# Evaluation of a Conceptual Site Model for Sediment Processes and Geochemical Conditions in a Large Industrial Port Facility (Augusta Bay, Sicily, Italy)

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## INTRODUCTION

Studies of sediment quality in the Augusta Bay industrial harbor identified elevated concentrations of mercury and other metals and organic chemicals in bay sediments. Previous studies primarily focused on the nature and extent of total mercury in sediments, after which a large-scale dredging remedy was proposed on an area of about 30km$^2$. The dredging remedy proposed was not based on an environmental impact analysis and engineering evaluation which considered physical, chemical, and ecological processes. While it had been demonstrated that contamination did exist, characterization of bioavailability of contaminants, indication of the source of ecotoxicity, and evidence of impact to the bay ecology had not been developed. It was unclear if any substances in the sediment posed ecological or human health risks, therefore it was premature to recommend an appropriate, safe and effective sediment remedy.

To address this deficiency, further study in 2008 focused on understanding hydrodynamic processes and the chemical and ecological conditions related to contamination in the harbor. First, a conceptual site model (Figure1) was developed to guide the work and establish a foundation to understand how mercury and other chemicals in the sediment enter the aquatic environment, how they are transported within the bay and deposited in sediment, and where routes of exposure to aquatic life and humans might occur.

On this basis, hydrodynamic monitoring, sediment transport analysis, and bathymetric and sediment profile imaging surveys were performed in representative regions of the industrial harbor. Sediment, surface water sampling, biota sampling, ecotoxicity testing and ecological risk assessment were also conducted at four stations representing different contaminant distributions, ship traffic activities, and hydrodynamic conditions.

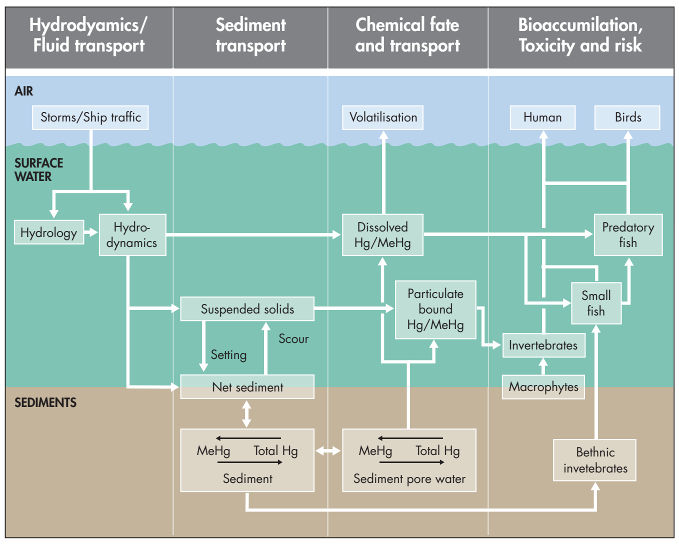


Figure 1. Conceptual site model used to guide ENVIRON work in Augusta Bay as a dynamic planning tool.

## CHEMISTRY

Sediment chemistry was investigated analyzing both mercury and methylmercury, as well as other chemicals and physical properties in several sediment samples from cores collected using vibracoring methods. Although total mercury was found in the collected sediments at concentrations ranging from 0.1 to 770mg/kg, methylmercury was only found at concentrations ranging from 0.00029 to 0.032 mg/kg.

To understand the influence of port activity on chemical concentration in the bay, surface water samples were also collected in the vicinity of ship activities and vessel movements in the bay. The water surface samples were analyzed for both mercury and methylmercury. Total and dissolved mercury were reported in some, but not all, surface water samples; concentrations ranged between <10 and 75ng/L for total mercury and <10 to 20ng/L for dissolved mercury.

## HYDRODYNAMIC & SEDIMENT TRANSPORT EVALUATION

Information on hydrodynamic conditions (eg tides, currents, wave action, and propeller wash) in Augusta Bay was developed from current meters (Acoustic Doppler Current Profiler, ADCP) deployed for 10 days at 3 locations chosen to capture both natural and vessel induced conditions. A water quality sonde was also deployed near the bed at each location to measure suspended solids, salinity, water level, and temperature. Additional current monitoring was performed using boat mounted ADCP and profiling sonde at various locations throughout the bay, including at bay entrances and behind vessels as they moved throughout the bay (Figure 2).

As further lines of evidence, sediment stability was tested using Sedflume instrumentation to measure critical shear stress and erosion rate profiles of the sediments at multiple locations.

In order to provide predictions of patterns of water column velocities and bottom shear stresses throughout areas of interest, a numerical hydrodynamic model was developed for the region using the Environmental Fluid Dynamics Code (EFDC). Modeled patterns of bottom shear stresses during vessel activity were used in conjunction with the Sedflume data to predict the potential for sediment resuspension. Measurements and predictions of propeller wash velocities combined with Sedflume measurements show potential sediment mixing to a depth of 0.3 to 1.6cm during berthing operations with the largest tugs. The simulations of sediment erosion events show that sediments are generally depositing within 200m of the ship berth. Finally, bathymetric analysis shows individual features outside of berthing regions due to ship movement and anchoring activities in deeper waters. The features represent discrete localized events that can mix surficial sediments to 19cm and are not representative of widespread transport in the bay.

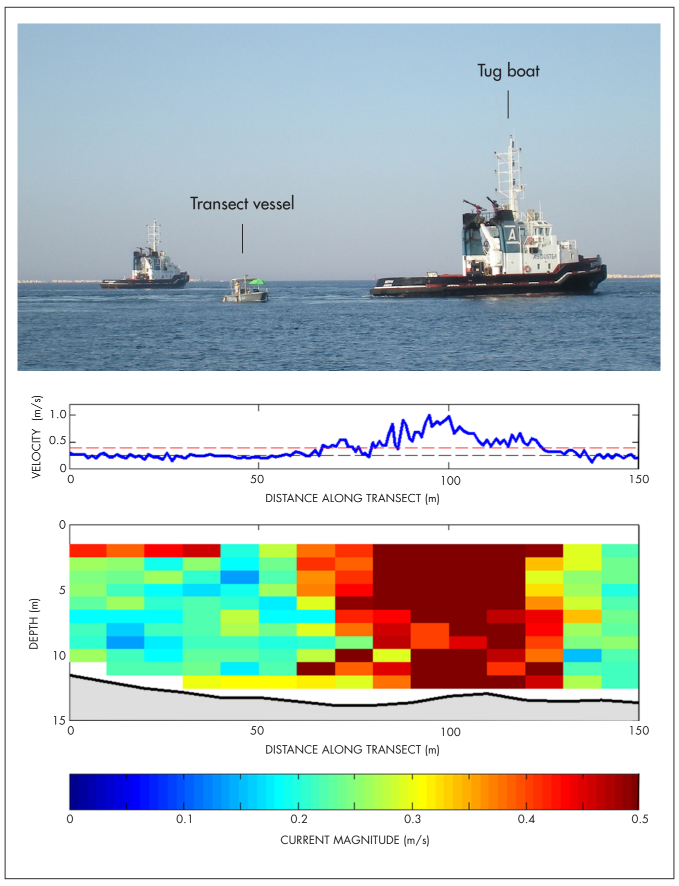


Figure 2. Velocity measurement in tug wake.

## SEDIMENT PROFILE IMAGING (SPI) SURVEY

A photographic survey of habitat and physical sediment conditions in the upper 15cm was performed for a total of 115 photo locations. Results showed that a large portion of the study area was colonized by a dense, mixed assemblage of *Caulerpa prolifera* (Figure 3) and *Caulerpa racemosa*, that stabilize the sediment bed and make it highly resistant to erosion. The study area was dominated by healthy, mature Stage 3 successional assemblages, and there was no significant difference between the successional status of benthic communities found in the reference area and those found in the site, indicating the relative health of the sedimentary habitat both in the shallow *Caulerpa* beds and the deeper soft muds.

There were only a few locations where organic loading (and possibly concurrent chemical contamination) appeared to be having an impact on benthic community structure.

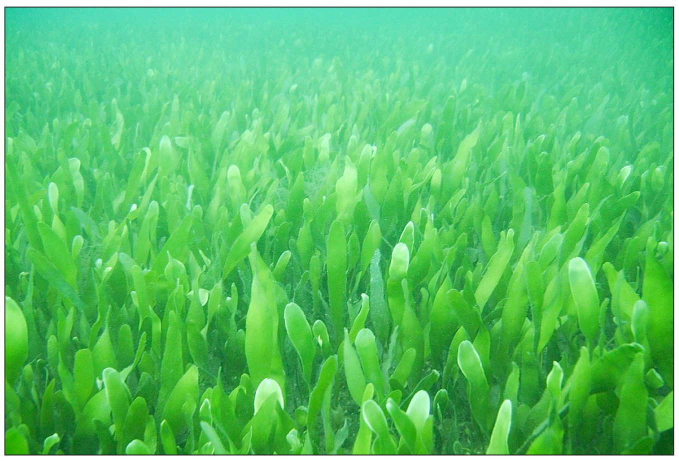

Figure 3. Image from Augusta Bay of the Native Mediterranean Common Green Algae *Caulerpa prolifera*.

## ECOTOXICITY TESTING

Ecotoxicity testing was conducted by the U.S. Army Corps of Engineers (USACE) (Vicksburg, MS USA). An investigation of several lines of evidence was conducted which includes:

- Sediment toxicity (10d) was tested on the amphipods *A. abdita*, *R. abronius* and *L. plumulosus*. Toxicity was not observed until total mercury bulk sediment concentrations exceeded 22mg/kg.
- A TIE test was conducted with different amendments using the amphipod *R. abronius*. Results suggest that multiple organic and inorganic contaminants are contributing to toxicity observed in Augusta Bay sediments. Pore water samples (collected by centrifugation of surface sediments) was also analyzed. Although high bulk sediment concentrations for mercury were observed (up to 497mg/kg), mercury concentrations in pore water were generally below ambient water quality criteria, indicting low bioavailability of mercury, while in pore water, high concentrations of PAHs and metals other than mercury were observed.
- A 28-d bioaccumulation study was conducted on polychaete worms (Neires virens). Bioaccumulation of total and methylmercury was low and tissue concentrations were below the literature concentration of 15.5mg/kg where no toxic effects are observed in polychaetes. The low tissue concentrations and low BAF for total mercury is evidence for low overall mercury bioavailability in Augusta Bay sediments.

## ECOLOGICAL RISK ASSESSMENT (ERA)

- **Benthic Invertebrate:** The Sediment Quality Triad analysis suggests that sediment chemicals are unlikely to adversely affect the benthic invertebrate community. Although sediment toxicity was observed at some locations, the effects were likely attributable to PAHs or a mixture of chemicals and physical conditions. The SPI survey revealed a healthy and mature ecological benthic community at nearly all locations in the study area; there was no evidence that benthic infauna have been adversely affected by sediment chemicals.
- **Pelagic Invertebrate:** Concentrations of PAHs, HCB, Hg and MeHg were measured in the soft tissues of both native and transplanted mussels. Mercury (0.1-1.6mg/kg, ww) were below tissue concentration thresholds reported in studies of adverse effects on growth and reproduction in limpet (a comparable mollusk species) exposed to mercury.
- **Fish:** Concentrations of PAHs, HCB, and mercury (total mercury and methylmercury) were measured in the whole body of 54 fish caught inside and outside the industrial harbor of Augusta Bay. The concentrations of mercury in fish at all locations were in the range of tissue concentrations associated with adverse effects on growth, mortality, and reproduction (0.2-0.5mg/kg, ww) reported in mummichog (*Fundulus heteroclitus*) exposed to mercury. However, mercury concentrations in fish from Augusta Bay are no higher than concentrations in fish from other areas of the Mediterranean Sea. The results suggest that, while mercury exposure to fish may be elevated in a small portion of Augusta Bay, the likelihood of chemically-induced adverse effects in Augusta Bay are no higher than other areas of the Mediterranean Sea.

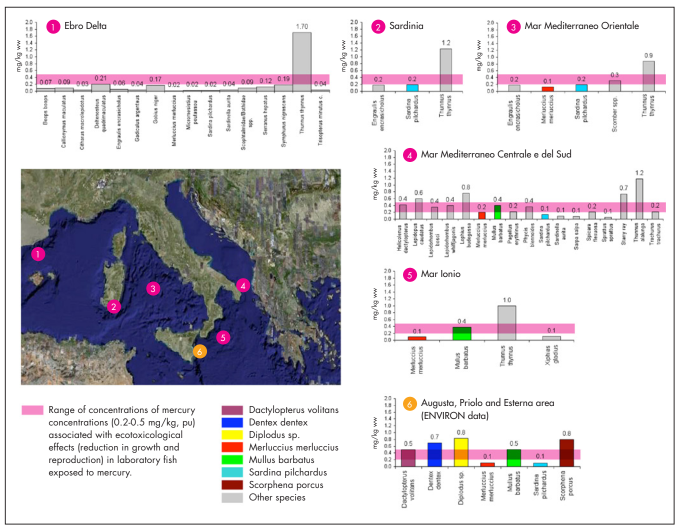


Figure 4. Concentrations of total mercury in fish in Augusta Bay and elsewhere in the Mediterranean Sea.

## CONCLUSION

Results from this work are summarized in Table 1; it is apparent that mercury in Augusta Bay does not pose a significant threat to the environment and sediment-associated mercury is tightly bound to the sediment, poses no to low toxicity to benthic organisms, and is largely not bioavailable to aquatic fauna. Furthermore, commercial shipping activities in the harbor do not significantly alter mercury conditions in the bay or create new or greater ecological risks. Therefore, the proposed large-scale dredging remedy for Augusta Bay is unwarranted, and if implemented, would destroy a complex functioning ecosystem.

Table 1. Results from the ENVIRON team investigation.

| KEY QUESTIONS | RESULTS |
|---|---|
| 1. Are mercury and other chemicals in surface sediments bioavailable? | • Bioaccumulation testing indicates limited mercury bioavailablity to infaunal invertebrates; uptake is less than expected given the high levels in some sediment.<br>• The bioavailability of mercury is low; it is not related to shipping activity.<br>• Other chemicals, particularly PAHs and certain metals, are bioavailable to infaunal invertebrates and contribute to ecotoxicity.<br>• While mercury concentrations are high at some locations, mercury binding capacity in sediments is also high. |
| 2. Do mercury and other chemicals pose unacceptable risks to human health and environment? | • No; mercury and other chemicals pose no greater risk than found outside Augusta Bay. |
| 3. Have sources of mercury and other chemicals to the bay been controlled? | • Active sources are not yet understood. |
| 4. Do buried sediments contribute mercury and other chemicals to surface sediments in quantities that cause unacceptable risks? | • Depth of sediment at risk of exposure has been characterized for the site; physical disturbances by natural forces are minimal.<br>• Ship activity and biological mixing disturb the sediment to equivalent depths (approximately 12–19cm). |
| 5. Do mercury and other chemicals in buried sediments have reasonable potential to reach the surface and become bioavailable? | • Sediment disturbance to approximately 12–19cm is possible, where mercury and other chemicals have the potential to become bioavailable. |

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