# IN-SITU REMEDIATION OF CONTAMINATED SEDIMENTS: CONCEIVABLE AND FEASIBLE?!

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## Summary

*In-situ* remediation has assumed large proportions in dealing with terrestrial soil pollution. Although implementation of *in-situ* remediation for contaminated sediments is restricted by the fact that dredging is necessary for nautical or water management reasons, it should not be discarded beforehand. In this paper a number of potentially relevant options for *in-situ* remediation of contaminated sediments are given. It is the intention of the authors to increase the decision makers' awareness that these options may be worth considering, if a number of boundary conditions are fulfilled. These refer to the risk reduction necessary, the time available, local conditions, etc.

## 1 Introduction

The maintenance of waterways in the Netherlands calls for regular dredging actions, both for nautical or water management reasons. This yields a large volume of dredged, often contaminated material. In a number of cases there is a need for remediation just because of the sediment quality and the ecological risks involved. The usual approach also in these cases comprises the removal of the contaminated material from the waterway by dredging. Sometimes, however, this approach has to be considered as less appropriate, or even undesirable, as will be outlined in the next section.

In the past the possibilities of *in-situ* remediation by addition of mixtures of various substances have been investigated. The addition of these substances to the sediment served two purposes: (1) to stimulate the biodegradation of organic contaminants and (2) to stimulate the degradation of natural organic matter (humic and fulvic acids, humins). The degradation of the organic matter was supposed to lead to a volume reduction of the sediment and hence to a possible postponement of maintenance dredging. The results obtained with the addition of these mixtures turned out to be disappointing, mainly because of an oxygen deficit. With this observation the chances for *in-situ* remediation options seemed to have faded.

However, recently a number of developments in remediation of terrestrial soil pollution have come about, both with respect to policy aspects as to technical developments. These developments have led to a powerful stimulation of *in-situ* remediation options. No longer it is deemed necessary that remediation actions have to be executed within a very short time period and should always result into "multifunctional" soil. The present and future function of the soil is now more accounted for in selecting the action to be taken. An assessment of human and ecological risks sets the main criteria. At the same time advantage is taken of natural processes (the self-cleaning capacity of the soil).

## 2 Options for in-situ sediment remediation

The possibilities of *in-situ* remediation options strongly depend on the local situation (*viz.* type and speciation of contaminants, extent of the pollution, functions, sizes and current conditions of the waterway). First of all, various methods and techniques can be listed that may be considered in different situations. In table 1 a number of potentially relevant options are summarised that emerged as a result of a study we carried out recently. These options are in the domain of stimulating (microbiological) degradation of organic contaminants (chlorinated substances included), concentrating metals into vegetation, immobilisation of metals or organic contaminants (*viz.* adsorption to various materials, binding in cement, vitrification) and reducing the advective dispersion of contaminants towards ground water or surface water (*viz.* by capping the soil, or by hydrological insulation of the waterway. In specific cases refraining from any action can come forward as the best option in connection with risk reduction considerations.

Various situations can be outlined in which an *in-situ* approach looks appropriate. For instance, when a conventional remediation (dredging) is either ineffective, or it leads to serious damage to nature values. A prerequisite for an *in-situ* approach is that short or long term risks are acceptable. Both existing risks, or risks introduced by the remediation action should be considered here.

**Tab. 1.** Options for *in-situ* sediment remediation

| Remediation type | Scope (type of contaminants) | Technological concept | Technological implementation | Feasibility C.E [1] | Feasibility E.E [2] |
|---|---|---|---|---|---|
| Stimulation of aerobic micro-biological degradation | Organics (PAH, mineral oil, etc.) | Increase degradation rate by addition of electron acceptors | Oxygen injection | - | - |
| | | | Rooting up of sediments (for instance with turbine jets) | -/+ | - |
| | | | Addition of nitrate as electron acceptor | - | -/+ |
| | | | Addition of humic substances as electron acceptors | -/+ | + |
| | | | Application of biological screens, or alternative reactive zones, if necessary combined with electrokinetic transport | -/+ | + |
| | | Increase degradation rates by addition of micro-organisms | Addition of especially grown organisms | - | + |
| | | | Inoculation with adapted organisms | -/+ | -/+ |
| | | Increase degradation rates by addition of nutrients | Addition of nutrients | - | - |
| | | Increase degradation rates by changing the environmental conditions | Use enhanced degradation of contaminants in soil near plant roots | + | + |
| Stimulation of micro-biological reductive dechlorination | Chlorinated organics | Increase degradation rates by changing the environmental conditions | Temporary deflection of river branches, or draining of harbours | -/+ | 0 |
| | | Increase degradation rates by addition of electron donors | Application of microbial mats | -/+ | + |
| | | | Addition of electron donors to capping layers, clay screens, etc. | -/+ | + |
| Stimulation of biological concentration and removal of contaminants | Metals (Ni, Zn, Cu, Cd) | Uptake of metals by plants (phyto-extraction) | Introduction of plants (e.g. willowherb, or sedge), harvest and incinerate | -/+ | + |
| | Phosphates | Uptake of phosphates by plants (phyto-extraction) | Introduction of plants, harvest and incinerate | -/+ | + |
| Using chemical trans-formations | All (if they can be oxidised or reduced) | Chemical oxidation or reduction of contaminants | Addition of oxidants (e.g. $H_2O_2$) | - | - |
| | | | Electrokinetic remediation | - | - |
| | Metals | Precipitation of metals as sulphides | Admission of salt seepage (sulphate containing water) | + | 0 |
| | | | Construction of wetlands (marshy zones) | -/+ | + |
| Fixation of contaminants (sorption or immo-bilisation) | Metals | Precipitation of metals as hydroxides or insoluble complexes | Increased pH by addition of lime or alternative hydroxides | -/+ | -/+ |
| | | | Precipitation or adsorption near or at plant roots (phytostabilisation) | + | + |
| | | Binding of metals in inorganic matrix | Addition of cement (and additives, if necessary) | -/+ | + |
| | | | Vitrification using electrical current | - | - |

*(table continued on next page)*

*(Table 1, continued from preceding page)*

| Remediation type | Scope (type of contaminants) | Technological concept | Technological implementation | Feasibility C.E [1] | Feasibility E.E [2] |
|---|---|---|---|---|---|
| | | Adsorption of metals at clay or aluminumsilicate surfaces | Application of a clay screen (with for instance zeolite, or beringite, if necessary) | -/+ | + |
| | | | Application of a capping layer | -/+ | 0 |
| | | | Addition of "adsorption marbles" | -/+ | + |
| | | Adsorption at plant roots | Introduction of plants | -/+ | + |
| | Organics | Adsorption of organic contaminants at clay surfaces and/or absorption in organic matter | Application of a clay screen, with addition of organic matter (humic material) and/or oxygen release compounds, if necessary | -/+ | + |
| | | | Application of a capping layer with clay, or compost (and oxygen release compounds, if necessary) | -/+ | 0 |
| | | | Addition of 'adsorption marbles' | -/+ | + |
| | | Adsorption at plant roots | Introduction of plants | -/+ | + |
| | Phosphates | Precipitation of phosphate as iron phosphate | Injection of iron chloride, or iron sulphate | - | - |
| Reduction of advective dispersion towards surface waters | All contaminants | Increased hydrological resistance | Application of a capping layer | + | 0 |
| | | | Densification of the sediment | -/+ | 0 |
| | | Reduction of bank erosion and wash out | Introduction of plants | + | + |
| | | Hydrological insulation | Deflection of brooks | + | 0 |
| Reduction of advective dispersion towards ground water | All contaminants | Increased hydrological resistance | Application of a clay screen | + | + |
| | | Hydrological insulation | Watermark control measures | + | 0 |
| Refraining from action | All contaminants | Risk reduction | Change function of waterway, or surroundings | + | 0 |

1 C.E. = Cost effectiveness. The symbols (-, -/+, +) designate a qualitative judgement varying from relatively unfavourable to relatively favourable; 0 = no judgement given (for instance, if this depends on specific local circumstances)

2 E.E. = Environmental effects. The symbols (-, -/+, +) designate a qualitative judgement varying from significantly negative to no effect; 0 = no judgement given (for instance, if this depends on specific local circumstances)

The possibilities for enhancing the rate of biodegradation processes are limited because these rates are often determined by the prevailing environmental conditions. A distinction should be made between processes using aerobic and anaerobic respiration, the latter to be subdivided into processes under nitrate, manganese, iron (III), or sulphate reducing conditions, and at very low redox potentials methanogenic conditions. Also fermentation processes may be relevant. Although a few publications have appeared that describe an anaerobic degradation of PAH and other aromatic or aliphatic hydrocarbons (Caldwell 1998, Coates 1998, Renner 1998), it is generally accepted that presence of oxygen in preferably high concentrations is required for the degradation of these substances (Meel 1997, Norris 1995, Harmsen 1995). In the case of small water systems measures may be taken in order to meet the oxygen demand connected with aerobic degradation processes, some of which are mentioned in Tab. 1.

Sometimes it may be conceivable that the conditions for reductive dechlorination of chlorinated hydrocarbons are optimised. This is particularly the case, if the waterway concerned can be temporarily isolated from the adjoining water system. Humics can be used as electron donor to stimulate the biodegradation processes (Kördel 1995, Lovley 1996, 1999). Also phytoremediation (for instance degradation of contaminants near plant roots) may be beneficial in certain cases (Ferro 1999, Rock 1998, Verkleij 1996).

As to the immobilisation of contaminants by adsorption one can think of applying clay screens, or clay layers (with or without additives). Specifically for metals, phytostabilisation or phytoextraction may offer perspectives in the long run. The advective dispersion of contaminants towards ground water or surface water can be reduced again by capping the polluted sediment with a clay layer, with organic matter (humus) or other materials as possible additives. The function of these additives is to increase the sorption capacity or to enhance the rates of biodegradation processes.

## 3 Feasibility of in-situ concepts

### 3.1 Local conditions

The feasibility of the options identified is hard to determine in general. The potential profits and risks for every specific location should be taken into consideration. For *in-situ* options to come into the picture a number of limiting conditions have to be fulfilled, for instance:

- dredging should not be necessary for nautical or water management reasons
- the *in-situ* option should fit in the time frame appropriate for the location (in relation to assigned functions)
- the action under consideration should result into a sufficient reduction of ecological risks and or dispersion of contaminants

For every single case the effects of the actions (either dredging, or *in-situ*) on the aquatic ecosystem will have to be accounted for. In concrete cases, where a conventional approach encounters serious difficulties, an investigation dedicated to the prevailing conditions will have to give a decisive judgement on the feasibility of an alternative (*in-situ*) approach. If certain options appear to offer good perspectives for application in practice a pilot-scale experiment may be planned as a subsequent step.

### 3.2 Demonstration in practical cases

A workshop has been organised in which the results of the aforementioned study were discussed. Some ideas have been proposed for relevant cases in which *in-situ* remediation actions might be implemented. We are now investigating the feasibility of these cases in a supplementary study financed by the Dutch Centre for Soil Quality Management and Knowledge Transfer (SKB). It is the aim of this study to analyse the proposed cases and to give insight into the efforts needed to come to application of *in-situ* options in practice. As a preliminary result of the analysis it can be stated that some of the proposed *in-situ* options look very promising. If this does turn out to be the conclusion of the study it is planned to further elaborate and investigate the possibilities for *in-situ* remediation of contaminated sediments.

## 4 Conclusions

Although it is still too early at this moment to draw final conclusion, the prospects for application of *in-situ* remediation options look more interesting than it was assumed until very recently. In specific cases it is necessary to realise and recognise that

- remediation measures should be based upon a risk evaluation,
- a quite conceivable result of this evaluation might be that removal of the sediment for environmental reasons only is not a prerequisite and
- the remediation does not necessarily have to be completed within a very short period of time, so one should be sufficiently patient to allow for slow biological processes to do their job.

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