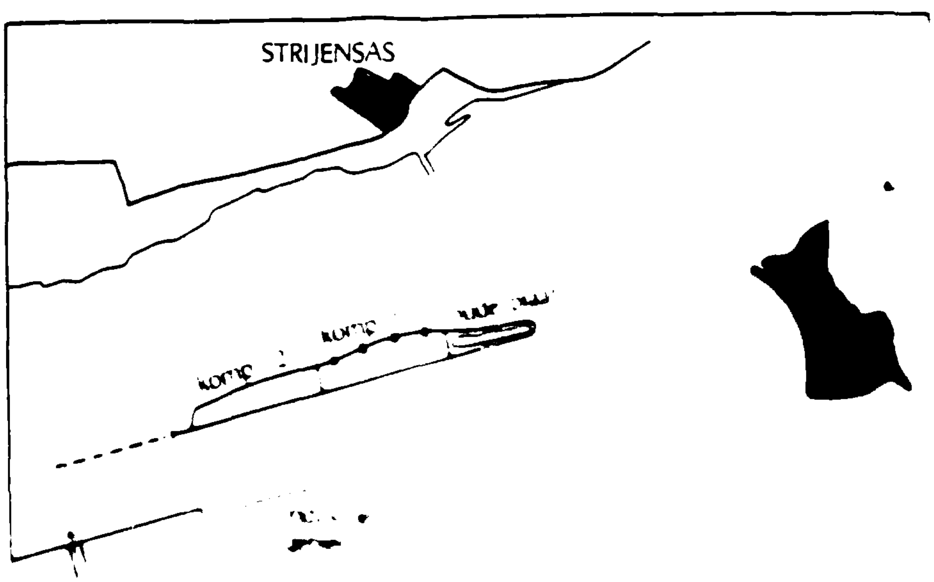
By means of civil-engineering projects, i.e. the formation of compartments or the construction of sediment-catches, the process of sedimentation can be influenced. This facilitates the possibility to decrease the burden on ecologically valuable areas. Consequently other areas will be burdened more heavily.

5.4 Remedial action on the riverbed

Remedial action on the riverbed is generally only effective when the source of the pollution is removed too. If this cannot be done the new sediment will again be polluted.

6. Conclusions

The contaminated riverbeds constitute one of the greatest problems of soil pollution as a whole. In Holland about 20% of the territory is occupied by water. In principle the problem rises in all sedimentation areas where up-stream pollution sources are found.
Because of the dynamic nature of watersystems the pollution is spread out mostly uncontrollable over vast areas. This often threatens wetlands with great ecological value. Furthermore interests regarding the production of drinking water, fishing and recreation can be endangered.
In the planning stage of big civil-engineering projects (such as dams, reclamations, etc.) the impact of these works on the quality of the river-beds are often neglected or recognized too late.
Measures to control the quality of the riverbeds will have to be based on a clear understanding of the functioning of the aquatic ecosystem as a whole.



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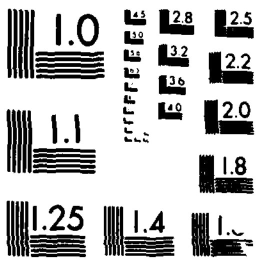

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

Aquatic -estuarine- macrophytes as monitoring organisms for trace metals

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There is some evidence in the literature that specific aquatic macrophytes may serve as good bio-accumulators of heavy metals and that these plants could be used to quantify the bioavailability of trace elements in estuaries. Furthermore, there are indications that several aquatic macrophytes may be used as biomonitoring organisms and may serve as candidates for heavy metal "watch" programs.

Aquatic macrophytes have some advantages over semi-terrestrial plants for aquatic monitoring programs. Their anatomy is less complex which reduces specific accumulation and transportation problems within the plant, and moreover they live submerged during their entire life cycle.

A project has been started in 1985 to find out whether specific estuarine macrophytes (the brown seaweeds *Fucus vesiculosus* and *Asophyllum nodosum* and the seagrass *Zostera marina*) may be good candidates for heavy metal monitoring. Part of the project is the construction of heavy metal budgets on the level of the dominant primary producers in estuarine ecosystems. To serve that purpose not only plant material is analysed for heavy metals but also surrounding water, sediment and detritus. So far, the preliminary results are promising.

Besides the establishment of a heavy metal "watch" along the west coast of Europe, based on metal concentrations in the brown seaweeds and/or in the seagrass *Zostera marina*, a further aim of the project is to reveal the bioavailability and consequent (negative) effects of heavy metals on higher levels of the estuarine food chains in which the macrophytes mentioned, dominate.

The project is located in a number of W. European and tropical estuaries (Coto Donana, Spain; Delta area of Rhine, Meuse and Scheldt, The Netherlands; Wadden Sea, The Netherlands, Germany; Flores Sea-Banda Sea, Indonesia; Bay of Jakarta, Indonesia) and includes a cooperation between a number of Dutch and foreign scientific institutes.

Criteria for sediments

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Contaminant criteria for sediments historically have been based on chemical assessment without consideration for ecological impact. Research has shown that sediment composition influences the contaminant loading of a sediment. One approach to sediment quality criteria used in the Netherlands is the chemical analysis of the sediment fraction less than 63 µm. Physical separation of this fraction in wet sediments and sample preparation may alter the amounts of contaminants sorbed to this fraction, however, It also may be difficult to compare the ecological impacts of contaminants when different sediments contain greatly differing quantities of this grain size fraction. Compositional differences in this fraction additionally may influence contaminant sorption

A second method of sediment evaluation uses the percent organic carbon or the carbonate free mineral fraction less than 16 µm as correction factors for organics and metals, respectively. Using the second method, three guidelines (Fig. 1) are defined with the reference points at 50% <16 µm (metals). On the basis of these guidelines, four classes of contamination have been established for sediments (Table 1). The quantitative formulation of these sediment classification guidelines is based partly on economic considerations and is a political decision. This method of sediment classification has problems which originate from sampling technique, chemical analyses, data processing, and interpretation.

With respect to sampling, it is important to know the proportion between sampling depth and the sedimentation velocity because, theoretically, this ratio may influence the total contaminant concentration and its corrected value. This may be caused by processes during or after settling. Examples of these are mixing and diagenesis (the latter in case organic carbon is used as the correction variable). Mixing results in a non-steady state situation. Consequently, problems associated with mixing may lead to erroneous conclusions regarding sediment classification and the need for sanitation measures.

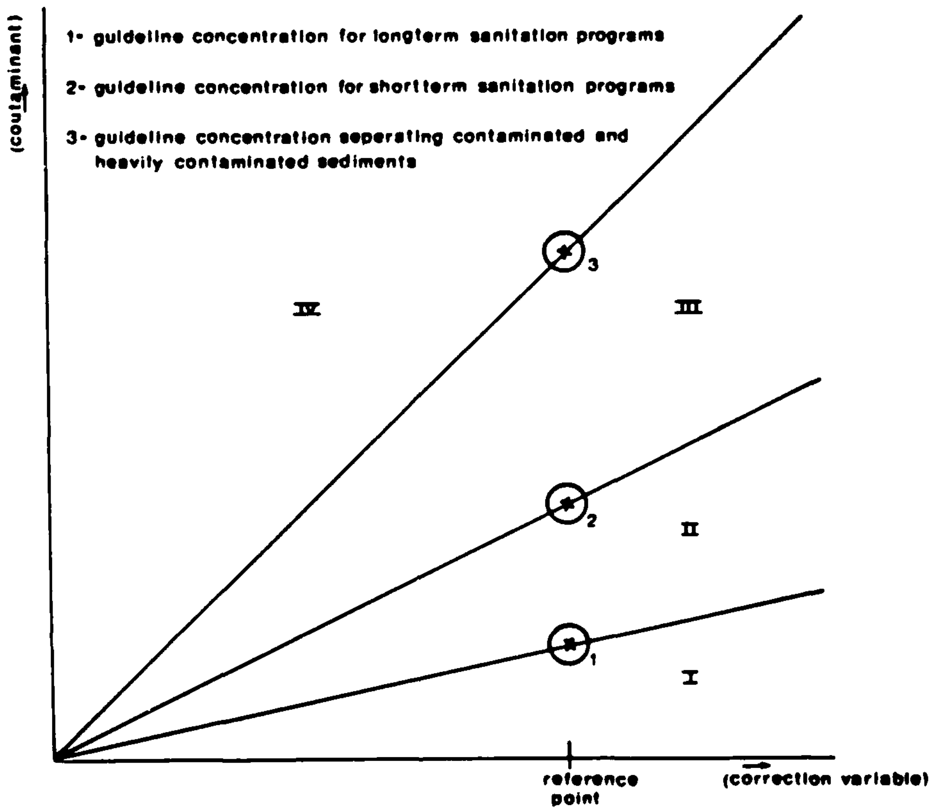

Figure 1

Diagenesis, on the other hand, may have two effects. The first is a reduction in the amount of the correction variable due to breakdown of organic matter. Assuming constant contaminant concentrations for two sediments, but a 50% change in the correction variable, the corrected concentrations in the sediment with extensive breakdown of organic matter may indicate a much higher contaminant level for that sediment. This implies that contamination level and decisions regarding sanitation programs are dependent upon the age of the sediment sampled. The second effect of diagenesis is a change in physicochemical conditions in the sediment (pH, Eh, etc.). For metals, this may result in a different retention mechanism (e.g., as sulfides) and may be important when considering the ecotoxicological effects of contamination levels. Both effects suggest that the use of organic carbon as a correction factor for metals is inappropriate.

Table 1 Classification program used in the Netherlands.

	Proposed legislation							
	(Soils) Interimwet 1)				(Sediments) Benedenrivieren 2)			
class / contaminant	1	2	3	4	1	2	3	4
As	< 20	20 - 30	30 - 50	> 50	< 23	23 - 32	32 - 110	> 220
Cd	< 1	1 - 5	5 - 20	> 20	< 6	6 - 19	19 - 32	> 32
Cr	<100	100 - 250	250 - 800	> 800	< 190	190 - 220	220 - 550	> 550
Cu	< 50	50 - 100	100 - 500	> 500	< 60	60 - 190	190 - 370	> 370
Hg	< 0.5	2	2 - 10	> 10	< 1,5	1,5- 9	9 - 16	> 16
Ni	< 50	50 - 100	100 - 500	> 500	< 35	35 - 65	65 - 80	> 80
Pb	< 50	50 - 150	150 - 600	> 600	< 110	110 - 460	460 - 660	> 660
Zn	<200	200 - 500	500 - 3000	> 3000	< 370	37 -1160	1160 - 2230	> 2330
oil	<100	100 -1000	1000 - 5000	> 5000	<1250	250 -2500	2500 - 4700	> 4700
HCHs 4)3)	<100	100 - 500	500 - 5000	> 5000	< 200	200 -2000	3000 -10000	>10000
HCB 3)	< 50	50 -1000	1000 -10000	>10000	< 200	200 -2000	2000 -10000	>10000
Heptachloor	<100	100 - 500	500 - 5000	> 5000	< 200	200 -2000	2000 -10000	>10000
Hept p 3)	<100	100 - 500	500 - 5000	> 5000	< 200	200 -2000	2000 -10000	>10000
Drins 4)3)	<100	100 - 500	500 - 5000	> 5000	< 200	200 -2000	2000 -10000	>10000
DDT-complex 4)3)	<100	100 - 500	500 - 5000	> 5000	< 200	200 -2000	2000 -10000	>10000
Endosul 4)3)	<100	100 - 500	500 - 5000	> 5000	< 200	200 -2000	2000 -10000	>10000
Σ6 PCBs 3)	< 50	50 - 250	250 - 1000	> 1000	< 100	100 - 250	250 - 500	> 500
Aroclor 1221	< 0.05	0.05- 0.2	0.2- 1.5	> 1.5	< 0.1	0.1- 0.3	0.3- 0.8	> 0.8
1242	< 0.05	0.05- 0.2	0.2- 1.5	> 1.5	< 0.1	0.1- 0.3	0.3- 0.8	> 0.8
1248	< 0.05	0.05- 0.3	0.3- 2.0	> 2.0	< 0.2	0.2- 0.5	0.5- 1.2	> 1.2
1254	< 0.05	0.05- 0.3	0.3- 2.0	> 2.0	< 0.2	0.2- 0.5	0.5- 1.2	> 1.2
1260	< 0.05	0.05- 0.2	0.2- 1.5	> 1.5	< 0.1	0.1- 0.3	0.3- 0.8	> 0.8
PCB 28 3)	< 10	10 - 40	40 - 150	> 150	< 20	20 - 40	40 - 80	> 80
52 3)	< 10	10 - 50	50 - 200	> 200	< 20	20 - 50	50 - 100	> 100
101 3)	< 10	10 - 50	50 - 200	> 200	< 20	20 - 50	50 - 100	> 100
138 3)	< 10	10 - 50	50 - 200	> 200	< 20	20 - 50	50 - 100	> 100
153 3)	< 10	10 - 50	50 - 200	> 20	< 20	20 - 50	50 - 100	> 100
180 3)	< 10	10 - 30	30 - 120	> 120	< 10	10 - 30	30 - 60	> 60
Σ6 PAHs	< 0.5	0.5 - 10	10 - 100	> 100	< 2.5	2.5- 5	5 - 19	> 19
fluoranthene	< 0.1	0.1 - 10	10 - 100	> 100	< 0.4	0.4- 1.0	1.0- 4.5	> 4.5
benz-b-fl anth	< 0.1	0.1 - 2	2 - 10	> 10	< 0.5	0.5- 1.0	1.0- 3.5	> 3.5
benz-k-fl anth	< 0.05	0.05- 1	1 - 5	> 5	< 0.2	0.2- 0.4	0.4- 1.0	> 1.0
benz-a-pyrene	< 0.05	0.05- 1	1 - 10	> 10	< 0.3	0.3- 0.6	0.6- 2.0	> 2.0
benz-ghi-perylene	< 0.05	0.05- 1	1 - 10	> 10	< 0.3	0.3- 0.6	0.6- 2.0	> 2.0
indeno 1,2,3 -c,d pyrene	< 0.1	0.1- 2	2 - 10	> 10	< 0.7	0.7- 1.0	1.0- 4.5	> 4.5

1) Concentrations in mg/kg.

2) . Metal- and oil concentrations are expressed as if the silt-content (% < 16 micron) of the sediment is 50%,
. The organic micropollutants are expressed in mg/kg organic matter.

3) Concentrations in μg/kg.

4) The different materials seperatively.

Comment on Table 1

1 Interimwet = interimlaw of soil sanitation from the Ministry of Public Health, Planning and Environment. This law is enforced on dry land.

Class 1: Back-ground level

Class 2: Minor contamination - no sanatation required

Class 3: Median contamination - further investigation is required before sanatation

Class 4: Highest contamination - soil will be sanatized.

Note: Concentrations are expressed in mg or µg per kg dry matter.

2 Benedenrivieren =

Classification used by Rijkswaterstaat in the Rotterdam-harbour area

Class 1: Slight contaminated dredging material from the west part of the Rotterdam harbour area (mostly sea sediments)

Class 2: Moderate contaminated dredging material from the middle point of the Rotterdam harbour area (50% sea sediments)

Class 3: Contaminated dredging material from the eastern part of the Rotterdam harbour and rivers (mostly river sediments)

Class 4: Locally heavy contaminated material

Note: Concentrations of metals and oils are expressed in mg per kg soil at 50% < 16 micron silt fraction and the concentrations of organic pollutants are expressed in mg per kg organic matter in the sediment.

Problems with chemical analyses also involve interlaboratory variability. Intercalibration exercises held by ICES member countries indicated that interlaboratory analyses for metals usually were precise and comparable, but analyses for 18 PAHs showed variations of about 60%.

Other problems are related to data processing, particularly extrapolation outside the measured interval of the correction variable. Also there is uncertainty whether the correction methods distinguish between the influence of sediment composition and other concentration-changing processes. Statistically, the correction is valid only if the relationship between contaminant and correction variable is the same for all comparison groups.

Another aspect is the ecotoxicological relevance of the corrected contaminant concentrations. In order to assess this relevance, one must know the fraction which is available for organisms. It has been recognized for some time that total contaminant concentrations have little or no relation to the bioavailable fraction. Since the actual bioavailability is determined by environmental parameters such as pH, redox, salinity, and concentration of other ligands, no simple chemical sediment classification system is imaginable which includes the effects. Pore water research may offer more prospects in this field. However, in order to relate the bioavailable contaminant concentrations in sediments or pore water to ecotoxicological effects, chemical research alone is not sufficient; additional considerations must be included, preferably based on biotest techniques, such as bio-assays, stress parameter research, and meso- or microcosm studies, etc. It may be a matter of consideration to base future guidelines on contaminant levels in organisms, although the effects of these levels on the organisms will be difficult to establish, if at all possible.

Contaminant mobility

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The chemistry, pollution and contaminant mobility of salt marshes is related to their morphology. As a salt marsh develops, the finer particulates are passed further into the marsh at high tide, creating mud flats, whereas the sandy particulates tend to drop out in the region of low tides.
This results in the development of a ravine between the salt marsh and the sand flat. There is a close relationship between this process and the movement of pollutants into a salt marsh. Generally, the higher the clay content is in the soils, the higher will be the pollutant content. As the finer particulates (i.e., clays) settle out, there is an almost linear relationshio between clay content and metal pollution. In water, the metals are adsorbed to the clay and humic matter (aerobic). In sediments there is a profile of contamination that is related to redox potential. Differences in redox potential depend upon elevation within the marsh and are responsible for determining the chemistry of the sediments. There is a tendency towards increasing concentrations of metals as depth within the sediment profile increases. The bioavailability of metals usually decreases with depth in the profile because of the anaerobic conditions. Bioavailable metals are associated largely with interstitial (pore) water. Metals also are bound into an exchangeable fraction (clay-humus); carbonates and amorphous oxides; organic matter; sulfides; and finally the crystalline lattice of sediment particles. Changing the redox conditions may drastically alter the chemistry of the sediments and consequently, the bioavailability of metals. When sampling sediments for metal contaminants, it is critical to keep the samples unchanged. Also, it is necessary to know from which layer in the profile a sediment sample was taken because of implications in bioavailability (For further information see the paper by Reynders following this abstract.

Contaminant mobility

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Introduction

Generally a soil profile is a genetic body in which physical and chemical reactions took place. As a result the profile can be divided into soil horizons, each with its own characteristics. It is therefore dangerous to characterize 'a soil by one sample' of a site and to explain the chemical properties accordingly. The contamination with heavy metals in soil are influenced by the properties of the various horizons. The underwater soils of the Western Scheldt estuarium are highly polluted with heavy metals. These soils present a good example for the distribution and mobility of the contaminants. A particular site at 'the Konijnenschor' was chosen.

Landscape morphology

The off-shore landscape in the tidal area of the Western Scheldt can be divided according to its morphology in:

- saltmarsh soils: they form the higher parts carrying vegetation. A subdivision can be made, based on the inundation time and frequency, in higher, medium and lower salt marshes. Natural levees along creeks and backswamps are found in these concave parts.
- mud and sandflats: they are found in front of the former soils, generally in a convex topography at a lower level. They are longer and more frequently inundated.
- sand and mudflats or banks in the middle of the stream.

Soil profile

The hydromorphic soils in these units have their own subdivision in genetic soil horizons. A general picture can be given from a natural levee in the salt marsh part, e.g.:

0 - 20 cm: AGo, brownish sandy loam, containing many roots and many rusty stains;

20 - 40 cm: Go, brownish loam with grey spots and rusty stains;
40 - 45 cm: Gr1, greyish loam;
45 - 75 cm: Gsu, black loam;
75 - 100 cm: Gr2, greyish sandy loam.

The horizons are not ripened.
Go-horizons are influenced by oxygen causing brown to rusty mottles, Gr-horizons are grey and completely reduced.
Gsu-horizons are also reduced and coloured black to dark grey because of the formation of black FeS Mackinawite.
The variation in soil colours and mottles are determined by the redox potential values of the profile illustrated in Figure 1.

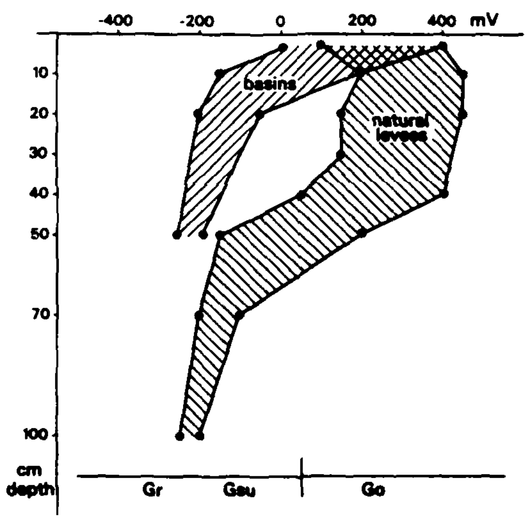

Figure 1 Relation redoxpotentials and depth in salt marsh soils.

The values are given for a natural levee and a backswamps in a middle high salt marsh. It is obvious that the blackish Gsu-horizons are found at Eh-values lower than +50 mV, while the Go-horizons have Eh-values between +400 mV and +50 mV. The formation and stability of FeS and the presence of alternating ferric and ferrous compounds fit very well in the stability fields of the Eh-pH-diagrams. The pH-values in these soils are found in the range 7.5 up to 8.5.

The horizons in the various landscape types may change in thickness and in colour intensity which depend on the inundation time, vegetation and soil texture. The presence and thickness and colour of the horizons depend also greatly on the redox profile of the soil. The redox values are a function of the permeability of the soil, the presence of oxygen, the bacterial activity and the nutritive elements, mainly organic material and sulfate (sea water). In the more clayey and less drained back swamps the Go- and Grl-horizons are very thin or they may disappear. In the mudflats the AGo-horizon is missing and the brownish upper horizons are reduced to a few millimeters to some centimeters. In the sandflats the upper Go and Gr may be deeper up to several decimeters.

Contaminants

The total content of a number of heavy metals have been analysed by a pre-treatment of $HF-HNO_3$ solution. In order to obtain comparable values all the results of the heavy metal contaminants have been recalculated up to one percent (or 50%) clay (fraction < 2 microns). These results have been given in Figure 2 and Figure 3.

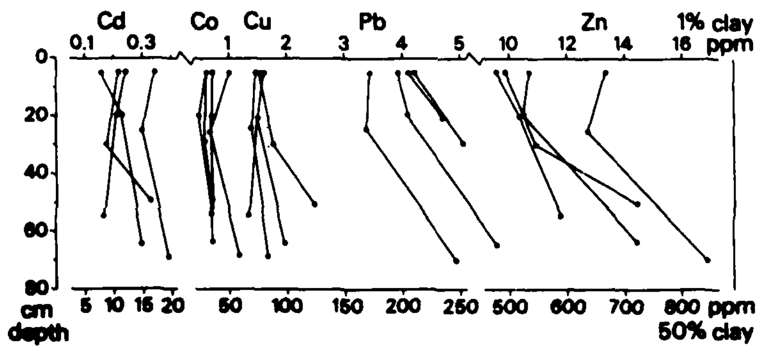

Figure 2 Heavy metal concentration in relation to depth.

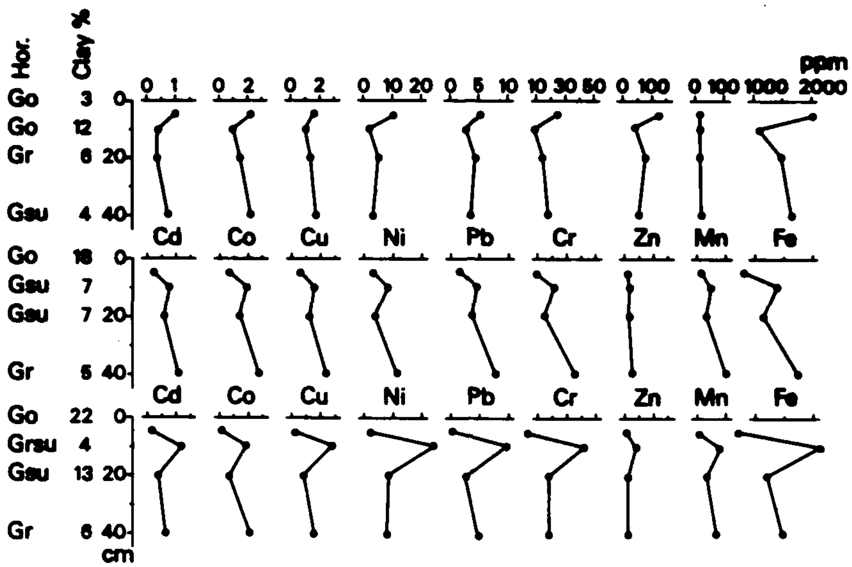

Figure 3 Heavy metal concentration per percent clay of mud flats (Hooge Platen) of the Western Scheldt estuarium.

Figure 2 represents the values of four profiles in the above mentioned Konijnenschor (salt marsh). It will be clear that generally the amount of contaminants increases in the reduced Gsu-horizons at a depth of about 30 cm to 80 cm. The original clay contents of these profiles vary between 0 to 60%.

Figure 3 illustrates the value of loamy sands and sandy loam of the mud flats of the Hooge Platen in the middle of the stream. In these cases it is also evident that per one percent clay higher values are obtained in the upper Gsu-horizons. These horizons are more shallow than in the salt marsh given above.

In the top soil horizons having Go-horizons the distribution of the heavy metals is different. The metals are present in a more soluble state in the higher redox potential range of the profile.

When these horizons are shallow the soluble heavy metals dissolve again into the above standing water. In those cases where these horizons are deeper the heavy metals are bound to the iron- and manganese hydroxides and oxides of these horizons. This means that the heavy metals can be bound to various compounds depending on the redox potential and the stability of these compounds at those potentials.

<u>Sequential analyses</u>

One profile was analysed according to a sequential extraction (compare Tessier et al. 1979, and Foerster et al. 1979).
The various fractions are given in Figure 4. The amount of zinc present in interstitial water was added. The analyses have been carried out in a nitrogen glove box. The total zinc concentrations are given in the figure. The clay contents of the various horizons from top downwards are 49.5, 55.0, 38.5 and 4.0%. With exception of the bottom-most horizon, in which the natural zinc amounts play a dominant part, the highest zinc total amounts per percent of clay are present in the upper Gsu-horizon.
However, the sequential analyses show the following picture. In the top horizon the zinc present in interstitial water and adsorbed at the clay-humus complex is rather low. It diminishes deeper in the profile.
Zinc bound to carbonate and to amorphous oxides is present in the Go-horizon, but decreases enormously in the completely reduced deeper horizons.

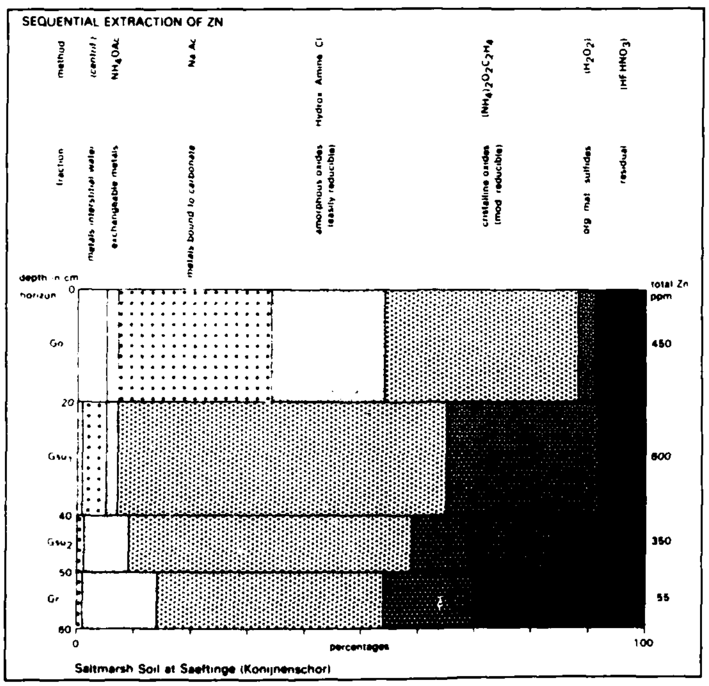

Figure 4 Sequential extraction of Zn.

In the latter horizons to these amorphous hydroxides and oxides are hardly present because of the lower Eh-values. The zinc bound to crystallized oxides are present in the Go-horizon, but proportionally the amount increases deeper in the profile. The same is true for the zinc bound to sulfides. The residual and evidently natural amount of zinc increases with depth and it seems to be more or less reversely proportional to the clay content.

Conclusions

- It can be concluded that heavy metals may move in the profile as a result of the redox potentials and solubility products of the compounds present.
- In the underwater soils horizons may be distinguished each with its own characteristics which may cause different sorption of heavy metals.
- The amount of available heavy metals for plant growth in a reduced environment is not expressed by the total amount, but it will be a certain fraction of it.
- The change of the environment, as a result of reclamation or dredging, may change the mobility of the heavy metals completely.

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Consequences of dredged material ageing in confined disposal facilities

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Abstract

Dredged material placed upland in a confined disposal facility (CDF) may eventually become a wildlife habitat or may be considered for other productive uses. This situation has occurred in many confined disposal facilities around the U.S. Great Lakes, where prolific wildlife habitats have developed on contaminated dredged material. It is important to note that processes such as weathering, leaching, and mobilization of some contaminants may result in a material that, after a period of time, has changed considerable from the original sediment dredged and used for initial laboratory predictive tests.

Introduction

The upland animal bioassay procedures applied were developed by Edwards (ref. 1) to evaluate the effects of new chemicals for the European Economic Community. The tests have been modified subsequently for use with dredged material, fill material, and contaminated soils, and applied both as a predictive test and for management guidance for old disposal sites (ref. 2, 3, 4 and 5).

These procedures address both the immediate response of animals to a newly-dredged sediment and the potential response of animals that may colonize the weathered dredged material in the future.

Methodology

Earthworms, *Eisenia foetida*, were placed in a reduced; highly contaminated, sediment from a freshwater harbor as a screening test prior to the initiation of the bioassay. An avoidance reaction by the earthworms and toxicity indicated that 28-day bioaccumulation testing was not possible. Various treatments were applied to the sediment to simulate the ageing under upland disposal conditions including: Ashing for 24 hr at 600°C, drying for 7 to 21 days in sunlight, drying for 21 days in sunlight plus a manure amendment, or ageing for 6 months. After each process, the material was air-dried, ground, and rewet before adding earthworms. Preliminary toxicity tests were conducted by adding worms to sub-samples of each material and recording survival during a 28-day period.

Only the 6-month aged sediment demonstrated survival for a 28-day test. This material was aged outdoors in shaded and covered 60-litre glass aquaria with regular mixing and demineralized water added to prevent complete drying and oxidation, and to promote microbial biodegradation. After ageing, the test material was placed in Plexiglas cylinders (30x15x3 cm) and watered by capillary action. Both ends of each cylinder were covered with bolting cloth to retain the substrate and earthworms.

Each bioassay container received 30 g of earthworms (counted and weighed before and after the 28-day test). The test was conducted at 15°C with continuous low-intensity lighting. The capillary watering method provided moisture stratification allowing the earthworms to "choose" their best environment. After recovery the earthworms were depurated for 48 hr on moist filter paper.

Tissue samples for analyses were homogenized prior to analysis. Organic compounds in sediments were extracted using hexane-acetone, and those in tissues were extracted with 4% sodium hydroxide. The PAHs were separated by silica gel chromatography and subjected to capillary gas chromatography.

Results

The ageing process caused changes in the concentrations of organic contaminants present in the original sediment. The greatest effect of the ageing process was on the PAHs, particularly naphthalene, which dropped to about 2% of its original concentration (Table 1). The earthworms burrowed as rapidly into the aged sediment as into the manure controls. Periodic examination indicated that the worms were active throughout the sediment in each cylinder. Earthworm recovery at the end of the exposure period exceeded 95 percent in both the manure controls and the aged sediments.

The bioaccumulation of PAH's by earthworms was significant only for 5 of the 16 contaminants analyzed (pyrene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, and indeno[1,2,3-c,d]pyrene).

Remaining PAHs were near or below detection limits in the worms. PAHs which bioaccumulated significantly were present in tissue concentrations of about 50 percent of that in the aged sediments.

Discussion and conclusions

The initial sediment toxicity apparently was the result of high concentrations of volatile organic compounds, such as naphthalene. The known presence of metals below toxicity levels probably did not contribute to the mortality (see ref. 6, 7, 8 and 9). The effects of PAHs on earthworms are unknown.

The acute toxicity to soil invertebrates by volatile PAHs, especially naphthalene is of concern in the upland disposal of this dredged material. These compounds would be expected to decrease rapidly in the sediment with time through a combination of volatilization, microbial activity, and photodegradation. Tissue PAH levels may reflect changes due to metabolism, although these are not well documented. Following the loss of the labile contaminants and the decrease in toxicity, the sediments possibly would be colonized by soil-dwelling invertebrates. Potential bioaccumulation of metals and the more persistent organic compounds then would be the major concern.

The results from the 6-month ageing of the sediment suggest that, with time, this sediment placed in a CDF may become habitable and develop into a biologically prolific ecosystem. This has occurred at the Times Beach CDF, Buffalo, NY (ref. 10) and elsewhere. This study indicated that the ageing procedures of the laboratory earthworm bioassay can predict the potential contaminant loss as well as bioaccumulation in soil invertebrates when a contaminated freshwater dredged material is placed in an upland environment, and suggests several PAHs that may require long-term management while others are critical only during the immediate post-disposal period.

Acknowledgements

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Table 1 Polynuclear aromatic hydrocarbon (PAH) concentrations in sediment and bioassay earthworms.

PAH	Original Sediment	Aged** Sediment	Time = 0 Earthworms	Time = 28 days Earthworms
Naphthalene	2033.33 ± 57.73a	46.27 ± 1.26b	d	d
Acenaphthylene	21.67 ± 0.58	d	d	d
Acenaphthene	105.33 ± 8.08	d	d	d
Fluorene	78.33 ± 8.14a	4.29 ± 0.73b	d	d
Phenanthrene	206.67 ± 11.55a	14.27 ± 3.65b	d	d
Anthracene	63.33 ± 1.53a	74.03 ± 6.27b	d	35.26 ± 16.37
Fluoranthene	160.00 ± 10.00a	36.93 ± 5.61b	d	d
Pyrene	143.33 ± 5.77a	74.03 ± 6.27b	d	35.26 ± 16.37
Chrysene	95.67 ± 4.04a	25.50 ± 5.72b	d	12.22 ± 5.92
Benzo(a)anthracene	102.00 ± 13.86a	21.63 ± 2.36b	d	d
Benzo(x)Fluoranthene@	156.67 ± 15.27a	41.70 ±19.21b	d	20.92 ± 10.49
Benzo(a)pyrene	105.67 ± 16.92a	33.90 ±10.79b	d	18.42 ± 5.90
Indeno(1,2,3-c,d)pyrene	57.00 ± 10.44a	18.51 ±12.49b	d	9.29 ± 2.78
Dibenzo(a,h)anthracene	13.67 ± 6.35a	d	d	d
Benzo(g,h,i)perylene	39.67 ± 4.16a	4.28 ± 7.70b	d	4.50 ± 0.74
Total PAH	3382.33 ± 142.39a	388.22 ± 80.76b		131.43 ± 11.17

* Means of three replicates ± sd expressed as ug/g (=ppm) dry weight. Means in a row followed by the same letter are not significantly different according to Duncan's new multiple range procedure at alpha = 0.05

** 6-month aging
Time = 0
Time = 28 days

@ Benzo(b)fluoranthene + Benzo(k)fluoranthene

d = Detection limit <0.05 ug/g

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Field Verification Program

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The Field Verification Program (FVP) is an outgrowth of the Longterm Effects of Dredging Operations (LEDO) program, which is a research program to develop techniques for the evaluation of dredged material. The FVP was initiated as a joint research effort between the U.S. Corps of Engineers Waterways Experiment Station (WES) and the Environmental Protection Agency (EPA) to evaluate the effects of disposal of a single dredged material in all three general disposal environments: aquatic, intertidal, and upland. In the past it had been possible to measure the effects of contaminants in old disposal sites where problems had occurred. But no pre-disposal data were available. The FVP was initiated to determine whether or not predictions regarding contaminant mobility that were based upon laboratory testing procedures actually occur under field conditions. Research under the FVP would evaluate existing techniques and compare alternatives. Studies included soil analyses; plant and animal bioassays in the laboratory; effluent, surface runoff and leaching tests; evaluation of colonization of the sites and analysis of colonizing organisms. An aquatic disposal site was selected in Long Island Sound near Bridgeport, CT. A confined upland and intertidal wetland were constructed at Tongue Point in Bridgeport. Contaminated sediments were dredged from Black Rock Harbor in Bridgeport and placed in a subaqueous mound (aquatic disposal) in April 1983 and in the artificial upland and wetland sites in November 1983. Final studies were concluded in 1986, and reports will be completed in 1987.

Preliminary results indicate good colonization and relatively minimal impacts in the aquatic site. In the upland, revegetation has been slow and is limited to very salt-tolerant species growing mainly in the cracks in surficial dredged sediments. Earthworms did not survive, due in part to osmotic stress as the result of high salinity. In the intertidal wetland, plant recolonization has been fair, and an invasion by larval polychaete worms (*Nereis succinea*) has resulted in a dense population of this species in the wetland dredged material. The results from the FVP will allow a better evaluation of the impacts of contaminated dredged material disposal and will provide guidance for future dredging and disposal activities.

Ecotoxicological risk

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Most contaminant research has been based on fear that some adverse effect may occur, without consideration of where in an ecosystem or community the presumed effect might be observed. In areas of limited size and with similar physicochemical conditions, good correlations sometimes are shown between the concentration of a contaminant (e.g., metal) in sediments and those in animals living on those sediments. This apparent relationship does not hold for different regions and different species. The results of various studies have shown that metals are bioaccumulated from the water rather than directly from the sediments and that bioaccumulation is well correlated only with the fraction of dissolved metals that are in a bioavailable form. In the case of Cd, leaching from the sediments into the water column was the source of Cd bioaccumulation. Likewise, studies with earthworms at the Times Beach confined disposal site (Buffalo, NY) suggested a linear relationship between Cu in sediments and in the worms. This relationship again does not hold for other sites where physicochemical conditions in the soils (e.g., CEC) are different.

The question at hand is how to predict potential contaminant problems. The bioassay was developed to allow prediction of potential bioaccumulation and effects of contaminants. The results of such bioassays often are difficult to interprete, and frequently the choice of experimental systems does not adequately address the question of concern. Should we look at simpler organisms near the bottom of the food chain or at the top predators? Do water analyses and toxicity tests really protect the environment, in general, and humans specifically? In the case of metals and persistent organic compounds (e.g., PCBs), there may be a critical threshold level in an organism's tissues above which toxicity occurs (e.g., acute Cu toxicity to mussels). Field biomonitoring studies with mussels also have shown that Cd bioaccumulation and toxicity is correlated only with the bioavailable fraction of the dissolved Cd.

Another consideration not addressed by routine bioassays is changes in the environment that occur with time. These changes may be physicochemical (e.g., drying and oxidation of sediments placed in an upland site) or may be enhanced by bioturbating processes (e.g., plant growth and animal movements). At Times Beach and in the Broekpolder, Cd enrichment of the upper soil strata has occurred as the result of Cd mobilization into the trees and deposition through leaf fall. Physicochemical (volatilization, leaching, and photodegradation) and biological processes (bacterial decomposition) at Times Beach have altered the composition of the PAHs in the surface strata relative to those in the deeper, anaerobic strata. Thus the evaluation of PAHs in a sediment as "total PAHs" is meaningless. Studies in which oil was applied to a tidal flat simulation system showed that the surface oil was incorporated to a depth of 40 cm by the action of lugworms. The oil components subsequently were released continuously into the system for a period of a year. Such problems as these indicate that the place to look for real effects is in the field.

Recent studies also have shown that the significant environmental effects frequently do not appear in organisms near the bottom of the food chain. Mussels from clean and contaminated areas were fed to ducks over a period of several years. Cadmium accumulated in the tissues but had no pathological effect. Yet PCB accumulated by the adult birds was bioaccumulated in the developing eggs. The result was reproductive failure as the result of PCB toxicity to the developing embryos. The mussels from the contaminated area were larger and apparently healthier than those from the clean area, apparently as the result of nutrient enrichment from the polluted sediments. No effects of PCBs were apparaent on the mussels because glycogen, rather than lipid, is the energy storage reserve in molluscs. Fats in the yolks of the birds' eggs contained high concentrations of PCBs passed on from the parent birds, however. When the yolk lipids were mobilized during embryonic development, the PCBs were released with resultant death of the embryos. Thus, organics are likely to cause problems at the top of the food chain. Metals, such as Cd, are more likely to be directly toxic to organisms near the bottom of the food chain (e.g. worms and molluscs), however. Neither bulk chemical analyses nor standard bioassay procedures can fully address the food chain effects of environmental pollution, especially where organic components are involved.

Dredging and disposal - Problems at the Port of Hamburg

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The river Elbe flows through Czechoslovakia and the German Democratic Republic before passing through Hamburg en route to the North Sea. At Hamburg, the Elbe divides into two branches that flow around parts of the city and rejoin. In this area, harbors have been built since medieval times. Eddies in the mouths of the harbors result in a sedimentation rate up to about 3 m/year and necessitate maintenance dredging of about 2 million m^3 anually. Harbor muds contain significant levels of contaminants, especially metals, which are associated primarily with the fine grain fraction (less than 63 µm). Prior to the recognition of the contaminant problem in the 1970's, the sands were separated and used for industrial sites, and the muds were used for agriculture. Older polder disposal sites had a problem with high metal uptake by plants due to the relatively low pH.
Experimentation with liming demonstrated increased crop productivity and reduced metal mobility. Liming was seen only as a temporary solution to the problem.

Currently, pilot plant studies are in progress to investigate solutions to the handling and disposal of the highly contaminated fine particulate mud fraction. Hydrocycloning, additional washing of the sand, and further dewatering of the mud fraction are being studied as a means of concentrating the highly contaminated fraction, thus reducing the amount of hazardous dredged material that must be placed in special disposal sites. The hydraulic transport of the dredged material consumes about 10 million m^3 of water per year, which must be treated (to remove suspended particulates and to oxidize nitrogenous compounds to nitrates) prior to discharge into the Elbe. For the highly contaminated fraction, a new disposal site is planned. This site will be lined with plastic and consolidated mud. Layers of dredged material will be placed with sealing layers in between; this will be topped with an additional barrier to prevent root penetration and then be covered with cultivatible materials. An additional plan involves subsurface disposal in a pit in the North Sea and capping with a sealing layer. A possible long-term solution might be thermal treatment (i.e., incineration) of the classified, dewatered mud, resulting in pellets. Using this method, the organic contaminants are burned off and most of the heavy metals are bound into the pellets. Volatile compounds (NO_x, SO_2, Hg, etc.) must be recovered before leaving the smokestack. The pellets do not leach contaminants and either can be used as a gravel substitute in construction or can be deposited.

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