Ministerie van Verkeer en Waterstaat

Directoraat-Generaal Rijkswaterstaat

Programma Ontwikkeling Saneringsprocessen Waterbodems POSW

Interim report

Development Programme for Treatment Processes for Polluted Sediments

POSW *Stage* II (1992-1996)

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Summary

The Development Programme Treatment Processes for Polluted Sediments (POSW-II) has entered the stage of demonstration tests and field tests. It appears that sediment clean-up and sludge treatment not only is technically feasible, but also yields useful products. For the specialized treatment of the clayey sludge, however, very little capacity is available as yet. Small-scale field tests and sediment clean-ups are still very costly.
During the remainder (1995-1996) of this second period, POSW-II is concentrating on several matters. Three pilot remediations are either still in progress or have just been finalized, i.e. Elburg harbour (successfully completed); a groyne field in the New Merwede River; Petroleumhaven (Petrol Harbour) in Amsterdam. Further field tests are conducted to explore a number of techniques, such as the dredging tests in Ketelmeer. The assessment of environmental effects and cost of remedial techniques and clean-up chains needs further refining. Finally, the possibilities for large-scale sludge treatment are explored.

Objectives POSW-II

POSW-II is aimed at the development and operationalization of environmentally friendly technology to remove and treat contaminated sediment. The technical applicability of this technology has to be demonstrated in practice.

Serving as a base for future policy decisions, the programme is expected to provide data on the technical possibilities of the methods developed. Also, it is to result in a thorough understanding of the environmental consequences and financial-economic aspects of such methods.

For the year 2000, government policy has set the objective of an operational treatment capacity of 20% of the polluted sediment released during maintenance and clean-up works. That is why methods to separate sand from sandy dredging spoil are being refined even now. In 1997, an evaluation will be conducted of both the treatment of contaminated sludge and any other methods which can be made operational before 2000 to reach the 20% goal.
The information provided by POSW-II also has to include data on the preparation and implementation of sediment clean-ups. It will be obvious that policy decisions based on the gathered knowledge and experience are not taken within the framework of the programme.

The subjects discussed in this report

This Interim Report describes the state of affairs at POSW-II in 1995, with regard to dredging and treatment methods and the assessment criteria of their costs and environmental effects.
The report will serve as a basis for the discussion on sediment policy, to be laid down in the 4th National Policy Document on Water Management. It also presents background information for the parliamentary debate on the Programme for Sediment Remediation in State-managed Waters 1996-2010.

All this report contains is facts. It summarizes the knowledge and experience gained within the framework of POSW. But it offers neither recommendations nor ready-made choices.

The results of the individual subprojects of POSW-II (such as the performance of a method or the costs per unit of treated sludge) have not yet been made uniform, which makes it difficult to compare these data. Numerical comparisons between various methods based on removal performance and cost per unit of treated sludge will therefore not be presented until the final reporting in 1997.

Conclusions Interim Report

In this report, technical conclusions are drawn with regard to:

- the limiting conditions which treatment methods for contaminated sediment have to meet before they are researched via POSW-II;
- methods which have proved applicable, with a view both to the removal and treatment of sludge and to evaluation of the results;
- the first pilot remediation: the clean-up of Elburg harbour.

Limiting conditions treatment methods

Treatment methods should not only be technically feasible, operable and environmentally friendly. They must also be applicable at acceptable cost and deliver useful products. Furthermore, they should be appropriate for most of the spoil types occurring in the Netherlands.
All these conditions can be met only when contaminated sludge is treated in large-scale plants, as is common practice with dry-soil treatment. Details of this approach are found in the „Feasibility Study for Large-Scale Treatment" (also see the section titled „Large-Scale Treatment").

Appropriate treatment methods

Treatment methods currently available for large-scale application are landfarming and ripening, separation of sand (possibly supplemented by washing or flotation) and immobilization.
It can also be concluded that a number of promising techniques are in an advanced stage of development: flotation of the fine fraction, bioreactors, wet oxidation, solvent-extraction and thermal techniques such as desorption and incineration. Several of the methods mentioned here have outgrown the laboratory scale. These will be demonstrated and assessed at pilot remediations during the second half of the programme period (1995-1996).

Besides treatment technology, methods have also been developed to gain insight into the financial and environmental consequences of a clean-up and treatment operation. These methods are to be used to assess the pilot remediations and to compare the alternatives for large-scale treatment plants.

The composition of the spoil (sand, clay and various pollutants) is crucial in the selection of (combinations of) methods to be applied. But the extent of the contamination plays an important role, too. In the Netherlands, many different types of spoil are encountered, with treatment costs for each type ranging from some tens of guilders per tonne to hundreds of guilders.

Pilot remediation

The first of the three planned pilot remediations (i.e. the clean-up of Elburg harbour) was completed successfully. Extensive preliminary studies at the location as well as accurate classification of the sediment have proved to be vital to the success of any such operation. A thorough preliminary study will save cost later on. It will enable dredgers to employ the most appropriate methods and work accurately around the boundaries of the contamination, saving on costs and optimizing environmental effects.

The pilot clean-up has proved the operationability of environmental dredging methods and of hydrocyclone techniques to separate the sand.

Large-scale treatment

At present, most methods can only be employed at a small scale, which is relatively expensive. But treatment methods have to be environmentally effective at acceptable cost, and also result in useful products. The solution lies in large-scale treatment of sludge, which requires considerable investments as well as several policy decisions.

It was decided to investigate this solution by implementing a feasibility study on large-scale treatment methods. The study is to describe the technical, financial, environmental and organizational aspects of the various options.

The first stage of this study - reconnaissance - has been completed. It sketches the possibilities and consequences of some options, which will be described and compared in more detail during the follow-up investigation (1996).

The costs for the treatment of contaminated sludge are currently estimated at 50-100 NLG per cubic meter, or 35-250 NLG per tonne d.m. The exact cost will depend on sand contents and pollutants of the spoil offered.

International position

The approach to the Dutch sediment problems is pragmatic, yet systematic and wide-ranging. Internationally speaking, the policy followed so far and the results achieved by POSW-II put the Netherlands in a leading position.

The future for POSW-II

During the final stage, experts at POSW-II plan to further research promising techniques and methods in more pilot remediations in New Merwede River and Petroleumhaven in Amsterdam. The instruments developed to assess costs and environmental effects will be further refined and be made available through the publication of manuals.

The results of POSW-II are to be used to prepare policy decisions (in connection with the 4th Policy Document on Water Management) as well as advice on future sediment remediations. Supported by a decision-making system, this will encompass not only the preparatory stage and the treatment of contaminated sludge, but also the actual remediation works and the application of the resulting products. Rijkswaterstaat has established separate departments to manage and control each project stage.

Technical progress continues, abroad as well as at home, and the social need to clean and treat contaminated sediments at acceptable cost is likely to figure increasingly prominently on the national political agenda.

In spite of reduction of emissions as well as clean-up operations, it is expected that, even after 2010, large quantities of contaminated spoil will be released during the maintenance of harbours and shipping routes.

Content

1 Introduction

1.1 Description of the problem

The sediments of the Dutch surface waters are contaminated. Over the past decades, many pollutants have been transported by the large rivers, ending up in our surface waters. These substances have adhered to sludge particles settled in the estuary and still present at the water bottoms. It is true that the river water has grown cleaner over the past few years, clearing up the settled sludge as well. The heritage from a 'dirtier' past, however, still rests beneath these relatively clean top layers. Not only do these sediments constitute a poor habitat for flora and fauna, but the pollutants contained in them are also gradually dispersed in the groundwater and surface waters.

Three ministerial papers (ref. 1-3) explicate the governmental policy to address this problem in the coming years. Prevention is the key word here: the sources of the water contamination have to be controlled to prevent the sludge and water bottoms from being re-contaminated. Diffuse sources, in particular, will receive ample attention. In the meantime, existing problem sites have to be cleaned up. This will require the expedited construction of several large-scale deposits, allowing the most seriously contaminated sediments to be remedied, wherever possible, before the year 2000. One large deposit site in Ketelmeer is expected to become available in 1997 or 1998.

The problem

The quality of the sediment is determined by the concentrations of pollutants contained by it. Target values, threshold values, testing values and intervention values have been defined for heavy metals and organic compounds. These standards constitute the boundaries between five categories of contamination (0-4), established on the basis of eco-toxicological tests. All sediments in which one or more pollutants exceed target values (which constitute a 'negligible hazard') are labeled 'contaminated' (class 1 or higher). Exceeding of the threshold value (classes 2, 3 or 4) means exceeding of a 'maximum admissible risk level': this defines a contamination which cannot be tolerated.

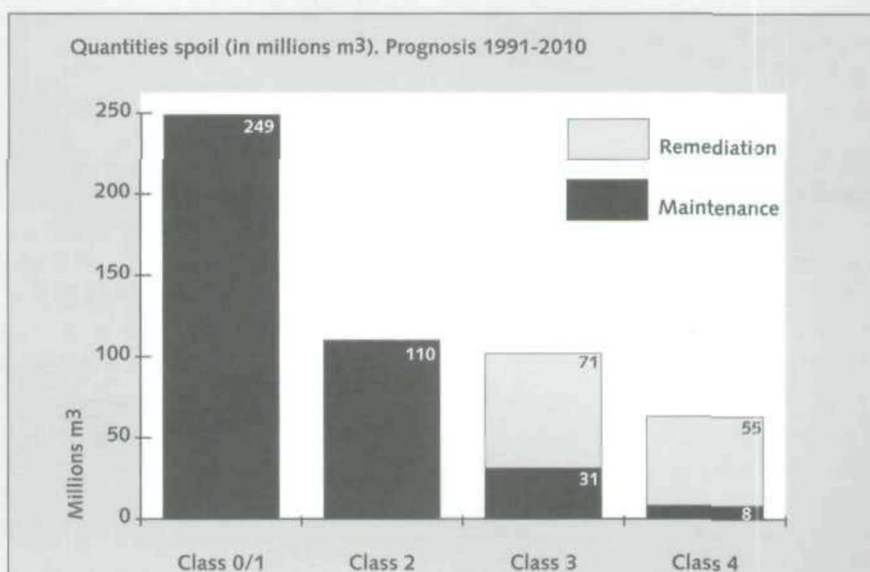
The Netherlands have some 6,000 km^2 of surface waters. Only one quarter of the waters under state control is estimated to be 'clean', or at least below threshold values. The rest is contaminated to a degree defined as medium (class 2), serious (class 3) or high (class 4) (ref.3). Sediments from regional waters are slightly less contaminated; more than one-third of these reach threshold values. The government expects that, between 1991 and 2010, a total of 87 million m^3 will have to be purified and recycled: 75 million m^3 sludge from state-controlled waters and 12 million m^3 from regional waters (ref. 2, 36, 38). An extra margin of uncertainty of 50% should be computed for these quantities, as the details of many cases of sediment pollution are not known as yet.
A total annual offer of 6.6 million m^3 of 'remediation spoil' can be expected over the period mentioned above. For the time being, this only concerns classes 3 and 4. Sediment of class 2 will not be up for remediation until after 2010, partly because of the costs involved and the lack of deposit space or treatment capacity.

Contaminated spoil from ditches and flood plains is not included, as no reliable inventory of this spoil has been drawn up so far. Estimates for ditch spoil range from 4 to 45 million m^3 a year (ref. 38).

Wherever dredging is required to maintain harbours, shipping routes and supply/discharge waterways, the financial aspect does not figure very largely in a possible decision to postpone the clean-up of contaminated sludge. During 1991-2010, an amount of 150 million m^3 of 'maintenance spoil' (classes 2, 3 and 4) is involved, i.e. 7.5 million m^3 annually. About half of this comes from the state-controlled waters and the Rotterdam harbours, mostly class 2 spoil.
So, until 2010, over 275 million m^3 of contaminated spoil will be offered, i.e. at least 14 million m^3 annually (classes 1-4). A train with a length of 4,000 km would be required to transport this spoil all at once!

If all of this would have to be deposited untreated, it would not only require enormous investments, but also take up gigantic space for deposits and storage sites. Even if 87 million m^3 out of this quantity is treated, that still leaves almost 200 million m^3 to be discharged in another way. By 2000, the government expects to dispose of three large-scale storage sites. Until 2010, the existing storage sites at Maasvlakte, Slufter and Papegaaienbek will be able to accommodate some 70 million m^3. From 1997, new deposits in Ketelmeer and Hollands Diep will have room for 50 million m^3 newly offered spoil. The importance of purification and recycling, as a sustainable alternative for depositing, will continue to grow as the year 2010 draws nearer.

Bar chart with rates contamination *class*



POSW

Yet, depositing is not an ideal solution, not even when it is done in accordance with the strict 'ICM limiting conditions' (insulation, control and monitoring). In view of its consequences for finances and physical planning, the option of treatment and recycling is to be preferred.
The objective of the Development Programme Treatment Processes (POSW) is the development and operationalization of selective dredging and treatment technology. The programme also aims at developing a generally useful body of

knowledge and experience, to serve as a tool for future sediment clean-ups and as a basis for sound policy decisions in this field.
The programme is supervised by the Directorate-General for Public Works and Water Management (Rijkswaterstaat) and is executed in cooperation with several other interested parties, such as various authorities, private companies and universities. In view of the general applicability of the results, the Association of Dutch Water Boards and the provincial authorities have also been involved in the programme since 1994.

The first stage of the project was finalized in October 1991 with the publication of an evaluation report, which was offered to Parliament (ref. 4). The main conclusion stated in this report was that only a handful of methods were currently operational, but that, within a few years, other techniques would reach the stage of applicability in the field. That is why POSW-II (1992-1996) is aiming at further researching, up-grading and field testing of promising methods.

Objective Interim report

This Interim report describes the intermediate state of affairs at POSW-II over 1995, reviewing dredging and treatment techniques, including the assessment criteria for the environmental effects and the costs.
As results of the individual subprojects within POSW-II - such as the performance of a method or the cost per unit of treated sludge - have not yet been made uniform, they cannot be compared to one another. Numerical comparisons between different methods based on the removal performance (in relation to the total amount of contaminated sediment), the environmental effects and the cost per unit of treated sludge will therefore not be presented until the final reporting in 1997.

The Interim report serves as a base for the discussion on sediment policy, as it will be laid down in the 4th Policy Document on Water Management. It will also provide background information for the parliamentary debate on the Remediation Programme Sediments in Waters under State Control 1996-2010.

Reader's guide

This report opens with a description of the objectives and methods of stage II of POSW until 1994 (Section 1.2). Chapter 2 describes the further research, up-grading and field testing of a large number of usable dredging and treatment methods. The progress in the evaluation of environmental effectiveness and costs of various techniques and treatment chains is discussed in Chapter 3. The next chapter (4) presents the pilot remediations, where the entire chain (preliminary study-removal-separation-purification-recycling-assessment) is tested in field situations. The Dutch experience in sediment clean-ups and sludge treatment outside the POSW-framework is also reviewed. Relevant experience abroad is discussed in Chapter 5. The final, 6th chapter presents the intermediate conclusions drawn from the results so far and pays attention to their practical applications.
The annexes comprise a review of POSW-II products and a list of references.

1.2 POSW-II

Objective POSW-II

POSW-I focused on the inventory of and preliminary research into methods which might be useful for sediment remediations. In stage II, the programme aims at further developing, operationalizing and field testing of technology for dredging, separation, treatment and immobilization. Such (affordable!) techniques will have to be made operational within the next three to ten years for large-scale clean-up and treatment operations of contaminated sediments.

The programme has gained weight by the publications of the Ministerial Statement on the Removal of Sediment and the Evaluation Document on Water. These state a policy objective whereby 20% of the total amount of contaminated spoil must have been treated and recycled by the year 2000. This objective concerns sludge categorized in the classes 2, 3 and 4. This political resolution has enlarged the pressure to make field-tested technology for large-scale treatments available as soon as possible. It has resulted, amongst other things, in an extension of POSW-II with a feasibility study, assessing the technical, economic, social and organizational feasibility of large-scale sludge treatment and marketing of recycled products.

Useful application

Several policy documents anticipate the useful application of recycled sludge before the turn of the century.
It is expected that, before the end of this year (1995), a Ministerial Order on Structural Materials will appear, to be enacted in stages until 1998. Preceding the enactment, studies, consultations with producers and consumers, and advising documents are currently being completed.
The Order will standardize the composition and leachability of soils and structural materials to be applied in construction works. Two categories are discerned: the first one can be applied without problems, the second one prescribes that certain standards for use be met and measures preventing the dispersal of pollutants be taken. Standards are also included for 'clean' soil, which can be used without restrictions.

Methods POSW-II

During the selection of promising treatment methods to be field-tested on the basis of previous study results, only technology which can be made operational within five years is chosen. With regard to contaminations, POSW-II concentrates on heavy metals (such as mercury and cadmium) and organic (micro-)contaminations such as mineral oil, PAH and PCBs.

First, the various parts of a clean-up chain are studied thoroughly: preliminary investigation-removal-separation-treatment-recycling. The methods are then tested more detailedly under complex field conditions, in a few pilot remediations.
POSW-II experts have also been developing assessment tools for the (technical and environmental) effectiveness and costs of a remediation. POSW-II employs a threefold method:

1. Making methods operational
2. Pilot remediations
3. Evaluation

The three parts are closely interwoven. The project organization guarantees that each sub-project can benefit from the experiences and intermediate results from other sub-projects. The joint results are included in the 'Feasibility Study Large-scale Treatment of Sludge'.

Costs and planning

The costs of POSW-II (1992-1996) have been estimated at over 32 million NLG. More than 13 million was set aside for the research of operational dredging and treatment methods and assessment tools; some 17.5 million was budgeted for pilot remediations, the remaining 1.3 million for organization, reporting and information.
The programme will be finalized in 1997. For this period, a total amount of 17 million NLG is still available (with 8.1 million earmarked for 1995, 7.9 million for 1996 and 2.6 million for 1997).

Developments outside POSW

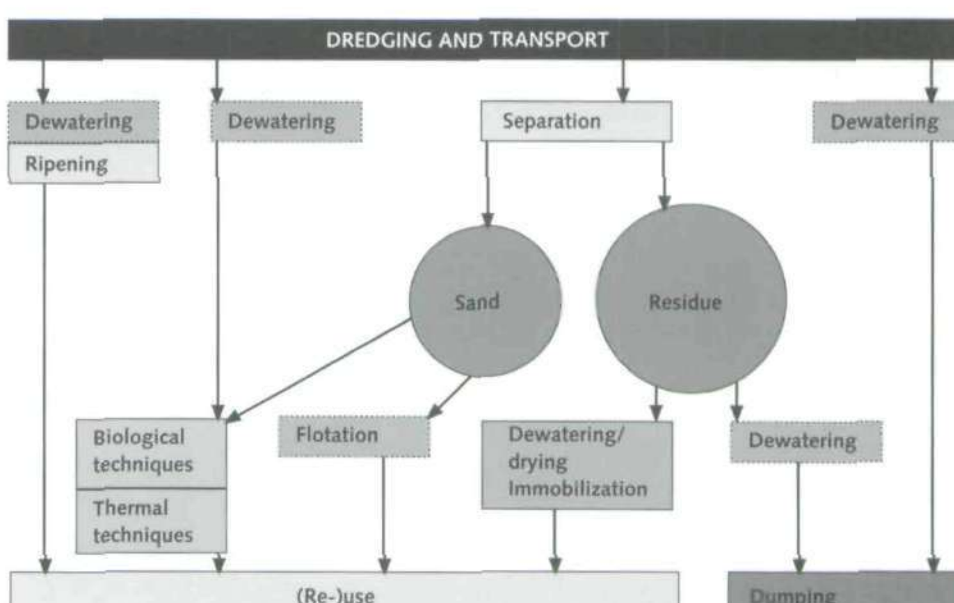
Outside the framework of POSW, too, important experiences are gained with sediment clean-ups and sludge treatment in various places in the Netherlands: the clean-up Zeehavenkanaal Delfzijl (Rijkswaterstaat); sand separation by settling and maturing of sludge on Maasvlakte (Rotterdam); settling basin (Regge and Dinkel); separation of sludge (Amsterdam); the occasional application of thermal or extraction methods to clean (sandy) sludge (such as Dommel); operations in Amersfoort and Ede.

2. Operationalization of methods

When making methods for sludge treatment operational, this mainly concerns environmental dredging, separation, purification and immobilization. POSW-II emphasizes the upgrading of technology which showed promise during the first stage of the programme. Interesting experiences from elsewhere are also taken into account (such as experiences from other authorities and conclusions drawn by experts abroad and in the field of 'dry-soil' remediation).

The tested methods have been selected guided by three criteria:
(chemical) performance and technical functioning;
the estimated period of making the method operational;
the costs of the method.
The last item, however, is not a decisive factor in this stage of the investigation; financial limiting conditions for sludge treatment have not yet been defined. In 1993, the government set a ceiling price for soil remediation of NLG 250 per tonne d.m. (excl. costs of removal, transport, discharge and VAT (ref.26)

Review of the operational possibilities for treatment of spoil



To approach contaminated sediment in a financially and environmentally effective way requires a preliminary study. The sediment also has to be typified to decide on the feasibility and best method of purification and/or concentration of the contamination in a certain fraction.

Several methods are available for the remediation itself:

a environmental dredging methods, allowing accurate dredging and limiting/preventing the dispersal of pollutants;

b physical treatment methods, emphasizing separation techniques which can decrease the volumes of sludge to be treated or deposited. These methods are also aimed at supplying a clean product suitable for re-use;

c *chemical and thermal treatment methods, which can reduce the quantity of* pollutants, or convert them into non-hazardous substances;

d biological treatment methods, where micro-organisms are used to degrade toxic organic compounds to harmless or less toxic substances;

e immobilization methods, aimed at physical-chemical bonding of the pollutants in such a way that the risk of dispersal into the environment becomes a negligible factor.

POSW-II has established separate project groups for each category of methods. The progress made in each group is discussed in this chapter. The working method generally followed was threefold:

- inventory and selection of potentially suitable techniques;
- short feasibility studies (based on e.g. literature review and laboratory tests), aimed at technical and financial feasibility as well as environmental performance;
- upgrading and further field testing.

Legends scale levels	
Laboratory scale:	**<1 m^3**
Bench scale:	**1-2 m^3**
Semi-technical scale:	**3-10m^3**
Pilot remediation:	**>1.000m^3**
Mean remediation:	**>10.000 m^3**

NB. These concern orders of magnitude

2.1 Project Site Investigation

Quite a lot of investigative work has to be carried out before the decision to remediate a sediment can be taken. Gaugings and borings are conducted and samplings are taken at various locations, after which the samples are analyzed for various pollutants in the laboratory. When a preliminary investigation shows a serious contamination, it is followed by a more detailed study to determine the urgency (risks) and extent of the contamination.
Every detail of the type, size and boundaries of the contamination has to be known before the clean-up operation can start: the horizontal and vertical boundaries between the pollution and the cleaner environment are charted, as is the profile of the water bottom.
The quality of the site investigation determines the efficiency of the dredging and facilitates the decision-making process on the treatment possibilities.

Site investigations are an important part of sediment clean-ups
Photograph: Haskoning

Objective

The subproject 'Site Investigation' researches and tests instruments to gather knowledge on the character, size and location of the contaminated sediment at the remediation site.
With the gathered data it is possible to determine the boundaries of the contamination and the best ways of dredging and treating the polluted spoil.

Short project description

For the optimization of these site investigations, a computer model has been developed by POSW-II: FAST. This is an important tool in determining the best ways of working highly accurately, yet at minimal cost.
Furthermore, a certain seismic method for more accurate mapping of the bottom geology has been tested.
Finally, an investigation of the usefulness of fast on-site screening methods for the determination of heavy-metal pollutants was recently initiated: X-ray fluorescence spectrometry. The initial results have been promising, and will be tested in future pilot remediations.
The final report of this project group is due in mid-1996. The reports on the pilot remediation in Elburg also pay attention to the results of this project (ref. 7, 8).

Optimization model FAST

In the period 1992-1994, POSW had an analysis made of the accuracies as well as of the measuring errors which may occur during the preliminary investigation and the dredging stage of a sediment clean-up, and of the possible consequences of these errors for the final result. This analysis led to the development of the computer model FAST (Fault Analysis Sanitation Track).

FAST can be used to design an optimal measuring and sampling plan in relation to the selected remediation objective. Its computations also allow the accuracies in the investigation and dredging stages to be geared at one another, resulting in a balanced removal plan with optimized total costs and results.

The program uses statistical analysis to translate the various uncertainties to volumes related to the actual remediation limit. For example, there will be a certain quantity of clean sediment within the remediation limit and outside the contamination limit as well as a certain quantity of polluted sediment outside the remediation limit and within the contamination limit. A quantity within the contamination limit, which is not removed, constitutes an ecological disadvantage. A quantity outside the contamination limit but nevertheless removed constitutes a financial disadvantage, as it was unnecessarily removed, transported and treated.

The development stage for FAST (including testing) was completed in mid-1994. FAST was then applied and tested in a number of field situations and actual clean-ups. Several parts of the model were subsequently expanded and corrected. The evaluation of this testing stage showed that FAST is very useful in sediment clean-ups.
The program will be made available for practical use at the end of this year. The experience so far has been described in a fact sheet (ref. 9).

The FAST Model - an example

The use of FAST had best be explained by a detailed example of a canal segment 1,000 m long and 35 m wide. At a longitudinal line of direction in the middle of the canal, the water depth varied between 1.6 m and 4.0 m. The thickness of the layer of sludge contaminated only with PAHs varied between 0 m and 1.4 m. Measurements and sample analyses showed that only the layer of sludge at the bottom of the canal was contaminated, and that the contamination limit was located at the (clear) dividing line between sludge and sand. PAH-concentrations at that level thus showed a sudden increase.
The water manager demanded that no more than 20% (in volume) of the contaminated sediment present be left behind, in other words a remediation efficiency of 80%, at a confidence rate of 90%. This meant that a monitoring plan for a clean-up study and a dredging plan had to be drawn up to meet the environmental requirements at minimum cost.

The characteristics of the soil entered in the model were typical for canals. Dredging would be conducted with a worm-wheel suction dredger. FAST automatically included the characteristics and accuracies of this machine (e.g. the systematic and random errors occurring horizontally and vertically during dredging, and the mean expectation regarding the extent of spillage typical of this equipment).

Processing cost of the dredging spoil was estimated at NLG 150 per m^3. FAST calculations show that with a decrease in grid distance costs for the demanded remediation efficiency are about 0.5 milion guilders lower.

Example FAST-calculations

Grid distance horizontal (m)	Excess depth dredging (m)	Total cost mln NLG	(%)	Remed.effic at 90% conf.
20	0	3.6	61%	65
	0.1	4.1	70%	74
	0.2	4.7	80%	83
	0.3	5.3	90%	89
	0.4	5.9	100%	92
10	0	3.6	61%	71
	0.1	4.2	71%	80
	0.2	4.8	81%	87
	0.3	5.3	90%	91

Seismic reflection methods

Most pollutants will firmly bond to the smallest sediment particles (clay). That is why the contaminations often remain limited to the layer of fine sediment in the water bottom profile. Conventional methods of determining the position of the clay layer with sounding rods or random samples are labour-intensive and not always accurate enough. In the period 1992-1993, it was therefore investigated whether seismic reflection methods might offer a feasible alternative.

Echoes, generated by ultrasonic sound pulses sent from the monitoring vessel, register sudden changes in density of the sediment. Through gauging by way of random samples, the thickness of the layer of clay can then be determined.

Experiments with 'multiple seismic reflection' (MSR) were conducted in Malburgerhaven (Arnhem). Single seismic reflection was used in Elburg harbour and also, outside the POSW-framework, in the river Rhine near Driel, in Eemshaven and Haringvliet.

The MSR test proved that this technique does not lead to a better understanding of the geology of the sediment than the more common single seismic reflection methods. All seismic measurements, however, were able to determine the thickness of the clay as accurately as the manual measuring techniques.

One advantage of seismic methods is that they convey a continuous image of the sediment profile (instead of merely an impression of the entry point of a spot boring). On the other hand, the method calls for a high setting accuracy of the equipment and skilled interpretation of the echo-monitoring results.

The experiences with seismic methods are described in a fact sheet (ref. 10).

X-ray fluorescence spectrometry

The horizontal and vertical remediation limits cannot be determined without reliable data on the extent of the contamination. These limits will usually be determined via a number of borings. The boring samples are analyzed in the laboratory for concentrations of pollutants. This method, however, is labour-intensive and relatively expensive. Besides, the measuring results will not be made available until some days after sampling.
Especially when checking the effectiveness of the clean-up operation, a faster determination of the extent of the contamination is most desirable.
POSW-II has therefore been testing a method which is capable of screening heavy metals in the sediment of the remediation site by way of X-ray fluorescence spectrometry (XRF). This screening is conducted on board the monitoring vessel or dredger.
To assess the feasibility of this technique, the number of measurements had to be expanded, especially with a view to judging the reliability, accuracy and preparation time of the samples. Three potentially suitable XRF-devices were therefore used in 1993 and 1994.

It proved possible to screen a large number of heavy metals in a sufficiently reliable and fast way. The method provides an impression of the contamination of the sediment while a clean-up operation is under way, and the pre-treatment of the samples is not very time-consuming.
The XRF-method will be field-tested during the pilot remediation in New Merwede (Section 4.2).

Completion subproject 'Site Investigation'

Within the framework of POSW-II, an inventory of the type of parameters to be analyzed in a site investigation was recently initiated, with a view to studying the treatment possibilities before a project is implemented.
Certain parameters appear to be decisive for the success rate of the treatment process (such as various macro-parameters for immobilization methods, or the sand content for separation or landfarming methods).
This inventory will be included in the final report of POSW-II.

2.2 Environmental dredging

Precision dredging of the contaminated sediment and preventing turbidity and spillage are co-determinants for the success rate of a remediation. Dredging tests during POSW-I proved that some conventional dredging methods leave too much contaminated spoil, or remove too much clean spoil; they may even result in unacceptable dispersal of the most contaminated fraction of sediment in the surface water.

Objective

The objective of the subproject 'Environmental Dredging' is the mutual comparison of potentially environmentally friendly dredging methods in a field situation, as well as developing an understanding of the process factors influencing the quality of the sediment after the remedial dredging works.

Short project description

An inventory of various existing dredging techniques was drawn up in the framework of POSW-II. Potentially environmentally friendly dredging methods were studied under field conditions. During these tests, several process-determining parameters were monitored, with turbidity as one of the main factors.

During one project stage, the emissions of organic micro-contaminations were quantified during transport of the spoil to the surface. This was done with the help of a computer model called Quantification of Emissions of Spoil (KEB in the Dutch abbreviation). Such a quantification appeared to be more complex for heavy metals.
Furthermore, field tests to compare various environmental dredging methods are currently being executed in Ketelmeer.

Inventory of available methods

An inventory and assessment study called 'Clean to the Bottom' was conducted of available and offered dredging methods and their adaptations (ref. 11). This has resulted in a number of promising dredging methods, which were then scrutinized at POSW.

Turbidity measurements

Due to turbidity during dredging, part of the finest fraction (often the most seriously contaminated part) enters the water phase, to resettle either locally or elsewhere. This will diminish the effectiveness of the clean-up and has an adverse effect on the habitat. Turbidity is determined not only by the method of dredging, but also by the sensitivity to this phenomenon of the water bottom as well as by locally determined aspects like flow and possible stratification of the surface water.

That is why standard methods were developed to define the sensitivity to turbidity of the sediment and surface water.
A fact sheet called 'Turbidity caused by dredging' has recently been published. It contains recommendations to minimize this phenomenon in future (ref. 14). It should be noted, however, that the care with which a chosen dredging method is applied may well affect turbidity more favourably than the choice of method.

Quantification Emissions Dredging Methods (KEB)

Dredging brings contaminated clay particles in resuspension from the often anoxic sediment, depositing them in a different physical-chemical environment. This will weaken the bond of many pollutants with the host particles, causing these pollutants to dissolve in the surface water (desorption). In dissolved form, they are often more toxic to aquatic organisms than they were when still bonded to clay particles.
The subproject 'Quantification emissions in dredging methods' was aimed at a more detailed assessment of these risks of releasing pollutants during and after dredging. So far, this project has produced a computer model which can make a reliable estimate of the occurrence of desorption of organic micropollutants during dredging and the period immediately following it. The quantification of emissions of heavy metals as a result of dredging has not progressed quite as far. KEB has provided a better understanding of the complexity of the various bonding shapes of metals to clay particles. This will require much fundamental research, which does not fit the concept of POSW.

Further testing of the model for the dispersal of organic micropollutants and establishing standards for practical purposes are still desirable goals. A fact sheet on the KEB-results will soon appear (ref. 15).

Field testing

A water injection dredge, an adapted sludge cutter dredge, an adapted bucket dredge and a wormwheel suction dredge were tested in field situations and appeared to be suitable for environmental dredging under (sometimes highly) specified conditions (ref. 16, 17).

For purposes of comparing various dredging methods under identical conditions, dredging tests were implemented in 1995 in Ketelmeer (ref. 18, 19). This was done in cooperation with the IJsselmeer Directorate of Rijkswaterstaat. A number of methods which can accurately remove spoil in thin layers is being tested. Hydrological and eco-toxicologic studies as well as measurements of turbidity and resettling will be included in the test procedure (which will continue into 1996).
Apart from the general significance of these tests for POSW, the results will be relevant to the conclusive remediation of Ketelmeer, which is to be implemented within the next four to ten years.

POSW has also conducted dredging tests with a wormwheel suction cutter

The pilot remediations also figure in the subproject 'Environmental Dredging', as here, too, dredging methods are tested in field situations.

2.3 Physical treatment methods

Pollutants often reside in different fractions of contaminated spoil. Many pollutants adhere more strongly to the clayey part (the fine fraction) than they do to the sandy part (the coarse fraction). By utilizing the difference in physical properties of clay and sand, the pollutants can be separated from the sand, thereby concentrating the pollutants in the clayey part of the spoil.

Objective

The objective of the subproject 'Physical Treatment Methods' is to gain insight into the parameters which determine the success of a separation method, and on the basis of which a system for process control can be developed.
This not only requires research of methods to typify sediments, but also tests conducted in the laboratory and the field of physical techniques with regard to their separation performance and their practical applicability.

During POSW-II, extra emphasis is laid on the study of flotation methods and dewatering of finely grained (sub) flows, as very little knowledge is available in these fields.

Short project description

The project experts have first tried to understand the parameters which determine the success of a separation method. To this end, they studied the characterization of sediments, such as the 'fingerprint method'.
Field experience with hydrocyclone separation showed that, for good separation results and a sufficient final quantity of clean sand, the sand fraction of the dredged spoil should amount to at least 50% of the total quantity. A smaller percentage diminishes the separation performance (i.e. the separated sand is less clean) and increases operational cost disproportionately (large quantities of sludge will have to be separated to produce small amounts of clean sand). Hydrocyclone separation is now applied at a practice scale.
Furthermore, a feasibility study of dewatering methods is conducted within the framework of the subproject 'Physical Treatment Methods'. This is done to take stock of the currently available operational methods for mechanical dewatering of very finely grained sediment, or finely grained subflows from wet separation processes. Dewatering is aimed at reducing the quantities to be deposited or treated, or at preparing the materials for recycling. Froth flotation and the usefulness of the flotation cyclone were also investigated. The former proved useful to treat an inadequately cleaned sand fraction leaving the hydrocyclone, and the method was also studied as a purification method for the clay fraction.
Practice tests were conducted with conventional froth flotation of sand and clay.

Component of
a separation plant

Characterization of sediment

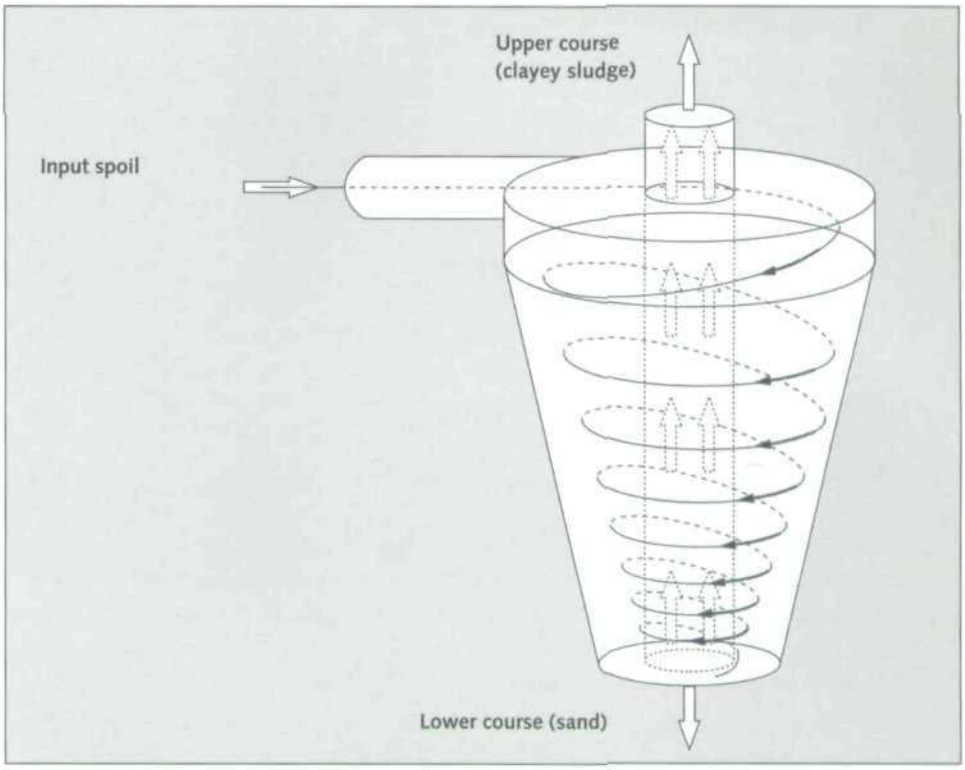
For a successful separation of contaminated sludge into a clean fraction and a contaminated fraction, the fraction containing the pollutants should first be identified (characterization of sediment). It depends on the subsequent process for the treatment of the sludge which typifying methods are used. If a fraction proves to be inadequately cleaned in a first separation cycle, a different method of characterization will be employed next. One frequently used method is the 'fingerprint method', which employs several small hydrocyclones to separate the sludge into multiple fractions. These are then analyzed for the concentration of pollutants. This yields a detailed image of the distribution of the pollutants across the differently grained fractions and allows experts to determine a suitable grain diameter for hydrcyclone separation.

If separation is not achieved by hydrocyclone, but through other methods (such as a settling basin or flotation), characterization by way of the fingerprint method is less useful, because the latter two use a different principle of separation. Other typifying methods studied by POSW also concentrate on a single specific treatment technique and do not review the possibilities for separation in general. A search for a more generally applicable method of characterization is currently being conducted, to enable selection of the separation method most appropriate for the type of spoil involved in a specific operation. Then the specific methods, such as the fingerprint method for hydrocyclone separation, had better be left to the contractor actually executing the process of separation.

Hydrocyclone

A hydrocyclone is a funnel-shaped centrifuge through which the contaminated sludge, diluted with water, is conveyed from the top downward. The high speed in the hydrocyclone makes the larger, heavier particles (sand) trickle down along the outside wall; these leave the cyclone via the 'lower course'. The lighter, finer particles (clay) stay on top, in the centre of the cyclone, and flow away via the 'upper course'. As the pollutants are usually bonded with the clay particles, they will be concentrated in the upper course. By executing the process twice, the sludge can be separated into three fractions: coarse sand, fine sand and clay. The sand fractions can be cleaned further, if desired, by way of polishing methods such as flotation (see elsewhere in this section). The separated and post-treated sand will then be clean enough to be used in civil or hydraulic engineering, or be re-introduced in the water system. The contaminated clay fraction has to be treated or deposited. The fractions can never be completely separated: a small part of the particles will always end up in the 'wrong' fraction. The separating capacity of a hydrocyclone is expressed in the diameter of the parts which have an equal chance of ending up in either the upper course or the lower course. This 'd50' will often be situated between 20 and 63 μm. For an optimum performance of the hydrocyclone, the dry-matter content of the slurry will have to be lower than 25%.

Hydrocyclone



Flotation methods

To prepare the spoil for flotation, it is first largely diluted with water. Next, small air bubbles are forced through the resulting suspension, to which flotation substances have been added. These substances make sure that the pollutants will adhere to the air bubbles. The bubbles move upward to the surface, where they form a frothy layer which is then skimmed. The flotation additives (called collectors or frothing agents) achieve a selective separation: only the pollutants adhere to the air bubbles and end up in the frothy layer. This requires a thorough understanding of the process to achieve the most effective combination of additives. The composition of the sludge and the contaminations are important variables in this respect. Flotation results in a residual flow (the froth) with a high concentration of pollutants. The treated sludge can be re-used, provided it is clean enough.

With regard to flotation of the (fine) clay fraction, laboratory tests were executed in the framework of POSW-II. These concerned both the conventional use in flotation cells and flotation using a flotation cyclone. The laboratory tests were followed by a test at semi-technical scale. At the time, the results were too discouraging to justify further research within the context of the programme.

But the tests at semi-technical scale with conventional froth flotation offered excellent prospects. The positive results led to a field test with the clay fraction released by the separation of spoil from Elburg harbour.

Field tests

During the pilot remediation in Elburg harbour (see Section 4.1), 40,000 m^3 of spoil was transported to Den Helder, were it was treated with the aid of hydrocyclone separation.
Clean sand and contaminated clayey sludge were separated in two steps, which resulted in three fractions.

The used separation configuration demonstrated that more than 10% of the sand, possibly still separable, had remained in the clay fraction. But this was condoned by the requirements in the specifications.
Too large a concentration of contaminated sludge in the clean sand fraction was rarely a problem and never constituted a quality problem. The entire bulk of separated sand could be marketed for civil engineering purposes.

Part of the fine fraction from the upper course of the hydrocyclone plant was flotated (ref. 22). The contamination by PAH appeared to be concentrated in a relatively small part of the fine clay fraction. Selective removal of heavy metals proved more problematic. In principle, the fine fraction treated by flotation met the standards set by the current (preliminary) Order on Structural Materials, and was therefore re-usable.

Conclusions

Insight in the parameters determining the performance of a separation method was gained by conducting various field tests. The methods of characterization currently available, however, are still too much geared at a single treatment method. That is why research on a more generally applicable method of characterization has been initiated.

Separation of fractions via hydrocyclones and/or settling basins (studied outside the context of POSW) is now operational and applied in the field. Hydrocyclone separation is suitable only to spoil with more than 50% sand, as the separation performance is diminished by lower contents (the separated sand is less clean), raising the operational cost disproportionately (separating large amounts of sludge to produce small quantities of clean sand).

Flotation works well with the sand fraction. Flotation of the fine clay fraction works reasonably well with regard to the organic contaminations, but the evaluation results for heavy metals remain unclear. Possibilities for application have been assessed during field tests.

2.4 Chemical and thermal treatment methods

Some toxic substances can be chemically converted to non-hazardous compounds. A good example is the incineration of toxic hydrocarbons to carbon dioxide and water.
The chemical release of bondings between pollutants and clay particles and the subsequent discharge of these pollutants through an extraction agent are also considered as a chemical purification method.

Objective

The objective of the subproject 'Chemical and Thermal Treatment Methods' is the selection and operationalization of chemical (also thermal) purification techniques, bringing them to a level where they can be employed in pilot remediations.

Short project description

During the first stage of POSW, the sulphuric acid-producing bacteria Thiobacillus ferro-oxydans, which had been employed for metal extraction purposes, seemed capable of also degrading mineral oil and PAHs. Metal extraction with the aid of the complexing agent EDTA, too, showed promise in POSW-I. Both applications were further studied, but proved non-feasible. Therefore, POSW-II went in search of new purification methods to be reconnoitred. Based on a number of selection criteria (costs, applicability, time required for upgrading to operational level) three new methods were chosen: wet oxidation, solvent extraction and thermal purification.

Thio-leaching

The bacteria Thiobacillus ferro-oxydans seemed capable of degrading oil and PAHs, too (POSW-I). This offered perspective for a combined biochemical purification of heavy metals and organic micro-pollutants. Since many sediments contain such 'cocktails' of contaminants, this was of great importance.

But neither effect could be proved within POSW-II. A mixed culture was used for the tests in the first stage, so the degradation of oil and PAH demonstrated previously could be ascribed to the presence of other bacteria. The degradation of organic substances by Thiobacillus is not confirmed in scientific publications either.

A great deal of lengthy research appears to be required to prove that 'thio-leaching' is a (non-)feasible option. Such research is outside the scope of POSW, which employs the firm limiting research condition of operationalization within five years.

EDTA-extraction

During POSW-I, the metal extraction from terrestrial soil and dredging spoil with the aid of the complexing agent EDTA (ethylenediamine-tetra-acetic acid). This was further explored in POSW-II at a semi-technical scale.

The tests were halted when the treatment performance in the first (dry) soil samples proved inadequate and the extraction time needed was too long, due to the competition of heavy metals with calcium-ions, amongst other causes. More laboratory research was required and, again, this would have gone beyond the maximum period of upgrading permitted within the scope of POSW. The upgrading project was therefore ended.

Wet oxidation

The feasibility of two methods using high-pressure oxygen to degrade mineral oil and PAH have been investigated in laboratory testing and literature review: the VerTech process and the Bayer-Loprox process (see Box 5). Both oxidation methods showed great promise in the laboratory, requiring more detailed studies with regard to process optimization and the production process and marketing of a final product.

As VerTech has the disposition of a full-scale operational plant, it was decided to conduct a sludge test under field conditions. This was done in the beginning of 1995. The results were favourable: not only were organic micro-pollutants reduced, but heavy metals were immobilized to a certain degree, decreasing their leachability.

Wet oxidation

The most widely known method of oxidation is incineration at extremely high temperatures. With regard to wet sludge, however (which often holds no more than 15-20% d.m. in the clay residue), this process requires extraordinary amounts of energy, as first the liquid has to evaporate. Organic compounds can also be degraded with the use of oxygen at lower

temperatures (under high pressure or by using catalysts) without the need to dewater the material beforehand: wet oxidation. Such methods have been employed for years in the purification of sewage sludge, regeneration of active carbon and other industrial purification processes.
For the purification of de-sanded spoil, two oxidation methods have been researched so far. Both methods require oxygen to be added to slurry, although, in itself, this is not sufficient to trigger the reaction of degradation.

VerTech

With regard to the VerTech-procedure, the solution was found in oxidation conditions of high pressure and a reaction temperature of 200-300°C. The pressure is realized by introducing the slurry into a tube reactor installed at great depth (1300 m). In February 1995, sludge from Elburg harbour (totaling 158 tonnes d.m.) was processed successfully in eight hours by the VerTech plant in Apeldoorn. This yielded better results than tests at laboratory scale had done: the PAH-concentrations could be decreased to target values (>98% was degraded). More than 70% of mineral oil was removed.
Furthermore, the produced sludge cake proved to be highly suitable to re-use in civil engineering works. The product differs from ordinary clay particularly in its imperviousness to settling.
On the basis of these results, the costs of treating medium sandy spoil (50% sand-50% clay) have been estimated at NLG 55 per tonne spoil (in-situ material). These costs do not include VAT, transport to the treatment plant, separation of sand and fine fraction, and the cost/benefit of marketing the sand and the treated fine fraction.

Loprox

The other option, the Loprox method, is based on lower pressure and temperatures (150-200°C). A catalyst has been added to guarantee a successful reaction under these less extreme circumstances. More than 99% of PAHs and mineral oil are degraded. Nitrogen is removed in the form of ammonium, which can be further denitrified in a water purifier.
The end product, a rather dry sludge cake, is very useful as a clay substitute, e.g. in dike bodies. Not only does it have favourable civil engineering properties, but the heavy metals contained in it have also been properly bonded due to the oxidation process.

Both processes require energy only to start: once the oxidation reaction has been triggered, it will perpetuate itself with the aid of the heat released during the process. More energy is needed for the production of the required oxygen and the supplementary water purification. But the total consumption of energy is quite low: some 270 kWh per tonne d.m. For the most economical processing, reactors with an hourly capacity of 25-90 tonnes slurry (15-20% d.m.) will have to be used. The excellent treatment performance, favourable mechanical properties of the final products, as well as the fact that the reactor can handle large quantities of slurry without prior dewatering, make wet oxidation an attractive alternative for the treatment of spoil contaminated by mineral oil and PAHs.

Solvent extraction

The method of solvent extraction removes organic micro-pollutants with the use of organic solvents.
Laboratory tests with acetone showed good results for PAH and PCBs. Unites States experts also employ other extraction agents; more research is needed to find out which method is best suited to sediments. The cost effectiveness is presently being estimated.

Thermal reduction

The Ecologic process is based on thermal desorption at 600°C and subsequent reduction of organic micro-pollutants with the aid of hydrogen at 900°C. The application of thermal reduction is especially interesting with a view to organochlorine compounds, such as PCBs, dioxines and furans. Laboratory tests of sludge in the Netherlands and field tests in the United States showed that this method does indeed result in extensive degradation of organochlorine compounds.
In view of the high indicative processing price under field conditions, it was decided to discontinue further upgrading during the second half of POSW-II.

Conclusions

The conducted research showed promise for: wet oxidation (PAH and mineral oil) and solvent extraction (PAH, oil, PCBs and pesticides). Thermal reduction, too, appears capable of delivering a comparable high treatment performance as well as comparable low residual concentrations (target level) for dredging spoil.

Follow-up

For 1995-1996, feasibility studies have been scheduled, featuring thermal desorption and incineration (techniques already operational for dry soil, but requiring further research for their application to sludge) as well as a new development aimed at the extraction of supercritical carbon dioxide.

A cost evaluation for solvent extraction has also been planned. One of these methods will be employed in field tests regarding the removal of hydrocarbons from the spoil of the pilot remediation at Petroleumhaven.

2.5 Biological treatment methods

At the base of biological treatment are natural processes, during which micro-organisms degrade organic micro-pollutants. Biological treatment will generally result in a fast initial degradation, after which a residual concentration of pollutants is left behind. The level of this concentration often approaches the application standards and varies per method applied and per type of sludge tested.

In the remediation of polluted terrestrial soil, biological processes are already being used (in a limited way). The principle of these processes is applicable to soils contaminated by organic compounds such as PAH, oil, HCB and PCBs. Bacteria require oxygen for the degradation of PAH and oil, whereas degradation of the other compounds requires first anoxic and subsequently oxygen-rich conditions. Especially the introduction of air into the wet and therefore anaerobic sediment differs from the treatment of terrestrial soils, which by nature contain more oxygen than do sediments.

Objective

The objective of the subproject 'Biological Treatment Methods' is the testing, further developing and upgrading of a few promising biological methods for the purification of sediments contaminated by PAH, oil and HCB.

Short project description

In the framework of POSW-I, laboratory tests were executed on the applicability of biological treatment of sediments. A few methods, such as landfarming and aeration basins, proved practically applicable in the near future. The second stage of the programme focuses on optimization and further upgrading of these and other promising methods, in particular with a view to the treatment of sediments contaminated by oil and PAH.

The possibility of in-situ remediation was also explored in a once-only project. Methods for ex-situ remediation based on landfarming and reactors were studied as well (using spoil from, for example, Petroleumhaven in Amsterdam).

An HCB-degradation test is presently executed in a deposit with sludge highly contaminated by HCB (around 20 mg/kg d.m.).

In-situ remediation (bio-dredging)

Biological treatment is based on natural processes, whereby contaminations are degraded in oxygen-rich conditions. It is not unthinkable for these processes to take place in the sediment itself. In 1992, several preparations were marketed which were said to speed up the natural degradation of organic compounds, amongst which were oil and PAH, in the sediment (in-situ). Simply scattering of these preparations (containing special bacteria, nutrients and/or oxygen-carrying compounds) onto the surface water, followed by their settling on the bottom, would be sufficient to let the bacteria do their useful job in the sediments of *shallow waterways*.

Their composition and the effect of these products on two different sediments have been investigated in the framework of POSW. It appeared that they contained hardly any degrading bacteria and /or oxygen-carrying compounds. Nor did they affect the degradation of oil and PAH (ref. 23).

Biological dechlorination

In oxygen-poor conditions, certain bacteria are capable of partially dechlorinating chlorous organic contaminations (such as PCBs and certain pesticides). After oxygen has been introduced, other micro-organisms take care of further biological degradation. This method is very attractive because of the high toxicity, the persistence and bio-accumulation of these contaminations. POSW-II follows up the positive laboratory tests conducted previously, and is investigating whether the dechlorination can be stimulated during storage in a deposit. This field test is conducted in a deposit in Delfzijl in which sludge from Eemskanaal is stored.

The effects of various carbon sources, host material and nutrients are studied. Although no significant lowering of the HCB-concentration has been observed so far, the generation of gas and discolouring indicate an increase of biological activity. The project will continue until the end of 1996.

Ex-situ biological degradation

Laboratory tests have shown large variations in the analysis results of sediments labeled 'medium contaminated' (by oil and PAH, 1500 and 30 mg/kg d.m. respectively). This makes a uniform interpretation of the results rather complicated.

It was decided to execute future optimization tests, as far as possible, with only highly contaminated sludge (oil and PAH at 10,000 and 500 mg/kg d.m. respectively). At this level, degradation is clearly measurable and the results are mutually comparable.

Extensive landfarming

With extensive landfarming, sludge is spread in thick layers (2 m) across an area and then planted. This method is based on the principle of removing a residual contamination from pre-treated sludge by giving time a chance (several years) to do its work. Sludge from Zierikzee and Geulhaven has been pre-treated by intensive landfarming during POSW-I, and the results of extensive landfarming of this sludge are now researched during the second stage. Intermediate results show that degradation is continuing.

The following methods were compared using sludge from Petroleumhaven, Amsterdam:

Image of a test section for landfarming

Intensive landfarming

For the execution of intensive landfarming, 250 m^3 of sludge was spread on dry land in a layer one meter thick. Apart from spoil from Petroleumhaven, spoil from Wemeldinge harbour (which was less contaminated) was also used in this study. The effect of natural maturing versus planting with reeds is investigated (see also box).

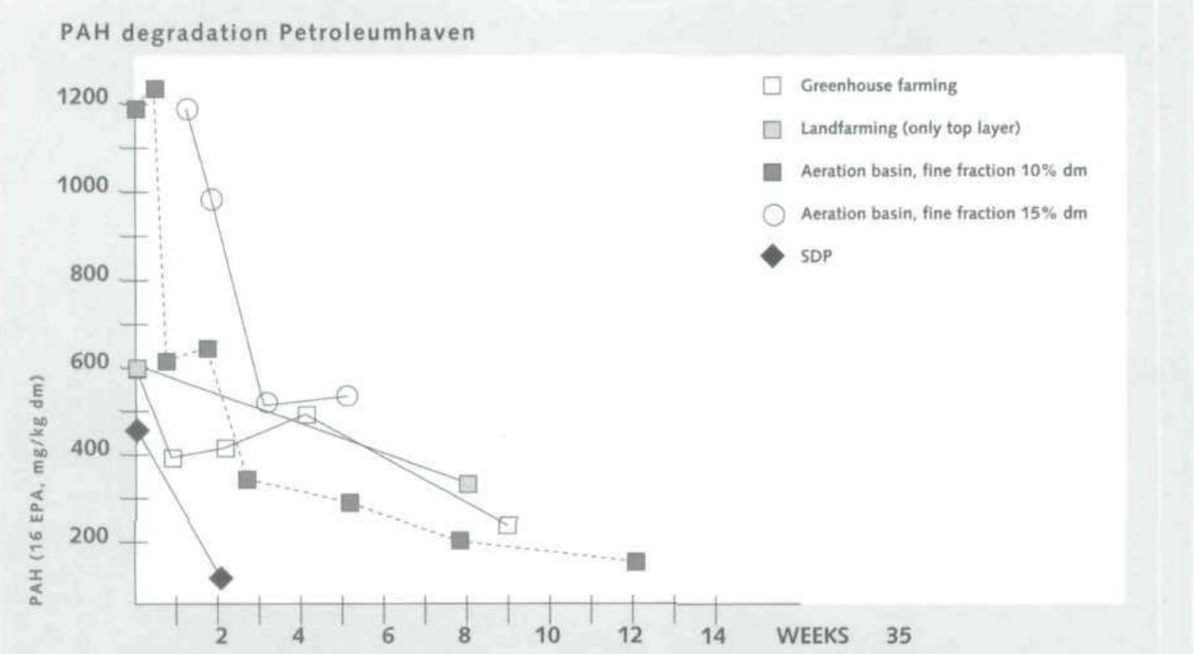
Greenhouse farming

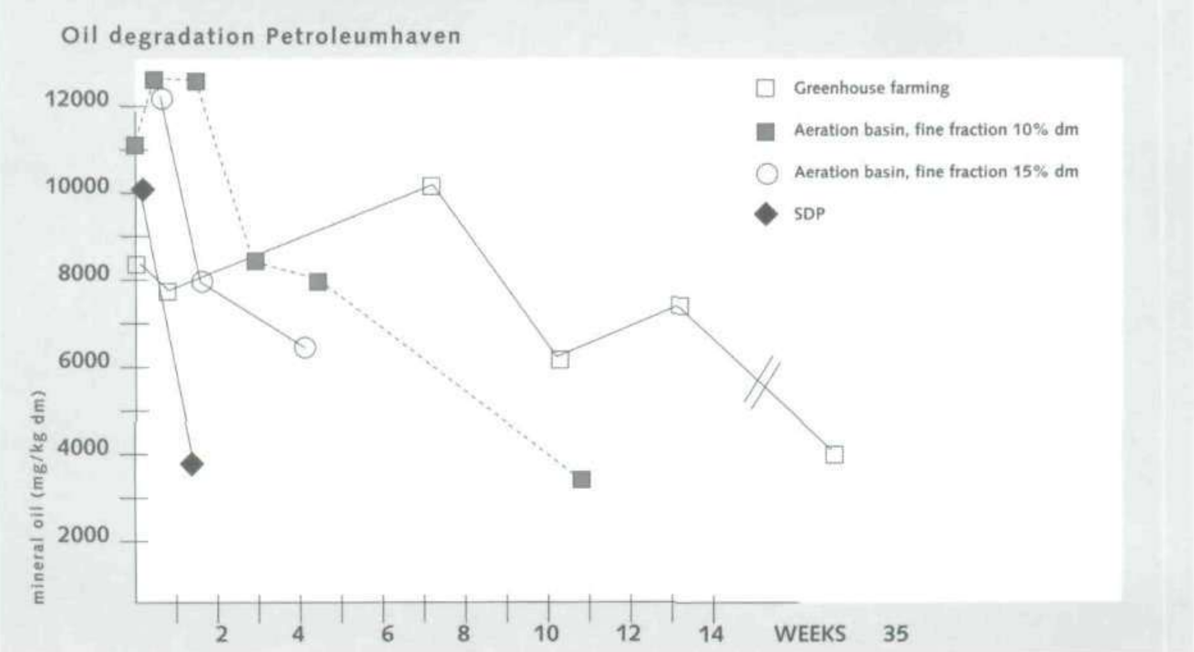
In the case of greenhouse farming, sludge is spread inside a glasshouse in a layer 50-100 cm thick. The biological activity in this layer is speeded up by active aeration and raising the temperature to 35°C.

Aeration basin
Here, the fine fraction resulting from hydrocyclone separation (<50 μm) is kept suspended at a temperature of 20°C (aeration). The aeration basin will eventually be shaped in a rectangle, in which moving aeration units keep the sludge suspended in a relatively simple and affordable way. This project was aimed at defining the optimum dry-matter input (10 and 15 per cent) as well as the best way to introduce oxygen in a reactor of 4 m^3.

Slurry Decontamination Process (SDP)
With this method, the entire amount of spoil is entered into a series of reactors, where it is first submitted to separation, then de-agglomeration, followed by bio-cascades and dewatering. The process was originally designed for the treatment of terrestrial soils. The possibilities for dredging spoil were investigated in a 4 m^3 testing plant.

The following graphics show the results for the degradation of PAH and oil.





The results show that the decrease of the contamination with the aid of the Slurry Decontamination Process occurs relatively fast compared to other biological treatments. For PAH, the target level defined in the Order for Structural Materials was achieved after a staying time of just two weeks. The degradation of oil stagnated at a value of 3,000 mg/kg d.m. This was probably due to the type of oil. Follow-up tests will concentrate on the improvement of the oil degradation.

Landfarming and reactors as biological treatment methods

Landfarming

Landfarming, already applied in the treatment of dry soils, can also function in the treatment of spoil. Immediately after dredging, the spoil is spread in layers of 0.5-1 m on dry land. After passive drying or dewatering, oxygen from the air can penetrate the material. This can be hastened by ploughing, aeration, planting and applying structural improving agents. Such conditions are favourable to the degradation of PAH and oily contaminations by micro-organisms. Applying host material and nutrients as well as heating and soil moisturizers will stimulate this process of degradation. Draining and covering by foil can prevent intermediate contamination of air, groundwater or surface water as well as excess wetness of the sludge to be treated.
Besides an intensive method, whereby thin layers receive regular care, there is an extensive method, to be applied for thicker layers. The latter is very time-consuming (some ten years), and can only be applied after intensive pre-treatment. Greenhouse farming takes places under optimized conditions in heated greenhouses.
This obviously demands more energy and money, but the degradation process is much faster (six months or less). More sludge can thus be treated on the same surface area.

Reactors

One step beyond greenhouse farming lies biological treatment in reactors, in which all relevant conditions can be controlled and optimized. Mixing and aeration can speed up the degradation process even further. Various methods for biological treatment of sludge by reactors are available. A 'bioreactor' cleans by centrifugal force in a revolving drum, treating the intact, unseparated spoil. Before the sludge is introduced in the 'slurry reactor' (see the Slurry Decontamination Process), however, it is first separated in several fractions and then submitted to biological treatment in various reactors. An 'aeration basin', finally, is used mostly for the fine fraction, keeping it suspended during treatment.

Field tests

In the framework of POSW-II, biological treatment methods have been applied at a scale of some hundreds of cubic metres.
Biological treatment will be tested at field scale in the pilot remediation in the Amsterdam Petroleumhaven, which has been planned for 1996 (Section 4.3).

Conclusions

Biological treatment methods for spoil appear promising. The selection of the method, however, depends on the available budget, time and space.
A biological treatment method is to be employed in the third POSW pilot remediation at the end of 1996, in Petroleumhaven, Amsterdam.
Before the end of 1995, an evaluation report on biological treatment techniques is due to be published (ref.24).

2.6 Immobilization methods

Not all kinds of contaminated sludge can be remediated through physical, chemical or biological methods. Particular problems are posed by spoil containing a cocktail of pollutants (high concentrations of both organic substances and heavy metals) as well as much finely grained material. Such a combination of pollutants had theoretically best be processed with multiple-step treatment. But this will lead to unacceptably high costs.
With such spoil and/or residual flows from other treatment processes, the pollutants can be bonded chemically and/or physically: immobilization. This will halt further dispersal of the pollutants in the environment.

Objective

The objective of the subproject 'Immobilization' is the mutual comparison and upgrading to field level of immobilization methods which have proved promising during POSW-I or in projects abroad. The project focuses mostly on thermal methods.

Short project description

In the framework of POSW-II, two thermal methods are concentrated on: sintering ('Ecogravel') and melting and crystallization, which takes place at higher temperatures (artificial basalt).
In the second pilot remediation, in New Merwede, the process of melting and crystallization will be employed to immobilize the pollutants in the fine fraction.

In the framework of POSW-II, more detailed study will be conducted on the question whether the heavy metals are bonded securely enough to meet the current statutory requirements.

Thermal immobilization

The leaching standard defined in the preliminary Order on Structural Materials is apparently not exceeded in thermal immobilization methods (vitrification and sintering). Organic pollutants disappear by incineration and metals are largely bonded in the crystal matrix.
The final products can be used as substitutes for gravel and basalt in civil engineering works. The costs for large-scale application appear to meet the defined limiting conditions.

Ecogravel

The production of gravel substitutes from contaminated sludge is quite similar to the traditional processes for baking ceramic products such as tiles and bricks. That is why the basic material must be a clay-like substance. By heating to 1200°C in a revolving drum furnace, the mineral substances (sand and clay particles) are sintered. Heavy metals are bonded to silicate grids of the 'baked' product.

Melting tests were first tried out at a small scale

Until the first months of 1993, several small-scale tests were conducted - also in the framework of POSW-II - of various types of contaminated sludge. It appeared that the sintering temperature had to be adjusted very accurately to achieve a stable (not too porous) final product. Organic pollutants were completely incinerated. Volatile metals (mercury, cadmium, lead) and fine particles (fly-ash) were released as waste via flue-gas washers. These substances were partially re-introduced in the sintering process, although per tonne of sludge (d.m.) some five kilograms of fly-ash had to be discharged. Furthermore, waste water was released during the dewatering and drying processes of the clayey sludge; this water had to be purified. Less than 1% of the locked-in metals (except for arsenic and molybdene) was released during leaching tests.
Ecogravel can be applied as a gravel substitute in asphalt concrete. A factsheet on this subject is being prepared.

Melting/crystallizing

Towards the end of POSW-I, in 1991, a feasibility study of sludge treatment at very high temperatures (1400°C) was initiated. At this temperature, organic pollutants are destroyed and mineral components melt. Heavy metals are absorbed in the mineral structure and thus immobilized.
An optimum distribution of grain size is achieved by separating the sand from the sludge, and additives are mixed in. The process of incineration, controlled solidification and crystallization will result in a final product closely resembling basalt, which can be applied in civil engineering works.

At POSW, numerous laboratory tests were conducted with class 4 sludge from various locations. As with sintering, waste products like volatile metals and fly-ash were found in the flue gases, and removed through flue-gas purification. The standards preventing the formation of dioxines applied here are just as strict as those applied to waste incineration plants. The final product of artificial basalt proved highly resistant to leaching: less than 1% of the total content of heavy metals was released.
A factsheet on the melting process has just been published.

Conclusion

At this moment, immobilization methods appear technically capable of handling all kinds of contaminated spoil, but they remain relatively expensive.

2.7 Summary

From a technical point of view, hydrocyclone separation of sand, possibly followed by scrubbing and polishing with froth flotation, seems to be extremely promising for sandy spoil (>50% sand). If the separated sand still contains pollutants, the sand fraction can be subjected to landfarming in addition to the above methods.

If the clayey residue from the sand separation is contaminated mostly by organic substances such as oil and PAH, the problem can be solved through thermal desorption, wet oxidation, flotation or treatment with bioreactors and aeration basins.

Finer sediments contaminated by a cocktail of pollutants can currently only be treated by thermal immobilization methods such as sintering or vitrification.

If the sand is not separated beforehand, the entire bulk of the spoil can be treated with biological methods, such as the slurry reactor or landfarming. Flotation is an option with sludge contaminated by organic micropollutants. Immobilization is an option when a cocktail of pollutants is found in the unseparated spoil.

With regard to materials most seriously contaminated with organic pollutants, it is quite possible that several other chemical or biological methods will become available in the near future.

Applicability of processing methods for treatment of fractions or types of pollutants

Technique	Fraction			Pollutant			
	total	coarse	fine	org.micro. pollut. (A)	oil,PAH (B)	metals (C)	cocktail (A+B+C)
hydrocyclone + density separation	+	+	+	o	o	o	o
settling basin	+	o	-	o	o	o	o
flotation (conventional)	+	+	o	+	+	o	o
flotation cyclone	-	-	-	-	-	-	-
wet oxidation	-	-	+	+	+	-	-
thermal desorption/reduction	+	+	+	+	+	-	-
solvent extraction	+	+	+	+	+	-	-
extensive landfarming	+	+	-	-	+	-	-
intensive landfarming	+	+	-	-	+	-	-
greenhouse farming	+	+	-	-	+	-	-
aeration basin	-	-	+	-	+	-	-
slurry reactor	+	+	+	-	+	-	-
sintering	+	-	+	+	+	+	+
vitrification	+	-	+	+	+	+	+

+ = applicable o = neutral - = non-applicable

3. The assessment of techniques and products

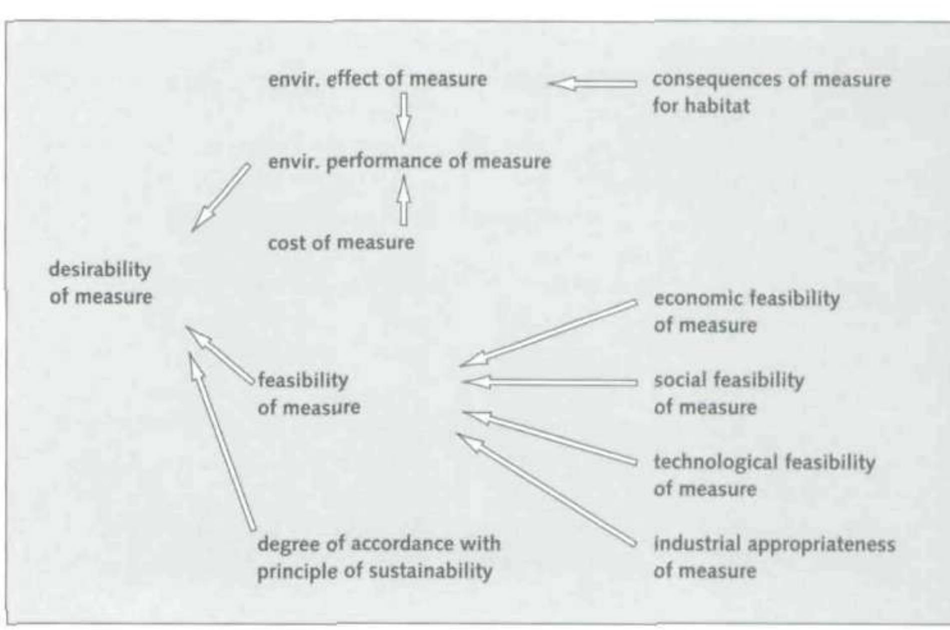
For each remediation situation, it should be possible to properly assess the environmental effectiveness and costs of the appropriate, complete clean-up chains. POSW-II is currently developing and testing suitable assessment methods both for techniques and for chains. Regarding the assessment of processing techniques, POSW focuses on their environmental effects and costs; additionally their economic, technological, organizational and social feasibility are taken into account (see the figure below).

3.1. Environmental effects

POSW's main purpose is to provide aids, which have been tested in practice, for the quantification of the environmental effects of individual dredging and processing techniques as well as for mutually comparing such techniques and processing chains.

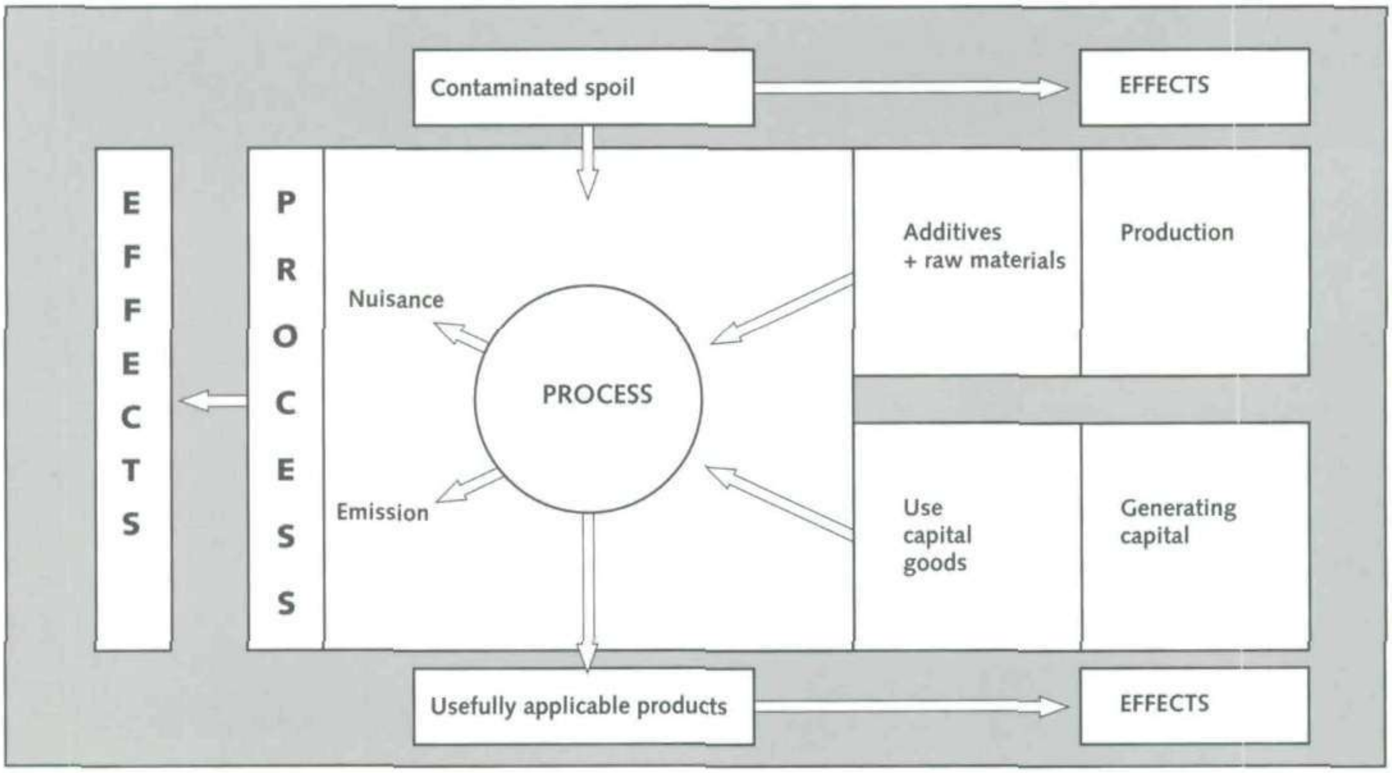
It should be possible to assess not only the environmental effects of processing chains but also those of individual processing techniques. This would involve such matters as the creation of waste flows to air, water and sediment. Furthermore, the extraction and use of energy and raw materials (during the remediation itself, as well as during transport) must be taken into account when making a final assessment of the environmental effects of a processing technique, as well as such aspects as the space occupied, nuisance caused to the surroundings, and the quality of the remedied sediment.

Diagram of desirability of environmental measures



The relevant environmental effects of a remedial intervention (i.e. the process) are diagrammed in the following figure. Here such an intervention is represented as a process with entering and exiting flows which may have environmental effects.

Diagram of the process-product approach



In order to carry out an integral analysis of the environmental effects of a processing chain, within POSW first the environmental effects of the chain are quantified; then, the results of this quantification can be classified and compared by means of a life cycle analysis (LCA).

The quantification of environmental effects

Within POSW, five criteria have been formulated for assessing the environmental effects of the remediation processes given in the above figure. They provide an insight into the advantages of a remediation alternative (e.g. reduction in volume of the contamination, remedied sediment, reduction in the quantity of dispersable pollutants, the quantity of recycled final products) versus its disadvantages (e.g. consumption of raw materials, nuisance, energy consumption, occupied space).
Such aspects can be derived from the parameters measured during the monitoring of processing tests (e.g. bioassays and leachability tests).

Life cycle analysis (LCA)

An LCA involves the analysis of the main process and accompanying processes. Of all these processes, data are systematically collected on the extent and quality of the waste flows, energy consumption, consumption of raw materials, emission of substances, space occupied, etc. Next, the data collected are summarized in the form of a few simple terms, enabling the assessment of the environmental aspects (e.g. aquatic, terrestrial and human toxicity, depletion of the ozone layer, contribution to the greenhouse effect and acidification). Internationally, occupied space is not considered a problem. However, in the

Netherlands it is a relevant environmental aspect demanding attention. Within the framework of POSW, an LCA analysis is currently being carried out based on Dutch standards for all environmental aspects.

Both environmental-effect and life-cycle analyses are objective assessment systems for the quantification of environmentally relevant parameters (here, those of a remediation process). However, neither of these two types of systems contain a second step for weighing the various parameters (i.e. subjectively assigning values to the various components).

Field tests

Both methods were elaborated on based on the data gathered during the pilot remediation carried out in Elburg (ref. 31). Three processing chains were compared with the following zero options: doing nothing (0a), and dredging and dumping without processing (0b).
The alternative processing chains were: (1) dredging and landfarming, (2) dredging, separation and dumping of the contaminated fraction, and (3) dredging, separation and thermal immobilization of the contaminated fraction. The direct effects ('first level') and energy generation ('second level') were found to be sufficiently distinctive to allow comparison of 1, 2 and 3. As regards comparison with 0b, effects of production and aspects such as capital goods ('third level') appeared to influence the analysis.

The analysis revealed that, from an environmental viewpoint, processing method 1 (dredging and landfarming) yielded the best result.
Method 3 (dredging, separation, thermal processing) appeared to be the worst alternative for nine of the thirteen environmental aspects, especially energy consumption and toxicity. However, the positive environmental effect of this method (i.e. the prevention of gravel extraction by producing artificial gravel) has not yet adequately been investigated. From an environmental viewpoint, the zero score regarding waste is clearly a positive aspect.
The environmental effect of method 2 (dredging, separation, and dumping of the residue) was somewhere in between the other two, especially because of the surplus of waste resulting from the contaminated sludge fraction.
From the LCA study it was concluded that more attention should be paid to the aspects of toxicity (e.g. as a result of the waste produced and the processing process itself) and occupied space.
Furthermore, effects of the 'third level' were found to be important when selecting a remediation alternative. In any case, transport of spoil must be avoided, if at all possible.

During an LCA, the bioassay results of both the processed and non-processed matter are assessed, as are the leaching results. It was found that data on toxicity play a supplementary role in the assessment of products. The differences in leachability before and after processing appeared to be very small, which means that for an LCA the aspect of 'change in leachability' seems to be of minor importance.

For the pilot remediation in Elburg, a plan for the monitoring of environmental effects was drawn up based on the environmental-effect method developed. As a result, the environmental effects could be included in the assessment report (Section 4.1).

Pilot projects

Within the framework of the assessment of environmental effects, the use of leachability tests (shake tests) and bioassays was investigated. For this purpose, both processed and non-processed spoil were investigated. The results of both methods are currently being assessed.

In view of the low leachability of spoil, it is hardly possible to observe differences in leachability before and after processing. Thus, this aspect is relevant mainly during the assessment of end products (column tests).

Data on toxicity play a supplementary role in the assessment of products. How to compare the bioassay results of processed and non-processed spoil is still under discussion in view of the physical changes occurring in the soil matrix.

Conclusions and recommendations

The project revealed especially the necessity of critically assessing complete clean-up chains on more aspects than only the current standards for substance concentrations.

LCA and the method for assessing environmental effects may be useful when choosing from the possible remediation methods. The final choice depends, of course, on the priorities set by the decision-maker (client, manager, policy-maker).

Follow-up

During the follow-up to this project, the assessment tools will be structured in the form of either a guide or an assessment model, which should be useful for the selection of individual processing techniques as well as complete clean-up chains. Furthermore, assessment methods and forms of presentation suitable for various target groups should be made available, and based on the guide or model it should be possible to develop a monitoring programme.

The role played by eco-toxicological tests (bioassays) and leachability tests in the assessment of techniques and clean-up chains is currently further being investigated. A database will be established to make available current data on relevant criteria and aspects of assessment.

Publications concerning the use of bioassays and the feasibility of the LCA method may be expected soon.

3.2. Cost Estimation

Objective

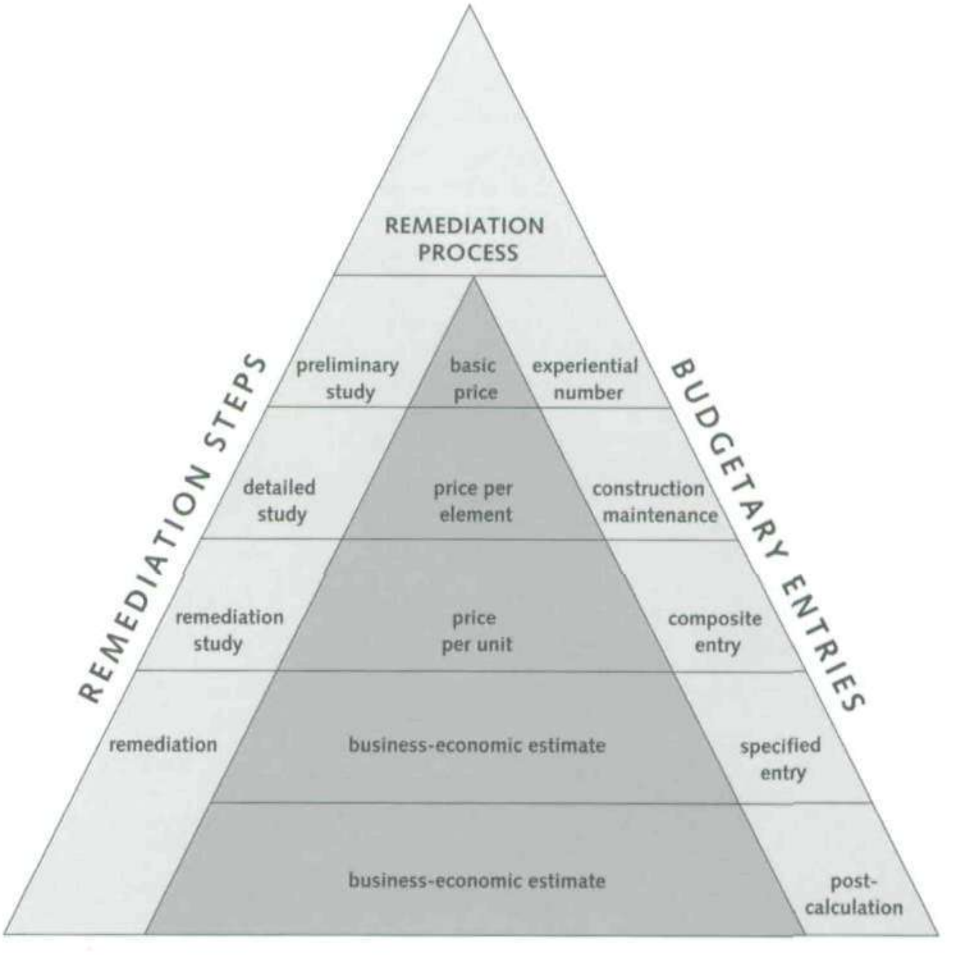
The aim of the subproject 'Cost Estimation' is to develop and maintain useful tools for estimating the costs of techniques for the processing of contaminated spoil at the earliest possible stage. For this purpose, among other things, a database is being established based on the index numbers generated during the POSW projects carried out.

Brief description of the project

Within POSW, various dredging and processing techniques are worked out and tested. After upgrading they will be applied on a commercial basis during remediation projects. The estimated cost must already be known during the selection of techniques qualifying for further upgrading, to determine whether their application will be possible at affordable rates.

The factors determining the cost price are technique-dependent. Therefore, there is a need for an aid with which cost factors can structurally be evaluated.

During the preparation of a remediation project, more and more insight is needed into the costs to be expected.
The detailedness of the prognoses, of course, heavily depends on the data available. For example, at an early stage the class of contamination, sand content and expected quantity of remediation spoil can often be estimated only roughly. Then the only way of estimating the (relative) costs is comparison of the various processing methods.
As the level of specifications is more closely approached, the uncertainties grow smaller and the cost estimates more accurate.



Information Pyramid Sediment Remediation

The development of a method for estimating costs
Based on the insights gained during various POSW projects, a database has been established containing the cost prices of various (aspects and components of) processing techniques.
Whenever new experiences have been gained, calculations are carried out based on the data collected, and then the index numbers are checked and, if necessary, adjusted. The above database is currently being computerized and coupled to the national cost price database.
This procedure is linked as closely as possible to the project 'Cost estimates Infrastructure' carried out by Rijkswaterstaat. The standard package for making cost estimates has been supplemented with a special checklist for sediment remediation.

The data presently available are included in a manual on the costs of sediment remediation issued in 1995, which enables experts to estimate costs when drafting specifications. Such a cost estimate was made during the pilot remediation in Elburg.

Practical experiences

One of the aims of pilot remediations is to test processing chains in practice and compare the actual costs with the estimated ones and the contract sum. During the Elburg remediation, the dredged quantities were found to diverge greatly from the estimated volume. Although this did not directly affect the unit rate for processing, it did affect the total costs of the operation.
The results of the subsequent re-calculation of data were used to adjust cost price index numbers and supplement the database.

Conclusions and recommendations

Based on the results achieved during POSW, a database has been established containing cost prices of (components of) dredging and processing techniques, which can be used to make cost estimates for sediment remediations. To properly estimate the costs of a remediation, the estimates of the quality and quantity of the spoil to be remedied must meet high requirements, especially with a view to the choice of clean-up chain and the quantity of spoil to be processed. Such a cost estimate is made more accurate if the errors possible during the estimation of these factors are properly weighed previously.

4. Pilot Remedations

POSW-II's main objective is to demonstrate in complex field-situations the practicability of methods and techniques proven to be promising during experiments. The entire clean-up chain is therefore currently being tested in three pilot studies.

During the selection of pilot locations, it was checked, among other things, whether the three potential locations differed sufficiently in type of contamination and composition of sediment. This allowed the testing of as many relevant remediation methods and processing techniques as possible. Other criteria were the progress of the detailed study (also with a view to remediation) at such a site; the logistic possibilities; necessity to remedy; administrative and financial limiting conditions.

The pilot locations selected were Elburg harbour, a groyne section in the New Merwede River, and Petroleumhaven in Amsterdam.
The Elburg clean-up was carried out in 1994, whereas the other two were inititated in 1995. They are carried out in collaboration with the regional directorates of Rijkswaterstaat. The South Holland directorate of this agency is also carrying out a pilot remediation in the Biesbosch delta in the province Noord-Brabant (Spijkerboor). Although this does not take place within the framework of POSW, frequent consultations are being held. This project will yield information on how to remedy sediments in nature reserves.

4.1. Pilot remediation carried out in Elburg harbour

Objective

The aim of the pilot remediation carried out in Elburg harbour was to apply, test and evaluate relevant knowledge in a coordinated manner and at a full scale, using a complete clean-up chain at a location representative of the Netherlands.

Technically, its aim was to raise the sediment quality to that of the surrounding Drontermeer (class 2, i.e. the removal of at least 90% of the PAH present).

Moreover, at least 50% of the dredged spoil had to be applied usefully.

Project description regarding the remediation carried out at Elburg harbour

Until 1994, Elburg harbour was heavily contaminated with PAH (class 4). Given the average mineral composition of the sandy spoil, the location qualified for separation, which at the time was the only upgraded processing method available.
Furthermore, from a dredging viewpoint, this harbour is representative of numerous Dutch harbours with contaminated sediments.

The harbour consists of an entrance channel and inner harbour, and until the mid-fifties it was used mainly as a fishing port. Today, it is used mainly for recreation purposes. Pollutants appeared to be concentrated largely in the upper layer of fine sediment with a thickness of a few decimetres.

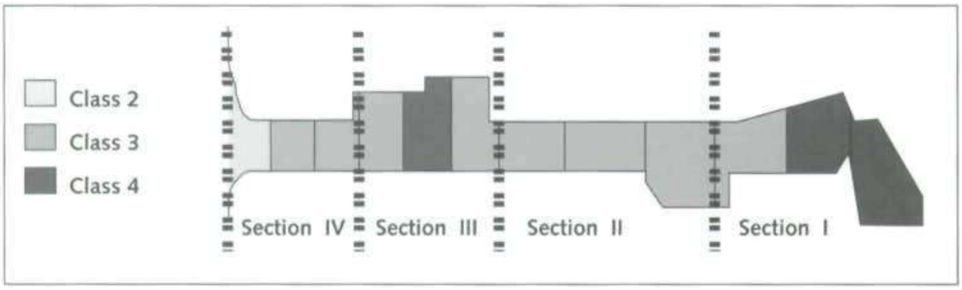


Diagram of Elburg harbour with the classification *ante* clean-up, in accordance with Dutch standards

However, in the inner harbour the contaminated upper layer was found to be much thicker and to contain much more sand. The quantity of contaminated sediment was estimated at 10,000 m^3.

Project preparation

The project group began its activities in 1993. An implementation plan was drawn up, including agreements on the objective, method, organization, costs, and the required capacity. Later, a bill of quantities, specifications and tender documents were drawn up. Representatives of various organizations formed an advisory committee and were requested to come up with ideas.

To establish the feasibility of sand separation as a remediation method, research had to be carried out into the granular size distribution in the sediment combined with research into the quality of the various fractions ('fingerprint method'). Only sand separation using hydrocyclones was considered feasible.
Large-scale sand separation by hydrocyclone was decided upon, as well as the useful application of the extracted sand and possibly ripened sludge to the greatest possible extent.

A preliminary site investigation revealed that nearly four times as much contaminated sediment as initially estimated had to be removed; that is, 37,750 m^3 rather than 10,000 m^3.
The Province of Gelderland required that an environmental impact assessment be carried out for the planned separation plant. To avert delays, it was then decided to have the dredging spoil processed in an existing separation plant located in Den Helder. Flat-bottomed craft were required to transport the spoil to this plant.

This environmental bucket was used in Elburg

Execution

The remedial dredging, begun in the spring of 1994, was carried out in two stages: a 'bulk stage', during which the largest possible quantity of high-density spoil was removed, and a 'clean-up stage', during which the remaining thin layer of contaminated sludge was carefully sucked up.
The former was carried out using an environmental bucket dredge, which functioned satisfactorily. The latter was delayed, because the mechanical, hydraulic dredger was not capable of handling the rubble present in the subsoil.
In the separation plant in Den Helder, the spoil was screened and then separated into three fractions: coarse and fine sand and silt, via two classifying production lines (two upflow classifiers and three hydrocyclones). The sand could be used partly as fill in road construction and drainage material in the sludge deposit, and partly as raw material in concrete slabs. After thickening, dewatering and ripening, part of the separated silt had been upgraded to such a quality that it could be used to construct a quay at and to cover the deposit. The remainder was transported to a disposal site.

Assessment of the project results

The assessment report on the pilot remediation, published in 1995 (ref. 32), contains numerous recommendations. These will be included in other POSW-II products, such as fact sheets, manuals, and working models. Additionally, they will of course be used during the preparation and execution of the pilot remediations at New Merwede and Petroleumhaven.

Organization

It was possible to carry out the pilot remediation within the brief period available only because it was executed along project lines. The entire project, from initiation to aftercare, took two years. The remediation itself took only four months. Nevertheless, unforeseen circumstances caused serious setbacks, such as the unexpectedly large quantity of contaminated sediment and the environmental impact assessment required by the provincial authorities.

These setbacks could have been prevented by a more thorough remediation investigation and more comprehensive preparation (focusing less on civil engineering aspects).
The size of the project group (fifteen participants) made it difficult to adequately control the project, although the discussions held by the advisory committee proved very useful. Generating adequate support from all authorities involved appeared to be vital to the success of the project.

It should be noted that the lengthy procedures prior to the (usually small-scale) on-site processing of spoil can result in (serious) delays. They may be used for NIMBY purposes; this acronym for 'Not in My Back Yard' is used to describe the attitude of people unwilling to tolerate a certain development or installation near their living environment. As a result, processing may be delayed for a long time, or the remediation may even be cancelled.

It is important to draw up detailed specifications formulating the duties and responsibilities of client and supervisor/contractor as clearly as possible.

Technical

The first thing revealed by the Elburg project was the necessity of investigating to what degree factors such as the thickness and quality of the sediment vary. Only then is it possible to determine the extent and accuracy of the measurements and sampling conducted in the framework of a successful *preliminary study. In Elburg, sediment-thickness determinations and* sediment-quality analyses had to be repeated several times. The experiences gained were used during the project Site Investigations (see Section 2.1).

It finally became clear how much sediment had to be dredged. However, the dredging accuracy exceeded the set margin of 10 cm (downwards), because the dredging profile to be followed had not been defined accurately enough. Nevertheless, the dredging left only 2% of the contaminated sediment and removed 3% of clean sediment in excess, which did not affect the final objective (90% removal and 50% useful application).

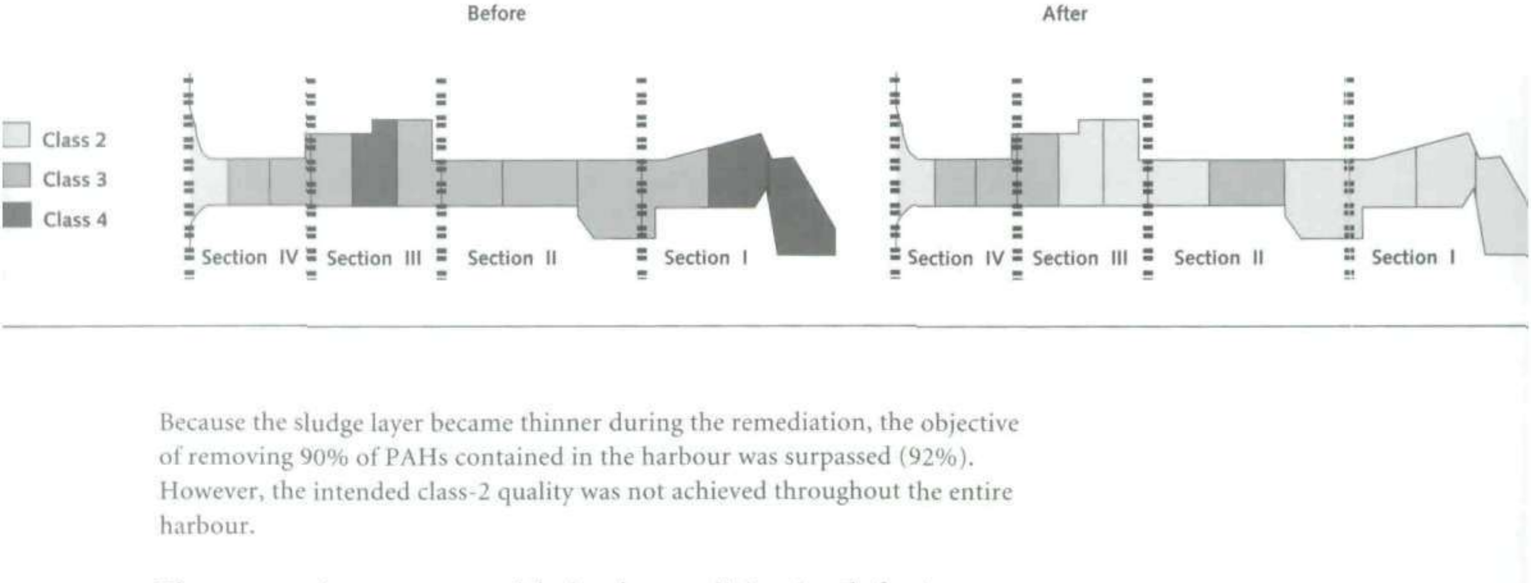
In Elburg, much attention was paid to the representativeness of the samples taken. As a result, the estimate that 70% of the sand would qualify for useful application was realized.

The positive results obtained during a small-scale flotation study using sediment from Elburg resulted in a larger-scale experiment (see Section 2.3).

Environmental effects

The environmental effects of the remediation were extensively investigated by recording all relevant parameters before, during and after the project. As a result of the remediation, the PAH content decreased by 50% (from 20 mg/kg d.m. to 11, for the sum of the ten PAHs listed in a Ministerial Order).

Diagrams of Elburg harbour, indicating the quality *ante* (left) and *post* (right) clean-up, in accordance with Dutch standards



Because the sludge layer became thinner during the remediation, the objective of removing 90% of PAHs contained in the harbour was surpassed (92%). However, the intended class-2 quality was not achieved throughout the entire harbour.

The amount of energy consumed during the remediation (partly for the transport of non-dewatered spoil to Den Helder) equaled 20 minutes' consumption by Dutch car-traffic (emission: 153 tonnes of carbon dioxide). The sludge-condensing agent used (polyelectrolyte) is biodegradable. During the transport and processing of the spoil, 15,000 litres of contaminated processing water was discharged into the sewage treatment plant at Den Helder. The noise level remained below the standard of 50 dB(A) during the entire dredging period of 102 days.

Costs

The operational costs exceeded the estimate by less than 10%, and amounted to NLG 11.4 million (incl. VAT). In addition, NLG 2.75 million was spent on research and engineering, which is a relatively high figure due to the pilot scale of the project. The cost of separation and processing amounted to NLG 50 per m^3 (ex. VAT), which is competitive with that of dumping untreated spoil into newly constructed, large-scale deposits.

Conclusions

The pilot remediation was successful and fulfilled the two operational objectives: reduction of the contaminations in the harbour by more than 90%, and useful application of the processing product in (great) excess of 50%.

After remediation, three-quarters of the harbour sediment came under contamination class 2, which means that the risks of dispersal of the contaminations towards the Drontermeer have been minimized.

Finally, the project achieved the POSW objective of gaining experience with the integrated application of new processing techniques in complex field situations.

4.2. Pilot remediation carried out in the New Merwede River

Objective

The primary aim of the pilot remediation currently being carried out in a groyne section in the New Merwede River is to test a complete clean-up chain at a full scale.
Another aim is to gain the practical experience required for the subsequent remediation of the remaining part of this river. Furthermore, it is necessary to create suitable conditions for recovery of the habitat at the clean-up site.
The processing process includes the application of thermal immobilization techniques.

Project description of the remediation carried out in the New Merwede River

One reason the New Merwede location was selected for the second POSW pilot remediation was because it is not a harbour (contrary to the pilot remediations carried out at Elburg and Amsterdam), but part of (and representative of large sections of) the extensive water system of the Dutch Downstream Rivers.

Pollutants present at such a location do not originate from local activities, as will often be the case in harbours. The contaminated sediment (classes 3/4) was carried along by Rhine water via the Waal. Such sediment constitutes a historical background contamination in the river basin, originating from numerous upstream sources.
Thus, if this pilot remediation succeeds, the approach followed will also be suitable for many other locations in the Downstream Riverbasins.

The river sediment at the investigated site contains a 'cocktail' of organic micropollutants, organochlorine compounds and heavy metals. As such sediment cannot be treated by individual techniques, the New Merwede sediment qualified for treatment with thermal immobilization techniques (sintering, melting).
River sediment is highly suitable to such treatment: non-contaminated river clay has for centuries been used to produce common ceramic products, such as bricks.

Location
A study of the contaminated sediment in the Downstream Rivers area (ref. 33) revealed that contaminated river sediment accumulates mainly in deep channels. It hardly spreads, because it is covered by a relatively clean sediment layer of more recent origin.
On the other hand, sediment deposited in shallow bank zones is more easily accessible to plants and animals, constituting a hazard to the habitat as well as to people holidaying near/in the water). Consequently, the pilot remediation focused on the bank area.
The site (surface area: 5 ha) is situated between two groynes on the southeastern bank of the New Merwede.

Planning phase
The planning stage of the project was finalized in October 1994. The civil engineering stage is to be completed in February 1996, at about which time the immobilization production will also just about be finished. The execution of the leachability tests and the reporting of their results are targeted for mid-1996.
When selecting a dredging technique, special attention has to be paid to the prevention of spillage and turbidity, because dredging is carried out in a flowing water-system.
After termination of the dredging, part of the sludge is desanded by hydrocyclone, dewatered, and passed through a melting furnace. The organic pollutants are thus removed and the heavy metals immobilized in artificial basalt, which is applied in a Rijkswaterstaat project.
The separated, slightly contaminated sand is used as construction material, and the clean sand redeposited on the bank for landscaping purposes.
The project is related to the sediment remediation project currently being carried out in the Biesbosch in the province Noord-Brabant (Spijkerboor). Although the latter is not a POSW project, it too is being carried out to investigate the effectiveness of a remedial approach aimed at ecological recovery.

Because the location is situated in an environmentally vulnerable national park much frequented by tourists, it is of major importance to inform the public. Especially at this location, this can help create support for the remediation of sediment. Therefore, several activities in this field (e.g. informational meeting, newsletter, brochure, information panels) are currently being performed.

Project preparation
The project was tendered in the summer of 1995; contracts were awarded for dredging and landscaping as well as immobilization. Before tendering, a plan had been drawn up in which the objectives were translated into a design for a complete clean-up chain. The project elements of site investigation, dredging and redesigning, immobilization, and monitoring and evaluation were worked out in the form of subplans, which resulted in technical bills of quantities. These plans are currently being carried out.

4.3. Pilot remediation carried out in Petroleumhaven, Amsterdam

Objective
The aim of the pilot remediation carried out in the Amsterdam Petroleumhaven is to test a complete clean-up chain at a full scale, especially regarding the degradation of oil and PAH. The project should yield information which may result in the complete remediation of Petroleumhaven.

Project description of the remediation of the Amsterdam Petroleumhaven

Petroleumhaven contains some of the most heavily contaminated sediments in the Netherlands. The location was proposed for remediation in the Remediation Programme for Sediments in state-controlled Waters (ref. 3). As the location is contaminated mainly by oil and PAH, the project is most suitable for the testing of biological and (possibly) some chemical treatment techniques.

In view of the large quantity of contaminated matter present in the harbour (300,000 m^3 of spoil) and the extent of the problem, complete remediation is not the final goal. However, the project should result in sufficient understanding of the problem to allow a final remediation plan to be drawn up. The North Holland Directorate of Rijkswaterstaat considers it of vital importance that the public should be very well informed on this project, to create maximum social support for the remediation of contaminated sediment.

Location

Petroleumhaven is located in the middle of a much frequented Amsterdam dock area, where for a long time now numerous industrial activities have been carried out. Especially the petroleum industry has been based here for a very long time. During the Second World War, vast quantities of oil ended up in the harbour. It is therefore not surprising that the bottom was categorized as contamination class 4. Indeed, given the measured PAH values, the sediment may even be characterized as chemical waste (ref. 34).

The contamination situation is complicated by the presence of several very deep contaminations (to 7 m below the sediment surface) and a few hot spots containing high dioxin concentrations. As the harbour is much frequented by ships, there is a high risk of dispersal. It is therefore urgent that the harbour be remedied. Dredging will be a difficult task, because the harbour has steep quays and banks.

Project preparation

The project aim was laid down in the Implementation Plan (ref. 35). It focuses on the northeastern part of the harbour in view of the occurrance of thin as well as thick sediment layers, less shipping traffic, and probably lower dioxin concentrations.
The first stage comprises the dredging of large quantities of contaminated sediment (at least 3,000 tonnes d.m.), although the pilot project is not intended to completely remedy the harbour.
At this stage, there will be no need to dredge very carefully, because of the turbidity caused by the heavy shipping traffic.

In principle, biological treatment, solvent extraction and thermal desorption qualify for the processing of this type of contaminated spoil.
In view of the state of the art, it was decided to remedy the spoil by biological treatment. In April 1995, tendering procedures were started for the processing of the above 3,000 tonnes of dry matter. Smaller pilot projects using other techniques may be carried out simultaneously.

5 International Developments

(This chapter is based on references 38, 39 and 40, and on personal information gathered by the POSW project management from international publications and during personal contacts and foreign trips).

Within POSW, looking for promising experiences gained abroad plays an important role, because much time and money is involved in the development of techniques for the processing of spoil, and one's work can be made more efficient by learning from experiences gained by others.
Furthermore, the discovery of gaps in foreign knowledge and experience may promote further development of Dutch remediation techniques. The presence of an international market for 'Dutch' processing techniques makes it more important for the companies involved to continue their innovative actions. All the more so, because the leading position of the Dutch in the field of dry-soil remediation technology gained in the eighties is increasingly threatened by countries such as the US, Germany and Great Britain.
The presence of such opportunities appears from the fact that the Netherlands lead the way regarding the development of a national sediment (remediation) policy. The US and Canada, for example, tend to focus more on the random development of technology.
Everywhere problems are encountered in financing the remediation of contaminated sediments. These problems may further promote the risk analysis assessments on contaminated sediments at present frequently conducted everywhere. There is certainly a growing need to establish strict priorities.

5.1. The situations in Japan, Canada, the US, Germany, and Belgium

Since other countries (Japan, Canada, the US and our neighbours, Germany and Belgium) have also gained experience with both dry and wet soil remediation, POSW experts are always searching for relevant information available in these countries.

Canada and the US

Of the above foreign countries, the ones which appear to carry out the most research into sediment remediation are Canada and (to a lesser extent) the US. The similarity in approaches followed by these countries and their cooperation are rather striking. The latter is promoted by the fact that the sediments of their shared Great Lakes area are (heavily) contaminated at numerous locations, mostly with organochlorine compounds (such as PCBs). Therefore, the Great Lakes are for both countries Areas of Concern (AOCs), within the framework of the American ARCS programme (Assessment and Remediation of Contaminated Sediments - ref. 38) and the Canadian CoSTTeP (Contaminated Sediment Treatment Technology Program - ref. 39).
Remedial action plans (RAPs) have been drawn up for these AOCs, comprising mainly maintenance dredging-works. Rather large sums of money are budgeted for this purpose: the Canada Great Lakes Cleanup Fund, for example, has at its disposal some 55 million Canadian dollars.
The strategy followed by Canada and the US is highly similar to the POSW

approach; the site investigation plays an important role, and the components of the clean-up chain are selected based on the expected environmental effects and on cost aspects.
The re-use of (components of) remedied spoil is not seriously considered. Volume reduction by the recovery of sand from spoil is considered interesting only if it will result in reduction of the quantity to be dumped. These countries, too, are confronted with the problem of 'Not in My Back Yard'.

Based on the results of previous research, it has been decided to continue developing nine methods, all of which are also being investigated in the Netherlands. As in the Netherlands, the selected techniques are first tested in the laboratory (bench-scale), then during pilot projects, and finally full-scale. It should be noted that, especially in the US, trials are carried out at a much smaller scale than they are in the Netherlands. In the US, a few grams to a few kilos are tested in a laboratory study, and several dozens to a few hundred kilos during a demonstration (and only seldom a few thousand 'cubic yards').

Neither the Netherlands nor Canada or the US have succeeded in developing methods for the removal of all types of pollutants from a 'cocktail contamination'.
For the time being, the application of any method is far more expensive than dumping.
Techniques considered promising in Canada and the US are sediment-washing technologies (e.g. the solvent method) and thermal desorption, especially for the treatment of spoil heavily contaminated with PAH and PCBs. Canada and the US focus almost exclusively on the investigation and remediation of heavily contaminated sediments (high concentrations of environmentally hazardous substances).
The above two methods have recently been adopted in the Netherlands. On the other hand, the Netherlands appear to be further advanced regarding biological methods and separation techniques by hydrocyclone and flotation.

A very extensive database has been established containing descriptions of all kinds of treatment methods. This was done based on an extensive, worldwide literature search, encompassing also knowledge from branches of industry such as the mining and metal industries.

Overall, the Netherlands do quite well compared to the other two countries. With respect to a few items, the Dutch POSW approach is far more extensive than the Canadian and US programmes.

Japan
Japan is not very active in the field of (research into) sediment remediation, especially in view of its international economic position. During the remediations carried out in Japan, mostly on-site immobilization techniques by cementation are employed. However, the realized effectiveness and environmental safety of this method does not appear to meet the requirements set in the Netherlands.
The Minamata Bay was remedied by dredging and then discharging the sediment into a deposit.

Germany
In Germany, various kinds of techniques for the processing of contaminated spoil are employed at various levels of scale. However, there is no national remediation policy. Decisions on remediation and processing are still taken

on an ad hoc basis; the German Republic's federal structure inhibits the achievement of a uniform policy.
The largest German project in the field of sediment remediation is carried out in Hamburg. The impressive METHA plant (investment: DM 135 million; capacity: 2 million m^3 per year) processes contaminated spoil from Hamburg Harbour and adjacent locations in the River Elbe (ref. 40). The main method employed is sand/silt separation by hydrocyclone. Part of the clean sand remaining after remediation is applied usefully; the contaminated sludge is dewatered and then dumped on a dry-land disposal site.

Belgium
In Belgium, there is a growing interest in (research on) sediment remediation. Initiatives are taken mostly by private companies. Due to the results obtained, Belgium companies are now competitors on the Dutch market for sediment remediation.

5.2 Conclusions based on a comparison with the situation in the Netherlands

It may thus be concluded that other countries have asyet gained only limited experience in the processing of spoil, and have focused mainly on preparing the material for dumping. In some cases, this seems to be the only intention - with sometimes quite unsatisfactory results; in other cases treatment at a later stage is explicitly considered an option.

Most of the international knowledge available has been derived from laboratory research and, to a more limited extent, pilot plants; at both scales, the work is executed with considerably smaller quantities than those used within POSW in the Netherlands.

Internationally, most experience has been gained with physical-mechanical separation techniques and chemical extraction methods. The Netherlands may be considered one of the countries most advanced in the development of separation techniques.
This does not apply to chemical techniques, where the US are in the forefront, but in the field of dredging, biological and immobilization methods the Netherlands leave the US and (certainly) other countries far behind.

The few references available seem to indicate that the Netherlands has been efficient in the selection of methods to be developed. Experiences gained abroad were elaborated upon, if possible, and supplemented with other attractive techniques. Furthermore, it should be noted that, in the Netherlands, the development of evaluative tools and logical methods for the construction and comparison of related clean-up chains has progressed very far as well.

Therefore, it may be concluded that the Dutch pilot programme is one of the most extensive, comprehensive and coherent in the world. Partly for this reason, it is advisable to stimulate the companies involved in POSW to extend their R&D activities to the international market: as a result, more promising remediation techniques may be made operational in the Netherlands.

6. Conclusions and prospcts

6.1. Interim conclusions regarding POSW-II

The primary objective of POSW-II is to upgrade (to an operational level) promising methods for the dredging and processing of contaminated sediment, using the experiences and insights gained during the first stage.
Its secondary aim is to supply information on processing techniques and chains (i.e. technical possibilities, costs and environmental effects). Based on this information, by 1997/1998 it should be possible to decide how the Netherlands must deal with the problem of contaminated spoil. This decision process will include determining what can be treated at reasonable rates, and what must be deposited.

Within POSW-II, techniques and methods were introduced which had not been tried before in the Netherlands, because it was expected that they prove operable at full scale within a few years. A system of tools has been developed to design potential processing chains, from which to select those chains most feasible from an economic, social, organizational and policy point of view. What progress has been made within POSW-II, two-thirds of which has now been completed?

Technological progress

Several techniques have proved suitable for application during specific site investigations. An example of this is the optimization of the sampling programme to be carried out prior to remediation (the FAST assessment model). This model is intended to gear the measurement activities as well as possible at the possibilities and degree of accuracy of dredging.
At a pilot scale, experience has been gained with various seismic investigation methods. Provided such methods are applied in addition to conventional sediment sampling, they allow a more accurate estimate to be made of the quantity and exact location of the sediment to be removed. A suitable method appears to have been developed for rapid analysis of heavy metals (XRF). In 1995, this method will be employed during the pilot remediation in the New Merwede.
Sediment characterization, supplemented with flotation and/or biodegradation tests, is important to determine the optimum processing method, which will make it easier to select a remediation method.

POSW-II is intended to develop rapid, standardized physico-chemical characterization tests for determining the factual possibilities of processing spoil.

Within the framework of the programme, a comprehensive survey of suitable, environmentally-friendly and selective dredging methods has been established. It has become clear that the way in which suitable dredging equipment is operated is as important as the actual techniques employed.

To be able to decide on the dredging method most suitable for remediation under certain conditions, field tests will be carried out in the Ketelmeer in 1995-1996. These tests will take place under similar conditions. Furthermore, within POSW-II a model is being developed to assess the dispersal of pollutants during and after dredging.

Regarding physical processing techniques, POSW-I showed that the separation of sand from sufficiently sandy sludge by hydrocyclone will yield sand suitable for useful application. Thus, a very high recycling percentage of spoil was realized during the pilot remediation carried out in Elburg. This project also showed ways of making the process even more profitable. Eventually, this method for treating sandy sludge will be only slightly more expensive than dumping without treatment. At the moment, this seems to be the most promising technique for the large-scale useful application of spoil.
The method of froth flotation surveyed during POSW-I appears to be suitable for the further 'polishing' of sand separated by hydrocyclone, or for the further separation of finer sediment into a clean and a contaminated fraction.
During POSW-II, physical techniques are being developed to concentrate the pollutants still present in the voluminous residual flow of contaminated matter, in an attempt to minimize the amount to be dumped.

At the end of POSW-I, it was thought that chemical processing techniques could soon be put into practice. However, during POSW-II it was discovered that none of these techniques, which at first looked promising, could be made operable within a 5-year time span. This does not necessarily mean that, with further development, these methods cannot be made to compete with other ones.
Renewed screening and testing at a laboratory scale has resulted in three promising techniques to be upgraded in the coming years, namely wet oxidation, solvent extraction, and thermal desorption. All are suitable for the removal or degradation of organic pollutants. Furthermore, the first field test with wet oxidation showed that heavy metals were immobilized to a certain extent. In the coming years, supplementary research will have to be carried out at a semi-full scale and beyond.
However, chemical techniques have a disadvantage in that they consume rather large amounts of energy and raw materials, and usually result in a residual flow of pollutants. Furthermore, presently no promising chemical techniques for the removal of heavy metals from sludge are available.

As far as biological treatment techniques are concerned, during POSW-I it was found that especially landfarming could possibly be applied cost-effectively for the degradation of oil and PAH. During POSW-II, this was confirmed at a semi-field scale. However, it is not expected that it will result in reduction of contamination levels to target values, although it is possible to use biologically treated sludge within the framework of the draft Order on Structural Materials. The choice to be made from among the various reactors and landfarming techniques depends on the type of spoil, processing time, finances, and space.
A biological technique for the treatment of sludge heavily contaminated with organochlorine compounds has been developed, but still has to prove its value outside the laboratory.
Preparations for the on-site biological treatment of sludge were found not to be effective and therefore were not further investigated within the framework of POSW.

Progress was made, too, regarding thermal immobilization techniques. At a laboratory scale, it was found that the production of ecogravel and artificial basalt from heated spoil results in a technically and environmentally sound product at not too high and possibly acceptable production costs (large-scale production).
In this, the most striking environmental effect is the high energy consumption. Research into upgrading must be continued in the coming years, partly because

immobilization of heavy metals is currently the only solution (except for dumping). Already at the end of POSW-I, chemical immobilization was no longer considered an option because of leachability aspects.

Environmental performance

Selection of individual processing techniques for further research is still feasible based on rules of thumb regarding the expected costs and environmental effects; however, the more POSW approaches application on a field scale, the more need there is for advanced methods for the assessment of complete processing chains.
During POSW-II, the development of systems for the assessment of environmental effects has reached an advanced stage, especially regarding systems for reliable cost estimation.

During the remaining part of the POSW programme, the system for the assessment of environmental effects and costs will be both integrated and put into practice, especially during pilot remediations. The development of such assessment methods has already proved useful when investigating the interim state of affairs with regard to the feasibility of various processing chains.

6.2. The feasibility of large-scale processing chains, and potential markets for products

Feasibility study

In February 1995, Rijkswaterstaat, the Ministry for the Environment, IPO (Interprovincial Consultation), the Union of Water Boards and the Association of Dutch Municipalities came to an agreement on the policy to be followed concerning the processing of spoil. According to this agreement, the separation of sand from spoil will be given priority during the period 1994-1997. For this purpose, Rijkswaterstaat has drafted an implementation plan. Within this framework, the project Re-use of Spoil plays a promoting and advisory role.

It has not yet been decided which processing techniques will be not only desirable from an environmental viewpoint, but also technically, economically and socially feasible in 1997.
Such a decision can probably not be made until the end of 1996, based on the results of the „Haalbaarheidsstudie grootschalige verwerking baggerspecie" (Feasibility study regarding the large-scale processing of spoil).
During the project, alternative processing chains and their technical and environmental feasibility are also being tested. Furthermore, much attention is being paid to the economic and social feasibility of these possible chains. Especially in view of the economic aspect, the findings of and experiences gained during the related project Re-use of Spoil were extensively consulted. The latter project is not part of POSW, but is being carried out by both private companies and Rijkswaterstaat.

The sale of treated products will be considerably promoted if Rijkswaterstaat pursues an active policy in this regard and purchases most of such products.

Project Re-use of Spoil

The project Re-use of Spoil (the Dutch acronym is PHB) was begun in 1992, especially with a view to the governmental objective to be able to process and apply usefully at least 20% of contaminated spoil by the year 2000 (see Section 1.1). PHB is not part of POSW but is being carried out simultaneously. It has a separate project structure and deals mainly with the steps to be taken after remediation and processing. For example, compared to POSW it focuses much more on the potential markets for and value of the processing products. Of course, the conclusions of both programmes have consequences for the planning of further activities within the framework of each. For example, during POSW certain techniques will no longer be investigated if PHB findings show that the accompanying end products are too expensive or cannot easily be sold. Therefore, PHB is actively involved in various POSW projects. During stage II, this applies especially to the pilot remediations, the project Immobilization Methods and other projects for making techniques operational (product assessment). The Feasibility Study on the Large-scale Processing of Spoil was conducted under the joint responsibility of POSW and PHB. For the purpose of market research, PHB pays attention to the environmental quality of processing products, partly by carrying out leachability tests. Furthermore, PHB is investigating several processing techniques which for quite some time now have been known for their purification capacity (e.g. the ripening of spoil). PHB supervises also processing projects not coming under POSW, for example, those carried out within the framework of remediation operations of regional directorates of Rijkswaterstaat, and the City of Rotterdam. As with POSW, PHB is executed under the responsibility of Rijkswaterstaat, and jointly directed by public authorities at various echelons and representatives of industry. PHB comes under the Civil Engineering Service within Rijkswaterstaat.

During stage 1 of the Feasibility Study, three alternative processing chains were formulated, based on the results of an initial, rough feasibility test (ref. 36). During stage 2 of this study, their feasibility will be extensively analyzed. Based on the results of a multicriteria analysis, preparations are made to select the types of large-scale processing plants and the locations where they will be realised.

During stage 2 of the above study, the following three alternative processing chains will be assessed:

- a limited ripening and landfarming, separation and polishing of (moderately) sandy sludge, and dumping of the (dewatered or nondewatered) residual product;
- b as under (a), supplemented with immobilization of the released flow of sludge;
- c as under (a), supplemented with more thorough thermal treatment of part of the sand fraction.

The first feasibility assessment was based on exact realisation of the 20% aim (i.e. the processing of at least 20% of the supply of contaminated spoil after 2000).

The costs of alternative (a) have been estimated at ca. NLG 410 million per year, those of alternative (b) at NLG 650 million per year, and those of alternative (c) at NLG 540 million per year, excluding dredging and transport

costs and without taking the proceeds of the marketed processing products into account.
For comparison, this means that alternative (a) will cost one and a half times as much as dumping untreated spoil, and alternatives (b) and (c) will cost around twice as much as such dumping. However, the cost estimates contain considerable uncertainties (15-50%).

The following table gives a survey of the estimated costs of the various processing methods per tonne of dry matter (ref. 36, p. 36).

Cost index numbers used

Chain	(combination of techniques)	costs used	range used	
A	Ripening	NLG 40,--/t.d.s.	NLG 35,--	NLG 70,--/t.d.s.
B	Landfarming	NLG 75,--/t.d.s.	NLG 50,--	NLG 100,--/t.d.s.
C1	Classifying, polishing, dewatering clay fraction, dumping dewatered clay fraction	NLG 80,--/t.d.s.	NLG 70,--	NLG 150,--/t.d.s.
C2	Classifying, polishing, dewatering clay fraction, immobilization clay fraction	NLG 250,--/t.d.s.	NLG 200,--	NLG 300,--/t.d.s.
D	Dewatering spoil, immobilization	NLG 500,--/t.d.s.	NLG 350,--	NLG 700,--/t.d.s.
E	Classifying, thermal treatment sand fraction, dewatering clay fraction, dumping clay fraction	NLG 135,--/t.d.s.	NLG 115,--	NLG 150,--/t.d.s.
F	Dumping in large-scale deposits	NLG 30,--/t.d.s.	NLG 25,--	NLG 45,--/t.d.s.

The potential markets for processing products appear favourable for clean sand and almost as favourable for the other end products: ecogravel, artificial basalt, clay, ripened soil, and the less clean sand fraction.
The following table gives a survey of the initial, interim estimates of the various parts of alternative c. All these aspects will be further investigated during stage 2.

Summary alternative c

Chain	Techniques	Type Spoil	Offer Product	Class 0	class 1	class 2	Total	Material	% Recycling
A	Ripening	Cl.2-clayey	0.11		0.11		0.11	clay	
B	Landfarming	Cl.3, part 4, sandy/ medium sandy	0.06		0.06		0.06	soil	
C1	Classifying, polishing, dewatering clayfraction	Cl.2,3,4-85%, rest sandy	1.57	0.44	0.66		1.10	sand	
		Cl.2,3,4-30%, rest sandy/medium sandy	1.07	0.17	0.26	0.43		sand	
E	Classifying, thermal treatm.sand fraction	Cl.2,3,4 sandy/ medium sandy	0.14	0.07			0.07	sand	
F	Deposits	Other spoil	5.91						
		Clayey sludge (dewatered from C1 and E)	1.18						20

6.3 The completion of POSW-II, and prospects

The completion of POSW-II

During the remaining part of POSW-II, the techniques and methods developed will be tested in practice and evaluated. Biological treatment and thermal immobilization will be employed during the pilot remediations in the Amsterdam Petroleumhaven and the New Merwede, respectively.
The testing of froth flotation, thermal treatment methods and wet oxidation will be continued at a field scale. Furthermore, it is important that methods for environmental effect assessment and the estimation of costs are made operational.

By the end of POSW-II, there should be a clear picture of the costs of all techniques and processing chains, in addition to a survey of the removal performances and environmental effects of all techniques. To be able to compare data on various techniques, the POSW management have suggested that rates should be expressed in amounts per tonne d.m., to make it possible to convert the resulting figures into rates per in-situ cubic metre for the entire processing chain. The experiences gained during the incomplete pilot remediations are indispensable for making such comparisons.
The information thus obtained will make it easier to make final well-founded decisions on the treatment of spoil resulting from maintenance and the remediation of sediment.

Furthermore, it is advisable to make an inventory of promising techniques which cannot be made operational before the year 2000. Although such techniques will not be taken into further consideration during POSW-II, they may become important in the future. Also technological developments will continue, in the Netherlands and abroad. After POSW-II has been completed, the decision must be made on how to deal with these future techniques.

Prospects

In the meantime, POSW has made a valuable contribution to the gathering of knowledge on the technical processing possibilities and costs of the remediation of contaminated sediment and the processing of sludge. After years of research and development, it is now time to make pragmatic choices.

On an administrative level, it has meanwhile been decided for the near future to focus on (sand) separation techniques. However, the results of the first phase of the above feasibility study show that the 20% aim cannot be achieved using only such techniques. Therefore, it is of major importance that also large-scale landfarming is applied wherever possible. Furthermore, it must be possible to use ripened, clay-rich class-2 sludge as a substitute for clay in civil engineering (e.g. the construction of dikes).

By employing more advanced separation techniques and by the large-scale application of froth flotation, a larger part of separated sand and sludge fractions can be made suitable for useful application.
In particular the heavily contaminated fine fraction (especially oil and PAH) can possibly be treated further by means of either bioreactors, wet oxidation or thermal desorption. The large-scale application of immobilization methods will soon be possible for the total processing and useful application of all types of spoil.

In combination with the processing of other wastes (e.g. sewage sludge, fly ash) or the use of residual heat from other industries, it will become feasible to use thermal immobilization techniques at a larger scale. This could occur at the end of large-scale and generally applicable treatment lines, the first step of which will consist of advanced separation techniques.

Which of these future scenarios are to be preferred will depend on the results of the feasibility study. For this purpose, further technical and financial building blocks will have to be provided during the remaining part of POSW-II.

On a longer term the building of large scale deposits will lead to an increase in sediment clean-up operations. Rijkswaterstaat has installed several project offices for advice in and support of such operations. Apart from that reduction in emissions will result in a decrease of polluted sediment to be remedied. So both clean-up operations and prevention can contribute significantly to a decrease in offer of sludge. Nevertheless it is expected that even after 2010 polluted sludge will be released during the maintenance of harbours and shipping routes.

Choosing between deposition and treatment of polluted sludge -also in future- still asks for further resreach and development of treatment techniques. Possible continuation of POSW should be decided upon in time.

Relation to other policy developments

The future of processing techniques depends very much on a number of non-technological aspects, especially:

1 the quantity of spoil which will be offered for treatment;
2 the future dumping rates of the large-scale deposits;
3 the available total budget for sediment remediation;
4 the standards for useful application which will be laid down in the final Order on Structural Materials;
5 the policy on the use of primary raw materials.

Sub 1:

The quantity of spoil which will be offered for treatment can be influenced by implementing bans on dumping and spreading coupled to quality standards and/or by taking financial measures. However, such measures cannot be taken before mid-1997 because of administrative agreements made on the processing of spoil (ref. 37).

Sub 2:

The future dumping rates of the large-scale depots (Ketelmeer, Hollands Diep) will have to be comparable to the estimated costs of (large-scale) processing of spoil; the former will depend mainly on the costs of facilities to be installed at large-scale deposits (e.g. insulation measures, level control, possible treatment of the return water to be discharged) and of the containment and aftercare phases of those deposits.

Sub 3:

It appears that in the future there will be no budget available for the processing of all spoil offered. Especially when the current estimated processing costs are compared with the current costs of large-scale wet dumping, the processing of spoil seems to be an unattractive option. However, compared to dumping on 'dry' locations, the processing of spoil is in many cases competitive even today.

An essential subject of the discussions currently being held within the framework of the fourth Policy Document on Water Management (1997) is how the cost ratio between the processing and dumping of spoil will develop after the completion of the planned, large-scale spoil depots (provided with insulation, and requiring containment measures and proper aftercare). POSW supplies relevant information for these discussions.

Sub 4:

The further design of the Order on Structural Materials may strongly affect the future of biological treatment in particular. Especially the formulation of the leachability requirements for organic pollutants will partly determine whether the future will still offer opportunities for biological treatment. It is expected that the end products of biological treatment will easily meet toxicologically founded leachability requirements, because after biodegradation the bioavailability of residual contamination is very low.

Sub 5:

Policy has been formulated which prefers the use of secondary rather than primary raw materials. The execution of this policy will determine to what extent the extraction of primary raw materials (e.g. opencast mining of gravel or sand) will be discouraged in favour of the use of secondary ones (e.g. the civil engineering application of sand from spoil, biologically treated spoil, or immobilisates (e.g. artificial basalt and ecogravel).

Annex 1a.
Overview of POSW Products

POSW PHASE II REPORTS

Programma Ontwikkeling Sanering Waterbodems Programmaplan Fase II (1992-1996)
Stokman, G.N.M., L.A. van Geldermalsen, W.A. Bruggeman, september 1992

Deel 1: Onderzoek naar produkten voor in situ biologische reiniging van waterbodems
Eindrapportage: Haskoning b.v./ POSW, april 1994
RIZA-Nota 94.035 ISBN 9036903343

Deel 2: Landfarming van baggerspecie: laboratorium- en praktijkonderzoek eindrapport
DHV Milieu en Infrastructuur, maart 1995
RIZA-Nota 95.013 ISBN 9036901057

Deel 3: Immobilisatie van verontreinigingen in baggerspecie en vaste afvalstoffen. Samenvatting van onderzoek en resultaten
Waterloopkundig Laboratorium, mei 1995
RIZA-Nota 95.014 ISBN 9036901154

Deel 4: Vervaardiging van kunstbasalt uit verontreinigde baggerspecie. Samenvattende rapportage
Heijmans Milieutechniek, Gemco Milieutechnologie, CSO Adviesbureau voor Milieuonderzoek, mei 1995
RIZA-Nota 95.015 ISBN 9036901251

Deel 5: Evaluatie van de waterbodemsanering van de haven van Elburg. Hoofdrapport
Van Geldermalsen, L.A. en L.J. Kappe, april 1995
RIZA-Nota 95.017 ISBN 9036901456

Deel 6: Levenscyclusanalyse en keuze saneringsmethode
Tauw Milieu, mei 1995
RIZA-Nota 95.024 ISBN 9036945410

Deel 7: Haalbaarheidsstudie Grootschalige Verwerking Baggerspecie. Eindrapport Fase 1: Verkenning en voorbereiding.
KPMG, HexaConsult, Grontmij & HAB Water & Milieu, juli 1995
RIZA-Nota 95.016 ISBN 9036901359

Deel 8: Scheiden van verontreinigd sediment
Gemeentewerken Rotterdam, Ingenieursbureau Havenwerken, augustus 1995
RIZA-Nota 95.025 ISBN 9036945518

These reports can be ordered through Hageman Verpakkers, PO Box 281, 2700 AG Zoetermeer, The Netherlands at NLG 25,- per copy. Payment on delivery

FACT SHEETS

1. Melting and crystallization
2. Flotation of sediments
3. Optimization of the remedial approach
4. Determining the thickness of sludge layers by means of seismic research
5. Turbidity caused by dredging

Further information:
RIZA, Project Office POSW, PO Box 17, 8200 AA
LELYSTAD, The Netherlands
tel. +31 320 - 270533/270456, fax +31 320 - 233691

Annex 1b. References

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4. Eindrapport Programma Ontwikkeling Saneringsprocessen Waterbodems, fase I (1989-1990), Lelystad, 1992.

5. Ontwerp-Bouwstoffenbesluit.

6. Project Hergebruik Baggerspecie.

7. Evaluatierapport pilot-sanering Elburg.

8. Milieurendement sanering haven van Elburg, maart 1995.

9. Fact sheet 'Optimalisatie van saneringsaanpak'

10. Fact sheet 'Bepaling sliblaagdikte met seismisch onderzoek'.

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22. Fact sheet 'Flotatie van baggerspecie'.

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Colophon
This Interim report was written by order of the Steering Committee of the Development Programme Treatment Processes for polluted sediments (POSW)

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