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Methodological approach for the environmental validation of a quarry fill in a coastal area using treated dredged seaport sediments

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Abstract:
Heavily polluted dredged seaport sediments cannot be dumped into the sea and thus raise problems regarding their management since classical terrestrial methods (incineration, depositing in dumps, etc.) are ill-adapted to their treatment, both economically and with respect to the volumes that can be absorbed. Among the alternative solutions considered, filling in dry quarries appears promising, in particular because it provides sufficient capacities for managing the large volumes involved. This method nonetheless requires launching a research program aimed at providing a methodology for assessing specific ecological risks, in order to validate the compatibility of each large-scale filling operation with neighbouring inland environments and ecosystems.
In this context, the objective of the ANR *SEDIGEST* program was twofold:
- operationally: to develop an ecological risk assessment methodology adapted to the management scenario mentioned above,
- scientifically: to remove the main barriers against drawing up such a methodology. These were mostly linked to still very partial understanding of the different physical chemical and biological mechanisms involved in their deposit on land.

After three years of works focusing on three sediment matrixes taken from seaports in the south and west of France (two in the Var department and one in that of Finistère), the SEDIGEST program resulted in a methodological proposal comprising four possible levels of complexity, usable for the environmental validation of a given project to fill quarries with seaport sediments.

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1. Introduction

Over the last twenty years, in different countries around the world, dredged seaport sediments have been the subject of increasingly complicated management procedures as they are frequently polluted by the industrial, commercial, urban and tourist activities carried out in these ports (LAU *et al*., 1993; ANDERSEN *et al*., 1998; MEEDDAT, 2008). The main families of pollutants concerned are heavy metals (ROMANO *et al*., 2004; COLACICCO *et al*., 2010; LEPLAND *et al*., 2010), polycyclic aromatic hydrocarbons or PAHs (GSCHWEND & HITES, 1981; SIMPSON *et al*., 1996; ROMANO *et al*., 2004; ANA, 2011), polychlorinated biphenils or PCBs (PAVLOU *et al*., 1982; FAVA *et al*., 2003; ROMANO *et al*., 2004; COLACICCO *et al*., 2010), and tributyltin compounds or TBTs (LANGSTON *et al*., 1987; BHOSLE *et al*., 2006; SAEKI *et al*., 2007; BLANCA, 2008). The ecotoxicity of these dredged sediments has often been confirmed by the bioassays carried out on them (WONG *et al*., 1995; CLEMENT *et al*., 2009; MAMINDY-PAJANY *et al*., 2009; SRUT *et al*., 2010). There is currently a large stock of contaminated sediments in France (about 10 million tons), located in seaports, that cannot be dredged due to recent changes in regulations prohibiting their dumping at sea (IFREMER, 2001). This leads to a new source of polluted materials for which no treatment method appears to exist since classical methods (incineration, depositing in dumps, etc.) are ill-adapted, uneconomic, and unable to cope with the volumes involved. With a view to finding viable solutions for these materials, research and development works have started, notably in France (GROSDEMANGE *et al*., 2008). One of the most promising alternative solutions considered is storage in dry quarries, since it is the best-adapted one both technically and economically, and it also provides sufficient capacities for managing the large volumes involved. However, this procedure requires an extensive research program aimed at proposing a "specific risk assessment methodology" to validate its compatibility with neighbouring inland terrestrial and aquatic ecosystems for each large scale fill operation, and with the preservation of water resources (groundwater).

The operational goal of this project is therefore to formulate an Ecological Risk Assessment Methodology (ERAM), adapted to these materials and this method, on the basis of "upstream" research focused on all the aspects of the problem (SEDIGEST, 2011).

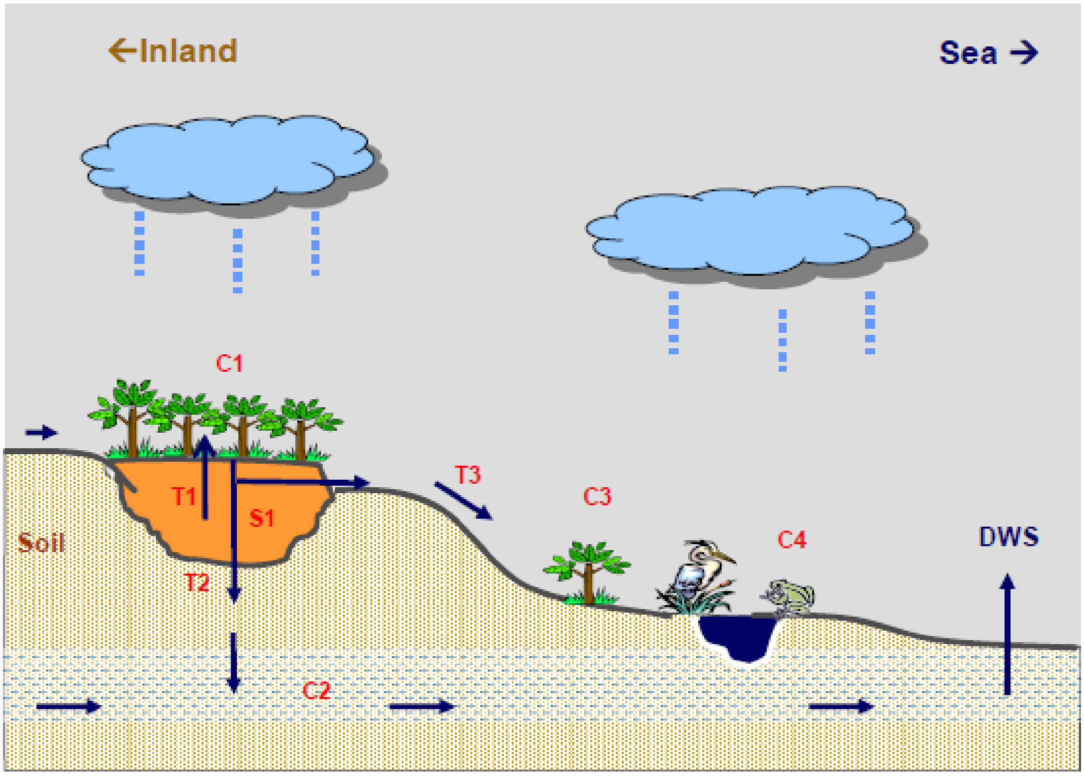
2. Materials and methods

Generally, at international level, the ERA methodologies developed for different scenarios for storing or using potentially pollutant materials (SUTER, 1993; RIVIERE, 1998; US EPA, 1998; PERRODIN *et al*., 2000; CETMEF, 2001; ADEME, 2002; ECB, 2003; EMMANUEL *et al*., 2005; HAYET, 2006; RECORD, 2006), include the four following steps:

a) formulation of the problem,

b) characterisation of target ecosystem exposure,
c) characterisation of the effects of pollutant flows on ecosystems,
d) final characterisation of ecological risks.

These four steps were formulated in the framework of the *SEDIGEST* program (see figure 1) for a scenario of type "storage of previously treated polluted sediments in a quarry".



S1: treated seaport sediment deposit in a quarry.
T1: transfer of pollutants from the deposit to the terrestrial ecosystem.
C1: ecosystem developing on the deposit.
T2: transfer of deposit pollutants through the soil and the saturated zone.
C2: groundwater located under the deposit that receives part of the leachates flowing from the sediments. The concentration of the latter varies through time.
T3: transfer of pollutants via the lateral runoff of deposit leachates.
C3: ecosystem close to the deposit receiving the lateral runoff from the deposit.
C4: aquatic environment: pond, canal or river located close to the deposit liable to receive lateral runoff from the deposit.
DWS: Drinking water supply

Figure 1. Formulated scenario.

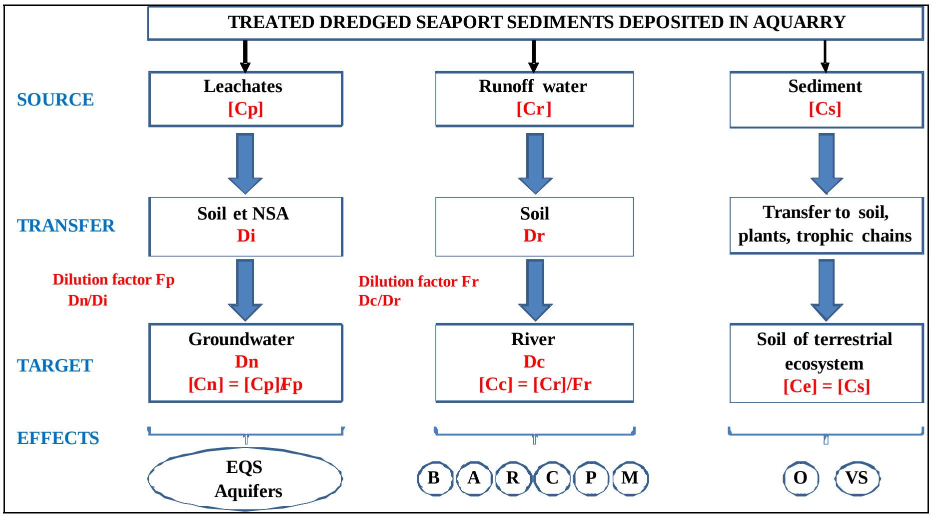
The main scientific deadlocks standing in the way of drawing up such a methodology were mostly linked to understanding of the different physical, chemical and biological mechanisms involved during the storage of such polluted saline materials on land, especially during the deposit phase, then under the action of rain and, lastly, the resulting contact between potentially contaminated water and neighbouring inland ecosystems. These deadlocks concerned in particular the need to take into account the

problem of changing spatial and time scales with a view to making realistic predictions of pollutant emissions and their long term impact or not on the environment.
Three sediment matrixes (two from Var and one from Finistère) were selected for the program on the basis of a compromise between the level of contamination and the type of preliminary treatment concerned. Three pilot-scale quarry lysimeters were then set up, taking into account the results obtained by hydromechanical tests on each of the three sediments. They permitted a simulation of the storage conditions, with the production of a water balance covering a twelve-month period, and collecting leachates analyzed regularly and used for ecotoxicity tests to assess the impacts on ecosystems close to the deposit. In addition, following the formulation of a typology of quarries present in the two pilot departments of the *SEDIGEST* program (Var and Finistère), two experimental sites were selected for field investigations. Structural analyzes, radar and seismic refraction prospections were performed on these sites, in three areas in a quarry in Var and two areas in a quarry in Finistère.

3. Results

3.1 Global conceptual model

To visualize all the interactions between the identified sources and the target populations, a conceptual model was built (see figure 2), specifying the sources of emission, transfer paths, target ecosystems and the different quantitative and qualitative elements characteristic of the scenario (mass/volume ratios, dilution factors, and the organisms and effect parameters to be tested). The results of the analysis of the hydromechanical characteristics of the deposit on land also permitted to specify the optimum conditions for implementing the three sediment matrixes when filling in quarries.



Cp: leachate concentration, Cr: concentration in runoff water, Cs concentration in sediment, NSA: Non Saturated Area, Ce: exposure concentration, Dn Dilution in groundwater, Dc dilution in river, EQS:Environmental Quality Standards, B:Bactéria, A:Algae, R: Rotifers, C:Crustaceans, P:Fish, M: Microorganisms

Figure 2. Construction of the conceptual model.

3.2 Deposit emissions

The characterization of potential pollutant emissions was performed according to a procedure based on a battery of complementary behaviour tests intended to assess the potential mobilization of pollutants present in the treated and untreated seaport sediments. The results show:

a) a low risk of mobilization of target metals (As, Cu, Pb and Zn) at natural pH but instability of the latter;
b) a more or less long term risk under specific leaching conditions (complexing medium, acid medium, etc.) and highlighting of environmental stress effects (carbonation, rainwater, anaerobiosis, etc.);
c) a predominant role of carbonates on controlling pH and mobilizing pollutants;
d) reactivity of sulphates (pyrite);
e) a predominant role of organic matter: solubilization and mineralization observed under alkaline and strongly acidic pH conditions;
f) heavy contamination by Polycyclic Aromatic Hydrocarbons (PAHs).

Geochemical modelling of pollutant emissions then permitted highlighting the consistency and synergy of the three approaches pursued (physicochemical, leaching and modelling). Emission modelling appears to be an interesting tool for understanding and obtaining knowledge of sediments, and it can be used as decision-aid for determining possible storage conditions.

3.3 Pollutant transfers

Following structural analyses on two pilot sites, 3D flow models were used to study transfers of water and pollutants in order to assess the impact of potentially polluted sediments on the underground environment.

3.4 Impact of pollutants

The impact on terrestrial ecosystems located at the surface of the deposit, approached through the assessment of effects on plant germination and growth (*Lolium perenne* and the halophyte plant *Armeria maritima)*, showed that germination and seedling development were possible for certain sediments after several years of leaching of the deposit surface by rainwater.

Regarding the impact study performed for peripheral aquatic environments, a functional diagnostic of these environments in the catchment areas of the two pilot sites was carried out first to determine the non commercial heritage and functional value of the aquatic ecosystems and estimate the vulnerability of these environments to the effluents stemming from the deposits. The main information obtained from this study was that one of the risks identified for aquatic communities is the eutrophication that can be caused by the release of phosphates originally present in the sediments of the river, due to a cascade reaction triggered by the sulphates transported by the leachate from the sediment deposit (SMOLDERS *et al.*, 2006). This study was then completed with standardized monospecific ecotoxicological assays [NF EN ISO 6341 (T90-301), 1996; ISO 11348-3, 1998; ISO 20079, 2005; NF EN ISO 8662 (T90-304), 2005; PR NF ISO 20666, 2007)]. This study showed that: (i) the bacteria *V. fisheri* is not sensitive to the leachates of certain sediments, that rotifers and green algae are the organisms most sensitive to the battery of assays and that toxicity did not evolve significantly through time; (ii) that a limed sediment is very toxic for aquatic organisms.

The assays performed on fish cell lines did not show any primary genotoxicity, but this remains to be verified as a function of exposure time.

Assays with 2-litre aquatic microcosms provided results consistent with those obtained with monospecific assays, therefore consolidating the results.

3.5 <u>Ecological risk assessment</u>

After conducting all the previous works, and taking into account the data and technical and economic limitations in the field, a methodology with four levels of possible complexity was formulated and proposed:

a) the first, called "substance approach" (see figure 3), consisted in comparing the level of concentration of the different pollutants predicted in the target environments (PECmg/l) (by performing a leaching test in a laboratory lysimeter on the sediments studied, followed by modelling transfers in soils and groundwater), with the maximum concentrations acceptable for the ecosystems concerned, obtainable from international databases (PNECmg/l);

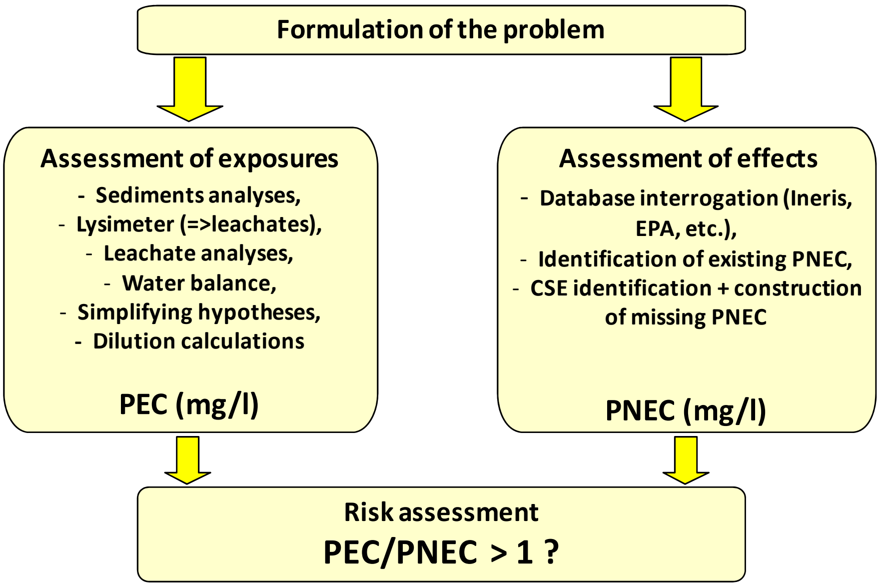


Figure 3 "Substances" approach.

b) the second, called the "matrix approach" (see figure 4), consists in comparing the percentage of leachate predicted in the receiving environments (PEC%) with the percentage of leachate admissible in each of them (PNEC%), by performing monospecific ecotoxicity assays on the leachate;

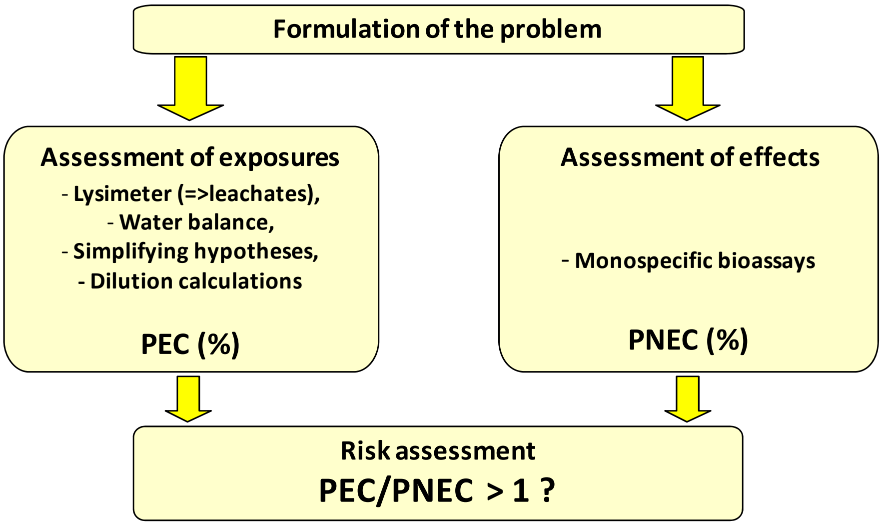


Figure 4 "Matrix" approach.

c) the third, called "thorough substance approach" (see figure 5), corresponds to the substance approach described above, consolidated by a series of sediment behaviour tests under varying environmental conditions (pH, REDOX potential, etc.) in order to verify the validity of the prediction performed for the long-term;

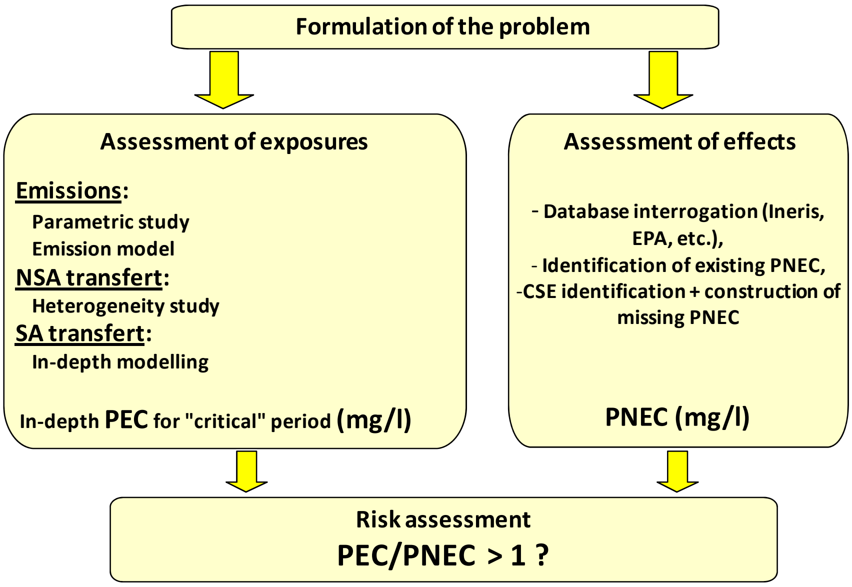


Figure 5. Thorough *"substances" approach.*

d) the fourth, called "thorough matrix approach" (see figure 6), consists in completing the assessment of the effects of the leachates presented above by performing assays on them in microcosms.

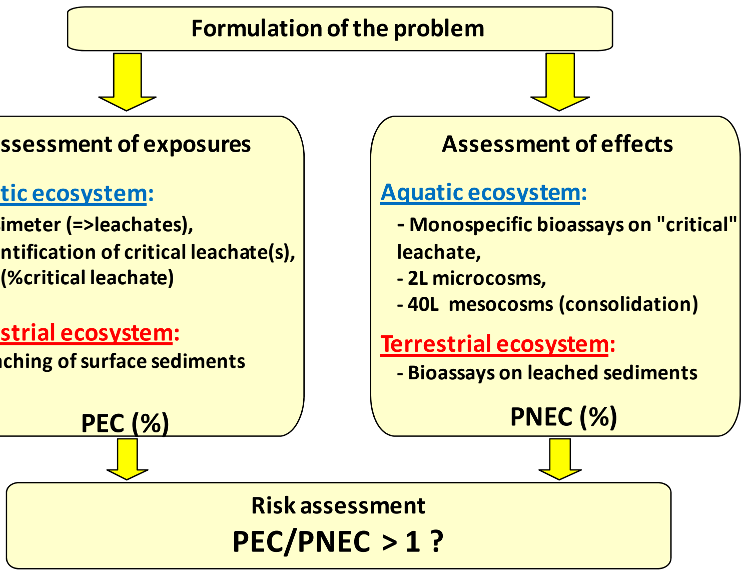


Figure 6 Thorough *matrix approach".*

The fact that these four methodologies are available allows managers to progressively make use of them and, if necessary, increase their complexity and cost as a function of local stakes and the results of previous approaches.

4. Conclusions

All the experimental and theoretical results obtained during the *SEDIGEST* program made it possible to formulate and validate a multi-level methodological approach at pilot scale, adapted for the environmental validation of projects to use dredged seaport sediments for quarries in coastal areas. This methodology remains to be applied to a certain number of pilot deposit sites that should be equipped with instruments and monitored over several years to define and validate the methodology at large scale. The extension of the method's scope of application to other procedures for managing dredged seaport sediments can be considered, provided that works of the same type as those of the *SEDIGEST* program are performed beforehand. These works will be defined in detail at the end of the first stage of the Ecological Risk Assessment, i.e. the "formulation of the problem".

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