In-situ management

The ”other” approach to remediating contaminated sediments

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Managing (remediating) contaminated sediments

- Reason
  - Contamination poses unacceptable risks to ecological and/or human receptors, risks that need to be "managed" in some way

- Goal
  - Reduce risks to acceptable levels (& maintain)

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Approaches to sediment remediation

ex-situ

displaced

removal
(dredging)

↓

treatment

↓

disposal

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Removal, treatment and disposal

Description

Removing contaminated sediment by dredging or excavation, followed by transport and disposal (with/without pre-treatment of sediment and/or water phases)

Approaches to sediment remediation

ex-situ

displaced

removal
(dredging)

↓

treatment

↓

disposal

Approaches to sediment remediation

ex-situ

displaced

removal
(dredging)

↓

treatment

↓

disposal

in-situ

in place

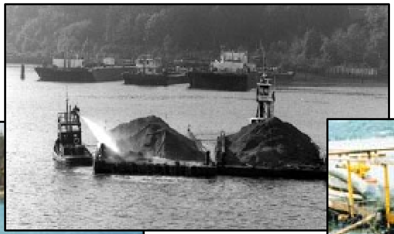
capping

treatment

In-situ capping

Description

Placing clean, conventional or innovative material of different thicknesses overtop contaminated sediment for the purpose of meeting performance objective(s)

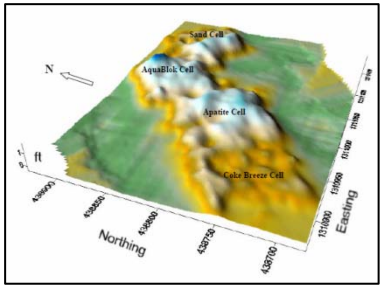


Biologge

CETCO

Birchenough et al., 2010

Biologge



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In-situ treatment

Description
Placing treatment agents into or overtop contaminated sediment to reduce COC mass, toxicity and/or bioavailability within the sediment's biological zone.

”Classic” method

•Inject agents *into* sediment mass
•Mechanically mix in

Approaches to sediment remediation

ex-situ

displaced

removal
(dredging)

↓

treatment

↓

disposal

in-situ

in place

capping

treatment

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Approaches to sediment remediation

ex-situ
displaced

removal
(dredging)

↓

treatment

↓

disposal

in-situ
in place

capping

treatment

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Approaches to sediment remediation

ex-situ

displaced

removal
(dredging)

↓

treatment

↓

disposal

in-situ

in place

capping

treatment

In-situ treatment

Description

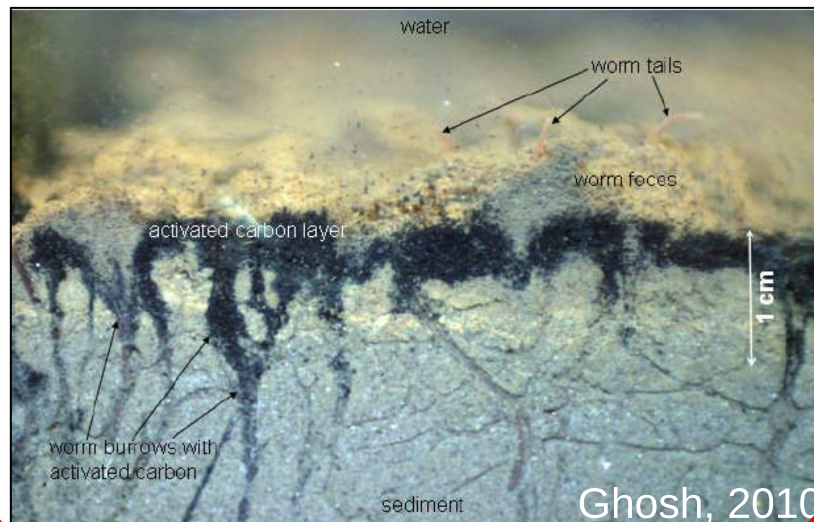
Placing treatment agents into or overtop contaminated sediment to reduce COC mass, toxicity and/or bioavailability within the sediment's biological zone.

”Classic” method

- Inject agents *into* sediment mass
- Mechanically mix in

”New” method

- Place agents *overtop* sediment surface
- Natural bioturbation activity mixes in



Approaches to sediment remediation

ex-situ
displaced

removal
(dredging)

↓

treatment

↓

disposal

in-situ
in place

capping

treatment

MNR
monitored natural recovery

Which remediation approach to use?

- Project-/site-specific decision, depends on
  - Rate and degree of risk reduction needed
  - COC(s)
  - Site conditions
  - Sediment characteristics
  - Cost

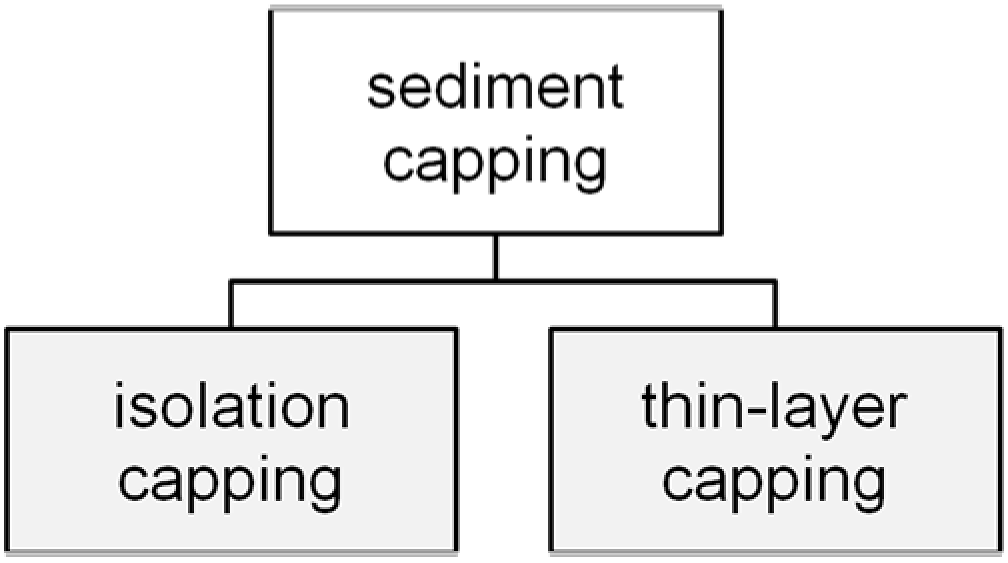
- *Combination* of approaches often attractive
  - e.g. removal followed by capping of residuals

In-situ capping
Strategy, design and materials

- Most appropriate strategy, design and material(s) depends on
  - Cap performance objectives
  - COC(s)
  - Site conditions
  - Sediment characteristics
  - Construction equipment/placement technique
  - Cost

Cap performance objectives

- Key factor in selecting appropriate strategy, design and materials
- Objectives differ depending on strategy



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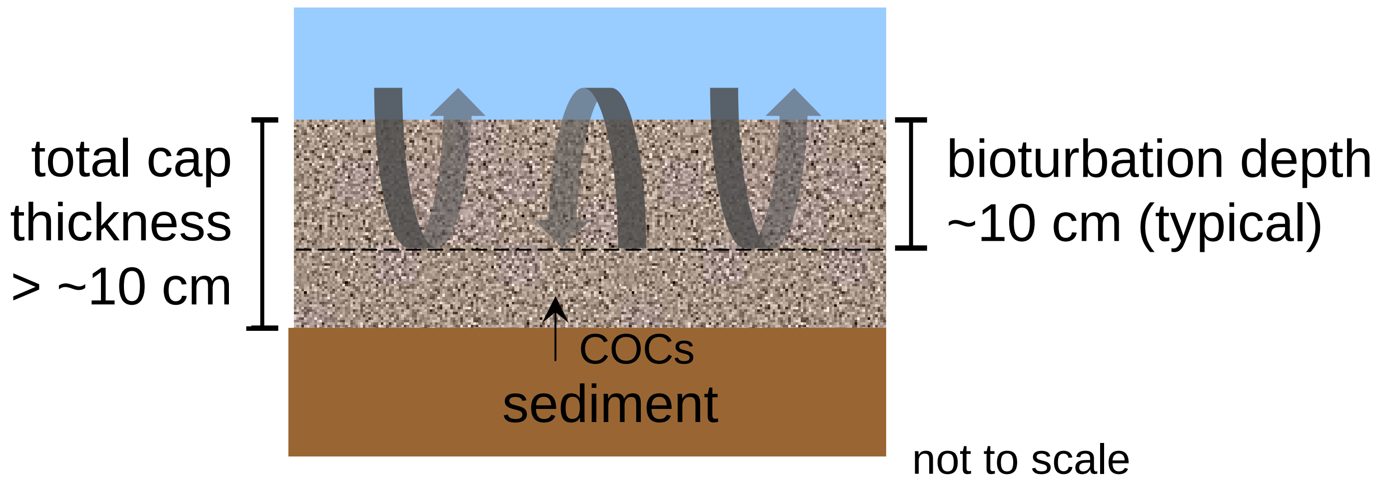
Isolation capping

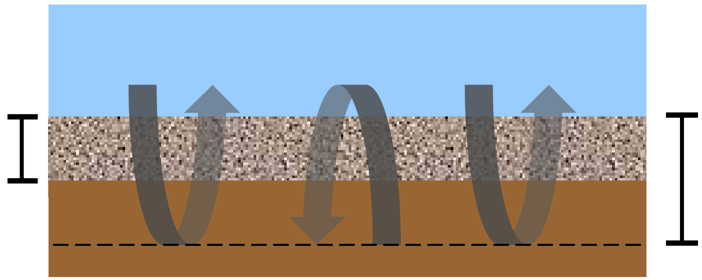
- Cap thickness > bioturbation depth



- Performance objectives: Reduce risks by
  1. Isolating sediments from bioturbating organisms
  2. Stabilizing sediments against erosional losses
  3. Minimizing COC migration up into bio zone

Thin-layer capping

- Cap thickness < bioturbation depth



not to scale

- Performance objectives: Reduce risks by
  1. Diluting total COC concentrations in bio zone
  2. Lowering porewater concentrations by *dilution*
  3. Lowering porewater concentrations by *sorption*

TLC also considered in-situ treatment (or eMNR)

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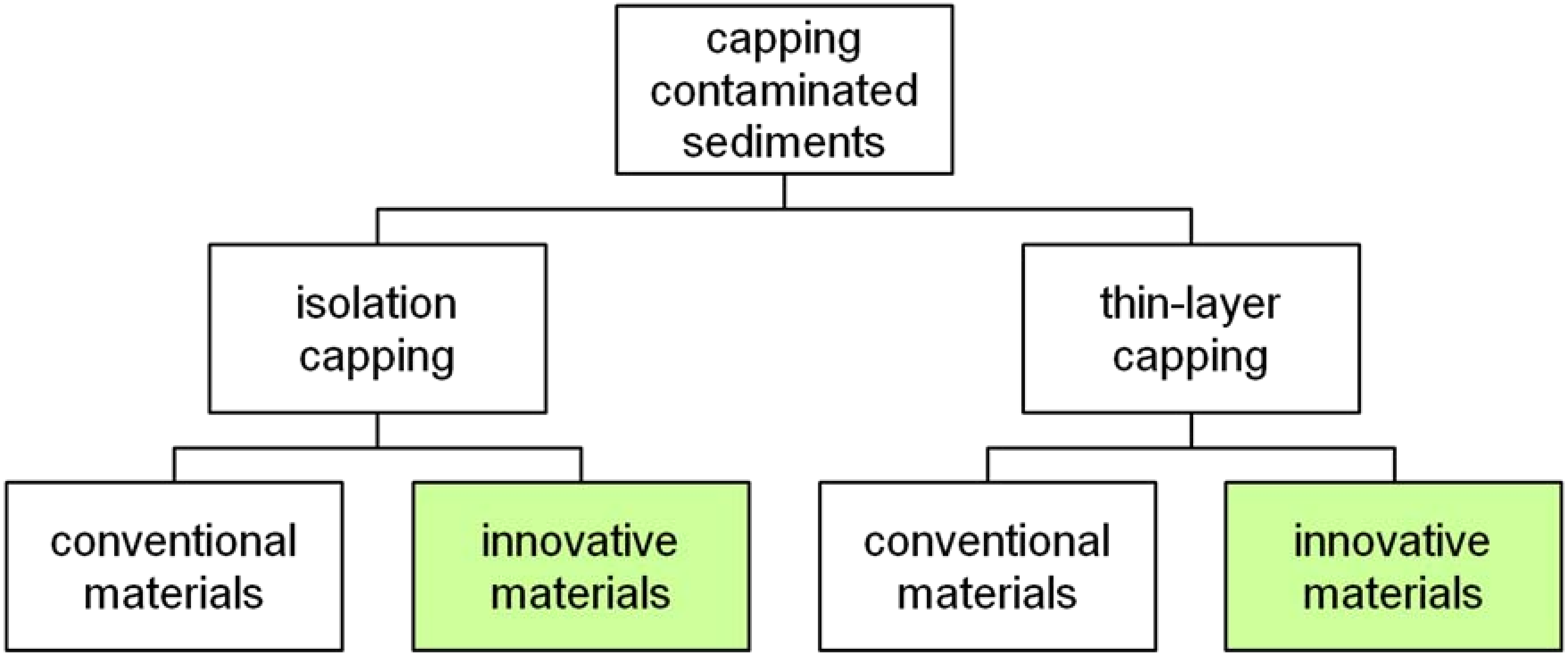
Isolation vs thin-layer capping

Selecting the ”best” strategy

- Factors to consider
  - Site’s depositional vs erosional character
  - Degree and spatial extent of contamination
  - COC(s)
  - Rate and degree of risk reduction needed
  - Cost
- Project-/site-specific decision

- Type of cap material another big factor

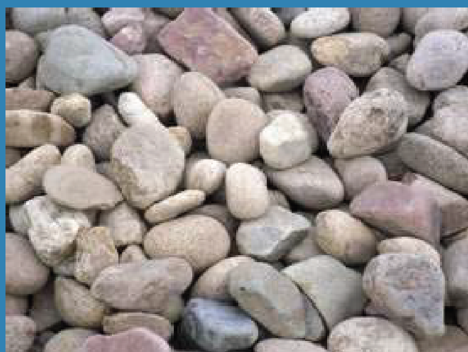
Capping strategies
Expand to include the ”material factor”



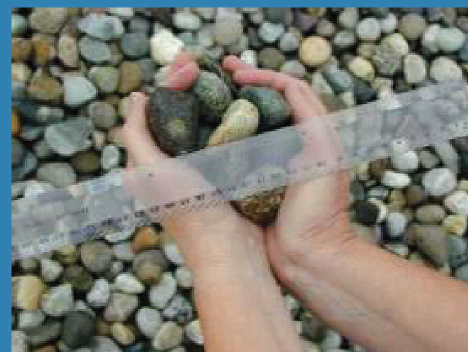
Conventional capping materials

- Inert, variable grain size & permeability

Cobbles

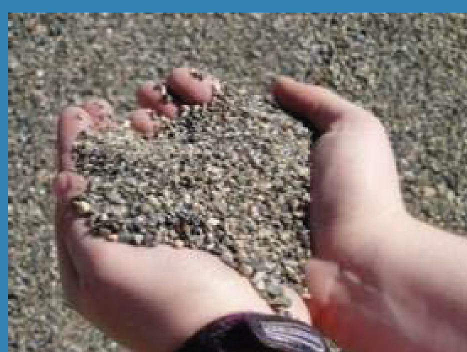


Coarse Gravel

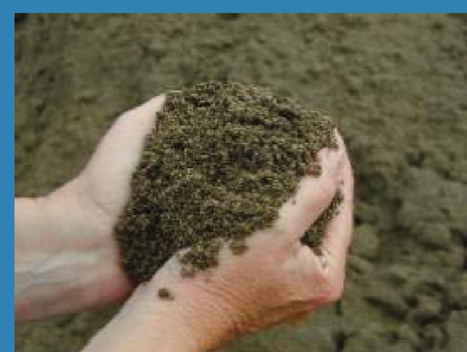


Fine Gravel

Coarse Sand



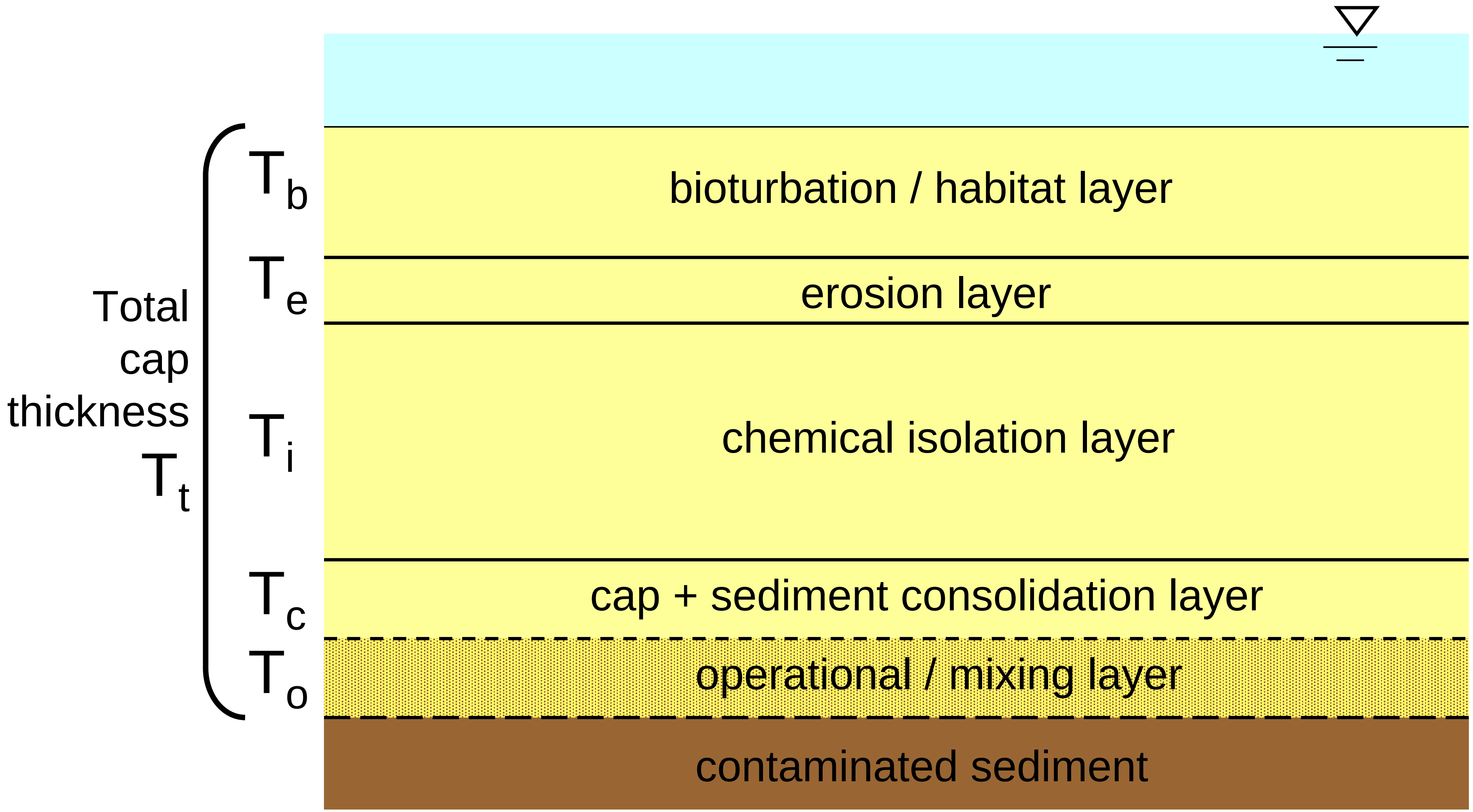
Medium Sand



LWG, 2010

Conventional isolation capping

Design components



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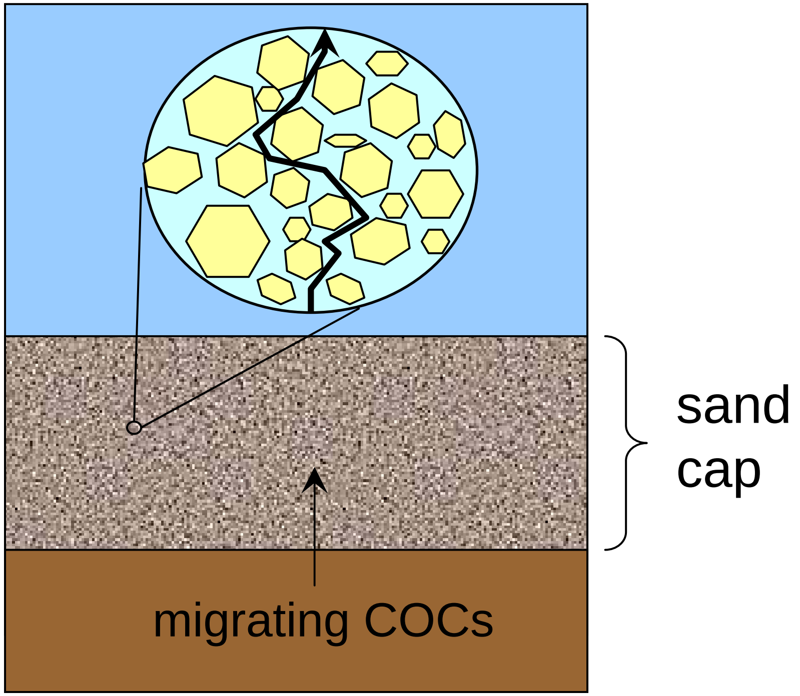
Conventional isolation capping
Use of approach

- Appropriate, adequate in many situations
- Used successfully at many sites, worldwide
- Will continue to be widely used



Conventional (isolation) capping projects, worldwide (1979-2001)

Sediment Project	Chemicals of Concern	Site Conditions	Design Thickness (feet)	Cap Material	Year Constructed	Performance Results	Comments
Great Lakes Region							
Sheboygan River/Harbor Wisconsin	PCBs		Composite of geotextile on fabric, 6" aggregate, geotextile, 6" cobble, with the perimeter anchored with gabions	armored stone composite	1989–1990	• Undetermined cap effectiveness • Some erosion of fine-grained material • WDNR/EPA order cap removal in ROD	Demonstration bench-scale project. Composite armored cap required as sediments were located in high-energy river environment. Gabions placed around the corners for anchoring. Additional course material placed into voids/gaps.
Wausau Steel Site Wisconsin	lead, zinc, mercury	Oxbow on the Big Rib River, nearshore cap	2	composite:s and over geotextile	1997	• Chemical isolation failed • Cap not physically stable	Methane gas trapped under the geotextile forced cap to rise in the center, pulling away geotextile from the edge. Sand erosion also occurred in the nearshore areas.
Manistique Capping Project Michigan (pilot)	PCBs		40-mil (0.1')	HDPE	1993	• Physical inspection of the temporary cap approximately 1 year after installation showed cap was physically intact and most anchors still in place, but was methane-filled	A 240' by 100' HDPE temporary cap was anchored by 38 2-ton concrete blocks placed around the perimeter of the cap. This temporary cap was installed to prevent erosion of contaminated sediments within a river hotspot with elevated surface concentrations.
Hamilton Harbor Ontario, Canada	PAHs		1.6	sand (2.5 acres) (in situ)	1995	• Chemical isolation effective • No erosion of cap	Cap monitoring in porewater ongoing.
Puget Sound Region							
Duwamish Waterway Seattle, Washington	heavy metals, PCBs		1–3	sand (4,000 cy)	1984	• Chemical isolation effective • No erosion of cap	Monitoring as recent as 1996 showed cap remains effective and stable. Split-hull dump barge placed sand over relocated sediments (CAD site) in 70' water.
One Tree Island Olympia, Washington	heavy metals, PAHs		4	sand	1987	• Chemical isolation effective • No erosion of cap	Last monitoring occurred in 1989 showed that sediment contaminants were contained.
St. Paul Waterway Tacoma, Washington	phenols, PAHs, dioxins		2–12	coarse sand	1988	• Chemical isolation effective • Cap within specifications	Some redistribution of cap materials has occurred, but overall remains >1.5 m (4.9'). C. californieus found in sediments, but never >1 m (3.3').
Pier 51 Ferry Terminal Seattle, Washington	mercury, PAHs, PCBs		1.5	coarse sand (4 acres) (in situ)	1989	• Chemical isolation effective • Cap within specifications • Recolonization observed	As recent as 1994, cap thickness remained within design specifications. While benthic infauna have recolonized the cap, there is no indication of cap breach due to bioturbation.
Denny Way CSO Seattle, Washington	heavy metals, PAHs, PCBs	water depth 18'–50'	2–3	sand (3 acres)	1990	• Chemical isolation effective • Cap within specifications • Recolonization observed	Cores taken in 1996 show that while cap surface chemistry shows signs of recontamination, there is no migration of isolated chemicals through the cap.
Piers 53–55 CSO Seattle, Washington	heavy metals, PAHs		1.3–2.6	sand (4.6 acres) (in situ)	1992	• Chemical isolation effective • Cap stable, and increased by 15 cm (6") of new deposition	Pre-cap infaunal communities were destroyed in the rapid burial associated with cap construction, but had recovered by 1996. The initial community established in the sand over time shifted as fine-grained material was redeposited on the cap.
Pier 64 Seattle, Washington	heavy metals, PAHs, phthalates, dibenzofuran		0.5–1.5	sand	1994	• Some loss of cap thickness • Reduction in surface chemical concentrations	Thin-layer capping was used to enhance natural recovery and to reduce resuspension of contaminants during pile driving.
GP lagoon Bellingham, Washington (in situ)	mercury	Shallow intertidal lagoon	3	sand	2001	• Chemical isolation effective at 3-months • Cap successfully placed	Ongoing monitoring.
East Eagle Harbor/Wyckoff Bainbridge Island, Washington	mercury, PAHs		1–3	sand (275,000 cy)	1994	• Chemical isolation effective • Cap erosion in ferry lanes • Some recontamination observed due to off-site sources	Cap erosion measured within first year of monitoring only in area proximal to heavily-used Washington ferry lane. Chemicals also observed in sediment traps. Ongoing monitoring.
West Eagle Harbor/Wyckoff Bainbridge Island, Washington (in situ)	mercury, PAHs	500-acre site	Thin cap 0.5' over 6 acres and thick cap 3' over 0.6 acre	sand (22,600 tons for thin cap and 7,400 tons for thick cap)	partial dredge and cap 1997	• Chemical isolation effective	To date, post-verification surface sediment samples have met the cleanup criteria established for the project. Ongoing monitoring.
California and Oregon							
PSWH Los Angeles, California	heavy metals, PAHs	15		sand	1995	• No data to date	Overall effective cap was >15'. This was not a function of design, but rather a function of the low contaminated-to-clean sediment volume.
Convair Lagoon San Diego, California	PCBs	5.7-acre cap in 10-acre site; water depth 10'–18'	2' of sand over 1' rock	sand over crushed rock	1998	• Chemical isolation effective • Cap was successfully placed • Some chemicals observed in cap	Ongoing monitoring for 20 to 50 years including diver inspection, cap coring, biological monitoring.
McCormick and Baxter Portland, Oregon	heavy metals, PAHs	15 acres of nearshore sediments and soils	NA	sand	planned, but not constructed	• No data to date	Long-term monitoring, OMMP, and institutional controls were also specified.
New England/New York							
Stamford-New Haven-N New Haven, Connecticut	metals, PAHs		1.6	sand	1978	• Chemical isolation effective	Cores collected in 1990.
Stamford-New Haven-S New Haven, Connecticut	metals, PAHs		1.6	silt	1978	• Chemical isolation effective	Cores collected in 1990.
New York Mud Dump Disposal Site New York	metals (from multiple harbor sources)		unknown	sand (12 million cy)	1980	• Chemical isolation effective	Cores taken in 1993 (3.5 years later) showed cap integrity over relocated sediments in 80' of water.
Mill-Quinniapiac River Connecticut	metals, PAHs		1.6	silt	1981	• Required additional cap	Cores collected in 1991.
Norwalk, Connecticut	metals, PAHs		1.6	silt	1981	• No problems	Routine monitoring.
Central Long Island Sound Disposal Site (CLIS) New York	multiple harbor sources		unknown	sand	1979–1983	• Some cores uniform structure with low-level chemicals • Some cores chemical isolation effective • Some slumping	Extensive coring study at multiple mounds showed cap stable at many locations. Poor recolonization in many areas.
Cap Site 1 Connecticut	metals, PAHs		1.6	silt	1983	• Chemical isolation effective	Cores collected in 1990.
Cap Site 2 Connecticut	metals, PAHs		1.6	sand	1983	• Required additional cap	Cores collected in 1990.
Experimental Mud Dam New York	metals, PAHs		3.3	sand	1983	• Chemical isolation effective	Cores collected in 1990.
New Haven Harbor New Haven, Connecticut	metals, PAHs		1.6	silt	1993	• Chemical isolation effective	Extensive coring study.
Port Newark/Elizabeth New York	metals, PAHs		5.3	sand	1993	• Chemical isolation effective	Extensive coring study.
52 Smaller Projects New England	metals, PAHs		1.6	silt	1980–1995	• Chemical isolation effective	Routine monitoring.
Other North American Projects							
Soda Lake, Wyoming	oil refinery residuals	soft, unconsolidated sediments	3	sand	2000	• Chemical isolation effective	Demonstration project that showed successful placement over soft sediments and isolation of PAHs and metals in refinery residuals.
International Projects							
Rotterdam Harbor Netherlands	oils	water depth5 to 12 m	2–3	silt/clay sediments	1984	• No available monitoring data	As pollution of groundwater was a potential concern, the site was lined with clay prior to sediment disposal and capping.
Hiroshima Bay Japan		Waterdepth 21 m	5.3	sand	1983	• No available data	

from Fox River ROD, 2007

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When conventional capping may *not* be adequate

- COCs don’t bind (partition) strongly to sediment’s solid phase
- Groundwater upwelling occurring
- Partitioning processes variable or uncertain
  - e.g. tributyltin (TBT)
- Non-aqueous phase liquids (NAPL) involved
- Need to manage ongoing inputs over time

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Innovative capping materials

- Different from conventional
  - Physically, mineralogically and/or chemically
- Various composition, grain size, permeability
- More effective than conventional at
  - Lowering porewater COC concentrations by strong partitioning to solid phase
  - Reducing COC migration by different processes (use of low-permeability clays)
  - Binding NAPLs
  - Promoting in-situ degradation of some organic COCs in (and below) capping layer

Innovative capping *materials* with proven, unique attributes

- Reactive (sorptive)
  - **Activated carbon (AC)**
  - Topsoil
  - Coke
  - Organoclay
  - Apatite
  - Zeolite
  - Bauxite
  - Fine-gr. crushed rock
  - Magnetite
  - Zero-valent metals

most relatively permeable

- Reactive (degradation)
  - Nutrients (solid, liquid)
  - ORC and HRC

- Low-permeability (very fine grained)
  - Phyllosilicate clays, e.g.
    - Bentonite
    - Palygorskite

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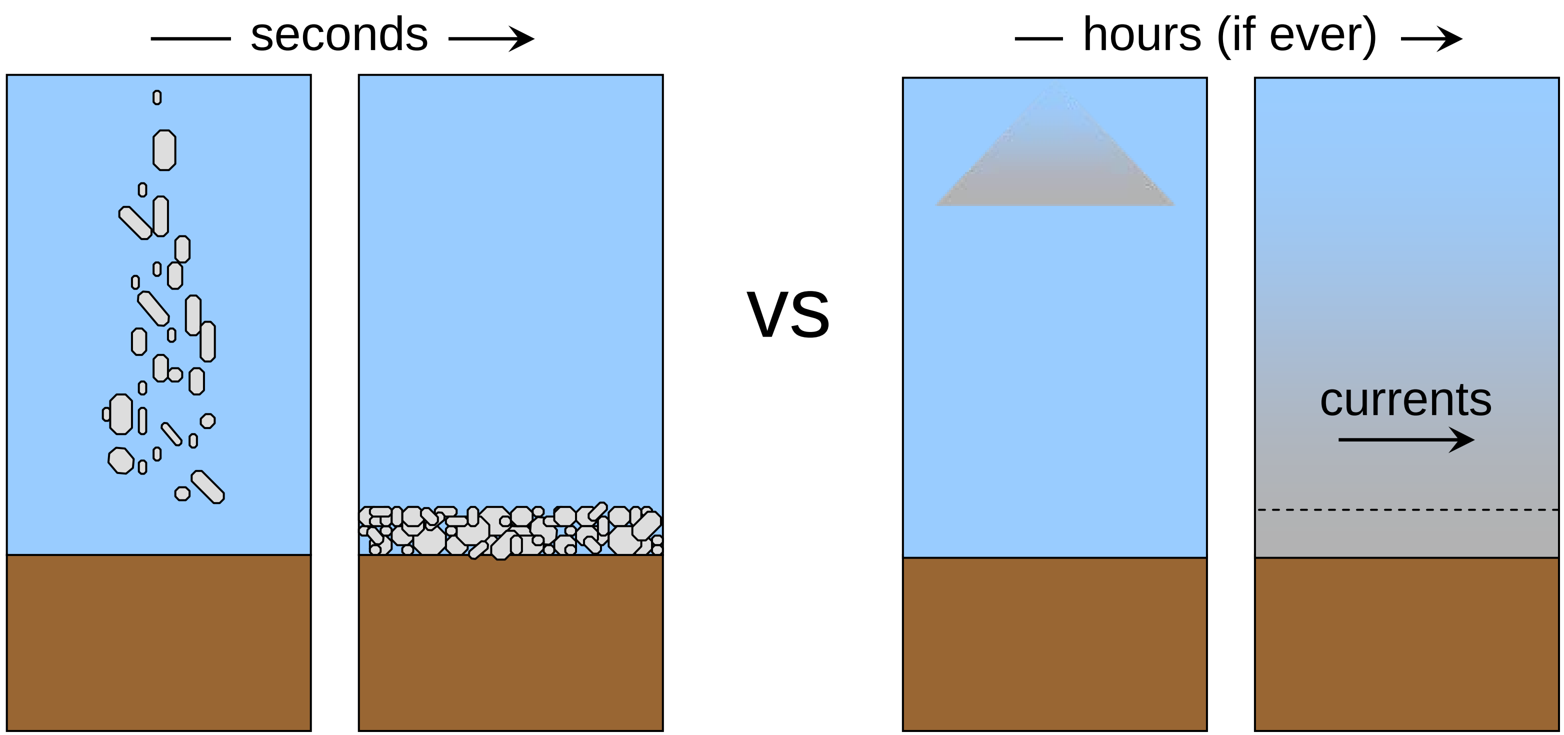
Ease of placing innovative materials in their natural state

Material characteristics
larger (granular) particles with
density of >> 1 g/cm^3

Material characteristics
smaller (fine) particles
of variable density



Innovative capping *products* *incorporating* innovative materials

- Higher-perm + reactive
  - Reactive Core Mats®, RCMs
  - Organoclay (granular)
  - **Bioblok Gate™**
  - P-control products

- Lower-perm + inert
  - Geosynthetic clay liners, GCLs
  - Bentonite chips, pellets
  - **BioBlok®**
  - Clay/cement composites

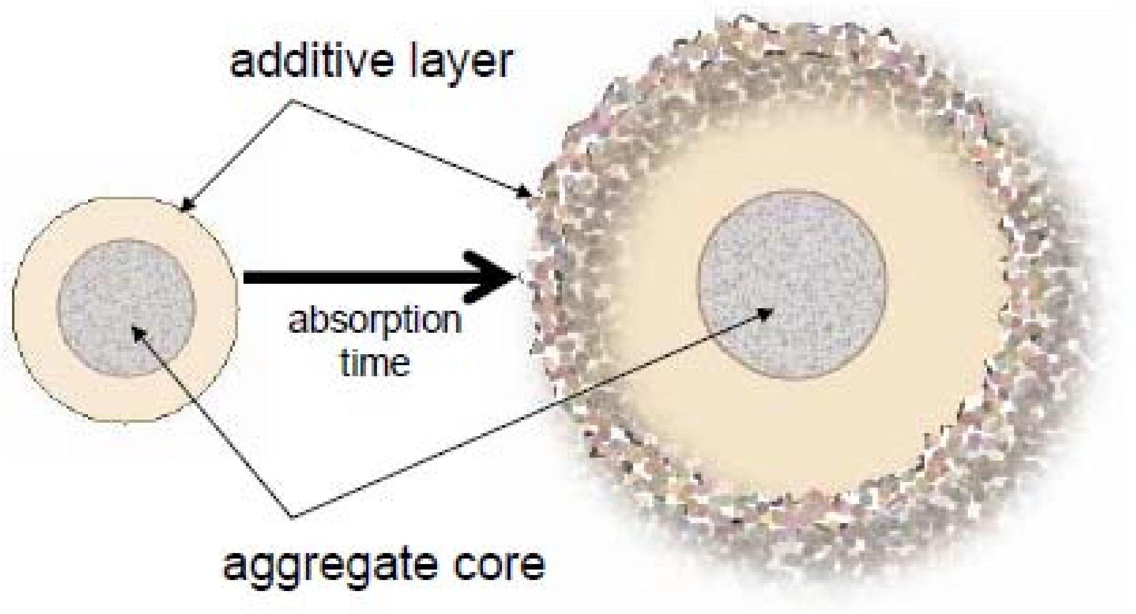
- Lower-perm + reactive
  - **BioBlok+™**
  - SediMite™

BioBlok® in Scandinavia
AquaBlok® in North America

AquaBlok® or BioBlok® particles

Clay-based AquaBlok

PAC-based BioBlok



Courtesy AquaBlok, Ltd. or Biologge AS

Selected innovative capping projects: USA and Norway

Where	What	Why	Who	When
Anacostia River Wash. DC, USA	**Isolation cap** - composite design - clay-based AquaBlok®	- permeability control	AquaBlok, Ltd.	2004
Aberdeen Proving Grounds, Md., USA	**Thin-layer cap** - monolayer design - PAC-based AquaBlok®	- bioavail. reduction	AquaBlok, Ltd.	2009
Sandefjord Harbor, Norway	**Isolation cap** - monolayer design - PAC-based BioBlok®	- chemical isolation - bioavail. reduction	Biologge AS	2010/11
Bergen Harbor (Kirkebukten), Norway	**Isolation cap** - mono, comp design - PAC-based BioBlok®	- chemical isolation - bioavail. reduction	Biologge AS	2011
Leirvik Sveis, Norway	**Isolation cap** - composite design - PAC-based BioBlok®	- physical isolation - bioavail. reduction	Biologge AS	2012
	Thin-layer cap - monolayer design - PAC-based BioBlok®	- bioavail. reduction		

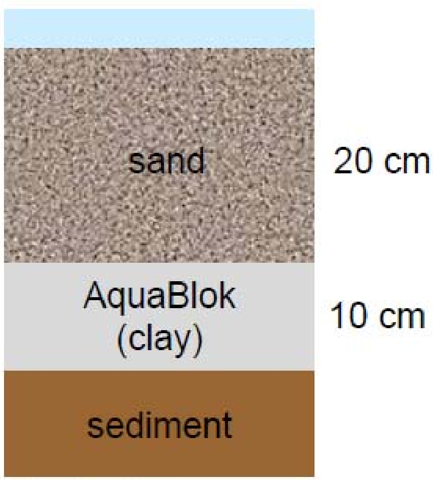
www.aquablokinfo.com www.biologge.no

Anacostia River, Wash. DC., USA

site

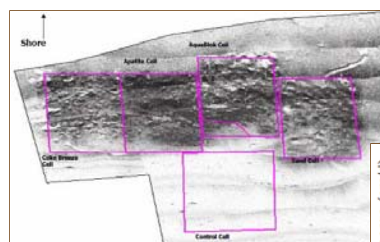
handling, placement

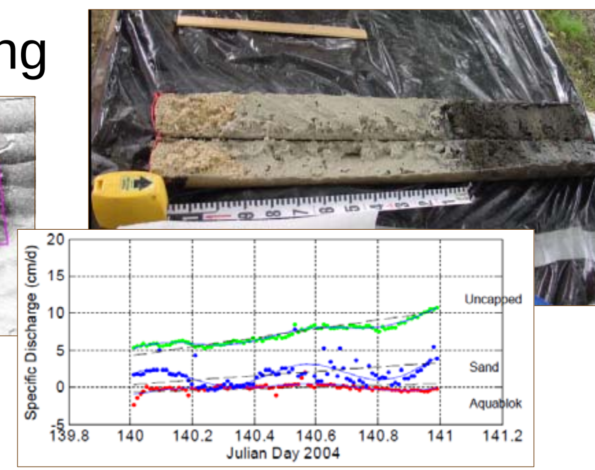
cap design



Not to scale

monitoring





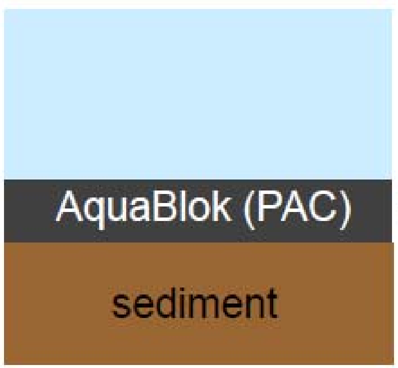
From Reible et al., 2005; USEPA, 2007

Aberdeen Proving Grounds, Md., USA

site

handling, placement

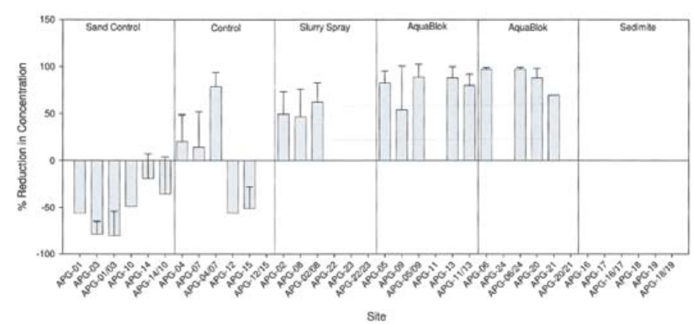
cap design



3 cm

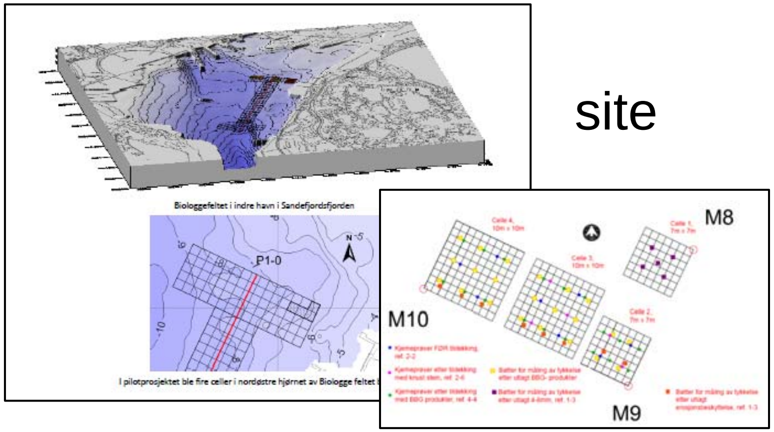
Not to scale

monitoring



Courtesy AquaBlok, Ltd.

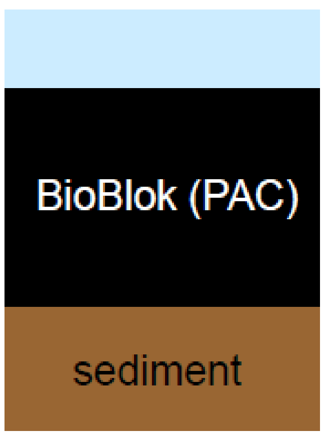
Sandefjord Harbor, Norway



site

handling, placement

cap design



10 or 15 cm

Not to scale

monitoring

Courtesy Biologge AS

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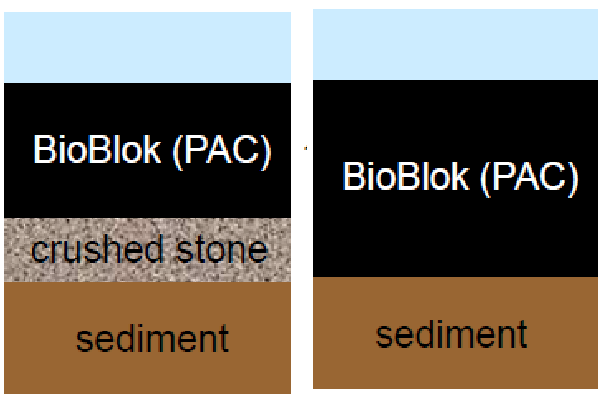
Bergen Harbor (Kirkebukten), Norway

site

handling, placement

cap designs



Not to scale   Not to scale

15 cm

monitoring

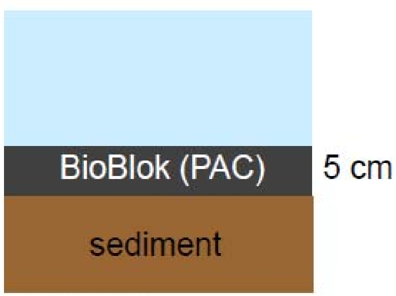
Courtesy Biologge AS

Leirvik Sveis, Norway

site

placement

cap designs



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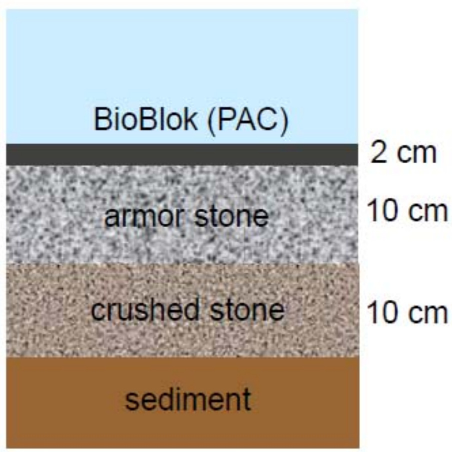
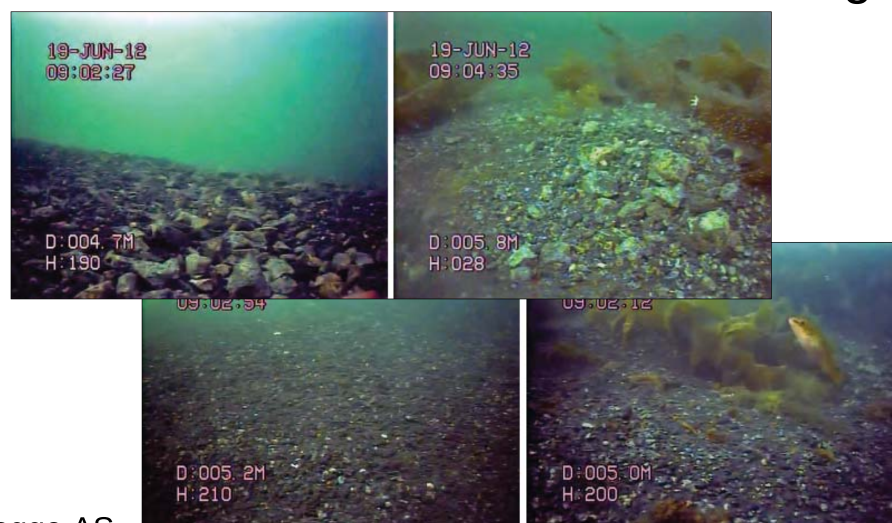


Not to scale

monitoring



From Biologge AS

SAO
ENVIRONMENTAL CONSULTING AB

Estimating capping costs:
Involves weighing several variables

A = Minimum thickness of material or product X required to achieve acceptable long-term protection

B = Material costs (delivered, offloaded)

C = Placement costs

$$\text{Cost/m}^2 \text{ seabed} = f(A, B, C)$$

General costs for sediment management

- Qualitatively
  - Remove (dredge) > in-situ cap > MNR
- Quantitatively (but very roughly!)

International

Remove/dredge (*SEK / m^3*)		In-situ cap (*SEK / m^2*)		MNR (*SEK / m^2 / yr*)
		Conventional isolation	Thin-layer (reactive, PAC)	
Total:	130 – 26,000	15 – 250	85 – 265	<< 1 – 4
Remove:	60 – 1,200			
Treat:	30 – 10,500			
Dispose:	40 – 2,300			

Norway

Dredge:	110 – 220	135	-----	-----
Dispose:	170 – 790			
"Rule of thumb" dredge+dispose	850			

Thanks for your attention!