Innovative Capping Remedies for Risk-Based Management of Contaminated Sediments in Shallower Inner-Harbor Areas

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Introduction: Different ex situ and in situ approaches exist for effectively managing risks posed by contaminated sediments, including removal, treatment, capping and natural recovery. In situ, risk-based approaches – particularly capping remedies – are rapidly gaining favor for many reasons. We focus herein on isolation capping, though the growing popularity of thin-layer capping, i.e. enhanced natural recovery, is also acknowledged.

Relatively permeable + inert isolation sediment caps composed of granular materials like quartz-rich sand have historically been the presumptive cap design and general capping material for various reasons. Conventional sand caps can indeed provide long-term contaminant isolation. However, because they function by presenting migrating contaminants with extended travel times, sand caps tend to be relatively thick, up to one meter or more. Such caps can intrude significantly into the water column, potentially limiting water depth in relatively shallow inner-harbor areas, where ship traffic and related port/shipyard activities are concentrated. In these cases, the original site limitation – contaminant-related risks – is replaced by a *new* limitation – depth-related restrictions on current/future water usage. Still greater depth-related restrictions may occur if armoring is required for cap erosion control.

The goal of this paper is to present different innoviative (non-conventional) isolation cap designs that can provide long-term contaminant isolation at lower cap thicknesses, such that current/future water uses are not significantly restricted. Implicit in such innovative cap designs is the use of non-conventional (relatively reactive and/or low-permeability) materials and/or engineered products in constructing an isolation cap's *chemical isolation layer*, which functions to minimize advective or diffusive migration of contaminants through the cap in different ways. Emphasis is placed on innovative capping remedies for managing sediment contamination in Norwegian inner-harbor areas.

Methods: To meet the goal of this paper, we: (1) describe different types of innovative isolation-layer designs that function in different ways; (2) discuss key factors to consider when determining which type of layer design is most appropriate for use under particular conditions; (3) inventory reactive and/or relatively low-permeability capping materials and engineered products available for use in isolation layer construction; and (4) consider pilot-scale testing of innovative isolation caps at representative inner-harbor locations in Norway.

Discussion: Different innovative isolation layer designs are identified that minimize advective or diffusive contaminant migration by being relatively: (a) permeable + reactive; (b) low-permeability + inert; <u>*or*</u> (c) low-permeability + reactive. The terms "reactive" and "low-permeability" are relative to a moderately well-graded quartz-rich sand, with reactive further referring to enhanced contaminant-specific sorption or biodegradation.

Assuming that capping is suitable for a given situation *in general*, determining specifically which of the above layer design(s) is most appropriate involves balancing various sediment-, site- and project-specific factors, including: groundwater flow conditions; contaminant characteristics; gas influence; water depth; costs; rate/extent of risk reduction required and current/future water uses.

Numerous relatively reactive and/or low-permeability materials and engineered products are available for constructing different types of isolation layer designs. Natural (or semi-natural) materials with reactive and/or low-permeability characteristics include: zero-valent metal; olivine; bentonite; apatite; zeolite and bauxite. Engineered reactive and/or low-permeability products include: activated carbon; organoclays; AquaBlok®; Reactive Core Mats®; Phoslock™ and Bauxsol™. We compare and contrast these materials and products with respect to contaminant-specific function/use; versatility; ease of controlled placement and overall cost.

Numerous impacted inner-harbor locations occur in Norway, with a number of them appropriate for demonstrating and comparing field-scale implementability and long-term effectiveness of different innovative isolation caps'. Potential test-cap designs are discussed within the context of control-based field pilot testing.