Sediment and Dredged Material Treatment

Synthesis of the SedNet Work Package 4 Outcomes

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Introduction

Sedimentation is a natural process and represents a fundamental part of ecosystem functioning. Due to human activities during the last decades, sediments have been contaminated, and it's likely that they will be contaminated also for the near future.

On the basis of a SedNet estimation, it can be assumed that around 100 and 200 million cubic meters of contaminated sediment might be produced yearly in Europe.

Nevertheless, dredging is necessary to prevent flooding, to facilitate sailing, to keep Europe's ports vital, to allow all the uses of a given water system (maintenance and capital dredging), but also for remediation, whereas the risk for the environment and health might be high. This dredging of the contaminated sediments will lead to the problem of the management of contaminated dredging.

Different aims for dredging will lead to different projects and, consequently, management of those kinds of dredged sediments will be very different as well. In the case of maintenance dredging, the operation is continuous over years and the characteristics of the sediments vary in a known range. For these reasons, it is common practice to relocate the largest part of the dredged material in the same water system. In the case of small dredging tasks, e.g. maintenance of ditches and rivers, the dredged material is disposed on the nearby embankment.

If these options are undesirable or impossible for environmental, morphological or spatial reasons, alternative options are applied such as beneficial use, treatment and/or confined disposal. The term 'beneficial use' is used if sediments (treated or not) are used for a certain purpose. Beneficial stands for 'having a helpful or useful effect' (Oxford dictionary). Sometimes there is a debate if dredged material should be treated before one can speak of beneficial use. However, also untreated, relatively clean dredged material can be used, for example, for filling up deep holes, which were for instance created due to sand extraction, or just for relocating it in the river basin. This latter option is generally considered to be a sustainable solution, as sediment is an essential, integral and dynamic part of our river basins. Therefore, we speak of sustainable relocation. So, this is why the term 'Beneficial use' is used for treated and untreated dredged material, while disposal in a disposal site is not considered to be a beneficial use.

Science alone, however convincing, cannot guarantee the successful application of beneficial use options for dredged material. The main reason for this is the large number of interests of an equally large number of stakeholders involved in a dredging project, who are trying to reach a consensus particularly in terms of timing and costs. Such difficulties can be overcome by long-term planning. The key to success for the beneficial use project planner is to identify how, when and where dredged material from a project can fulfil an economic need, whilst paying due regard to environmental considerations and limitations. Identification of economic and/or social benefits, and raising of awareness to that may help overcome some environmental opposition to the use of dredged material.

In any case, dredging and sediment treatment need to be integrated in the river basin management and they should not result in unwanted impacts elsewhere or any time in the river system.

National legislation and the current developments at the European level (Water Framework Directive, Soil Communication) are likely to have a further impact on dredged material management such as dredging, treatment and/or disposal in national and international catchment areas.

It is clear that an effective sediment treatment strategy could never only implement the so-called 'end of pipe' approach, and it is also necessary to keep in mind that source control is the prerequisite to reach a sediment quality in the future, which does not pose a risk to aquatic systems or upland use (source: plant, urban areas, etc.).

Investments in source control upstream are often more economical than treatment downstream and it can be considered as a sustainable solution as it, for instance, guarantees good sediment quality for relocation (see above), which is a very relevant aim of sediment management.

1 Treatment as Part of Sediment Management

Treatment of dredged material is part of sediment management. The flow chart representing the management options leading to the needs for dredging and/or treatment is reported in **Fig. 1**.

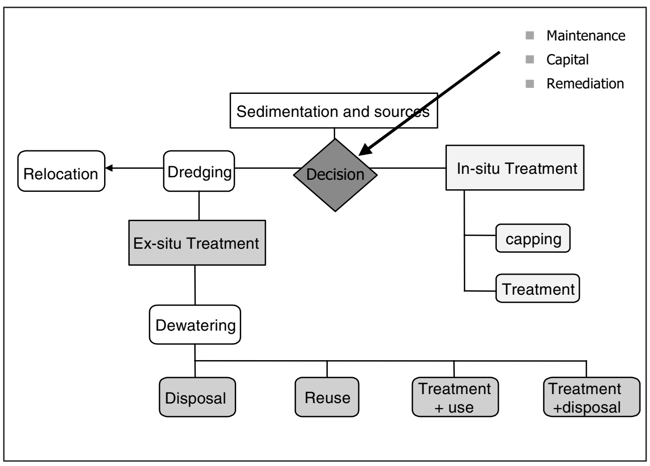

Fig. 1: Flow chart representing the management options leading to the needs for dredging and/or treatment

As can be seen, sediment management takes into account two kinds of projects: remediation projects with *in-situ* and *ex-situ* treatment options and maintenance/capital dredging with the consequence of *ex-situ*-treatment or disposal.

Between the detection of the problem and the decision about the destination of sediments, an assessment is needed at least three times:

1. Sediment assessment to decide if remediation dredging is necessary due to a not acceptable risk posed to the environment by sediments or for other reasons like capital dredging, maintenance and flood-protection;
2. Assessing the feasibility of different treatment units (see Table 1) considering different groups of criteria fixed by local conditions and legislations;
3. Comparing different potential treatment chains as a basis for decision making.

It can be stated that all these aspects of the assessment always have to be taken into consideration when a treatment technology has to be chosen. Therefore, it would never be a generic solution, but different solutions have to be assessed every time case by case, which means that a treatment technology choice is very much site specific.

2 Treatment Techniques and Treatment Chains

Different treatment and disposal technologies are well known. On the one hand, there are worldwide experiences in handling and treating dredged material and sediment. On the other hand, in many cases, the experiences of the soil treatment and soil remediation industry as well as mining industry can be useful adapted for the requested tasks. In general, sediment and/or dredged material treatment technologies can be categorised as described in **Table 1**.

The decision, if a given technology is applicable, depends on different factors. For instance, the chemical-physical characteristics of the sediment itself define whether a process principle is applicable or not. The physical condition of the sediment has to be taken into consideration when a special technique is chosen, e.g. the grain size distribution. Nevertheless, if there is contaminated sediment, there will in many cases be a relation between the grain size distribution and the contamination of the sediment. Different investigations have shown that the content of heavy metals and organic contaminants is primarily governed by the grain size. The finer the particles and the higher the content of organic matter in the sediment, the higher will be the content of contamination.

On this basis, it is possible to arrange a pre-selection of treatment technologies reported in Table 1 according to the sediment/dredged material characteristics.

In **Table 2**, a decision frame shows under what condition sediments and/or dredged materials can be treated by a given treatment technique.

A treatment is generally applicable if there is tree times a plus (+). In some cases, also with one or two plus, a technique can be useful if the singular process option is part of a treatment chain. On the other hand, if there is only one minus, the technology will not be helpful.

Table 1: Categorisation of treatment technologies

Processing Principle	
1. Relocation	1. Open water disposal
	2. Injection dredging
2. Mechanical separation	1. Classification
	2. Sorting
3. Dewatering	1. Evaporation
	2. Mechanical dewatering
4. Contaminant separation	1. Chemical extraction
	2. Thermal desorption
5. Contaminant destruction	1. Biological reduction
	2. Chemical oxidation
	3. Thermal oxidation
6. Contaminant immobilisation	1. Chemical immobilisation
	2. Thermal immobilisation
7. Disposal	1. Sub-aquatic confined disposal
	2. Upland disposal

Table 2: Technical criteria of process principles

Process principle	Type of sediment			Level of contamination			Type of contamination	
	Silty	Silty / Sandy	Sandy	Low	Medium	High	Organic	In-organic
1.1. Open water disposal	+	+	+	+	+/–	–	+	+
1.2. Injection dredging	+	+/–	–	+	+/–	–	+	+
2.1. Classification	+/–	+	+	+	+	+	+	+
2.2. Sorting	+/–	+	+	+	+	+	+	+
3.1. Evaporation	+	+	+	+	+	+	+	+
3.2. Mechanical dewatering	+	+	+	+	+	+	+/–	+
4.1. Chemical extraction	+	+	+	+/–	+	+	–	+
4.2. Thermal desorption	+	+	+	+/–	+	+	+	–
5.1. Biological reduction	+/–	+	+	+	+	+/–	+	+/–
5.2. Chemical oxidation	+	+	+	+/–	+	+	+	–
5.3. Thermal oxidation	+	+	+	+/–	+	+	+	–
6.1. Chemical immobilisation	+	+	+/–	+	+	+	+/–	+
6.2. Thermal immobilisation	+	+	+/–	+	+	+	+/–	+
7.1. Sub-aquatic disposal	+	+	+	+	+	+	+	+
7.2. Upland disposal	+	+	+	+	+	+	+	+

\+ Process is technically available or not negatively affected
+/– Process is technically mostly available or mostly not negatively affected
– Process is technically not available or negatively affected

In several European countries, treatment chains were examined and compared, comprising one or more of the above mentioned technologies. In principle, all types of treatment and disposal options can be combined. If there are land-based technologies, and no disposal is foreseen at the end of a treatment chain, beneficial use of the products from dredged material must be available. But there could not be a European-wide solution at the moment because the beneficial use of mineral waste is regulated nationally. Some of the most promising treatment chains were described some years ago in the Netherlands using a simplified drawing. In **Fig. 2**, a modified drawing gives an overview on available treat-

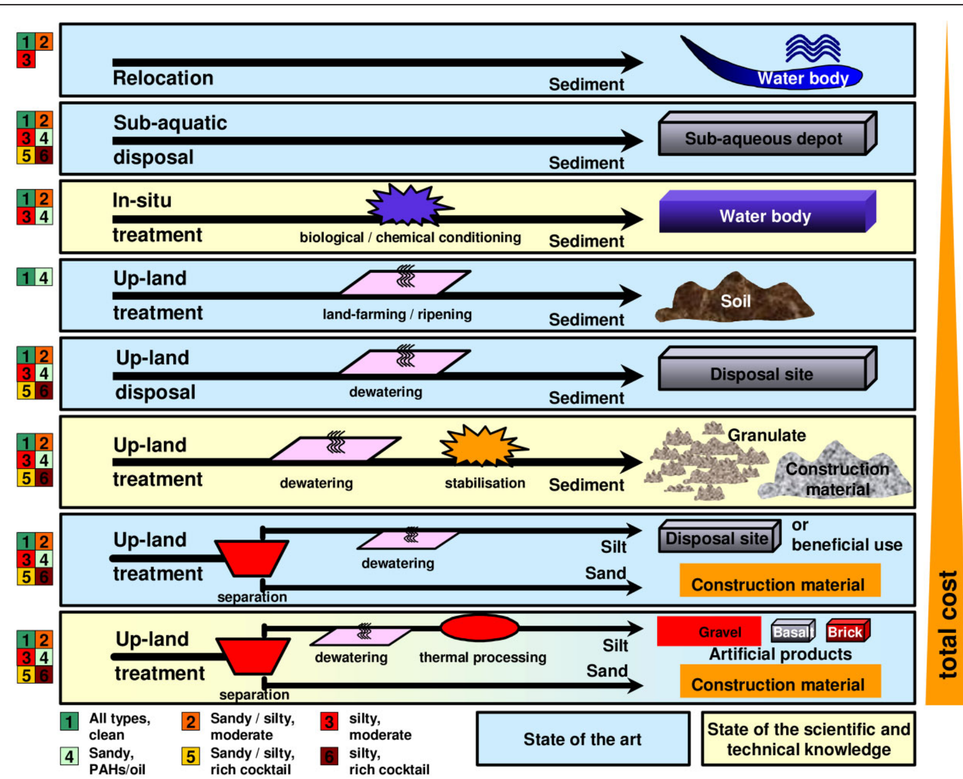

Fig. 2: Modified overview on available treatment chains based on AKWA (2000)

ment chains with the respect of these former begins. Available treatment chains are in operation in a large scale or have reached a standard that it will be possible to operate them in a large scale.

Anyway, the main factors that determine the applicability of technologies are the properties of the sediments and the possibilities for use of the products as building materials, or more generally the beneficial reuse.

3 Constraints

The assessment of treatment and disposal options under the considerations of sustainability requires the application (and if necessary development as well) of tools to integrate economic, environmental and social criteria into the assessment strategy.

In general, the concept of sustainability sets a direction to implement options that are economically feasible, that ensure the protection of the environment (not only on a local level) and that are acceptable by stakeholders in general. Such integrated approaches have the challenge of not only combining economic, environmental and social factors on a river basin scale, but also to integrate the different types of information relevant to those factors to support decision-making procedures (e.g. integrating environmental factors such as chemical concentrations, effect based in bioassays, energy consumption, etc.).

These factors, however, lead to constrains in the application of treatment.

3.1 Economic constraints

Nowadays, the costs of the treatment are often that high that the funds for continuous financial support for dredging activities are not sufficient to cover these costs.

Therefore, these higher costs represent an extra burden to society. Depending on the location and social pressure, as experienced in North-western European ports, it is known that costs should not exceed the range of values reported in **Fig. 3** as practice has learned that society is not willing to pay more than this.

An important issue for the costs evaluation is the 'market' for the beneficial reuse. To make a treatment method successful, it is important to have a market for the products. If no market is found, treatment is useless. In this perspective, clean sediment is also considered to be a product for the environment as it provides a clean habitat for organisms.

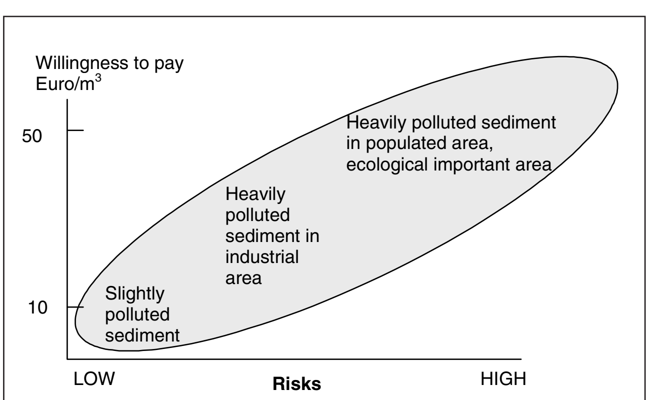

Fig. 3: Schematic diagram of sediment treatment costs

3.2 Social constraints

Beside the costs, the acceptability of the solution is fundamental. The different technologies or options might be environmentally sound and cost effective, but not accepted by the public, such as the NIMBY opinion on disposal facilities and the low acceptance of products coming from processed sediment.

Since each treatment option processes the dredged material into a product, and the latter might be clean sediment; sand, bricks, etc., the first consideration in the treatment choice should be, "are these products accepted by private or public users?" If the products are not accepted, the options are not feasible.

3.3 Environmental constraints

A general principle is that dredging and treatment should be managed as much as possible in line with the natural processes. This means that the favourite options for the management of the dredged material have to be the natural ones, such as relocation or the reuse of dredged material as 'fertile' soil. An ideal ranking for the management options is therefore reported in **Fig. 4**.

An assessment approach accounting for the complete range of effects associated to a process remains a complex problem. Nevertheless, the need to incorporate at least the environmental aspects over the whole chain of processes is clear in order to account for 'hidden' environmental impacts and to protect environmental assets for which no criteria such as threshold values exist.

An example of this new way of process assessment is the development of the methodology of the life-cycle assessment (LCA) and its progressive introduction to decision-making schemes and even strategies for policy making in the public sector.

The overall assessment process can be summarised in **Fig. 5**.

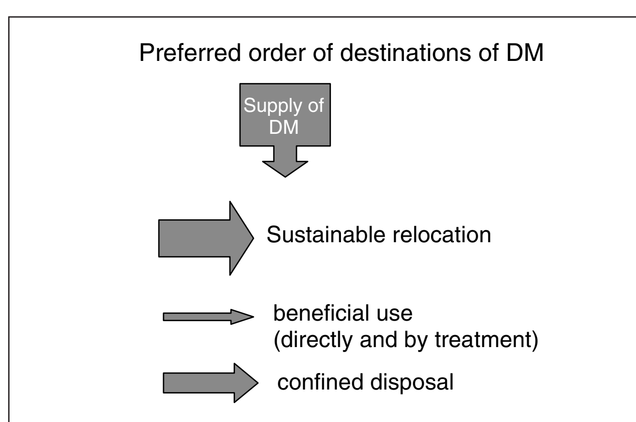

Fig. 4: Preferred order of destinations of dredged materials (DM)

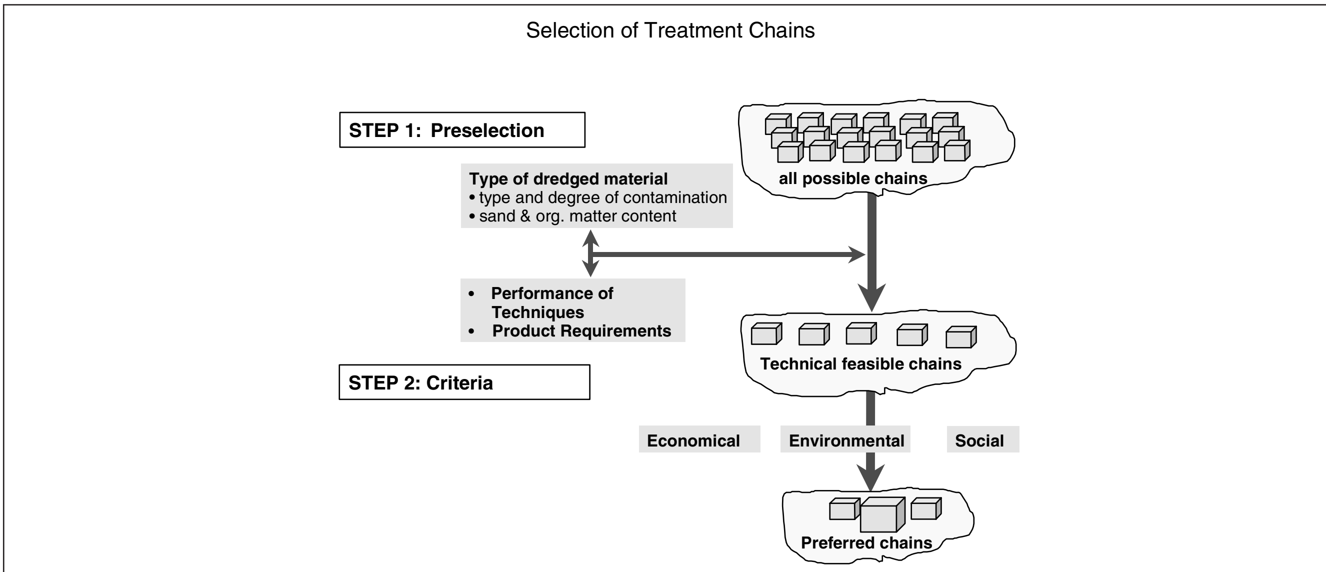

Fig. 5: Assessment and selection process of sediment treatment technologies

4 Treatment and Disposal Costs

It is evident that by applying simple technologies such as sand separation, land farming, ripening and stabilization, only a limited amount of dredged material can be processed into usable products, while by applying more advanced technologies, such as thermal immobilisation, more heavily contaminated sediments and residues from sand separation can be processed.

Experience still has to be gained for the technology of large-scale thermal immobilization and the market potential of the products.

Of great importance are the costs of different treatment options. They depend very much on the specific circumstances. It should be noted that depending on the circumstances (e.g. scale, disposal costs) large variations in costs occur. For example, the costs for sub-aquatic disposal facilities are lower for large-sized confined disposal sites.

Simple technologies such as sand separation and land farming / ripening are generally slightly more expensive than disposal, while costs for stabilisation and thermal immobilisation technologies are substantially higher. A summary of the ex-situ treatment costs is reported in **Fig. 6**.

In order to make more effective the comparison among the different treatment and disposal options all benefits (economical and societal) expressed in € for each sector should be compared with management costs of dredging. This might represent a powerful tool for policy-making to set priorities for investments.

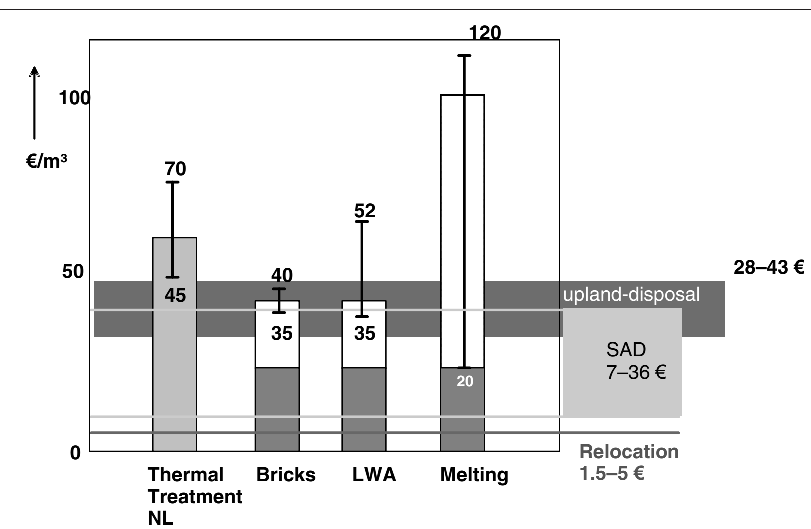

Fig. 6: Range of ex-situ (thermal) treatment costs (LWA=Light Weight Aggregate; SAD=Subaquatic Disposal compared to disposal or relocation costs

5 Summary of Conclusions and Recommendations

5.1 Sediment management

- Acknowledgement of the need for dredging
- Source control + remediation to reach quality targets
- Solutions should be found in the context of the whole river system and in close interaction with the stakeholders
- Solutions need to respect natural processes and functioning
- Relocation should be the first option, followed by beneficial use & finally confined disposal
- Stress the importance of realistic solutions based on site-specific conditions and type of dredged material
- Joint effort of authorities along a river system to meet the national and EU policy targets and comply with legislation
- Coordination of sediment/dredged material management within a – transboundary – river system
- Integrated approach from inland to coastal waters

5.2 Recommendations treatment and disposal

- All types of technologies for treatment and confined disposal are available: technology is not the problem, but innovation that leads to more efficient technologies is welcome
- Treatment of dredged material is only useful if it leads to fewer disposals and/or less disposal costs. This means that the products have to be applied in practice for acceptable costs
- Experience still has to be gained for the large-scale application of technologies, logistics and the market potential of the products
- For beneficial use at a larger scale it is imperative to develop markets for the application of dredged material and products from treatment of dredged material
- Confined disposal is a cost-effective and environmentally sound solution, if properly designed, constructed and monitored. Sub-aquatic confined disposal is generally less costly than upland disposal
- Treatment and confined disposal should not always be considered as opposed options. Both can be environmentally sound and acceptable options that can be complementary
- A site-specific approach is necessary for the choice of best available treatment or disposal option
- It is of crucial importance to involve the public and other stakeholders in the decision-making process of treatment and disposal options. Public support is a critical factor, not only for the location of disposal sites, but also for the location of treatment plants and the beneficial use of the products
- Taking into account regional conditions in ports and water systems, balanced treatment and disposal concepts have been developed that fulfill all aspects of technical, ecological and economic requirements. Additional financial means and especially markets for beneficial use will be required to transfer these concepts into long-term concepts and realization

5.3 Costs and contracting

- Costs can be reduced if there is an economy of scale, long-term engagement by the problem owner
- Cooperation in Public-Private-Partnership (PPP) is an important tool for optimization of costs, sharing of risks and finding solutions for beneficial use
- Smart and innovative tendering, large-scale contracting of dredging projects
- Combine dredging operations for several policy targets, e.g. flood control, remediation and maintenance

5.4 Assessment methods

- It must be recommended that a combination of tools (costs, LCA, costs benefit analyses, risk assessment studies) should become assessment routine before decision-making
- Harmonize assessment methods in a river basin and between states to avoid transport and treatment or disposal based on different standards
- The SedNet mission makes obvious that sustainability is only achievable on a new spatial and time scale. Since the present structures for decision-making are mostly local or regional acting administrations, however their actions have often consequences on a bigger scale, the river basin scale. Additionally, to build up a sustainable sediment management long-term-effects over the time span of a generation or more have to be considered. According to the aim of a sustainable sediment management we recommend assessment on a river basin scale considering a sustainable time scale of one generation.
- European standards for assessing treatment and disposal alternatives should consider the present know-how about long-term effects (e.g. the life-cycle of sediments and products and effects on mobility and bio-availability of pollutants with time) and the discrepancy between the results of biological and chemical methods applied for the same sediments

5.5 Recommendations for further research

- Looking at sustainability some benefits like the reduction of space consumption, climate or re-use of secondary material substituting primary resources are complicated to be evaluated. So, we recommend conducting research in fields that provide us with parameters or better tools to evaluate goods like 'the landscape', 'space consumption', etc. useful to improve decision-making
- Methods and standards of investigation should consider the present know-how about long-term effects (life-cycle of sediments and products) and the discrepancy between the results of biological and chemical methods applied on sediments and products of treatment

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ANNEX I: Life Cycle Assessment

The life cycle assessment (LCA) is an environmental assessment tool that enables the quantification of environmental impacts of processes and products over their complete life-cycle, i.e. "from cradle to grave". LCA enables the evaluation of the environmental performance of a system and allows coupling material and energy balances to environmental impacts.

LCA has gained wider application in the 1990s due to the standardisation of its methodology and has been mostly applied in the assessment of products, services and processes. It also finds applications in the phases of process design, optimisation, selection and comparison. LCA has been traditionally oriented towards the following objectives (Azapagic and Clift, 1999):

- The identification of the steps of a process that could be improved in terms of their environmental performance.
- Providing information in terms of environmental performance to support decision-makers to select among alternative processes or locations.
- Defining relevant environmental indicators to evaluate processes.
- Product marketing, e.g. eco-labelling, product declaration, etc.

Although the need of applying LCA to evaluate sediment treatment chains has been recognised in the past (Stokman and Bruggeman, 1995); and that in some cases it has already been applied as a tool to support decision making procedures regarding sediment treatment chains (AKWA, 2000); carrying out a comprehensive LCA study is a very resource and time intensive procedure. This is due to the complexity of process life-cycles and because the interpretation of results and their application in decision-making schemes require the participation of several stakeholders and the internalisation of the conceptual logic of life-cycle thinking. These are challenges that have to be overcome in order to introduce LCA as an assessment tool for sediment treatment chains to complement other environmental assessment tools.

The implementation of an approach based on LCA to assess and compare sediment treatment chains has the following advantages:

- The standard LCA methodology has gained acceptance in the public sector as a tool that enables decision-making from a system oriented perspective, providing transparency to decision-making procedures as well.
- It is clear that no single environmental assessment tool can cover all relevant aspects related to sediment treatment chains. In this context, the inclusion of an approach based on life-cycle thinking is able to account for hidden impacts not normally considered in site specific environmental evaluation tools. For instance the environmental benefits of using dredged material for substituting traditional raw materials can be assessed, e.g. the use of sand separated from dredged material as construction material or the substitution of natural clay in a brick making process.
- The methodology of LCA is compatible with decision-making procedures under multiple criteria (Seppälä et al. 2002) . It has to be kept in mind that decision-making under the notion of sustainability is inherently a multi-criteria problem, e.g. economic, environmental, social, socio-economic criteria have to be considered. To reach sustainability oriented decisions considering conflicting criteria remains a complex task and demands suitable methods to identify compromises and trade-offs between the criteria in order to reach 'better' decisions.

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ANNEX II: Treatment and Disposal Technologies

Relocation is the principle bringing back dredged sediments into the water system without any treatment. Two types of relocation are known – the open water disposal and the injection dredging.

- ***Open water disposal*** depends on dredging and dumping at another place in the water system. Hopper dredgers or other types of dredgers and additional barges are in operation for dredging, transport and relocation.
- ***Injection dredging*** depends on the injection of e.g. water or air into the sediment layer. The sediment is re-suspended and flushed away by the current. It can be operated in rivers or tidal zones.

Mechanical Separation is the principle of dividing dredged material in a fraction of coarser or finer particles or in fractions of different quality standards e.g. different mineral fractions or different contaminated fractions. Two types of mechanical separation are known – the classification and the sorting.

- ***Classification*** depends on separation of a less contaminated coarser fraction and a more contaminated fine fraction from the original DM. Separation principle is the separation by grain size. Contaminants are very often adsorbed at the surface of the particles and the finer the particle the higher is the specific surface. It can be done e.g. by sieves e.g. drum- or vibration-screens or hydro-cyclones. Separation is mainly used in the grain size range of 20–63 µm and in the field of security sieving in the grain size range of up to some centimetres.
- ***Sorting*** depends on separation into fractions of less contaminated particles and more contaminated particles or into fractions of different mineral and / or organic qualities. Separation principles depend mainly on different specific weight of the particles or on different conditions on the particle surface. Sorting can be done by upstream-current-classifiers, spirals, jigs, flotation-cells or sedimentation basins.

Dewatering depends on separation of water from the solids. Two types of dewatering are known – the evaporation and the mechanical dewatering.

- ***Evaporation*** of water can be done by natural forces like wind and sun or technical by warming up or forming a vacuum. It can be done e.g. in dewatering (ripening) fields, in ovens or vacuum chambers.
- ***Mechanical dewatering*** depends on the reduction of the pore volume between the particles. It can be done e.g. with centrifuges or presses like filter-belt-presses or membrane-chamber-filter-presses.

Contaminant Separation is the principle of separation contaminants, mostly adsorbed on particle surface, and original mineral particles. Two types of contaminant separation are well known – the chemical extraction and the thermal desorption.

- ***Chemical extraction*** depends on extraction of contaminants using acids or complexing agents. A chemical process plant is necessary with two main parts – first an extraction plant, and second a separation plant to separate solids and washing liquid. Mainly inorganic harmful substances e.g. heavy metals can be washed out.
- ***Thermal desorption*** depends on the difference of the relative volatility of the contaminants and mineral sediment particles. It is normally operated in the temperature range of about 450 °C in special ovens with an additional product gas cooling and cleaning system. Mainly organic harmful substances can be separated.

Contaminant destruction is the principle of destroying e.g. through oxidation or the lixiviation and in a second step the separation of harmful substances. Three types of contaminant destruction are known – the biological reduction, the chemical oxidation and the thermal oxidation.

- ***Biological reduction*** depends on one hand on bacteriological lixiviation e.g. using various types of thio-bacteria to solubilise or to oxidise different types of contaminants and on the other hand the capacity of various plants e.g. willows and giant knotweed (reynoutria sachalinense) to collect different contaminants and stock the harmful substances in their roots and shoots and in leaves. Biological reduction can take place in technical plants using reaction tanks for lixiviation or e.g. in flushing fields that are cultivated.
- ***Chemical oxidation*** depends on addition of a chemical reactant. Mainly organic contaminants are transformed into non-toxic compounds by oxidation.
- ***Thermal oxidation*** depends on combustion of organic material at high temperatures. All types of organic material can be burned. Special combustion ovens need an additional waste gas cleaning. (Mostly together with thermal immobilisation)

Contaminant immobilisation depends on stabilisation in a way that contaminants are no longer available to the environment. Two types of contaminant immobilisation are known – the chemical immobilisation and the thermal immobilisation.

- ***Chemical immobilisation*** depends on addition and mixing of dredged material or sediment and reactants e.g. clay, lime, cement or fly ash. After mixing there will be hydraulic-setting system and the contaminants will be bind into the matrix. Chemical immobilisation is possible in-situ as well as on land to produce e.g. artificial gravel.
- ***Thermal immobilisation*** depends on the binding of contaminants like heavy metals in the mineral phase at high temperatures. Products of thermal immobilisation could be bricks, pellets and glass. (Mostly together with thermal oxidation.

ANNEX III: Products for Beneficial Use

Rock is a valuable construction material and whether or not it can be used economically depends on its quantity and size.

Gravel and sand are generally considered the most valuable material for use that a dredging project can provide. They can find wider application as a resource material to a number of engineered uses and most frequently without the need to sort (or pre-wash) the material prior to being used. The engineered uses mainly are land reclamation, construction material, replacement fill, land improvement, capping, beach nourishment and offshore berms. "The range of engineering applications for dredged material is diverse being limited only by the ingenuity of the designer".

Clay and silt are the most common material acquired from maintenance dredging in rivers, canals and ports. Consolidated clay can find more engineered uses than soft clay, whereas silt in particular is more suitable for agricultural / horticultural purposes and all forms of habitat creation and/or enhancement. The economical uses of the products differs in terms of preparation work prior to their beneficial use.

Silt and soft clay almost always need dewatering. Also silt, being fine-grained sediment can contain contaminants, which necessitate a certain degree of treatment prior to beneficial use.

The product after treatment can differ. It depends on the treatment technique.

Products without treatment
untreated sediment (all grainsizes):
- rocks
- gravel
- sand
- clay
- a mix of gravel, sand and / or clay

Products from 'simple' treatment techniques
- treated clay (ripened or from landfarming)
- sand (product from separation)

Products from cold immobilisation
- ground (product from cold immobilisation)
- cement

Products from thermal immobilisation
- Light weight aggregates; heavy weight aggregates
- bricks

In **Table A-3** an overview is given of the products, the output level of contamination, the treatment method, the possible application and the intensity of reuse.

Table A-3: Overview of the products, the output level of contamination, the treatment method, the possible application and the intensity of reuse

Rock beneficial use options		
Engineered uses	**Agricultural/product uses**	**Environmental enhancement**
– Land creation – Land improvement – Offshore berms – Shore protection – Replacement fill	– Construction materials	– Upland habitats – Fisheries improvement
Gravel and sand beneficial use options		
Engineered uses	**Agricultural/product uses**	**Environmental enhancement**
– Land creation – Land improvement – Offshore berms – Shore protection – Replacement fill	– Construction materials	– Upland habitats – Fisheries improvement
Consolidated / ripened clay beneficial use options		
Engineered uses	**Agricultural/product uses**	**Environmental enhancement**
– Land creation – Land improvement – Offshore berms – Shore protection	– Aquaculture – Construction materials	– Wetland creation – Upland habitats – Fisheries improvement
Silt / soft clay beneficial use options		
Engineered uses	**Agricultural/product uses**	**Environmental enhancement**
– Land creation – Land improvement	– Topsoil – Aquaculture – Construction materials	– Wetland creation – Upland habitats – Fisheries improvement
Mixture beneficial use options		
Engineered uses	**Agricultural/product uses**	**Environmental enhancement**
– Land creation – Land improvement – Offshore berms – Capping – Replacement fill	– Topsoil – Aquaculture – Construction materials	– Wetland creation – Upland habitats – Fisheries improvement
Cement Beneficial use options		
Engineered uses	**Agricultural/product uses**	**Environmental enhancement**
–	– Construction materials	–
LWA beneficial use options		
Engineered uses	**Agricultural/product uses**	**Environmental enhancement**
– Capping – Replacement fill	– Aquaculture – Construction materials	–
Briks beneficial use options		
Engineered uses	**Agricultural/product uses**	**Environmental enhancement**
–	– Construction materials	–