A photograph of a pink starfish resting on a dark, muddy sediment surface. The starfish is positioned in the upper left quadrant of the frame. The sediment is dark grey to black, with some small, light-colored debris scattered throughout. The starfish has five arms and a central disk, with a slightly textured appearance. The overall scene suggests a contaminated or polluted environment.

# Challenges in remediation of contaminated sediments in Norway

Gijs D. Breedveld, Gerard Cornelissen, Espen Eek,  
Amy M.P. Oen, Arne Pettersen, Anne Kibsgaard and  
Audun Hauge

Norwegian Geotechnical Institute

# Norway

- Area: 324000 km<sup>2</sup>
- Population: 4.6 mill.
- Coastline:
  - 2650 km netto,
  - with fjords 25000 km,
  - with islands 57000 km





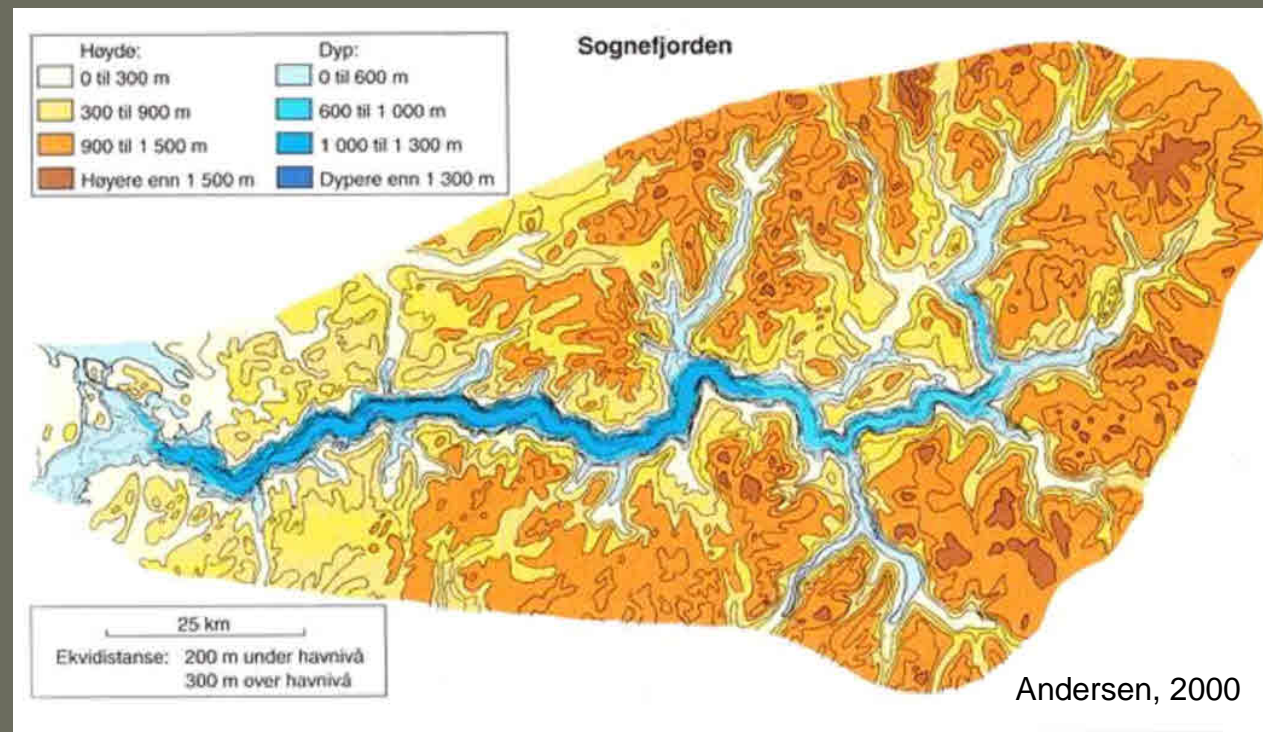
Fjellanger Widerøe Foto AS

NGI

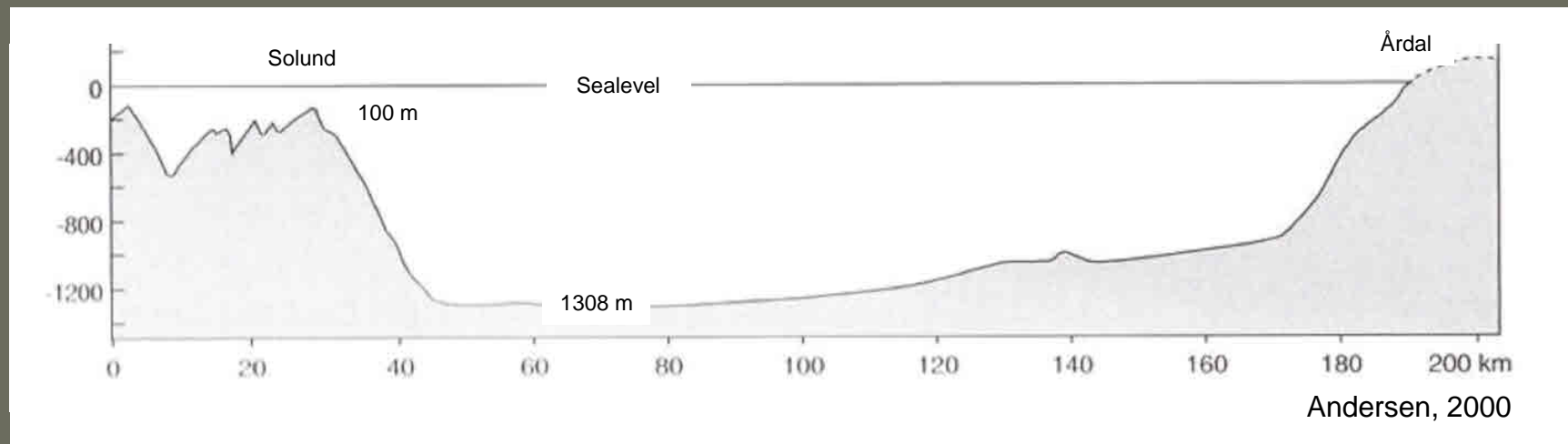
# Sognefjord



# Sognefjord - bathymetry



# Sognefjord - length profile



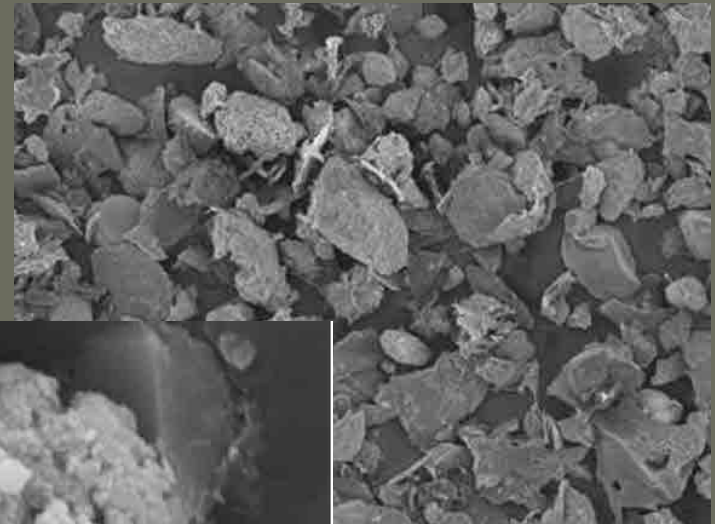
# Contamination History

- Industrial sources
- Urbanisation
- Wastewater treatment
- Traffic



# Contamination History

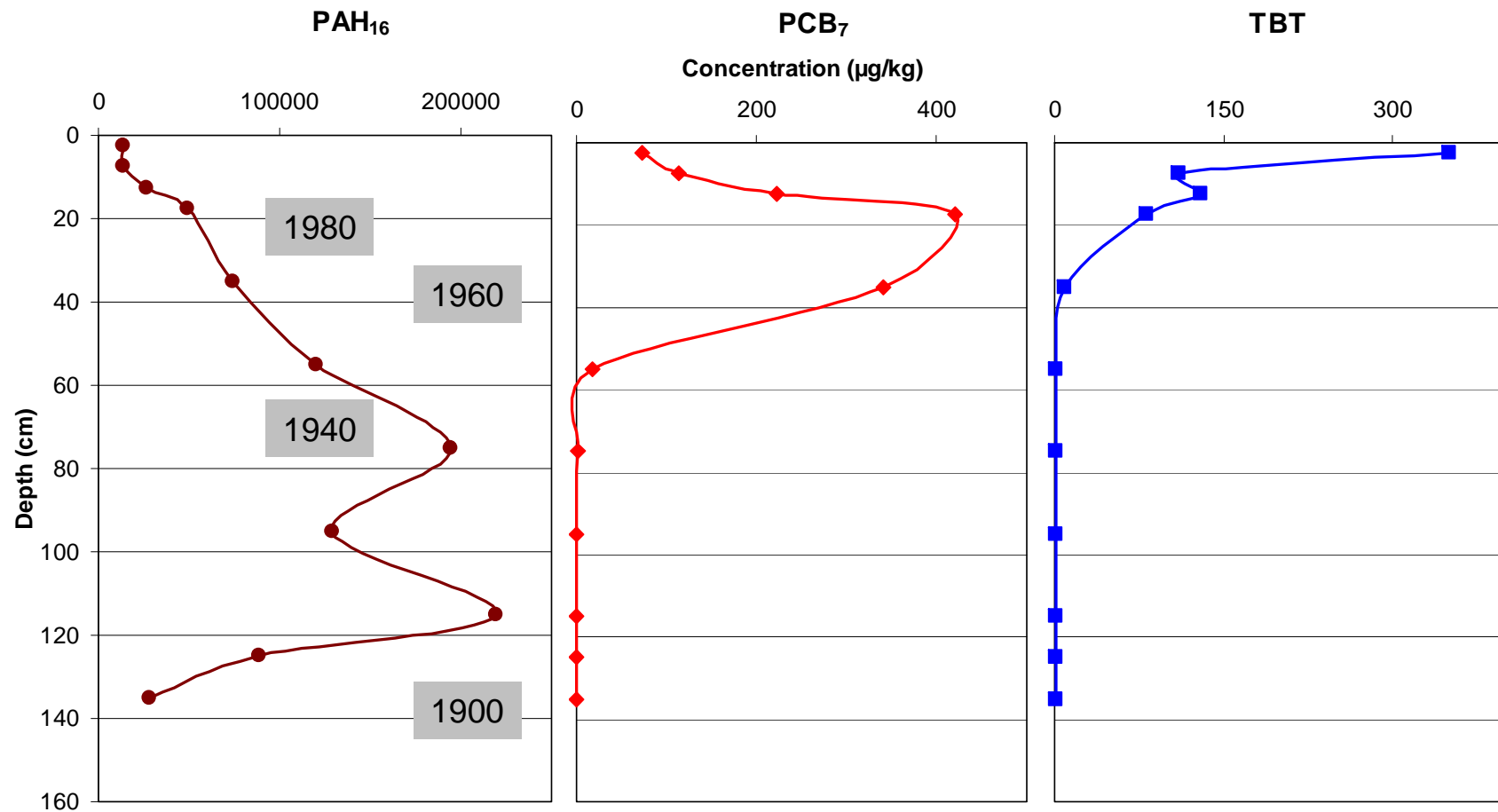
- Industrial sources
- Urbanisation
- Wastewater treatment
- Traffic



Oen et al. , Env. Poll., 2006



# Contamination History



## Sink or Source

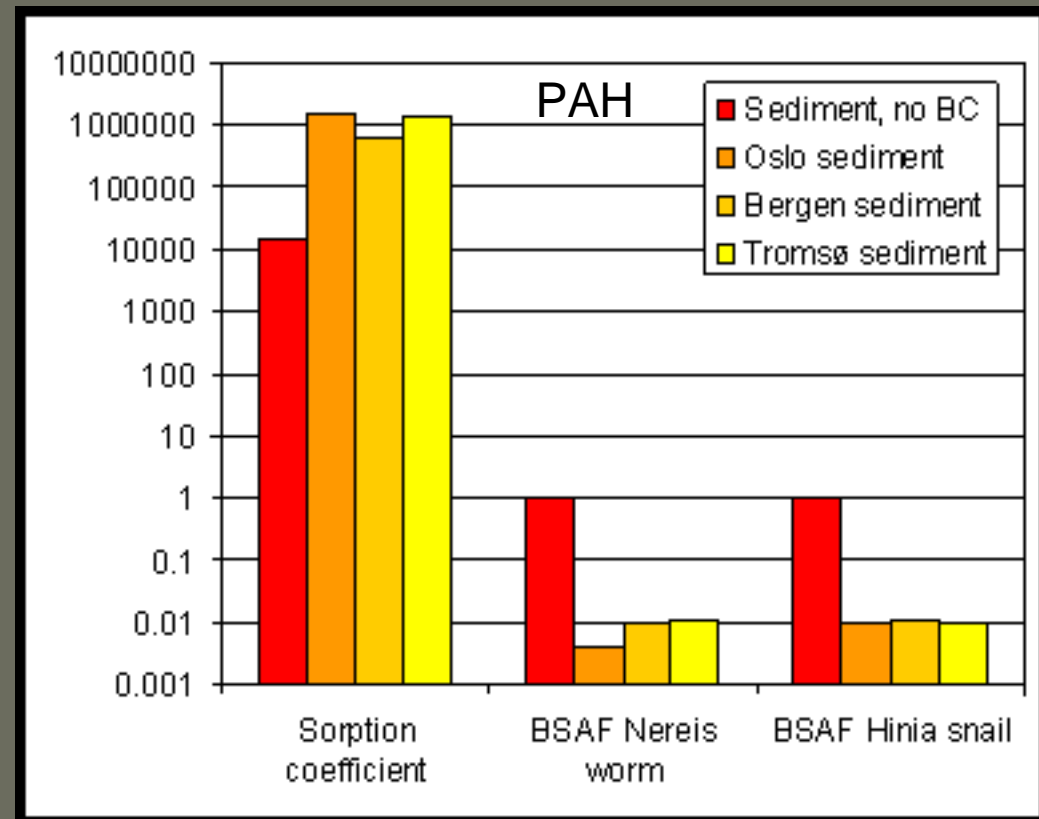
- Sequestration
- Activity ratios
- Fluxes and direction



Breedveld et al. ES&T, 2007

## Sink or Source

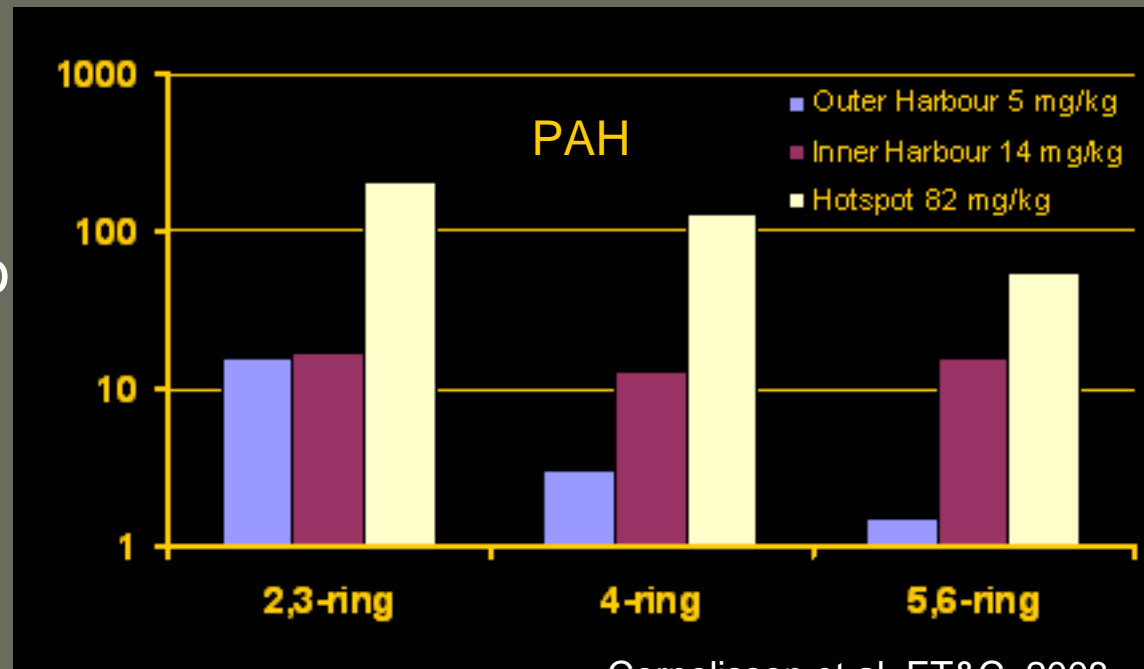
- Sequestration
- Activity ratios
- Fluxes and direction



Cornelissen et al, ET&C, 2006; ES&T, 2006

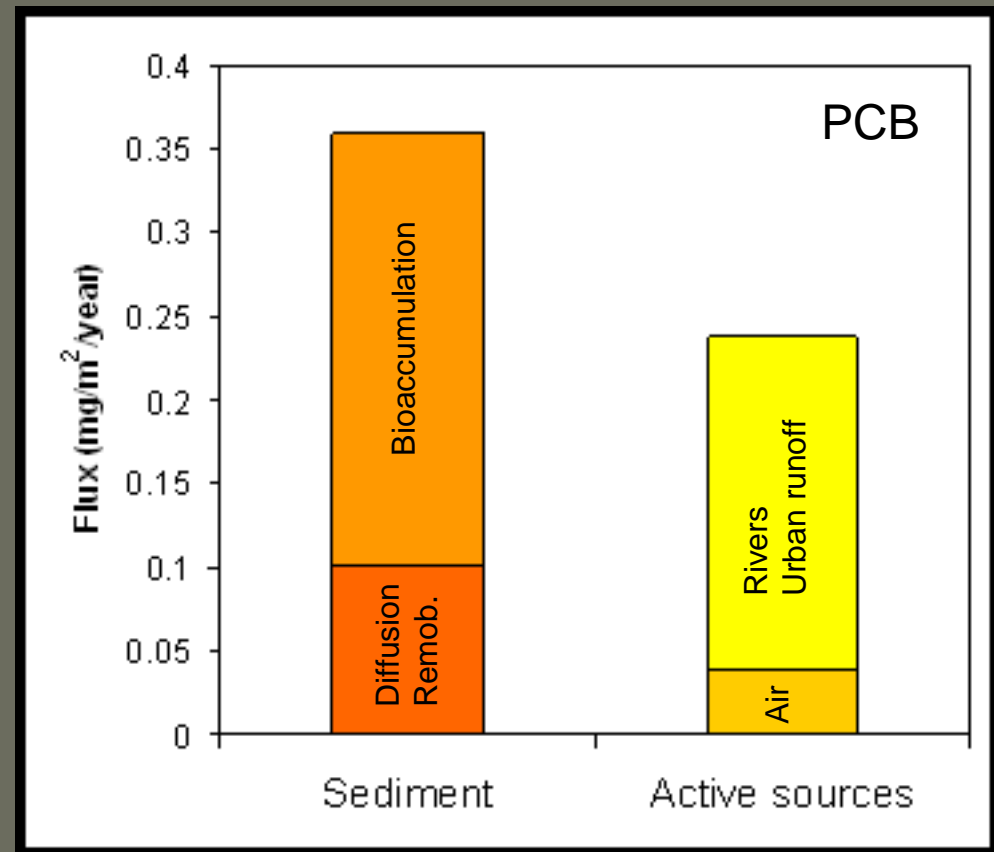
## Sink or Source

- Sequestration
- Activity ratios
- Fluxes and direction



## Sink or Source

- Sequestration
- Activity ratios
- Fluxes and direction



Schaanning et al., NIVA, 2005

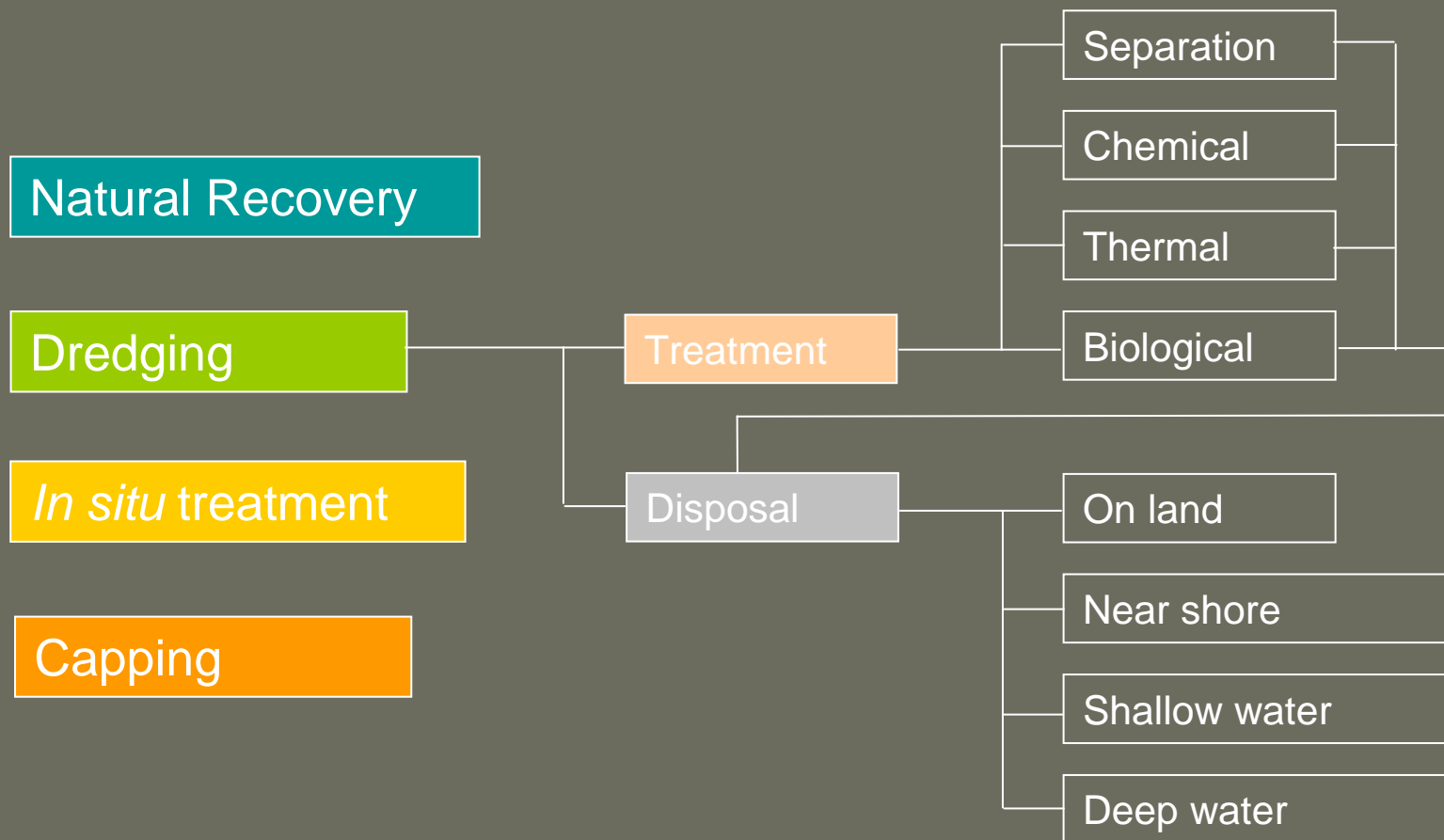
## Sink or Source

- Sequestration
- Activity ratios
- Fluxes and direction



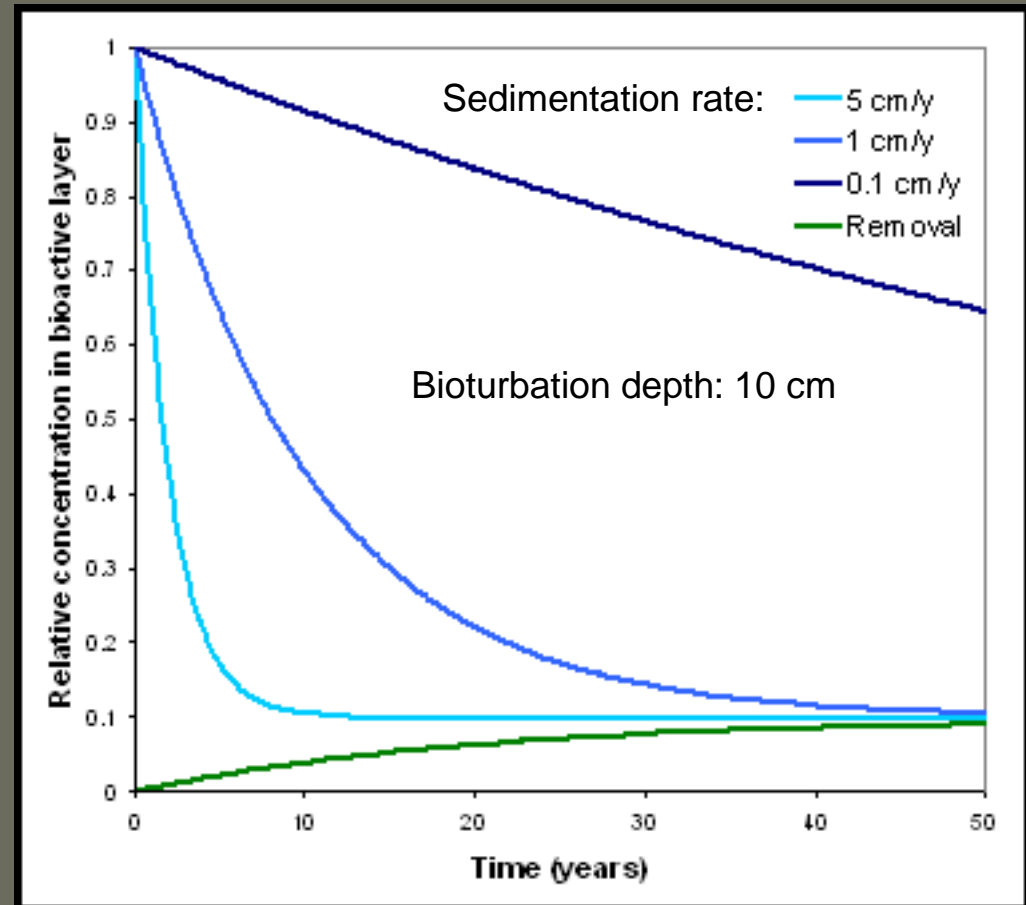
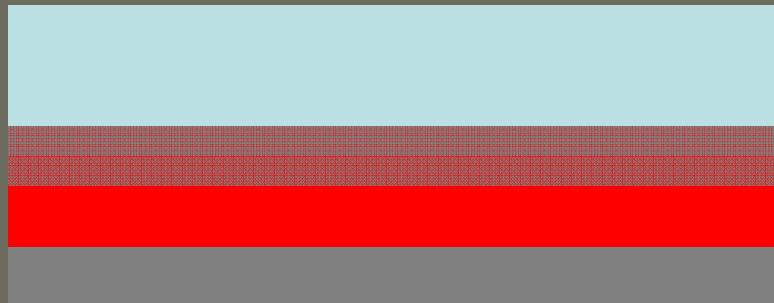
Eek, PhD thesis UiO, 2008

# Finding solutions for contaminated sediments



# Natural Recovery

- Remove sources
- Resedimentation
- Bioturbation



EEK, PhD thesis UiO, 2008

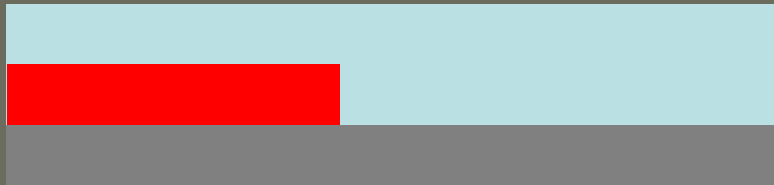


# Removal

- Dredging
- Remove the complete layer of contamination
- Prevent resuspension



Foto: Agder Marine





# New Opera house and F 18 road tunnel

18 000 tons of sediments



## Near shore disposal

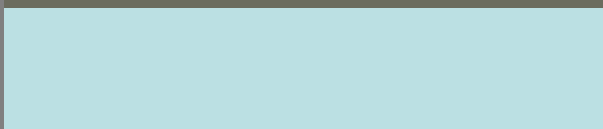
- Limited transport
- Land reclamation
- Capping effect
- Consolidation time
- Monitoring of runoff





# Solidification/Stabilisation

- Ideal binder:
- improves strength
- reduces permeability
- reduces leaching

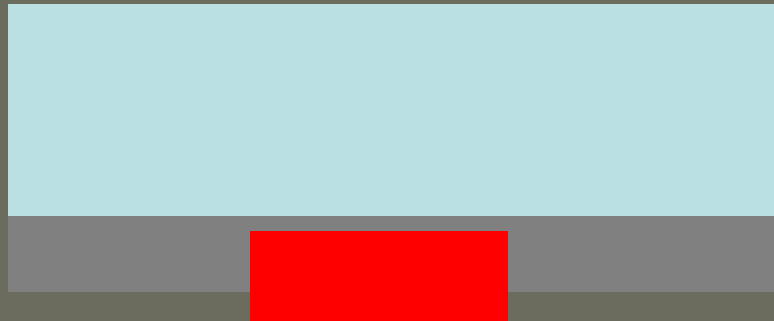


# Trondheim harbour - stabilisation of CDF



## Confined aqueous disposal

- Storage below water surface
- Reduced area of exposure
- Capping after deposition
- Reduced contact with benthic organisms



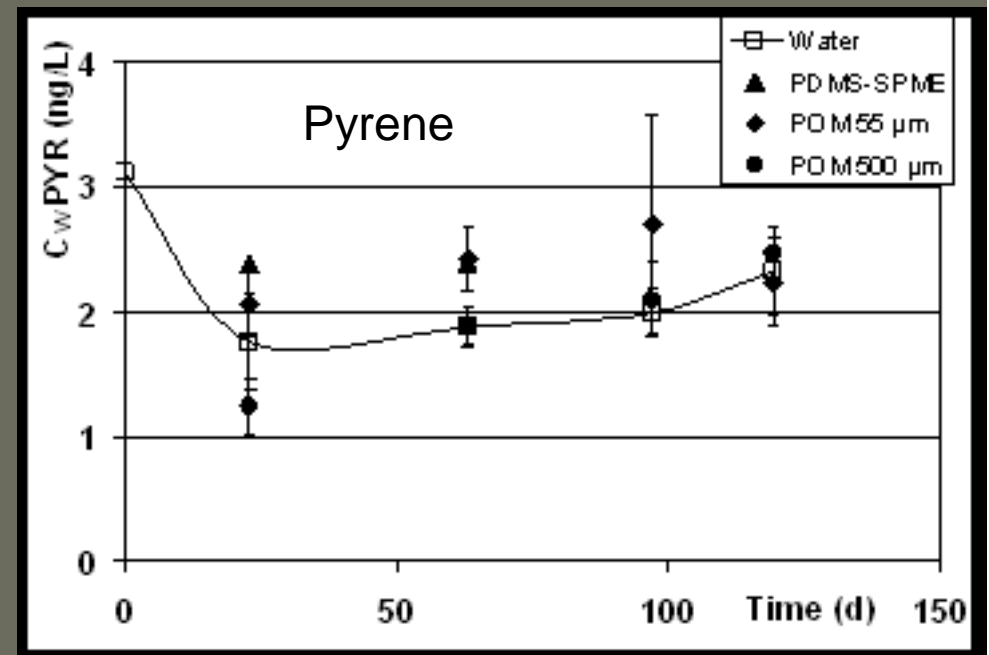


# Monitoring using passive samplers



# Passive sampling

- 3-6 weeks time integrated sampling
- dissolved contaminants
- at low levels  $< 0,1$  pg/L

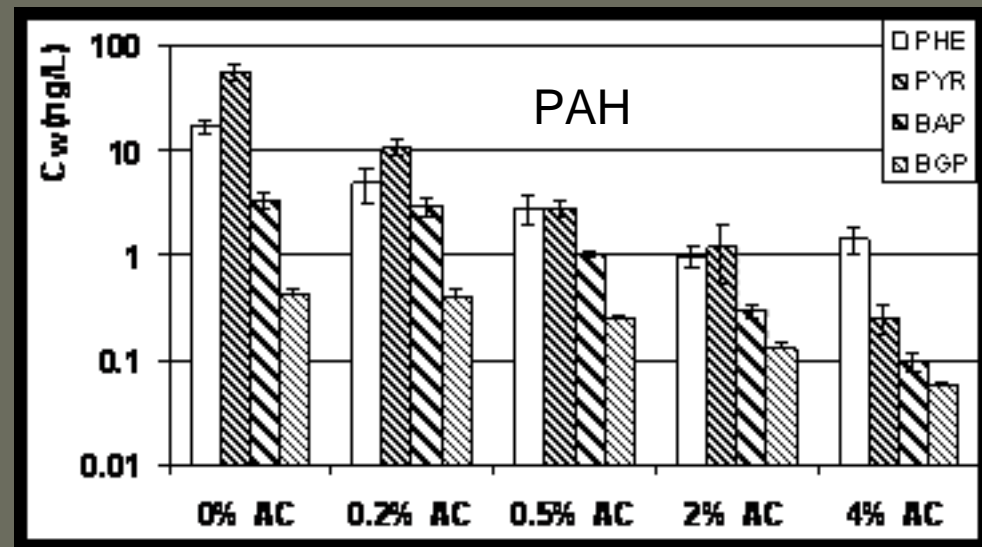
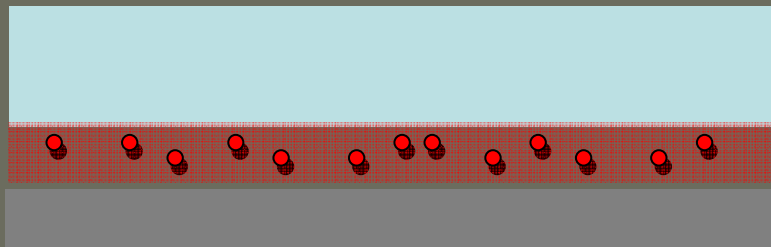


Cornelissen et al, ET&C, 2008

# In-situ remediation

## Chemical stabilisation

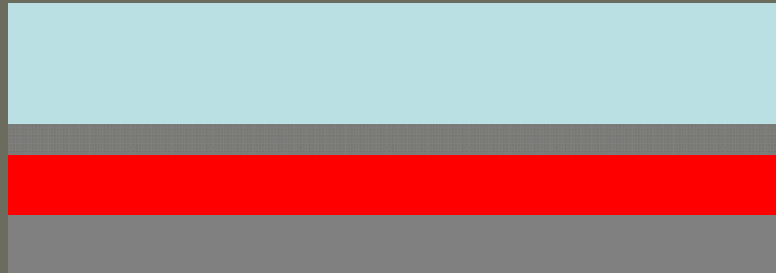
- Amendment with strongly sorbing material
- Reduced aqueous concentration
- Reduced uptake in benthic organisms



Cornelissen et al, ES&T, 2006

# Capping

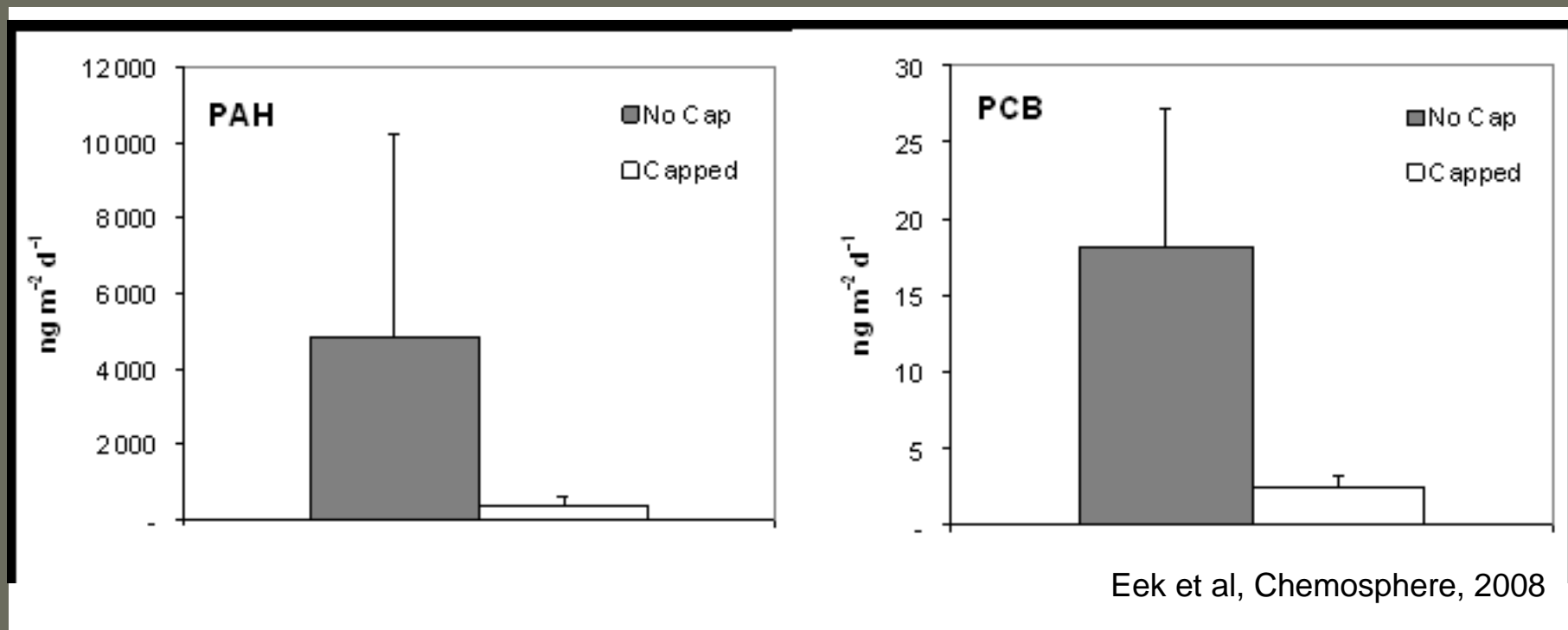
- Covering with clean sediment
- Prevent contact with benthic organisms
- Prevent remobilisation



## Pilot capping Malmøykalven, bearing capacity

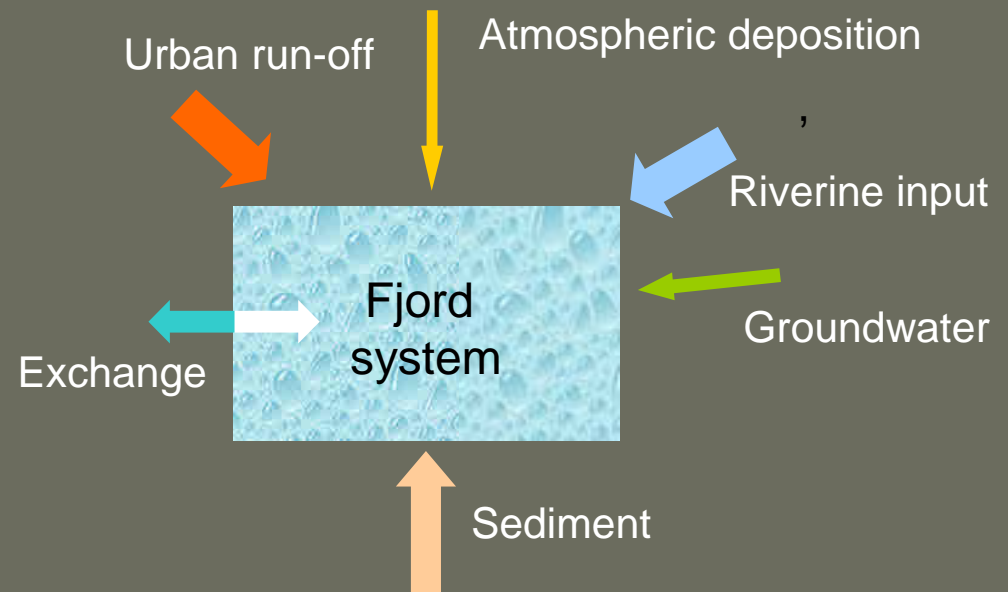


# Capping efficiency



## Effectiveness of solutions

- Sediments as part of a system
- Realistic expectations
- Source control



## Site-specific solutions

- Based on local conditions
- Support nature's recovery potential
- Understand the fate of the contaminants
- Optimal environmental effect
- "Toolbox" of methods





Oslo



Tromsø



Trondheim



Bergen

