Final Report

Development Programme for Treatment Processes for Contaminated Sediments

Development Programme for Treatment Processes for Contaminated Sediments
Stage II (1992-1996)

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Prologue

Partial processing of dredging sludge remains a highly ambitious target for some, whereas others see it opening up new vistas. This report, which deals with the extensive research of the Dutch Development Programme for Treatment Processes for Contaminated Sediments (POSW) presents optimists, pessimists and realists alike with facts and figures on the possibilities of processing polluted sediments. In doing so, it contributes valuable information to support the decision-making process on this subject.

Sludge processing appears technically feasible, although the effort it requires depends on the type of sludge (Chapter 2). Scenarios for large-scale processing, which incorporate several of the feasible methods, yield processing percentages and reduced bulk densities in accordance with the policy objective for processing (Chapter 3). They come with a price tag, however, and include assessments of the overall environmental effects (Chapter 3).

The line of approach adopted by POSW has been practically oriented. The knowledge and experience gathered over the years can be deployed to guide the executive stage, should a policy of processing contaminated dredging sludge be adopted.

1 Introduction

One of the results of the inferior water quality in the past decades was that the bottoms of the surface waters in the Netherlands grew highly contaminated. The adverse effect was strengthened by the country's location at the receiving end of main international river courses. The low flow rates of our waters caused the contaminated sludge particles transported by them to settle. Although relatively cleaner sediment was then deposited on top of the contaminated layers, the habitat remains impoverished. There is also a risk that leaching will cause contaminants to spread from the sediment to the surrounding groundwater and surface waters.

The Evaluation Memorandum on Water and the Policy Document on the Removal of Dredging Sludge explicated the governmental views on the future of the contaminated sediments. The Programme of Treatment Processes for Public Waters 1995-2010 elaborated this policy with regard to the water bodies under state control. The mainstay of this policy is prevention at the source of water contamination, thus preventing the contamination of newly formed sediments. Meanwhile, existing problematic sites will have to be cleaned.
The speedy construction of several large-scale deposit sites should allow clean-up operations of the most seriously contaminated sediments to be implemented even before the turn of the century.

POSW

Depositing of the sludge seems a relatively simple and obvious tail-piece of decontamination. This takes up room, however, and causes problems with spatial planning: no more than 60% of the supply of sludge can be accommodated in the existing and planned deposits, which underlines the necessity to look for alternatives. One option, if financially and practically feasible, is to process the contaminated sludge destined for discharge and to utilize the resulting clean products in one or more useful applications.
The importance attached to processing and useful application was expressed, amongst other things, in the funds allocated by the authorities to the Development Programme for Treatment Processes for Contaminated Sediments (POSW). Stage II of this programme, which received 34.5 million NLG, had as its objective "the delivery of a number of operational, environmentally friendly dredging and processing methods. The technical applicability has to be demonstrated in practice, as part of an integrated remedial chain." The programme had to produce data "required to assess the technical possibilities, environmental consequences and financial-economic aspects of dredging and processing methods in the framework of the remediation of sediments". The project should furthermore prevent that dredging and processing methods had to be made operational for each separate clean-up.

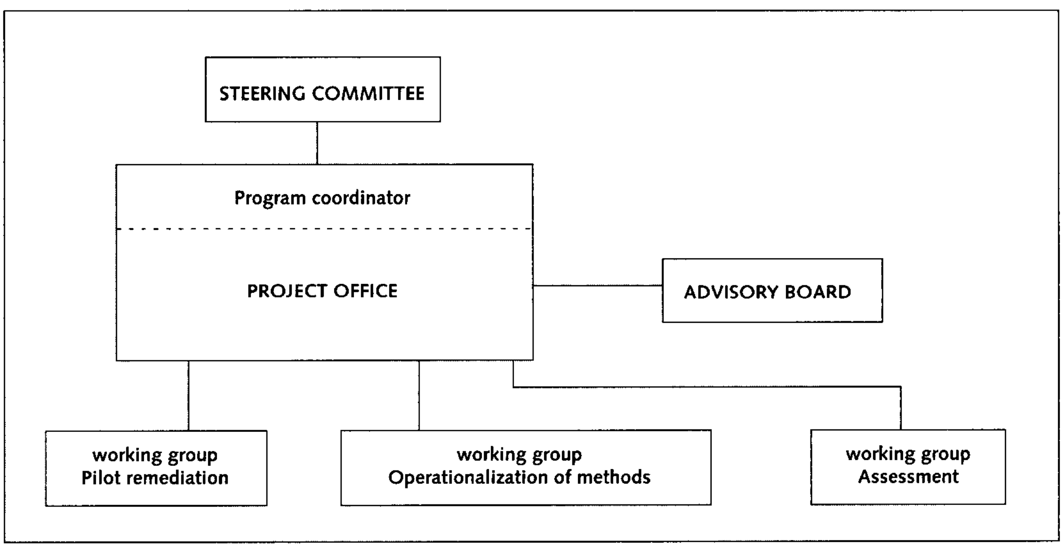
After an exploratory stage (POSW-I, 1988-1991), a number of promising processing methods were researched further, selected, developed and tested in accordance with the assignment. Any improvements needed in the initial stages of the remedial chain - site study and dredging technology - also received in-depth attention. A final stage of the programme consisted of the implementation of several pilot clean-ups, which yielded field experience gained across the entire spectrum of the chain: remediation study - removal - separation - purification - application - assessment.

Once the programme was underway, it gained momentum through the publication of the Evaluation Memorandum on Water and the Policy Document on the Removal of Dredging Sludge. The policy outlined in these documents set a target of 20% of the contaminated sludge to be processed and recycled by the year 2000. The Building Materials Decree and the initiation of the Project Bureau for the Re-use of Dredging Sludge PHB, by *Rijkswaterstaat* (Netherlands Directorate-General for Public Works and Water Management) also anticipated the practical application of recycled products before the turn of the millennium. These factors all influenced the process to make available field-tested, widely applicable methods and technology, to be used in large-scale processing and at acceptable cost. Another aspect clamoring for attention was the marketing of the recycled sludge products: the market had to be explored and a niche in it prepared. With a view to the explicit aims of processing and recycling, the second stage of POSW was extended halfway by a Feasibility Study on the Large-scale Processing of Contaminated Dredged Material, in cooperation with PHB.

Organization

The programme came under the responsibility of Rijkswaterstaat, but other parties representing national and provincial authorities or bordering interests of water and soil were also involved, such as the Ministry of Housing, Spatial Planning and the Environment, Rotterdam Municipal Port Management, the Union of District Water Boards, and the Association of the provinces of the Netherlands. Several of these bodies were already represented in the organizational structure of POSW, or involved through the pilot testings. These and other channels aided POSW in attuning their activities with other domestic and international programmes to promote research, development and funding in this field.

Organizational structure of POSW



Reporting

The first stage, POSW-I, was concluded in October 1991 with the submittance of a report to Parliament. Its main conclusion: only a handful of methods are currently operational, but within a few years several more will probably become applicable on a practical scale. POSW-II (1992-1996) therefore focused on further reconnaisance, upgrading and field-testing of promising methods.
In October 1996, the POSW-II Interim Report presented the score to date of the results of the second stage. Several processing methods were described, some with definite possibilities for large-scale application and others in an advanced stage of development. The report also noted the progress made with regard to ways of calculating and comparing the cost and environmental effects of decontamination and processing. An account of the first stage of the Feasibility Study on the Large-scale Processing of Contaminated Dredged Material was also included in the Interim Report.

The current report is the final accounting of POSW-II as drawn up at the end of 1996. It reflects the state of affairs in a limited number of fields, as not all activities had been completed at that point in time.
As with other POSW-reports, this one, too, refrains from stating policy decisions, as it is intended only to present information as a base for such decisions. The results can thus play a role in the decisions on the clean-up of sediments and on dealing with contaminated sludge, which are to be set out in the coming Fourth Policy Document on Water Management.

Reading guide

Chapter 2 of this report presents the results of the investigation of methods during POSW-II. One section deals with the pre-dredging survey and dredging, the other sections with *processing* methods. These methods have been clustered around certain technologies, as was the investigation itself. This chapter is interspersed with small intermezzos describing, amongst other things, the executed pilot remediations.
This report was based on the Interim Report published in 1995 and the detailed final reports yet to be published by the various project groups and referred to throughout the text. That is why the methods, the investigation and the results are not dealt with in great detail in Chapter 2.
The feasible technologies are summarized at the end of Chapter 2.

Chapter 3 looks at the ways in which usable methods fit into an actual remediation of sediments, and the conditions needed to implement processing. Various aspects play a role: not just technical possibilities, but also environmental effects, costs, marketing opportunities of recycled products, and the administrative context.
The environmental aspects of dredging, transportation and processing are reviewed in Section 3.2. The purely ecological approach differs from the *matrix* model so often employed in discussions on waste processing. The latter is a *quantitative* approach concentrating on the extraction of useful products (raw materials) from a fraction which otherwise would be dumped in its entirety as waste. In this vein, Chapter 3 discusses profit in the form of clean products as a main aspect for assessment.
The other sections of Chapter 3 focus on the results of the Feasibility Study on the Large-scale Processing of Contaminated Dredged Material. Various processing alternatives were developed, calculated as to cost and

environmental aspects, mutually compared and tested against the reference option of 'dumping'. The study also paid attention to major contributing factors such as the market for products, the financial and administrative contexts and managerial tools.

The final Chapter 4 summarizes the state of affairs and discusses the prospects.
A list of used abbreviations has been included at the back of the report, after the references.

2 Studying and testing of methods

2.1 Introduction

Two project groups of POSW-II focused on the activities at the beginning of the remediation chain: the pre-dredging survey and the dredging. Other project groups researched the processing technology, clustered around certain *principles*. Point of departure was always the processing of dredged spoil ('ex situ' processing). Only one project group, which researched 'biological treatment', initially included the option of *in-situ* processing (treating the sediments on-site).
This chapter is interspersed with intermezzos summarizing pilot clean-ups, a writing concept often found in reports on such operations: a description of a pilot remediation is included in the (general) description of the processing method involved, even though the pilot remediation may have offered many other learning features besides knowledge of the technology, such as planning and organization. Some of the intermezzos are concerned with a combination of methods, in which cases the positioning was somewhat arbitrary.

Apart from immediate study results, POSW-II indirectly affected other parties (involvement, support, initiatives), as is witnessed by examples in various sections of this report: continuation of research and practical application outside the framework of POSW-II, the development of a new tendering method, interest in processing expressed by the market, the acceptance of a specific processing concept as a viable option.

The costs of the methods are discussed in Chapter 3 - insofar as they result from the calculations in the Feasibility Study on the Large-scale Processing of Contaminated Dredged Material. The context of these calculations (points of departure, principles, types of sludge and working methods) is presented in a clear and unambiguous way, so as to guarantee a uniform calculating method.

The principle environmental aspects of each processing concept are presented in this chapter in a non-quantitative way. Section 2.3 shows how an integrated environmental assessment of methods - or remedial chains composed from them - can be achieved on the basis of quantitative data on highly diverse environmental effects of the methods.

2.2 Site study and dredging

Absolutely vital in guiding the dredging works is a dependable pre-dredging survey, which accurately estimates the quantity and quality of the sludge to be released and predicts the quality of the sediment after remediation. The FAST computer model was developed for this purpose (FAST: Fault Analysis Sanitation Trajectory). Its fast screening methods simplify the site study. Classification of the sludge at this early stage helps to match the most suitable processing method to the particular type of sludge. The dredging technique and the working method during the decontamination are major factors which influence the end result, determine the quantity of released sludge and minimize the taxing of the environment from turbidity and spillage. The dredging operation itself can be carried out with great accuracy.

RESULTS

Pre-dredging survey

+ Delivery of FAST-model, to establish a detailed, cost-effective study to measure.
+ Clear picture of the possibilities for fast screening of the geology and geological composition.
+ Practical experience in pilot remediations (including planning and organization).

Dredging

+ Clarity on ways of limiting turbidity and spillage.
+ Clarity on the degree of accuracy to be achieved with various methods.
+ Optimizing control and monitoring by using digital terrain models.
+ Practical experience in pilot remediations (including planning and organization).

The final reports (only available in Dutch) on site studies and dredging carry more details on this POSW-subprogramme.

Site studies

The contamination contours (which form the boundary between contaminated and 'clean' sediments) have to be determined with a high degree of accuracy. Future surprises can cause major budgetary problems, in view of the cost of dredging and processing (to leave no doubt: this concerns the *decontamination* of sediments; with maintenance dredging, the dredging profile is simply dictated by the depth needed for shipping traffic). The FAST model was developed in the framework of POSW-I. When input on the survey method is fed into this computer program, the inherent choices are translated to the cost of the entire clean-up operation (including the survey). It will also compute the success rate of the desired result.
An example of a choice to be made in study methods is the detailedness with which the waterbottom is sampled and mapped.
Rijkswaterstaat has introduced facts of knowledge and experience into the model; subsequent POSW pilot clean-ups offered a good opportunity to test and improve it further. FAST is now a useful tool, licenses for which are marketed by AVECO at low cost to promote the use of the model wherever and whenever it is required.

The hazards of underestimation (Intermezzo)

Pilot remediations showed that, in several cases, the quantities of sludge which were actually removed proved far larger than the estimated ones. As one of the main purposes of a pre-dredging survey is to draw up a budget and set aside finances, this is an unfortunate area to make mistakes.

Such mistakes may be partly due to miscommunication: the detailed investigation defines the *quantity* of *contaminated sediment* present in a certain location, whereas the dredger may well opt for some extra depth to ensure a cleaner result. This leeway causes extra sediment to be removed.

A more common cause, however, is that the site study is too limited in either scope or quality to achieve a true result. More is the pity, as the returns on expenses early in the chain are far larger than later benefits: every additonal tonne (dry matter) of sludge will cost NLG 30 at dumping.

POSW-II has looked for faster and cheaper ways to map the quality and geology of the sediment, bringing more detailed and extensive methods for pre-dredging surveys within reach. Apart from reliable charting, continuous feedback is achieved by monitoring *during* the dredging activities (providing direct data on the material as it is being released).

Methods to measure the quality of the sediment *in-situ* are still being developed and show great promise.

In-loco methods for such measurements are already operational. These still require sampling the sediment, as do traditional methods, but the samples are analyzed on-site (in loco) instead of in a laboratory.

The in-loco technique of X-ray-fluorescence-spectrometry (XRF) has proved its reliability with regard to fast screening of most heavy metal contents. This concept, although in the final stage of development, is already operational and commercially available.

The contents of dry matter and organic substances of muddy sediments can be determined by the Microwave method. Another such method is laser diffraction, which is used to define the fractions of clay particles and silt in such sediments. Both methods are commercially available. They yield supplementary data for the site study, and can provide feedback during the dredging activities. The selection of a specific processing method will always require an extensive classification.

Another in-loco method which is already operational and commercially available (dry matter, organic substances, calcite, density and grain size distribution) utilizes 'near infrared light' and relates reflection patterns to sediment structures. A proto-type of an in-situ probe will shortly become available.

The last technical principle made operational and available for site studies is the seismic method. This is only useful within certain limits; its accuracy is restricted by a difficult interpretation of the images, which only show different rates of density in the sediment. The image can therefore be used to define the quality of the sediment only if the contours of the contamination happen to coincide with such rate differences. The results can furthermore be distorted by gas bubbles trapped in the sediment. A seismic study on its own will never suffice as a mapping method, although it can be a valuable aid in revealing aspects such as unexpected, capricious geological patterns.

Historical investigation (Intermezzo)

Another essential component of the site study is the historical investigation, which eliminates the element of surprise. Are certain spots within the site perhaps more seriously contaminated as a result of activities in the past? Is there a chance that the dredging work will be bogged down by rubble which was overlooked during sampling? Are there any old channels, training walls, etcetera? Was the sediment profile perhaps seriously disrupted by sand extraction in the past?

Dredging

Research showed that the turbidity caused by dredging activities cannot as yet be predicted reliably or monitored unambiguously. To a smaller extent this also goes for spillage. That is why prevention - by using quality equipment and performing with accuracy - is of the essence.
The comparison of POSW-II field tests with regard to this aspect helped define evaluative criteria for the methods proposed by contractors. These criteria will be developed further and standardized by Rijkswaterstaat in the framework of another programme. The fundamental conclusion was that, if an approach is to guarantee accuracy, it must incorporate a serious effort to limit spillage and turbidity. Such an effort remains vital even in cases where accuracy is not of the essence.

The accuracy of dredging methods is determined by the precision with which the defined remediation profile is dredged: precision dredging. Various methods, based on highly diverse principles, appeared to have quite similar rates of accuracy. The differences in concepts became even less relevant when tested against the accuracy in the pre-dredging survey and the rate of monitoring accuracy achievable with precision dredging.
A precision performance within 10 cm is a reasonable requirement, which the contractor should be able to meet. Various options to achieve this accuracy are available to the contracting company.

Dredging methods (Intermezzo)

The following methods were tested for precision dredging: the sweepdredger, the environmental disc cutter, the bucket dredger and grab bucket dredger, and methods using worm wheels.

When the sediment includes coarse material, the advantage of mechanical equipment (grabs and buckets) is its relatively slight susceptibility to damage from this material. It is no easy task, however, to ascertain the presence of such matter in advance. Tests focusing on the detection of coarse objects (by way of seismic studies, amongst other things) showed that probably the only way to get a fair indication of local conditions is by dredging a test channel.

The environmental bucket was used in the pilot remediation Elburg Harbour

Many contractors are already deploying digital terrain models (DTM), which identify the desired excavation profile and are capable of controlling the dredging equipment. Conversely, registration of the movements of the equipment also traces the actual excavation profile in a DTM-system. POSW-II experiments offered the contractors the opportunity of optimizing these systems. The requirement to utilize a DTM can thus be included in the specifications, provided such precision is really necessary.

Despite the far-reaching automation, 'human factors' still co-determine the quality of the work. The people who conduct the activities (and their supervisors) should be aware of their actions and the possible effects on the final result.

Pre-dredging surveys and dredging in pilot remediations

The pilot clean-ups offered not only practical experience with sludge processing, but also served to define various planning and organizational aspects of the activities as well as the application of geological surveying and dredging technology.

A detailed preparation must be part of the planning phase; it should include a complete survey of the needed permits and allow sufficient time to complete all procedures before the implementation of the works.
It is necessary from the start to have an overview of the entire remedial chain (target and approach) in order to attune the site study to it.
This study should produce useful and relevant data for the decision-making process on the decontamination. The kind of information needed is indicated in the Guideline Soil Conservancy of the Ministry of Housing, Spatial Planning and the Environment (VROM) and is set out in detail in research protocols for soils and sediments (see Intermezzo). The formal information need for the decision-making process remains unimpaired under all conditions. As to the study of the presence of pollutants, the investigative effort called for may be excessive in some specific cases. This pressure point has been recognized from many sides, which is why the need for information is presently being re-assessed (Intermezzo).

Protocol (Intermezzo)

The view expressed in the Guideline Soil Conservancy was elaborated by the Netherlands Organization for Applied Scientific Research (TNO), commissioned by VROM. The details were set out in research protocols for soils and sediments, the latter in cooperation with Rijkswaterstaat. A distinction was made between the need for information during a preliminary survey and during a detailed investigation. To a greater extent than in the preliminary stage, detailed data-gathering serves to underpin the conclusion that the sediment involved is seriously contaminated, and to define the nature and size of the contamination in order to work out remedial measures. Bottlenecks related to the need for information thus formally defined are reviewed in a project stemming from administrative consultations, in which Rijkswaterstaat also takes part. Anticipating the results of this review, the Institute for Inland Water Management and Waste Water Treatment (RIZA) is currently adapting the first part of the research protocol for sediments.

Useful data, by the way, have a limited 'shelf life'. After a short while, they no longer represent the actual state of the sediment, since the conditions mapped previously are constantly affected by settling processes, erosion and nautical movements. And, last but not least, a requirement in every dredging permit states that the activities be based on recent study data.

The specifications for a survey or dredging activities should cover a wide range and prescribe detailed information to be provided by the study, and the quality of dredging which is expected. The specifications must be so compelling that their terms cannot be avoided in proposals.

During the pilot remediations, experience was gained in assessing proposals, taking both quality and price into consideration (Intermezzo).

Two-envelopes system (Intermezzo)

A tendering system was introduced in consultation with two professional associations. Proposals are assessed with regard to both quality and price of pilot remediations. Contractors submit a proposal which includes a working method and a cost estimate, but the prices are not viewed until after a separate pre-selection has taken place. This pre-selection is based upon quality standards stated previously and clearly. This is called a two-envelopes system.

The client himself should preferably take responsibility for a remedial dredging operation by prescribing a dredging profile rather than the quality of sludge to be delivered. Failing to do so implies that he is willing to take the risk that the contractor will dredge beyond the lower contour, releasing excessive volumes of sludge, to guarantee a good result.

Another, more obvious, way of ensuring the quality of the study and the remediation itself is a close supervision of the operating method.

2.3 Separating sludge into subflows (physical methods)

The separating technologies are aimed at achieving a relatively clean, recyclable coarse fraction and a fine fraction which still holds a concentration of contaminants. A sound classification beforehand will help identify ways to achieve this aim. The separating methods are based on the deployment of a hydrocyclone, upstream separation and a settling basin - or derivatives or combinations of these. They are technically capable of processing sludge which contains a sufficient amount of sand (see Intermezzo). The sandy fraction is quite clean and can easily be purified further, if so desired. The polluted fraction can either be dumped in a smaller space than the one claimed by the original integrated sludge, or be treated further. This pre-separation into two fractions paves the way for some processing options which would be too expensive with untreated, non-desanded sludge.

The investigation focused on the separation of sand as well as alternatives to clean the finer fraction further through flotation (see below). Few tangible results have been reached with this method so far. Finally, the performance made possible by (extensive) dewatering of fine fractions (residual flows) has also been charted in detail.

RESULTS

+ Existing methods were optimized. The combination of existing technology with the experience gained from POSW and other programmes allows contractors to retrieve usable construction materials from sandy sludges.
+ Clarity on flotation of sludge: not feasible for the time being.
+ Clarity on the extent to which residual flows can be dewatered.
+ A successful pilot remediation in which separation methods have been applied.

The final report on physical separation methods (only available in Dutch) carries a more detailed description of this POSW-subprogramme.

Required sand content (Intermezzo)

Separation is not considered feasible for sludge containing a weight percentage of sand of less than 50. Not only will less sand be retrieved, but the benefit of reducing the discharge volume is also lost: the natural dewatering process through consolidation of the residue (to reduce the amount prior to dumping) cannot occur in a residue containing so few heavier particles.

Prior classification of the sludge

It is important to gain a good understanding of the composition of the sludge prior to dredging: the materials it is composed of; the grain size distribution; the nature of the contaminants present and the kind of sludge fractions they are attached to. Answers can be found by passing the material through several sieves and by chemically analyzing the resulting fractions. A highly appropriate method to determine the points of separation (grain sizes where separation should occur to achieve fractions of a predetermined quality) is the T2000 suitability test, from VROM. The concept is based on the use of sieves and separation of densities, and was developed in cooperation with TNO and POSW, amongst other parties.

Methods of separation according to grain size

Experience with hydrocyclones and upstream separation has been gained in the framework of POSW. The activities were aimed at optimizing the existing methods for the processing of sludge. The technology presently available and the practical experience gained by contractors in the decontamination of sediments render it possible to extract building materials (class 1 of the Building Materials Decree) from sandy sludge.
Apart from the positive ecological effects of processing - less dumping space needed, saving on the extraction of primary materials - the processing itself has negative side-effects. The separation of sand is energy-consuming and requires water to dilute the input. The water is recycled during the process, but any surplus will have to be treated, either locally or in a purifier elsewhere.

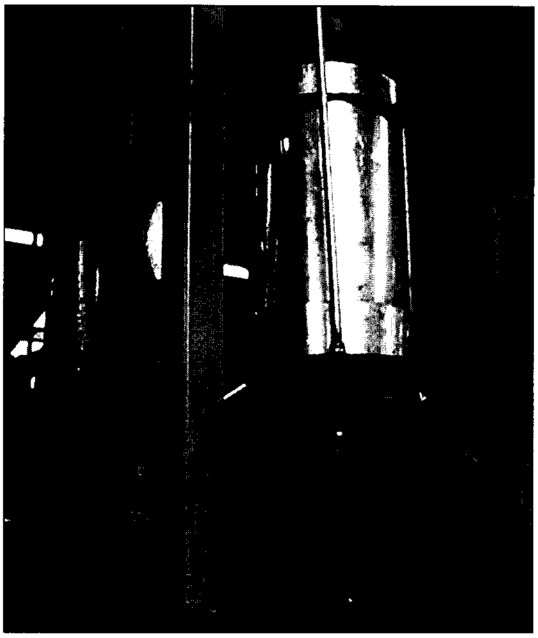
Pilot remediation Elburg Harbour (Intermezzo)

The objective was to remove a minimum of 90% of the pollutants present (PAH and mineral oil) in the harbour, and to process the sludge in such a way that at least 50% of the material could be recycled. The pilot remediation succeeded in doing so. It was the first of three decontaminations carried out in the framework of POSW-II and the requirements of precision dredging were new at the time. The contractor developed a special grab and improved the controlling equipment to meet the requirements.
The sand in this project was separated by hydrocyclone. In this process, diluted sludge is introduced into the top of a funnel-shaped barrel. The tangential pouring causes the material to rotate in the barrel. The heavier sand travels down the outer wall and leaves the cyclone through the lower flow outlet, while the lighter clay particles are expelled through the upper flow outlet. No upgrading of an existing method was involved here, but Rijkswaterstaat gained experience in drawing up specifications which demand a certain quality level for the operating method. The contractor succeeded in meeting these high standards: 53% of the dredged spoil could be separated as sand clean enough to be used as construction material in a housing programme of the town of Den Helder. A further 32% of extracted sand could be marketed as filtering sand and embankment fill in a deposit site for polluted soil.

The possibilities of sludge flotation

POSW-II staff was also involved in researching the possibilities to purify the fine fraction - i.e. the residual flow after the separation of sand - by means of flotation (see Intermezzo). This was tried initially in the pilot remediation of Elburg, later in the framework of the project *Flotation North and South-Holland provinces*, in which POSW participated along with water boards, provincial authorities and Rijkswaterstaat.
Unlike the flotation of sand, the heavy metal contents of silt remain practically unchanged after flotation, because such substances are bonded very tightly to clay minerals. That is why flotation, when deployed to purify the fine fraction, only affects the content of organic pollutants. The fine fraction, however, is generally contaminated with mineral oil and PAH to such an extent that, after treatment, the concentrations still exceed the provisional warnings value.
A method to separate the fine fraction into yet smaller particles ('cutting' at a smaller grain size), followed by flotation of the relatively coarse fraction left behind (the intermediate fraction) is still being developed. If this works, more recyclable products can be extracted, which will further reduce the residue to be dumped. This investigation, however, remains outside the framework of POSW, as a spin-off from the research of sludge flotation.

Hydrocyclone, part of a separation installation



Flotation (Intermezzo)

Flotation is a polishing technique, whereby certain substances are added to the input material. These additives ensure that pollutants adhere to air bubbles introduced into the flow, either by aeration, or by compression followed by decompression. When these air bubbles float upward, they form a highly contaminated layer of froth which can be skimmed.

Mechanical dewatering

The fine fraction which results from separation as a residual flow will often have to be dewatered for further processing, or dumped in a more compact shape. It is therefore important to know the rate of dewatering that can be achieved and its costs for various types of sludge. In the course of POSW-II, a questionnaire was submitted to users and suppliers of dewatering equipment, particularly the commonly used belt press. The answers served to list the various dewatering rates achievable for fine sludge compounds varying in contents of organic substances and in grain size distributions.

The environmental effects of mechanical dewatering concern not only energy consumption and the use of poly-electrolyte, but also the output of waste water requiring treatment.

2.4 Thermic and chemical treatment methods

A number of treatment methods are aimed at releasing the contaminants from the source material (desorption). This is achieved by applying high temperatures (thermic treatment) or solvents (chemical treatment). Wet or dry thermic treatment will cause the substances to partially disintegrate or incinerate (oxidize), depending on the temperature and method used. From the known concepts, two thermic methods are operational. They mainly affect the *organic* substances occurring in the source material.

As one of these methods was specifically designed for the fine fraction of the sludge, this has to be separated from the sand prior to treatment.

RESULTS

+ Usable (thermic) methods for the treatment of sludge which is mainly contaminated by organic substances. One of the methods, i.e. thermic desorption and incineration, fully guarantees that the end product is a usable construction material.
+ Clearness on treatment with the aid of solvents (acetone): this process shows promise, but cannot be made operational within the next 3 years.

The final report on thermic and chemical treatments (only available in Dutch) explicates this POSW-subprogramme in further detail.

Treatment by dry heating (thermic desorption and incineration)

The research of thermic methods was concentrated increasingly on the principle of the rotary screen furnace, as applied in operational domestic soil treatment plants. This method does not require the sand to be separated beforehand. This might in fact be disadvantageous: the results in the drying stage are improved by using the integrated sludge, whereas the capacity will be reduced by the input of the fine fraction only (although this is technically feasible). Furthermore, the concentrations of metal in the end product are lower if the relatively clean sand is allowed to remain in the source material. Field tests proved that, even when the input was very heavily contaminated by PAH and mineral oil (sludge in the pilot remediation Petroleum Harbour), the presence of these pollutants could no longer be demonstrated in the residual product. Heavy metals (with the exception of mercury) are not removed by this treatment, therefore only input material with low concentrations can be recycled. The leachability of heavy metals is decreased by the treatment, although the opposite effect is achieved with some substances (molybdene, arsenic and fluor).
This thermic concept can be implemented, but existing plants have not as yet been licensed for the processing of *sludge*, and some require a few (probably not very complicated) adaptations to make the process fully successful. As the POSW-test involved only a single type of sludge, the ideal dimensioning can not as yet be predicted. The testing and experiences with soil remediation have made it quite clear, however, that this treatment has a *purifying result.*

Environmental effects of the method involve energy consumption, the discharge of waste water and emissions into the air.

Treatment by wet oxidation

POSW-II offered the opportunity to gain in-depth field experience with the wet oxidation of silt (fine residual flow after sand separation) during the pilot remediation of Elburg Harbour. This was conducted in an existing plant for wet oxidation of sewage sludge (VerTech process). Caution should be exercised in extrapolating the results to practical processing, since the test concerned only a single type of sludge. Still, the test showed, at least for that particular type, that wet oxidation reduces the organic contamination considerably. The oil content in the residual product, however, proved problematic. The concentration was reduced to 70-80% of the original content, but this still exceeded the application standards of the Building Materials Decree. The wet oxidation did change the structure of the remaining oil, which was 'pre-cracked'. A small-scale landfarming test conducted by POSW showed that this oil could be degraded fast and completely in a biological way.
The contents of heavy metals were not affected by the wet oxidation, but their leachability was reduced.

Environmental effects of wet oxidation involve energy consumption, the discharge of waste water and emissions into the air.

Wet oxidation (Intermezzo)

Wet oxidation involves incineration of wet sludge, which has not been dewatered, by introducing oxygen at low temperatures (200-300 °C). The VerTech concept achieves this by using high pressure in a tubular reactor. The VerTech reactor in Apeldoorn reaches underground as deep as 1300 m in order to build up the required pressure.

Treatment with solvent extraction

The tests conducted during POSW-II with extraction by acetone (in cooperation with the Agricultural University of Wageningen and TNO) are still in progress. The design of the reactor remains a problematic factor, delaying the implementation of this method in the near future. Insofar as other useful information on existing alternatives reached POSW (mainly from the USA), the residual concentrations achieved with these methods appeared to be unacceptably high for Dutch standards. The method has the potential advantage that, depending on the solvent applied, not only PAH and mineral oil but also other kinds of organic pollutants (such as PCB, dioxines) can be removed. Compared to thermic treatment, this concept also scores better on the counts of energy consumption and emissions into the air.

Environmental effects of solvent extraction involve energy consumption, discharge of waste water and emissions into the air.

2.5 Biological treatment

Biological methods use bacteria or fungi for the degradation of organic contaminations (particularly oil and PAH). Spreading and drying are the means used in the methods of landfarming and greenhouse farming to enhance the presence of oxygen, which is a main condition for degradation; mechanical aeration is used for treatment in reactors.
As the heavy metal contents are not reduced by these processes, they are more suitable to the treatment of organically contaminated sludge with, at most, a tolerated concentration of heavy metals. It should be noted that biological treatment may slightly enhance the mobility of heavy metals.

Part of the organic contaminants in the sludge is easily reached by the organisms. Another part of these substances, however, is tightly bonded to the sediment matrix and will only very slowly become available for degradation. That is why, in the first stage of a biological treatment, degradation is always speedy until it reaches a certain level. In the following stage, the residual concentrations are reduced far slower: in this stage, the contents of mineral oil, in particular, remain a bottleneck for application of the product in construction.
Before biological treatment of a certain type of sludge is engaged in, the feasible residual concentrations at different staying times have to be determined in a laboratory. This potential can be translated to practical results, albeit with some latitude.

Apart from treating the sludge in parcels of land, greenhouses or reactors, POSW-II also included studies of 'in-situ' treatment of sediments and dechlorination in a deposit (see Intermezzo).

RESULTS

+ Tests and a pilot remediation of POSW confirmed that part of the organic contamination can be removed fast in a biological way (intensive landfarming, greenhouse farming, reactors). POSW helped improve this technology.
+ At high starting concentrations and/or the presence of only slightly available substances, the resulting product remains contaminated to an unacceptable degree. POSW demonstrated the feasibility of further degradation by means of second-stage extensive landfarming.
+ The Dutch Institute for Inland Water Management and Waste Water Treatment (RIZA) has issued an advice with regard to in-situ treatment (see Intermezzo).

The basic report on biological treatment (only available in Dutch) explicates this POSW-subprogramme in further detail.

Treatment in-situ and in a deposit (Intermezzo)

In-situ treatment is based on the idea that additives carrying nutrients, bacteria and/or oxygen-carrying compounds, initiate a biological process of degradation in the soil or sediment. The four 'bio-dredging' products researched during POSW proved inactive, whereupon RIZA advised that, henceforth, such products be made subject to licensing. Permit applications are not declared admissible until a laboratory study has determined beyond all doubt that the process has no negative side-effects.
The biological degradation of chlorated compounds in deposits has also been investigated (by POSW in cooperation with the Rijkswaterstaat Directorate North-Holland). This process requires anoxic conditions first, followed by oxygen-rich conditions. The anoxic nature of the sludge can initially be preserved by providing a covering layer of water in the deposit. The study focused on the degradation of hexachlorobenzene in anoxic conditions, in a deposit filled with sludge containing this pollutant. Half-lives of 10 months were observed. This simple way of controlling environmental conditions may reduce an 'eternal' storage in a deposit to a possible staying time of five to ten years.

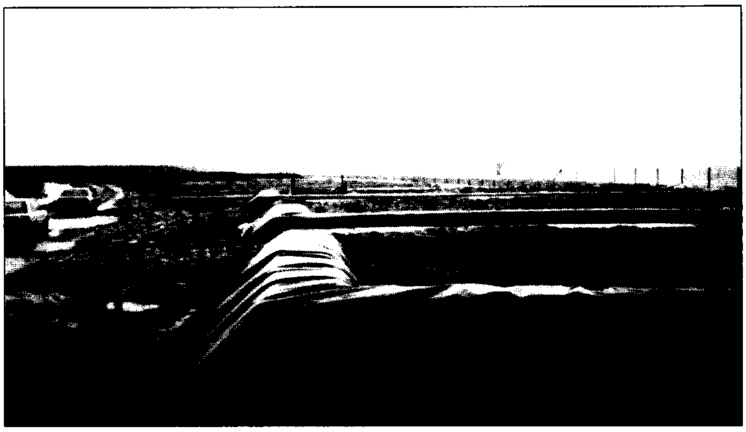
Treatment by landfarming and greenhouse farming

Landfarming involves the spreading of sludge on parcels in the open air. The sludge should preferable hold a reasonable proportion of sand, as the resulting structure favours speedy drainage and the absorbing of oxygen. After dewatering and ripening (structurization), the sludge will hold sufficient air to encourage biological activity. Two types of landfarming are discerned: extensive and intensive. With the latter, the oxygen supply is kept up by regular ploughing, whereas this supply is stimulated in extensive landfarming only by planting. Intensive landfarming is most effective during the first stage, when regular supplies of oxygen activate the process of degradation. In the second stage, degradation depends on the availability of the contaminants; it would therefore be logical at that point to switch to extensive farming.

Intensive landfarming requires staying times between 1.5 and 2.5 years in the first stage, when, depending on the type of sludge, 25-92% of PAH and 60-80% of mineral oil are removed. POSW-tests with various types of sludge produced a sound understanding of practical features, such as the timing of the process with regard to the seasons, and the physical planning of the lots. The method is fully operational, as is also shown by the decision of the Rijkswaterstaat Directorate Zeeland (also involved in POSW-tests) to deploy landfarming for the decontamination of sludge from Wemeldinge Harbour (see Intermezzo).

Wemeldinge Harbour (Intermezzo)

Landfarming tests with sludge from the harbour of Wemeldinge showed degradation rates of 25% for PAH and 61% for oil. Rijkswaterstaat Directorate Zeeland achieved similar results during the actual remediation of this harbour, although the degradation was speeded up by improvements inspired by POSW-II tests. After two years of intensive landfarming, the erstwhile sludge will be available as construction material.



Landfarming test-site

Extensive landfarming in the second stage is directed at removing also the residual concentrations of organic substances by allowing enough time to reach diffusion of the contaminations. The sludge is spread across the area in much thicker layers, planted and treated extensively in five to fifteen years - with no further effort at all. This concept proved to be feasible in a four-year project.

Spatial claims, temporary and long-term, form the most relevant environmental aspect of landfarming. The emissions into the air are negligible. Drainage water can be discharged without major problems, although it may have to be purified first. There appears to be very little risk of substances dispersing from the landfarming parcels to the subsoil by way of the drainage water. Permits used to prescribe the use of a foil bottom insulation and proper drainage, but the absence of oil and PAHs in the drainage water demonstrated that a (cheaper) bottom insulation of peat would serve just as well.
One point of study remains: the possibility to combine extensive landfarming with the growing of certain crops, which would more easily justify the space occupied by landfarming projects. Plants capable of withdrawing heavy metals from the sludge might also play a role in the treatment.

Greenhouse farming, which consists of biological treatment in greenhouses, can be considered a form of landfarming under more controllable conditions. Contractors use this method to clean sandy, oil-containing soils. With sludge being so much wetter and more finely grained, adaptations were called for. Dewatering and structurization (ripening in open-air lots) are absolute pre-conditions. *Indirect* greenhouse farming is based on these pre-conditions: the result for PAH and oil, achieved in a glasshouse within three months, is similar to the result of one full year of open air landfarming.
The application of indirect greenhouse farming in the colder seasons can relieve logistic problems and extend the capacity of intensive landfarming. Aeration and heating without pre-treatment *(direct greenhouse farming)* does not appear to be cost-effective.

The most relevant environmental feature of greenhouse farming is the consumption of energy. No major emissions into the air occur during the treatment. The drainage water, which may have to be treated, can be discharged without major problems. Compared to landfarming, this treatment is far less space-consuming.

Treatment in reactors

Treatment in reactors involves introducing the sludge as slurry in tanks, where it is constantly kept moving and aerated. The slurry can be treated batch-wise or in a continuous process.
Within the framework of POSW, two types of bio-reactors were tested on a scale of some cubic metres, and were deemed suitable: the Slurry Decontamination Process (SDP, continuous system) and the Aeration Basin (batch system). The latter is suitable for the treatment of fine fractions from a hydrocyclone, the first for the treatment of both separated and non-separated sludge.

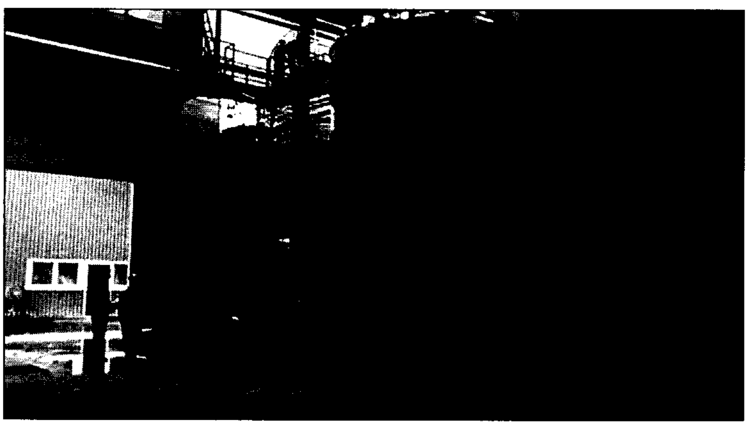
The treatment with reactors is on the whole four to ten times as expensive as landfarming, but the required staying times are decreased commensurately. The results achieved in this shorter period remain similar. Costs are expected to decrease further with upscaling of the treatment plants and commercialization of the market.

Pilot remediation Petroleum Harbour (Intermezzo)

The sediments in the Amsterdam Petroleum Harbour were seriously contaminated by mineral oil (to 20,000 ppm) and PAH (to 1000 ppm). This harbour was selected for a pilot remediation emphasizing the biological treatment of sludge. A continuous type of bio-reactor was utilized. Pre-conditions were quality requirements for the final product and a decontamination period of 100 days.
A total of 5000 cubic metres of sludge was dredged and processed. Pre-treatment with a hydrocyclone produced a coarse and a fine fraction. The former was subjected to flotation, whereas the fine fraction was dewatered to the desired density. It was next biologically treated in a continuous process in a series of bio-reactors and, finally, dewatered. Tests with a few cubic metres of material showed that PAH and oil could be removed from the sludge, by 92% and 76%, respectively. When departing from extremely high concentrations of oil, a residual the product as a construction material.

Emissions into the air are not an ecologically problematic feature of bio-reactors. The treatment involves the recycling of water, the surplus of which can be discharged - after purification if need be. Another environmental aspect is the energy consumption of this method.

Biological treatment of dredged material from the Petroleum Harbour



2.6 Locking contaminations in products (immobilization)

Immobilization involves the locking of contaminations in a solid residual product (insofar as the method used does not degrade, or otherwise release, the contaminations). The contaminants cannot be allowed to be released from the final products except in very limited quantities (through leaching or erosion). These methods are emphatically aimed at the production of building materials, which should therefore amply meet the requirements set out by the Building Materials Decree.
Immobilization is the major follow-up treatment for mixtures of pollutants, including heavy metals. Other processing methods which are currently, or will shortly become, available can after all achieve no more than a considerable reduction of the organic pollution. Two *thermic* immobilization processes (melting and sintering) result in products which are usable from an environmental point of view. The civil engineering usability of melting products has been proven. The prognosis for sintering, of which the civil engineering possibilities are still being studied, is favourable.

RESULTS

+ Two suitable *thermic* immobilization methods are available for sludge contaminated by organic substances and heavy metals.
+ Melting and sintering yield usable products from an ecological viewpoint. The applicability of melting products in civil engineering has been proven; the prognosis for sintered products is favourable.
+ Melting (final product: artificial basalt) has been used in the pilot remediation of New Merwede River.

The final report on immobilization (only available in Dutch) carries more details on this POSW-subprogramme.

Thermic immobilization: melting or sintering

Sintering and melting were tested more extensively as POSW progressed (see Intermezzo). *Ecogravel* was produced on a small scale through sintering, and the melting method was deployed to process material from a pilot remediation (see Intermezzo). The thermic methods are operational and can be implemented on a practical scale as soon as sufficient capacity has been realized.

Sintering and melting (Intermezzo)

Thermic immobilization involves the following process: after the sludge has been passed through a hydrocyclone, the fine fraction is dewatered by a belt press and processed to dry pellets. These are introduced into an oven, with additives if needed. The temperature inside determines whether the material is sintered (melting of outer layer) or completely melted. The first method produces Ecogravel, the second one - depending on the way of cooling - artificial basalt or a glass-like product.

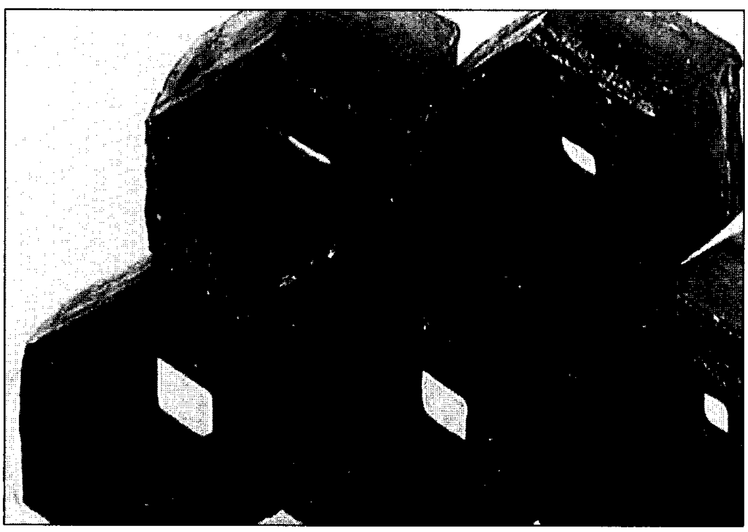
The civil engineering qualities and leaching properties of the products were tested. Artificial basalt rated 'reasonable' to 'good' for the qualities of solidity and durability. The leaching test showed it to be a quite freely applicable building material (class 0 of the Building Materials Decree). Rijkswaterstaat will extend the practical experience by constructing a test area in a dike from artificial basalt blocks and *basalton* (concrete in which broken artificial basalt replaces the gravel).

Leaching tests demonstrated the usefulness of Ecogravel (a sintering product), although its use may be restricted by the leaching of arsenic; in that case, insulated application may be in order. The civil engineering study on Ecogravel has yet to be completed, but tests so far show it to be a usable product. Once all tests are completed, the production of this gravel may be upgraded to a commercial level.

Pilot remediation New Merwede River (Intermezzo)

The type of sludge and the nature of the contamination in the selected groyne field in the New Merwede River are representative of the conditions found in many waters in the Lower River Basins of the Netherlands. The objective of the operation was the clean-up of the entire groyne field with a view to halting further spreading of the contamination into the environment and restoring the balance in the local habitat. During the detailed survey, it appeared that the pre-dredging survey had overlooked a sludge-filled old channel in the groyne field. A full remediation would now require much larger volumes to be dredged and high unforeseen costs. Only a 1.5 m thick layer was therefore excavated (with a bucket dredger and grab), after which the sediment was covered with clean sand. The objective of processing the sludge (see below) was realized. The results have yet to be tested against the environmental targets. Rijkswaterstaat Directorate Zuid-Holland is responsible for monitoring the ecological restoration in the groyne field.

Part of the sludge was immobilized into artificial basalt (moulded and broken materials). The method suffices and the product constitutes an ecologically sound and usable construction material. The company selected for processing was one of four interested contractors, who had made it clear that they were capable of processing the volumes of sludge the moment they would be offered.



Artificial basalt from dredged material from the New Merwede River

At the end of the eighties, immobilization was not a politically acceptable topic, as it was taken to stand for 'non-destroying' of waste substances. POSW-II contributed to a easier acceptance of the method as a realistic way of processing. Building Materials Decree also stimulated this development by offering a frame of reference, and by approaching residual flows as (potential) products. A number of companies have grown very enthusiastic and are prepared to further implement the method, albeit with guarantees concerning supplies of sludge or purchase of products.

Environmental effects of thermic immobilization are created by energy consumption, waste gases and residues from the treatment of these gases (see Intermezzo). The consumption of additives, insofar as they constitute primary materials, should furthermore be mentioned, but efforts are made to use other waste materials instead.

Thermic immobilization and the environment (Intermezzo)

Thermic immobilization takes place at very high temperatures, which are generally associated with a high consumption of energy. The drying stage (removal of water) requires the most, whereas the subsequent melting of dry material is far less energy-consuming. The difference in energy-consumption rates for incineration, sintering and melting amounts to only a few per cent. Besides, the reclaiming of energy is relatively easy at high temperatures, which means that the benefits from the energy used are quite high.

Part of the heavy metals escapes via the waste gases, which therefore have to be purified thoroughly. The metals are concentrated in relatively small quantities of fly-ash: 5 kilo/tonne of produce can be realized in a full-scale treatment plant. It may be possible to regain the heavy metals from this waste flow.

2.7 Usable researched methods (summary)

Reviewing the previous sections, Tables 2.7.I and 2.7.II list the usable methods, their status quo and applications. Costs were not included in this summary, the reasons for which have been explained in the introduction to this chapter.

Table 2.7.I: Site study, classification and dredging

Method	Status	Application
FAST model	commercially available method	aid in organizing cost-effective detailed study to measure, and in decisions implementation of dredging works predicting quality sediment after dredging
X-ray fluorescencespectrometry (XRF)	commercially available in-loco method	fast screening in the field (in loco) of heavy-metal contents in samples
- microwave method - laser diffraction method - study of 'near infrared' light	commercially available method for in-loco measurements	fast image (in loco) composition sludge: (depending on method: dm content, fractions clay particles and silt, organic substances, grain size distribution, calcite and density)
seismic study	commercially available method	supplementary role determining sediment profile in site study
T-2000 suitability test according to Ministry of the Environment	available and applicable method	extensive classification sludge for processing (separation)
dredging equipment principles: - sweepdredger - environmental disc cutter - bucket dredge and grab - wormwheel	commercially available method	precision performance technically feasible control systems and human factor also important
digital terrain models	commercially available method	support (guidance, feedback) dredging

Table 2.7.II: Processing methods sludge or residual flows

Method	Status	Application
upstream classifiers and hydrocyclones (may be combined)	commercially available method	separation sandy sludge according to grain size (extraction of useful fractions, concentration of pollutants in residue)
spirals	commercially available method	further treatment (separation by density) of sandy fractions after separation
flotation	commercially available method	further treatment (polishing) of sandy fractions after separation
belt press	commercially available method	intensive dewatering of fine fraction after separation sand
thermic treatment (rotary screen principle)	- operational for soil, commercially available method - capacity available for sludge (after slight adaptations)	removal organic pollutants
wet oxidation (VerTech method)	- operational for sewage sludge, commercially available method - effective at least for sludge (residue) tested for POSW-II	reducing organic pollution of fine residual flow after separation of sand
landfarming	- usable and used in practice, commercially available method	reducing organic pollutants of sufficient sandy sludge
greenhous farming	- existing method for soil remed - should be adapted for sludge processing (previous dewatering and ripening required)	reducing organic pollutants of residual flow after separation of sand
slury reactors	upgraded to semi-practice at pilot remedation	reducing organic pollutants of residual flow after separation of sand
thermic immobilization (melting, sintering)	- operational and applied in pilot remedation - large-scale implementation requires realizing of capacity	- removal and incineration of organic pollutants in residual flows after sand separation - heavy metals are locked in the product or extracted during the process

The assessment for usability remains a *relative* assessment of different methods. This qualification within POSW is furthermore related to the researched working modes, the input of certain source materials, etcetera. With this restriction in mind, the following less useful/promising methods may be noted besides the methods described before: flotation of *silt*, chemical treatment with solvents, biological in-situ treatment, *direct* greenhouse farming and chemical immobilization.

3 From theory to practice

3.1 Introduction

The mere fact that a method is technologically feasible does not imply that it is always implemented. Practical feasibility, cost, environmental effects, marketing prospects for processed products and the administrative context all play a role.

The possibilities to quantify and assess the environmental effects of processing are discussed in the following section of this chapter. Such an evaluation does not merely address the issues of processing chains and scenarios, but also compares the environmental efficiency of a clean-up to a situation where decontamination is either omitted or dealt with in a different way.

A number of processing alternatives are discussed in the subsequent sections. These were developed in the Feasibility Study on the Large-scale Processing of Contaminated Dredged Material, which was commissioned by POSW and PHB, another project office of Rijkswaterstaat (see Intermezzo).
These options only concern *processing*: the pre-dredging survey and the dredging works - two activities in the front of the processing chain - are part of every clean-up. The FAST-model (see Section 2.2) can support the detailed decision-making during the site study. Furthermore, a selection of existing methods, all rather similar in cost and accuracy, is readily available for the dredging activities. Options for transportation have been omitted from the scenarios, although the transport *cost* was calculated for each alternative.

The first step in the development of the processing options was the selection of appropriate methods. These formed the basis for each scenario, while making allowance for the various amounts and qualities of sludge which might be offered. The cost and environmental effects of each scenario were calculated next. This made it possible to compare them to the reference strategy of 'dumping', which was calculated in a similar way during this study. The policy objective to process 20% of the contaminated dredging sludge by the year 2000 was a key point in all of the scenarios. These were designed to achieve a useful application of 20% of the supply, taking into consideration the performance of each individual method and an estimate of its practical feasibility. That is why, in the end, the actual proportions of useful application were not calculated to be 20%; this was subsequently corrected by mutual comparisons.

Other subjects in the Feasibility Study were the major environmental factors constituted by the market for processed products and the administrative context. The final sections deal with this market, with key conditions in the financial and administrative realm, and the prospects to promote processing.

Project Bureau for the Re-use of Dredging Sludge - PHB (Intermezzo)

PHB is a Rijkswaterstaat project office set up to develop proposals for commercially, technically and environmentally viable methods for applying (non-)processed sludge. Government policy discerns between the processing of more heavily contaminated sludge and the recycling of all types of dredging sludge. The office's tasks involve both processing and recycling. Knowledge is gathered and transferred, in close cooperation with all parties involved.

3.2 Assessing the environmental effects of processing chains

When dredging contaminated sediment, the removal of environmentally hazardous substances influences the environment in a positive way. However, the dredging, transportation and processing also have negative environmental effects, such as energy consumption and waste production. These effects were summarized for each processing method in the previous chapter.

It is vital to gain an early understanding of all expected environmental effects of dredging, transportation and processing. The negative effects can thus be minimized, at an early stage by taking them into account when designing the dredging and processing chains and, at a later stage, when the final decisions on the methods are taken. The environmental efficiency is also influenced by technical, social, financial and administrative feasibilities. The quantification and evaluation of environmental effects of dredging, transport and processing have the additional advantage of allowing an objective comparison with other options - such as applying a covering layer of clean sand in places where no dredging is required for the purpose of maintenance.

It is characteristic of an environmental assessment to review nothing but environmental effects, unlike the 'matrix' way of thinking, which is so often emphasized in processing. Matrix thinking implies that the main objective is to extract as much useful material as possible from the source material, thus reducing the amount to be discharged. Performance is measured in terms of quantity (rate of extraction) and quality of the products (tested against the Building Materials Decree). An environmental assessment, however, also reviews the environmental effects of processing and even the release of substances from materials fully in accordance with the Ministerial Order. Since it cannot be taken for granted that the performance of processing will result in a proportional performance for the environment, explicit attention should be paid to environmental aspects. This point will be discussed again during the assessment of scenarios in Section 3.5, under the heading Environmental Effects.

Within the framework of POSW, a method called LCA-Plus was developed to introduce environmental considerations into the designing of separate processing chains, and into decision-making processes of remedial chains for dredging sludge. Recommendations for its use and further development are presented in the subsequent Intermezzo (see under Table 3.2.1). The method is in accordance with national and international developments and can therefore be recognized and supported fairly universally.

RESULT

+ LCA-Plus is a useful method to introduce environmental considerations into the designing of separate processing chains, and into decision-making processes. It is recommended that, with regard to toxic substances, this method be supplemented with an assessment of the real and current risks for humans and ecosystems.

This POSW subprogramme is explicated in more detail in the final report on the subject (only available in Dutch).

LCA-Plus

The method to analyze and assess the environmental effects of processing chains is based on the life cycle analysis (LCA). The method, which is still in the developing stage, is commonly accepted in the Netherlands and worldwide for the assessment of the environmental effects of processes and products. It has been adapted and specified, in the framework of POSW, to deal with the problems of dredging sludge.

The first step consists of the visualization of processing chains, in the shape of environmentally-focused, simple processing diagrams.
Next comes the quantification of environmental aspects: the deployment of scarce materials, emissions, and the originating of substances which cannot be used in ecological or economic cycles (wastes).
The results of this second step are classified as scores (characteristic values) of the processing chain according to theme indicators. The results are expressed in a unit common to that particular theme, such as CO_2-equivalents for the indicator 'emission of greenhouse gases'. The themes and their indicators (such as the emission of greenhouse gases or the consumption of fossil energy carriers, see Table 3.2.1) link up with the LCA-method and the Second National Environmental Policy Plan.

Table 3.2.1: Basic list of environmental themes and indicators

Theme	Theme-indicator	Abbreviation
Depletion, wasting	deployment of non-renewable materials	ADP
	deployment of fossil energy carriers	EDP
	permanent spatial claim by dumping final wastes	WAS
	temporary spatial claim	TLU
Depletion and desiccating	use of groundwater	WAT
Dispersion	emission of human-toxic substances	HT
	emission of eco-toxic substances to water	ECA
	emission of eco-toxic substances to soil/sediments	ECT
Climatic changes	emission of greenhouse gases	GWP
Formation of smog	emission of smog-forming substances	POCP
Depletion of the ozone layer	emission of ozone layer- depleting substances	ODP
Acidification	emission of acidifying substances	AP
Over-fertilizing	emission of over-fertilizing substances	NP
Disturbance, nuisance	smell, noise, safety	HIN

Two final steps in the analysis: standardization and weighing (see Intermezzo) are optional. They are not always considered useful in view of unreliabilities (in totals per country against which the score is tested and in weighing factors) and in view of the loss of data incurred during processing. An alternative can be found in the use of characteristic values for dominant themes, such as the deployment of fossile energy carriers (EDP = Energy Depletion Potential) of a processing chain or the spatial claim/waste production.

Standardizing and weighing (Intermezzo)

An integrated assessment demands that the use or emission is first standardized according to theme, through comparison with the national use or emission. The resulting number indicates the relative contribution of a method or chain to the thematic issue being addressed. A 'Distance to Target'-method, which still has to be perfected, is then employed to assign a weighing factor. The difference between actual use/emission and the target determines the weight ascribed to a theme. An aggregate stipulation of the standardized and weighed numbers yields an environmental characteristic value (eco-value) indicating the environmental load of a specific chain.

Results

The method offers insight into major environmental aspects of processing chains: qualitative aspects; dominant, characteristic effects (quantifiable in characteristic values); responsible processes and activities; the integrated environmental load (or eco-value) for each processing chain (per tonne of dry matter, for example, or per cubic meter of dredging sludge).

Tables I, II and III in Annex 1 indicate the qualitative results of an environmental assessment for a few groups of related methods. This assessment was based on POSW-II studies and experiments.

An environmental assessment of transporting methods was carried out, but has not been presented in this final report. Dredging methods were not evaluated in this way, although the method would lend itself to this purpose. The reason was that differences in dredging methods are not expected to have a discerning effect on the environmental assessment of processing chains.

The study indicated a dominance of the theme indicators related to energy consumption and the generation of waste, especially where fossil energy was involved.

The developed method was also applied to the pilot remediations of Elburg Harbour (described in the Intermezzo in Section 2.3) and New Merwede River (Intermezzo in Section 2.6). The results offer a clear insight into the environmental effects. Caution has to be exercized when comparing decontaminations in this field, as the scores are co-determined by the scale of remediation and the type of sludge released by it.

Recommendations (Intermezzo)

LCA-Plus makes it possible to include environmental considerations in the design of processing chains and in decision-making processes. When using this method of assessment and presenting its results, the demarcation, points of departure and assumptions which form the basis should be defined explicitly. it is further recommended that the effects of contingencies in numbers and assumptions be reviewed in a sensitivity analysis.
It should be noted that, with an assessment of the overall ecological effect of a remedial chain, the (positive) effect achieved by the removal of substances is still determined by defining the burden to the ecosystem. This entails a consideration of potential environmental effects on the basis of the properties of substances. With regard to toxic materials, however, this approach should be supplemented with an assessment of current risks for humans and ecosystems, including routes of dispersal and exposure. Monitoring the eco-toxicity (of sediment, sludge, and -residual- products) by bio-assays would be a step in the right direction. Experience with the application and interpretation of such tests was gained during POSW; it is recommended that this experience be called upon for future projects.

3.3 Selection of methods for large-scale processing

The Feasibility Study on the Large-scale Processing of Contaminated Dredged Material features methods which were selected for their suitability for large-scale processing of sludge. The study results justify the conclusion that there are currently no real technical restrictions to processing. Two selection rounds and an assessment of the principle performance characteristics (see below) resulted in a package of available basic technologies offering sufficient processing options to accommodate practically all types of sludge.
There is not much difference between the costs of the various basic methods.

RESULTS

+ More detailed selection (qualification) of methods for large-scale processing, distinguishing between basic and follow-up methods.
+ The conclusion is justified that there are currently no real technical restrictions to processing.

The selection and results are described, in greater detail than below, in the Feasibility Study on the Large-scale Processing of Contaminated Dredged Material (only available in Dutch).

First selection

An important criterion for a pre-selection from the available processing methods was their proven technical feasibility and the availability of reliable design information (see Intermezzo).

First selection (Intermezzo)

The following processing methods were pre-selected for further elaboration:

- Separation of sand (classification, see Section 2.3), possibly followed by further treatment (polishing) of the sand fraction and dewatering of the fine residual flow.
- Thermic treatment (see Section 2.4) applied to residual flows after classification/polishing, and to non-desanded sludge.
- Thermic immobilization (see Section 2.6) of residual flows after classification/polishing, distinguishing melting and sintering.
- Wet oxidation (VerTech process, see Section 2.4), to be applied to residual flows after classification/polishing.
- Sedimentation in sedimentation basins (see Intermezzo), possibly followed by landfarming. Sedimentation has been studied by another Rijkswaterstaat project office, PHB.
- (Extensive) landfarming (see Section 2.5).
- Ripening in a special deposit (see Intermezzo). This method was studied by PHB.

Second selection: basic methods and follow-up methods

The (basic) methods selected for the development of scenarios were first reviewed in a second round, where their cost, effectiveness (quality, product) and benefit (proportion of useful product to input) were scrutinized.
Dewatering, natural sedimentation, (extensive) landfarming, classification, classification with polishing, and ripening were defined as basic methods which can be implemented in processing chains. Practically all types of sludge are thus covered.

Thermic treatment, thermic immobilization and wet oxidation did not make the final grade as basic treatments, but may be considered as follow-up treatments. Their (dis-)qualification was based on cost (all three methods), plus the fact that the latter two can only applied to materials with a very low sand content. Such materials could also be dumped, the cost of which will have to compared to costly treatment. It is more logical to apply thermic immobilization and wet oxidation as follow-up treatments (processing the 'condensedly' polluted residual flows resulting from separation).

Sedimentation and ripening (Intermezzo)

The methods of sedimentation and ripening were studied by the Rijkswaterstaat project office of PHB and were therefore omitted from Chapter 2 of this POSW report. With sedimentation, water-diluted sludge is passed through a sedimentation basin, separating the settling sand fraction from the still flowing muddy fraction. The sand can be applied in a useful way, the residual silt can be dewatered in a settling basin for subsequent dumping, or be further separated in a classifier.

Ripening was mentioned in Chapter 2 as a first step in the processing of sludge through landfarming or greenhouse farming. The ripening meant here is a more independent processing method, through which fine, clayey types of sludge with (relatively) low contents of sand and organic substances are processed. Once the material has been entered in a basin, physical, chemical and micro-biological processes are set in motion. The volume is reduced by the evaporation of water and consolidation of the sludge, in which part of the interstitial water is forced out through the sludge's own weight. The product is a diggable 'light clay' which, depending on the quality, can be deployed as a construction material. Ripening is not considered suitable for class 4 sludge.

The tables in Annex 2 provide more details on the cost of basic methods for processing, and the quality of the resulting products.

Appropriate methods for use in scenarios

The basic suitability of the selected processing methods was finally assessed on the basis of performance characteristics: the type and quality of sludge most suited to be handled through a certain method, with sufficient efficiency, and resulting in usable products. Ripening, for example, is an appropriate method for sludge with a low sand content (less than 50%), with the exception of class 4 sludge - conversion of this type will result in a non-usable product. Such insights obviously determine the role played by a selected method in a strategy. A table of the results of the assessment is included in Annex 3.

The selection of methods for scenarios was never intended to hamper the progress of less developed methods; on the contrary, the need for future research and gaining further experience is emphatically recognized here.

3.4 Scenarios for large-scale processing

The processing strategies developed during the Feasibility Study on the Large-scale Processing of Contaminated Dredged Material were written from the desire to explore the limits of processing. In the course of preparing the Fourth Memorandum on Water Management, other scenarios may emerge, in which new combinations of methods shift to the middle ground.

RESULT

+ Three scenarios for large-scale processing, based on the use of different processing methods and variations in types of sludge to be treated.

More details of (the development of) strategies are presented in the final report on the Feasibility Study mentioned above (only available in Dutch).

All strategies foresee sand separation as the start of the treatment. The extreme on one side of the developed scenarios (Table 3.4.1) is characterized by a maximum input of the more straightforward basic methods (treating by dewatering on parcels of land, landfarming, sedimentation and ripening), especially for the treatment of the less seriously contaminated sludge (scenario I). The opposite extreme focuses on a maximum input of advanced technology (in treatment plants), mainly for the processing of heavily contaminated sludge (scenario III). Simply speaking, the extremes are distinguished by their technological levels and the choice between a 'head' or 'tail' approach of the sludge supply. Scenario II takes a middle position in every respect.
The processing combinations of technology and types of sludge follow a logical route: the quality of products from more seriously contaminated classes of sludge can only be guaranteed by using high-performance technology with ample control possibilities.
Each strategy has at least two options, as they were based on two types of sludge supply (see Intermezzo).

Supply (Intermezzo)

The supply of sludge in the near future remains an uncertain factor. This study was based on the data provided by the supplement to the EIS. These data are included in Annex 4. In view of the importance of the factor 'supply' in the entire planning, more certainty on this point should be gained. For the purpose of this study, the supply of sludge was classified according to new categories, which more clearly define the characteristics on which the selection of processing methods is based.
A major uncertainty in the supply is the still pending policy decision on whether or not (part of) class 2 sludge will be spread after the year 2000. The information presented in this study can support the decision-making process. A minimum of two options has been developed for each scenario: one option is based on the large potential supply in case the spreading of class 2 sludge is prohibited after 2000, and the other option is based on the situation in which the current spreading policy is largely continued after 2000. The processing possibilities for each of the two scenario variants were revealed by the study.

Follow-up methods as an alternative are discussed in Scenario II, with regard to the quantity of residual flows in combination with the chemical quality of the material (partly waste officially labelled 'hazardous'). Thermic immobilization is considered particularly feasible in this case. Compared to other follow-up methods, the advantage is that this method can accommodate mixtures of contaminants, including heavy metals. Under certain conditions, this method can also be cost-efficient (see Section 3.5, under Costs).

Table 3.4.I: Developed scenarios for the large-scale processing of sludge

Inherent objective	Use of technology	Scenario characteristics
scenario I Simple sand separation and production of clay mainly focusing on class 2 and (partly) class 3 sludge	'natural' processes in treatment plants (sedimentation, dewatering, landfarming, ripening)	- mostly classes 2 and 3 - limited residual flows - large (temporary) spatial claims - limited operating costs - less sensitive to supply fluctuations - uncertain quality of products
scenario II measured (simple) sand separation (with suitable use of ripening) mostly for class 3 sludge	combination of 'natural' processes in plants and simple units for wet separation (classification)	- emphasis on class 3 and (partly) class 2 and 4 - residual flow, possibly including hazardous wastes - relatively large (temporary) spatial claim
scenario III maximum sand separation (with suitable deployment ripening) focusing on class 3 and 4 sludge	maximum deployment of classifying and polishing methods	- emphasis class 3 and 4 - residual flow including hazardous wastes, possibly recyclable - relatively high operating cost - sensitive to supply fluctuations - quality product not very sensitive to input variations
processing residual flow	deployment follow-up methods (esp. immobilization)	- reduction dumping volume

Annex 5 indicates the quantities of sludge, itemized according to class, which can be processed in each scenario. The total volume of sludge dumped is also indicated for every option.

3.5 Scenarios and characteristics

Official policy has set a target of 20% of the dredging sludge to be processed and recycled by the year 2000. Calculations show that all scenarios are able to achieve this target, sometimes even exceeding it (see Annex 6, Table 1). The options also save substantially on dumping space (varying from an ample 15% to a scant 30%).

Compared to the reference scenario of 'dumping', the annual cost of the processing scenarios is higher, ranging from some tens of millions of guilders to over one hundred million (Figure 3.5.1 and Table 3.5.1). The extra cost compared to the dumping rates is not extravagant, particularly when viewed in the light of the overall costs *inclusive of* dredging and transportation.
This warrants the conclusion that processing is viable, not only from a technical but also a financial point of view.

Mutual comparison of the costs and the ecological benefits of the scenarios does not yield a conclusive preference for a single option. The aspect of spatial claims of the processing methods therefore gains weight (and here scenarios I and II receive unfavourable scores). It also brings to the fore subordinate arguments, such as whether to start at the 'head' or the 'tail' of the classifying range. From a practical point of view, it may be preferable to select (a combination of) technologies which allow the management to react flexibly to unexpected deviations in the composition of the sludge supply.

Computations also demonstrate the fact that the variations in the supply of sludge are not necessarily a dominant factor in the final cost. The costs of the strategic options in supply variant 2 (continuing spreading of part of class 2 sludge) are partially within the range of cost of the strategic options for supply variant 1 (spreading prohibited, storage of class 2 sludge).

RESULTS

+ The proportional useful application of products and the space requirements of all scenarios were calculated. Each of the strategies can achieve a useful application of at least 20%, whereas the spatial claims for deposits may be expected to be reduced by 15-29%.
+ Understanding of the costs of processing scenarios and the reference option of 'dumping'. The former are not considerably more expensive than the latter, nor does mutual comparison between the processing scenarios reveal any large differences.
  Extra costs are largely due to processing; the cost of dredging and transportation can therefore be excluded from a *comparison* of costs of the scenarios. They should of course be included in a full cost estimate. Some costs in the options of supply variant 2 for spreading should be included; this had been neglected in past calculations.
+ The environmental effects and spatial claims required by processing were calculated for the scenarios. The current analysis revealed few environmental differences; only spatial claims formed a true discerning characteristic.

The final report on the Feasibility Study on the Large-scale Processing of Contaminated Dredged Material carries more details on the characteristics of the scenarios.

Costs

The cost estimate was based on a clear and exhaustive comparison of objective socio-economic costs (see Intermezzo). The extra costs of the processing scenarios vary from 20 to 110 million NLG annually. Table 3.5.1 shows the absolute cost for each strategy. The amounts do not include the costs of dredging and transport: these can be omitted from a comparison, as the extra costs of scenarios lie mainly in the processing technology. All strategies carry similar costs of post-dredging transportation, with the assumption that the processing capacity will be realized in the vicinity of dumping locations. The supply variants, too, have little or no effect on the cost of transportation, as even variant 2 (continuing spreading of class 2 sludge) requires the sludge to be transported to the area of spreading (Figure 3.5.1).

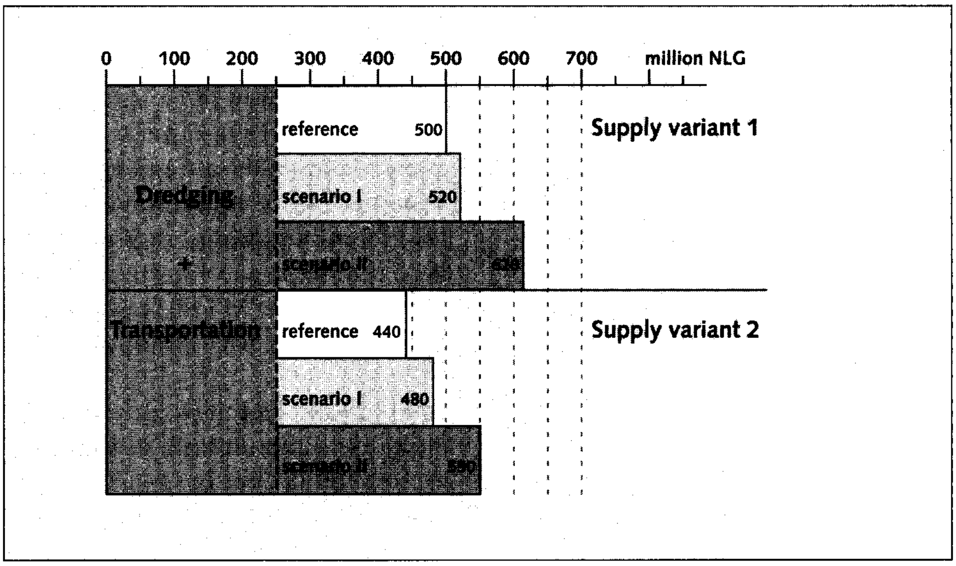


Figure 3.5.1

The scenario costs in Table 3.5.1 refer to the full costs of processing, dumping of sludge not processed in a particular strategy, and processing of the residue. The computations did not include the profits from products released by the processing.

The strategies of 'dumping' are the reference scenarios of supply variant 1 (future prohibition of spreading of class 2 sludge, at a total annual cost of 247 million NLG) or supply variant 2 (continuing spreading of part of class 2 sludge, at 186 million NLG annually).

Table 3.5.I: Costs and extra costs of scenarios

Scenario variant	cost* scenarios (mill.NLG/yr)	proportion dumping cost (mill.NLG/yr)	extra cost of scenarios compared to reference scenarios (mill.NLG/yr)
Supply variant 1			
Scenario I	268/282**	193/187**	21/35**
Scenario II	321	186	74
Scenario III	360	173	113
Scenario 'dumping'	247	247	-
Supply variant 2			
Scenario I	227	146	41
Scenario II	232	145	46
Scenario III	295	105	109
Scenario 'dumping'	186	186	-

Explanation:

* Total costs of processing, dumping of sludge not processed in the scenario involved, and processing of residue

** Two numbers to distinguish two sub-scenarios

The annual costs of the processing scenarios, including dredging and transport, vary between 520 and 620 million NLG (supply variant 1), or between 480 and 550 million NLG (supply variant 2). The annual cost of the reference scenario, including dredging and transport, requires 500 million NLG (supply variant 1) or 440 million NLG (supply variant 2).

The full financial picture for each strategy, however, is not complete without taking into account the cost of spreading the sludge in supply variant 2. This concerns the cost of the distribution itself: where spreading is involved at all, the item transportation required for the spreading is already included in the total cost estimate for transport.

The consequences of including the method of immobilization in the scenarios were also computed: this would raise the extra costs to a considerable extent.

Cost estimate and presentation (Intermezzo)

The calculations were based on the cost of methods, which were all computed in the same way and from similar points of departure. These mutually comparable numbers were used in calculations with regard to the scenarios. The cost of such strategies could be expressed in several ways: total cost for each scenario, per tonne of dry matter of the total supply, or per tonne of dry matter of processed sludge... The scenarios resulted in different percentages of usable products and/or savings on dumping volume (Annex 6, Table I) and were equalized by computing the cost of achieving the exact target of 20% (Annex 6, Table II).

All calculations were based on the 'pure', socio-economic costs, such as the cost of purchasing land for the construction of a deposit site, even where there is no need to purchase since the depositor already owns a suitable field.

Environmental effects

When comparing the scores of the overall environmental effects of the scenarios, a first glance reveals little difference between the various strategies. This is because the scores are influenced by the 80% of residual sludge (still dumped in all options) rather than by the 20% that is processed. Dumping receives low rates for the aspects of (permanent) spatial claims and emissions to the groundwater and surface waters. The score differences are also reduced by the residual flows originating from some scenarios, which have to be dumped. Useful application of products, too, can have a negative environmental effect through leaching - even in legally admissible quantities. When the themes 'spatial claims' and 'emission to water' are not considered, the score is mainly determined by the extent to which residual flows originate, which have to be stored under strict conditions. Scenario I is then awarded a relatively positive score.

The LCA-method used in the calculation is obviously suitable to determining the environmental effect of just *processing*. Further adaptation is required to eliminate the problem of the 'levelling dominance' of the environmental effects of dumping non-processed sludge. This will make it a valuable tool in the assessment of the overall environmental effects of entire scenarios.

Spatial claims

Space is required not only for dumping - which already counts as an environmental effect - but also for processing, especially where dewatering, landfarming and ripening are concerned. Spatial claims form a major characteristic of the scenarios. The geographic siting of the supply demands a large processing capacity in the western part of the Netherlands - where space is a scarce commodity. Scenarios I and II are the most space-consuming options.

3.6 Marketing processed products

The quality of the final products is described for the various methods in Chapter 2 of this report. Most of them meet the standards of the Building Materials Decree, which makes them applicable as building materials (freely or conditionally). The oil contents of the products (see Intermezzo) appear to be the main bottleneck.

Oil residues (Intermezzo)

The Building Materials Decree has set strict standards with regard to oil contamination. The question to which extent residues of oil in a product remain an environmental danger was brought up with biological treatment, which selectively deals with the directly available part of the contamination. This is currently being researched through long-term ecological tests, the results of which are outside the context of this report.

The Feasibility Study on the Large-scale Processing of Contaminated Dredged Material studied the marketing possibilities for processed products, supported by the expertise of PHB. The study proved the quality of the

products resulting from the various scenarios to be such that marketing them should be no problem. Furthermore, the market should be able to absorb the expected quantities of these products without its balance being disturbed.
In spite of these bright prospects, practical problems may still arise, necessitating regulating and promoting measures. These can include tuning in with other regulations and legislation, modifying the current obligation to take back waste (see Intermezzo), promoting sales at new civil works and providing information.

RESULT

+ Understanding of the market for products, and the possible bottlenecks. Obstructions are insufficient promotion and regulations and legislation rather than the quality or marketing prospects of the products.

The final report on the Feasibility Study on the Large-scale Processing of Contaminated Dredged Material (only available in Dutch) presents more details on the marketing prospects for products.

Obstructions (intermezzo)

The use of construction materials which meet the legal standards can be obstructed in practice by other statutory frameworks. An application may require a permit according to the Pollution of Surface Waters Act, for example. Careful tuning with existing laws and regulations is therefore a matter of importance.
Another impediment to acceptance may lie in the legal obligation to take back waste: the party using the construction material is obliged to take it back and process it when the works it was used in becomes dysfunctional. It is uncertain which standards will prevail at that point in time.

Treated sand from the Petroleum Harbour used in road construction

3.7 Conditions and guidance

When a basic decision in favour of a scenario, or a combination thereof, for large-scale processing has been taken, several vital conditions have to be met to implement the processing. The Feasibility Study on the Large-scale Processing of Contaminated Dredged Material reviewed these conditions and came to the main conclusion that:

RESULT

+ Emphasis in guidance and promotion should be on the pre-conditions of adequate funding and a clear policy.

Financial means

A primary condition for the realization of large-scale processing of sludge is the availability of adequate funding. Supplementary means should be found either within existing budgets (by shifting) or by levies.

Administrative agreements and promoting measures

The discussion should neither focus on the question whether a separate administrative body should be established, nor emphasize administrative measures. The first issue to be addressed has to be the outlining of a clear policy on processing. Only then can explicit administrative agreements be translated to working agreements, and enjoy adequate support without the need of an embellished policy instrument.
A clear policy offering distinct perspectives is also crucial in extending the processing capacity for dredging sludge. In view of the experience with soils, such a policy will incite more initiatives in the market place.

The following aspects are examples of administrative agreements: a clear policy with regard to class 2 sludge, a clear and verifiable funding (sharing of cost), access to budgets, a clear decision on (the firmness of) the period within which useful application has to be realized, standards for useful application and agreements on the application of the products. The administrative agreements should of course include progress control and corrective measures if needed.
The establishment of an administrative body or deployment of controlling measures (see Intermezzo) may have to be resorted to, but only as a supplementary measure.

Supplementary measures (Intermezzo)

Possible supplementary measures can consist of financial control (tariffs for dumping/processing, levies on primary materials, supply guarantees, co-investments, etcetera), organizational control (establishment of an administrative body) and regulations pertaining to private or administrative law.

4 Epilogue *(summary and prospect)*

In accordance with the assignment of POSW-II, the programme has yielded information on the assessment of the technical possibilities of dredging and processing methods.
Next to a critical review of the pre-dredging survey and the dredging technology, a study was conducted of the various principles of processing, and of several concrete processing methods based on them. This resulted in a clear definition of the practical and technological feasibilities of separation, (biological, chemical and thermic) treatment and immobilization. POSW-II achieved more than just an inventory: methods were also tested, some at a virtually practical scale through pilot remediations. The decontaminations and smaller-scale tests also helped improve methods already available and operational.
This practice-oriented approach within POSW-II has succeeded in supplying a package of operational and environmentally sound methods for dredging and processing.

Even more important: a joint POSW-PHB study joined selected methods to complete scenarios, defining a range of options to implement large-scale processing. Environmental assessment and costs - also addressed in POSW-projects - were major subjects of computations for the benefit of these scenarios. The strategies offered for large-scale processing in this way are considered truly viable options.

POSW yielded the following results, categorized by subject:

Pre-dredging survey

+ Development of the FAST-model to conduct a cost-effective detailed study to measure.
+ Image of the possibilities for fast screening of the geology and the composition of sediments.
+ Practical experience gained in pilot remediations (including planning and organization).

Dredging

+ Clarity on the measures to limit turbidity and spillage.
+ Clarity on the achievable rate of accuracy for various methods.
+ Optimized control and monitoring through digital terrain models.
+ Practical experience gained in pilot remediations (including planning and organization).

Separation of sludge in fractions

+ Existing methods were improved. Using these and the experience gained within POSW and PHB, contractors can extract applicable materials from sandy sludge.
+ Clarity on flotation of the fine fraction of sludge: not feasible in the near future.
+ Clarity on the achievable dewatering rate of the residual flow.
+ Successful pilot remediation in which separation methods were deployed.

Thermic and chemical treatments

+ Usable thermic methods for the treatment of sludge contaminated with organic pollutants. One concept, thermic desorption and incineration, provides a definite guarantee of a usable final product.
+ Clarity on methods involving solvents (acetone): promising, but not operational within the next three years.

Biological treatment

+ Tests and a pilot remediation within POSW confirmed that part of the organic contamination can be treated fast by biological means: intensive landfarming, greenhouse farming, reactors. POSW contributed to the improvement of these methods.
+ Pollutants in high output concentrations and/or poor availability will cause the final product to remain contaminated to an unacceptable degree. POSW-tests proved that, in such cases, second-stage extensive landfarming will bring about a further degradation.
+ Prompting of an advice to be issued on in-situ treatment (by the Netherlands Institute for Inland Water Management and Waste Water Treatment - RIZA).

Immobilization of pollutants in products

+ Two *thermic* processes of immobilization are suitable for sludge contaminated by organic substances and heavy metals.
+ From an ecological point of view, melting and sintering yield applicable products. Melting products are suitable for civil works and - according to a tentative conclusion - so are sintering products.
+ Melting (production of artificial basalt) was applied in the pilot remediation in New Merwede River.

Assessment of environmental effects

+ LCA-plus proved a usable method for the assessment of environmental effects in the design of processing chains and in decision-making processes. It is recommended that, with regard to toxic substances, the method be supplemented with an assessment of the real and current risks for humans and ecosystems.

Scenarios for large-scale treatment

+ Further qualification of useful methods for large-scale processing, distinguishing between basic technology and follow-up methods.
+ Justification of the conclusion that, technically speaking, processing is a truly viable concept.
+ Three scenarios for large-scale processing, based on the deployment of several methods and classification of the types of sludge to be processed.
+ The useful application and savings on spatial requirements of each scenario were calculated. Each of the scenarios can effect a useful application of at least 20%. The savings rates of spatial claims are between 15% and 29%.
+ Understanding of the costs of processing scenarios and the reference scenario of 'dumping'. Compared to the reference scenario, the extra costs of the other scenarios are limited. Mutual comparison of scenarios reveals little difference. Extra costs are mainly due to the processing itself.
+ Environmental effects and spatial requirements of scenarios were calculated. The former show few differences, but spatial claims are a discerning characteristic.

'Environmental factors' for large-scale processing

+ Understanding of the market for products and of possible bottlenecks - which are in the field of insufficient promotion and in laws and regulations, rather than in the quality of the products or marketing prospects.
+ Adequate funding and clear policies are emphasized as pre-conditions for control and promotion.

Technological progress is continuous, therefore a study of processing is of necessity somewhat open-ended. Continuing attention should be paid to optimization of existing methods and the exploration and stimulation of new developments. One stage was definitely completed with the ending of POSW-II: the question whether present-day technology would allow processing at this point in time could be answered positively. Subsequent activities can thus be focused on policy preparations and the support of practical processing on the basis of newly found as well as long-existing knowledge and experience.

5 References

The following POSW-publications are available in English:

Interim report. Development Programme for Treatment Processes for Contaminated Sediments (POSW) Stage II (1992-1996). RIZA-publication 95.026, Lelystad, October 1996.

POSW-factsheets (1995-1997):

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

6. Ecogravel

7. Wet oxidation of dredging sludge

6 List of abbreviations

AP	Acidification Potential
ADP	Abiotic Depletion Potential
BAGA	Ministerial Order on the Release of Hazardous Wastes
DTM	Digitaal Terrain Model
ECA	Aquatic Ecotoxicity
ECT	Terrestic Ecotoxicity
EDP	Energy Depletion Potential
FAST	Fault Analysis SanitationTraject
GWP	Global Warming Potential
HIN	Hindrance
HT	Human Toxicity
LCA	Life Cycle Analysis
NP	Nutrification Potential
ODP	Ozone Depletion Potential
PHB	Project Bureau for the Re-use of Dredging Sludge
POCP	Photochemical Ozone Creation Potential
POSW	Development Programme for Treatment Processes for Contaminated Sediments
RIZA	Institute for Inland Water Management and Waste Water Treatment
SDP	Slurry Decontamination Process
TLU	Temporary Land Use
TNO	Netherlands Organization for Applied Scientific Research
VROM	Ministry of Housing, Spatial Planning and the Environment
WAS	Waste production
WAT	Water use
XRF	X-ray fluorescence spectrometry

7 Annexes

Annex 1 Results Environmental Impact Assessment of the methods

Tables I, II and III reflect the qualitative results of an environmental assessment for a few groups of related methods/activities. This assessment was based on studies and tests conducted in the framework of POSW. Only the relevant and discerning theme indicators have been included in these tables. A method can be considered to be one of several links making up an entire processing chain; evaluation of its environmental impact affects the integrated chain.
It should be noted that residual flows from processing can be recycled rather than dumped. This improves the rates of waste (referred to as WAS) originating from a combination (such as classification, polishing, and processing of the residual flow by melting).

Table I: Environmental assessment of methods for the processing of sludge (per tonne of dry matter)

Method	EDP*	WAT*	WAS*	TLU*	HT*	GWP*	AP*	NP*	HIN*
Classification / Polishing	o	o	---	o	o	o	o	o	o
Landfarming	o	o	o	-	o	o	o	-	--
Ripening	o	o	o	-	o	o	o	o	--
Sedimentation-basin	o	o	---	-	o	o	o	o	--
Thermic treatment	-	-	--	o	-	--	-	-	o

Explanation:
o = No contribution or a negligible one
- = Slight contribution
-- = Medium contribution
--- = Relatively large contribution
* = Theme indicator, see also list of abbreviations and Section 3.2, Table 3.2.I

Table II: Environmental assessment of methods for the processing of residual flows (per tonne of dry matter)

Method	EDP*	WAT*	WAS*	HT*	ECA*	GWP*	POCP*	AP*	NP*
Wet air oxidation	-	--	-	-	-	-	-	-	-
Sintering	-	-	-	-	-	--	o	-	-
Melting	--	-	-	---	-	---	o	--	--

Explanation:
o = No contribution, or a negligible one
- = Slight contribution
-- = Medium contribution
--- = Relatively large contribution
* = Theme indicator, see list of abbreviations and Section 3.2, Table 3.2.I

Table III: Environmental assessment of final destinations (per tonne of dry matter)

Final destination	WAS*	HT*	ECA*	ECT*	NP*	HIN*
Recycling	o	o	o	o	o	o
Useful application	o	-	--	-	o	o
Dumping	---	o	-	-	-	-

Explanation:
o = No contribution, or a negligible one
- = Slight contribution
-- = Medium contribution
--- = Relatively large contribution
* = Theme indicator, see list of abbreviations and Section 3.2, Table 3.2.I

Annex 2 Basic methods: cost and quality of products

The tables contain details on the costs of methods (Table I) and the quality of the products originating from them (Table II). The costs only involve the processing. The activities prior to processing, i.e. site study and dredging, are a (non-optional) part of every clean-up operation. The details of the site study can be supplied by the FAST model (Section 2.2). As for dredging, a choice can be made from several existing methods, all rather similar in price and precision.

Table I: Unit prices basic methods

Methods	Capacity in 1000 tonnes of dry matter/year	Cost per type of sludge per tonne dry matter (in NLG)			
		A	B	O	general
Dewatering	100	20	20		-
Landfarming	50	50	50		-
Ripening	50			40	-
Sedimentation	50	29	38		-
Classification	200	37	46		-
Classification/polishing	200	48	56		-
Dumping other types of sludge				30	
Dumping residue				35	

Explanation:
- As these costs also depend on the selected scale of processing, the above prices are linked to the processing capacity mentioned with them.
- The types of sludge referred to in the table are 'reference types' for processing:
  Type A: 67% dry matter; 5% (% d.m.) organic substances; 95% (% d.m.) minerals, 80% (% d.m.) sand >63 mm; 15% (% d.m.) fine mineral fractions <63 mm; 20% (% d.m.) light fractions (org. subst + fine mineral fractions <63 mm)
  Type B: 52% dry matter; 10% (% d.m.) organic substances; 90% (% d.m.) minera-ls, 50% (% d.m.) sand >63 mm; 40% (% d.m.) fine mineral fractions <63 mm; 50% (% d.m.) light fractions (org. subst + fine mineral fractions <63 mm)
  Type O: other types of sludge

Table II: Nature and quality of the products originating from the basic methods

Processing/ treatment method	Input sludge/residue	Output: product
Dewatering	loamy sand/sand (>80% sand), cl. 2, 3 sandy loam/loamy sand (50-80% sand), cl. 2, 3	loamy sand/sand, cat. 1 sandy loam, loamy sand/loam, cat. 1
Landfarming	loamy sand/sand (80% sand), cl. 2, 3 sandy loam/loamy sand (50-80% sand), cl. 2, 3	loamy sand/sand, cat. 1 sandy loam/loam, cat. 1
Ripening	loam/clay (<50% sand), cl. 2, 3	clay, cat. 1 (poss. part of cat. 2 with class 3)
Sedimentation	loamy sand/sand, cl. 2, 3 sandy loam/loamy sand, cl. 2, 3	sand, cat. 1
Classification	loamy sand/sand, cl. 2, 3, 4 sandy loam/loamy sand, cl. 2, 3, 4	sand, cat. 0 en 1
Classification/polishing	loamy sand/sand, cl. 3, 4 sandy loam/loamy sand, cl. 3, 4	sand, cat. 0 and 1

Explanation:
- Classification according to Evaluation Memorandum on Water
- Categories 0, 1 and 2 according to Building Materials Decree

Annex 3 Evaluation of fundamental suitability of methods

The table indicates the results of an evaluation of the suitability of methods on the basis of their performance characteristics: the type and quality of sludge that could be handled by a method, with sufficient profit and yielding usable products.

Table: Evaluation of fundamental suitability of methods

Method		Sludge class 2 sand content			Class 3 sand content			Class 4 sand content			Suitability for processing of residual flows
		> 80%	50%-80%	<50%	> 80%	50%-80%	<50%	> 80%	50%-80%	<50%	
Dewatering	1)	+	+	-	o	o	-	-	-	-	-
	2)	+	+	-	o	o	-	-	-	-	-
Sedimentation	1)	+	+	-	+	+	-	o	-	-	-
	2)	+/o	+/o	-	+	o	-	o	-	-	-
Landfarming	1)	+	+	-	+	o	-	+	-	-	-
	2)	n.a.	n.a.	-	o	o	-	o	-	-	-
Ripening for clay	1)	-	-	+	-	-	o	-	-	-	-
production	2)	-	-	+	-	-	o	-	-	-	-
Classification	1)	+	+	-	+	+	-	o	o	-	-
(basic method)	2)	+/o	+/o	-	+	o	-	o	o	-	-
Classification/polishing	1)	+	+	-	+	+	-	+	+	-	-
	2)	n.a.	n.a.	-	+	+	-	+	+	-	-
Thermic treatment	1)	+	+	o	+	+	+	o/+	o/+	o	+
Thermic immobilization	1)	-	-	-	-	-	-	-	-	-	+
Wet oxidation	1)	-	-	-	-	-	-	-	-	-	+

Explanation:

1) = Fundamental suitability at methodical level
2) = Fundamental suitability compared to other methods
\+ = Suitable
\- = Unsuitable
o = Partially suitable
o/+ = Suitable *in absence of other methods*

The follow-up methods of 'thermic immobilization' and 'wet oxidation' received poor ratings in the first columns, but they can be quite attractive to treat *residual* flows if so desired (last column). *The rather positive picture painted about thermic treatment requires some nuancing: this method works best with non-separated sludge, a material which is also suitable for several other attractive methods.*

Annex 4 Sludge supply

The table presents data on the expected supply of dredging sludge.

Table: Quantities of dredging sludge (in millions of m^3), prognosis 1991-2010

Class	From maintenance	From remediation	Total
0/1	249	-	249
2	110	-	110
3	31	40	71
4	8	47	55
total	393	87	485

Annex 5 Scenarios and quantities of treated/dumped sludge

The table presents the quantities of sludge processed or dumped in the scenarios. The quantity of sludge in each scenario is classified according to type of sludge.

Table: Scenarios and quantities of treated/dumped sludge

Scenario variant	Processing sludge class 2 (tonne d.m.)	Processing sludge class 3 (tonne d.m.)	Processing sludge class 4 (tonne d.m.)	To be dumped (tonne d.m.)
Supply variant 1				
Scenario I	1558/1558*	821/1011*	-/-	6436/6247*
Scenario II	1558	800	247	6210
Scenario III	670	1219	1157	5769
Scenario 'dumping'	-	-	-	8815
Supply variant 2				
Scenario I	339	1432	-	4860
Scenario II	223	1327	247	4833
Scenario III	223	1746	1157	3504
Scenario 'dumping'				

* Two numbers, since two subscenarios were discerned

Annex 6 Scenarios and useful application/saving on spatial requirements

Table I shows the percentage of useful application or saving on spatial requirement of a deposit, to be achieved by the various scenarios. Point of departure for supply variant 1 is the large potential supply, should the dispersion of class 2 sludge be discontinued after 2000. Supply variant 2 is based on the assumption that the present policy of spreading of class 2 sludge is continued after 2000. The consequences of both variants were calculated for each of the three selected scenarios.

Table I: Useful application/savings on spatial requirements of scenarios

	% useful application	% saving on spatial requirements
Supply variant 1		
Reference scenario 'dumping'	-	-
Scenario I	27/25 *	22/20*
Scenario II	20	16
Scenario III**	24	19
Supply variant 2		
Reference scenario 'dumping'	-	-
Scenario I	21	15
Scenario II	21	16
Scenario III	33	29

Explanation:

* Two numbers, since two subscenarios were discerned

** Assuming that residual material need not be dumped in a land-based deposit

Table II presents the costs related to a resulting useful application or saving on spatial claims. A comparison of cost without such equalization would ignore the fact that scenarios have different results with regard to these aspects.

Table II: Equalized annual costs (related to useful application/saving on spatial claim)

	Cost per tonne d.m. of useful application after equalization of the scenarios to 20% (in millions of NLG)	cost expressed in one per cent saving on spatial requirements
Supply variant 1		
Scenario I	13/14*	12/14*
Scenario II	16	20
Scenario III**	18	19
Supply variant 2		
ref. scenario 'dumping'	11	15
Scenario I	12	15
Scenario II	14	10
Scenario III		

Explanation:

* Two numbers, since two subscenarios were discerned

** Assuming that residual material need not be dumped in a land-based deposit