CHEMICAL ENGINEERING TRANSACTIONS
VOL. 28, 2012
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at: www.aidic.it/cet
Guest Editor: Carlo Merli

**ISBN** 978-88-95608-19-8; **ISSN** 1974-9791
DOI: 10.3303/CET1228028

# Preliminary Results of the Life+ Project: CO-ordinated Approach for Sediment Treatment and Beneficial Reuse in Small Harbours Networks

Sara Dastoli[a], Giorgia De Gioannis[b], Maurizio Morelli[c], Aldo Muntoni[b], Roberto Peretti[d], Alessandra Polettini[e], Raffaella Pomi[e*], Elena Romano[a], Antonello Serci[b], Alessio Stramazzo[e], Barbara Villani[c], Antonello Zucca[d]

[a] ISPRA (Italian Institute for Environmental Protection and Research).
Via Vitaliano Brancati, 60 - 00144 Rome (Italy)
[b] Università di Cagliari – Dipartimento di Geoingegneria e Tecnologie Ambientali.
Piazza d'Armi, 1 – 09123 Cagliari (Italy)
[c] ARPA Emilia Romagna (Agenzia Regionale Prevenzione e Ambiente).
Largo Caduti del Lavoro, 6 - 40121 Bologna (Italy)
[d] CNR (Consiglio Nazionale delle Ricerche) – Istituto di Geologia Ambientale e Geoingegneria.
Piazza d'Armi, 19 – 09123 Cagliari (Italy)
[e] Università degli Studi di Roma "La Sapienza" – Dipartimento di Ingegneria Civile, Edile ed Ambientale.
Via Eudossiana, 18 – 00184 Rome (Italy)
raffaella.pomi@uniroma1.it

Dredging operations in harbour and marine coastal areas, usually performed to maintain operational water-depth, might represent a viable option to mitigate environmental pollution if applied to remove contaminated sediments from the water body. Sediment landfilling could generate relevant environmental burdens due to the amounts of materials to be disposed of; however, the implementation of alternative management options aimed at re-use is hindered by the high cost of technology and the absence of a market for the recovered materials. The present project, named COAST BEST "CO-ordinated Approach for Sediment Treatment and BEneficial reuse in Small harbours networks" and funded in the framework of the LIFE08+ ENV European call, is aimed to find out a method to integrate all the phases of sediments management, through the creation of a network-based system including different small harbours, i.e., harbours of regional/interregional relevance, which can be geographically interconnected.

## 1. Introduction

Surface waters receive local and/or wide discharges of various liquid and solid wastes, often containing contaminants which may sorb onto sediment particles. Consequently, sediments can be considered as a reservoir of contaminants having the potential of dissolving or migrating them into the water column. Dredging might be applied to restore water quality and prevent pollutants diffusion as the application of in-situ treatment technologies such as capping may not be suitable for harbour areas where operational water-depth should be guarantee. Thus, huge amounts of contaminated sediments have to be dredged, dewatered and treated before reuse or final disposal. Around 500 million $m^3$ of sediments are dredged each year for navigational purposes and roughly 1 - 4 % requires dewatering and treatment prior to disposal, increasing the cost of dredging activities by a factor of 300 - 500. The

Please cite this article as: Dastoli S., De Gioannis G., Morelli M., Muntoni A., Peretti R., Polettini A., Pomi R., Romano E., Serci A., Stramazzo A., Villani B. and Zucca A., 2012, Preliminary results of the life+ project: co-ordinated approach for sediment treatment and beneficial reuse in small harbours networks, Chemical Engineering Transactions, 28, 163-168 DOI: 10.3303/CET1228028

applicability of soil remediation processes depends on the specific characteristics of sediments, such as the high water and salt content and the presence of fines. Due to the presence of several contaminants in dredged sediments, remediation often requires a combination of techniques, i.e. a "treatment train". Despite decades of research, surprisingly up to now sediment treatment has not been frequently practiced due to the huge volumes involved, the high costs and the risk of poor effectiveness. Such criticisms are particularly severe in case of small harbours and channels. In this contest, the present project is aimed at preserving the quality of coastal zones by 1) developing an integrated sediment management system (vertical integration) and 2) creating a network of small harbours (horizontal integration). The study area consists of the nine small harbours of the Emilia-Romagna Region coastline, facing the Adriatic sea which is the northernmost eastern arm of the Mediterranean sea. The developed method is expected to be used to manage similar areas as well. On the basis of the sediment characteristic and financial constraints typical of small harbours, mechanical washing was considered as the most suitable treatment system. The most cost-effective treatment identified consists of sediment separation in two or more fractions by size classification. Mechanical washing is capable of achieving high removal efficiencies, even if the process yield may be adversely affected by a significant silt content, which may be rather typical of sediments. In the project, techniques such as size classification (sieving, cycloning, etc.), gravimetric separation, flotation and attrition washing are tested at lab-scale and scaled-up for the pilot-scale survey. The definition of the most appropriate management strategy of each sediment fraction will be also exploited. The results of sediment sample characterization, as well as the results from the laboratory separation tests are reported in the manuscript.

## 2. Characterization of the pilot area

### 3.1 Sampling plan strategy

In order to implement and test an integrated management system of dredged sediments, a coastal area, including 9 small harbours of Emilia-Romagna Region, was chosen as pilot site. In order to assess the amount and quality of sediments to be dredged, as well as to gain a preliminary evaluation of the feasibility of sand recovery, a detailed characterization plan was designed. Starting from existing information, ISPRA experience and the guidelines reported in the "*Manual for the handling of marine sediments*" (ICRAM-APAT, 2007) which also contains the reference values for marine sediments quality evaluation, a conceptual model of the site was developed. It takes into account the potential variability of sediment quality, the type and location of harbours facilities, as well as the areas and volume to be dredged. On the basis of the conceptual model, the sampling plan was designed and the target parameters were identified. Specifically, the sampling survey was designed in order to: 1) identify the vertical and horizontal distribution of sediments characteristics (particle size, contaminants concentration, ecotoxicity, etc.); 2) identify contaminated areas where dredging have to be performed even if the water depth is adequate for shipping activities.

The sampling grid was designed taking into account the potential sources of contamination and the extension of the area: 1) 50x50 m close to port facilities (wharves, breakwaters, etc.); 2) from 100 x 100 m up to 200 x 200 m at increasing distances of the sampling point from harbour facilities or coastline.

For each grid, a sediment core was sampled, while the core length was defined according to the foreseen height of the sediment layer to be dredged. The conceptual model and the sampling campaign were developed for Porto Garibaldi, Cervia, Cesenatico and Bellaria-Igea-Marina, considered to be representative of the whole pilot area. The main feauters of the 4 ports are reported in Table 1. To collect representative and undisturbed samples, the criticisms existing in small harbours were mitigated, including the presence of docking areas and boat transit.

### 3.2 Materials and methods

A percussion corer, equipped with an internal PVC liner, was used for sampling with the aid of a diver. A GPS detector was used as positioning system. In order to assess sediment quality, a list of chemical-physical parameters was analyzed according to specific Methodical procedures (Table 2).

*Table 1: Activities [fishing (F), recreational (R)], number of moorings, and amount of dredged sediments in each harbour (in brackets: dredging period)*

| | Porto Garibaldi | Cervia | Cesenatico | Bellaria-Igea Marina |
|---|---|---|---|---|
| Activities | F/R | R | F/R | F/R |
| n. of moorings | ~480 | ~400 | ~400 | ~120 |
| dredged sediments ($m^3$) | 33,000 (in 1996)<br>36'000 (in 2006) | 80,000 (1985-95) | ~65,550 (in 1996)<br>11,250 (in 2003)<br>24,800 (in 2005) | ~103,000 (2000-08) |

*Table 2: Physical-chemical analyses. Methods and procedures*

| Parameter | Method |
|---|---|
| Grain size distribution | Romano et al., 2009 |
| Al, As, Cd, Cr(tot), Hg, Ni, Pb, Cu, V, Zn | Hyde et al. (2011) |
| Polychlorobiphenyls (PCB) | EPA 3550, 3620, 3660, 3665 and 8082 modified |
| Polycyclic Aromatic Hydrocarbons (PAHs) | EPA 8310 and 3550 modified |
| Hydrocarbons (C ≤ 12) | EPA 5021 and EPA 8015 D |
| Hydrocarbons (C> 12) | EPA 8270c and 8440 modified |
| Tributyltin | Metodologie analitiche di riferimento (ICRAM 1999) |

### 3.3 Characterization results

In the present sectionthe analytical results obtained for Porto Garibaldi and Cesenatico are discussed. A geostatistical approach was used to assess the spatial variability of sediment characteristics (Figure 1).

Porto Garibaldi. Sand content (section 0 - 50 cm)

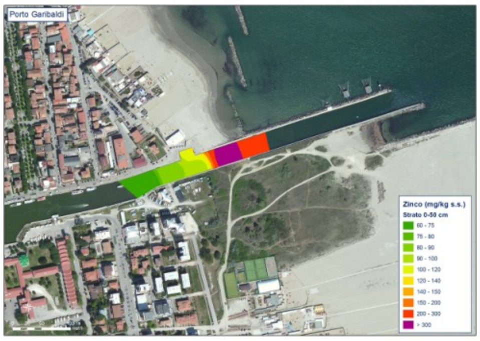
Porto Garibaldi. Sand content (section 50 - 100 cm)

Cesenatico. Sand content (section 0 - 50 cm)

Cesenatico. Sand content (section 50 - 100 cm)

*Figure 1: Grain size distribution in sediments of Porto Garibaldi e Cesenatico harbours*

Sand content in the upper (0 - 50 cm) and lower (50 - 100 cm) sediment section is shown, along with the spatial distribution of Zn and PAH content in the upper layer of Porto Garibaldi and Cesenatico, respectively. Both in Porto Garibaldi and in Cesenatico, the pelite fraction decreased at increasing the distance from harbour mouth. The presence of Cd and Zn was detected along the layer depth, with a wide variability of the spatial distribution and the highest values close to the limit values reported in ICRAM-APAT (2007). PAH were found at the entrance of Cesenatico harbour.




Porto Garibaldi. Zn concentration (section 0 - 50 cm)


Cesenatico. PAH concentration (section 0 - 50 cm)

*Figure 2: Zn and PAH content distribution in sediments of Porto Garibaldi e Cesenatico harbours*

### 3. Lab-scale separation tests

Approximately 100 kg dry matter of sediments from Cesenatico and Porto Garibaldi named respectively POCES and POGAR, were used to test the lab-scale mechanical washing treatment. Sediment samples were pre-treated to remove the excess water and then oven-dried at 40 °C to constant weight. Homogenised dry samples were temporarily stored in polyethylene bags at 4 °C. Different size separation processes were tested, including dry/wet sieving and hydrocyclone separation. Ultrasonication was also applied to improve physical separation of solid particles. As regard to POCES sample, the content of fine particles was found to be remarkable ($\phi$ < 20 µm higher than 40 % by weight). Being the $\phi$ < 53 µm fraction approximately 64 - 68 % of the sample weight, sand recovery is not feasible. Moreover, the quality of fraction $\phi$ > 53 µm is adversely affected by the presence of organic material and mica minerals. The particle size distribution of the fraction $\phi$ < 20 µm was further investigated through a specific laser device (Sedigraph). The results confirmed that ~ 93 % of the analysed sample is actually composed of particles with an equivalent diameter lower than 20 µm, this confirming the high efficiency of the separation process. Moreover, roughly 80 % and 60 % of the $\phi$ < 20 µm fraction was found to be smaller than 10 µm and 5 µm, respectively. In Table 3, POCES properties are summarized and compared with the limit values of column A (soil for residential use) and column B (soil for industrial use ) of Legislative Decree n. 152/2006 (2006), so as to derive preliminary indications on the feasibility of sediment fraction utilization. Considering the values in column A, Zn, As, benzo(a)pyrene, benzo(a)perylene, and hydrocarbons C > 12 appear to be critical elements (see Table 3). After separation, Zn concentration is higher than the regulatory limit for all the fractions, the Cd content was found to be higher in the fractions 53 < $\phi$ < 125 and $\phi$ < 20 µm, while As content exceeded the limit values for the sole $\phi$ < 20 µm fraction. When organic pollutants are considered, benzo(a)pyrene and C > 12 appeared to be critical in the 53 < $\phi$ < 125 fraction and < 20 µm, respectively. The significant contamination of the fine fraction, which is the most abundant in the sediment, make the POCES sediment not suitable for the goals of the project. A possible treatment train which could be suitable for the considered sediment is described in Figure 3.

*Table 3: Chemical-physical characterization of the POCES sediment (values higher than related legislation limits in red bold)*

| Parameter (unit of measure) | POCES2 | POCES2 53<ϕ<125 μm | POCES2 20<ϕ<53 μm | POCES2 ϕ<20 μm | POGAR | POGAR Φ>500 μm | POGAR 63<Φ<500 μm | POGAR Φ<63 μm |
|---|---|---|---|---|---|---|---|---|
| Grain size (Shepard, 1954) | Sandy silt | - | - | - | Sand | - | - | - |
| Grain size (Nota, 1954) | Sandy pelite | - | - | - | Sand | - | - | - |
| VS(^) | 14.78 | - | - | - | 3.44 | - | 1.48 | - |
| TC (^) | 4.41 | - | - | - | 2.89 | - | 2,45 | - |
| IC (^) | 1.80 | - | - | - | 1.36 | - | 2,03 | - |
| TOC(^) | 2.61 | - | - | - | 1.53 | - | 0.42 | - |
| $O_2$ cons. (after 1626 h) (°) | 7411 | - | - | - | 1429.1 | - | 1156.5 | - |
| Zn(*) | **227.2** | **282.67** | **179.42** | **210.6** | 127.70 | **1110.4** | 73.30 | **171.40** |
| Ni(*) | 71.87 | 77.84 | 65.86 | 69.86 | 74.60 | **540.64** | 50.60 | 98.60 |
| Cd(*) | n.a. | **5.99** | 0.00 | **5.99** | 0.71 | **12.80** | 0.13 | 0.25 |
| Pb(*) | 57.89 | 61.89 | 71.85 | 75.85 | 25.90 | - | 28.30 | 33.20 |
| Cr(*) | 49.91 | 49.91 | 43.91 | 43.91 | 90.60 | **544.41** | 66.60 | 133.20 |
| As(*) | **33.42** | 14.38 | 14.13 | **24.07** | 7.31 | 13.64 | 6.76 | 14.37 |
| Benzoanthracene(*) | 0.229 | 0.072 | 0.015 | 0.007 | 0.016 | **1.572** | 0.003 | 0.013 |
| Benzo(a)pyrene(*) | **0.226** | **0.100** | 0.021 | 0.010 | 0.011 | **1.089** | 0.003 | 0.013 |
| Benzo(b)fluoranthene(*) | 0.295 | 0.121 | 0.036 | 0.028 | 0.012 | **0.858** | 0.005 | 0.022 |
| Benzo(k)fluoranthene (*) | 0.130 | 0.051 | 0.012 | 0.007 | 0.005 | **0.526** | 0.001 | 0.007 |
| Benzo(a)perylene (*) | **0.160** | 0.079 | 0.023 | 0.018 | 0.006 | **0.382** | 0.003 | 0.012 |
| Chrysene(*) | 0.321 | 0.137 | 0.030 | 0.017 | 0.021 | 1.449 | 0.007 | 0.020 |
| Dibenzo(a,h)anthracene(*) | 0.030 | 0.011 | 0.003 | 0.002 | 0.001 | **0.136** | n.d. | 0.001 |
| Indeno(1,2,3,c,d)pyrene(*) | 0.069 | 0.061 | 0.017 | 0.003 | 0.006 | **0.593** | 0.001 | 0.010 |
| Pyrene(*) | 0.472 | 0.192 | 0.047 | 0.032 | 0.030 | 2.234 | 0.010 | 0.041 |
| Total PAH(*) | 3.28 | 1.35 | 0.355 | 0.268 | 0.165 | **14.269** | 0.056 | 0.229 |
| Total PCB(*) | 0.010 | 0.013 | 0.0073 | 0.0079 | 0.006 | 0.029 | 0.005 | 0.017 |
| Hydrocarbons C>12 (*) | **64.80** | 43.94 | 46.67 | **91.20** | 13.00 | **67.00** | 12.00 | 34.00 |
| Tributyl tin (#) | 1.94 | **22.40** | 1.32 | 1.11 | **5.6** | **12.7** | **9.2** | **9.2** |

(^) %TS; (*) mg/kg; (°)mg $O_2$/kg TS; (#) μg/kg

As far as the sediment POGAR was concerned, the content of sand resulted to be remarkable (roughly 92 %). From Table 2, it is evident the good quality of the sandy fraction, being all the values lower than the Italian legislation limits. Conversely, metals, hydrocarbons C > 12, total PAHs and most of the individual PAHs appear to be concentrated in the fraction ϕ>500 μm probably due to the presence of natural organic matter which is known to have a strong affinity for pollutants. The polluted fractions represent only 3.3 % (ϕ > 500 μm ) and 4.6 % (ϕ < 63 μm) of the sediment mass, respectively, thus POGAR sample could be directly used for beach nourishment. A treatment train was developed in order to further improve the sediment quality, including coarse sieving, spiral classifier, densifier + filter or centrifuge for fine fractions dewatering, an optional sand refining sieving (i.e. by attrition), an optional hydrocyclone for treating the overflow of the spiral classifier.

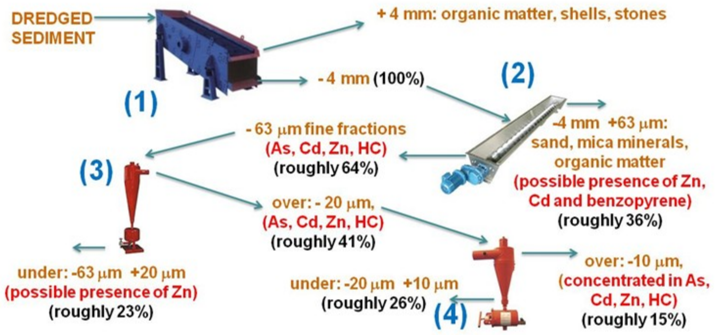



*Figure 3: Proposed treatment train (POCES sediment) and related potential mass balances: (1) coarse sieving; (2) spiral classifier; (3) hydro-cycloning; (4) hydro-cycloning; all mass % refers to the whole mass fed to the system (<4 mm, after coarse sieving)*

## 4. Conclusions

The experimentation carried out so far will contribute to develop a comprehensive and consistent method for sediment management in small harbours. It also helps to assess different scenarios for sediment fraction management and to integrate site-characterization, dredging and treatment activities. The final target will be the reduction of sediment landfilling and identification of sustainable management options. Analysis of sediment samples collected at Porto Garibaldi and Cesenatico harbour allowed to gain some preliminary information for the identification of feasible treatment routes. The results of both the characterization showed for both the harbours a low contamination due to heavy metal and organic compound. However, a different grain size distribution was detected, with higher pelite content in Cesenatico and higher sand content in Porto Garibaldi. The POGAR sediment characteristics appeared to be adequate for a direct sediment reuse, even if a treatment train was tested in order to further increase the sediment quality. On the basis of the experimental results, a treatment train was thus designed and tested, and it will be scaled up during the second part of the project acitivities.

### References

Decreto Legislativo 3 aprile 2006, n. 152, Environmental Regulations (in Italian), G.U. n. 88 del 14 aprile 2006, Supplemento Ordinario n. 96 e successive modifiche e integrazioni.

Hyde T.I., Ash P.W., Boyd D.A., Randlshofer G., Rothenbacher K., Sankar G., 2011, X-Ray Absorption Spectroscopic Studies of Platinum Speciation in Fresh and Road Aged Light-Duty Diesel Vehicle Emission Control Catalysts, Platinum Metals Rev., 55 (4), 233.

ICRAM 1999 Metodologie analitiche di riferimento – Ministero dell’Ambiente e della Tutela del Territorio – Servizio Difesa Mare. Monitoring program for the control of the marine-coastal (years 2001-2003) (in Italian)

ICRAM-APAT, 2007, Manual for the handling of marine sediments.

Nota D.J.G., 1958. Sediments of the western Guyana shelf. Report of Orinoco shelf expedition, 2, Mendedel. Landbomvhogedrool, Wegeningera, 98.

Romano E., Bergamin L., Ausili A., Pierfranceschi G., Maggi C., Sesta G., Gabellini M., 2009, The impact of the Bagnoli industrial site (Naples, Italy), on sea-bottom environment. Chemical and textural features of sediments and the related response of benthic foraminifera, Mar. Pollut. Bull., 59, 245-256.

Shepard F.P., 1954. Nomenclature based on sand–silt–clay ratios. J Sed Petr 24, 151-158