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# Case study of contaminated sediments in a harbour area

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## ABSTRACT

To deepen the water column near the docking area of a yacht club, the sediments need to be removed from a selected area to facilitate the passage of the larger yachts. Prior to dredging, the quality of the sediments needed to be determined. Sampling and analysis of a series of sediments in the proposed dredging area were performed. Two sets of samples were taken within the proposed dredging zone. The first set consisted of surface samples taken with a Birge Ekman sampler and the second set were core composite samples to reach sediments of approximately 46 cm in depth (the proposed dredging depth). Overall, the samples in the extreme regions will need to be handled with care due to contamination most likely from boat maintenance and from upstream industries. The sediments cannot be disposed of in open water. The region needs to be defined by further sampling. The middle region could potentially be disposed of in open water. In order for open water disposal to occur, samples would need to be subjected to toxicity tests.

## RÉSUMÉ

Pour approfondir le colonne d'eau d'un port de plaisance, les sédiments doivent être enlevés pour faciliter le passages des grands yachts. Avant le dragage, la qualité des sédiments doivent être déterminée. L'échantillonnage et l'analyses des sédiments dans le zone de dragage prévu ont été effectués. Le premier set consistait des échantillons de surfaces, prélevé par un Birge Ekman échantillonneur et le deuxième set était des échantillons composites d'un profondeur jusqu'à 46 cm (le profondeur de dragage proposé). Dans l'ensemble, les échantillons des extremes doivent être traités avec prudence à cause de la contamination reliée à l'entretien des yachts est des décharges industriels amonts. Les sédiments ne peuvent pas être déposés dans l'eau ouvert. Le région doit être définir avec plus d'échantillonnage. La partie centrale des sédiments pouvait être déposé dans l'eau si les tests de toxicité sont effectués et donnent des résultats positifs.

## 1 INTRODUCTION

Approximately, 900 million cubic meters of sediment are contaminated. These cause potential risk to fish, humans, and animals that eat the fish (USEPA 1998). The rate of survival, immunity to diseases and growth of fish such as salmon may be affected by exposure to contaminated sediments early in life (Varanasi et al. 1993). Although an essential and valuable resource in river basins and other aqueous environments sediment, however, have received much less attention from researchers, policy-makers, and other professionals than other components. Due to the large biodiversity living in the sediments, they are a source of life and resources for humans as construction materials, sand for beaches, and farmland and wetland nutrients.

Due to the close contact of sediments with the water environment, there is a need to develop a better understanding of the sediment-water environment. Better management practices due to their potential impact on human health and the environment are also required.

Pollution enters the aquatic environment via point and diffuse sources. Agricultural, urban and industrial activities, spills and accidents contribute to the pollution. Manufacturing and energy production, urban centres, municipalities, service industries, airborne and groundwater transported contaminants all contribute contaminants to the sediments. Effluents are either surface runoffs that discharge into the rivers, lakes and

groundwater or are point sources from municipal, industrial or other sources.

Sediment dredging is extensively used for maintenance of rivers, harbors, canals and other areas to ensure boat navigation. For example, in France more than 19 Mm<sup>3</sup> of sediments are dredged to maintain the Seine, Garonne and Loire estuaries (Chamely 2003). This activity increases the levels of suspended matter into the water which is subject to transport. In addition, dredged sediments which can contain high levels of contaminants that must be either landfilled or ocean disposed. Heavy metals including arsenic, cadmium, copper, mercury, nickel, lead, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), pharmaceutical and bacterial and viral contaminants are often found in the harbor sediments.

Transport of the sediments over long distances may also be required for their disposal. There is also the potential for return of the sediments to the water due to runoff or leaching of the contaminants. Dredging is often delayed due to management problems but this can lead to further risks. Harbor sediments, in particular, can be contaminated. Recently, Sector 103 of the Port of Montreal was dredged to remove the contamination from heavy metals and hydrocarbons. In a Great Lakes harbor, navigational dredging has not been performed since 1972 since there are no economically and environmentally feasible ways to manage the dredged sediment (USACE 1995). Increased levels of sediment restrict the entry of ships and loading/unloading is becoming problematic. All

of these problems increase transportation costs and decrease shipping capacity.

A yacht club would like to deepen the water column near the docking area of the yachts. To accomplish this, they would like to remove the sediments (over an area of approximately 1000 m<sup>2</sup>) to facilitate the passage of the larger yachts. Dredging had not been performed for at least 10 years. Prior to dredging, an evaluation of the quality of the sediments was required. Sampling and analysis of a series of sediments in the proposed dredging area were performed. The objectives of this paper are thus to evaluate the state of the sediments and to make recommendations regarding further steps.

## 2 MATERIALS AND METHODS

### 2.1 Sediment Sampling and Characterization

Two sets of samples were taken for the area of a marina in the province of Quebec within the proposed dredging zone according to the *Sediment Sampling Guide for Dredging and Marine Engineering Projects in the St. Lawrence River (Environment Canada 2002)*. The first set were surface samples taken with a Birge Ekman sampler and the second set were core composite samples that reached sediments of approximately 0.5 m in depth (the proposed dredging depth). The samples described in this paper represent the first and second sets.

Surface sediment samples were collected (Fig. 1) by a surface sediment sampler. It was a Birge-Ekman grab type sampler from Wildco, Wildlife Supply Company. The sampler was lowered inside the water until it reached to the sediments. The messenger (in this case, a heavy object which slides along the string, attached to the sampler) was released thus releasing also the spring so that the hinged side can close and grab sediment samples.

Core sediments were collected using a core tube sampler inserted into the sediment bed along the yellow line (Fig. 2) using a sediment core device from a boat. The sample locations were noted for each sample from GPS readings. The collected sediments were then carried to an ice cooled box inside the car and transferred to the laboratory for

### 2.2 Analytical Parameters

The analytical parameters were selected according to Environment Canada and Ministère du Développement durable, de l'Environnement et des Parcs du Québec (2007) and included:

- Metals and metalloids (arsenic, chromium, copper, mercury, nickel, lead and zinc)
- Polycyclic chlorinated biphenyls (PCBs)
- Polycyclic aromatic hydrocarbons (PAHs)
- Grain size distribution
- Loss of ignition to represent total organic carbon (LOI)
- Petroleum hydrocarbons (C10-C50).



Figure 1. Surface sediment sample points from the first set of samples.

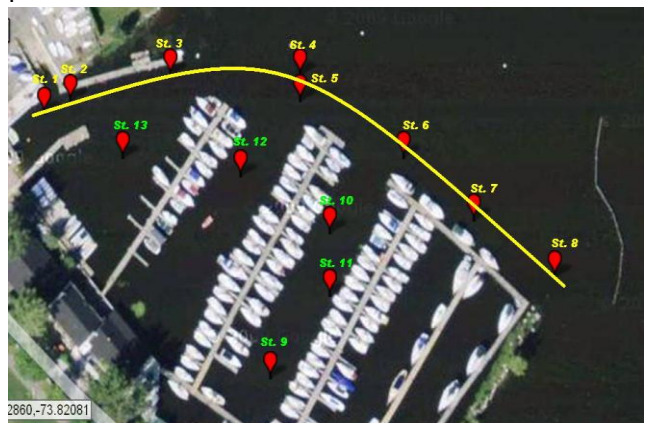


Figure 2. Locations of the core sediment samples. Samples are numbered accordingly. The yellow line represents the area of proposed dredging

Samples were analysed for particle size distribution, pH and loss of ignition (550°C). The particle size distribution for the sediment samples was performed using the laser scattering analyzer (HORIBA, LA- 950V2). The diameters at which there were 60%, 30% and 10% of the sediment particles, D<sub>60</sub>, D<sub>30</sub> and D<sub>10</sub>, respectively were determined. The coefficient of uniformity, C<sub>u</sub> and, C<sub>c</sub>, coefficient of gradation were calculated using the following equations:

$$C_u = \frac{D_{60}}{D_{10}} \quad [1]$$

$$C_c = \frac{(D_{30})^2}{D_{10} * D_{60}} \quad [2]$$

Both C<sub>u</sub> and C<sub>c</sub> will be 1 for a single-sized soil C<sub>u</sub> > 5 indicates a well-graded soil

$C_u < 3$  indicates a uniform soil  
 $C_c$  between 0.5 and 2.0 indicates a well-graded soil  
 $C_c < 0.1$  indicates a possible gap-graded soil

All samples were highly uniform in size and mainly in the fine silt range (2 to 60 microns) (Fig. 3).

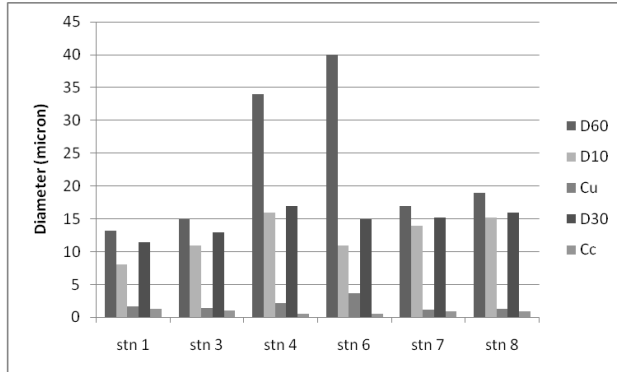


Figure 3. Particle size analysis of core sediment samples

Sediment pH was measured using a Fisher Scientific pH meter model AR25, dual channel pH/Ion meter. Sediments and de-ionized water at a ratio of 1:10 were taken. pH was found to be mainly in the range from 7.1 to 7.8. The loss of ignition (LOI) was calculated according to ASTM D2974-00 method. Oven dried (105°C) sediments were placed in furnace at 550°C for 4 hours. The sediments were cooled down in a desiccator and their weights were measured using a digital scale. The LOI was calculated based on the following equation:

$$LOI = \frac{W_{105^{\circ}C}}{W_{550^{\circ}C}} \times 100 \% \quad [3]$$

Fig. 4A shows the analysis of the surface samples which indicates a high organic content due to growth of algae and other plant material within the water column. Due to the high degree of algae, the algae had to be removed from the samples before analysis by sieving. Fig. 4B shows the LOI and pH for the core samples. Since the algae and plant growth was not as evident it was not removed prior to LOI analysis. Therefore, the LOI content is higher for the core samples in some cases than the surface samples.

### 2.3 Tests for Resuspension of Sediments

A resuspension experiment was done to simulate an alternate method of remediation. Sediment and water samples were prepared at a 1:25 ratio and transferred to a 500 mL beaker, for aeration and stirring. For resuspension with aeration, air was passed (from the air-line in the laboratory) inside the water. Before entering the air directly into the sediment-water mixture, it was passed through a sparger to distribute the air flow evenly inside water. Air flow rate was not measured but it was controlled time to time so that the water-sediment mixture does not overflow or squirt outside of the beaker. Resuspension without aeration was performed without air. The magnetic stirrer was turned on initially for mixing of

the sediments and water. For both tests with and without aeration, the sediments were allowed to settle down naturally under gravity and total suspended solids in the overlying water was measured at different time intervals (1h, 6h, 18h, 24h, 48h.....216h).

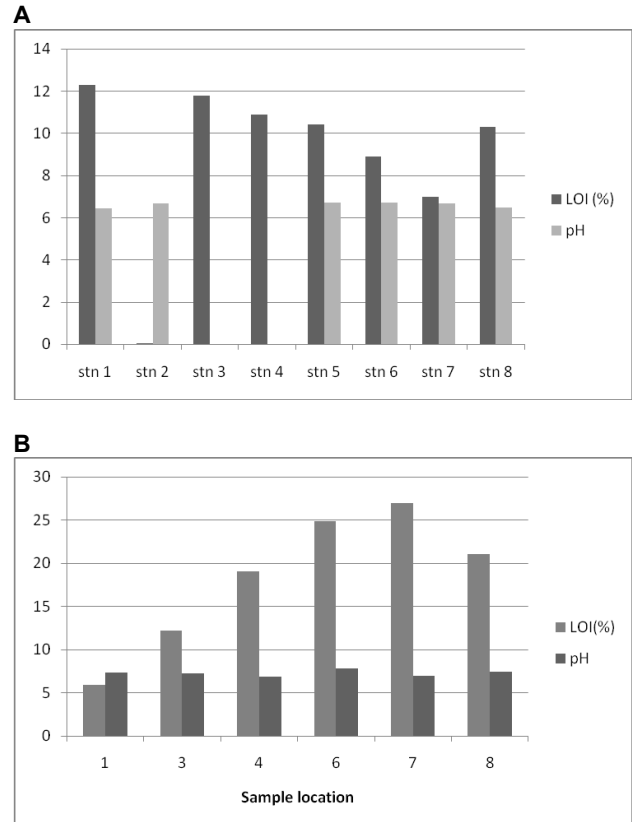


Figure 4. Results for LOI and pH of the (A) surface and (B) core sediment samples. pH was not determined for stn 3 and 4 surface sediment samples.

## 3 RESULTS AND DISCUSSION

According to the guidelines (Environment Canada and MDDEP, 2008), dredged material requiring disposal should be managed according to the class. The presence of one substance exceeding the criteria requires that the sediments be classified according to the class of the highest level contaminant. The occasional effect level (OEL) and the frequent effect levels (FEL) are used for classification purposes. For substances above the FEL (Class 3), open water disposal is prohibited and the sediments must be treated or contained safely. For substances about the OEL (Class 2), there is the probability of detecting adverse biological effects. Open water disposal is possible if toxicity tests indicate that the sediments will not adversely affect the environment. Class 1 is below the OEL and indicates that there is little probability of adverse biological effects and open water

disposal is possible, provided it does not deteriorate the environment.

### 3.1 Surface Sediments

Results for the surface sediments samples (2 to 7) are shown in the A parts of Figures 5 to 7. It can be seen for Sample 2, that the metal concentrations (Fig. 5A) for copper and lead were elevated but did not exceed the FEL. Many of the other metals were below detection level. However, copper in sample 3 and lead in sample 5 exceeded OEL. Zinc levels for samples 2, 3, 5 and 6 exceeded OEL levels. It is difficult to make conclusions based on these XRF analyses.

The PCBs and PAHs were analysed at an outside lab. The excessive amounts of algae and plants were removed as much as possible before sending for analyses. Several PAHs (Figs. 6A and 7A) such as pyrene exceeded FEL levels for sample 2. Samples 3 and 6 showed PAH levels that exceeded OEL. For sample 4, some PAHs slightly exceeded FEL (dibenzo[a,h]anthracene, phenanthrene, chrysene and acenaphthylene). However, pyrene levels were double the FEL. Sample 5 showed that OEL levels were exceeded with the exception of pyrene which was slightly above FEL. Sample 7 showed levels of benzo[a]anthracene that slightly exceeded FEL and pyrene levels equal to FEL. PCB levels for samples 4, 6 and 7 exceeded OEL levels. C10-C50 content of the sediment samples were all at or below 100 mg/kg.

### 3.2 Core Sediments

Results for the core sediment samples are shown in the B parts of Figures 5 to 7. It can be seen for Sample 1, for the PAHs, pyrene levels equal FEL and levels for dibenzo[a,h]anthracene and benzo[a]anthracene exceed FEL. Other PAHs, total PCBs, copper, lead and zinc levels exceed OEL. Thus it is considered as class 3 and open water disposal is prohibited.

For the core sediment sample 3 (Fig. 5B), levels exceeds OEL for various substances in the metal (arsenic, cadmium, chromium and zinc), total PCBs, and for numerous PAHs. The benzo[a]anthracene level slightly exceeds FEL levels but could be considered as equal to FEL. Samples 4 and 6 (Figs. 5B to 7 B) exceed the OEL levels for various metals and PAHs. Therefore, samples 3, 4 and 6 can be classified as class 2. The C10-C50 contents of the sediment samples were all at or below 100 mg/kg.

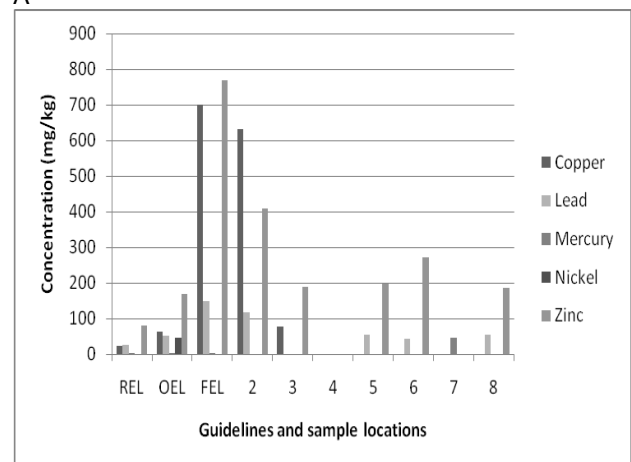
For core samples 7 and 8, chromium levels exceed FEL. In the case of chromium, natural concentrations in the clay can be considered. The ambient levels for Lake Saint-Louis are considered to be 93 mg/kg. This level is considered to be the natural level in Lake Saint-Louis. These natural levels are higher than the OEL levels and are thus considered as the non-contaminated levels. The PCBs FEL levels are exceeded for sample 7 and this sample is thus considered class 3. Most of the PAHs for samples 7 and 8 exceed OEL. Sample 8 can be considered as Class 2 despite the high levels of chromium due to the natural levels in the Lake Saint-Louis sediment. For the surface sediment sample 7,

pyrene levels equal FEL. Several other PAHs in samples 6 and 7 exceed OEL levels. The PCBs levels were higher in these samples also than the other surface sediment samples.

Overall, it can be noted that the sediments are more contaminated in the low number samples and the higher number samples. This is most likely for two different reasons. Samples 1-3 are located near the visitor's dock. This area is used for boat maintenance. In the past, various paints have been applied to boats which contain in particular various metals such as copper and lead. Sediment samples in this area exhibited higher contents of these metals than in other areas. Various PAHs were also much higher in this area as well. This is most likely due to other maintenance activities in this area. No dredging had been performed for more than 10 years.

In the outer section (samples 7 and 8), levels of various contaminants were also elevated. This area is an inlet for the water flow from the St. Lawrence River. Although some of the sediment content can be contributed to the natural levels for metals such as chromium, it is highly likely that many of the contaminants originate from the industrial discharges upstream that have been transported downstream over time.

A



B

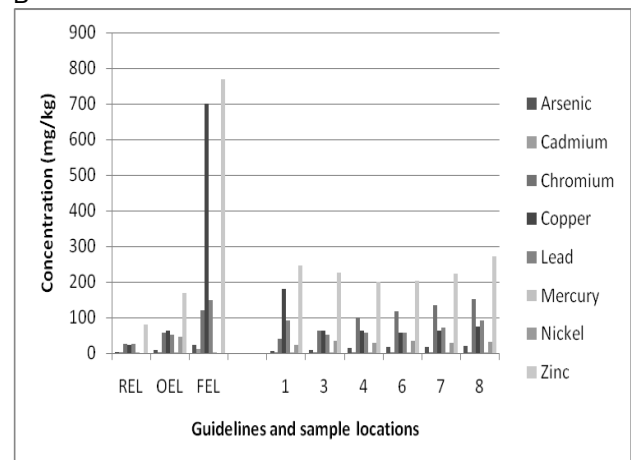


Figure 5. Guideline values and metal contents of the surface (A) and the core (B) sediment samples

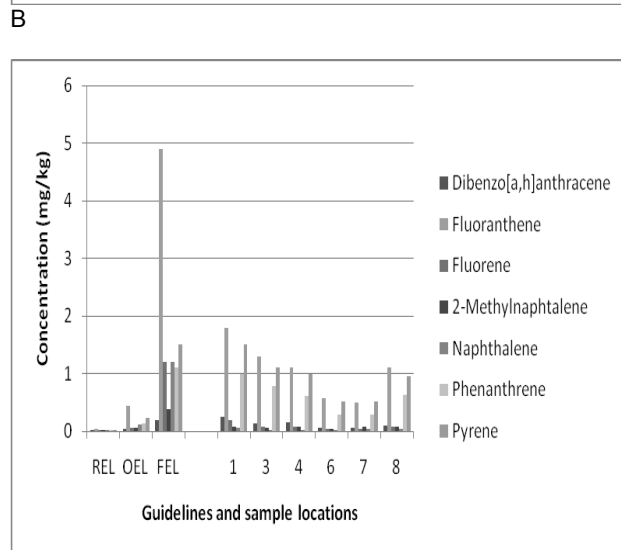
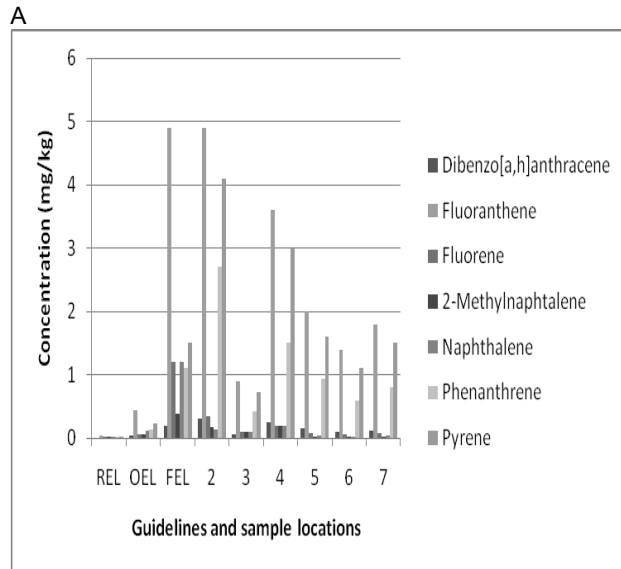


Figure 6. Guidelines and various PAH contents of the (A) surface and (B) core sediment samples

### 3.3 Resuspension tests

Figure 8 illustrates the time series analysis of aerated and non-aerated sediment samples. For both cases, resuspension resulted in a substantial initial increase upon mixing or aeration and then a decrease in TSS within 24 hours due to gravitational settling. It is desirable to have a substantially high TSS. The larger particles would settle leaving the higher organic and small particles suspended. This fraction would then be removed by pumping as indicated in Figure 9. The suspension would be dewatered by filter bags leaving a relatively low water content of sediment for disposal. Therefore according to these initial tests, the filtration would need to be performed within 24 h to remove the suspended solids.

The resuspension with aeration seemed to be more effective.

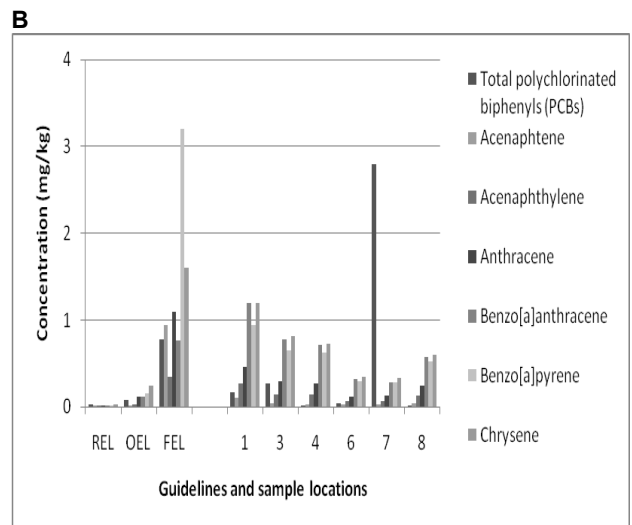
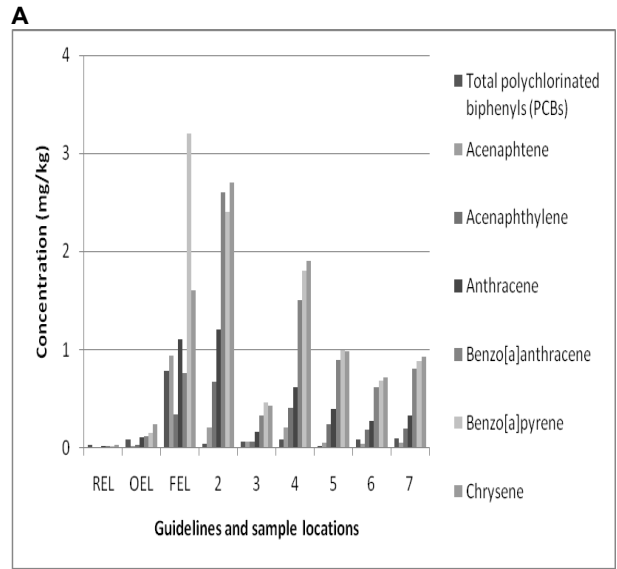


Figure 7. Guideline values, total PCBs and selected PAHs contents of the (A) surface and (B) core sediment samples

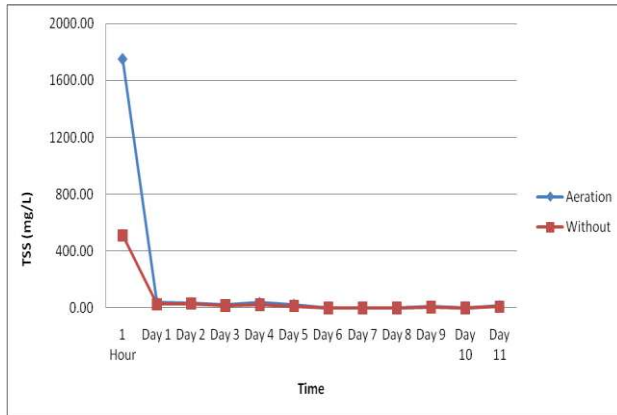


Figure 8. Effect of time on TSS of sediments after aeration or mixing

The study of resuspension was a lab scale, but could be employed in the case of the harbour area. An air-water jet can be used to aerate the sediments and at the same time resuspend the sediments. This technology is being pilot tested in Japan, and has been developed in Tokai University, Japan (Mulligan et al. 2010). After resuspension, the smaller more contaminated sediments remain in suspension and then are removed from the water column by a floating filtration unit. The removed sediments that are dewatered can be disposed of as required.

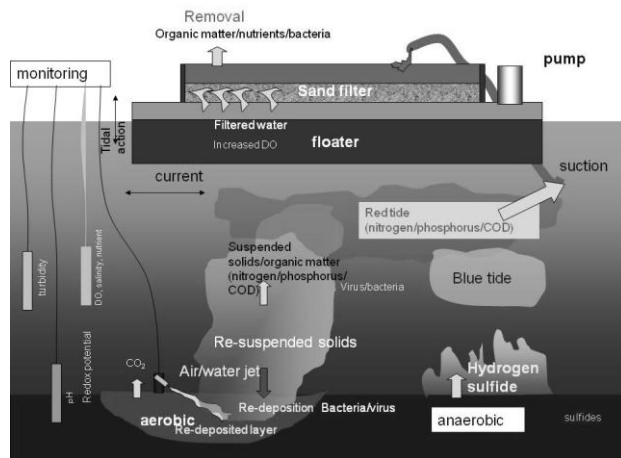


Figure 9. Resuspension of sediments followed by filtration to remove contaminated sediments (Mulligan et al. 2010).

#### 4 CONCLUSIONS

Surface and core sediment samples were taken at a marina. Only core samples were considered for regulatory purposes due to the interference and difficulties with organic matter in the surface sediment samples. This caused excessive delays in sending the samples to the external laboratory. XRF analyses were not sensitive enough for the levels to be considered for many of the metals such as arsenic and mercury. The surface samples were only used as a preliminary

evaluation. They indicated that some samples particularly near the shore could be more contaminated than other samples. Samples 4 and 7 exhibited PAH levels higher than FEL.

The core samples in the extreme regions, 1 and 7, can be classified as class 3 and will need to be handled with care. They cannot be disposed of in open water. The precise region is not known and would need to be defined by further sampling. The middle region (3 to 6 and the end region 8) are classified as Class 2 and could potentially be disposed of in open water. Toxicity and possibly leaching would be required. It was estimated that dredging would cost in the order of \$140,000 that would have to be born by the club members. Alternative approaches for less costly remediation are being investigated such as the resuspension technique.

#### ACKNOWLEDGEMENTS

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