How to Document the Effect of Sediment Remediation?

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Contamination History
Brominated flame retardants

Concentration PBDE and HBCD (ng/g)

Concentration PCB (ng/g)

Depth (cm)

- Tri-HeptaBDE
- DecaBDE
- HBCD
- PCB
Historical deposition rates

Particle Deposition Near Oslo Harbour Coast (μg/m²y)

- HBCD
- Triclosan
- PBDE
- PCB-7
- CP
- PAH-12
Finding solutions for contaminated sediments

Natural Recovery

Dredging

In situ treatment

Capping

Treatment

Disposal

Passive

Active

Separation

Chemical

Thermal

Biological

On land

Near shore

Shallow water

Deep water
Remediation effect
Remediation effect

![Graph showing the comparison between Contaminant transport (g/yr) over Time (years) with and without Remediation. The graph highlights the Period of Remediation and Period of Recovery with and without Remediation.]
Sediment classification

- Generic risk assessment
- Standard sediment
- Default fjord/harbour
- Visualization of result
Total concentration in sediments

Sequestration:
- Strong sorption to coal tar/black carbon
- Reduced porewater concentration

\[
\log K_{\text{TOC}} = 0.98 \log K_{\text{OW}} - 0.32
\]

\[
\log K_{\text{TOC}} = 1.23 \log K_{\text{OW}}; r^2 = 0.889
\]

Breedveld et al. ES&T, 2007
Total concentration in sediments

Sequestration:
• Reduced flux
• Reduced uptake in benthic organisms

Cornelissen et al, ET&C, 2006; ES&T, 2006
Inputs and Outputs of Contaminants in a Fjord

**Input**
- polluted air
- urban runoff
- river discharge
- sewage

**Particulate Settling**
- $C_{aerosols}$

**Free Flux**
- $C_{air}$

**Output**
- atmospheric
- oceanic
- sediment burial

**Input**
- polluted air
- urban runoff
- river discharge
- sewage

**Output**
- atmospheric
Sediment traps

- Quantity and quality of sediments in the water column
- Sedimentary transport
- Indication of future sediment quality
Measuring All Phases With One Passive Sampler
Passive sampling – polyoxymethylene (POM)

- Time integrated measurements
- 2-5 weeks to equilibrium in the field
- Free concentrations
- Dissolved contaminants at low levels < 0.1 pg/L

Photo: DNV
Where are the Water Contaminants Coming From?

Air: source of PAH in surface water

Sediment: source of PAH in deep water

Atmospheric PAHs from traffic (automobile and boat) are a major source of PAHs.

Arp et al. 2009, Havkyst Project 178141
Fluxes of PCBs near Oslo Harbor

Air: near equilibrium with water surface, but not for all PCBs

Sediment: major source of PCBs to water phase

Some PCBs still coming in from airphase after ban, but sediments are important source

Arp et al. 2009, Havkyst Project 178141
Measuring flux from sediment to water
Benthic diffusion chamber with an "infinite sink"

Eek et al. ES&T, 2010
Flux chamber principles

infinite sink: SPMD or silicon

Diffusive boundary layer inside chamber

Diffusive boundary layer DBL outside

Sediment

Concentration

Z

C₀

Cpw >> Cw

Extraction

Chemical analysis by GC-MS
Capping of contaminated sediments (example: Oslo harbour)

Eek et al, Chemosphere, 2008
Fjord model

- Fate model
- Monitoring data
- Bayesian calibration
- Predicting long-term effect

Example:
Drammensfjord

Arp et al. 2012
“When will the TBT go away” (in prep)
How to document the effect of sediment remediation?

- Total sediment concentrations are not expressing activity of contaminants
- Passive sampling can measure activity (porewater/surfacewater)
- Flux measurements can quantify contribution to marine environment
- Fate modelling allows prediction of the future state