Contaminated sediments in Italy: Methodological approaches and state of the art of characterisation and reclamation activities carried out within Sites of National Interest

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ICRAM and SIAP

Istituto Centrale per la Ricerca scientifica e tecnologica Applicata al Mare
(Central Institute for Marine Research)

Provides scientific and technical support to Local and National Authorities, i.e. guidelines, standard procedures, applied research on:
- Monitoring of coastal waters, offshore dumping sites and offshore oil and gas platforms;
- Harbour dredging and beach nourishment;
- Characterization and evaluation of marine polluted areas;
- Experimental sediment clean up or remediation;
- Fisheries and aquaculture;
- Marine Protected Areas and biodiversity conservation

SIAP

Provides technical support and operative activities to Ministry of Environment and Regional Authorities on:
- Characterization and evaluation of polluted sites of National Interest;
- Planning and design of Emergency and Safety measures and Remediation projects;
- Preparation of technical specifications;
- Public tenders for characterization and remediation of polluted sites;
- Supervising and Job Management of field site works

ICRAM and SIAP are respectively the technical-scientific and the working structure that carry out characterization and remediation plans for National Interest contaminated sites.
Contaminated sediments in Italy

**PROCESS METHODOLOGY**

1. **Data gathering**
2. **Study**
3. **Conceptual model**

Identification of the characterization strategy

- Definition of protocols for sampling, analysis and data reporting
- Execution of sampling and analysis
- Data evaluation
- Identification of action levels
- Data processing and reporting
- Proposals for emergency interventions and remediation actions

Case studies

SIAP
CHARACTERIZATION GOALS

• Determination of the horizontal and vertical distribution of contaminants in sediments
• Determination of possible correlations between sediment pollutants distribution and sediment grain size characteristics
• Evaluation of the effects of contamination to marine organisms and identification of pollutants bioavailability and potential transfer to the food chain
• Determination of the concentration of contaminants along the water column (in particular cases and sensitive areas)
• Determination of the natural contribution to heavy metals and trace elements concentration (geochemical anomalies)

• Identification of more critical areas
• Identification of technical elements and criteria for the definition of safety actions and remediation interventions
CHARACTERIZATION ACTIVITIES

- Gathering of all available information on the areas of interest with respect to:
  - surrounding environment
  - soil, surface water and ground water contamination
  - marine areas, with particular care to legitimate uses and sanitary risks
- Execution of geophysical investigation surveys for bottom morphology and bottom stratigraphy
- Execution of surveys to identify remaining submerged war weapons
- Execution of sediment sampling for physical, chemical and microbiological analyses
- Execution of ecotoxicological analyses on sediments
- Execution of bioaccumulation tests on selected marine organisms
- Eventual sampling and analysis along the water column
### Sediment Sampling Strategy (Sea Bottom and Beaches)

**SITE TYPOLOGY**
- Coastal area located directly in front or sideway of the upland contaminated site
- “Partially closed” or enclosed port area
- Lagoon

### Characterization Strategy

**On bottom sediments:**
- regular grid (from 450x450 m to 150x150 m, up to 50x50 m)
  - one sampling station per grid (cores)
- transects perpendicular to the coast at fixed distance
  - from 3 to 5 sampling stations along each transect (superficial samples and/or cores)

**On beaches**
- transects perpendicular to the coast at fixed distance
  - from 1 to 3 sampling stations along each transect (cores)
- regular grid (up to about 50x50 m)
  - one sampling station per grid (cores)
• Cores of length ≥2 m and diameter ≥10 cm by means of vibrocores
• Sampling of specific sections along the sediment core
• In ports and lagoons sampling of the superficial 0-20 cm section instead of the 0-10 cm and 10-30 cm sections
• Sampling with grab or box-corer for a section representative of the superficial layer
• Execution of the analyses on a limited number of sections
• Execution of some “continuous” cores, with analyses of some elements on small consecutive sections, in order to find out the contamination trend in time, the contributions of local natural geochemical characteristics, and the reference concentration values in the area
**Superficial sample**
Sampled at the same location with grab or box-corer, for a thickness similar to the superficial section of the core (selected for the chemical analyses)

**Deep sample**
Obtained mixing the right upper and the lower sediment layer of the section selected along the core for the chemical analyses
Contaminated sediments in Italy

**PHYSICAL, CHEMICAL & MICROBIOLOGICAL ANALYSES TO BE EXECUTED ON SEDIMENTS**

**GENERAL PARAMETERS** (to be investigated on all samples)
- pH, redox potential
- Grain size, water content
- Concentration of:
  - Metals and trace elements (Al, As, Cd, Cr, Hg, Ni, Pb, Cu, Zn, V)
  - PCBs
  - Chlorinated pesticides
  - PAHs
  - Hydrocarbons (<=C12, >C12)
  - Total nitrogen and phosphorous
  - Cyanide
  - Total Organic Carbon

**SITE SPECIFIC PARAMETERS**
(to be investigated on a reduced number of selected sections)
- Concentration of:
  - Chloroaromatics
  - Phenols
  - Aromatic solvents (BTEX)
  - Organotin compounds (TBTs)
  - ............
  - Asbest
  - Dioxins

**MICROBIOLOGICAL ANALYSES**
(to be investigated on a limited number of selected sections)
- Faecal Streptococci, Salmonellas, Spores of sulphite-reducing clostridiums, Eschericia coli, Mycetes
To be executed on a reduced percentage of selected sediment samples:

- on two matrices:
  - Centrifuged sediment or whole sediment
  - Pore water or elutriate

- by means of a battery of bioassays containing at least two of the following species, selected on specific and recognized protocols:
  - *Vibrio fischeri* (Bacteria)
  - *Dunaliella tertiolecta* (Chlorophyceae)
  - *Brachionus plicatilis* (Rotifera)
  - *Corophium* spp (Amphipoda)
  - *Paracentrotus lividus* (Echinoida)
  - *Dicentrarchus labrax* (Moronidae)
Marine organisms with proper characteristics:

- filter-breeding organisms such as, for example, clams (*Mytilus galloprovincialis*)
- necto-bentonic species, selected among those who live closer to the bottom, such as, for example: *Mullus barbatus, Salpa spp, Serranus cabrilla, Mugil spp*

**Selected chemical analyses:**
- heavy metals and trace elements
- PAHs
- PCBs
- Specific parameters

(USACE, 2002)
PROCESS METHODOLOGY

Data gathering

- Identification of the characterization strategy
- Definition of protocols for sampling, analysis and data reporting
- Execution of sampling and analysis
- Data evaluation
- Identification of action levels

Data processing and reporting

- Proposals for emergency interventions and remediation actions

Case studies
On the basis of chemical and ecotoxicological criteria and taking into account the local geochemical characteristics, ICRAM has found out, for marine and lagoon sediments, within some of the contaminated sites of national interest:

- **“action levels”**: for sediments of coastal and marine water bodies, highly modified due to past or present human activities (port areas, industrial areas, etc.), in order to evaluate the sediment contamination level and the correspondent potential danger for the aquatic environment, allowing the identification of the areas where intervention actions are urgently needed.

- **“reference values”**: for sediments of coastal and marine water bodies, to have reference concentration levels compatible with all legitimate uses (aquaculture, bathing, etc.).

In line with the EC Directive 2000/60/CE for specific water bodies:

- **“GREEN” SEDIMENTS**: Concentration values lower than the action levels - no remediation intervention is needed.

- **“YELLOW” SEDIMENTS**: Concentration values for which further investigation and/or remediation interventions are needed.

- **“ORANGE” SEDIMENTS**: Concentration values for which remediation interventions need to be activated.

- **“RED” SEDIMENTS**: Concentration values for which remediation interventions need to be realized immediately.
A. Site specific PEL (Probable Effect Level);

B. International reference values (EPA, CCME, etc.)

C. Local geochemical and mineralogical characteristics

D. Toxicity, ecotoxicity, persistence, contaminants bioaccumulation tendency

E. Specific bibliography

F. Specific additional investigations, executed together with or after the site characterization process

SEDIMENT QUALITY EVALUATION: THE ACTION LEVELS

THE (SITE SPECIFIC) ACTION LEVELS ARE BASED ON:

- Continuous analyses of heavy metals
- Sequential extraction
- Bioassays
- Bioaccumulation tests
THE INTERVENTION PROCEDURE IS ACTIVATED DEPENDING ON:

- How much the parameters are above the action levels
- Which parameter is above the action levels
- Volumes and spatial distribution of sediments with concentrations higher than the action levels
- Use of the area

The intervention procedure is activated in the following cases:

- More than 10% of the samples have concentration values higher than the action levels;
- One or more parameters have concentration values higher than the following thresholds:
  - 110% of the action levels for Cd, Hg, Organotin compounds, Dioxins, PCBs
  - 150% of the action levels for Cu, Zn
  - 100% of the action level for PAHs
  - 120% of the action levels for all remaining parameters

The intervention procedure is not activated in the following cases:

- All parameters have concentration values lower or equal to the action levels
- Less than 10% (or 10%) of the samples have concentration values higher than the action levels and the above thresholds are never crossed
Contaminated sediments in Italy

LEGEND:
- Officially proposed
- To be defined
Contaminated sediments in Italy

**PROCESS METHODOLOGY**

- Data gathering
- Study
- Conceptual model
  - Identification of the characterization strategy
  - Definition of protocols for sampling, analysis and data reporting
  - Execution of sampling and analysis
  - Data evaluation
    - Identification of action levels
  - Data processing and reporting
  - Proposals for emergency interventions and remediation actions
    - Case studies
    - Case studies
CHARACTERIZATION RESULTS IN THE CONTAMINATED SITE OF NATIONAL INTEREST OF PITELLI (GULF OF LA SPEZIA)

Contaminated sediments in Italy
CHARACTERIZATION RESULTS IN THE CONTAMINATED SITE OF NATIONAL INTEREST OF PITELLI (GULF OF LA SPEZIA)

189 CORES SAMPLED
759 SAMPLES ANALYSED

ANALYSES:
- on 759 samples: pH, redox potential, grain size, heavy metals and trace elements, PAHs, PCBs, N, P, TOC, Cyanide, Hydrocarbons C>12 and C<=12
- on 220 samples: microbiological analyses
- on 160 samples: organotin compounds
- on about 80 samples: Sn, Co, chlorobenzene, chlorofenols, aromatic solvents
- on about 20 samples: dioxins and furans, asbest
- on 15 samples: ecotoxicological analyses

Executed by:
- ARPAL (n.105 cores), on request of Region Liguria
- Sviluppo Italia Aree Produttive S.p.A. (n. 65 cores), on request of Region Liguria
- La Spezia Port Authority (n.19 cores)

Contaminated sediments in Italy
“GREEN” SEDIMENTS
Concentration values lower than the action levels - no remediation intervention is needed

“YELLOW” SEDIMENTS
Concentration values for which further investigation and/or remediation interventions are needed

“ORANGE” SEDIMENTS
Concentration values for which remediation interventions need to be activated

“RED” SEDIMENTS
Concentration values for which remediation interventions need to be realized immediately
### Characterization Results in the Contaminated Site of National Interest of Pitelli (Gulf of La Spezia):

Volumes of Sediment that Needs Remediation

<table>
<thead>
<tr>
<th>Layer [cm]</th>
<th>Sediment Volume “Yellow” [m³]</th>
<th>Sediment Volume “Orange” [m³]</th>
<th>Sediment Volume “Red” [m³]</th>
<th>Total Volume per Layer [m³]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-50</td>
<td>1.770.600</td>
<td>855.150</td>
<td>458.550</td>
<td>3.084.300</td>
</tr>
<tr>
<td>50-100</td>
<td>1.123.050</td>
<td>452.350</td>
<td>253.700</td>
<td>1.829.100</td>
</tr>
<tr>
<td>100-150</td>
<td>571.900</td>
<td>139.800</td>
<td>140.700</td>
<td>852.400</td>
</tr>
<tr>
<td>150-200</td>
<td>272.700</td>
<td>93.900</td>
<td>29.300</td>
<td>395.900</td>
</tr>
<tr>
<td>200-250</td>
<td>186.150</td>
<td>49.250</td>
<td>6.100</td>
<td>241.500</td>
</tr>
<tr>
<td>250-300</td>
<td>126.600</td>
<td>59.450</td>
<td>4.250</td>
<td>190.300</td>
</tr>
<tr>
<td>Total up to 3 m</td>
<td>4.051.000</td>
<td>1.649.900</td>
<td>892.600</td>
<td>6.593.500</td>
</tr>
</tbody>
</table>
### PRELIMINARY REMEDIATION PROJECT: POSSIBLE MANAGEMENT OPTIONS

<table>
<thead>
<tr>
<th>SEDIMENTS</th>
<th>Options</th>
</tr>
</thead>
</table>
| **“RED” SEDIMENTS** | - Disposal in an upland waste site  
- (Ex situ) treatment for later disposal in CDF or coastal confined structures |
| **“ORANGE” SEDIMENTS** | - Dredging and disposal in CDF or coastal confined structures  
- Dredging and (ex situ) treatment for later reuse in civil works, according to the existing legislation |
| **“YELLOW” SEDIMENTS** | - Additional investigation and monitoring  
- In situ treatment  
- Dredging and disposal in CDF or coastal confined structures  
- Dredging and (ex situ) treatment for later reuse in civil works, according to the existing legislation |

**AN INTERVENTION HYPOTHESIS MUST:**
- be formulated in line with human and environmental protection (concentration values, risk for contamination diffusion, use of the area)  
- adopt specific mitigating measures  
- include a monitoring plan of all intervention phases in order to minimise the impacts and check the effectiveness of the mitigating measures  
- include monitoring activities of the “residual” contamination  
- foresee eventual limitations of the legitimate uses of a specific area
CHARACTERIZATION RESULTS IN THE CONTAMINATED SITE OF NATIONAL INTEREST OF PRIOLO (PORT OF AUGUSTA)
CHARACTERIZATION RESULTS IN THE CONTAMINATED SITE OF NATIONAL INTEREST OF PRI OLO (PORT OF AUGUSTA) - 1st phase

Contaminated sediments in Italy

**Hg**
- up to 30 mg/kg
- up to 651 mg/kg

**Hydrocarbons C>12**
- up to 28.430 mg/kg
- up to 61.882 mg/kg
CHARACTERIZATION RESULTS IN THE CONTAMINATED SITE OF NATIONAL INTEREST OF PRIOLO (PORT OF AUGUSTA) – 1st phase

Contaminated sediments in Italy

Hg up to 6,82 mg/ kg

Hg up to 7,76 mg/ kg

Hg up to 153 mg/ kg

Hydrocarbons C>12 up to 31.412 mg/ kg

Hydrocarbons C>12 up to 7.351 mg/ kg
CHARACTERIZATION RESULTS IN THE CONTAMINATED SITE OF NATIONAL INTEREST OF PRIOLO (PORT OF AUGUSTA) - 2nd phase
### Characterization Results in the Contaminated Site of National Interest of Priolo (Port of Augusta):

Volumes of Sediment That Needs Remediation

<table>
<thead>
<tr>
<th>Layer</th>
<th>V.I. &lt; Conc. &lt; 90% col. B [m³]</th>
<th>90% col. B &lt; Conc. &lt; 10x90% col. B D.M. 471/99 [m³]</th>
<th>10x90% col.B D.M. 471/99&lt;Conc.&lt;100x90% col.B D.M. 471/99 [m³]</th>
<th>Conc.&gt;100x90% col.B D.M. 471/99 [m³]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-50</td>
<td>4.217.046</td>
<td>4.902.490</td>
<td>728.054</td>
<td>0</td>
</tr>
<tr>
<td>50-100</td>
<td>4.361.436</td>
<td>2.551.436</td>
<td>153.277</td>
<td>17.382</td>
</tr>
<tr>
<td>100-150</td>
<td>508.455</td>
<td>299.980</td>
<td>17.400</td>
<td>0</td>
</tr>
<tr>
<td>150-200</td>
<td>122.289</td>
<td>139.020</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Tot</td>
<td>9.209.226</td>
<td>7.892.924</td>
<td>898.731</td>
<td>17.382</td>
</tr>
<tr>
<td>TOTAL</td>
<td>8.809.037</td>
<td>8.809.037</td>
<td>18.018.263 m³</td>
<td></td>
</tr>
</tbody>
</table>
Contaminated sediments in Italy

PROCESS METHODOLOGY

Data gathering → Study → Conceptual model

- Identification of the characterization strategy
- Definition of protocols for sampling, analysis and data reporting
- Execution of sampling and analysis
- Data evaluation → Identification of action levels
- Data processing and reporting

- Proposals for emergency interventions and remediation actions
- Case studies
THE PROBLEM

- Presence of large volumes of heavily contaminated sediments, and a high bioavailability of contaminants.
- European Directive about water bodies (2000/60/CE)
- Few known handling options of contaminated sediments
- Huge quantities of contaminated materials that need to be treated before a possible re-use or disposal, with high managing costs
- Poor national legislation

Costs [€/m³]

Risk

SEDNET WP 4
Contaminated sediments in Italy

DEFINITION OF INTERVENTION ACTIONS

Characterization

- No action
- Definition of possible interventions
- Additional characterization

Evaluation

Processing

Environmental monitoring

Emergency actions and/or remediation actions

In situ management options

- Limited area uses
- Confining
- Monitoring
- In situ treatment:
  - Biofarming
  - Phytoremediation
  - Capping

Ex situ management options

- Environmental dredging
  - Open water
  - CDF treatment
- Waste disposal site

Beneficial uses
SITE APPROACH (according site characterization)

Site characters
- Geology, coastal morphology, meteomarine factors, sediments balance, site seismic

Augusta harbour characters
- Harbour plan, public and private stakeholders and concessionaires, ships traffic and movement, harbour development

Land and cultural liabilities
- Landscape and environmental obligations according D.lgs 42/2004, Site use limitations for specific environmental resources

Intervention scenarios evaluation
- a) On/Off site treatment,
  b) On-site confinement,
  c) Landfill discharge
- Evaluation, comparison and “plausible” scenario

Detailed investigation
- Geothecnical characterization, Hydrodynamic and solid transport in the harbour, sediment treatment treatability tests

Containment basin localization and available volumes

Building criteria
- Containment typology, stability evaluation (seismic), sediment pressure field, drainage systems, waterproofing system, final covering

Final design guidelines and preliminary economic computation (also for economical development)
Contaminated sediments in Italy

INTERVENTION ACTION FOR PRIOLO SITE (PORT OF AUGUSTA)

- New quay basin
  - 12.7 ha
- Central dam basin
  - 68.7 ha
- South dam basin
  - 16.8 ha
Contaminated sediments in Italy

INTERVENTION ACTION FOR PRIOLO SITE (PORT OF AUGUSTA)
Main characters of containment basins

<table>
<thead>
<tr>
<th>BASIN</th>
<th>Available volume from preliminary dredging (m³)</th>
<th>Constructed basin volume (m³)</th>
<th>Reduced volume from bottom capping (m³)</th>
<th>Concrete cells available volume (m³)</th>
<th>TOTAL (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>New quay basin</td>
<td>40.840,00</td>
<td>1.014.445,00</td>
<td>- 452.660,09</td>
<td>688.759,09</td>
<td>1.291.420,09</td>
</tr>
<tr>
<td>Central dam basin</td>
<td>821.412,00</td>
<td>9.697.683,00</td>
<td>- 2.284.880,00</td>
<td>1.663.265,90</td>
<td>9.897.480,90</td>
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<tr>
<td>South dam basin</td>
<td>212.422,00</td>
<td>1.175.835,00</td>
<td>- 513.240,00</td>
<td>367.647,46</td>
<td>1.242.664,46</td>
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<tr>
<td></td>
<td>1.074.674,00</td>
<td>11.887.963,00</td>
<td>- 3.250.780,00</td>
<td>2.719.708,45</td>
<td>12.431.565,45</td>
</tr>
</tbody>
</table>
Tens and tens of “wild” discharges from industrial sites posed serious pollution problems on sediments of marine areas, directly raising health disease (up to carcinogenic and mutagenic effects!).

Over hundred of Million m³ of polluted sediments presently lie in 25 National Interest Sites, involving huge technical and economical problems.

There is a need of a systematic approach and common choises, in order to reduce the economic impact of the problem according “human health safeguard” principles.

A possible solution could be a “marriage” between environmental/health items and economical development (or re-development) of sites where pollution occurred, to transform a “free-grant burden” in a territorial opportunity.